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Application of Redirection-based Optimization Algorithm in Automated Model Generation Techniques for Indoor Layout

Yang Wang[1] and Yiqiong Wang[2,*]
[1] School of Information and Media, Sanmenxia Polytechnic, Sanmenxia, 472000, China
[2] School of Architectural Engineering, Sanmenxia Polytechnic, Sanmenxia, 472000, China
Corresponding authors: (e-mail: yiqiong03wang@outlook.com).

Abstract In practice, many design practices focus on graphic layout, such as branding and advertising design. As the demand for interior layout is increasing, the technology of automatic model generation is receiving considerable attention from researchers in the field of interior layout. To address the numerous problems in current interior layout design, this study recommends conducting research on interior layout optimization methods using single-sample data. For a small-scale indoor scene, the study proposes the use of a scene redirection algorithm that incorporates a multi-scale model. By incorporating a redirection operation during the layout process, the algorithm can adjust the layout while maintaining its integrity, resulting in a more rational and optimized layout. The experimental results showed that the execution time of the comparison algorithm exceeded 2 hours, and the redirection algorithm stopped before obtaining the results. This indicated that the redirection algorithm took less time and was more effective in solving complicated problems. The redirection-based optimization algorithm facilitates the rapid generation of logical and refined interior layout models, enabling automation and robust support for the interior design industry.

Index Terms redirection algorithms, graphic design, spatial layout design, automated models, data-driven

I. Introduction

Layout design typically involves the arrangement and placement of objects in a rational and appropriate manner. In modern engineering and practical applications, numerous layout challenges arise, including the layout of ultra-large scale integrated circuits, the loading and unloading of containers in ports, and the spatial layout of buildings [1]. In everyday life, layout problems arise in many designs, and interior design is a particularly important area [2]. Interior design involves the consideration of human life and production activities. The modeling of interior scenes has become increasingly popular in various fields [3]. Interior design problems have significant research value compared to other types of design problems. Interior layout has diverse applications in interior design, computer games, and virtual reality [4], [5]. Automated interior layout design and optimization is a valuable research area. Although interior layout has various practical applications, traditional design methods rely heavily on manual labor, which leads to inefficiency. Moreover, existing layout design methods are not mature because they are often singular and produce suboptimal results while requiring extensive human interaction [6], [7]. In the modeling of indoor environments, the layout of indoor spaces is crucial for their generation. The study also explores the potential applications of the proposed technique. The study addresses various problems present in current indoor layout design and proposes an automated indoor layout model generation technique based on the redirection optimization algorithm (ROA).

The study is divided into four parts. First, the research background is presented and related studies are summarized. Second, the specific methodology for implementing the automated layout model for graphic design with ROA is described. Third, the automated layout model for graphic design is validated and the results are experimentally verified. Finally, the entire research is summarized and an outlook is given.

II. Related Works

Redirection algorithms (RAs) and their optimization algorithms are widely used in scientific research. Khansoltani et al. presented an algorithm that selects the most appropriate alternative server by evaluating qualitative and quantitative features from different sources. The problem was defined as a multi-feature decision problem, and the use of content distribution networks is considered one of the most efficient methods for implementing distributed services. One of the key challenges in content distribution networks is the process of selecting appropriate alternative servers to satisfy user requests. A commonly used approach is to recommend the user request to the closest alternative server. The proposed approach performs better than this conventional method, with faster response time on average [8]. Van et al. proposed a control-oriented free vortex wake model for 2D and 3D actuator disks to represent the wake of a wind turbine, giving preliminary results for average power maximization in a two-turbine case study. The free vortex wake model with gradient information showed the potential for effective optimization [9]. Xia et al. focused on controller load balancing using in-request packet redirection, i.e., given the instantaneous state of the system, determining whether or not to redirect in-request packets for each switch in order to minimize the overall response time of the control plane. To address the above problem, a framework based on Lyapunov optimization was proposed to implement a prototype controller for in-request packet redirection, and trace-driven simulations were performed to validate the theoretical results [10]. Faced with the problem that localized traffic saves bandwidth and reduces latency, but leads to overloading of optical

line terminals, Tang et al. proposed a P2P redirection strategy based on cloud edge collaboration techniques. Optical line terminals played the role of cloud computing center in this strategy. Simulation results showed that the IRS-ECT strategy could reduce the delay by almost half and reduce the traffic load on the optical line terminals in the cloud computing center [11]. The irreversible reorientation of ventilators between lattices was controlled by macroscopic simulations of the quantum Landau-Zener tunneling effect, where the energy of the pulse initially induced in the "excited lattice" was passively and irreversibly redirected into the "absorbing lattice". In this work, Wang C et al. showed that redirection of LZT ventilators in dissipative networks occurs only when the normalized linear mutual coupling stiffness was greater than the individual viscous damping ratio. A reduced-order model was used to guide the selection of lattice network system parameters for robust fan reorientation in the presence of dissipation [12].

Various techniques can be used to model interior layouts, such as 3D modeling, virtual reality, and wall projection. For this study, ROA was used. Kim S et al. proposed a new method for retrieving interior structures from raster images of complex floor plans. A conditional generative adversarial network was used to integrate different floor plan formats into a unified style prior to vectorization. This style-transformed floor plan following the unified style visually represented the spatial structure and was easy to vectorize due to its concise representation [13]. Lakey et al. developed a new model by considering gas phase diffusion through a surface boundary layer and turbulent multi-layer reversible suction on a rough surface. Sensitivity tests showed that high turbulence conditions led to more than twice the film growth compared to low turbulence conditions. The presence of chemical reactions in the membrane had the potential to nearly triple the membrane growth rate [14]. Uddin et al. provided a comprehensive modeling framework to study the impact of room layout on occupant energy conservation behavior by integrating agent-based modeling, system dynamics, and building information modeling. Real energy data collected from customized sensors were used to validate the proposed model. It was shown that adjusting the interior layout could improve the building energy performance by 14.9%. In terms of model validation, the proposed hybrid model showed an acceptable level of accuracy with an average accuracy of 10.5%, MBE of 1.5%, and R2 of 0.77 [15]. A large-scale analysis of real web pages with different aesthetic levels was conducted. The results showed that there were significant differences between aesthetic and non-aesthetic web pages in several aspects of layout design. To determine whether a Web page layout was aesthetically pleasing or not, Wan et al. proposed a new Web page layout aesthetics evaluation model based on the improved Adaboost algorithm to automatically predict the aesthetics of Web page layouts. Experimental results showed that the Web page layout aesthetics evaluation model was significantly better than other existing methods [16]. Nie presented an approach for automatic modeling of indoor scenes using deep features of neural networks. Given a single RGB image, semantic content, 3D geometry, and object relationships were simultaneously recovered by reasoning about the context of the indoor environment. A shallow-to-deep architecture based on convolutional networks was specifically designed for semantic scene understanding and modeling. It involved multi-level convolutional networks that parse indoor semantics/geometry into non-relational and relational knowledge [17].

In summary, the academic application of RA rarely includes the graphic design layout aspect. Therefore, the research is innovative and it is of great research significance to apply the improved ROA to the automated design of graphic models. By combining RA with graphic design layout, more efficient and accurate design solutions can be provided, providing new ideas and methods for further development in the field of interior layout design.

III. ROA in Automated Model Generation Techniques for Indoor Layout

An indoor scene is defined as a complex collection of a multitude of indoor objects. It is one of the most prevalent and typical scene types in 3D scenes, as well as the most widely used [18].

III. A. Optimization Study Based on Heavy Quantitative Algorithm in Single Sample Driven Indoor Layout Optimization

RA input indoor scenes with new interior spaces, the indoor scenes include home-based 3D scenes to the reorientation algorithms are described in detail with the aim of finding appropriate mappings. Φ In addition to the need to satisfy the hard constraint Φ(V) ∈ P , at the same time it is necessary to maintain the original indoor spatial layout and control the geometric scale of indoor objects in a reasonable variation interval to ensure the spatial feeling of the indoor scene. Therefore, the project proposes to investigate a new spatial information-based RA for indoor scenes. The goal is to optimize P by rearranging the objects in V in such a way that it retains as much perceptibility of space as possible in the interior environment. Based on a given interior scene, a smaller background image is obtained while maintaining the original layout structure. Firstly, a simple uniform scaling of the input indoor scene V is performed, knowing that the scaled scene Vs can be adequately accommodated in the given indoor space R . The scale factor of the homogenization process is expressed in equation (1).

$$\min\{\frac{l_p}{l_v}, \frac{\omega_p}{\omega_v}\} \tag{1}$$

In equation (1), lv and wv are the long widths of V , and Vs is considered as the knowledge layout of the algorithm. For the object-level energy term, the aim is to encourage each indoor object to be located at a similar position in the uniformly scaled scene Vs , as shown in equation (2).

$$E_p = \sum_{\{s_j\}} e^{s[(c_i - c_{i,s})^2 - R]} \tag{2}$$

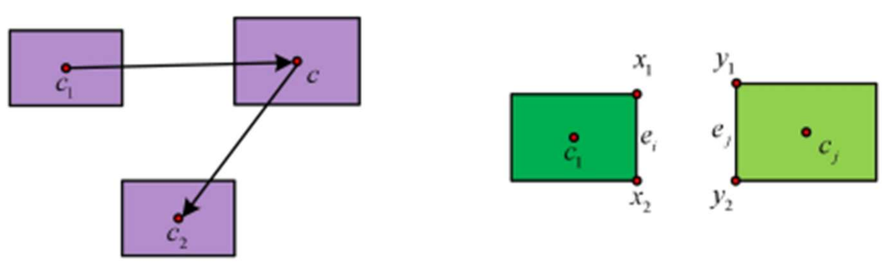
In equation (2), S and R are constants. ci ,s and ci are the centre positions after uniform scaling. For the energy terms at the scene level, the study expects each indoor object to have a known neighbourhood relationship in Vs . During the reorientation process, the inter-relationship system of Sf in between should be maintained. The goal is to make the distance between each interior object as close as possible to the corresponding distance of the interior object in Vs .

$$E_r = \sum_{\{s_j\}} \sum_{s_j \in \Omega(s_j)} \frac{\left\|c_i - c_j\right\|_2^2}{\left\|c_{i,s} - c_{j,s}\right\|_2^2} + \frac{\left\|c_{i,s} - c_{j,s}\right\|_2^2}{\left\|c_i - c_j\right\|_2^2} \tag{3}$$

In equation (3), Ω(si) is represented by the equation (4).

$$\Omega(s_i) = \{s_j \left\| c_{i,s} - c_{j,s} \right\|_2 \le \varepsilon_d\} \tag{4}$$

In equation (4), εd is the distance threshold used to define the domain as shown in Fig. 1(a). The study discusses the maintenance of spatial perception in indoor scenes in terms of dimensional, structural, spatial, and visual aspects. The relationship between indoor objects is shown in Fig. 1.



(a) Neighborhood of indoor objects

(b) The relationship between the distance between indoor objects and channel width

Figure 1: The relationship between indoor objects

An important factor in measuring spatial perception in indoor scenes is having a comfortable walking space, so some spatial constraint relationships must be taken into account [19], [20]. Without maintaining spatial perception, the main corridor of an indoor scene becomes too narrow to walk through. By constraining the width of the road to be greater than wth , it is required that the distance between any two objects (si, sj) on either side of the road exceeds wth . Therefore, a penalty function Ψ is introduced as shown in equation (5).

$$\psi(d) = \begin{cases} (\max(0, \frac{\varepsilon}{d - \xi} - 1)^2, if d > \xi \\ +\infty, otherwise \end{cases} \tag{5}$$

In equation (5), ε and ξ denote two positive parameters. If d - ξ> ε , then Ψ (d) = 0 . si and sj are represented on the side of the road as shown in equation (6).

$$ei = x1, x2 \tag{6}$$

sj is represented at the side of the road as shown in equation (7).

$$ej = y1, y2 \tag{7}$$

The distance di ,j between si and sj is shown in equation (8).

$$d_{i,j} = \min\{dp2s(x1, ej), dp2s(x2, ej), dp2s(y1, ei), dp2s(y2, ei)\} \tag{8}$$

In equation (8), dp2s represents the distance from the point to the line segment as shown in Fig. 1(b). Therefore, the energy term that constrains the width of the road is represented as shown in the public notice (9).

$$E_{\omega} = \sum_{(s_i, s_j)} \psi(d_{i,j}) \tag{9}$$

In an interior scene, there are often functional combinations of multiple objects according to a certain organizational pattern known as a "hyperstructure". The most common type of hyperstructure in indoor scenes is the alignment structure. Alignment is the arrangement of a set of interior objects along a line, with linear equation constraints, as shown in Fig. 2.

Figure 2: Linear equality constraint

In Fig. 2(a), the most important and common hyperstructure in indoor scenes is the alignment structure, where the alignment is a series of indoor objects arranged along a straight line. The redirection result should preserve this hyperstructure. To establish alignment constraints, the first task is to detect the combination of two or more objects in an indoor scene, then the alignment constraints are realized by requiring that the coordinates of all aligned objects are equal in the alignment direction. To maintain generality, the study mainly considers the direction in which the two axes are aligned. In Fig. 2(b), which shows the adjacency relationship, the adjacency relationship refers to the positional relationship between objects that plays a role in connecting and combining different functional areas in the interior layout. The utilization and functionality of the interior space can be improved by a reasonable design of the neighborhood relations. In the study, several linear equation constraints are added to the interior layout to keep the visualization detailed, as shown in Fig. 3.

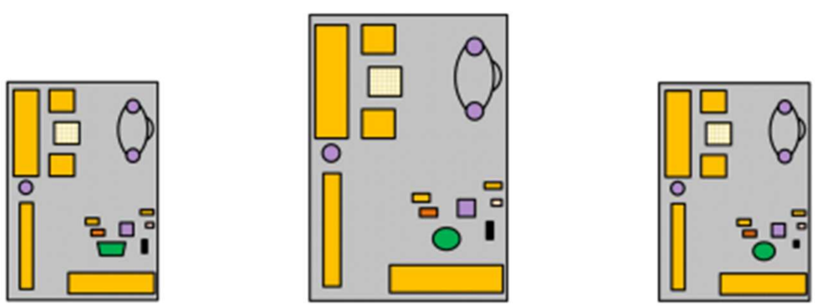


Figure 3: Linear equality constraints preserve the visual details ofindoor spatial layout

In Fig. 3, Fig. 3(a) shows the reorientation scene without linear equation constraints. Fig. 3(b) shows the original indoor scene. Fig. 3(c) represents the reorientation scene with linear equation constraints. Overall, the linear equation constraints can better preserve the visual details of the interior hole spacing layout. The linear constraint representation is shown in equation (10).

$$AC=b \tag{10}$$

*

The final aim is to determine a new scenario S by minimizing the following energy function according to the limitations of the linear equation. S* is expressed in terms of a equation as shown in equation (11).

$$S^* = \{s_i^*\} \tag{11}$$

Equation (11) is algebraized and expressed as equation (12).

$$\left\{ \begin{array}{l} \{s_i^*\} = \arg\min_{\{s_i\}} E_r)(\{s_i\}) \\ s.t, AC = b \end{array} \right\} \tag{12}$$

In equation (12), Espace is the weighted sum of Escale , Eobject , Escene , and Espace . Moreover, the experiments set the air coefficients to be 0.0002, 200, 50, and 0.001. Finally, based on the above optimization method, the multi-objective retargeting method oriented to multi-layer space is investigated. Hierarchical algorithms are studied because in real life, the structure and layout of indoor environments are very complex and usually contain multiple hierarchical structures, such as tables, chairs, and desks. On this basis, a two-dimensional spatial layout method based on hierarchical structures is proposed. The optimal algorithm proposed in the study is based on the above two hierarchical planar layouts and is optimized level by level. Said maintained size-aware energy term Es of said overall indoor environment is the sum of said maintained size-aware energy terms (including said width and said length) for each of said objects in said indoor environment, as shown in equation (13).

$$E_s = \sum_{\{s_i\}} \text{El ,si + Ew,si} \tag{13}$$

In equation (13), El ,si and Ew,si denote the hold size-aware energy term for each object in the aspect direction. Among them, the scaling factor for the length of si is shown in equation (14).

$$\rho_i = \frac{l_i}{l_i^0} \tag{14}$$

In equation (14), li0 is the length of input si . The scaling factor for the width of si is shown in equation (15).

$$\rho_i = \frac{\omega_i}{\omega_i^0} \tag{15}$$

In equation (15), wi0 is the width of input si .

III. B. Data Driven Interior Space Layout Design

Floor plan design is an important part of house building, the floor plan is the design drawing of the house building, which reflects the type, direction, size, adjacency and distribution of the walls of the house building. Traditionally, floor plan drawings are generally a time-consuming and labor-intensive task for interior designers, as they try and try again, and require considerable professional knowledge and design experience. The goal of the research is to automate this design process so that the proper layout of the interior of a residential building is automated and efficient. Layout areas are entered and an automated design methodology is considered for the interior layout of the house. The residential interior layout map generated by the given constraints and data-driven technique is shown in Fig. 4.

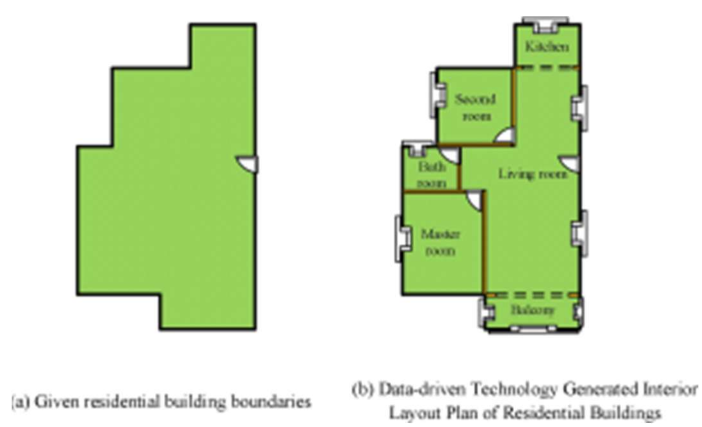


Figure 4: Indoor layout plan of residential buildings generated by given boundaries and data-driven technology

In Fig. 4, Fig. 4(a) represents a given boundary. Fig. 4(b) represents a floor plan of an interior layout of a residential building generated based on the input of the given boundary. Automatic and efficient generation of floor plans from known boundaries is a real need in virtual scenarios such as computer games and networks. This study proposes a computer-aided automatic design method based on interior space planning and applies it to residential remodeling. Since the boundaries of the floor plan are given without specifying any design constraints, the automatic generation of the floor plan is guided by learning the relevant design rules from the floor plan dataset. As the learning algorithm is only provided with the boundaries of the layout, it is challenging to generate a layout that is comparable to the designer's original design in a short timeframe. To facilitate the process of generating a comparable layout, it is essential to have access to a room that already exists in the real world and has complete and detailed annotations. However, no such dataset has previously existed. Nevertheless, a greater reliance on incoming data is necessary to achieve this objective. To address this issue, the study proposes a data-driven technique that utilizes the RPLAN dataset as the foundation. This dataset encompasses interior floor plans of actual residential structures, enabling the efficient generation of an indoor layout plan for a residence with specified boundaries. The data-driven two-phase approach is illustrated in Fig. 5.

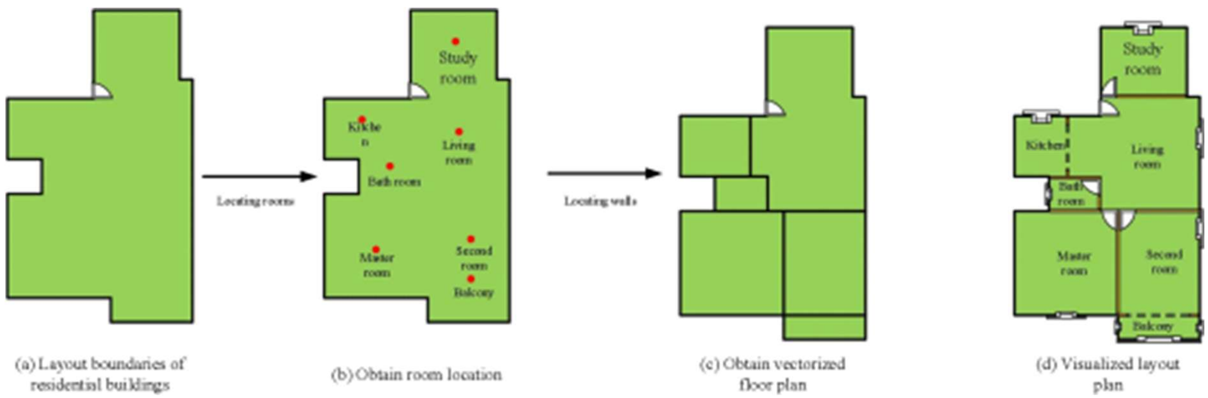


Figure 5: Two-stage indoor space layout design algorithm

Fig. 5(a) depicts the layout boundaries of the housing building. Fig. 5(b) illustrates the interior spatial layout, wherein the room types and locations are initially predicted. An iterative learning strategy is employed for location prediction. As illustrated in Fig. 5(c), an encoder-decoder network is employed, in conjunction with specific rules, to ascertain the location of walls within the interior spatial arrangement. Fig. 5(d) depicts the visualized layout plan, which has been enhanced with details of doors and windows. The RPLAN dataset is presented in Fig. 6.

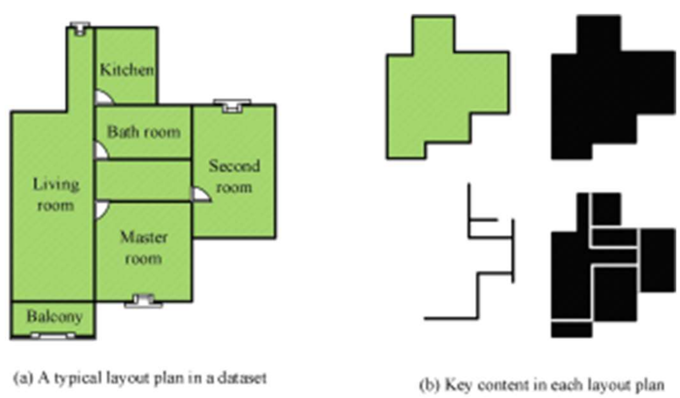


Figure 6: RPLAN Dataset

In Fig. 6, Fig. 6(a) represents a typical planar layout of the dataset, and Fig. 6(b) is a 256*256 resolution image transformed from Fig. 6(a) to accommodate the proposed methodology of the study. The study utilizes the PyTorch architecture to run and train the network. All network models are trained and tested on NVIDIA GeForce (GTX) 980 GPUs.

IV. Analysis and Comparative Study of the Effectiveness of Interior Layout Optimization

In presenting the results of the indoor scene retargeting algorithm, the effectiveness of RA is demonstrated by comparing the results with uniform scaling. Different elements in an indoor scene can be scaled in different proportions to provide visual guidance and focus the observer's attention.

IV. A. A. Analysis of the Efectiveness of Re-quantification Algorithm Based Optimization Studies in Single Sample Driven Indoor Layout Optimization

To verify the effectiveness of the indoor scene RA, an indoor scene V is selected and the indoor scene RA is used to compare it with the uniform scaling algorithm to generate a completely new indoor scene VS so that it can fit into the given indoor space R. The new indoor scene generated by the indoor scene reorientation algorithm is shown in Fig. 7.

In Fig. 7, the algorithm is able to preserve the layout and structure of the original office environment in Fig. 7(a) very well. The new scene is much smaller than the previous one, but overall it is much more compact and the layout is much more reasonable. In Fig. 7(b), the algorithm maximizes the use of space, for example, the method rearranges the clutter boxes scattered around the warehouse, resulting in a more compact arrangement of the clutter boxes and improving the use of space. There are usually two approaches to uniform scaling of a 3D scene, one is to scale uniformly in the length and width directions only, while leaving the height unchanged, and the second is to perform isometric transformations in 3D space simultaneously. In this study, the initial type of uniform scaling is the sole focus, as implementing uniform scaling in three-dimensional space simultaneously results in the user experiencing a visual perception of being in a reduced version of space. The scene RA is compared to the uniform scaling method as shown in Fig. 8.

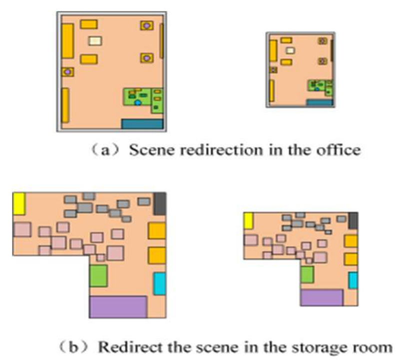


Figure 7: New indoor scenes generated through indoor scene redirection algorithm

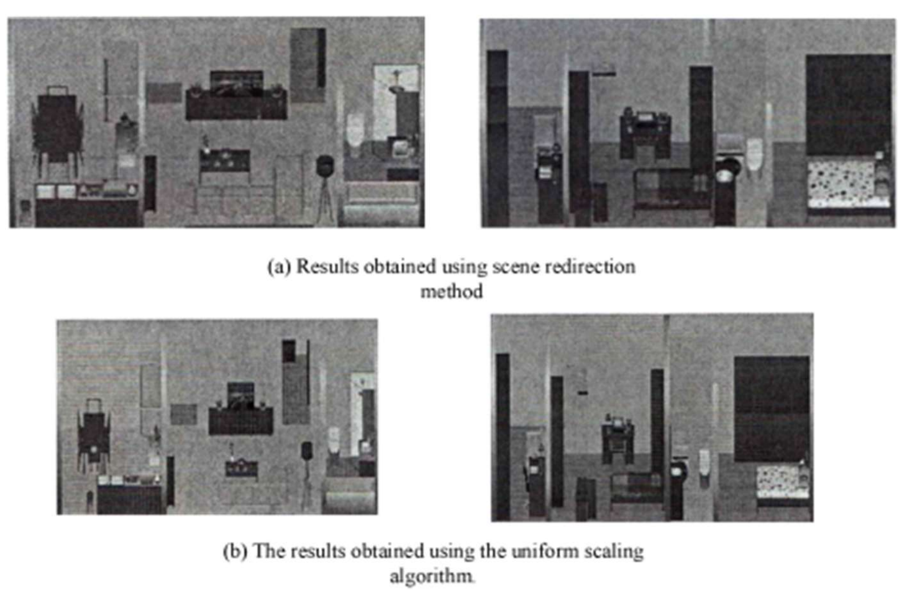


Figure 8: Comparison between scene redirection algorithms and uniform scaling methods

In Fig. 8, Fig. 8(a) represents the result obtained by scene RA. Fig. 8(b) illustrates the outcome of the uniform scaling method. It can be observed that, while uniform scaling maintains the original layout and structure, it also generates a considerable amount of distortion. The reorientation method is able to strike a good balance between the two problems.

IV. B. Data Driven Evaluation ofInterior Space Layout Design Results

Indoor scene generation networks can be used to determine the location of a room, referred to as ISSNet. For a given room, the least squares method (MIQP) is utilized, based on which the optimal solution is performed. Based on this, the methods used in both studies are combined and end up with four sets of comparable targets. The first comparison object is used to determine the orientation of the room using the ISSNet method and then the orientation of the wall using the MIQP method, called ISSNet+MIQP method. The goal of the second comparison is to determine the orientation of the house using the proposed method and then the orientation of the walls using the MIQP method, called Stagel+MIQP method. the goal of the third comparison is to determine the orientation of the house using the ISSNet method and then the orientation of the walls using the proposed method, called ISSNet+Stage2. The fourth group compares it with the designer's work to make a comparison and represented it as Human. For these four comparisons, a research is conducted and the statistics of the results obtained from the research subjects are shown in Table 1.

Table 1: The Results of the Research Subjects Are Consistent

Competitor	*pr of*	a_{avg} / *a dev*	*prof*	y_{avg} / y_{dev}	t_{avg} / t_{dev}
ISSNet+MIQP	70	26.47/5.19	23	3.54/2.67	3.36/1.63
Stagel+MIQP	58	25.37/4.75	27	2.06/1.45	2.76/1.69
ISSNet+Stage2	62	25.67/5.99	28	2.53/2.04	3.26/1.63
Human	70	26.67/5.74	34	3.29/2.259	4.97/2.69

In Table 1, p r of denotes the number of participants in the experiment who passed the preliminary test, aavg denotes their mean age, and a dev denotes the standard deviation of their age. yavg and ydev denote the mean and standard deviation of the design work performed by the respondents. tavg and tdev denote the time taken by the respondents to complete the questionnaire. The number of layout floor plans generated by the chosen optimized method is denoted as N , and the mean and standard deviation are denoted by Navg as and Nstd , respectively. The distribution of N in ISSNet+MIQP, Stagel+MIQP is represented in Fig. 9.

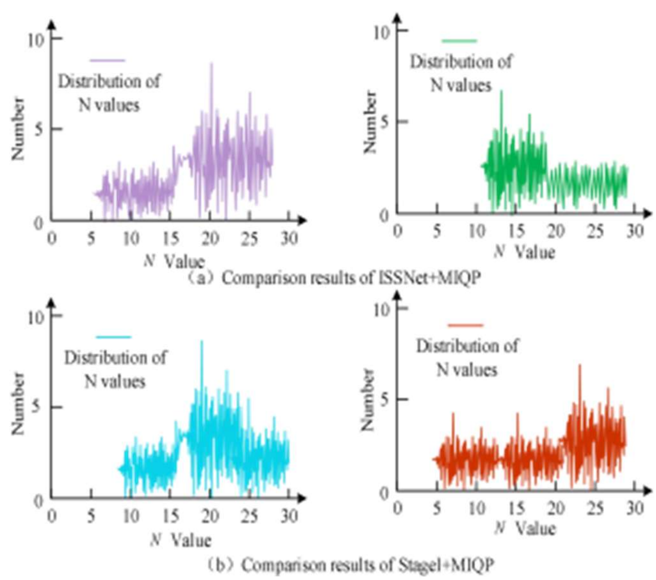


Figure 9: Distribution ofN in ISSNet+MIQP, Stage+MIQP

As shown in Fig. 9, relative to Human, the average score of the average user is 14.58, while the average score of the designer is 11.87. The designer usually notices certain details in the room plan, such as the location and size of the rooms, while the average user judges whether the room plan is reasonable or not from his point of view.

There is no need to study these issues in depth. The distribution of N for ISSNet+Stage2 and Human is shown in Fig. 10.

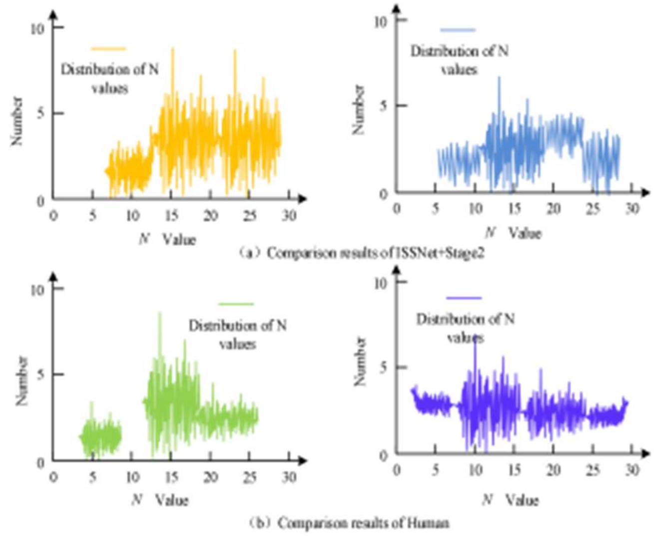


Figure 10: Distribution ofN in ISSNet+Stage2, Human

As shown in Fig. 10, the average score for general users is lower than the average score for designers. Compared to Human, the average score for general users is 13.68, while the average score for designers is 10.39. Designers tend to focus on some details on space planning, such as the orientation and size of the space, while general users judge the rationality of space planning from their own point of view. It is not always possible to explore these issues well. Therefore, participants in the design community preferred to use artificial floor plans as opposed to general users. This study compares the performance of the RA with that of simulated annealing algorithms at varying levels of complexity.

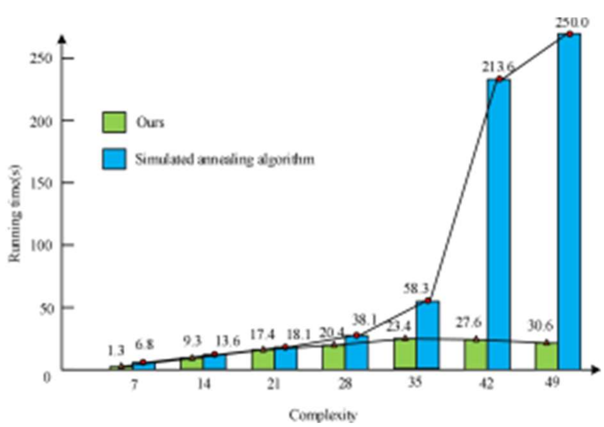


Figure 11: Comparison of runtime between simulated annealing algorithm and redirection algorithm

In the simulated annealing algorithm, as the complexity of the problem increases, its computational speed increases accordingly. However, RA is relatively slow in terms of computational speed compared to the simulated annealing algorithm. In the last study, the simulated annealing algorithm performed the computation, but the study is stopped before the results are obtained because the execution time exceeded two hours. This illustrates the lower time cost and higher efficiency of RA in dealing with complex problems.

V. Conclusion

In modern times, the growing need for interior design has led to its emergence as a significant and favored field of research within design. The wise use of CAD technology has attracted more and more interest in interior design. Interior design is a multifaceted task that must take into account numerous factors such as space utilization efficiency, functional organization, and human movement. A study was conducted to optimize indoor layouts using single sample data. For small indoor scenes, this study proposed a multi-scale model-based scene RA based on the ROA, which aimed to reduce the scale of the model to an adaptive range. The algorithm attempted to maintain spatial consistency between the new and original scene by introducing redirection in the layout process. Experimental results showed that the approach successfully reduced the scale of the scene without compromising its internal spatial information. RA was less time-consuming and more effective in solving complex problems. It could provide interior designers and users with personalized layout options, thereby increasing the efficiency and comfort of interior space utilization. However, the study has several shortcomings, especially regarding the need for objective criteria in judging design work. The study lacks such criteria, indicating that the study of evaluation criteria has great potential for future research.

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