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Visualization and analysis of multifunctional spatial transformation of virtual reality technology applied to cruise ship interior design

Jiping Gong[1,*], Rui Jiang[1], Lili Wang[1] and Shanying Li[1]

[1] Jiangsu Maritime Institute, Nanjing, Jiangsu, 211199, China

Corresponding authors: (e-mail: 19951929917@163.com).

Abstract The study is based on VR technology to design the optimal layout plan for the building space. The cruise ship indoor space environment is projected into a two-dimensional xoy plane to determine the geometric features of the cruise ship indoor space and the layout attributes of the layout objects, and then the two-dimensional drawings are imported into the virtual reality platform to generate a three-dimensional spatial model of the cruise ship indoor space. According to the 3D spatial model, take the layout attributes of the layout objects as constraints, and construct one-to-one models of layout elements within different layout objects. The appropriate layout element model is selected in the database and imported into the virtual display platform for positioning and editing to generate the interactive effect of the layout scene of the cruise ship indoor space, and the binocular camera is used to carry out roaming control to realize the functions of revealing and hiding of the different layout elements in the layout objects, replacing the materials of the layout elements, as well as replacing and adjusting the different elements under the roaming control. The simulation results show that the optimal layout scheme can be obtained by using the above method, and compared with the original scheme, the optimized layout scheme of this paper's method improves 4.59, 16.84 and 13.82 percentage points in the three dimensions of cabin adjacent strength, away strength and circulation strength respectively, which is of good applicability.

Index Terms interior design, architectural space, optimal layout, three-dimensional spatial modeling, VR technology

I. Introduction

Modern people's economic income level has been greatly improved compared with the past, so there are many people choose to travel in their leisure time, which can not only allow tourists to relax physically and mentally, but also drive China's tourism industry to achieve the goal of stable development [1], [2]. In addition to the common car, train and other means of transportation, there are also a lot of tourists choose to cruise out travel, which can not only drive the development of tourism industry, but also help to accelerate the speed of development of the cruise industry. Accordingly, in order to fully meet the ride needs of different tourists, should strengthen the research efforts on the cruise ship interior design strategy, in order to promote the development speed of China's tourism industry to do to create good conditions [3], [4].

In the cruise ship cabin environment, the appropriate cruise ship interior environment design helps to build a distinctive, warm and comfortable living environment in the overall design process of the room, so that the overall environment of the room can boost the mood of tourists and have a positive impact on the psychology of tourists, significantly enhance the travel experience of tourists, and enhance the overall evaluation of tourists on cruise travel [5]–[8].

At present, the design of cruise ship cabins presents the development trend of standardization and modularization. Cabin design program show more engineering drawings, rendering diagrams, sample cabins and other ways to present, but engineering drawings, rendering diagrams and other plane effect display is often not intuitive enough, or with the real experience of the passengers deviation, sample cabin experience can be the most intuitive embodiment of the effect of the cabin design program, but the layout of the sample cabins to display the more cumbersome, it is difficult to show more than one set of design programs or design program for the design modification adjustment [9], [10]. Virtual reality technology as one of the cutting-edge technologies that have flourished in recent years, its technical level is gradually maturing, along with its application in various fields continues to deepen, virtual reality technology shows a great application prospect in the field of scene visualization. Virtual reality technology combines the virtual program design with the real space scene to construct a simulated space environment. Based on virtual reality technology to promote the design of cabin environment in the field of ships, it can improve the fidelity of the design scheme of the cruise ship cabin environment, reduce the cost of the real scene scheme display, facilitate the adjustment of the design scheme in the scheme design stage of the whole life cycle of the cabin design, and to a large extent, improve the fit between the user and the ship's cabin environment, and enhance the user's experience of the cabin environment [11]–[14].

Cruise ship interior space is relatively closed, travelers in the cruise travel process have a lot of time in a relatively closed cabin environment, so the environmental design of the cruise ship cabin will have a direct impact on the traveler's travel experience. Piardi et al. [15] conceptualized a new cruise concept aimed at designing a cruise entity with civic functions to meet the travel and tourism needs of individual tourists, making the cruise ship an extension of the city's functions. Massey [16] describes the meaning and history of cruise ship interior design, stating that the design of cruise ship interior spaces encompasses national identity, gender, class, and racial meanings, and that the ideas and analyses presented can be an important addition to cruise ship interior design. Buqi et al. [17] developed an application that can provide high-quality services and products to enhance in-cabin comfort for cruise passengers, which makes decisions by sensing various indoor metrics and combining them with tourist behavioral traits and preferences, and then targeting the creation and design of an in-cabin space that makes tourists feel comfortable and healthy. Carmosino et al. [18] illustrated the development of intelligence in the cruise ship sector, which has brought about new changes in both interior and exterior design of ships, and explored the potential of intelligent technologies for ships as well as the field of reactive materials in driving sustainable development of ships from a multidimensional perspective. Dridea et al. [19] talked about the cabin and architectural design of cruise ships in the context of the epidemic incorporating consumer behavior, cruise inland, and ocean-going uses to innovate and optimize with the aim of meeting the needs of tourists and providing them with better service. Su and Wang [20] designed a cruise ship cabin human-machine environment evaluation index framework and a comprehensive assessment model based on virtual reality technology, which facilitated the optimization of cruise ship cabin design and environment design.

With the continuous development of virtual reality technology, its application in the field of interior design is becoming more and more widespread. Kán and Kaufmann [21] conceived a program that can realize the intensification of the filling of the interior virtual scene, which supports the selection and filling of furniture of different types, colors, and materials, and promotes the harmonization and unity of the furniture matching and color distribution in the process of interior layout and design. Obeid and Demirkan [22] examined based on pedagogical experimental methods and revealed that immersive virtual design technologies and environments are more conducive to innovation and creativity among interior designers and noted that designer motivation showed a strong positive correlation with the state of mind-flow, while spatial competence showed a weak positive correlation with the state of mind-flow. Milovanovic et al. [23] reviewed and analyzed the research literature related to VR and AR devices in the field of construction design in order to discover the potentials and limitations faced by VR and AR technologies in the field of architectural design and developed a design assistance program that can support designers in the use of VR, AR and other technologies for architectural design. Wolfartsberger et al. [24] envisioned a low-cost multi-modal industrial design review model with virtual reality technology as the core logic for quantifying and visualizing complex engineering data. Naz et al. [25] designed an analytical experiment based on a six-surface projection immersive display to investigate whether elements such as color, light, and texture of a virtual space can influence individual mood and emotions, and the study confirmed that virtual and real spaces have the same emotional responses, thus suggesting that virtual indoor spaces can be designed using VR to accommodate activities with a clear emotional orientation.

The traditional cruise ship cabin design mainly uses the combination of CAD drawing and 3D modeling, but this design can not meet the actual needs of passengers on the cabin. Therefore, the innovation point of this paper is to apply VR technology to the design of cruise ship cabin space, and build a new cruise ship interior design method. First, establish the cruise ship cabin space model. The spatial environment of the cruise ship cabin is projected into a two-dimensional plane, the geometric characteristics of the cruise ship cabin are determined, and the attributes of the layout objects are used to generate a three-dimensional spatial model for multifunctional spatial conversion. Second, the internal space design of the cruise ship cabin is modeled. Using Photoshop, CAD and 3ds Max and other three-dimensional animation rendering software for 1:1 modeling of the cabin space layout. And the three-dimensional animation rendering model of the cruise ship cabin space is imported into the VR environment, and the immersive interactive design of the layout design of the cruise ship cabin space is realized by wearing VR glasses, VR patches and other perception devices. Finally, a large cruise ship is simulated as an example to test the effectiveness of the method proposed in the paper.

II. Application of VR Technology in Architectural Interior Design

II. A. Two-way interaction mechanism of VR interior design

The continuous development and rapid updating of information technology improves the possibility of realizing this complex cyclic design process, and "virtual reality" as a more mature digital information technology with participatory interactivity can become the technical support for the two-way interactive architectural interior design process.

The design principle of public participation based on two-way interaction of virtual reality (VR) technology is aimed at applying the two-way interactive characteristics of virtual reality technology to the form of public participation, thus becoming the guiding principle of interactive design. The interior interactive design mechanism of public participation is shown in Figure 1, in which interaction has a double meaning, one of which is the interaction between the relevant people in the design process.

The design process, based on deep participation and circularity, requires designers to interact with decision makers and the public. The second is the interaction between personnel and information technology, which is enabled by VR technology to enable the interaction between designers, decision makers and the public to proceed smoothly.

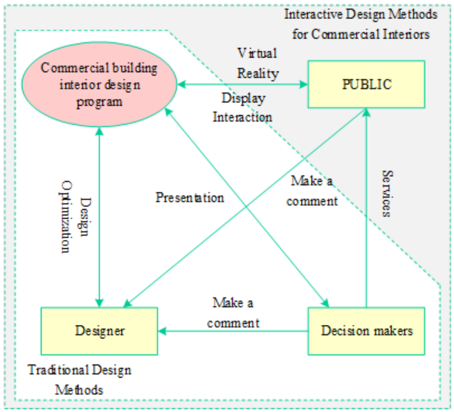


Figure 1: Diverse people participate in the design of commercial architecture

II. B. Construction and realization of virtual scene

Based on the existing theories of interactive and adaptive architecture, we use virtual reality (VR) technology to test its comfort or functionality to avoid the consequences of insufficient design after completion.VR technology can simulate the built form of architectural interiors and adapt to computer-mediated environments, and utilize simulated images of virtual reality technology to study users' interactive responses to architectural interiors and scenarios. Scene's interactive response. Therefore, the degree of realization of the virtual scene is the premise and foundation for the realization of the interactive design method, and the realization of the virtual scene this stage process consists of two parts.

II. B. 1) Computer-aided design software modeling

Virtual scene visualization process shown in Figure 2, the preliminary design of the program after thinking about modifications to deepen the design, the designer is generally in accordance with traditional habits will be used, such as AutoCAD and other modeling software sketching the original floor plan, the program for electronic presentation. Next, according to the planned floor plan for three-dimensional modeling, this time usually with the help of computer modeling software such as SketchUp, 3DSmax, Revit and so on. The specific process can be based on the following basic steps:

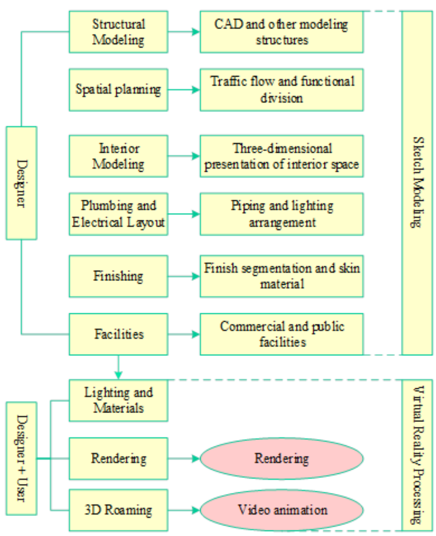


Figure 2: Visual operation flow of virtual scene

(1) Three-dimensional presentation of space, mainly in simple geometric forms such as rectangles, cylinders and other model combinations, the main demand is to quickly and easily present the basic structure of the building space, the need to provide commonly used components such as doors, windows, walls, columns, fast parametric input and modification functions.

(2) Space planning, then continue to design the functional division of indoor space, while corresponding to the functional space design traffic flow.

(3) Detailed construction of the model, the next class can refer to the traditional architectural interior design process, in order to arrange the piping and lighting facilities in the space.

(4) Model refinement processing, this step is not only in the form of refinement processing, at the same time in the space of the material, wall or partition of the decorative surface treatment and division, etc. are more in-depth construction.

(5) Add supporting facilities, and finally add the corresponding public facilities and non-building components such as display facilities according to functional zoning.

II. B. 2) Visualization of virtual reality

The next step is to carry out virtual reality visualization processing on the identified architectural model, and this part can make use of VR software such as LUX Walker, Iris VR, Mars, etc. to carry out 3D simulation modeling and rendering of virtual reality scenes.

(1) Light source and material settings, this step first needs to set up the material and texture that can be seen in the sketch model of the architectural interior, and reasonably arrange the light source of the architectural interior according to the texture of the material and the expression of the mood.

(2) The next step is to enrich the details of all kinds of objects in the building interior to maximize the restoration of the real building interior environment, in order to improve the immersion of designers and users in the virtual space.

(3) Finally, model rendering is performed, and camera paths are set up for exporting renderings and video animations of the virtual scene from different angles, as well as a real-time touring system that is subsequently used by the designers and users in the discussion and adjustment of the scenarios.

The purpose of this link is to adjust the model accuracy and software performance, so that it can meet the real-time rendering at the same time to obtain the most realistic virtual experience of the interior space of the building, so that the user can feel the realistic spatial environment, observation of the interior details, try different ways of designing the space or the choice of materials and colors. And can make changes or edits to the program design in the virtual scene in real time. Thus, the "immersion" in the virtual scene as the basis of interaction, so that the public can directly and quickly participate in the interaction, to help designers make decisions to further optimize the design scheme, improve design efficiency and improve the expression of the scheme.

III. Spatial Layout Optimization of Cruise Ship Cabins Based on VR Technology

With the booming development of the yacht market, cruise ships have gradually become an important symbol of people's high-end consumption. Under the background of people pay more attention to comfort and safety, it is especially necessary for designers to optimize the design of cruise ship cabin space. Traditional cruise ship cabin design mainly uses CAD drawing and 3D modeling, but this design can not meet the actual needs of passengers on the cabin. For this reason, the designers introduced VR technology into the design of cruise ship cabin space, using three-dimensional simulation interactive experience to meet the real needs of passengers, so as to enhance the personalized design and aesthetic experience of the cruise ship cabin.

III. A. Optimal layout method for cabin space

After modeling the interior space design of the cruise ship cabin, in order to make the cruise ship cabin better serve the passengers, the designer can design the interior space layout of the cabin. Not only to the windows, walls, and living room, bathroom and other functional space division, so that it has a reasonable line of motion, but also need to bed, sofa, and cabinets and other furniture and artifacts size, placement planning. After planning the cabin space layout and detail design, the designer can use Photoshop, CAD and 3ds Max and other three-dimensional animation rendering software for cabin space layout 1:1 modeling. Finally, the three-dimensional animation rendering model of the cruise ship cabin space is imported into the VR environment, and by wearing VR glasses, VR patches and other perception equipment, the designer can have an immersive experience of the layout design of the cruise ship cabin space and perceive the real design effect of the cabin.

III. A. 1) Cabin space model construction

The interior spatial environment of a cruise ship's cabin is projected into a two-dimensional xoy-plane, thus generating a closed space. In order to obtain the optimal layout of the cruise ship cabin space, it is necessary to normalize the interior space and determine the spatial scale and orientation. The coordinate system is introduced into the space of the cruise ship cabin, and the y-axis positive direction and the origin are set as the minimum coordinates of the entry direction and the vertex of the space of the cruise ship cabin, while the x-axis and the y-axis correspond to the width value (W) and the length value (L) of the space of the cruise ship cabin, respectively.

(K_x, K_y) denotes the entrance coordinates of the cruise ship cabin space, which is normalized to the entrance door coordinates in the local coordinate system of the cruise ship cabin space. D, R and S represent the extension, aspect ratio and area of the shape of the cruise ship cabin space, and D and S describe the area of the polygon formed by the horizontal and irregular edges of the rectangular shape of the cruise ship cabin space, respectively.

If the geometric characterization of the cruise ship cabin space is expressed as F, it can be described as:

$$F = (K_x, K_y, D, R, S)\,. \tag{1}$$

The functional area of the cruise ship cabin space is the cruise ship interior space layout object, with (x_p, y_p) indicating the layout object location coordinate attribute, the calculation formula is as follows:

$$\begin{cases} x_p = \frac{x}{W} \\ y_p = \frac{y}{L} \end{cases} \tag{2}$$

where x and y denote the coordinate values of the position points of the layout object in the xoy-plane on the x-axis and y-axis, respectively, and x_p and y_p are in the range of $[0, 1]$. If ξ_p is the orientation attribute, it is described by the following equation:

$$\xi_p = \frac{\xi}{\frac{\pi}{2}+1}, \tag{3}$$

where ξ denotes the orientation angle of the layout object in the interior space of the cruise ship.

If (l_p, w_p) is the dimensional scale, it is described as:

$$\begin{cases} l_p = \frac{l_y}{L} \\ w_p = \frac{l_x}{W} \end{cases} \tag{4}$$

Based on the above attributes it is possible to obtain layout attributes $\pi(M)$ for the layout object M in the cruise ship cabin space:

$$\pi(M) = (x_p, y_p, \xi_p, l_p, w_p)\,. \tag{5}$$

For the cabin space of the cruise ship to be laid out, the 2D drawings are imported through the virtual reality platform, and the layout attributes of the layout objects are defined to generate a 3D spatial model of the cabin space.

III. A. 2) 3D modeling of layout elements

Based on the constructed 3D spatial model, the layout elements within different layout objects are modeled one-to-one with the layout attributes of the layout objects as constraints, and the rendering and baking processes are implemented.

The process of constructing 3D geometric models of layout elements within the 3D Studio MAX platform and determining the shape feature extraction of layout elements is [26]:

$$Q(i) = \sum_{j=0}^{i} p_i(j) = \sum_{j=0}^{i} \frac{n_i}{n} \qquad \text{for all } i = 0, 1, 2, \cdots, L-1. \tag{6}$$

Based on the attribute feature $Q(i)$ of the layout element, stereo matching of optical imaging of the layout element is carried out, thus realizing the rendering of the screen effect of the layout element and completing the stereo matching of the color, form and pattern of different layout elements within the layout object of the cabin space. In the process of constructing multi-level details of layout elements, the separation surface cropping method is selected, and the color matching degree is determined by setting the attribute value, and the function expression is determined as follows:

$$\hat{f}(x,y) = \begin{cases} g(x,y)-1, & g(x,y)-\hat{f}_{Lee}(x,y) \geq t, \\ g(x,y)+1, & g(x,y)-\hat{f}_{Lee}(x,y) < t, \\ g(x,y), & \text{else}. \end{cases} \tag{7}$$

Using the above equation, we are able to obtain the joint estimation coefficients $\hat{f}\,(x,y)$ for the rendering of the different layout elements, and in accordance with the GPU rendering of the VR imaging, determine the $3D$ model size information difference C_i for the different layout elements:

$$C_l = \begin{cases} 1, & l = 0, L, \\ \left[2\pi \cdot \frac{D}{2} \cdot \frac{\sin\eta}{l_t}\right], & l = 1, 2, \cdots, L-1, \end{cases} \tag{8}$$

where $l_t = \pi \cdot \frac{D}{2L}$ denotes the holographic projection pixel value.

Within the layout objects, the weight coefficients are used to correct the reconstruction errors of the layout element models to realize the view reproduction of different local elements within different layout objects in the cruise ship cabin space.

III. A. 3) Interactive VR layout scene generation

The sixth rod is the corresponding rod of the binocular camera during the interactive roaming control of the layout scene, and its position and attitude are affected by the fourth and fifth rods. The rotation angle of the fourth lever centered on axis Z is represented by ∂, which controls the rotation motion of the binocular camera. ϕ indicates the rotation angle of the fifth rod centered on axis Z, whose main function is to control the tilt movement of the binocular camera. With σ indicating the rotation angle of the sixth rod member centered on axis z, which is used to control the panning control of the binocular camera. ${}^4P_0$ indicates the position of the fourth rod relative to the base coordinate system, and its components in the x-axis, y-axis and z-axis are indicated by P_x, P_y and P_z, respectively.

Through the input devices σ, ϕ, σ and ${}^4P_0$ are determined and they are used as known conditions for the implementation of the motion control of the camera. According to the kinematic relations between the different rods of the virtual robot it is possible to determine the matrix of chi-square variations between the different virtual rods, which is described by the following formula [27]:

$$ {}_0^4T = \left[\frac{R(z_3, \partial)}{0} \left| \frac{{}^4P_0}{1} \right. \right], \tag{9} $$

$$ {}_4^5T = \left[\frac{R\left(y_4, -\frac{\pi}{2}\right)}{0} \left| \frac{0}{1} \right. \right] \left[\frac{R(z_4, \phi)}{0} \left| \frac{0}{1} \right. \right], \tag{10} $$

$$ {}_5^6T = \left[\frac{0}{0} \left| \frac{T_{rans}(x_5, d_5)}{1} \right. \right] \left[\frac{R\left(x_5, -\frac{\pi}{2}\right)}{0} \left| \frac{0}{1} \right. \right] \left[\frac{R(z_5, \sigma)}{0} \left| \frac{0}{1} \right. \right], \tag{11} $$

where, $R(A, \varepsilon)$ and $T_{rans}(A, \delta)$ describe the rotation matrix formed by rotating the local coordinate system by ε angles around A axes and the translation matrix formed by translating δ according to A axes, respectively. Based on the above process, the position of the binocular camera during the interactive roaming control of the layout scene is obtained according to the DH kinematic method, described by the formula:

$$ {}_0^6T ={}_0^4 T_4^5 T_5^6 T. \tag{12} $$

Under the interactive roaming control of the cabin space layout scene, it realizes the functions of revealing and hiding different layout elements in the layout object, replacing the materials of layout elements, and replacing and adjusting different elements. Finally, the interactive cabin space layout scene is generated.

III. B. Visual information acquisition of cabin spatial layout

The main function of the visual feature acquisition of the spatial layout of the cruise ship cabin is to clarify the corresponding relationship between the planar image of the indoor spatial layout acquired by the fisheye camera and the three-dimensional points, to acquire the corresponding color information (including its own color and light irradiation), and to carry out the indoor spatial calibration based on the three-dimensional vision.

III. B. 1) Light and shadow effect design

The light and shadow effect is a light and dark effect produced by the transformation of the position between the object and the reflecting mirror. The correlation between the sensor plane and the reflecting mirror surface during the light and shadow transformation is:

$$ \delta p = \delta \begin{bmatrix} Y''T \\ E'' \end{bmatrix} = \delta \begin{bmatrix} j(\|h''\|) \\ d(\|h''\|) \end{bmatrix} = P \cdot M, \delta > 0, \tag{13} $$

where δ and p are the matching coefficients and indoor spatial coordinates, Y'' and E'' are the reflecting mirror surface and sensor plane, and T is the distance between the spatial point and the reflecting mirror surface. $j(\cdot)$ and $d(\cdot)$ are the visual parallax function and the linear recombination equation of light transformation of the indoor spatial layout display, h'' is the distance between any point in the imaging plane and the center point of the plane, and P and M are the center coordinates of the spatial point and the projective image matrix, respectively.

The correlation between the fisheye camera imaging plane and the indoor space layout plane is:

$$ h'' = Qh' + t. \tag{14} $$

Is obtained by introducing Eq. (14) within Eq. (13):

$$\delta p = \delta \begin{bmatrix} j\left(\|Qh' + t\|\right) \\ d\left(\|Qh' + t\|\right) \end{bmatrix} = P \cdot M, \qquad \delta > 0. \tag{15}$$

Due to the existence of two-side symmetry properties of the hyperboloid of the fisheye camera, the function f is described using Eq. (15) to obtain:

$$f\left(\|h''\|\right) = a_0 + a_1 \|Qh' + t\| + a_2 \|Qh' + t\|^2 + \cdots + a_n \|Qh' + t\|^n, \tag{16}$$

where a_n is the angle of incidence of the spatial viewpoint of the cruise ship cabin.

The use of fisheye camera to obtain the indoor space layout plane image by the quality of the device and other external factors have a greater probability of bias, need to contain the deviation of the non-ideal imaging model is converted to:

$$\delta p = \delta \begin{bmatrix} h'' \\ f\left(\|h''\|\right) \end{bmatrix} = \delta \begin{bmatrix} Qh' + t \\ f\left(\|Ah' + t\|\right) \end{bmatrix} = P \cdot M, \qquad \delta > 0. \tag{17}$$

III. B. 2) Color layout design

In the process of calibrating the indoor space of the cruise ship cabin, the correlation between the 3D indoor space points and the 2D imaging pixels is constructed and solved based on the panoramic 2D image of the indoor space layout acquired by the fisheye camera in 360°.

After determining the parameters related to the indoor space, the correlation between the 2D imaging image plane pixel points and the image incident points is constructed, and the formula is described as follows:

$$\tan \alpha = \frac{\delta p}{q_0 + q_1 \|Qh' + t\| + q_2 \|Qh' + t\|^2 + \cdots + q_n \|Qh' + t\|^n}. \tag{18}$$

Under the indoor space calibration condition, the 3D coordinates of the points in the space are initially obtained to extract the color information and coordinate information within the 3D view of the indoor space, and the formula is described as follows:

$$\begin{cases} g_{j(z)} = \frac{j(z)}{\cos \alpha_w}, \\ \alpha_{j(z)} = \arctan \frac{q_0 \|h''\|}{q_2 \|j(z) \beta_w^2\|}, \end{cases} \tag{19}$$

$$\begin{cases} x = g \cos \alpha, \\ y = g \cos \beta, \\ z = g \sin \alpha, \end{cases} \tag{20}$$

where g describes the proximity between a point in space and the origin of the coordinates.

III. C. Versatile spatial transformations for geometric modeling

The 3D geometric modeling is mainly based on the results of visual feature acquisition to construct a 3D model of the interior space layout display within the 3ds MAX software. The feature extraction expression for the display shape of the multifunctional space conversion in the cruise ship cabin is as follows:

$$V(i) = \sum_{j=0}^{i} p_i(j). \tag{21}$$

Based on the image attribute characteristics of the cabin space display optical imaging three-dimensional alignment, through the rendering to obtain high-level texture of the imaging effect, to complete the three-dimensional alignment between the color, light, form and pattern of the cruise ship cabin space display.

According to Eq. (10), the joint estimation parameters for the rendering of the indoor space display are determined, and in accordance with the GPU rendering of the optical VR imaging of the indoor space display, the standardized Dirac decomposition is implemented to determine the 3D geometric modeling scale information parameter of the indoor space, which is described by U_t:

$$U_t = \left[2\pi \cdot \frac{D}{2} \cdot \frac{\sin \eta}{l_{triangle}} \right] \hat{f}\left(x, y\right), \tag{22}$$

where l and L describe the holographic projection pixel value and the total length of the spatial distribution contour in the cabin, respectively, $l_{triangle} = \pi \cdot \frac{D}{2L}$. Using the above equation, we can get the 3D geometric modeling scale information parameter of the cruise ship, through which we can provide data support for the multifunctional spatial transformation in the interior design of the cruise ship in order to generate the three-dimensional simulation image.

IV. Visualization and Analysis of Spatial Transformations in Cruise Cabins

This chapter establishes a cruise ship cabin space design scheme for visualization assessment and analysis. Its purpose is to reduce the workload of repetitive calculations, improve the accuracy of the evaluation results, increase the sense of immersive reality, realize roaming in the virtual luxury cruise ship as well as real-time verification of the overall environment and facilities and equipment features. The feasibility and rationality of the program is evaluated in the most intuitive and accurate way, so that the visualization design of the space in the cruise ship cabin becomes a strong practical, easy-to-operate, structurally sound, and operationally reliable method as much as possible.

IV. A. Overview of target cruise ships

The cruise ship has a gross tonnage of about 124,800, an overall hull length of 376.2m, a beam of 36.5m, 2,054 staterooms, and can carry 5,428 passengers at the same time. The cruise ship has comfortable living space, complete living facilities, and provides a wealth of entertainment activities. The living and entertainment area has 12 floors with several cinemas and small theaters, large theaters, duty-free stores, various restaurants, libraries, arenas, gyms, bars, cafes, art galleries, youth activity centers, SPA centers, water parks, swimming pools, and other facilities. In this paper, the representative 8th deck general arrangement scheme is selected as the evaluation object of visualization general arrangement design scheme. There are six main vertical zones on the 8th deck of the cruise ship from the bow to the transom direction, with zones 1 and 2 being the passenger accommodation area, designed with more than a hundred passenger cabins such as sea-view rooms and inner cabins, zone 3 being the recreational areas such as open-air parks, swimming and dining areas, zones 4 and 5 being the large-scale restaurant concentration areas, and the transom in zone 6 being the open-air bathing area and dining area.

IV. B. Application of VR technology in cabin space layout

IV. B. 1) Optimal layout design of cabin space

The facility layout problem is similar to the ship space or cabin layout problem, and the facility, internal structural walls and floors can be regarded as the ship's cabins, watertight transverse bulkheads and decks respectively. In this paper, under the VR environment, the optimal layout of cabin space is applied to the optimal layout of the cabin of a large cruise ship, and finally the results can be compared and analyzed with the actual cabin layout by running the genetic algorithm.

A large cruise ship on the 8th floor of the living cabin layout layout location shown in Figure 3, the target optimization cabin for the dotted line box selected area, which consists of 20 with a curved boundary shape compartments. The sequence of cabins is: living cabin 1 (1), living cabin 2 (2), living cabin 3 (3), lavatory 1 (4), lavatory 2 (5), lavatory 3 (6), galley (7), dining room (8), pantry (9), activity room (10), recreation room (11), library (12), power distribution room (13), washroom (14), storeroom (15), medical room (16), ambulance room (17), medicine room (18), tool room (18), and maintenance room (20). Each deck has two watertight transverse bulkheads, two horizontal passages, and two vertical passages, which we can simplify to optimize the facility space layout problem discussed previously.

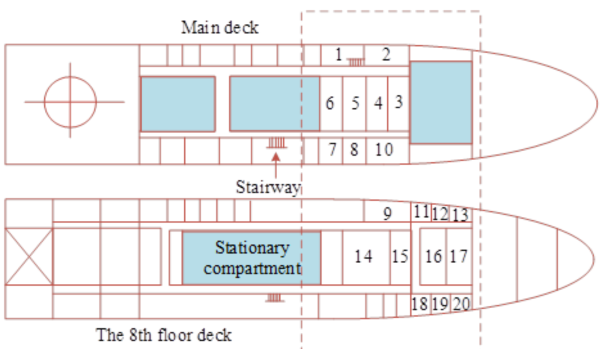


Figure 3: Living cabin layout position

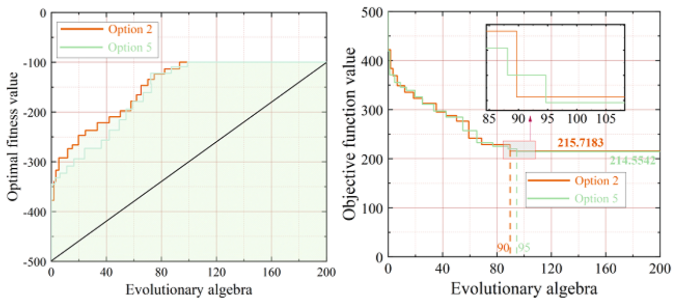
The construction of the optimal cabin space layout optimization mathematical model has been completed in the previous section III-A, and in this paper, the mathematical model will be optimally solved by genetic algorithms to obtain a number of feasible Pareto solution sequences X, which together constitute the set of feasible cabin space layout solutions [28].

According to the algorithm flow, Matlab programming was used to carry out the calculation. The algorithm parameters are set as follows, population size $N = 100$, maximum evolutionary generations $G_{max} = 200$, crossover probability $P_c = 0.8$, mutation probability $P_m = 0.2$, algorithm stopping criterion for evolutionary generations k to reach the upper limit G_{max}, and the set of Pareto sequence solutions is calculated as shown in Table 1. There is no absolute optimal solution for cabin layout optimization, and all the optimized solutions are Pareto solutions, i.e., non-inferior or efficient solutions. Each cabin sequence solution can be analyzed and constructed to generate feasible layout schemes, of which the objective function values of schemes 2 and 5 are 215.7183 and 214.5542 respectively, which are the highest among the 10 schemes. The size of the objective function value of a solution reflects its relative degree of satisfaction of the optimization objective. The compartment layout problem studied in this paper is in fact based on the optimized compartment segment layout design problem, so no assumptions are made about the compartment layout before optimization.

Option	Cabin sequence	*F*(*X*)
1	16-1-6-4-18-17-11-10-3-8-7-9-15-14-5-12-2-20-19-13	208.7253
2	16-12-6-4-17-18-10-11-1-8-9-7-15-14-5-2-3-13-20-19	215.7183
3	16-13-14-6-17-18-10-11-1-8-7-9-4-5-15-12-2-19-20-3	203.478
4	3-1-17-18-4-6-10-11-16-8-7-9-14-15-5-12-2-13-20-19	211.8823
5	10-3-6-11-16-14-7-9-8-1-12-15-18-17-5-4-2-20-19-13	214.5542
6	10-2-5-1-15-14-7-9-18-3-12-16-17-8-4-6-11-13-20-19	203.797
7	3-1-18-17-4-6-10-12-16-7-9-8-14-15-5-11-2-13-20-19	201.8605
8	10-6-3-16-11-14-9-7-8-1-12-15-18-17-5-4-2-20-19-13	206.3501
9	10-2-5-1-15-14-7-9-18-3-12-17-16-4-8-11-6-13-19-20	205.8214
10	16-2-6-4-18-17-11-10-3-8-7-9-15-5-14-12-1-19-13-20	214.2254

Table 1: Pareto sequence solution set of cabin layout and its objective function values

For the above solution sets, when only considering cabin adjacencies and circulation, Scenarios 2 and 5 have the largest $F(X)$, indicating that they are integrally optimal in these two aspects. The adaptation value curves of the two spatial layout schemes, as well as the objective function value curves, are shown in Figure 4, respectively. It can be seen that Scheme 2 completes the convergence faster than Scheme 5, and the objective value is larger, indicating that Scheme 2 is easier to achieve the comprehensive optimization in the two aspects of adjacency and circulation.



(a) Optimal adaptive value (b)Optimal target function

Figure 4: Curves of adaptation value and objective function value of two spatial layout schemes

According to scheme 2, the size of each cabin is adjusted, and the spatial layout design is carried out in the plane of the cabin section, and the optimal spatial arrangement of the living compartments on the 10th floor of the cruise ship is obtained as shown in the sketch of Figure 5.

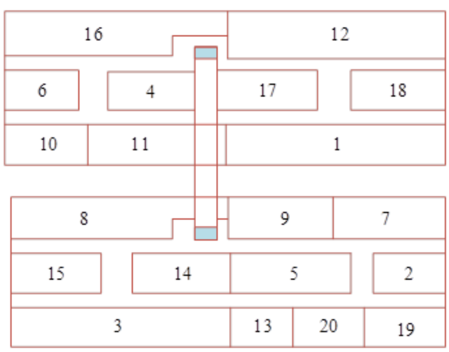


Figure 5: Sketch of cabin space layout for option 2

IV. B. 2) Assessment of space accessibility in cruise cabins

Modern cruise ships have a wide range of entertainment facilities for passengers to enjoy a diverse range of cruise experiences and services, including dining, entertainment, recreation, shopping, fitness and more. Cruise ships have a large number of deck levels, and passengers need to use elevators or stairs frequently during a full round-trip cruise. The convenience of cabin access is related to the distance to the nearest elevator/stairwell. The importance of cabin access convenience is better demonstrated when passengers use the elevators or stairs at a high frequency. The following is a specific assessment of the access convenience of the optimal living cabin space layout in Option 2 above.

Obviously, the closer the cabin is to the elevator/stairwell, the higher the accessibility. In order to calculate the accessibility of the interior spaces of the cruise ship, the overall superstructure space of the cruise ship is roughly divided into 6 zones based on the vertical positions of the 3 elevators/stairwells as shown in Figure 6.

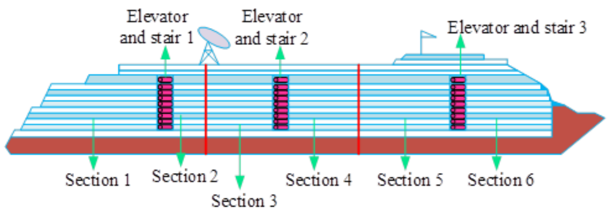


Figure 6: Space division of cruise superstructure

The access convenience calculation for 2054 passenger cabins of the layout target cruise ship was summarized to obtain the distance between the passenger cabins and the nearby elevators/stairwells in six regions as shown in Figure 7. It can be seen that the passenger cabins located in regions 2 to 5 are relatively close to the nearby elevators/stairwells, of which the maximum distance between region 5 and the nearby elevators/stairwells is 31522 mm, and the average distance between region 4 and the nearby elevators/stairwells is 16,060 mm, which represents that all the passenger cabins in the spatial layout plan 2 are at a medium level of access convenience, which is a general level acceptable to the passenger cabins of this cruise liner in terms of the design of access convenience, and the access convenience of the passenger cabins in this region is considered to be relatively suitable. It is considered that the accessibility of the passenger cabins in this region is relatively appropriate and general.

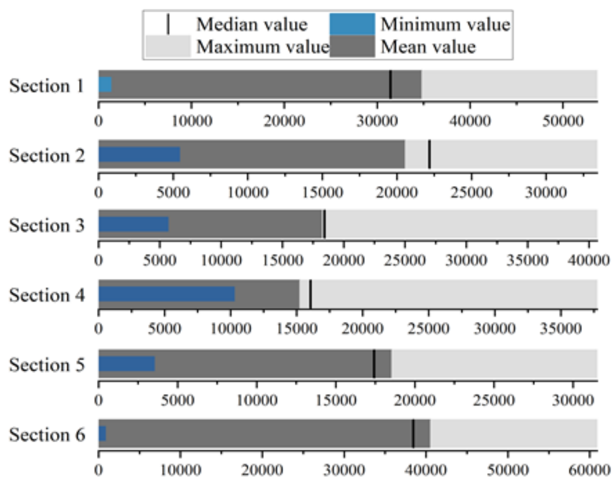


Figure 7: Summary of cruise cabin access accessibility (mm)

The cabins located in the aft section of Area 1 and the bow section of Area 6, on the other hand, are relatively far away from the nearby elevators/stairwells, with a maximum distance of 53,680 mm and 60,110 mm, respectively, which is far from that of the cabins in Areas 2 to 5, and it can be considered that the accessibility of the cabins in these areas is relatively poor.

IV. C. Analysis of the effect of optimal layout of cabin space

Observing the optimized layout plan, the crew accommodation, crew office, ward room and other cabins are centrally located and far away from the kitchen, power distribution room and other cabins that generate fumes or noise. The dining room is surrounded by cabins such as crew cabins and offices, and the circulation distance of personnel is shorter. Wards and infirmary, kitchen and dining room, and two crew cabins, which have a high demand for adjacency, are all located next to each other. In summary, the layout plan derived from the method of this paper not only conforms to the cruise ship design guidelines, but also better meets the actual living needs of the guest sources, and improves the convenience of work and the comfort of living.

In order to further verify the effectiveness of the cruise ship cabin space layout optimization method based on VR technology proposed in this paper, the results of calculating the objective function values of the original cabin space layout scheme of the cruise ship using the established mathematical model are shown in Figure 8. The objective function values of cabin adjacent strength $F1$, cabin away strength $F2$ and cabin circulation strength $F3$ of the original layout scheme are 79.51, 80.33 and 87.26 respectively, and the corresponding values of the three functions of the layout scheme optimized by the method of this paper are 83.16, 93.86 and 99.32 respectively. After calculation, the three indexes are optimized by 4.59%, 16.84% and 13.82% respectively. 13.82%. It can be concluded that the cruise ship cabin space layout optimization method based on VR technology proposed in this paper is feasible in solving the cruise ship cabin space layout problem. The optimal cabin layout derived from this paper's method is superior only in three aspects: cabin adjacency strength, cabin away strength, and cabin circulation strength, which can be adjusted by the designers and shipowners according to other needs.

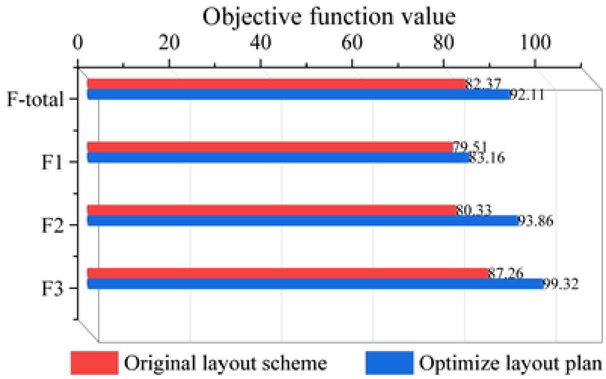


Figure 8: Comparison of the effect of layout schemes

V. Conclusion

VR technology can provide a more realistic experience of the layout design of cruise ship cabin space, and the experience of interactive virtual scenes also makes people's perception of the effect of cruise ship cabin space design more comprehensive. In this study, a visual assessment of the total layout of the cruise ship space is carried out based on VR technology and space layout optimization method, which helps to improve the design accuracy, shorten the design cycle, reduce the technical risk, reduce the waste of resources and improve the design level. However, it should be noted that when constructing the 3D spatial model of the cruise ship cabin and rendering it with animation, the designer should incorporate the elements of color, lighting and texture texture to make the rendering effect of the furniture and artifacts in the cabin more realistic. Only in this way, after importing the 3D model database of the cruise ship cabin space into the VR environment, can we fully experience the realistic effect of the cabin, so as to truly realize the interaction with the cabin space.

After importing the cruise ship cabin space model into the VR environment, the generated VR scene can be changed at will, and people only need to edit the model to realize. Designers can use the VR editor to position the required replacement items, and then re-edit and run to generate new scene interaction effects. The test found that compared to the original layout scheme, the cabin adjacency strength, cabin away strength and cabin circulation strength of the optimized scheme are improved by 4.59%, 16.84% and 13.82% respectively, which helps designers to make accurate designs according to passenger needs. It can be seen that the spatial design of cruise ship cabins based on VR technology is of great significance, which can effectively improve the interior design effect of cruise ship cabins, and has an important role in the development of the cruise market that cannot be ignored.

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