

Optimal path finding in 3D environment: Application for the exhibition space through 3D visualization and BIM

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Abstract. The application of 3D visualization technology in building construction has also increased. The study used Revit software to construct a 3D building information model (BIM) for the exhibition space of Chuzhou Higher Education City Development Collaborative Innovation Center to achieve a 3D visualization display; based on the 3D visualization, a particle swarm optimization (PSO) algorithm was used to find the optimal path for the exhibition space, so as to achieve the layout design of the exhibition space. The PSO algorithm was optimized in terms of inertia weight, acceleration coefficient, and initial population to obtain the improved PSO (IPSO) algorithm. The experimental results showed that the optimal path found by the IPSO algorithm was 78.56 meters in distance, 98.2 seconds in time consumption, and 50.11% in smoothness, which were better than the other two algorithms. Meanwhile, the IPSO algorithm had a lower value of particle fitness function, indicating that the IPSO algorithm had the highest performance and the strongest path finding ability among the three algorithms. It is confirmed that it is feasible to use the IPSO algorithm for optimal visit path finding in 3D environment. It is effective to visualize the exhibition space in 3D by constructing a BIM.

Keywords: 3D visualization / Spatial design / Building information model / Particle swarm optimization algorithm

1 Introduction

With the rapid development of computer technology, computer 3D visualization techniques have been widely used in the architectural industry, mainly including 3D simulation software and some 3D modeling tools [1]. The application of these 3D visualization techniques to architectural space design has greatly improved the perceptibility, interactivity, immersion, and other characteristics for designers and visitors. Related research on exhibition space design are as follows. Zhang et al. [2] used MultiGen Creator 3D modeling technology to reconstruct the interior landscape. The simulation results showed that 3D virtual visualization technology had a good guidance for interior design, visual effects, and landscape color integration. Zhang [3] proposed an augmented reality-based architectural scene framework. The experimental results showed that the framework had features of realistic immersion and easy scalability, which can help designers to evaluate architectural designs more rationally. Mizobuti et al. [4] proposed a new method using structural topology optimization to evaluate and generate bionic architectural designs, and experimentally demonstrated that it was

feasible to use structural topology optimization techniques as a basis for generating innovative ideas to solve complex architectural stability problems. Jin et al. [5] proposed an innovative PtD tool with the designer as the primary end-user. After a case study, the results showed that the tool was able to assess safety risks throughout a multi-story project and visualize the safety risks before construction. Lu [6] mainly used building information model (BIM) techniques to initially construct virtualized building models. The experimental results showed that BIM-based building design had the advantage of low resource consumption and high safety factor. Tafraout et al. [7] proposed an innovative method based on the genetic algorithm that automatically exports the best structure for a given building configuration in industry foundation class format or BIM platform. The obtained results showed that the proposed method was very effective in generating optimal structures that meet the predefined criteria and satisfy the structural design requirements for the considered building configurations. In terms of path optimization, Ning et al. [8] designed a new pheromone smoothing mechanism to improve the ant colony optimization algorithm for path optimization. The experiment found that the method was better in terms of solution diversity and convergence speed. Zhu et al. [9] designed an algorithm

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combining the particle swarm optimization (PSO) algorithm and the genetic algorithm for solving the rescue path optimization problem in passenger ship tilting accidents and proved the feasibility of the algorithm through simulation experiments. Zhu et al. [10] proposed a reverse order labeling algorithm based on the traditional Dijkstra algorithm. Simulation experiments showed that the method had good stability and efficiency. The PSO algorithm is a common method in path optimization, but its accuracy still needs to be improved. Therefore, this paper optimized the PSO algorithm in terms of inertia weight, acceleration coefficient, and initial population. The 3D BIM of the exhibition space of Chuzhou Higher Education City Development Collaborative Innovation Center was constructed using Revit software to achieve a 3D visual representation of the exhibition space; on this basis, the improved PSO (IPSO) algorithm was used to optimize the path of the exhibition space in the 3D environment to achieve the layout design of the exhibition space. The reliability of the IPSO algorithm on path optimization was proved by experimental analysis. The research in this paper not only verifies the reliability of 3D BIM in spatial design and provides a new algorithm for path optimization, but also provides theoretical support for further optimization of the PSO algorithm.

2 Build a 3D visualization model of science and technology display space

2.1 3D visualization

Initially, 3D visualization was applied to show, describe and understand the characteristics of many geological phenomena underground and on the ground, and later it was also applied in architectural design management. In architectural design, 3D visualization refers to the use of computer graphics technology, through the modeling of three-dimensional objects, photography and rendering to generate three-dimensional images, can achieve real-time modeling of three-dimensional objects, display and interaction. That is, the space and the actual situation, which was not clearly displayed in the 2D plan, is actually displayed in 3D. This paper will also study the science and technology display space from the 3D level. Compared with the 2D visualization analysis used previously, 3D will be closer to the real state of people's experience in the science and technology display space. By designing the technology display space through 3D visualization, it is believed that more accurate and practical design results can be obtained.

2.2 3D visualization model construction

2.2.1 Software selection

To achieve 3D visual modeling of space in research, a more widely used approach is based on 3D modeling tool software for modeling. The usual 3D design software, such as SketchUP [11], Rhino [12], Revit [13], etc., can be used for 3D visualization model creation. In this paper, Revit software is chosen to draw the BIM 3D architectural model of the exhibition space. Revit is built for BIM, and in the

current construction industry BIM system is one of the most commonly used software, and is often applied to the spatial structure of buildings for display and simulation.

2.2.2 3D BIM construction

BIM [14] has emerged to provide a three-dimensional visualization idea, overcoming the problem that traditional two-dimensional drawings cannot visually show the real structure of the building, which can help to save the building cost and improve the building quality, and the effect of BIM can be maximized if it is combined with technologies such as artificial intelligence and machine learning [15]. When BIM technology is applied to the design of science and technology exhibition space, the building entity can be reflected by using 3D graphics, which can better identify the errors and unreasonable points in the design process. In this paper, BIM technology was applied to the 3D visualization design of science and technology exhibition space. The steps to build a BIM in Revit software are as follows:

- determine identify specific information about the project through field measurements, aerial photography by drones, etc., and then establish a ground plane;
- create large building model elements and incorporate structural and system components into the building model;
- refine the model by adding detail information and refining the appearance of the model;
- produce a pseudo-true image of the modeling model in order to present the design to the client.

3 Research on spatial design by path optimization under 3D visualization model

3.1 PSO algorithm

After the construction of the 3D BIM of the exhibition space of the Chuzhou Higher Education City Development Collaborative Innovation Center above, how to design the layout of the exhibition space by finding the optimal path becomes the next research goal of this paper. The PSO algorithm [16] is initialized as a group of random particles, and the particles are updated by tracking two “extreme values” ($pbest$, $gbest$) in each iteration. After finding these two optimal values, the particles update their velocity and position by the following two formulas.

$$v_i = v_i + c_1 * rand() * (pbest_i - x_i) + c_2 * rand() * (gbest_i - x_i)$$

$$x_i = x_i + v_i$$

where i denotes the total number of particles in the cluster, v_i denotes the velocity of the particles (the maximum value is v_{max} , greater than 0), $rand()$ denotes a random number in $(0, 1)$, x_i denotes the current position of the particles, and c_1 and c_2 are acceleration coefficients, which are usually equal and equal to 2.



Fig. 1. The design diagram of the exhibition space in Chuzhou Higher Education City Development Collaborative Innovation Center.

The algorithm has the advantages of easy to understand principle and easy to implement, but also has disadvantages such as easy to fall into local optimal solution and poor local search ability. Therefore, to address these disadvantages, this paper improved the PSO algorithm from three perspectives.

First, the inertia coefficient of the PSO algorithm is adjusted and improved, and the adjusted inertia coefficient formula is:

$$w = w_{\max} - (w_{\max} - w_{\min}) \frac{iter}{iter_{\max}}$$

where w_{\max} and w_{\min} are the maximum and minimum inertia weights, respectively, $iter$ denotes the number of current iterations, and $iter_{\max}$ denotes the maximum number of iterations. The optimization of the algorithm is accomplished by the above equation, i.e., inertia weight w is reduced by increasing the number of iterations, which allows the PSO algorithm to improve its global and local convergence capabilities.

Then, the value of the acceleration coefficient is adjusted. The update formula of the adjusted acceleration coefficient is:

$$\begin{cases} c_1 = c_{1e} + (c_{1e} - c_{1s}) \arcsin \frac{iter}{iter_{\max}} \\ c_2 = c_{2s} + (c_{2e} - c_{2s}) \arcsin \frac{iter}{iter_{\max}} \end{cases}$$

where c_{1s} and c_{1e} are the start and end values of c_1 , and c_{2s} and c_{2e} are the start and end values of c_2 .

Finally, to obtain particles with relatively even distribution, the logistic mapping model is used to generate the initial population, and the expression is:

$$x_{i+1} = 4x_i(1 - x_i), x_i \in (0, 1), i = 1, 2, \dots, N - 1$$

3.2 Introduction to the study area

The exhibition space of the Collaborative Innovation Center for the Development of Chuzhou Higher Education City was selected as the subject of this paper, with a total building plane area of 1,209 m² (36 m × 33.6 m). The layout of this exhibition space adopts the layout of large space into small space, and the place is divided into preface hall, origin chapter, integration chapter, innovation chapter, and future chapter. The overall blue and white tone of the exhibition hall is soft and clean, visually playing a role of integration and expansion. The material is flat and sharp to emphasize the futuristic feeling of the exhibition hall. The lighting of the exhibition hall combines area light source and linear light source. The area light source can evenly cover the exhibition hall, making the exhibition environment softer and improving the viewing experience of visitors. The linear light source enriches the surface light source level, making the exhibition hall level rich and dynamic. [Figure 1](#) shows the overall effect diagram of the project.

4 Experiment and analysis

4.1 Experimental design

Since the case object of the experiment was determined to be the exhibition space of Chuzhou Higher Education City Development Collaborative Innovation Center, this experiment first required the use of Revit software to construct the 3D BIM of the case and realize the 3D visualization display of the exhibition space. According to the constructed 3D model, the start position (S) and destination position (D) of the path planning were determined. Then, the designed IPSO algorithm was used to find the optimal path of the exhibition space in the 3D visualization environment. The optimal path search result of the IPSO algorithm was compared with that of the ant colony optimization (ACO) algorithm [17] and artificial bee colony (ABC) algorithm [18] to prove the feasibility of using the IPSO algorithm. The population scale of the ACO algorithm was 30, and the maximum number of iterations was 400. The population scale of the ABC algorithm was 40 (the number of scout bees was 10), and the number of iterations was 400.

4.2 Evaluation method of path finding

This study planned the optimal path according to the logic of optimal planning of path finding in the exhibition space: the shortest path distance, the shortest path time consumption, and the optimal path smoothness [19], which are three different needs of different visitors. Therefore, the path distance, time consumption, and smoothness were used as the evaluation index of the algorithm. The reliability of the PSO algorithm in finding the optimal path was proved by calculating the path distance, time consumption, and smoothness and comparing the data. The followings are the expressions for calculating the evaluation functions of the three indexes.

$$L_{SD} = \sum_{i=1}^n \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2}.$$

The above equation is the formula for calculating the path distance. L_{SD} denotes the sum of Euclidean distances between all adjacent nodes in a particle, which is the length of the whole path.

$$T_{SD} = \sum_{i=1}^n \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2} / 0.8.$$

The above equation is the formula for calculating the entire path elapsed time. In the equation, 0.8 is the average walking speed of visitors set in this paper, and its unit is m/s. The time consumed in walking the entire path was obtained by dividing the path distance by the speed.

$$S_{SD} = \sum_{i=1}^n \lambda_i.$$

The above equation is the formula for calculating the smoothness of the whole path. λ is the deflection angle λ between the two line segments of the three adjacent nodes in the path. All λ in one path was summed to approximate the smoothness of the evaluated path. The value of smoothness ranges from 0% to 100%; the larger the value, the smoother the path.

Also in order to judge the quality of the generated paths more intuitively, L_{SD} , T_{SD} , and S_{SD} were combined to obtain the particle fitness function (f) to obtain the evaluation index for judging the comprehensive quality of the generated path. The formula is:

$$f = k_1 * L_{SD} + k_2 * T_{SD} + k_3 * S_{SD}$$

In the above equation, f is a particle fitness function that combines path distance, elapsed time, and smoothness to evaluate the comprehensive quality of the path; k_1 , k_2 , and k_3 are the weight coefficients in (0, 1), which is used to flexibly configure the relationships between L_{SD} , T_{SD} , and S_{SD} .

4.3 Analysis of results

Figure 2 is a graph of the fitness function values of the three algorithms under different numbers of iterations in the 3D visualization environment. The comparison of the sum of the particle fitness function values for each path planning could reflect the ability of different algorithms in the optimal path finding. According to the rule that the smaller the sum of fitness function values, the better the planned path, it was very intuitive to see from Figure 2 that the IPSO algorithm had the lowest final particle fitness function value. This proved that the IPSO algorithm had the best performance in finding the optimal path.

The plane sketch of the path generated by the ACO algorithm, the ABC algorithm, and the IPSO algorithm in the 3D visualization environment (Fig. 3) and the path data were compared. As shown in Table 1, in terms of distance, the ACO algorithm was 111.26 m, the ABC algorithm was 95.97 m, and the IPSO algorithm was 78.56 m; in terms of time consumption, the ACO algorithm was 124.56 s, the ABC algorithm was 115.84 s, and the IPSO was 98.2 s; in terms of smoothness, the ACO algorithm was 35.62%, the ABC algorithm was 42.36%, and the IPSO algorithm was 50.11%. It was found that the evaluation index values of the IPSO algorithm were better than the other two algorithms in terms of path distance, path time consumption, and path smoothness. This proved that the optimal path found by the IPSO algorithm had the shortest distance, the shortest time consumption, and the best smoothness, and was most consistent with the logic of path optimization planning of the exhibition space determined in this study.

From Table 2, it was seen that in the 3D visualization environment, all three algorithms could find the optimal path, but in terms of the number of times to find the optimal path, the IPSO algorithm was significantly more than the other two algorithms, reaching eight times. In terms of the average number of iterations to find the

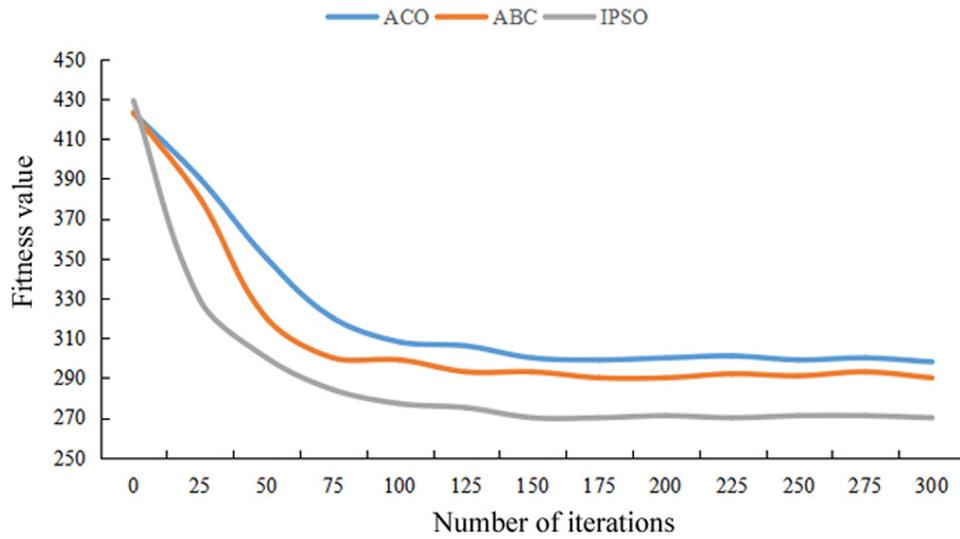


Fig. 2. Fitness value curves under different number of iterations.

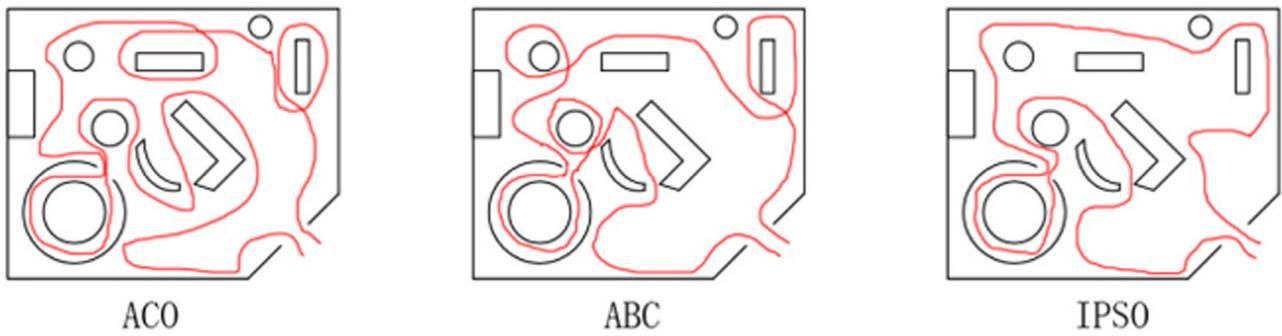


Fig. 3. Plane sketch of the paths generated by different algorithms.

Table 1. Comparison of generated paths between different algorithms.

Algorithm	Distance/m	Time consumption/s	Smoothness/%
ACO algorithm	111.26	124.56	35.62
ABC algorithm	95.97	115.84	42.36
IPSO algorithm	78.56	98.2	50.11

optimal path, it was seen that the ABC algorithm required 246 iterations, the highest, and the IPSO algorithm required 150 iterations, the lowest. In terms of the average running time to find the optimal path, the ACO algorithm

Table 2. Comparison of search results between different algorithms.

	ACO algorithm	ABC algorithm	IPSO algorithm
Number of times to find the optimal path	2	4	8
Average number of iterations to find the optimal path	207	246	150
Average running time to find the optimal path (s)	15.64	10.97	7.29



Fig. 4. Schematic diagram of the optimal path.

took the longest time, 15.64s, while the IPSO algorithm took the shortest time, 7.29 s. The results indicated that the IPSO algorithm had the highest overall performance in finding the optimal path among the three algorithms.

The optimal path found by the IPSO algorithm is reflected in the BIM 3D visualization model of the exhibition space, and the final effect picture is shown in Figure 4. The line of movement is a return type, i.e. the entrance and exit doors were the same. The location of different booths in Figure 4 is as follows:

- preface hall: leadership message and theme advertisement;
- origin chapter: Chuzhou’s strategic positioning, development advantages and development ideas;
- integration chapter: the positioning, work idea, work plan and work target of the innovation center;
- innovation chapter: the industry display, health and beauty industry, information industry, medical industry, equipment manufacturing industry, artificial intelligence industry, and innovation incubation enterprises (Rainforest Space International Incubator);
- future chapter: the service support, science and technology financial services, international innovation cooperation, dual innovation services, and innovation talent services.

5 Conclusion

This paper briefly introduced the concept of 3D visualization, BIM, and PSO algorithm. The study used Revit software to construct a 3D BIM of the exhibition space of the Chuzhou Higher Education City Development Collaborative Innovation Center to realize the 3D visualization display of the exhibition space; on this basis, the IPSO algorithm was used to optimize the path to the

exhibition space, so as to achieve the layout design of the exhibition space. The experimental results showed that the optimal path generated by the IPSO algorithm was 78.56 m in distance, 98.2 s in time consumption, and 50.11% in smoothness, which were better than the other two algorithms. It proves that it is feasible to use the IPSO algorithm to find the optimal visiting path for the spatial layout design of the science and technology display space under the environment of 3D visualization.

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