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Precise Indoor Path Planning Based on Hybrid Model of GeoSOT and BIM

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Abstract: With the improvement of urban infrastructure and the increase in the coverage of high-rise buildings, the demand for location information services inside buildings is becoming more and more urgent. Moreover, indoor path planning, as a prerequisite and basis for realizing path guidance inside buildings, has become a research focus in the field of location services. This makes the accurate planning of indoor paths an urgent problem to be solved at present. This requires dynamic and precise planning from static fuzzy planning, and the corresponding scene converted from a two-dimensional plane to a three-dimensional one. However, most of the existing indoor path planning methods focus on the use of two-dimensional floor plans in buildings to build indoor maps and rely on traditional path search algorithms for pathfinding, which lack in the efficient use of the building's own geometric and attribute information and lack consideration of the internal spatial topology of the building, making it difficult to meet the needs of indoor multi-layer continuous space path planning. Considering this relationship, it is difficult to meet the path planning needs of indoor multi-layer continuous spaces. In addition, the two-dimensional expression dominated by arrows and line drawings also greatly reduces the intuitiveness and interactivity of path expression. Regarding this, this paper combines the GeoSOT grid with accurate real geographic information and the BIM model and proposes an accurate indoor path planning method. Finally, using Guanlan Commercial Street in Baiyin City as the experimental object, the precise planning and generation of indoor paths and the interaction of visual displays on the web page are realized. It has been verified that the method has certain reference and application values for meeting the demand of location information services in buildings and building an integrated indoor–outdoor navigation service platform.

Keywords: indoor path planning; GeoSOT-A*; GIS-BIM; Map Topology Model

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1. Introduction

As the core of indoor navigation services, indoor path planning, together with indoor positioning technology and space display technology, constitute a complete indoor navigation system, which is the premise and foundation of indoor navigation services [1]. At present, with the improvement of urban infrastructure and the continuous improvement of building coverage, the need for location information services based on space in buildings are increasingly urgent in various fields of society [2], especially in some public buildings where people gather, such as large shopping malls, high-rise office buildings, etc. People often need to know their location and how to quickly reach designated shops and offices. In addition, in the field of emergency rescue, for firefighters and people trapped in buildings, sudden emergency situations require rescue and escape, respectively. Due to changes such as road damage and inoperable elevators, path planning should also have corresponding flexibility according to the different indoor environment changes [3,4]. Therefore, the research on indoor path planning needs to comprehensively consider the distribution of indoor obstacles, the opening and closing status of room doors, and the rich semantic information of indoor components.

For the path planning requirements across floors, the physical connection of elevators and escalators between floors should also be considered. However, due to the complex internal space structure of the building, which requires high precision, and the traditional GPS-based (Global Positioning System) navigation and positioning technology, which are affected by obstacles indoors causing the signal to become weak, outdoor navigation technology cannot be directly applied to indoor navigation. Therefore, the development of navigation technology in the building indoor environment, which occupies 70–80% of people's production and living space, is relatively slow.

At present, the main research methods proposed by many experts and scholars in this field are as follows:

1. A method of finding the shortest path using GPS signal transmitters or based on 2D floor plan architectural drawings [5]. However, due to the lack of basic building data information, it is difficult to ensure the accuracy of the indoor map because it cannot take into account indoor obstacle entities, and, therefore, there are many errors in the planned paths, and there are many limitations in the intuitiveness and practicality of path representation and the planning of cross-floor paths within the building.
2. The method of adding the indoor map function to the outdoor navigation map is adopted [6–9]. Users can view the interior of the building through the indoor map and can switch to different floors to view. Nonetheless, the display of the indoor map is based on the uploading of the indoor 2D floor plan, and the location information service for the 3D visualization of the interior space of the building has not yet been realized.
3. In the third method, the computer adopts the indoor path planning method based on BIM (Building Information modeling) technology [10–16]. Using the BIM model as the data source for path planning, and traversing all the nodes in the model through an algorithm, the indoor path can be obtained. However, this method is more suitable for the situation of simple building structure and a few room units. Traversing all nodes takes a lot of time, thereby affecting the optimality of the path. It lacks the efficient use of the building's own geometry and attribute information, as well as the consideration of the internal spatial topology of the building. It is difficult to meet the indoor multi-layer continuous path planning needs of the space.

Through the analysis of the above research and applications, we found a new method is urgently needed to solve the problem for the precise planning of indoor paths. Starting from the geographic space location, this paper applies the related ideas of GIS (Geographic Information System) technology to the BIM model and proposes a precise indoor path planning method based on the GeoSOT (Geographic Coordinate Subdividing Grid with One Dimension Integral Coding on 2^n Tree) grid and BIM to meet the needs. First, we took the BIM model as the data source and parsed and extracted the underlying data, including the detailed geometric and semantic information about the building. Second, using the GeoSOT subdivision grid as the data processing method, the data grid processing was realized from the bottom layer, thereby generating an accurate indoor grid topology map. Finally, the traditional advantage algorithm A* algorithm was improved and optimized, and an indoor path planning algorithm was based on the GeoSOT grid as the carrier and based on the spatial relationship of the building, it was proposed to realize the accurate path planning of indoor single-floor and multi-floor buildings.

The contribution of the method in this paper is that it applies the related ideas of GIS technology to the BIM model. To define this model more definitively, the integration of the GeoSOT grid that can accurately express the real geographic information and the BIM model, and based on this, a precise indoor path planning method is obtained. This method integrates the advantages of GeoSOT mesh accuracy and BIM model's rich geometric and semantic information. By analyzing the BIM model, information such as the coordinates inside the building can be obtained. Combined with the GeoSOT grid coding, the grid topology map of the entire building is generated. Once the grid 90 topology map is obtained, it is combined with the GeoSOT-A* algorithm proposed in this paper, and the accurate planning of indoor paths is realized.

2. Models and Methods

This section mainly introduces the method proposed in this paper in detail, and the general idea is shown in Figure 1. In the first scenario, by relying on the Cesium platform [17–19], the 96 BIM model is used as the data source to load the earth space decomposed into a multi-scale, nested space, three-dimensional grid system according to the GeoSOT subdivision technology. In the second scenario, the BIM model is meshed to generate an indoor precise mesh topology map, combined with the GeoSOT-A* algorithm, to achieve precise indoor path planning.

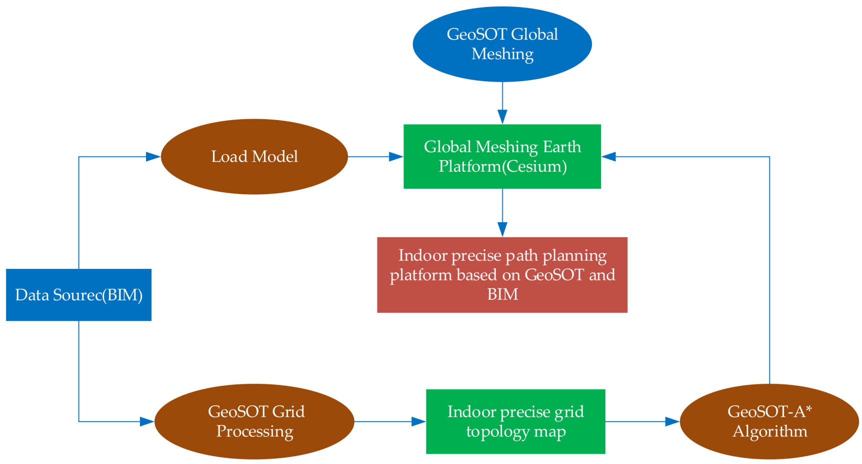


Figure 1. The General idea of the paper.

2.1. GeoSOT Global Meshing

GeoSOT is a set of global subdivision grids centered on the intersection of the prime meridian and the equator [20,21], and is divided into two-dimensional space and three-dimensional space. A 32-level multi-scale grid system is formed according to quadratic recursive division and octagonal recursion [22,23]. The core idea is to extend the earth space of the original latitude and longitude system three times (Firstly, the traditional earth region of $180° \times 360°$ is extended to $512° \times 512°$, and then the longitude and latitude of 60 decimal degrees is virtually extended to 64 decimal degrees, $1°$ is extended to $64'$, and $1'$ is extended to $64''$). Then, with the difference in the longitude and latitude of the Earth as the division range, the quadtree dissection of the whole score and whole degree is carried out for each level, and, finally, a 32-level quadtree dissection grid system of equal longitude and latitude is formed [24–26], as shown in Figure 2. In the same way, for three-dimensional space, it is also through three expansions of the Earth. The Earth space is expanded to $512° \times 512° \times 512°$, and then $1°$ is expanded to $64'$ and $1'$ is expanded to $64''$. We implemented recursive octree partitioning [26] for whole degrees, minutes, and seconds, as shown in Figure 3. The GeoSOT grid level table is shown in Table 1.

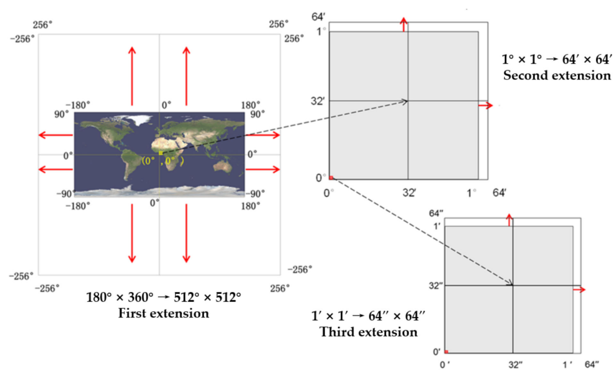


Figure 2. GeoSOT mesh three expansion process [25].

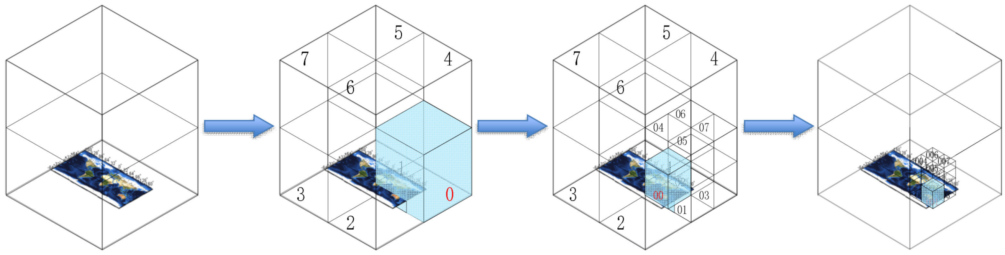
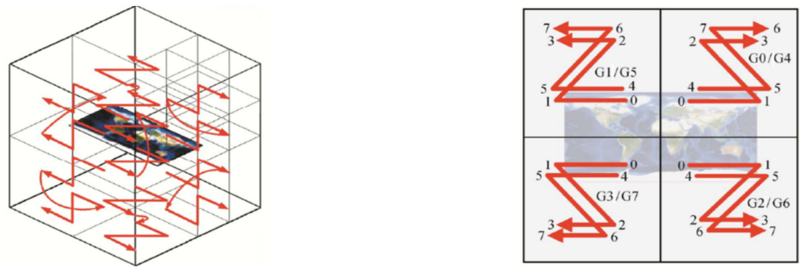


Figure 3. GeoSOT 3D meshing [26].

Table 1. GeoSOT Grid Level Table.

Level	Grid Size	Approximate Size Near the Equator
1	$256° \times 256°$	-
2	$128° \times 128°$	-
3	$64° \times 64°$	-
4	$32° \times 32°$	-
5	$16° \times 16°$	-
6	$8° \times 8°$	1024 km
7	$4° \times 4°$	512 km
8	$2° \times 2°$	256 km
9	$1° \times 1°$	128 km
10	$32' \times 32'$	64 km
11	$16' \times 16'$	32 km
12	$8' \times 8'$	16 km
13	$4' \times 4'$	8 km
14	$2' \times 2'$	4 km
15	$1' \times 1'$	2 km
16	$32'' \times 32''$	1 km
17	$16'' \times 16''$	512 m
18	$8'' \times 8''$	256 m
19	$4'' \times 4''$	128 m
20	$2'' \times 2''$	64 m
21	$1'' \times 1''$	32 m
22	$\frac{1}{2}'' \times \frac{1}{2}''$	16 m
23	$\frac{1}{4}'' \times \frac{1}{4}''$	8 m
24	$\frac{1}{8}'' \times \frac{1}{8}''$	4 m
25	$\frac{1}{16}'' \times \frac{1}{16}''$	2 m
26	$\frac{1}{32}'' \times \frac{1}{32}''$	1 m
27	$\frac{1}{64}'' \times \frac{1}{64}''$	0.5 m
28	$\frac{1}{128}'' \times \frac{1}{128}''$	25 cm
29	$\frac{1}{256}'' \times \frac{1}{256}''$	12.5 cm
30	$\frac{1}{512}'' \times \frac{1}{512}''$	6.2 cm
31	$\frac{1}{1024}'' \times \frac{1}{1024}''$	3.1 cm
32	$\frac{1}{2048}'' \times \frac{1}{2048}''$	1.5 cm

On the basis of GeoSOT grid division, whether it is the 2D grid coding or the 3D grid coding, hierarchical coding is assigned to each grid according to the "Z" sequence, as shown in Figure 4. There are various encoding forms, including binary one-dimensional encoding, binary two-dimensional encoding, binary three-dimensional encoding, quaternary one-dimensional encoding, octal one-dimensional encoding and integer encoding, etc. These encoding types can be easily converted to each other according to certain mathematical rules and 132 still have internal consistency.



(**a**) (**b**)

Figure 4. Schematic diagram of the coding sequence of GeoSOT 3D grid cells [26]. (**a**) Oblique view; (**b**) Top view.

The GeoSOT global subdivision grid coding calculation is as mentioned above. According to the rules of the GeoSOT subdivision framework, there is a conversion relationship between the GeoSOT global subdivision grid and the existing European space latitude, longitude, and altitude coordinate system. This coordinate system includes two main aspects:

1. The first aspect converts the latitude, longitude, and elevation to the GeoSOT global grid code. For example, given the longitude, latitude, and elevation of a certain point, this method finds the voxel code corresponding to the GeoSOT global grid corresponding to the point.
2. The second aspect converts the GeoSOT global grid to latitude, longitude, and elevation. This method, given a GeoSOT global grid voxel code, finds the longitude, latitude, and elevation of the positioning corner of the grid voxel code.

Based on this information, we can make the following assumptions: for any point P in the Earth space, its longitude, latitude, and elevation coordinates are $N(L, B, H)$, where $L \in [-180°, 180°]$, $B \in [-90°, 90°]$, $H \in [0, 5, 100, 000 \text{ m}]$. Its binary three-dimensional code is expressed as: $Code(CodeL, CodeB, CodeH, Level)$, where $Level$ represents the level, and $CodeL$, $CodeB$, $CodeH$ represent the longitude, latitude, and height dimension in binary one-dimensional codes, respectively. Its longitude, latitude, and elevation are converted to GeoSOT global grid code as shown in Equation (1), and the GeoSOT global grid is converted to longitude, latitude, and elevation as shown in Equation (2).

- **Longitude, Latitude, and Elevation to GeoSOT Global Grid Code.**

$$\begin{cases} CodeL_n = \begin{cases} \left[\frac{L+256}{2^{9-n}})\right]_{(2)} & 0 \le n \le 9 \\ CodeL_9 \times \left(\frac{64}{2^{15-n}}\right) + \left[(L + 256 - CodeB_9) \times \frac{64}{2^{15-n}})\right]_{(2)} & 10 \le n \le 15 \\ CodeL_{15} \times \left(\frac{64}{2^{21-n}}\right) + \left[(L + 256 - CodeB_{15}) \times \frac{64}{2^{21-n}})\right]_{(2)} & 16 \le n \le 32 \end{cases} \\ CodeB_n = \begin{cases} \left[\frac{B+256}{2^{9-n}})\right]_{(2)} & 0 \le n \le 9 \\ CodeB_9 \times \left(\frac{64}{2^{15-n}}\right) + \left[(B + 256 - CodeB_9) \times \frac{64}{2^{15-n}})\right]_{(2)} & 10 \le n \le 15 \\ CodeB_{15} \times \left(\frac{64}{2^{21-n}}\right) + \left[(B + 256 - CodeB_{15}) \times \frac{64}{2^{21-n}})\right]_{(2)} & 16 \le n \le 32 \end{cases} \\ CodeH_n = \left[H \times (\frac{2^n}{512 \times 111300})\right]_{(2)} \quad 0 \le n \le 32 \end{cases} \tag{1}$$

- **GeoSOT Global Subdivision Grid to Latitude and Longitude and Elevation.**

$$\begin{cases} L_n = \begin{cases} CodeL_{n(10)} \times 2^{(9-n)} - 256 & 0 \le n \le 9 \\ L_9 + \left(CodeL_n - L_9 \times 2^{(n-9)}\right) \times \frac{2^{(15-n)}}{60} - 256 & 10 \le n \le 15 \\ L_{15} + \left(CodeL_n - L_{15} \times 2^{(n-15)}\right) \times \frac{2^{(21-n)}}{36000} - 256 & 16 \le n \le 32 \end{cases} \\ B_n = \begin{cases} CodeB_{n(10)} \times 2^{(9-n)} - 256 & 0 \le n \le 9 \\ B_9 + \left(CodeB_n - B_9 \times 2^{(n-9)}\right) \times \frac{2^{(15-n)}}{60} - 256 & 10 \le n \le 15 \\ B_{15} + \left(CodeB_n - B_{15} \times 2^{(n-15)}\right) \times \frac{2^{(21-n)}}{36000} - 256 & 16 \le n \le 32 \end{cases} \\ H_n = CodeH_n \times \frac{512 \times 111300}{2^{32}} \quad 0 \le n \le 32 \end{cases} \tag{2}$$

2.2. Building Information Modeling

BIM realizes the integration of building information and integrates various information into a 3D-model information database [27–29]. These databases have been widely recognized by the global industry [30,31]. BIM technology has the following advantages in indoor path planning:

1. **Building data information integration.** The parametric model established by BIM technology is an integrated expression of building information. This subset covers complete building data information including geometric data, functional data, and attribute data. These data information sets are associated with each other and can be updated and recalled in real time [32]. BIM models, therefore, can be used as "building data sources" for indoor path planning. Through model analysis and information extraction, combined with GeoSOT grid division, an accurate indoor grid map can be generated, thereby laying the foundation for indoor path planning.
2. **Model information is highly versatile**. The BIM model adopts the object-oriented method to describe the complete information data of the building including the three-dimensional geometric shape information and attribute information. These object-oriented information data are editable and extensible [33]. The model information storage adopts IFC (Industry Foundation Classes) [34–36], a common data model standard in the international intelligent building field—as the 3D data interaction format. IFC regulates the various information descriptions and definitions during the use of the building information model [37]; it can, therefore, not only meet the application requirements of indoor path planning, but also support multi-platform information sharing and improve the accuracy and versatility of indoor paths from planning to expression through the introduction of information models.

2.3. Precise Indoor Path Planning

2.3.1. Indoor Grid Map Design and Construction

The indoor precise grid map is the premise of precise path planning. To generate an indoor precise grid map, it is necessary to analyze and process the BIM model data source, design the size and level of the subdivision grid, and design the data stored in a single grid unit, as shown in Figure 5. The specific steps are as follows:

1. BIM model data pre-processing, including BIM model format conversion, BIM model parsing, and BIM model coordinate conversion, which are combined.
    - Format conversion, mainly for the problem that the Cesium platform does not support loading, converts the file into an easy-to-parse and loadable GLTF file.
    - Model parsing is used mainly to parse the converted GLTF file to obtain the attributes and coordinates of each indoor building.
    - Coordinate transformation, the coordinates parsed from the BIM model, are relative coordinates. To clarify, the coordinates are the offset relative to the center point of the model. Therefore, it is necessary to unify to the WGS84 (World Geodetic System 1984).

2. The design and generation of internal grid maps of BIM models, including the design of grid size and level and the design of data storage in a single grid unit.
   - GeoSOT divides the mesh size and level design according to the size of the actual building model, selects the mesh level suitable for the scale and determines the size of a single mesh. According to the estimate of half of the actual door width, the size of a single grid used is 0.5 m (Approximate size near the equator). Referring to the GeoSOT grid level table, it can be seen the level is 27 levels.
   - The design of the storage data of a single grid unit, the coordinate information and attribute information of each component of the building obtained by analysis, such as walls, stairs, doors, and windows, etc., are analyzed and gridded separately, and finally the accurate grid map inside the building information model is generated. According to the [0, 1] binary method, it is used as a flag to judge whether the grid is passable or not. Among them, 0 is passable and 1 is not passable.

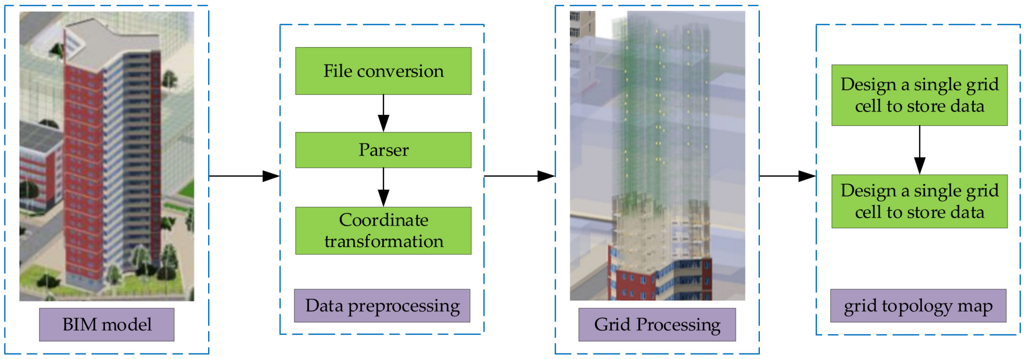


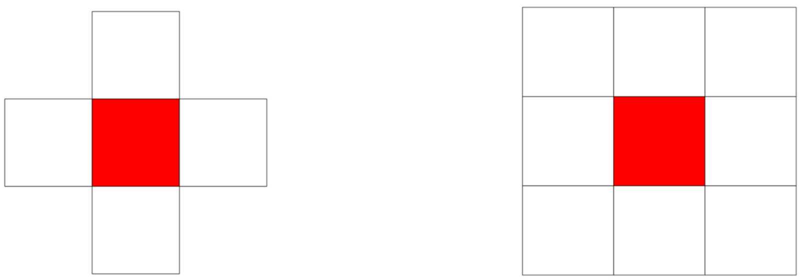
Figure 5. Indoor grid map construction process.

2.3.2. Indoor Space Grid Computing

The indoor grid map has two major functions: spatial neighborhood grid calculation and path navigation planning. Its spatial grid calculation includes two parts: spatial grid neighborhood position calculation and spatial grid distance calculation. The following is an example of a two-dimensional space:

1. Spatial grid neighborhood location calculation.

The purpose of the calculation of the neighborhood position of the space grid is to calculate the grid code of the adjacent spatial grid through the grid code corresponding to the spatial grid. Once this is completed, the adjacent grid is obtained. According to the different target requirements, the neighborhood location calculation can be divided into four neighborhoods and eight neighborhoods, as shown in Figure 6.



(**a**) (**b**)

Figure 6. Neighborhood location calculation. (**a**) Four neighborhoods; (**b**) Eight neighborhoods.

Regardless of the needs of neighborhood computation, however, for the essence of spatial grid neighborhood location computation, it is still the grid encoding of adjacent spatial grids in both the longitudinal and latitudinal directions of the spatial grid. The four-neighborhoods and eight-neighborhoods are just free combinations of adjacent codes in the two dimensions of warp and latitude. Taking the four-neighborhoods grid as an example, assuming the interior scene of the building, a spatial grid is C, its binary two-dimensional grid code is (C_{lon}, C_{lat}), and the level is level, then the neighborhood grid codes in each direction are:

- Forward longitude neighborhood encoding:

$$C_{lon}^{+} = C_{lon} + 2^{32-level} \tag{3}$$

- Negative longitude neighborhood encoding:

$$C_{lon}^{-} = C_{lon} - 2^{32-level} \tag{4}$$

- Forward latitude neighborhood encoding:

$$C_{lat}^{+} = C_{lat} + 2^{32-level} \tag{5}$$

- Negative latitude neighborhood encoding:

$$C_{lat}^{-} = C_{lat} - 2^{32-level} \tag{6}$$

2. Spatial grid distance calculation.

The spatial grid distance in this paper belongs to the two-dimensional space calculation. The grid distance calculation is based on the GeoSOT binary three-dimensional code. The GeoSOT binary two-dimensional code is obtained by removing the elevation, and then the spatial grid distance is calculated. In the calculation of the spatial grid distance in this paper, the spatial grid distance is defined as the Manhattan distance between two spatial grids, as shown in Figure 7, and the defined spatial grid distance satisfies the following two conditions:

- The two spatial grids of the input calculation distance are at the same level.
- If the input two spatial grids are M and N, respectively, the GeoSOT binary two-dimensional codes are (M_{lon}, M_{lat}), (N_{lon}, N_{lat}). Assuming the function of the total distance between two grids in the longitude direction or the latitude direction is F_{MN}, the distance DMN between the two two-dimensional space grids satisfies the Equation (7).

$$D_{MN} = F_{MN}(M_{lon},\ N_{lon}) + F_{MN}(M_{lat},\ N_{lat}) \tag{7}$$

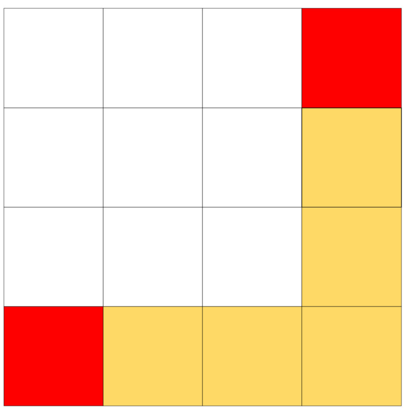


Figure 7. Two-dimensional space grid distance.

For the grid map designed in this paper, since the GeoSOT grid level is fixed at 27 levels and the grid size is 0.5 m, the actual distance d_{MN} of the two spatial grids in the two-dimensional spatial grid can be obtained to satisfy the Equation (8):

$$d_{MN} = \sqrt{(0.5F_{MN}(M_{lon},\ N_{lon}))^2 + (0.5F_{MN}(M_{lat},\ N_{lat}))^2} \tag{8}$$

2.3.3. GeoSOT-A* Algorithm

The A* algorithm belongs to the type of heuristic search algorithm. It is further processed on the basis of the Dijkstra algorithm and is widely used to solve the path search problem. The A* algorithm is the most efficient, direct search algorithm for finding the shortest path among all the pathfinding algorithms [38]. The basic principle is as follows: for the entire path search process, the evaluation function $F(n)$ is defined using the global information as a reference. Calculate the estimated cost of the distance between the current position and the end position of each new node according to the evaluation function $F(n)$. Then, the result obtained by the evaluation function $F(n)$ is used as the basis for the reasonable sequence of the entire path search planning. This can reduce the number of computation paths, which in turn improves the search efficiency [39].

The A* algorithm considers two aspects for optimal path search: in the first aspect, the A* algorithm calculates the distance value from the starting point to the current node; in the second aspect, the A* algorithm estimates the cost from the current node to the end point. The latter aspect is used as the basis for judging whether the current node is the optimal path, considerably narrowing the search range. The expression of the A* algorithm function is shown in Equation (9):

$$F(n) = G(n) + H(n) \tag{9}$$

In these calculations, $F(n)$ refers to the evaluation function from the starting point to the end point, and $G(n)$ refers to the actual cost from the starting point to the current node. $G(n)$ can be obtained by summing the cost of each node. As a heuristic function, *H(n)* refers to the estimated cost from the current node to the end point. Generally, the value of the Euclidean distance or the Manhattan distance is selected as the estimated cost, as shown in Equations (10) and (11). The value of the evaluation function $F(n)$ of each node in the indoor planning area is judged by the sum of $G(n)$ and $H(n)$.

$$H(n) = \sqrt{\left(x_n - x_{goal}\right)^2 + \left(y_n - y_{goal}\right)^2} \tag{10}$$

$$H(n) = \left|x_n - x_{goal}\right| + \left|y_n - y_{goal}\right| \tag{11}$$

The specific form of $H(n)$ can be determined according to actual needs, but it cannot exceed the actual shortest distance from the starting point to the ending point. The A* algorithm implements the heuristic search until it finds the best path, which is achieved by continuously revising the evaluation function $F(n)$. Therefore, for indoor path planning, if there is a shortest path, as long as $H(n)$ does not exceed the actual shortest distance, the A* algorithm can definitely find the optimal path [40,41].

By analyzing the principle and applicable scenarios of the traditional indoor path planning algorithm A* algorithm, combined with the actual needs of single-story and multi-layer space path planning in the interior environment of the building, and based on the coding model of this paper, the traditional heuristic A* algorithm is improved. As shown in Figure 8, A* algorithm is extended to the multiple nodes from the previous start position to the end position, to the start position to the middle position, and then to the end position.

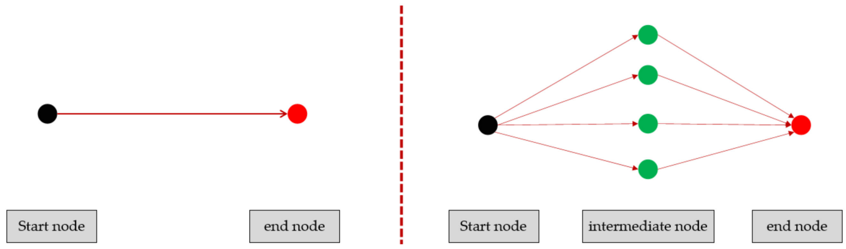


Figure 8. Extended A* Algorithm.

Before path planning, first the indoor grid map needs to be generated as described in detail in the previous section. Then, for the BIM model after model information extraction and the GeoSOT meshing, under the premise of fully considering the size of the door, the distribution of obstacles, and the spatial connection relationship of each floor in the indoor environment, indoor path planning can be divided into single-layer path planning and multi-layer path planning. The GeoSOT-A* algorithm flow is shown in Figure 9.

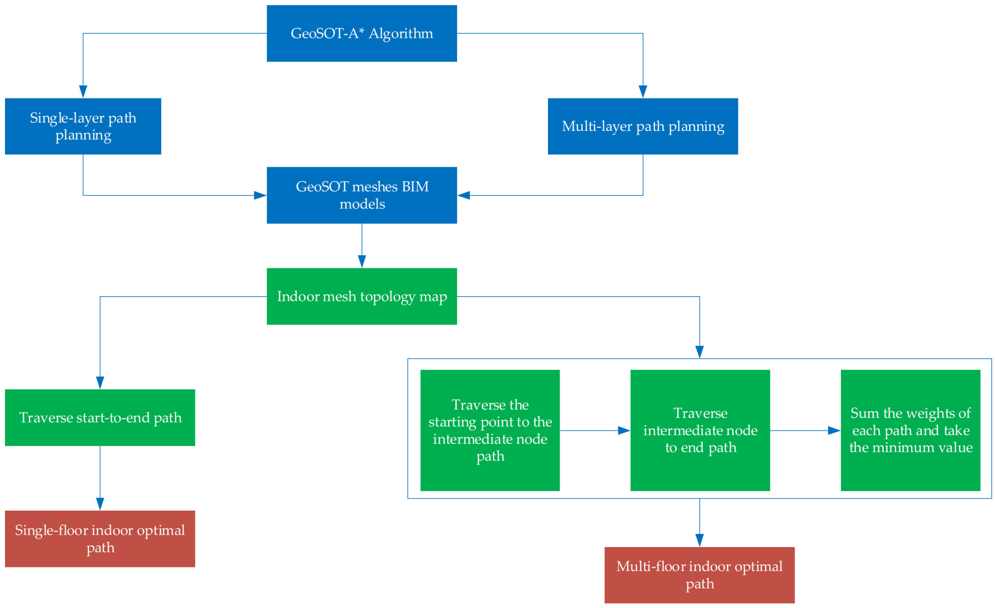


Figure 9. GeoSOT-A* algorithm flow.

1. Indoor single-story path planning, based on the GeoSOT grid division processing the floor area, uses the A* algorithm to search the target area and determines the best path through the optimal evaluation of the A* algorithm.
2. Indoor multi-story path planning, based on the GeoSOT-A* algorithm for the starting floor and the target floor in the BIM model, respectively—on the basis of the GeoSOT meshing—the A* algorithm is used to search the path of the starting floor and the target floor at the same time. Taking the stairs in the building as the intermediate node of multi-floor path planning, the optimality evaluation of the planned paths in each floor is carried out. Finally, through the comparison of the weight values of each path, the optimal path of the multi-layer indoor space is determined.

The specific steps of the above GeoSOT-A* algorithm can be embodied by an example, as shown in Figure 10 below. Assuming the starting floor in the scene is the first floor of the building, the target floor is the third floor of the building, and the floors are connected by three stair passages. The starting floor paths are D1, D2, and D3, the intermediate floor paths are M1, M2, and M3, and the destination floor paths are N1, N2, and N3. The sum of the path weights of each floor is set as S1, S2, and S3, and the sizes of S1, S2, and S3 are compared and the minimum value is taken.

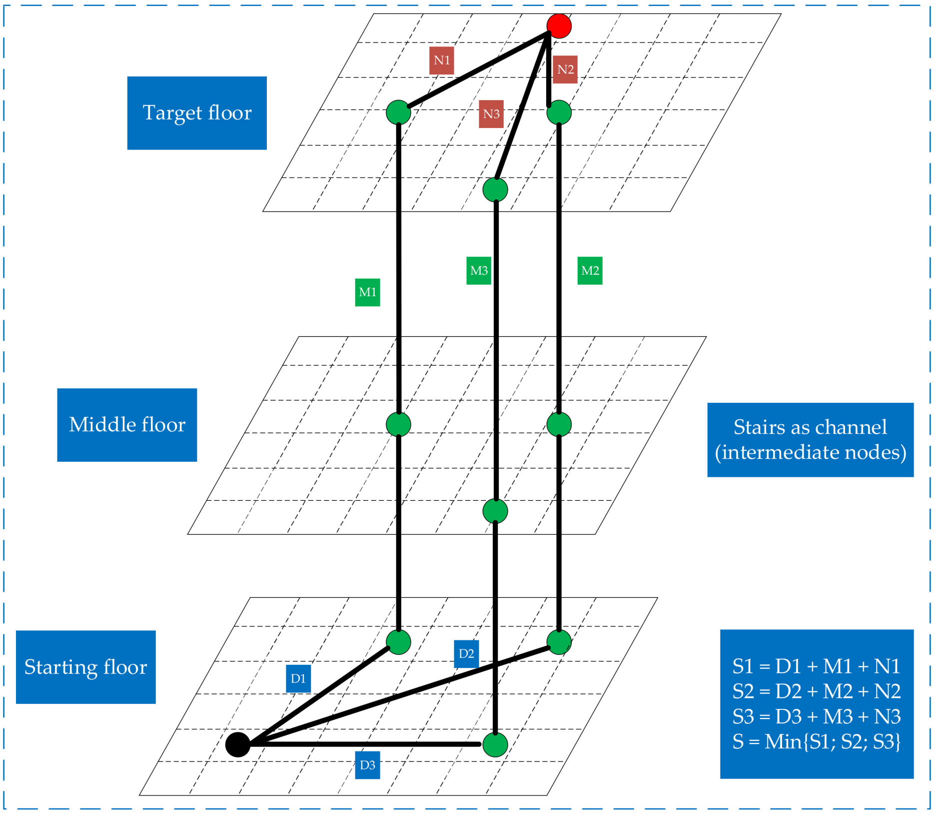


Figure 10. GeoSOT-A* Algorithm Path Planning Display.

3. Results

The data used in this paper is the BIM model of Guanlan Commercial Street in Baiyin City, as shown in Figure 11.

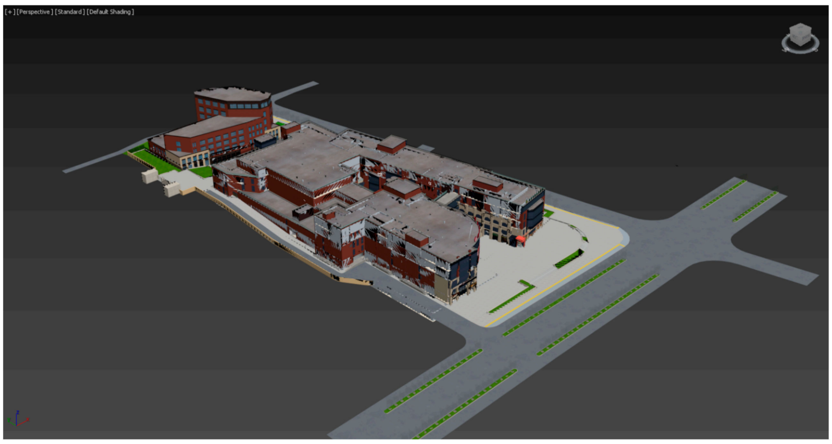
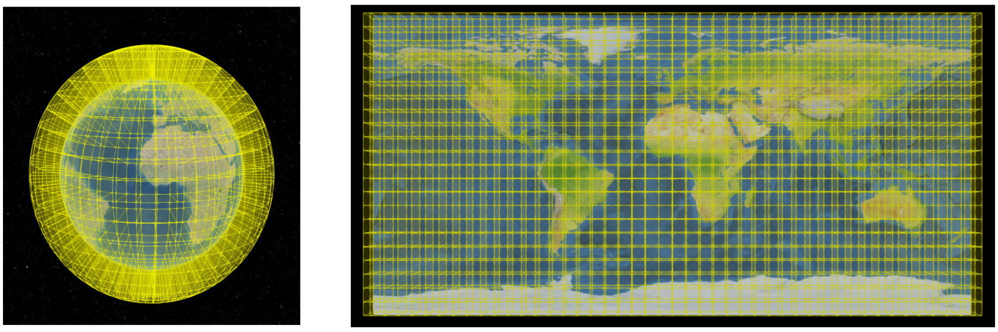


Figure 11. BIM Data Source.

The experimental results of this paper include the following aspects:

1. GeoSOT meshes the Earth. A three-dimensional digital globe is built on the Cesium platform, which is a cross-platform virtual globe for dynamic spatial data visualization [13,15]. Then, the earth space is decomposed into a multi-scale nested space three-dimensional grid system according to the GeoSOT subdivision technology to realize the GeoSOT grid subdivision of the Earth, as shown in Figure 12.



(**a**) (**b**)

Figure 12. GeoSOT global grid display (**a**) 3D display; (**b**) 2D display.

2. BIM model parsing and loading. The BIM model is loaded in the real location of the building (Guanlan Commercial Street, Baiyin City) according to the 1:1 scale of the real object, as shown in Figure 13.

Figure 13. BIM model loads and resolves internal structure.

3. The BIM model analyzes and generates an indoor grid topology map. As mentioned above, by analyzing the BIM model, the coordinates and attribute information of each component in the building model are obtained. Then, after the coordinate conversion processing, the WGS84 geographic coordinates of each component on the three-dimensional sphere are obtained. According to the indoor grid map generation steps described above, the grid map inside the BIM model is obtained, as shown in Figure 14. In this map, black indicates impassable areas, light colors indicate passable areas, and each mesh is associated with the attributes of specific entity components inside the model, such as key information like stair passages.

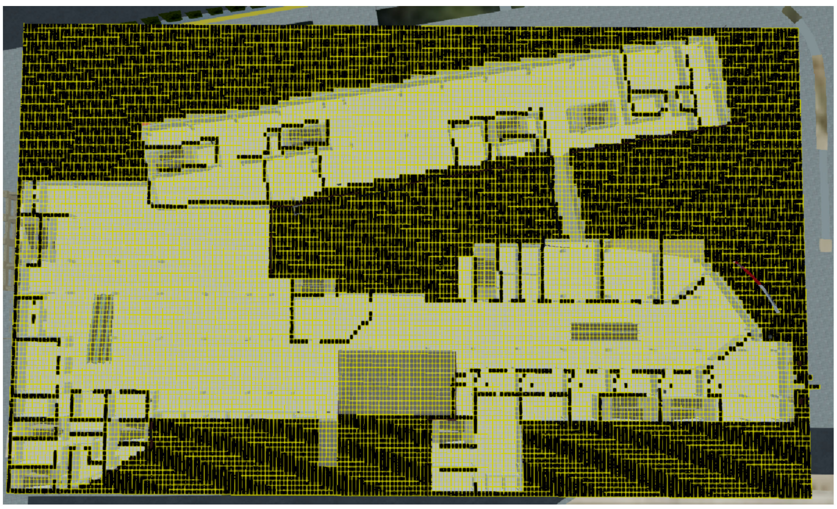


Figure 14. BIM model analysis to generate indoor grid topology map.

4. The topology of the floor grid after meshing the BIM model is displayed in the whole interface, and the optimal path planning diagram from the starting position to the target position is shown. Set the starting point and target point, the blue circle indicates the starting position, the red circle indicates the target position, the green indicates the planned path, and the red column indicates the channel between floors. The experimental results of single-floor path planning are shown in Figure 15 and the experimental results of multi-floor path planning are shown in Figure 16. This experiment proves the correctness and feasibility of the path planning analysis method based on GeoSOT and BIM, and also proves the correctness and feasibility of the GeoSOT-A* algorithm designed in this paper.

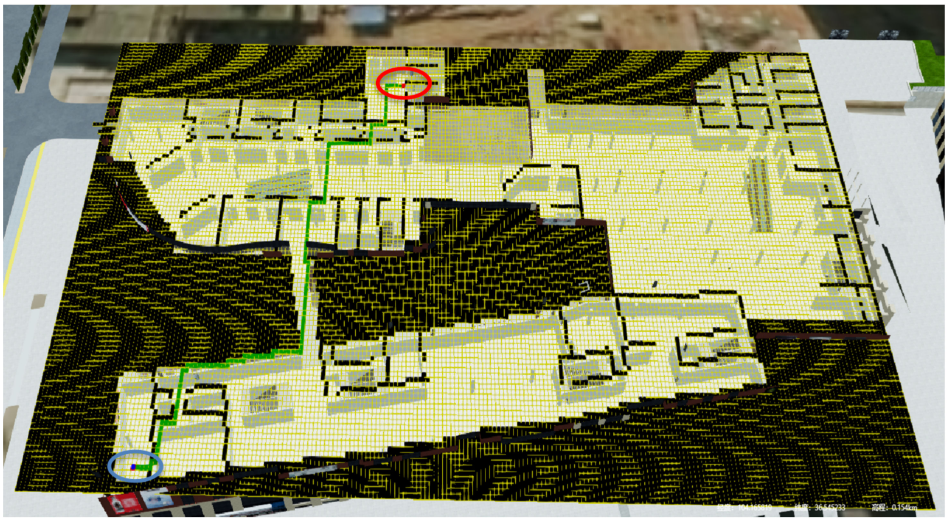


Figure 15. Single-floor path planning.

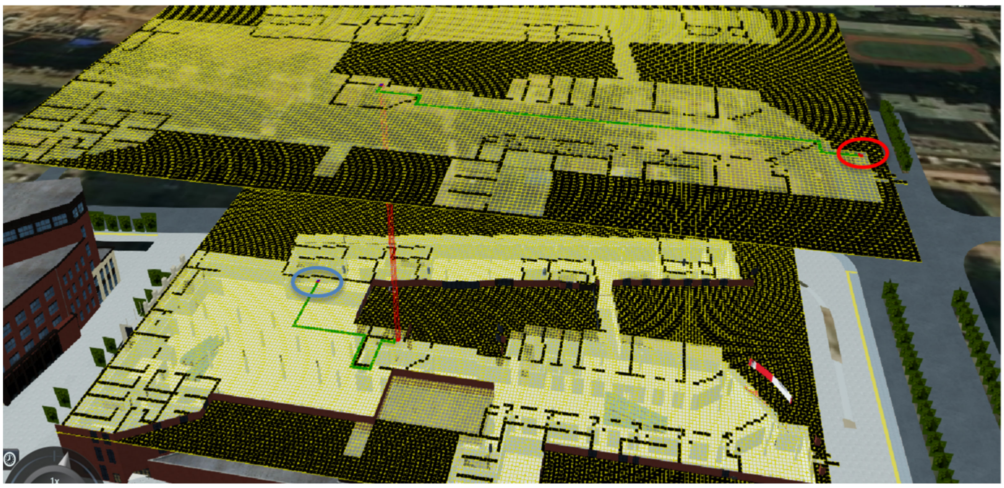


Figure 16. Multi-floor path planning.

4. Discussion

From the analysis of the above experimental results, the following conclusions can be drawn:

1. From the experimental results shown in Figures 12 and 13, it can be concluded that it is indeed feasible to apply GIS technology-related ideas to the BIM model. Indeed, the method fuses the GeoSOT grids with real geographic information and building information models and enables indoor path planning. For these results, the GeoSOT grid makes up for the deficiency of the BIM model having all the attribute information of the indoor building and lacking the real geographical location attribute.

2. From the experimental results in Figure 14, it can be concluded that the method does accurately generate the indoor grid topology map, and if one of the grids is selected, the coordinates and attribute information corresponding to the BIM model contained in the grid can also be consulted. This is because the BIM model has complete information about the building, which can accurately express the relative position of the components in the building, and the GeoSOT grid is multi-level and multi-scale, with an accuracy at the centimeter level, which can accurately express the real geographic space position.
3. From the results in Figures 15 and 16, it can be obtained that the indoor path planning algorithm (GeoSOT-A* algorithm), based on the spatial relationships proposed in this paper, can reasonably identify and avoid the edges of indoor floor obstacles and realize the optimal path planning of indoor continuous space across floors.
4. This method is widely used and has strong scalability. The BIM model of Guanlan Commercial Street in Baiyin City was selected as the method application object, and the BIM model is processed by GeoSOT global meshing to generate the indoor mesh topology map. Then, based on the pathfinding algorithm, the precise planning of the indoor path is realized. The result analysis shows the method proposed in this paper has certain application value and significance for meeting the location information service requirements of indoor space in smart city construction.

5. Conclusions

Currently, with the rapid development of cities, the improvement of urban infrastructure, and the increasing coverage of high-rise buildings, people have an increasingly urgent need for location information services in buildings. The proposed GIS and BIM combination, based on GeoSOT grid code and BIM, achieves accurate indoor path planning based on the spatial relationship in the building, which solves the defects of current methods for indoor path planning that cannot achieve accurate and efficient cross-floor planning. In addition, the method proposed in this paper can be extended and studied more deeply. Through the combination of GIS and BIM, the integration of GIS technology and BIM technology in data storage, data management, and interaction is realized. The advantages of the BIM model data source can be fully utilized and combined with the outdoor navigation technology, which is more mature at present, to realize the integrated indoor and outdoor location information service by using building big data. This is also an important reference and application value for the current construction of digital twin cities based on smart cities [42,43].

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