

Indoor Navigation Network Model Construction Method Based on Building Information Model

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Abstract

In view of the poor information integrity of the 3D model used to make the indoor road network and the lack of versatility of the constructed indoor road network, a method for building an indoor navigation network model that can be seamlessly connected with outdoor paths is proposed in this paper. First, the IFC model is converted to the CityGML model using the BIM model as the indoor data source. Then, using GIS technology and limited Delaunay triangulation refinement algorithm, the necessary elements of indoor navigation network model such as semantic information, geometric information and topological relationship contained in CityGML model are extracted. Finally, it is visualized and verified based on experimental model data. The results show that the indoor navigation network model constructed based on the CityGML model can accurately perform indoor navigation, make the constructed road network more general, and provide reference and technical support for the integrated construction of indoor and outdoor road network models.

Keywords

IFC, CityGML, Indoor Navigation Network, Delaunay, Dijkstra, Integrated Navigation

1. Introduction

With the introduction of the concept of smart city, the development of two spatial data visualization technologies, namely building information modeling (BIM) in the construction industry and geographic information system (GIS) in the geographic industry, is in full swing [1]. The BIM model can provide detailed information inside the building, but it is based on a relative coordinate system,

and there are analysis defects related to the building and geographical conditions, making the building facilities unable to integrate into the environment [2]. However, the building model constructed by the existing GIS 3D platform only has the appearance display, without detailed indoor information and attribute information, but GIS is widely used in the spatial analysis outside the building. However, the two cannot directly realize data interconnection and interoperability, resulting in the problem of information islands. The BIM single building model with rich attribute information is used as a data source, imported into the GIS platform capable of large-scale spatial display, and the coordinate values of the absolute coordinate system are assigned to the BIM model, which can provide the necessary coordinate basis for navigation. Building an indoor navigation network model based on coordinated query, internal roaming, and spatial measurement in the GIS platform [3] can provide solutions for the integrated construction of indoor and outdoor road network models in the real world.

The basis of indoor navigation is the construction of indoor road network models [4] [5] [6] [7]. The indoor road network models that have been constructed categorize data into location data, 2D planar data and 3D model data from data sources [8]. Mengying Fu *et al.* [9] used indoor trajectory data to obtain inter-floor connectivity points in order to construct an indoor navigation network. Tao Liu [10] used visual data and sensor data to construct indoor navigation maps. However, the location data to construct the indoor road network model ignores the connectivity of each room in the room, which is insufficient for indoor navigation. The construction of indoor navigation networks from 2D planar data is one of the most used methods today. Examples include rasterizing paths [11] or using abstraction methods to abstract indoor navigation elements into nodes and edges and construct topological relationships [12] [13]. However, the two-dimensional planes are poorly time-sensitive and they mostly lack semantic information. Therefore, many scholars have turned their attention to 3D model data. Mengxuan Ye [14] *et al.* proposed an automatic generation method for indoor navigation networks based on CityGML (City Geography Markup Language), Peiyao Li [15] *et al.* proposed an indoor navigation element extraction method based on the IFC (Industry Foundation Classes) model. The 3D model data is rich in semantic and geometric information, but the utilization of semantic information is limited in existing methods.

Vanclouster [16] believes that indoor data for route planning needs to include semantic information, indoor road network, and building entrances (connecting indoor and outdoor), which can be effectively realized through the integration of GIS and BIM. In order to make the indoor road network no longer an “information island” [17], this paper combines the BIM model with the GIS environment to provide detailed indoor data and coordinate systems for the indoor navigation network model to achieve seamless integration with the outdoor road network. This paper converts the IFC model into the CityGML model, and uses GIS technology and Delaunay triangulation refinement algorithm to extract the se-

mantic information, geometric information and topological relationship contained in the basic elements of the indoor navigation network model such as the CityGML model. Finally, a visual representation is made, and the feasibility of it is verified by using Dijkstra's algorithm.

2. Model Conversion

2.1. Conversion of IFC Model to CityGML Model Geometry Elements

Geometric element conversion is to realize the conversion of the model building form between both IFC and CityGML [18] [19]. The navigation network construction requires more detailed indoor information, so the IFC is converted to CityGML Lod4 level-of-detail model. Firstly, the IFC model is parsed, and the parsed elements are filtered and selected, keeping only elements with geometric information, such as IfcDoor, IfcWindow, IfcSlab, etc. [20], while elements that represent the relationship between building components are filtered, such as IfcRelFillsElement relationship that inserts IfcDoor into IfcOpeningElement, and IfcRelAggregates relationship that aggregates IfcDoor with IfcWall. Secondly, the coordinates of each vertex of the geometric elements are extracted so as to extract each surface, and then they are reorganized to form a surface model that meets the requirements of CityGML standard for model elements; finally, the IFC model expressed in relative coordinates is converted into the CityGML model expressed in absolute coordinates [21]. The geometric element conversion process is shown in **Figure 1**.

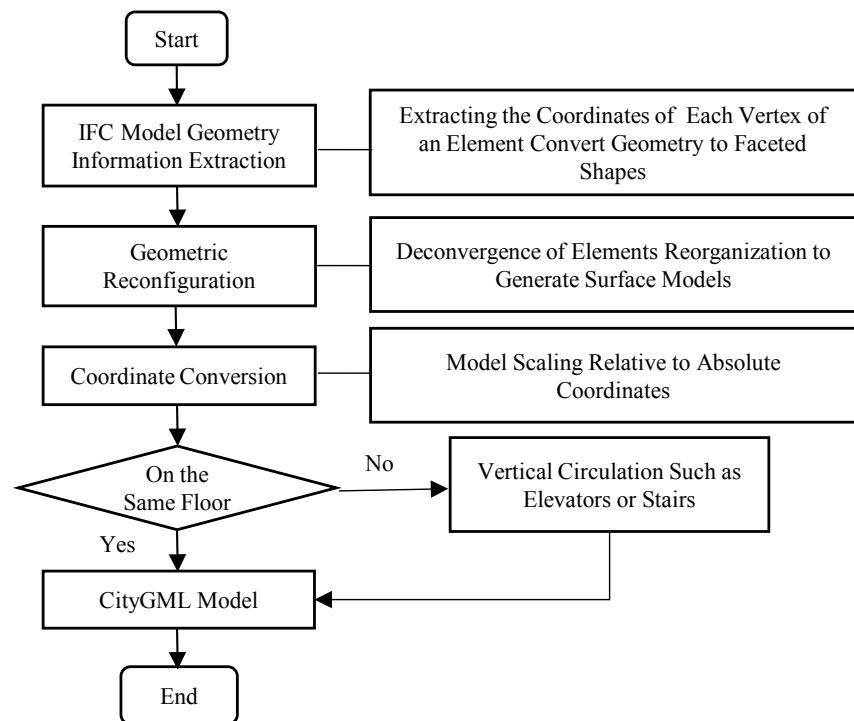


Figure 1. Model geometry conversion flowchart.

2.2. Semantic Mapping of IFC Models to CityGML Models

Compared to CityGML, the intermediate elements in IFC and the descriptive semantics of fine components are not involved in CityGML. Therefore, based on the above analysis, there are three mapping relationships between IFC model semantics and CityGML model semantics: one-to-one, one-to-many, and many-to-one [22]. The semantic mapping relationships between IFC and CityGML are shown in **Table 1**. Therefore, the semantic transformation will be mapped according to the inter-semantic correspondence.

3. Indoor Navigation Network Model Construction

3.1. Indoor Navigation Network Model Data Structure

After converting the IFC model to CityGML model, detailed indoor information and absolute coordinate system are provided for the construction of indoor navigation network model based on CityGML model. Indoor navigation network models mainly include CityGML model, simplified indoor geometric network model based on navigation requirements, and indoor semantic network model. The CityGML model includes geometric representation of 3D buildings with topological relationships such as adjacency, inclusion and separation between geometric components, and is used to provide indoor data information and navigation visualization. The indoor geometric network model uses points and line segments as the main elements to provide accurate geometric information for indoor route planning through spatial coordinates. The indoor semantic network model contains the attributes of indoor navigation elements and the relationships between elements, which can provide users with spatial services such as location information query, proximity query and cross-floor path query.

Table 1. Semantic mapping correspondence table between IFC and CityGML.

IFC Entity	CityGML Element	Mapping Method	
IfcDoor	Door	One-to-one	
IfcWindow	Window		
IfcBeam	Building Installation	Many-to-One	
IfcColumn			
IfcRamp			
IfcStair			
IfcRailing			
IfcStairFlight	WallSurface	Many-to-One	
IfcWall			InteriorWallSurface
			RoofSurface
IfcSlab	OuterFloorSurface		
	OuterCeilingSurface		

3.2. Indoor Geometric Network Model

Based on the CityGML model, the interior space is divided into navigable and non-navigable areas. The navigable areas are generally connected by objects such as rooms, doors and corridors, while the non-navigable areas are composed of immovable components such as beams and columns in the BuildingInstallation class and dynamic obstacles such as tables, chairs and sofas in the BuildingFurniture class. The construction of the indoor geometric network requires eliminating the elements in the non-navigable area and keeping only the objects in the navigable area, extracting the corridor centerline using a limited Delaunay triangulation refinement algorithm, and constructing an indoor geometric network model consisting of the objects in the navigable area and their topological relationships.

3.2.1. Construction of Floor Level Navigation Paths

1) Mapping the horizontal floors of the CityGML model

Based on the geometric information of the horizontal floors of the CityGML model, a 2D geometric representation using the geometric curve set type is currently supported. The third floor is used as an example to study the construction of an indoor road network on the same floor, as shown in **Figure 2**. A 2D bounded graph is generated by mapping the boundaries of the navigable area of the horizontal floor and its internal rooms, doors, corridors and other elements.

2) Defined Delaunay triangular refinement of the corridor

The navigable area contains elements such as rooms, doors and corridors. The essence of the construction of horizontal navigation path network is to realize the connectivity between rooms, doors and corridors. In this paper, the center points of interior rooms and doors are extracted, but the center lines of corridors cannot be extracted directly, so a specific algorithm is needed to extract the center lines of corridors. The restricted Delaunay triangular dissection refinement algorithm can divide various irregular areas of the interior into unstructured triangular meshes [23]. Thus, the corridor boundary coordinate information is extracted and fed into the qualified Delaunay triangle profile refinement algorithm. After the refinement of the dissection, the midpoints of all triangular edges inside the subspace are selected as path points, which can avoid the result of generating a zigzag path due to the selection of the triangular center of gravity



Figure 2. Schematic diagram of the third floor of the CityGML model.

[24]. The bending of the roadbed can be avoided to a greater extent, and in addition the path points cannot be located on the external or internal restriction boundaries.

3) Linking Waypoints

Based on the relationship between the triangle and the boundary, the linking method of the path is determined, and the path points are only linked to the path points on the triangle adjacent to them. The linking of path points is achieved by building a BSP tree structure, and the algorithm steps are as follows.

a) The path point in the lower left corner of the subspace is taken as the root node, and the triangle in which it is located is the source triangle, and the neighboring triangles sharing its edge are the subtrees.

b) If there are no neighboring triangles other than the source triangle, it means that it is a regular rectangle and no refinement of the dissection is performed, and only the path points on its shared edges are retained.

c) If there are one or two neighboring triangles in addition to the source triangle, the midpoint of the common side on the neighboring triangle is inserted into the BSP tree and linked with the root node.

d) Starting from the root node, judge the relationship between the adjacent triangle and the source triangle according to the common edge, traverse the front left subtree, and then traverse the right subtree, and traverse all the structured triangles to finally form a complete path network in the subspace.

As seen in **Figure 3**, the partition plane where path points 1, 2, 3, 4 and 5 are located divides the room into six regions A, B, C, D, E and F. Taking 1 as the root node, Traverse adjacent split planes to get all possible BSP structure trees, thus linking each path point. As can be seen from **Figure 4**, this method is also applicable to narrow corridors and can reflect the available navigation network paths in a more complete way.

4) Indoor horizontal path generation

The room center of gravity, door center of gravity, and corridor centerline obtained in the previous step are connected and used to generate interior horizontal paths. In addition, the room center of gravity and door center of gravity of each floor are coded in turn and stored in their respective attribute tables for subsequent association with the attribute information of the room and door elements of the CityGML model.

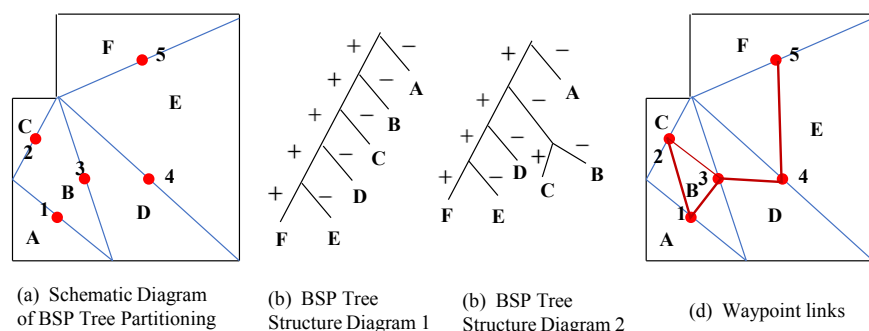


Figure 3. BSP tree path link diagram.

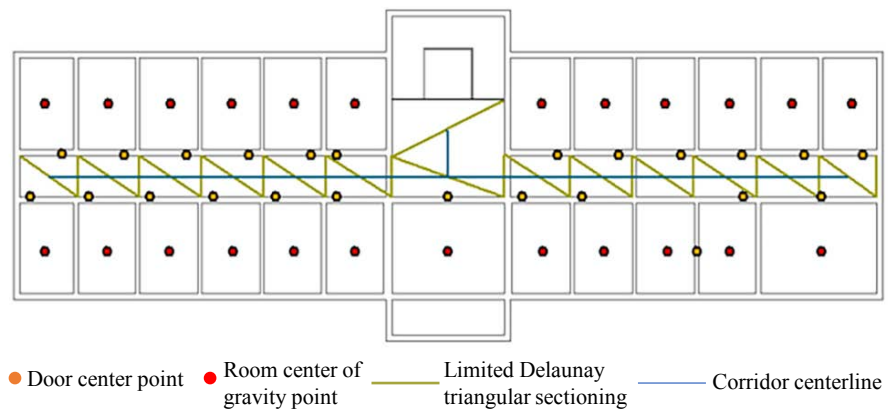


Figure 4. Corridor geometric network path.

3.2.2. Construction of Vertical Navigation Paths on Floors

Within large indoor venues such as museums, shopping malls, and parking lots, stairs and elevators are the most common paths of access across floors [25]. In the CityGML model, elements such as beams, columns, stairs, and elevators are uniformly grouped into the BuildingInstallation class, resulting in the inability to directly extract stairs and elevators to obtain the connection relationships of vertical spaces. Therefore, for stairs, the feature points of the first step, last step and middle step of the stairs are captured, and these feature points are connected to form a path consistent with the geometric features of the stairs. For elevators, the elevators are divided into units per floor, and the center of gravity of each unit after division is extracted as feature points, and these feature points are connected to form the elevator path.

3.3. Indoor Semantic Network Model

The indoor semantic network model plays an important role in spatial services such as user location information query and cross-floor path query [26] [27]. The construction of the semantic network model is divided into three parts. First, the attribute information of rooms, doors and other components in the CityGML model is classified and organized, and the attribute information of these elements is exported and stored in XLS files in a classified manner. Second, because each room ID in the CityGML model is determined at the time of model construction, the IDs of rooms and doors in the indoor semantic network model should be numbered in an orderly manner according to the rules in the CityGML model. Third, the attribute information of the CityGML model and the indoor semantic network model are associated according to the same fields to obtain an indoor semantic network model containing rich attribute information.

4. Experiments and Results Validation

4.1. Experimental Procedure

The data for this experiment comes from the IFC model in the IFC Open Model Library, which has been proofread by professionals, thus ensuring the reliability

of the model, and the experimental model is shown in **Figure 5(a)**. The experiments use FME visual programming software to realize the conversion of IFC model and CityGML model. The converted CityGML model was imported into Arcscene software for display, and the display results are shown in **Figure 5(b)**, **Figure 5(c)**. From **Figure 5(c)**, it can be seen that the interior rooms, doors, windows, furniture, stairs, etc. are well expressed and no errors are seen.

The process of building the indoor navigation network model is very complex. The center points of rooms, doors and other elements in the horizontal navigable area of each floor are extracted by Arcgis, and then the boundaries of the corridor on each floor are extracted and fed into the qualified Delaunay triangular dissection refinement algorithm to complete the extraction of the corridor centerline, thus realizing the construction of the indoor horizontal network. The formation of vertical navigation network is accomplished by capturing the feature points of elevators, stairs and other vertical elements by Arcscene. The construction of indoor semantic network model is achieved by using Arcgis' powerful attribute analysis function to correlate the attribute information of CityGML model and indoor geometric network model. The indoor navigation network model is shown in **Figure 6**, and simple indoor navigation can be realized based on the visual road network model shown in **Figure 6**.

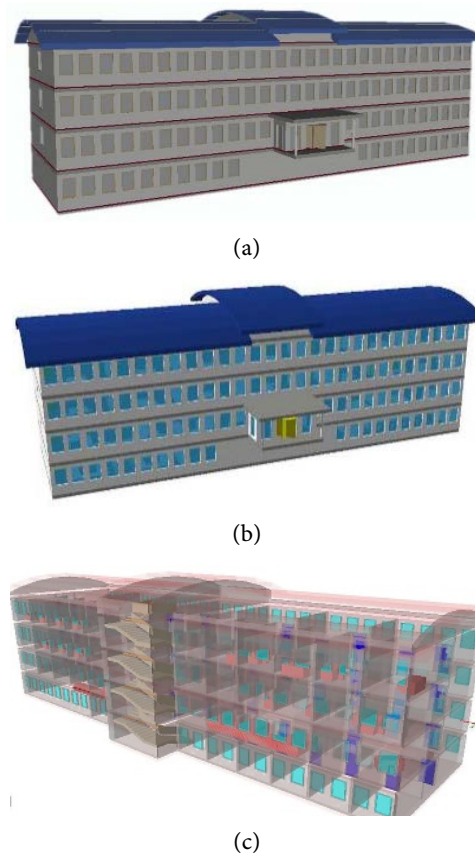


Figure 5. (a) IFC Model for experimental testing; (b), (c) The Converted CityGML Lod 4 Model Display and Interior Detail Information Display.

4.2. Result Verification

Dijkstra's algorithm is a classic application for solving pathfinding problems in the field of network analysis and navigation computing. The constructed indoor navigation network is verified for path length accuracy using Dijkstra's algorithm. The validation using Dijkstra's algorithm requires the construction of a network dataset. Therefore, a network dataset is built for the indoor navigation network, and the distance length is set as the impedance factor. 5 navigation routes are randomly selected in the model, such as same floor and cross-floor, and the navigation paths are shown in **Figure 7**. Finally, the actual lengths of the 5 routes in the model were compared and analyzed with the experimental value data, and the statistics were obtained as shown in **Table 2**.

As can be seen from **Table 2**, the Delaunay algorithm was used to profile the corridor for this experiment, which resulted in errors between the test path and the real path of the model due to its profile characteristics and the construction of the network data set. The average error of the path length constructed in the model relative to the actual length of the model is basically within 2.5%. Therefore, the accuracy of the indoor navigation network basically meets the indoor navigation requirements and verifies the feasibility of the method.

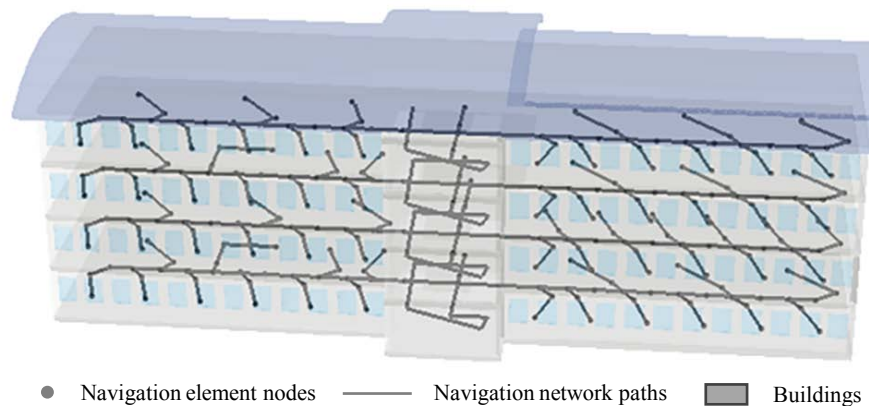


Figure 6. Indoor navigation road network model.

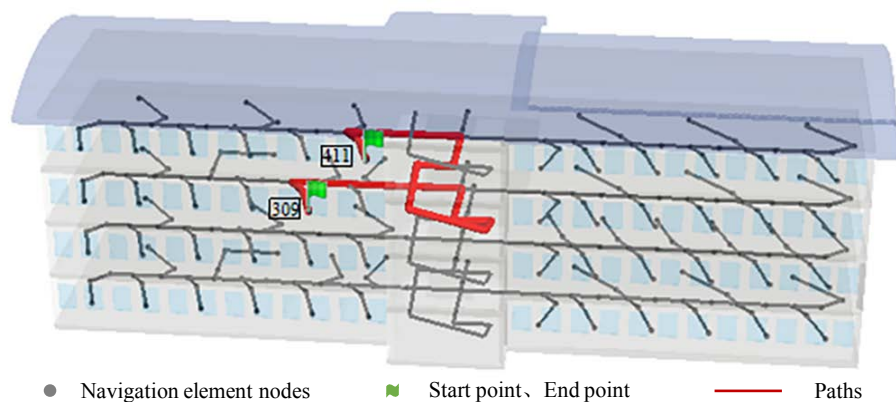


Figure 7. Navigation path from room 309 to room 411.

Table 2. Distance data statistics table.

Number	Start point	End point	Model actual value/m	Experimental values/m	Error value/m
1	1F-101	1F-113	33.92	34.33	0.41
2	3F-309	4F-411	60.01	60.59	0.58
3	1F-109	3F-313	42.32	42.89	0.57
4	2F-211	3F-323	65.18	65.82	0.64
5	2F-209	4F-402	91.21	92.02	0.81

5. Conclusion

This paper proposes to combine the BIM model with GIS data to construct an indoor navigation network model with detailed indoor information and universal applicability. It makes up for the shortcomings of using relative coordinates in the BIM model, and also provides detailed indoor information for the construction of indoor navigation network models in the GIS environment, and provides reference and technical support for the research of indoor and outdoor integrated navigation. Although this study has explored and practiced the indoor navigation network model that can be connected to the outdoor road network, there are still some areas that need improvement, such as the low degree of automation in the extraction process of the vertical navigation road network, and this defect requires further research. In addition, the research on indoor road network automation construction and indoor and outdoor integrated road network construction will be the next research focus.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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