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A Semantic-Sensitive Approach to Indoor and Outdoor 3D Data Organization

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Abstract: Building model data organization is often programmed to solve a specific problem, resulting in the inability to organize indoor and outdoor 3D scenes in an integrated manner. In this paper, existing building spatial data models are studied, and the characteristics of building information modeling standards (IFC), city geographic modeling language (CityGML), indoor modeling language (IndoorGML), and other models are compared and analyzed. CityGML and IndoorGML models face challenges in satisfying diverse application scenarios and requirements due to limitations in their expression capabilities. It is proposed to combine the semantic information of the model objects to effectively partition and organize the indoor and outdoor spatial 3D model data and to construct the indoor and outdoor data organization mechanism of "chunk-layer-subobject-entrances-area-detail object." This method is verified by proposing a 3D data organization method for indoor and outdoor space and constructing a 3D visualization system based on it.

Keywords: Integrated data organization; Indoor and outdoor 3D data models; Semantic models; Spatial segmentation

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1. Introduction

With the increasing complexity of urban construction and management [1], buildings, as the most important elements in the city, carry most of the human activities, and the main space of human activities is shifting from outdoor to indoor. However, compared to outdoor information, indoor information in urban 3D Geographic Information Systems (3D GIS) remains significantly limited. Consequently, for a comprehensive digital city application system, it is essential to integrate various buildings with indoor scenarios. This integration not only enhances our understanding of the city but also adds vitality to the application. A development pattern of outdoor to indoor will be inevitable for digital cities in the future [2].

The study of indoor data models focuses on conceptualization, standardization, and representation of the various spaces that constitute the indoor environment and its relationships, as well as adapting and customizing the existing data models according to the needs of application services [3]. Two types of models can be extended: (1) generalized indoor models for specific classes of users and (2) models for specific purposes. Many studies have based their modeling on indoor spatial standards; these include CityGML, IndoorGML, and the IndoorGML Core Module, which consists of basic modeling components; and the IndoorGML Navigation Module, which refers to an extension of the Core Module to the IndoorGML Navigation Module. The navigation module is based on an open data model for indoor spatial information and IndoorGML, the XML schema of the Open Geospatial Consortium (OGC) standard. Unlike the object-based CityGML, IndoorGML represents indoor spaces as constrained semantic spaces, and thus IndoorGML-based models are better suited to represent the connectivity of a variety of indoor spaces [4]. Srivastava et al. proposed an extension to the IndoorGML core module aimed at merging semantic information. Consequently, the then-existing IndoorGML structure did not support semantic information storage [5,6]. Park *et al.* proposed a data model that can be easily applied to indoor spatial information services for PWDs based on the mobility of people with disabilities (PWDs) in indoor environments, which extends the attributes of the TransitionSpace module in IndoorGML [7-9]. Anchor nodes are points in IndoorGML that define a seamless connection between indoors and outdoors, but the design of this module is not detailed; at least one common opening unit (anchor node) is required to go from outdoor space to indoor space, and the anchor node can be non-existent or invalid due to a number of reasons (e.g., the disappearance of a door due to a natural disaster, or prohibiting access to a specific group of users [safe area] or allowing access to the store only according to a specific time intervals) and thus it is not possible to switch between outdoor and indoor space via anchor nodes.

In the indoor-outdoor 3D model data, a "chunk-layer-object-entrance-area-detail-object" indoor-outdoor scene data organization mechanism is constructed. Combined with the information of the model objects, the 3D model data of indoor and outdoor space is effectively divided and organized, and the integrated indoor and outdoor data organization can organically combine the data in different spaces, which makes the data flow more naturally and conveniently in the whole system. Through the indoor-outdoor integrated data organization, data can be better utilized and the value and efficiency of the data can be improved, thus better meeting the needs of different fields.

2. Indoor and outdoor 3D model data association organization method

2.1. Indoor and outdoor 3D semantic modeling

The root of the model will focus on organizing indoor and outdoor three-dimensional spatial objects. The organization will follow a spatial division structure, characterized by the "chunk-layer-subobject-entrance-area-object detail" format. The outdoor 3D model objects include buildings, transportation facilities, vegetation, and other ancillary facilities models, etc. The indoor 3D model is the basic spatial element data that constitutes the indoor scene, and it is mainly for the indoor fine architecture and equipment facilities 3D model data. The main semantic element is the name of the model object, such as road, building, door, window, wall, room, etc. Specific semantic information can be assigned to indoor and outdoor 3D models according to the naming rules shown in **Figure 1**.

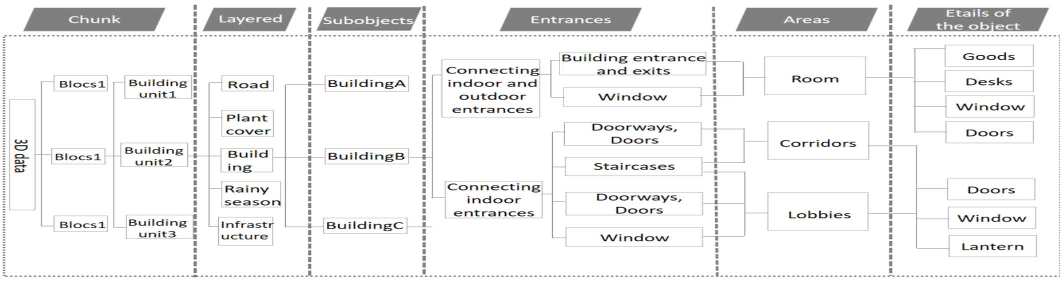

Figure 1. Semantic organization of indoor and outdoor 3D model data

Chunking according to the working or administrative area: chunking serves to seamlessly divide the modeling area into chunks horizontally. The area is divided by natural, artificial, or administrative boundaries. Each chunk of the same boundary should be kept in a moderate size to avoid excessive differences.

Layering by elements: layering serves to vertically divide the modeling objects according to different types, which can be classified according to the classification of urban 3D models, i.e., building models, traffic facilities models, pipeline models, greening models, and other models. More subdivisions can be made on this basis. Outdoor space building objects can be classified into different buildings, e.g. Building A, Building B, and Building C.

A portal is defined as a spatial object through which regional objects are interconnected. It may be model objects that exist directly in the 3D model, such as doors, windows, etc. Semantic information are assigned to such model objects and these categories of objects are added to the list of entrance categories so that they can be extracted directly as entrance objects (e.g. Door1_Room321). In contrast, entrances such as patio doors that do not have corresponding model entity objects are represented by adding transparent model objects, which ensures the correctness of the visualization while guaranteeing the completeness of the area-entrance structure in terms of model object correspondence.

Most of the indoor spaces are composed of several independent functional areas, such as rooms, corridors, etc., and each functional area is connected by doors and other entrances. Each functional area is given a unique name (e.g. Room_321), and the area object is required to be an independent spatial unit that can form a closed space. Area categories are managed by a list, with objects containing extracted name semantic information from this list being categorized accordingly.

In indoor 3D space, the objects and furniture in the room should be separated from the area models and be made independent. This separation is essential for equipment management. Additionally, since the data volume for objects within a room is typically much larger than that of the building itself, it is often necessary to construct detailed level models to mitigate data volume during the visualization process. The object models in the room are extracted as detail objects according to the application requirements, and the required semantic and attribute information are added to these objects (e.g. Desk1_Room321). The detail objects are associated with the region objects in a containment relationship.

2.2. Indoor and outdoor data association processing

The indoor and outdoor 3D data processing and organization proposed in this paper does not consider the large range of raster data such as DEM or DOM. Instead, it only contains indoor and outdoor 3D models and other 3D urban spatial models that are distributed complexly in terms of buildings. the quadtree and octree organization and indexing methods do not conform to the spatial distribution rules and visualization characteristics of indoor and outdoor scene data. Therefore, we need to establish a data indexing organization method that conforms to the characteristics of indoor and outdoor roaming and visualization (**Figure 2**).

Based on the indoor and outdoor 3D semantic model, the model of indoor and outdoor space is divided into six categories for extraction and segmentation: chunking achieves reasonable partition of the 3D scene, dividing the complex 3D scene into multiple smaller regions, making the management and processing of the scene more efficient and flexible; layering categorizes the 3D scene according to different elements, and each element is represented as an independent model Monoliths, such as roads, vegetation, buildings; sub-objects represent independent buildings in outdoor space; entrances represent connecting objects between areas such as doors between rooms and corridor passages, and windows between rooms and outdoor areas. Detail objects denote relatively independent 3D model monoliths such as tables, chairs, and computers; regions denote spatially functional regional objects such as rooms, corridors, and halls.

According to the semantic information, on the basis of each type of object preserving its own attribute information, all types of objects are integrated according to the subordinate relationship between regions and the connection between objects, forming a chunk-layer-subobject-entrance-area-detailed object structure.

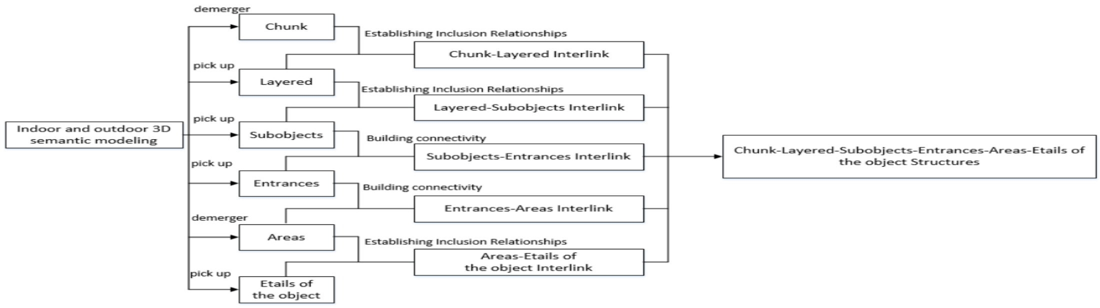

Figure 2. Indoor and outdoor data correlation

2.3. Indoor and outdoor 3D model data organization

The outdoor 3D scene data is organized using traditional quadtree organization. The process involves determining the location of the indoor building model and obtaining the quadtree leaf node containing the building's three-dimensional model. This leaf node encompasses outdoor 3D scene data such as roads, vegetation, infrastructure, and other elements. Additionally, connections between indoor and outdoor entrances are added to the outdoor area, facilitating integration between indoor and outdoor spaces. This is illustrated in **Figure 3**.

The 3D scene data are organized using a traditional quadtree. The leaf nodes of the quadtree containing the 3D model of the building containing the indoor model are determined by the location of the building containing the indoor model. These leaf nodes contain outdoor 3D scene data such as roads, vegetation, and infrastructure data. Buildings and objects connecting indoor and outdoor entrances are also added to the outdoor area to increase the completeness and realism of the scene. Large-scale outdoor scene data can be easily managed and indexed using a quadtree. By dividing the scene into nodes of a quadtree, the data in a specific area can be quickly located and retrieved, increasing the efficiency of data access.

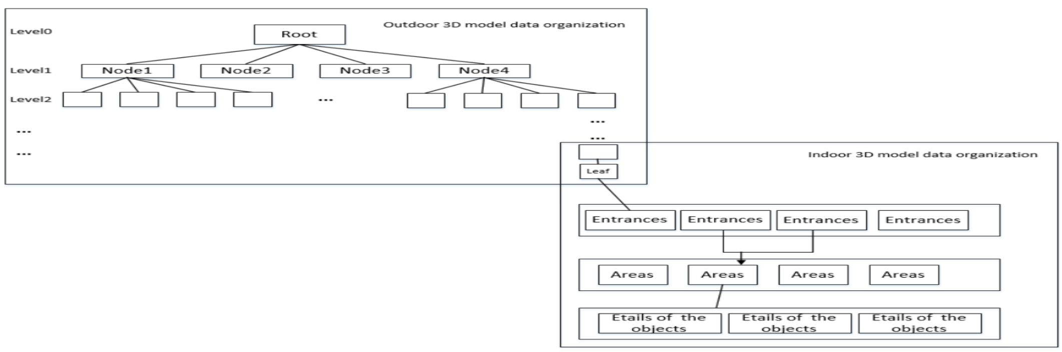

Figure 3. Indoor and outdoor 3D data organization methods

3. Experiment

In order to verify the practicality of the method proposed in this paper, conducted indoor-outdoor 3D data visualization experiments. **Figure 4** and **Figure 5** show the visualization effect and fluency experiments using the method in this paper. When observing the roaming visualization effect, the method employed in this paper demonstrated minimal stagnation or deformation, resulting in smooth and fluent roaming. Comparing the initial data input volume, Moments 1 and 3 showed slightly lower values than the traditional method, while Moment 2 remained equal to the traditional method. However, in terms of response time, the method proposed in this paper significantly outperformed the traditional method across all three moments. This means that the proposed method can organize indoor and outdoor 3D data faster with the same amount of data transfer.

Figure 4. Visualization of renderings

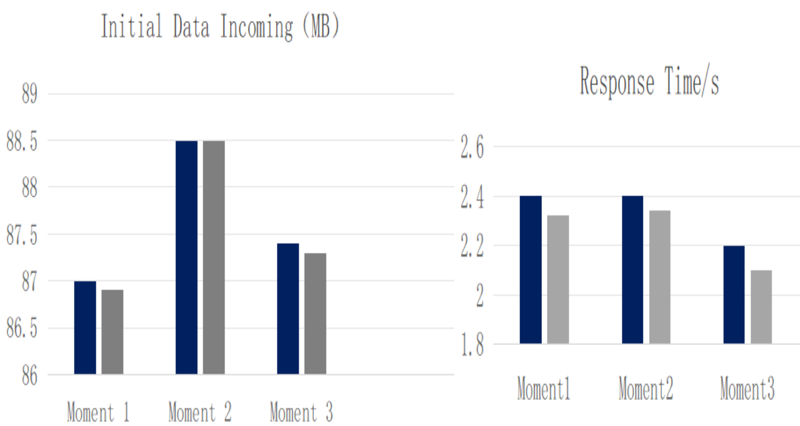

Figure 5. Fluency comparison

4. Conclusion

A semantic integrated organization method for indoor and outdoor 3D model data was proposed in this paper, which organizes the indoor and outdoor 3D model data in the form of "chunking-layering-objects-entrances-areas-detail objects." With the continuous development of digital building technology, the integrated indoor and outdoor data organization will be improved to provide more powerful support and guarantee for the construction of smart cities.

Disclosure statement

The author declares no conflict of interest.

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