A Lightweight BIM-GIS Integration Method for Rural Building Design and Construction

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Abstract

Building Information Model (BIM) and Geographic Information System (GIS) are both important data sources in the design and construction of buildings, and they have different emphasis on building information definition. A unified database that integrates BIM and GIS information is needed in many cases. However, most of the studies and applications of BIM-GIS integration are concentrated in urban buildings. Research on BIM-GIS integration in rural buildings is still rare. In fact, rural residences usually have different information characteristics with urban buildings. These characteristics need to be carefully considered to achieve effective information integration. A lightweight BIM-GIS integration method for rural building design and construction was proposed in this paper. The proposed method integrates BIM and GIS based on the Cesium platform, and realizes multi-scale lightweight algorithm based on the characteristics of rural houses. Based on a case study, the proposed method demonstrates its feasibility and efficiency in integrating BIM and GIS data. We believe it can assist with the design and construction of rural buildings.

Keywords: BIM, GIS, integration, lightweight algorithm, rural building

1. Introduction

Building Information Model (BIM) is a technology for storage, management, exchange and expression of building information based on three-dimensional models [1]. Geographic Information System (GIS) is an information system for storage, query, analysis and visualization of geographic data [2]. The integration of BIM and GIS is a promising task and has drawn the attention of researchers and practitioners. Some recent studies have applied BIM-GIS integration to support facility management [3], flood damage assessment and visualization [4], traffic noise analysis [5] and construction supply chain management[6], [7]. These studies have involved both building data and geographic data, and validated the effectiveness of the integrated BIM-GIS database in improving the efficiency of data acquisition and processing. However, most of the research in this field focuses on urban buildings or large public buildings. These buildings are characterized by their complex spatial topological information and numerous facilities. Almost none of these studies are involved in rural buildings. In fact, rural residence usually has different information characteristics with urban buildings which needs to be considered carefully.

Due to the vast area and sparse population, most rural buildings are designed as single-family houses with one or two stories and courtyards [8]. Compared with those high-rise urban buildings, the structure of rural buildings is relatively simple and the number of mechanical and electrical equipment is small. However, the village-level structure is often an important factor that needs to be considered in the design and construction of rural buildings [9]. This makes the information model of rural houses needs to integrate village-level spatial structure composed of tens to hundreds of buildings. At the same time, the surrounding

environment and landform will have a greater impact on the building in rural areas, which makes a greater emphasis on the integration of GIS data. Moreover, high-performance computing devices are not common in rural areas, especially in rural areas of developing countries. Mobile devices are often the main source of information for villagers. As a result, lightweight algorithms need to be carefully designed to adapt to the performance of computing devices.

Ma and Ren [10] reviewed recent BIM-GIS integration studies and summarized the patterns of integrating BIM and GIS into three categories, including extracting BIM information into GIS, extracting GIS information into BIM, and extracting both BIM and GIS information into another system. Among them, integrating BIM into GIS is a common way and has been applied by many studies [3, 5]. Some commonly used platforms include ArcGIS [11], Google Earth [12] and Cesium [13].

A lightweight BIM-GIS integration method was proposed in this paper to assist rural building design and construction. The method implements information integration base on the Cesium platform [13], and the characteristics of rural buildings are fully considered. Cesium is a web-based light weight platform for GIS data visualization and analysis [13]. The platform is written in JavaScript and supports access from both desktop application and mobile devices. Some Cesium-based researches on GIS data visualization and analysis have been carried out, and the results have proved its effectiveness in processing massive GIS data [14, 15].

The proposed method in this paper will be implemented base on Cesium, and achieves information integration by extracting BIM information into GIS model. The remainder of this paper is organized as follows. The proposed BIM-GIS integration method is first presented. The lightweight algorithm for rural building is then introduced. The next section gives a case study to evaluate the performance of the proposed approach. Finally, the discussion and conclusion are given.

2. BIM-GIS integration methodology

As shown in Figure 1, an original BIM-GIS integration method is proposed in this paper. IFC is selected as the BIM data format for its versatility in building information exchange. The GIS information to be integrated involves several data sources. Among them, CityGML is selected as the storage format for 3D building geometric information. And 2D geographic data is represented in GML and GeoJson files. Multiple open source tools are involved in the proposed method. These tools are shown in blue italics in the fugure. Finally, all information is integrated into the Cesium platform.
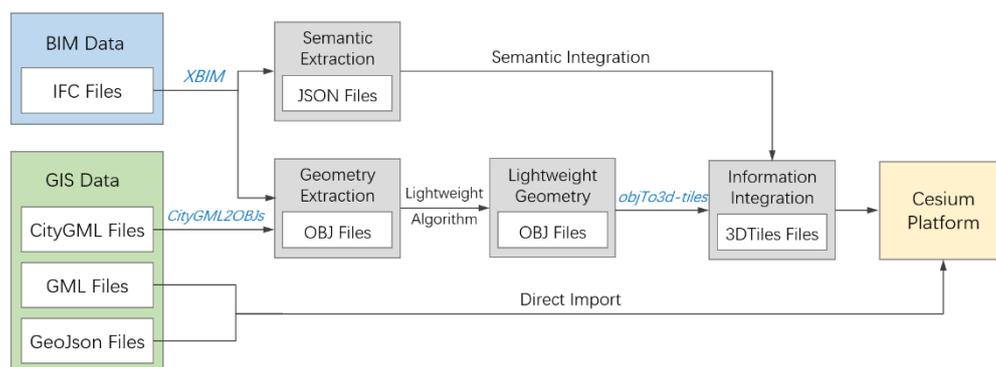

Fig. 1. BIM-GIS Integration Methodology

2.1. Integration with BIM

BIM files contain geometric information and rich semantic information of the building. An open source package xBIM [16] was applied in this paper to extract this information from the IFC files. The geometric and semantic information was decoupled and stored in different intermediate files.

As suggested by Chen et al. [17], the extracted geometric information was stored in OBJ files for that many open source tools for geometric format conversion are built around this format. A lightweight algorithm

was then implemented. Subsequently, the lightweight OBJ files were converted to 3D Tiles format using the open source tool objTo3d-tiles [18]. 3D Tiles is a specification proposed by Cesium for streaming massive and heterogeneous 3D geographic data. It could be read by the Cesium platform to achieve the integration of geometric information.

The semantic information is mainly semantic attributes of buildings and components, such as names, materials, and topological connections. Among them, the material information was written into the MTL file, which is a subsidiary of the OBJ file, to support geometry integration. The remaining information was stored in JSON format. The geometric and semantic information of a building component is linked by its identifier in the IFC file. In addition, to integrate multiple buildings in the village, the geographical location of each rural house also needs to be provided. This information can be obtained from the corresponding CityGML file or specified manually. 3D Tiles have a Batch Table structure to record additional information about the model. All semantic data was written into Batch Table to achieve information integration.

2.2. Integration with GIS

Three GIS data formats including CityGML, GML and GeoJson are involved in the proposed approach. CityGML contains 3D geometric information of a building or building groups. In the proposed approach, this information is extracted by the open source tool CityGML2OBJs [19] and written into OBJ files. These files are merged with geometric information from BIM to perform the lightweight and format conversion process. For GML and GeoJson formats, Cesium provides Application Programming Interfaces (APIs) for reading files. This information can be integrated to the platform directly.

3. Multiscale Lightweight Algorithm

In order to display large-scale building models in mobile devices, lightweight algorithms are necessary. In this paper, a multiscale lightweight algorithm was proposed. This method consists of multiple lightweight algorithms, each of which is applicable to a display scale. Building information is organized into multiple levels according to its boundary scale, and lightweight algorithms are applied respectively. It has been proven that multiscale information model is an effective way to organize building data [20]. Specifically, building information are divided into three levels in this paper: single building interior, single building exterior, and the building complex level.

3.1. Lightweight algorithm for single building interior

The single building interior scale is displayed when observing the interior of a building. This scale contains information inside the building, including building components, furniture, and spatial layout of rooms. At this scale, only the part of the building where the camera is located needs to be displayed. And it is not necessary to show the information of the whole building and the building group. With this feature, a lightweight algorithm for filtering display information can be designed to improve visualization efficiency.

Octrees are applied in this paper to organize the geometric data. As shown in figure 2, the root node of the octree records all the spatial information of the building. The space of the building is then evenly divided into eight parts to generate eight child nodes. Building components inside or intersecting the space will be recorded in the node. The division of space proceeds until the divided space is similar in size to a room. For common rural houses, one or two divisions are appropriate.

When displaying the interior geometry of a building, not all nodes in the octree need to be displayed. In the case of a section view, only the nodes that intersect the section plane need to be shown. And in the case of perspective projection, the node where the camera is located should be first determined. Only this node and its adjacent nodes need to be displayed. The number of components that need to be rendered can be then reduced.
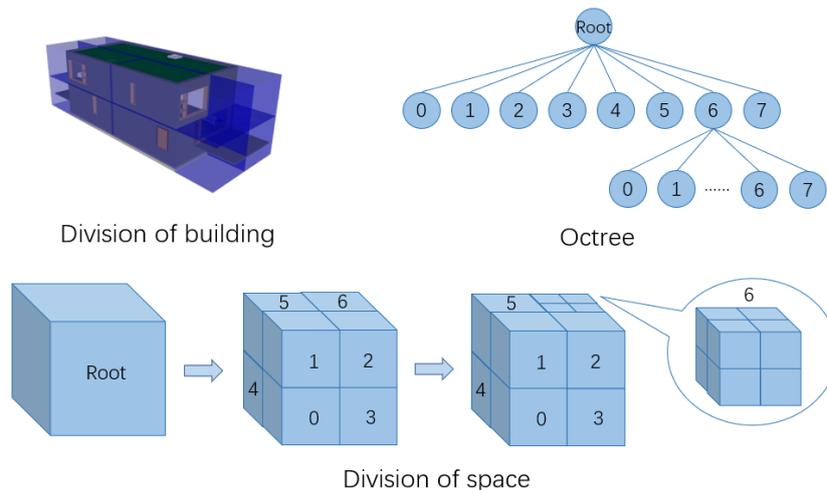
Fig. 2. Octree and the division of space.

3.2. Lightweight algorithm for single building exterior

The single building exterior scale is displayed when the building is viewed from the outside. This scale contains geometric information about the exterior surface of the building, including exterior walls, windows, and other external components. At this scale, geometric data inside the building does not need to be displayed. Therefore, a lightweight algorithm can be designed to filter out the information inside the building and reduce the size of models.

The algorithm also applies octree to store spatial data. Different from the algorithm in the previous section, the octree here needs to be continuously divided until the nodes do not contain any building components (In other words, all components have intersected some nodes). The leaf nodes will be then marked into three categories, including empty, boundary, and internal. The empty nodes are nodes that do not intersect any building component. A Boundary node is a node that is not empty and have no non-empty nodes on its outside. The internal nodes are nodes with boundary nodes on the outside. A depth-first-search process is carried out to mark each nodes, and only the boundary nodes need to be displayed.

3.3. Lightweight algorithm for single building complex

The spatial layout of the village needs to be considered in the design and construction of rural building, and the visualization of the building complex is required. The amount of calculation will multiply to render multiple building models in the same scene. At this scale, the location and orientation of the building are mainly displayed, and the geometric characteristics of the single building can be simplified. Light weight algorithms can be designed based on this feature.

In the proposed method, the exterior components obtained in the previous section are further filtered by their semantic information. Only building components belonging to the categories of walls, columns, slabs and roofs are retained. The openings on the walls for windows and doors are also ignored. The number of triangular faces to be displayed can be then reduced.

4. A Case study

A case study was performed to verify the feasibility of the proposed approach. Multiple BIM and GIS models were collected from the Internet and integrated into the Cesium platform using the proposed method. The introduction of the integrated files is shown in Table 1. And the integration of these models into the Cesium platform is shown in Fig. 3. Models from different sources and formats are integrated by the proposed method and displayed together in a Web browser.

Table 1. Introduction of the integrated files

| File name	Format	File size	Data source
20191126AZUMA9	IFC (Model 1)	10.0 MB	University of Auckland (2019)
Duplex_A_20110907	IFC (Model 2)	2.3 MB	National Institute of Building Sciences (2019)
Clinic_A_20110906	IFC (Model 3)	17.3 MB	National Institute of Building Sciences (2019)
FZK Haus	CityGML	15.9 MB	Karlsruhe Institute of Technology (2017)
Region	GeoJson	1.69 KB	Created Manually
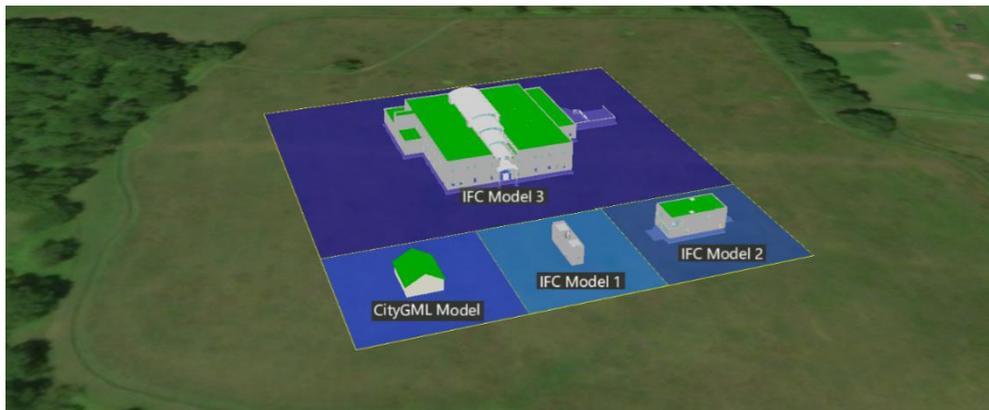
Fig. 3. Integration of the building models

The clinic model file is selected to estimate the effect of lightweight algorithm. The effect of the algorithm is illustrated in Fig. 4. Compared with the original model, the lightweight algorithms at three scales can all reduce the model size and number of triangles. Lightweight algorithms on the single building interior and exterior scales can reduce model size while retaining the appearance of the model. At the building complex scale, the proposed method can greatly reduce the model size, at the cost of rough model appearance. The cost is acceptable since the location and orientation of the building are mainly concerned at this scale.
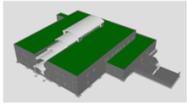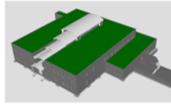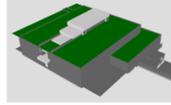
Model scale	Model view	Model Scale	Model View	Model scale	Model view	Model Scale	Model View
Original File		Single building interior		Single building exterior		Building complex	
File size	19.1 MB	File size	5.48 MB	File size	11.8 MB	File size	75 KB
Triangle count	533207	Triangle count	162413	Triangle count	334062	Triangle count	2016

Fig. 4 Effect of the algorithm applied to the model Clinic_A_20110906

5. Discussion and conclusion

The design and construction of rural building have different characteristics from urban houses. A lightweight BIM-GIS integration method for rural building is proposed in this paper to consider these features. Considering that the complex village-level spatial structure is required in the integration, an integration method was designed to integrate building models from different sources and formats in the village. A multi-scale information structure was proposed to achieve the model switching between single building and village scale. The integration and visualization platform are designed for web browsers considering that mobile devices are the main information acquisition tools in rural areas. Based on the multi-scale information structure, lightweight algorithms were proposed for each scale to address the lack of high-performance computing devices. Characteristics of rural building were considered in the lightweight algorithms to reduce the amount of calculation in the visualization process.

As a conclusion, a BIM-GIS integration method for rural building design and construction was proposed in this paper. The method is based on the Cesium platform and integrates BIM and GIS files in IFC, CityGML, GML and GeoJson formats. A multi-scale lightweight algorithm based on the characteristics of rural houses

was then implemented. Algorithms applicable to three scales, including single building interior, single building exterior and building complex scale, were designed. The proposed method was validated by a case study, and the result proved its effectiveness. We believe it can support the rural building design and construction process.

6. Acknowledgements

7. References

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