Research on fusion and integration method of BIM and GIS data

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Abstract. Building Information Model (BIM) provides a detailed description of various information throughout the lifecycle of a micro building, but it lacks the expression of macro geographical scene and has insufficient spatial analysis capability, while 3D Geographic Information Systems (GIS) focuses on describing macro geographical scenes. The integration of the two can complement each other's strengths to play greater value which is of great significance for the establishment of large-scale and high-precision 3D models and the promotion of the construction of the digital city. This paper proposes a fusion architecture of BIM and GIS based on the data exchange standard IFC for BIM and the data exchange standard CityGML for GIS. It maps IFC to CityGML from both geometry and semantics and presents an algorithm for mapping IFC wall elements to interior and exterior walls in CityGML, achieving a multi-dimensional and multi-level unification of BIM and GIS.

Keywords: BIM, GIS, IFC, CityGML, data fusion

1 INTRODUCTION

Building Information Modeling (BIM) was born in the 1970s and has been widely used in many fields such as 3D design, engineering management, and digital city since its birth. It describes the entire process of a building from design, construction to operation and maintenance, and demolition, integrating various information in different fields at different stages of the whole engineering lifecycle. It is an important means of integrating information resources, data exchange and sharing, and improving the efficiency of information resource utilization. BIM is a three-dimensional model which consist of building components. Its objectification and parameterization ensure the model's precision and have significant advantages in integrating building internal structure and attribute information[1] . However, BIM focuses on the micro level of representation, with limited spatial scope and spatial analysis capability. In contrast to BIM, 3D Geographic Information Systems (GIS) focus on describing three-dimensional geographical scene at a macro level, but is inadequate for spatial descriptions at the micro level,

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such as neglecting the management of building interiors and their constituent components[2] . BIM and GIS play different roles in the construction of 3D digital city, and their integration can make up their own shortcomings while allowing each to better take advantage of their strengths. By combining the micro-level building interior with macro-level geographical scene, integrating building internal geometry, semantic information, and various geographic information resources, a larger and more accurate 3D model can be established. This integration can promote the construction and development of urban real 3D scene and provide practical guidance for urban management and planning.

Current research on the integration of BIM and GIS mainly focuses on three aspects: data conversion, standard extension, and ontology-based methods. In terms of data conversion, most of research mainly focuses on the conversion between Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML). Donkers [3] extracted and reconstructed geometric model information from IFC into GIS surface model and assigned the correct semantic information, achieving automatic conversion from IFC models to CityGML LOD3 models. Shengjun Tang et al. [4] proposed a filtering method for IFC geometric elements and a semantic mapping rule from IFC to CityGML, which provides a common method for geometric and semantic information interoperability between IFC and CityGML. There are also some studies that realize the conversion between the two with the help of relevant softwares [5] [6] [7] [8] , such as ArcGIS, Google Earth, Super Map, etc. Other studies realized IFC to shapefile conversion using the automatic multipatch generation (AMG) algorithm based on the spatial structure of IFC. In terms of standard extension, Biljecki et al. [9] proposed Application Domain Extension (ADE) for CityGML, which enables precise conversion of semantics parts that cannot be converted from the IFC to CityGML, thereby reducing the loss of information. Some research fusing IFC and CityGML has led to the creation of new data standards, among which the City Information Model (CIM) [10] is a typical case, in which IFC and CityGML reclassify their respective defined entities and integrating them to form a new data model which ultimately divided into modules such as urban facilities, buildings, transportation, equipment and pipelines, and water. Additionally, there are Unified Building Model (UBM) [11] , Urban Information Model (UIM), and others [12] . In terms of ontology-based methods, Usmani, A. U. et al. [13] generated ontologies based on the IFC and CityGML, on the base of which the mapping between BIM and GIS is realized using semantic and structural consistency constraints. Jianyong Shi et al. [14] proposed an ontology-based BIM, GIS, and Internet of Things (IoT) data integration technology framework, establishing a universal CIM ontology that integrates heterogeneous BIM, GIS, and IoT.

BIM integrates various types of data from different fields throughout the entire lifecycle of an engineering project, with a large quantity and variety of data. Currently, the fusion of BIM and GIS still faces challenges such as data loss and semantic mismatch. To address this issue, this study proposes a fusion architecture for BIM and GIS that considers both micro-level entity objects and macro-level geographic scene. Based on the BIM data exchange standard IFC and the GIS data exchange standard CityGML, the study maps IFC to CityGML. Furthermore, to tackle the conversion problem from IFC to CityGML LOD4 level, an algorithm is proposed for mapping IFC wall entities to internal and external walls in CityGML. This approach ensures the integrity and accuracy of data fusion while reducing data redundancy, enabling the unified integration of multi-dimensions and multi-levels in geometry, semantics and son on.

2 OVERALL ARCHITECTURE FOR BIM AND GIS FUSION

BIM data can be classified into unstructured data and structured data based on file formats or data standards. Unstructured data includes engineering documents, reports, image information, etc. Structured data refers to data that can be organized and stored according to a certain data model, such as the portion of data that can be described using IFC. Therefore, it is necessary to categorize BIM data into unstructured and structured data firstly, and then integrate the structured part with GIS data. To achieve the construction of a three-dimensional integrated scene for above-ground and underground areas, it is necessary to integrate and process GIS spatial data from various sources. Different sources of data have varying formats, geometry, semantics, and spatial topological descriptions, so it is necessary to perform format conversion, coordinate matching, and so on.

IFC and CityGML are widely used data exchange standards for BIM and GIS respectively. IFC is a BIM data exchange standard developed by the International Alliance for Interoperability (IAI). It contains rich semantic information and defines three geometric representation methods. A geometric entity can be composed of one or multiple boundary representation (B-Rep), sweeping body, or constructive solid geometry (CSG). Building components defined in IFC are organized in a hierarchical structure. A building consists of multiple floors, each floor contains multiple rooms, and each room is composed of various elements. The relationships between elements are also recorded. CityGML is a format for storing and exchanging three-dimensional city models based on Extensible Markup Language (XML). It emphasizes the multi-scale representation of spatial objects and consistent representation of geometry, topology, and semantics. CityGML defines a large set of geographic object classes, as well as their geometric, semantic, and appearance properties of the city. It can be used for complex analysis in various domains such as simulation, data mining, and facility management. CityGML categorizes geographic elements into different thematic models, including buildings, Digital Terrain Models (DTM), transportation, vegetation, land use, etc. each of which defines five levels of detail (LOD0-LOD4) to represent different levels of detail. In terms of geometric expression, CityGML uses B-Rep. To describe spatial position, CityGML uses three-dimensional spatial coordinates. And topological relationships are used to describe the relationships between geographic objects. The similarities and differences between IFC and CityGML are summarized in Table 1.

Table 1. The similarities and differences between IFC and CityGML

content	IFC	CityGML
geometric expression	B-Rep, sweeping body, CSG	B-Rep

model appearance	texture mapping	material
semantic information	rich detail description and relationships between different components	levels of detail
expression scale	a single building composed of components	geographical big scene

IFC and CityGML both separate geometry and semantics, and they are connected through relationships [15] . This study achieves the mapping from IFC to CityGML in both geometry and semantics. The geometry processing includes three aspects: geometric filtering, geometric reconstruction, and coordinate transformation. Regarding semantics, the study maps the rich semantic information of IFC to the five-level LOD model of CityGML. The specific process is shown in Figure 1.

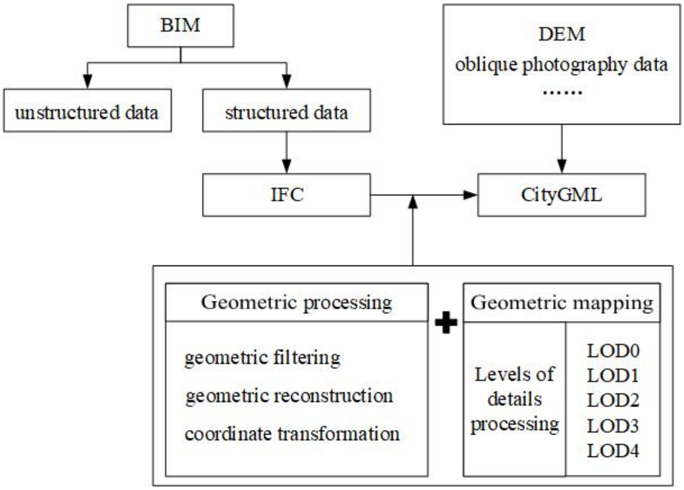

Fig. 1. BIM and GIS fusion architecture

3 MAPPING FOR GEOMETRY AND SEMANTICS

3.1 Geometric information extraction

IFC records a large number of geometric and non-geometric types, but not every geometric type is defined in CityGML. Therefore, during the process of geometry conversion, it is necessary to first extract the required geometric information, which is called geometric filtering. First, determine the desired geometric types to extract. Then, iterate through all IFC entity types. If a type has geometric information, continue to check if it is the desired type. If it is, output its geometric information and corresponding attribute information.

IFC and CityGML have different ways of representing geometry, so geometric reconstruction is needed. It involves converting geometric entity defined using the sweeping body and CSG methods in IFC into B-Rep representation. IFC defines geometry in a parametric modeling approach. Sweeping body are defined by a cross-section, a sweeping direction vector, and a sweeping distance. CSG body are defined by simple geometric shapes (such as boxes, spheres, etc.) and Boolean operations. The cross-section of a sweeping body is described by point coordinates. Therefore, other point coordinates, except for the cross-section, can be calculated from the cross-section's point coordinates, sweeping direction vector, and sweeping distance. The conversion from CSG to B-Rep mainly involves decomposing and traversing shape→shell→face→edge→point hierarchically [16].

IFC components use local relative coordinates, while CityGML uses global absolute coordinates. Therefore, it is necessary to transform IFC's relative coordinates to CityGML's global coordinates. This can be achieved by solving the coordinate transformation matrix from the IFC local coordinate system to the CityGML global coordinate system.

3.2 Semantic mapping

Due to the fact that the IFC standard model does not include the expression of LOD models for building objects and the descriptions of the five levels of LOD models for building models in CityGML are different, when mapping from IFC to CityGML, it is necessary to hierarchically extract components from IFC. LOD0 describes the corresponding ground area of a building, which can be generated from the ground plane of the building in IFC. LOD1 describes a block model (cuboid) representing the volume of the building, which can be generated based on the height and ground outline of the building. The roof in LOD2 is no longer a simple plane, which can roughly reflect the shape of the building and may also include chimneys, balconies, antennas, etc. LOD3 refines the appearance description by adding descriptions of "gap" in the building, such as doors, windows, etc. LOD4 adds descriptions of the internal structure of the building, such as rooms, stairs, furniture, etc. The respective IFC components needs to be extracted at each level from LOD2 to LOD4.

In IFC, a wall is defined as IfcWall, referring to the entire wall, while in CityGML, walls are usually distinguished as WallSurface and InteriorWallSurface. WallSurface refers to the visible exterior walls from outside of a building, while InteriorWallSurface refers to the walls inside the building that separate different rooms or corridors. Therefore, when mapping from IFC to CityGML, we need to consider how to map the entire wall in IFC to interior and exterior walls .

In this paper, we perform the conversion of IFC walls to CityGML interior and exterior walls on a per-floor basis. First, the outline of the building floor is extracted as the exterior wall in CityGML, and then the interior wall is further extracted. We extract the bottom outline based on the bottom plane of the floor, followed by adding the height of the wall to obtain the entire interior and exterior wall. Taking the bottom plane of a single wall Wn as an example, the thickness of the wall is recorded as WH, and its bottom point coordinates are recorded as Pn1, Pn1', Pn2, and Pn2' (where Pn2 is a point not on the diagonal line with Pn1 and not at a distance of WH from Pn1). The positive direction of the wall is from Pn1 to Pn2, as shown in Figure 2. The extraction algorithm for the exterior wall is as follows:

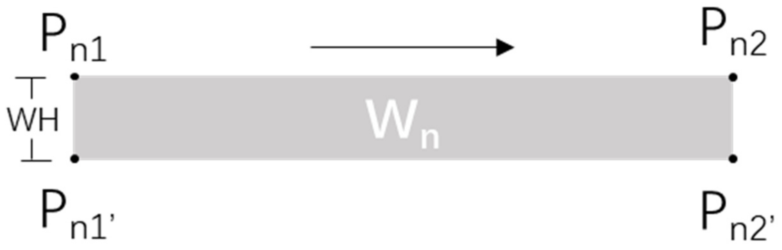

Fig. 2. Example drawing of the bottom of a wall

1. Starting from the point P_{11} (Xmin, Ymin) with the smallest coordinates on the bottom plane, this point is taken as the first corner point of the exterior wall. At the same time, the wall to which this point belongs is marked as W_1.
2. Find the point P_{n2} of the current wall W_n. The next corner point is either P_{n2} or a point P on the extension line of P_{n1} P_{n2} at a distance of WH from P_{n2}. If there exists a point $P_{(n+1)1}$ that coincides with P, then the next corner point is $P_{(n+1)1}$, and move the current wall to $W_{(n+1)}$. Otherwise, the next corner point is P_{n2}, and $P_{n2'}$ becomes the point $P_{(n+1)1}$ of the wall $W_{(n+1)}$, moving the current wall to $W_{(n+1)}$.
3. Determine if the current corner point coincides with the first corner point P_{11}. If they coincide, the extraction of the exterior wall surface is complete. If they do not coincide, return to step 2).

The extraction of interior walls in a building is essentially equivalent to extracting the spatial extent of rooms in the building. First, translate the outer contour by a distance of WH towards the interior of the building to obtain the inner contour. Simultaneously, the vertices of the remaining walls except for walls which belong to the exterior wall and the corner points of the inner walls constitute the set of V_N, and record which wall or walls each point belongs to. During the extraction of interior walls, the extraction is carried out in units of rooms. Each completion of the traversal represents the completion of a room wall extraction, and when all the points in the point set have been visited the extraction of all interior walls is completed.

The algorithm for extracting interior walls within a single room is as follows:

1. Start with an unvisited point V_i in the point set V_N and visit this point.
2. If the current point belongs to two walls, proceed along the positive direction of one wall to find the next point V_j. If the distance between V_i and V_j is WH, continue along the positive direction of the other wall to find the next point V_k and visit V_k. Otherwise, visit V_j directly. If the current point belongs to only one wall, visit the adjacent unvisited point V_j of the same wall.
3. Check if the current point coincides with the starting point. If they overlap, the extraction of interior walls for one room is complete. Otherwise, return to step 2).

4 METHOD IMPLEMENTATION

In this paper, the BIM data FZK Haus and Office Building, and oblique photography data are tested as an example. Figure 3 shows the fusion result of the exterior of the Office Building and oblique photography data.

Fig. 3. Result of the exterior of the Office Building and oblique photography data

In terms of indoor mapping, taking FZK Haus as an example, Figure 4 shows the bottom projection of the first-floor walls of FZK Haus. In the extraction of the exterior walls, a total of 8 points were accessed: P_{11}, P_{12}, $P_{12'}/P_{21}$, P_{22}, P_{31}, P_{32}, $P_{32'}/P_{41}$, and P_{42}. Among these points, P_{11}, P_{12}, P_{31}, and P_{32} are the corner points of the exterior wall surface. For the extraction of interior wall surfaces, taking Room1 as an example, the sequence of visiting vertices is shown in Figure 5. Figure 6 shows the mapping result from IFC to CityGML for the first floor of FZK Haus.

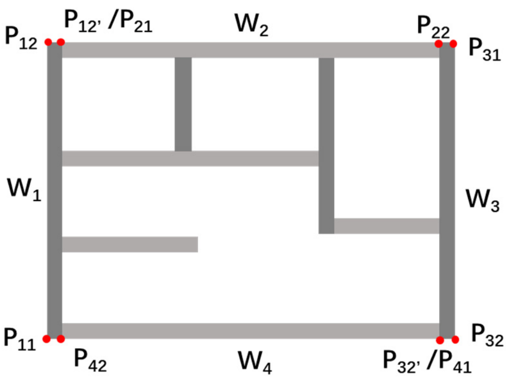

Fig. 4. Bottom projection of the first-floor walls of FZK Haus

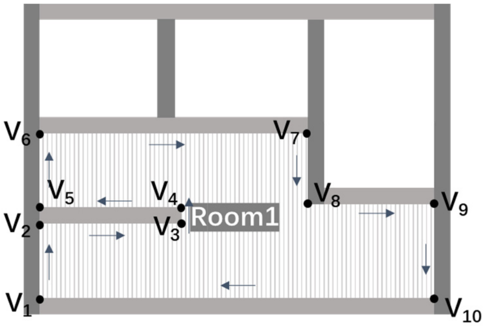

Fig. 5. The sequence of visiting vertices of Room1

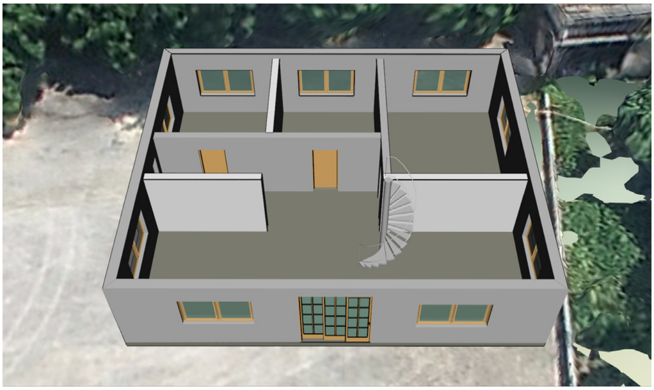

Fig. 6. Result from IFC to CityGML for the first floor of FZK Haus.

5 CONCLUSIONS

This study proposes a fusion architecture of BIM and GIS that combines micro-level entity objects with macro-level geographic scene. The fusion of BIM and GIS data is achieved through a method based on the conversion from IFC to CityGML. Due to a large number of entity types defined in IFC, it needs to be filtered when converting to CityGML. At the same time, the types defined in IFC and CityGML do not have a one-to-one correspondence, it is necessary to consider the correspondence between the two when converting. In this paper, we propose a mapping algorithm from IFC walls to CityGML interior and exterior walls from both geometric and semantic respectively, while considering the multi-detail level characteristics of CityGML. While reducing data redundancy, this approach ensures the integrity and accuracy of data fusion, achieving a unified integration of multi-dimensions and multi-levels in both geometry and semantics.

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REFERENCES

1. Jiang Shaohua, Zhang Haiyan, “Research on BIM-based Construction Domain Text Information Management,” Journal of Engineering Management, 27(04):16-20(2013).
2. Zhu Xu, “Research on the lifecycle information model of the ancient buildings of the Ming and Qing based on BIM,” Xi’an: Xi'an University of Architecture and Technology(2016).
3. Donkers Sjors, “Automatic generation of CityGML LoD3 building models from IFC models,” Delft University of Technology(2013).
4. Tang Shengjun, Zhu Qing, Zhao Junqiao, “Towards Interoperating of BIM and GIS Model: Geometric and Semantic Integration of CityGML and IFC Building Model,” Journal of information technology in civil engineering and architecture, 6(04):11-17(2014).
5. Zhang Y., Li J., "Application of BIM and GIS in Emergency Management of Smart Cities," 2021 3rd International Symposium on Smart and Healthy Cities (ISHC), 1-5(2021).
6. Xiang W., Wang F. and Zhang X., "Research on Integration of Multi-source BIM Models Based on GIS Platform," 2019 5th International Conference on Information Management (ICIM), 40-44(2019).
7. Hajji, R., Yaagoubi, R., Meliana, I., Laafou, I., Gholabzouri, A.E,” Development of an Integrated BIM-3D GIS Approach for 3D Cadastre in Morocco,” ISPRS International Journal of Geo-Information, 10, 351(2021).
8. Fernández-Alvarado J.F., Fernández-Rodríguez S., “3D environmental urban BIM using LiDAR data for visualisation on Google Earth,Automation in Construction”, 138(2022).
9. Biljecki F, Lim J, Crawford J, et al, “Extending Citygml for IFC-sourced 3D City Models,” Automation in Construction, 103440(2021).
10. Xu X., et al. “From building information modeling to city information modeling,” 19 (17) , 292-307 (2014).
11. El-Mekawy M., Östman A., Hijazi I., “A unified building model for 3D urban GIS,” ISPRS International Journal of Geo-Information, 1 (2), 120-145(2012).
12. Mignard C., Nicolle C., “Merging BIM and GIS using ontologies application to Urban facility management in ACTIVe3D,” Computers in Industry, 65 (9), 1276-1290 (2014).
13. Usmani, A. U., Jadidi, M., and Sohn, G., “Towards the automatic ontology generation and alignment of BIM and GIS data formats,” ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 183-188(2021).
14. Shi Jianyong, Pan Zeyu, Jiang Liu, Zhai Xiaohui, “An ontology-based methodology to establish city information model of digital twin city by merging BIM, GIS and IoT,” Advanced Engineering Informatics, 57(2023).
15. Tan, Y., Liang, Y., Zhu, J, “CityGML in the Integration of BIM and the GIS: Challenges and Opportunities,” Buildings, 13(7), 1758(2023).
16. Lv Huiling, Li Peiyao, Tang Shengjun, Zhu Qing, Xu Li, “Transformation method from BIM model to GIS model in different levels of details,” Journal of Spatio-temporal Information, 23(04), 64-70(2016).