A New Level of Detail Concept for Building Indoor Scene

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Abstract. Concomitant with the acceleration of urbanization, the indoor scene of buildings becoming increasingly complex in recent years. In order to meet the needs of diverse indoor application analysis, the multi-level of detail (LOD) model of indoor scene has been paid increasing attention. However, there are two kinds of LODs in the fields of geographic information and building information, which cannot be effectively integrated. From the perspective of geographic scenario, this paper proposes a new concept of LOD to realize the construction of indoor scene model under different details. According to the effects on indoor space, the indoor components are divided into three semantic levels: enclosing component, connecting component and decorating component. Finally, several examples of indoor models combining semantic LOD, geometric LOD and process LOD are introduced.

Keywords: indoor scene, semantic LOD, geometric LOD, process LOD, indoor component.

1. Introduction

With the development of digital cities, intelligent buildings are an indispensable part of the urbanization process. Research on building data models, building 3D modeling methods and related application analysis has attracted a wide range of concerns from researchers [1]. Building models with multiple levels of detail (LOD) can effectively support the refined application services of digital urban geospatial [2]. The daily life and work of modern residents are mostly concentrated in the indoor environment of buildings, time has occupied 80%-90% of the whole day, and different indoor activities have different requirements for the complexity of the indoor model [3]. Therefore, the multi-detail level expression of the indoor dynamic scene model is particularly important.

According to different research fields, the multi-detail level research of building indoor scene models is mainly divided into two categories. The first category is the level of detail (LOD) in the field of geographic information science (GIS), mainly focusing on the semantic and geometric detail of architectural entities. CityGML is an extendible international standard for virtual 3D city spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211. The latest version of CityGML2.0 was released in 2012. In this standard, the detail of urban building model is divided into five discrete levels. With respect to the exterior building shell, the LOD4 data model is
identical to that of LOD3. But LOD4 provides the possibility to model the interior structure of a building with the classes IntBuildingInstallation and Room [4]. The main disadvantage of the current CityGML LOD classification is that only all the entities of the internal building are assigned to one level, namely LOD4, which cannot satisfy the inability to adapt to increasingly complex indoor applications [3,5,6]. At the same time, the LOD required for the building model is different in diversities applications. If the indoor analysis is performed, the accuracy of the building shell can be low; if the outdoor analysis is performed, only the building shell is required and the accuracy of the indoor object can be lower or not included.

To overcome these deficiencies, modifications or extension of the LOD concept have been proposed [3, 5, 6, 7, 8, and 9]. Tang et al. proposed an extended indoor LOD (ILOD) specification, particularly for indoor spaces, allowing the existing outdoor LOD to become a more precise indoor model by exploiting the advantages of two other international standards: Industry foundation classes (IFC) and IndoorGML [6]. Chen presented a framework for organizing semantic LODs by first classifying them based on the tangibility of indoor entities and then partitioning each class based on the idea of permanence [7]. Löwner et al. proposed a new separated LOD concept for CityGML buildings that differentiates a geometrical level of detail (GLoD) and a semantical level of detail (SLOD) [3]. These two LOD concepts are separately defined for the interior characteristics and the outer shell of a building, respectively. Löwner et al. presented a multi representation concept (MRC) that enables a user-defined definition of LODs as a meta model for the further definition of an LOD concept for CityGML 3.0 [5]. Building is a geographical entity with a full life cycle and its evolution process. However, the buildings expressed in these studies are only static, whether indoors or outer shell entities.

The second category is the level of development (LODt) in the building information model (BIM), which focuses on the degree of information attachment to the building model [10, 11, 12, 13, 14, and 15]. LODt are not included in IFC standard but some guidelines, established by factories or institutes as AIA (American Institute of Architects) introduce LODt adapted to their working context. The level of development are used to specify and articulate with a high level of clarity the content and reliability of BIM at various stages in the design and construction process [10]. The enhancement of BIM can be seen through the use of LODt in construction projects [11]. BIM models developed by different stakeholders are often presented with different level of development [12]. Therefore, it is difficult to give a universal definition of LODt used in BIM unlike normalized CityGML LOD although both are summited to interpretation [13]. Trani et al. proposed a Construction Site Information Model (COSIM) for different phases of a construction process [14]. COSIM is developed by BIM-based method with a specific level of detail (both graphical and informative) for construction site design each phase. Boton et al indicated that the ultimate goal can be the creation of standardized 4D LOD, as combinations of graphical LOD and temporal LOD [12]. The current LOD problems in BIM don’t give a unified LOD standard. The level of detail of the output model is determined by the degree of object information required during the project implementation process.

In summary, the current LOD research have certain problems in the term of indoor scene expression. First, the existing LOD of indoor model cannot solve the evolution process problem at each phase. The indoor scene is not static, and the objects in the indoor scene have a full life cycle. During the construction phase, the building structure is from scratch and the process of continuous improvement. In the maintenance phase, the position of indoor furniture is a change process because of the furniture can be moved. With the increasing analysis and applications of indoor spaces, these dynamic information need to be supported from the data model itself. However, the evolution process information is not included in each LOD of model, which does not meet the needs of indoor analytical applications. Second, for the diverse applications in indoor scenes, the complexity required for dynamic building components is obviously different, and the current BIM methods cannot achieve a reasonable level of abstraction for specific applications or tasks. For example, when facing the indoor navigation, the building structure object needs to be coarser, while the indoor furniture object needs to
be more precise. Therefore, how to reasonably combine different levels of detail of building components is essential.

The framework of this paper is as follows. Section 2 presents the basic idea and overall procedure of the indoor scene LOD method. Section 3 describes the core concepts for indoor scene, and presents a new level of detail for indoor scene. Section 4 presents the conclusions of the paper.

2. Basic ideas
Indoor scene models often face their inherent complexity. To achieve the correct and appropriate level of abstraction for a particular application or task, a LOD of indoor model is required and must be specified for the corresponding modeling scheme and format. Meanwhile, the indoor scene object is not immutable, but an evolving process in its whole life cycle. In some stages, the evolution speed is relatively fast, while in other stages, the evolution speed may be slow. Therefore, the LOD of semantic and related geometry, attribute information of each process is different.

This study proposes a spatio-temporal LOD concept that integrates semantic LOD, geometric LOD and process LOD. It implements aggregation of level of detail and level of development from different domains, and implements a customizable and configurable building indoor scene model according to specific applications.

3. A New Level of Detail for Indoor Scene

3.1. Core concepts for Indoor Scene

As an artificial and important part of geographical scene, indoor scene is proposed to organize indoor information and data. Lv (2017) proposed that at least six elements of geographic information should be used to describe geographic scenes [16]. Six elements include semantics, geometric shapes, the related evolutionary processes, location, attributes of geographic elements, and the relationships among elements. In this study, we propose a new LOD concept for the indoor dynamic scenes that integrates semantic LOD, geometric LOD and process LOD (see Figure 1). We introduce them in turn in the following sections.

![Figure 1. Integration of SLOD, PLOD, and GLOD.](image)

3.2. Semantic Level of Detail
Semantics is the meaning of the descriptions of scenes and inner components. The semantics of indoor scene preserve local conception of abstracted indoor information and help people to distinguish and
exchange ideas related to the building. The semantical LOD of indoor scene denotes the degree to which the semantical information of a real indoor scene is reflected in the model.

The design of the indoor scene components is centered on the function or beautification of the indoor space. According to the different effects on the indoor spaces, the components of the indoor scene can be divided into three categories (Figure 2): the components that to enclose the indoor spaces (enclosing components), the components that connect the indoor spaces (connecting components) and the components that decorate the indoor spaces (decorating components).

![Figure 2. Indoor spaces and components.](image)

(1) Indoor Spaces

The indoor spaces of the building are separated from the natural space by using the building components. From low to high (Figure 3), the semantic LODs of indoor spaces can be divided into three generalized levels: building spaces, storey spaces and functional spaces. Functional space may have different functions in the view of different users, usually confirmed by furniture or equipment installed in the room (for example, a room with bed is always considered as bedroom). Building spaces can be divided into several parts along the vertical direction with different storey space semantics (such as the fifth floor). In the same floor, different functional spaces are combined into storey spaces. Regardless of the redefinition of floor space and functional space room, the overall internal space of the building does not change because the building shell maybe unchanged.

![Figure 3. Levels of Indoor spaces SLOD.](image)
(2) Enclosing components

The building enclosing components are the basic entities that compose indoor scenes. First, they act as the shell structural border between the interior space of the building and the external geographical environment. Then, they are used alone or in combination with other internal components to separate the functional spaces of indoor scenes, such as corridors and rooms. In this study, building components that enclose and divide the interior space are referred to as enclosing components. As illustrated in Figure 4, this paper designates the enclosing components SLODs as shell structural components, internal structural components, and structural appurtenances.

Enclosing components are entities that define the boundary of the building indoor space. Extracting the semantic and geometric information of indoor space boundary components is the basic condition for indoor space extraction [17, 18]. The building structural components used to enclose the interior space mainly include: walls, curtain walls, floor slabs, roofs, columns, and railings. The enclosing components represent the boundary of indoor spaces typically that geometrically restrict the indoor space. Table 1 describes the semantic information of the following enclosing components of building.

![Figure 4. Levels of enclosing components SLOD.](image)

| Name          | Semantic Description                                                                 |
|---------------|--------------------------------------------------------------------------------------|
| Wall          | Main enclosing component in the vertical direction. It plays load-bearing, enclosure, and space separation roles and is the main enclosing components of the boundary for indoor space in the vertical direction. |
| Column        | Mainly supports the vertical load of the building.                                   |
| Floor slab    | Platform that directly bears loads and divides a building space in the horizontal direction to multiple storey spaces. |
| Curtain wall  | Consists of a metal frame and a plate and does not bear the load of the main structure. |
| Railing       | Height between the human chest and abdomen; used to ensure personal safety or separate a space. |

(3) Connecting components

As shown in Figure 5, the components used to connect the indoor space mainly include three categories: navigation networks components, pipe networks components, and sensor networks components. The first category is the building components such as doors, windows, stairs, elevators, etc. used for indoor navigation; the second category is the indoor pipe network system used for
material flow transmission. These connecting components are mainly used to meet the indoor material demand of residents including water, electricity, electric heating, air conditioning, information and other resources. Sensor network is a kind of computer network composed of many sensing devices distributed in indoor space. These sensors monitor environmental conditions (such as voice, video, temperature, humidity, pressure or pollutants), and use collaborative way to sense, collect and process specific information in the network coverage area. The previous researches of indoor modelling pay more attention to the structural components such as doors and windows, stairs, etc., but ignore the pipe network and sensor network system. Table 2 describes the partial semantic information of the connecting components.

![Connecting components](image)

**Figure 5.** Levels of connecting components SLOD.

**Table 2.** Building connecting components.

| Name          | Semantic Description |
|---------------|----------------------|
| Door          | Main connecting component for indoor spaces. It used to provide controlled access for people and goods in the horizontal direction. |
| Stair         | As a building connection component for vertical transportation between floors. |
| Elevator      | Mainly supports the vertical transportation of the building. |
| Window        | Building components provided for lighting, ventilation, sunlight, etc. can be used for exit in case of emergency evacuation. |
| Plumbing      | Mainly used to meet the indoor water demand of residents including drainage system and fire protection. |
| Hvac          | Defines basic components required for interoperability within the heating, ventilating and air conditioning (HVAC) system. |
| Electrical    | It defines components of cabled systems where the cabling carries electrical supply, data, telephone signals or other forms of cable transmission. |
| Temperature Sensor | A sensor that senses temperature and converts it into a usable output signal. |
| Humidity Sensor | Senses humidity and converts it into a usable output signal. |
| Pressure Sensor | A device that can sense a pressure signal and convert it into an available output electrical signal according to certain rules. |

**(4) Decorating components**

The indoor spaces of the building have different functions and the environment in which they are located is also diverse. In order to make the indoor space to achieve a safe, hygienic, functional, comfortable and beautiful effect, it is necessary to use different interior components for indoor
decoration. Components for indoor decoration can be divided into equipment, furniture, and ornament (Figure 6). The equipment are generally installed at the end of the connecting components and needs to be fixed on the enclosing components, mainly including kitchenware, sanitary ware, lamps, vents and other equipment. Furniture consist of sofa, bed, cabinet, table and chair, etc. Ornament generally consist of crafts, painting, potted plants, pillow and so on, used to decorate the indoor space to make it beautiful. This is mainly to effectively design the multi-level of detail of the dynamic scene inside the building.

![Decorating components](image)

**Figure 6.** Levels of decorating components SLOD.

### 3.3. Indoor Scene Geometric Level of Detail (GLOD)

The geometric shape is the geometric information that remains when location, scale, orientation, and reflection are removed from the description of a geometric element [19]. In this study, the geometric LOD division of indoor scene refers to the previous research [5]. As shown in Figure 7, the bounding box (GLOD1) is adopted as the simplified geometric representation of indoor components. It is the smallest box around the interior component model. The projection of indoor scene components on two-dimensional plane is obtained, and the convex hull of plane geometry (GLOD2) is stretched. Exact geometry information of indoor components is contained in Geometric Level of Detail 3 (GLOD3). These models are generally precise geometric models that can be implemented from design and manufacturer.

![Geometric LOD](image)

**Figure 7.** Indoor scene Geometric LOD.

### 3.4. Indoor Scene Evolutionary Processes Level of Detail (PLOD)

Evolutionary processes describe changes or variations in indoor scene related indoor components and indoor spaces. From the perspective of six element model, evolutionary information includes the semantic, geometric, location, attribute and relationship of indoor scene components. Every indoor
artificial component experiences the appearance, development, maintenance and extinction, according to geographic laws and rules. In this case, the description of evolutionary processes LOD naturally covers the expression of temporal information, which is regarded as another key component of geographic information.

In this section, we define a continuous PLOD specification for 3D indoor models from PLOD1 to PLOD4 (Figure 8), as using the following graduations.

**Process Level of Detail 1 (PLOD1):** Cycle process only records the emergence and extinction time of indoor components, and does not involve any intermediate detail of evolution process information.

**Process Level of Detail 2 (PLOD2):** Stage process records the starting and ending time of each evolution stage of the whole life cycle, and there are obvious changes between stages. Indoor artificial scenes cycle process can be divided into several large stages on the time axis, such as planning, design, construction, maintenance, demolition.

**Process Level of Detail 3 (PLOD3):** The sequence can answer more time sequence information of indoor components. Multiple sequences form a process stage. Sequences generally describe repeatable and executable processes.

**Process Level of Detail 4 (PLOD4):** The evolutionary slice can answer the information of indoor components at any time point related geometry, semantics, relationship, and attribute. In this level, indoor components are continuous in time and space, and the evolutionary process between two slices can be described, expressed and executed.

![Process LOD](image)

**Figure 8.** Indoor scene Process LOD.

### 3.5. Possible Combinations of SLOD, GLOD and PLOD for indoor Scene

In order to meet different indoor application requirements, the LOD of the indoor scene model must be customizable and configurable. Based on the separation of semantic, geometric and process levels of detail, we present several different combinations of indoor scenes.

The combination of semantic and geometric levels of detail can only realize the expression of static building indoor model. Figure 9 shows examples for the enclosing components of storey shell with GLOD1. The 3D geometry of storey space is displayed in Figure 10.
Figure 9. The shell structure with enclosing components.

Figure 10. Storey space.

Figure 11 shows the indoor and outdoor enclosing components. Within enhanced semantic LOD enclosing components, the detail of interior space of building is more specific. Due to the addition of indoor enclosing components, the storey space is subdivided into smaller functional space (see Figure 12).

Figure 12. The different functional spaces bounded by enclosing components with GLOD2.

The evolutionary process is to describe the change process of semantic and geometric elements of indoor components. In the building structure construction stage, the model does not need to pay attention to the interior decoration details. In the interior decoration stage of indoor scene model, the geometric LOD3 is used in interior decoration components. And the 3D geometric shape of the structure components that enclose the interior functional space are GLOD2 only (Figure 13).
4. Conclusion
In this study, we proposed a new concept of LOD for building indoor scene based on a composition of semantic LOD, geometric LOD and process LOD. Semantics, geometry and process are the essential expression elements of geographic information. We divide the semantic of indoor components into enclosing, connecting, and decoration components according to the effect to the indoor space. The geometric LOD division of indoor 3D scene refers to the previous research. The LOD of the whole life cycle evolutionary process can be divided into four categories: cycle process, stage process, sequence process and slice process. Through analysing the detail level of indoor scene from these three aspects, we can combine into the various indoor model that contribute to more indoor analysis applications. Simultaneously, this study provides support for the development of unified indoor scene model from 3D to 4D, 5D.

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