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3D modeling of the ownership structure of condominium units

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ABSTRACT

Existing studies on modeling immovable ownership have not explored the internal structure and internal semantic relations of the ownership of condominium units in depth. This paper suggests extending CityGML with legal concepts from the Land Administration Domain Model (LADM) via the application domain extension (ADE) mechanism of the CityGML as a feasible approach for describing the ownership structure of condominium units. Based on legislation in China, a CityGML–LADM ADE model is proposed to precisely present the ownership structure of a condominium unit, which reflects the interrelations of legal objects and their physical counterparts. Finally, the proposed model is validated by two case studies.

1. Introduction

Rapid urbanization has led to an increased demand for the three-dimensional (3D) use of urban land space in terms of land administration. Because various complex buildings have posed a challenge to current 2D (or parcel)-based land administration systems, 2D parcel-based systems cannot effectively support the management of property in 3D space with a more accurate mode. Therefore, 3D cadastres have been developed to meet the management of 3D land use space and 3D properties (Williamson, Enemark et al. 2010, Guo et al., 2013, Stoter, Ploeger, & van Oosterom, 2013, Jazayeri, Rajabifard, & Kalantari, 2014, Karabin, 2014). This development helps meet the increasing social demand for the precise management of immovable property.

The core of administration of cadastres and properties is to explicitly and clearly register the rights, restrictions, and responsibilities (RRRs) of the property (Enemark, 2009), where the ownership is the crux of property management. Ownership is the lawful disposal of a property assigned to the people who own the property. A property has both bona fide and legal aspects (Aien, Kalantari, Rajabifard, Williamson, & Wallace, 2013, Jazayeri et al., 2014, Ying, Guo, Li, Van Oosterom, & Stoter, 2014), and it is considered a compound object that combines the physical object with the legal treatment of the object. The physical object (or usable space) is the base of the ownership and other rights. The legal aspect of property is generally attached to the physical object. When a physical object is constructed with several parts, the legal treatment included in the ownership would be different and specific for these parts, and the ownership may consequently show an internal heterogeneity. This internal heterogeneity reflects the disparity of the lawful disposal of the different parts of an object and requires differentiating ownership in a property management system.

With the current abundance of information and growing stress on personal property, more precise management of property includes not only land space and the vertical spatial extent of the property but also the horizontal extent of the property and the ownership structure, which corresponds to the spatial components of the property. An ownership of a property (such as a condominium unit) may be divided into several parts that are associated with their physical structural components in terms of right homogeneity. For example, an ownership of a condominium unit may include two physical objects: the exclusively owned apartment itself and some shared space (such as elevators and corridors) with others. Furthermore, with respect to the legal spatial extent of a property in some countries such as China, even for exclusively owned objects (or spaces), the room space is physically recorded into the legal spatial extent, and a balcony (space) may be half-recorded into the legal spatial extent. Such subdivisions of ownership with legal space are critical in taxation, load, and insurance. Current cadastre management systems or property registration systems only record the ownership as a whole and do not differentiate the ownership by its internal heterogeneity.

Condominiums are a special type of property with a common or shared ground parcel. A building of condominiums is divided into private and common parts. On the one hand, an owner can dispose his own private parts according to the corresponding laws, which implies an exclusive ownership. On the other hand, the common parts and ground parcel cannot be disposed at someone's will and must be at a common disposal, which indicates a common or shared ownership. This complex co-ownership has been discussed by many authors

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(Çağdaş, 2013, Pouliot, Vasseur, & Boubehrezh, 2011, 2013, Rajabifard et al., 2013). These studies mainly discussed the legal aspect of complexity, representing condominiums in the third dimension. The internal semantic relations of the ownership of a condominium unit have not yet been studied adequately. Such an ownership internal structure should be expressed in a spatially explicit manner to more precisely manage property.

The internal structure of a building can be clearly presented with rich semantic and 3D information due to the development of the CityGML model or building information models (BIMs). Considerable effort has been made to adopt CityGML or BIMs in the field of land administration and property management (Amirebrahimi, 2012, Çağdaş, 2013, Dsilva, 2009, El-Mekawy, Paasch, & Paulsson, 2014, Góźdź, Pachelski, Van Oosterom, & Coors, 2014). CityGML and BIMs have proven to be a feasible means of exploring the internal heterogeneity of the ownership of condominiums and clarifying the spatial differences within the ownership. The contribution of this study lies in presenting the ownership structure by mapping its physical parts (private or common) and their corresponding legal treatments and proposing an available method to model such ownership structures by an application domain extension (ADE) of CityGML with the Land Administration Domain Model (LADM).

This paper is organized as follows: Related works are provided in Section 2. In Section 3, the legal context of condominium ownership in China is discussed and the ownership structure is presented based on spatial mapping. Section 4 presents a 3D model for the ownership structure by extending legal concepts from the LADM into CityGML, followed by two examples that demonstrate the availability of the proposed 3D model (in Section 5). Finally, conclusions are drawn and future work is discussed in Section 6.

2. Related works

2.1. 3D models for property management

2.1.1. Geometrical representation of 3D property objects

The geometric representation of 3D property has been widely discussed with the development of 3D modeling. The ISO 19107 Spatial Schema, which was proposed by the Open Geospatial Consortium (OGC), provides geometry and topology elements to describe spatial objects. The geometry package of ISO 19107 contains geometric primitives, geometric aggregates, geometric complexes, coordinate geometry, etc., in which four basic geometric elements are included: *GM_Point*, *GM_Curve*, *GM_Surface*, and *GM_Solid*. This model represents 3D geometry according to the well-known boundary representation approach (B-Rep). Every geometry object, that is, point, curve, surface, and volume, is bounded by lower-dimensional geometry objects, that is, null, point, curve, and surface. In addition, topological primitives in four dimensions, that is, *TP_Node*, *TP_Edge*, *TP_Face*, and *TP_Solid*, are defined in the package.

Some cadastral data models were established based on the standard ISO 19107 Spatial Schema, such as the ePlan model (ePlan, 2010) and LADM (ISO19152, 2012), both of which represent 3D properties according to B-Rep. In the ePlan model, 3D properties were maintained using the *VolumetricGeom* concept, which is based on *GM_MultiSurface*, to model 3D objects. The LADM uses Class *LA_BoundaryFace*, which is also based on *GM_MultiSurface*, to represent a 3D spatial unit (*LA_SpatialUnit*) such as apartment units. According to ISO 19107, *GM_MultiSurface* does not return volumetric measurements. *GM_MultiSurface* only returns the accumulated areas and perimeters of all the *GM_Surfaces* contained in the *GM_MultiSurface* (ISO19107, 2003). The ePlan model and LADM do not support solid geometries (*GM_Solid*), which could impede 3D volumetric computation, 3D spatial analytical methods (3D buffering, overlap, intersect, etc.), the interoperability of 3D data (integration and data discovery), and 3D visualization.

Solid models have been applied to model the geometry of 3D spatial objects to overcome these limitations. For instance, the 3D cadastral data model (3DCDM), which was proposed by Aien et al. (Aien et al., 2013), supports the representation of 3D property objects with solid geometries (*GM_Solid*) based on the GML profile (ISO19136, 2007). The full 3D cadastral system that was designed by Guo and Li (Guo et al., 2013) represents the geometry of a 3D property with two solid components: a 3D model of the construction and a 3D container that represents the spatial extent of the land space used by the construction. Ying et al. (Ying et al., 2014) constructed various volumetric objects, including non-manifold 3D cadastral objects. A straightforward approach based on input consisting of loose boundary 3D faces from surveyors and the methods of face sorting and face connecting was presented to identify and construct valid volumetric cadastral objects from the given faces and build the topological relationships among 3D cadastral objects on the fly.

2.1.2. Integration of legal objects and physical objects

The management and registration of 3D property rights, restrictions, and responsibilities (3D RRRs) forms the core of 3D property administration. In terms of spatial extent, the legal objects define the spaces with 3D RRRs (Kaufmann & Steudler, 1998). Ownership spaces may utilize the structure of a building to specify the location of boundaries (Aien et al., 2013, Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013); that is, the boundaries of the legal volume are defined based on the actual structures of a building. Visualizing 3D RRRs alone without the physical counterparts of legal objects would not clearly represent the actual information of ownership RRRs and would not reduce boundary confusion among owners and owner corporations. The integration of physical and legal objects, by contrast, will clearly represent the legal structure of a building (Aien et al., 2013).

Generally, the legal information of a property exists in cadastral or property management systems. For example, the ePlan model, which was proposed by the ICSM's ePlan Working Group, was developed to represent all elements in cadastral survey plans for Australia, such as parcels, building format lots, and administrative and metadata information (ePlan, 2010). The ePlan model has been adopted for ePlan protocols such as the *Cadastral Information File* (*CIF*), which contains information that appears in survey plans for registration, to support digital lodgment and automated processing. Stoter et al. (Stoter et al., 2013) presented the solution and implementation of a cadastral system extension for the registration of 3D rights and restrictions on legal units in the Netherlands within the LADM. The implementation was conducted in two phases. The first phase of the solution did not require changing the legal and cadastral frameworks. For multilevel properties, the original parcel was maintained as a cadastral object. For additional 3D cadastral objects, a detailed 3D representation in a 3D pdf format that provides insight into the property situations was added to the original parcel. The second phase implemented a combination of traditional, infinite parcel columns and volume parcels, which were defined by 3D geometrical data and were not limited by 3D drawings. The proposed solution could explicitly represent multilevel properties, such as the rights of superficies, long leases, or easement and apartment complexes. However, because cadastres were developed for legal purposes, these cadastral data models only cover legal space, that is, the space that is relevant for the land administration (bounding envelope of the object). Further, these models do not integrate their physical counterparts, such as buildings and utility networks, on, above, and under the surface.

The representation of both legal and physical objects has been included in a few cadastral data models. Examples include the LADM (ISO19152, 2012), the 3DCDM (Aien et al., 2013), and the CityGML–LADM ADE model that was proposed by Góźdź (Góźdź & Pachelski, 2014). The LADM itself only covers the “legal space.” The LADM provides external links to support connecting legal objects to their physical counterparts, such as physical buildings and utility network data. This feature indicates that the physical information is outside the scope of