A BIM-BASED APPROACH FOR REPRESENTATION AND VISUALIZATION OF 3D CADASTRAL BOUNDARIES

KEY WORDS: 3D cadastral, BIM, visualization, CityGML, LADM, 3D cadastral data modelling

ABSTRACT:

A 3D real property is the basic unit of a 3D cadastre that is bounded both horizontally and vertically as a closed volume. The current 3D property formation in most countries is registered using two-dimensional (2D) documentation, as well as the legal property boundaries presented in a verbal description. However, if the cadastral boundaries in the digital index map only involve overview illustrations of boundaries, major geometric errors will occur in regard of actual location. Thus, it is necessary to identify accurate cadastral boundaries with integrated legal information and physical models. Building Information Modelling (BIM) is a digital representation including detailed physical information of a building, which could be used as a physical model to integrate legal information and define accurate cadastral boundaries. To make an overview of and visualize a 3D cadastral data model in a city, CityGML is another physical model to integrate a legal model (Land Administration Domain Model, LADM) with a CityGML Application Domain Extension (ADE). In our research, we define the 3D property boundaries by incorporating legal information into BIM data and convert the integrated model into CityGML. A CityGML-LADM ADE model will be proposed at the conceptual level and discussed concerning 3D representation and visualization of 3D property boundaries.

EXTENDED ABSTRACT:

Over the past decade, three-dimensional (3D) digital cadastre has been of increasing interest for stakeholders such as municipalities, land surveyors, architects, contractors, property owners, and property management companies. A 3D real property is the basic unit of a 3D cadastre that is bounded both horizontally and vertically as a closed volume, for example a block of residential apartments or a part of a multistore building with offices or a shopping mall (Li et al., 2016; Atazadeh et al., 2017; Andrée et al., 2018). However, current 3D property formation is still in most countries registered using two-dimensional (2D) documentation, as well as the legal property boundaries are presented in a verbal description and shown on 2D maps and drawings, which also applies for rights, restrictions and responsibilities (RRRs) (Shojaei et al., 2013; Larsson et al., 2018). This representation of the 3D cadastre is often insufficient, since the graphical representation is limited to land parcels and strata plan drawings (Drobež et al., 2017). Furthermore, the digital index map only involves overview illustrations of cadastral boundaries, which may lead to major geometric errors in regard of actual location (Larsson et al., 2018; Sun et al., 2018a). Therefore, several studies have proposed the use of 3D models of the physical space for representing and visualizing the 3D cadaster. The challenge is then how to integrate the legal information and the 3D models.

The legal information model is often stored in the *Land Administration Domain Model* (LADM) which is an international standard for land administration with four basic classes: *LA_Party*, *LA_RRR*, *LA_BAUnit*, and *LA_SpatialUnit* (ISO, 2012). It is currently used to describe 3D property and manage cadastral legal information. LADM uses the class *LA_BoundaryFaceString* to represent 2D *LA_SpatialUnit* and *LA_BoundaryFace* (semantic object but merely represents the bound shape of a spatial unit with surfaces) to represent 3D *LA_SpatialUnit* such as 3D parcels (Rönsdorff et al., 2014; Aien et al., 2017).

Two 3D models of the physical space are most commonly used: *Building Information Modelling* (BIM) from the BIM data aspect and CityGML from the *Geographic Information System* (GIS) data aspect (Atazadeh et al., 2017). Both BIM and city models are interesting from a 3D cadastre perspective. BIM is a digital representation of a building in the life cycle phases from design through construction to operation and maintenance (Eastman et al., 2011). BIM includes detailed physical information and facilitates cross-disciplinary collaboration among different actors between the different phases. IFC is an open international standard of BIM involved in a hybrid standardization process designed to enable indirect horizontal compatibility between architecture, engineering and construction (AEC) and facility management (FM) software applications (ISO, 2013). All physical building elements could be modelled, stored and managed hierarchically in IFC standard, which is easy to exchange building information for multiple purposes in different BIM platforms. To realize the integrated reference for process and reliable data exchange, an Information Delivery Manual (IDM) describes the information processes across the life cycle project and promotes digital collaboration between actors (ISO, 2016). On the other hand, from 3D GIS aspects, city models are often stored in the Open Geospatial Consortium specification CityGML. CityGML provides an open standardized geometry model to represent the geometric, topologic, semantic and visual aspects of 3D city models with five level of details (LODs), ranging from LOD0 to LOD4 (Gröger and Plümer, 2012). To enrich the data model, CityGML Application Domain Extension (ADE) is a built-in mechanism of CityGML to support additional requirements by certain use cases (OGC, 2014; Biljecki et al., 2018; Stouffs et al., 2018). CityGML ADE extends new classes and attributes for new feature types based on the rules and guidelines specified in CityGML 2.0 (Biljecki et al., 2018). It could be implemented by a *Unified Modeling Language* (UML) model and then derived into an *Extensible Markup Language* (XML) schema. Some studies integrated CityGML and LADM at the conceptual level, and proposed a CityGML-LADM ADE model to represent 3D cadastre (Góźdź et al., 2014; Rönsdorff et al., 2014; Li et al., 2016).

It is noteworthy that there are some differences when integrating physical models with building cadastral legal information. One of the largest differences between these two physical models is how to identify the building boundary type of specific elements. For example BIM/IFC supports defining external, median and internal wall boundaries separately, while in representing wall boundaries CityGML only contains subclasses "WallSurface" and "InteriorWallSurface" without a median boundary in the semantic query, even in the upcoming version CityGML 3.0 (Kutzner and Kolbe, 2018). Another difference is the coordinate system. The BIMs have a Cartesian coordinate system (often called an engineering system), whereas the CityGML models have a geodetic reference system, most commonly based on a conformal map projection and an orthometric height system. If IFC models store coordinate information, then it is called georeferenced. Moreover, if the CityGML models are based on a map projection, this georeferenced is still not straightforward due to geometric differences between two systems. However, if the BIM is small, for example for a single building, the scale distortions will be small and errors could be negligible. The BIMs provide a detailed description of the building necessary for the definition of the 3D cadastre unit as well as the RRRs. The shortcoming with the BIM model is that it cannot provide the overview in city scale on e.g. the 2D and 3D cadastre. For this purpose we need a city model. This is analogue to the 2D cadastre where we have the details in the cadastre maps (as part of the cadastral dossiers) and the cadastral index maps.

In Sweden, the developer/entrepreneur provides 3D Computer Aided Design (CAD) drawings that contain and represent the 3D real property boundaries in the digital index map and the cadastral dossiers recorded in 2D (El-Mekawy et al., 2014). El-Mekawy et al. summarize the real property formation process in regard to utilizing 3D CAD construction plans. Representing a complete 3D cadastre with BIM 3D aspects could be classified into four groups: legal, technical, registration and organizational (Paulsson and Paasch, 2013). They illustrate that legal aspects defined the boundaries of a property, area calculation and the content of a property; technical aspects concern how 3D properties could be visualized, geometrically represented, managed and extracted on technical applications.

In our research, we focus on how to represent and visualize 3D cadastral boundaries legally and technically. In the first step we aim to incorporate legal information into BIM data and define the 3D property boundaries. The parcel boundaries surrounding the building and the property boundaries within the building is identified and represented with high quality of position accuracy in the BIM extended model. The discussion above leads to that if 3D cadastre should be integrated in 3D models of physical space we need to be able to integrate the cadastre information with both the BIM and the city model. In terms of the information models described above, we integrate the legal information with IFC, and then transform the integrated IFC model to CityGML. In the next step we aim at making the connection of LADM to the city model. Thus, a CityGML-LADM ADE model will be proposed at the conceptual level and discussed concerning 3D representation and visualization of 3D property boundaries, see general workflow of methodology in Figure 1.

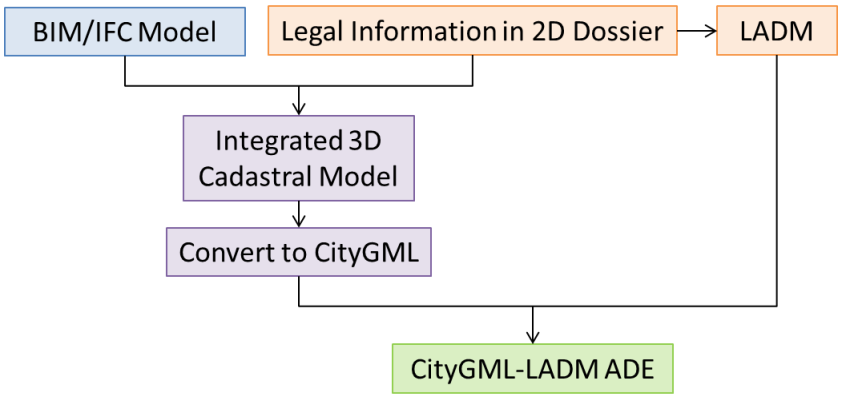

Figure 1. General workflow of methodology

A newly built multi-storey building in Sweden, Multihuset, is used as a case study to perform the process and address geometric aspects in the 3D cadastral data model. The legal information of the 3D registered property is stored in 2D documents including index map (Figure 2) with coordinates of space boundaries, cadastral dossiers including verbal descriptions of boundaries, property areas, heights in national reference system (Figure 3) and construction plans (Figure 4). Figure 3 gives a brief description of the location in height between level around "+ 24.71 meter" and "+ 33.87 meter" in the Swedish national height system RH2000 ("ca" means around). The 3D cadastral parcel stored in a dwg file will be used to identify surrounding boundaries of the building. The IFC model of Multihuset is an As-built model at the Level of Development (LoD) 500 of BIM, which means even furniture elements are stored in the model. Figure 5 shows the IFC model in Revit and Figure 6 illustrates the 3D cadastral parcel linked into a simplified model, see below.

Figure 2. Cadastral map of Multihuset, Malmö, Sweden (*Source*: NCC Company)

BRYGGAN 1

Boende Lotta Fyra AB, lagfaren ägare

Avstyckning	Avstår till Bryggan 2	fig 1	3387 m²
	Avstår till Bryggan 2	fig 2	3D-utrymme
	Avstår till Bryggan 2	fig 3	3D-utrymme
	Erhåller från Bryggan 2	fig 4	3D-utrymme

Utbredningen i horisontalplanet ca 74 kvm.
Mellan ca +24,71 och +33,87 meter i höjdsystem RH2000.

Areal enligt fastighetsregistret efter förrättningen 596 m²

Figure 3. Parts of textual 3D information (in Swedish) in Multihuset cadastral document (*Source*: NCC Company)

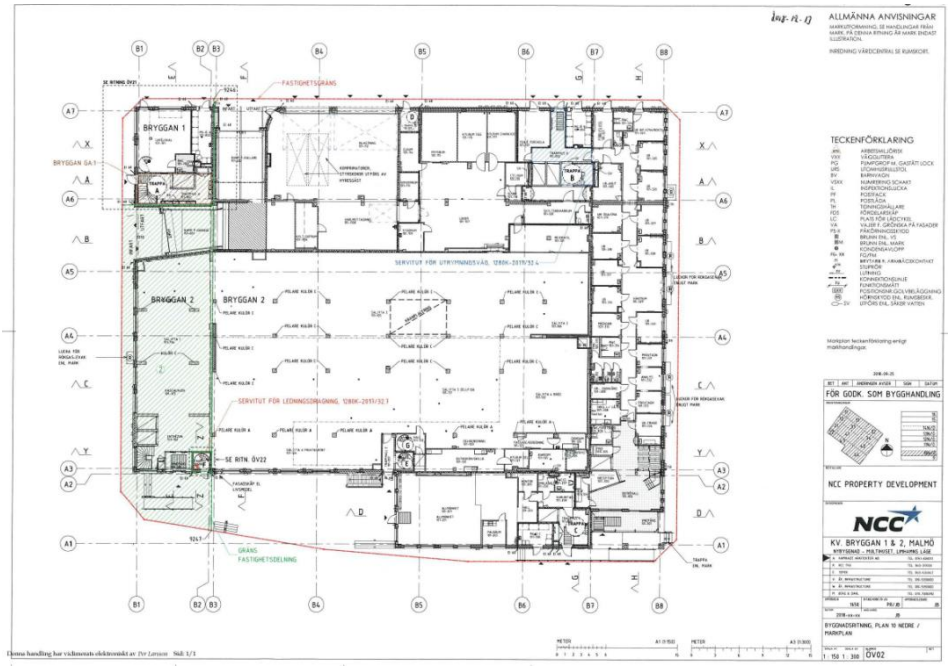

Figure 4. Example of CAD construction plans in Multihuset as part of the actual property formation dossier (*Source*: NCC Company)

Figure 5. IFC model shown in Revit (*Source*: NCC Company)

Figure 6. Link 3D cadastral parcel into simplified model

To address the complexity of physical aspects, we need to simplify the building model firstly and keep necessary elements to further generate spaces as the 3D cadastral unit. When embedding legal information into BIM, some questions need to be noticed and addressed:

1. What is the general process of 3D property formation and how is the information exchanging through the lifecycle of a construction project?
2. Which cadastral legal information should be integrated with BIM?
3. For different purposes, which LoD of BIM should be used and which building elements are necessary to generate the spatial unit?
4. How to generate a 3D accuracy reference system when using a local reference system in BIM?
5. How to identify virtual space boundaries by building elements?

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