Towards 3D Cadastral Level of Detail

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Key words: Cadastral Level of Detail (CLOD), 3D cadastre, BIM/IFC, 3D GIS, LADM, LOD

SUMMARY

The cadastre has gained increasing interests within the last decade under transition from 2D to 3D with the help of 3D spatial technologies 3D GIS and BIM, integrating with cadastral legal information. However, the 3D GIS and BIM domains represent and model geometric and semantic building information with their own hierarchical data structure - Level of Detail (LOD) and Level of Development (LOD) respectively. Both of them have different levels of granularity and focus on different aspects of the built environment. When generating 3D cadastral models and converting between BIM and 3D GIS, it will create problems with defining and representing legal information in 3D models accurately, maturely and reliably due to the fact that current 3D cadastre has no hierarchical data structure of its own and levels of detail.

To address those issues, a conceptual definition Cadastral Level of Detail (CLOD) is proposed to represent both legal information, rights, restrictions and responsibilities (RRRs) and geometric information for 3D cadastral models. The CLODs are the link to combine legal and spatial cadastral information, as well as to represent and visualize hierarchically in 2D cadastral maps and 3D cadastral models. The classification of CLODs corresponds to both the levels of detail of physical models (such as BIM/IFC and 3D GIS models) and the legal information/models (for example LADM models), ranging from CLOD0 to CLOD4. It aims to satisfy the cadastral geometry and legal requirements, save time and cost for further development of efficient and effective information retrieval, address the gap for harmonizing the cadastre, BIM and GIS database in order to implement in the cadastre ecosystem. It will be beneficial for different stakeholders to digitalize and standardize 3D cadastral management in a uniform way, as further strategically to support urban planning, detailed plans, and digital twins.

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1. INTRODUCTION

For title registration of traditional cadastre, legal information including textual documents and index maps that is recorded in cadastral dossiers is the fundament in the cadastral system (van Oosterom, 2013). From geometric point of view, a cadastre registers legal information with parcel-based cadastral maps (Paulsson and Paasch, 2013). The parcel may reflect a homogeneity in legal on behalf of legal cadastral purposes such as rights, restrictions and responsibilities (RRRs), or reflect a homogeneity in use on behalf of land use purposes. In many countries, the RRRs of the parcels are created together with the registration.

Within the last decade, the cadastre that is under transition from two-dimension (2D) to three-dimension (3D) has gained increasing interests with the help of 3D spatial technologies – 3D Geo Information System (GIS) and Building Information Modelling (BIM). 3D cadastral models are normally based on the integration of legal information with physical models from 3D GIS (e.g. CityGML, IndoorGML, LandInfra etc.) and/or BIM models to represent 3D property units and 3D property boundaries (Sun et al., 2021).

In this paper, we will leverage the results of previous research, namely the concepts of the Cadastre Ecosystem that have been proposed in the project "BIM-based 3D cadastral management" within Smart Built Environment, a holistic 3D cadastral management with five ecosystem elements: *Policy*, *Actors*, *Process*, *Technology* and *Business* (Sun, 2022). In other words, to a large extent, cadastre is a tool/system (*Technology*) to register land parcels (*Process*) including RRRs and values (*Business*) by government authorities (*Actors*) according to land law and regulations (*Policy*). Each ecosystem element affects and is effected by each other. It is of importance that the legal information of 3D property units and 3D property boundaries must be considered and represented completely in the BIM/GIS models. Currently, there are several international open standards normally used to manage and exchange geospatial data such as IFC, CityGML, IndoorGML and LandGML. Both 3D GIS and BIM domains represent and model geometric and semantic building information with their international standards and own hierarchical data structure - Level of Detail (LOD) and Level of Development (LOD) respectively (Sun et al., 2020).

However, the cadastre focuses on both legal and geometric information referring to land ownership, property boundaries and land use. While the LOD applied in those standards aims to represent geometry of 3D models, they have different levels of granularity and focus on different aspects of the built environment. Therefore, when generating 3D cadastral models and converting between BIM and 3D GIS, it may cause problems of defining and representing legal information in 3D models accurately, maturely and reliably, due to the fact that the current 3D cadastre has no hierarchical data structure and levels of detail of its own.

To resolve these problems, the main purpose of the study is to address the gap for harmonizing the cadastre, BIM and GIS database in order to facilitate the transformations efficiently from the hybrid stage towards the full 3D cadastre stage. Therefore, in this paper, we propose a conceptual definition of Cadastral Levels of Detail (CLOD) to represent both legal information including RRRs and geometric information of 3D cadastral models in details hierarchically. It aims to reinforce the legal aspects in each level of detail associated with all types of cadastral properties, for example buildings and infrastructures, regardless of data structures such as IFC, CityGML or LandInfra. There are five levels of detail ranging from LOD0 to LOD4, where each level of detail specifies both different levels of legal and geometric granularity in the 3D cadastral models. The legal level-of-detail specification is corresponding with LADM, while the geometry level-of-detail specification refers to LOD in 3D GIS. It could provide a basic requisite to develop a link between different datasets and pathways to implement the Cadastre Ecosystem.

The paper is organized as follows. In section 2, we describe the background of the cadastre ecosystem and overview the level of detail in CityGML, IndoorGML and LandInfra, level of development for BIM/IFC, as well as LADM. Section 3 presents a concept of the cadastral level of detail and designs the classifications from CLOD0 to CLOD4. Then we discuss and conclude with further directions in Section 4.

2. RELATED WORK

2.1 Cadastre Ecosystem

Sun (2022) has proposed a Cadastre Ecosystem and developed a conceptual framework that consists of five ecosystem components: Policy, Actors, Process, Technology and Business at a generalized level (Figure 1).

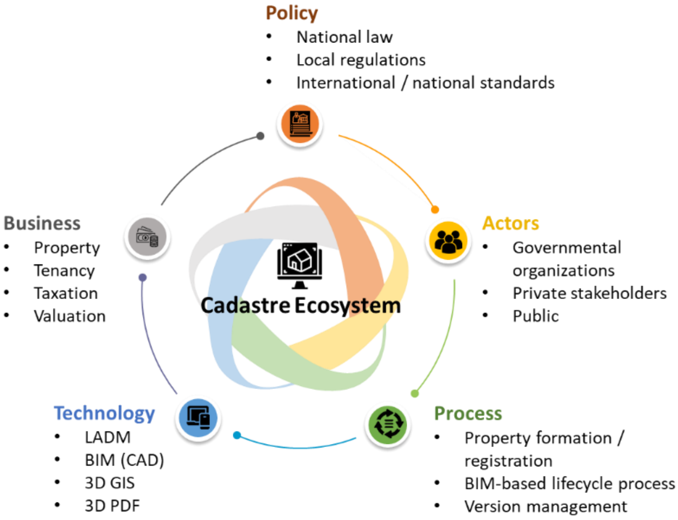

Figure 1. The Cadastre Ecosystem with five main components: policy, actors, process, technology and business (Sun, 2022).

The framework represents how 3D cadastral management by components link dynamically to each other, thereby giving rise to the cadastre strategic initiatives (Sun, 2022). Each ecosystem component could be interrelated and interdependent of other components, which covers legal, social, organizational, technical and economic perspectives of 3D cadastral management. A network model has also been proposed to identify 20 mechanisms (unidirectional arrows) between the cadastre ecosystem components, showing in Figure 2 (Sun, 2022).

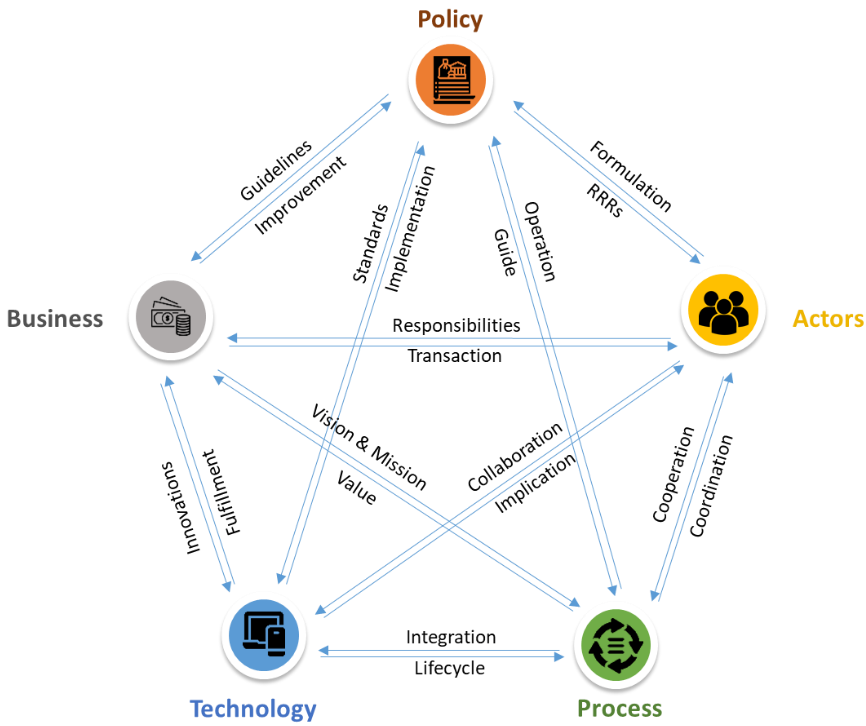

Figure 2. The network of relationships between Cadastre Ecosystem components (Sun, 2022).

The cadastre ecosystem reflects that 3D cadastral management is complex and dynamic, which requires close coordination and collaboration among different actors for ensuring the efficient and effective process of land and property management to support economic development. The actors in a cadastre ecosystem can include e.g. local government, cadastre agencies responsible for land management, cadastral surveyors, land registrars, lawyers, real estate agents, and property owners. From technical points of view, the cadastre domain needs a well-defined hierarchical data structure and level of detail to provide cadastral data specifications clearly, where the risk of spatial representation with legal information being misunderstood will be reduced. Therefore, there is an eager and practical demand to design and develop cadastral level of detail as a basic prerequisite to implement the Cadastre Ecosystem. It will be conductive to removing bottlenecks in the 3D cadastre development.

2.2 LEVEL OF DETAIL (LOD)

The LOD concept that originated in computer graphics has been adapted for 3D modelling to describe the level of detail and accuracy of 3D models in a standardized way. The LOD in 3D GIS can also be used to support different types of applications, such as visualization, simulation, analysis, and decision-making (Gröger and Plümer, 2012). It has been widely used in CityGML to describe the level of detail of city objects terrain, buildings, vegetation, and other features in a 3D model (Gröger et al., 2012; Biljecki et al., 2016; Sun et al., 2019; Eriksson et al., 2021). Nevertheless, it can be applied to most 3D GIS models regardless of its underlying data structure – CityGML (CityJSON), IndoorGML or LandInfra. These data models have different origins but are closely related to 3D cadastre, as well as BIM/IFC (Thompson and Wallace, 2013; Ledoux et al., 2017; Merlo et al., 2018; Kolbe et al., 2019; Koeva et al., 2021; Mwangi et al., 2020; Rajabifard et al., 2016; Stoter et al., 2018; Atazadeh et al., 2021).

2.2.1 CityGML

CityGML, developed by the Open Geospatial Consortium (OGC), is an XML-based open data model for the representation, storage and exchange of virtual 3D city models and landscapes, standardized (Gröger et al., 2012; Kolbe et al., 2021; Kutzner et al., 2020). The latest version is CityGML 3.0 that was released in 2021.

In CityGML, the LOD concept is used to represent different levels of detail for urban objects of the same real world such as buildings, trees, and roads. The different LODs, both regarding geometry and semantics, support multi-resolution modelling of a city, from simple surface models to detailed models including interior features (Uggla et al., 2023). Compared with CityGML 2.0 with five different levels of detail (LOD0 to LOD4), the LODs in CityGML 3.0 have been revised and provide different spatial representations (see Figure 3) in LOD0 (highly generalized model), LOD1 (block model / extrusion objects), LOD2 (realistic, but still generalized model) and LOD3 (highly detailed model) (Kolbe et al., 2021).

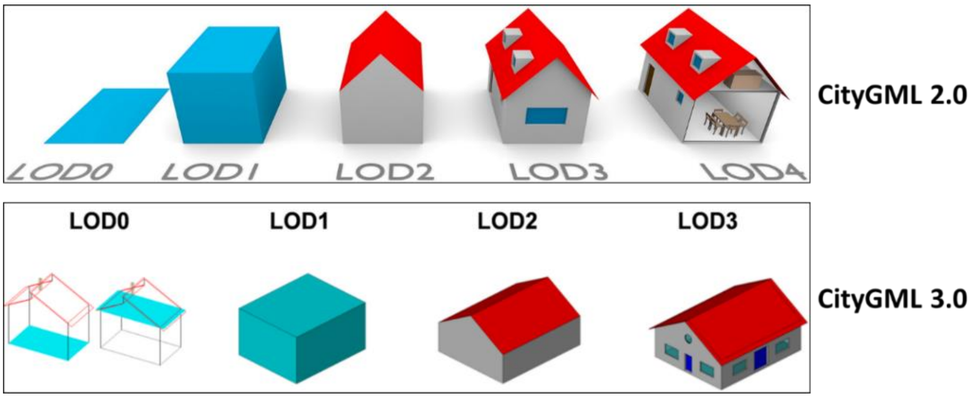

Figure 3. LODs in CityGML 2.0 and revised LODs in CityGML 3.0, adapted from Biljecki et al., 2016, and Kolbe et al., 2021 (Sun, 2022).

2.2.2 IndoorGML

IndoorGML is an open data model developed by OGC for indoor mapping and navigation (OGC, 2020). It is an XML-based language for encoding geospatial data that can be used in a variety of applications, such as indoor navigation systems, emergency response planning, facility management, and indoor location-based services (Jung and Lee, 2015; Tashakkori et al., 2015; Xu et al., 2016). IndoorGML intentionally focuses on modeling indoor spaces for navigation purposes (OGC, 2020). Therefore, the LOD in IndoorGML is similar to CityGML from LOD0 to LOD3, but aims to represent a different level of geometric detail, topology, and semantic information for indoor objects and spaces. However, there is no exact definitions of the LOD in IndoorGML in the OGC standard.

2.2.3 LandInfra

LandInfra is an open conceptual data standard developed by OGC supporting land and civil engineering infrastructure facilities, where the conceptual model subject areas include facilities, projects, alignment, road, rail, survey, land features, and land division (OGC, 2016). It integrates concepts from CAD (Computer Aided Design), BIM, and GIS, and has overlaps with CityGML and IFC (OGC, 2017). However, despite that LandInfra was designed as a connecting bridge between the two domains, LODs are not supported in LandInfra (Kumar et al., 2019).

2.3 LEVEL OF DEVELOPMENT (LOD)

Similar to the LOD in 3D GIS, the LOD concept in BIM/IFC models could also be applied to geometry of building elements, but mainly only describes the graphical content of models. However, regarding BIM and its implementation in the projects, the concept Level of Development (also abbreviated as LOD) is in widespread use that refers to the level of development needed in relation to the contents of the elements of the model (Bianchini et al., 2021).

The American Institute of Architecture (AIA) defines that “the Level of Development (LOD) describes the minimum dimensional, spatial, quantitative, qualitative, and other data included in a model element to support the Authorized Uses associated with such LOD” from LOD100 to LOD500 (AIA, 2013). An LOD defines both the required geometric detail (also denoted as Level of Geometry – LOG) as well as the required alphanumeric information (also denoted as Level of Information – LOI). (Borrmann et al., 2018).

In summary, these two LOD concepts are different. The Level of Detail concerns the geometric information of urban objects. In other words, the Level of Detail is essentially how much detail is included in the model element, while the Level of Development is the degree to which the element’s geometry and attached information has been thought through – the degree to which project team members may rely on the information when using the model (Latiffi et al., 2015; BIMForum, 2021).

2.4 LADM

The Land Administration Domain Model (LADM) is an ISO standard for land administration. The LADM is also widely used as a conceptual legal information model of 3D cadastre to represent the legal cadastral information, describe 3D property rights and support registration of legal information (Lemmen et al., 2021; Sun et al., 2019). It provides a basic and standardized terminology for describing entities in the domain and their relationships, including RRRs influencing real property, which can be expanded to fit a nation's needs. An example is different types of rights (or absence of rights) of different parties in particular situations (Hjelmblom et al., 2019). Even if being a conceptual, legal and administrative standard, it has been subject for research and basis for development of technical applications. For example, Sürmeneli et al. (2020) have developed CityGML Application Domain Extension (ADE) for the cadastral objects to integrate LADM and CityGML data model with the legal and administrative concepts defined in the Turkish Law.

The data structure of LADM Edition I is organized into the three main packages Party Package, Administrative Package, Spatial Unit Package (and one sub package of Spatial Unit Package: Surveying and Representation Package) (ISO, 2012). It consists of four basic classes: *LA_Party*, *LA_RRR*, *LA_BAUnit* and *LA_SpatialUnit* for full-length definitions, shown in Figure 4 (ISO, 2012). *LA_Party* is on behalf of persons or organizations that play roles in a rights transaction, which is associated to *LA_RRR*. *LA_RRR* is an abstract class for modelling various types of RRRs with three specialization classes *LA_Right*, *LA_Restriction*, and *LA_Responsibility*. *LA_BAUnit* represents the administrative entity, subject to registration (by law), or recordation. *LA_SpatialUnit* is for single or multiple areas of land and/or water, or a single volume or multiple volumes of space. The LADM Edition II that has been under revision aims to use different standards (BIM/IFC, CityGML, LandXML, InfraGML, IndoorGML, RDF/linked data, GeoJSON, and INTERLIS) to improve geometric and topological properties (Sürmeneli et al., 2020; Kalogianni et al, 2021; Lemmen et al., 2021).

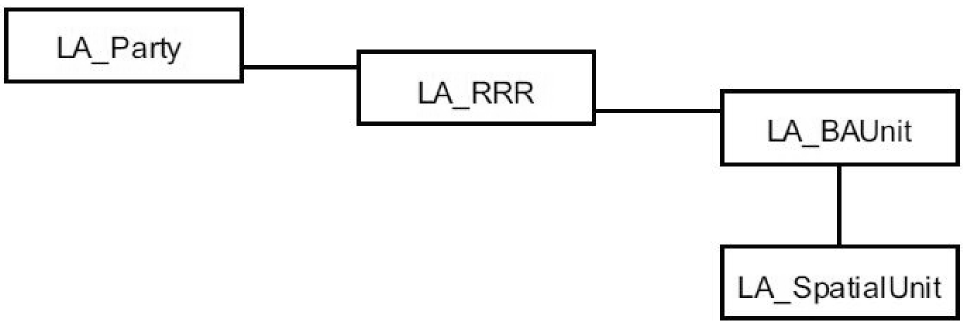

Figure 4. Four basic classes of LADM (ISO, 2012).

3. CADASTRAL LEVEL OF DETAIL – CLOD

As introduced in Section 2, the LOD is an important factor in ensuring that 3D physical models represent the real world accurately and provide useful information for analysis, planning, and decision-making. However, its narrow classifications for interior features cannot accommodate increasingly complex indoor applications, which may require interior structures of varying accuracy levels (Tang et al., 2018). When focusing on the 3D cadastre and cadastral management, how to represent legal information in the cadastral models is essential that hence some studies have mapped legal information or LADM into BIM and 3D GIS models (Atazadeh et al., 2021; Sun et al., 2019; Sürmeneli et al.; 2020; Zlatanova et al., 2016). In terms of 3D cadastral data specification, however, there is a lack to define a complex 3D cadastre representation with both legal and geometrical levels of detail. Therefore, the idea of the paper is to provide a conceptual definition for representation of legal and geometry information in 3D cadastral models hierarchically, rather than an approach to map or encode legal information into 3D GIS/BIM models. To address these issues, we propose a concept Cadastral Level of Detail (CLOD) to describe different levels of legal granularity and geometry accuracy of 3D cadastral models in a hierarchical way. The definition of CLOD could be suitable for all types of cadastral properties, for example buildings and infrastructures. In this paper, we only focus on representation of CLODs in buildings (Figure 5).

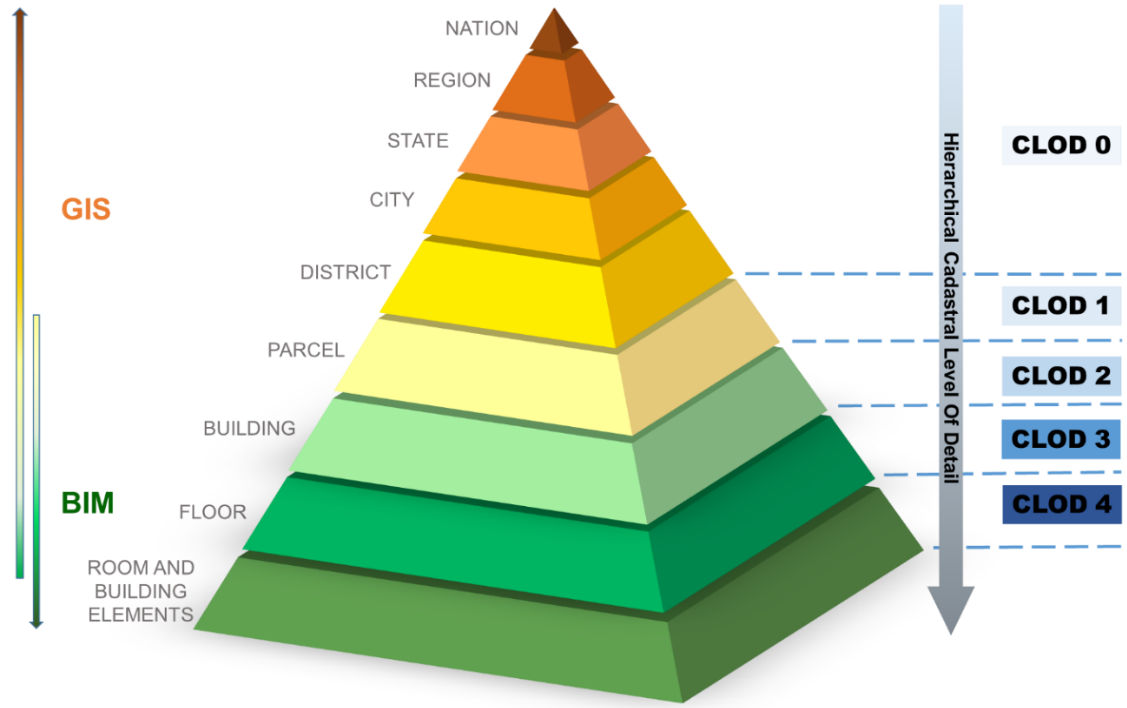

Figure 5.Hierarchical Cadastral Level of Detail with five CLODs.

In this paper, we focus on buildings and take BIM/IFC models as example to explain the CLOD concept and its classifications. The reasons are that most currently new-built buildings are using BIM/IFC models through the entire phases in the building environment and IFC can be easily transformed into other data structures. However, it must be noticed that the geometry aspect of CLOD refers to LOD (Level of Detail) in 3D GIS rather than LOD (Level of Development) in BIM (see the comparison in Section 2.3).

The legal level-of-detail specification is corresponding with LADM, and thus our work is in line with the international standard. One the other hand, the geometry level-of-detail specification refers to LOD in 3D GIS. Both legal and geometrical details are represented in five classifications: CLOD0 in 2D and CLOD1 to CLOD4 in 3D. Figure 6 illustrates the concept of CLODs and its five classifications, ranging from CLOD0 to CLOD4 by using BIM/IFC models as physical models for explanations.

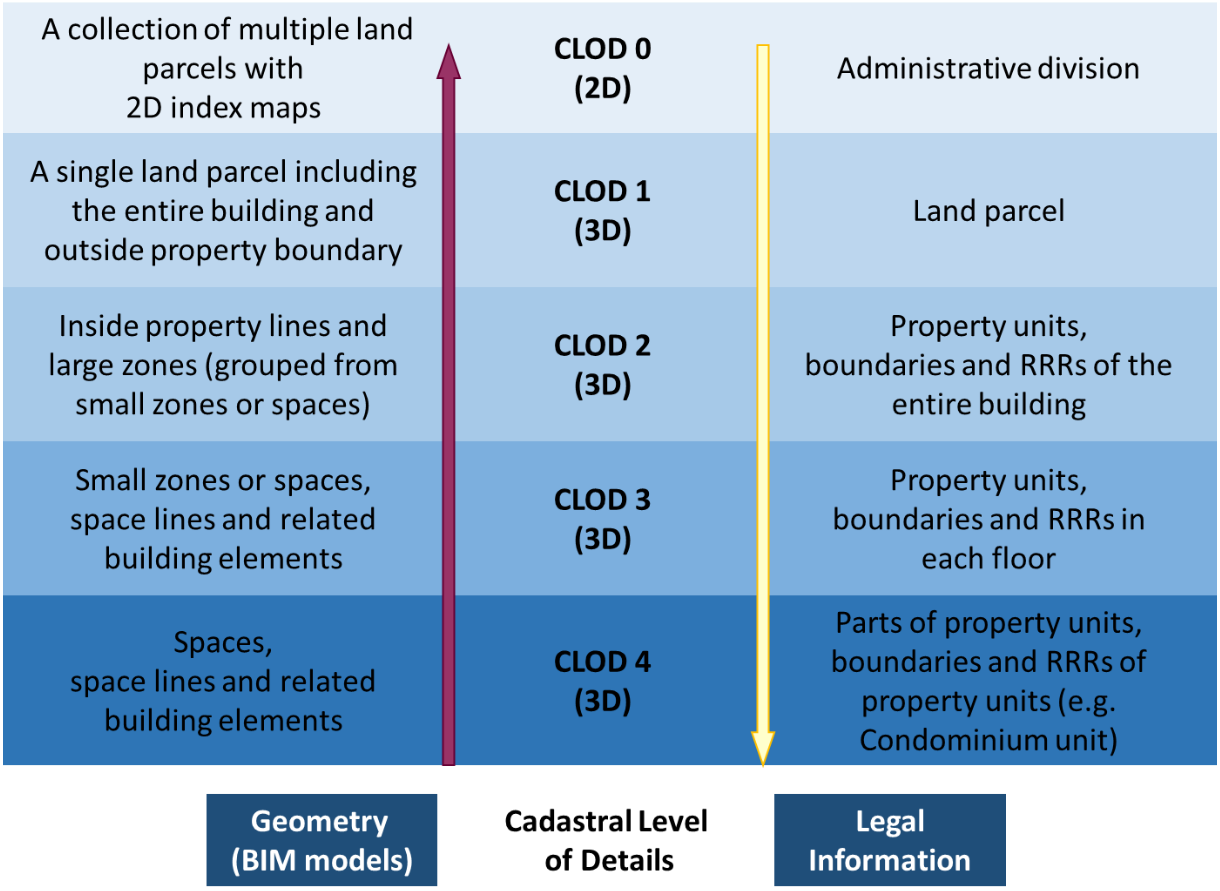

Figure 6. Classification of the CLODs, ranging from CLOD0 to CLOD4 (BIM/IFC models as physical examples for explanations).

Each level of detail specifies both legal information and geometry in the 3D cadastral models. The geometry level-of-detail specification of CLOD classifications is referring to but is different from LOD. The first reason is to ensure that the CLOD can meet practical cadastral requirements of different stakeholders; and the second reason is to support different data structures e.g. BIM/IFC models, CityGML or LandInfra as 3D cadastral physical models to represent cadastral geometric granularity. Meanwhile, the legal level-of-detail specification corresponds to the LADM standard with associated classes, e.g. *LA_Party*, *LA_RRR*, *LA_BAUnit* and *LA_SpatialUnit* in the classifications of CLOD to represent legal information in associated relationships hierarchically.

The conceptual classifications are described as follows:

- CLOD0: 2D, represents a collection of multiple land parcels with 2D index maps (in geometry), on behalf of the political and judicial administrative division of state in large-scale in legal.
- CLOD1: 3D, in physical models, represents an entire building and outside property boundary in a single land parcel, specified in law/registration
- CLOD2: 3D, represents large zones and inside property lines corresponding to property units and property boundaries that are registered in the system with its defined RRRs.
- CLOD3: 3D, in geometry, represents building parts subdivided by floor with smaller zones (or same as CLOD4); in legal, represents the same property units, property boundaries and RRRs of CLOD2 in each floor of a multi-storage building (or same as CLOD4).
- CLOD4: 3D, represents detailed spaces and space lines including related building elements and their relationships in physical models; while in legal, represents parts of property units, boundaries and RRRs of property units, for example condominium unit, garage or parking.

Note that easements and their RRRs can be included in different classifications, from CLOD1 to CLOD4. The representation of legal and geometric specification of easements will follow the general requirements in every classification.

It needs to be noted that the current CLODs classifications are designed to represent complex levels of detail for most buildings. In some specific situations, CLOD3 may be the same as CLOD4. Case studies with different situations will be implemented in further research. The concept of CLOD for infrastructure will be refined in future work.

The concept aims to reinforce the legal aspects in each level of detail associated with cadastral properties regardless of data structures such as IFC, CityGML or LandInfra. CLODs could provide detailed information about the geometric and legal context of properties. It is possible to select an appropriate CLOD for a given purpose to ensure that the 3D cadastral model could meet the requirements from different actors.

4. CONCLUSIONS

Traditional 2D cadastre provides a useful tool for managing and registering legal and geometrical data associated with the property, nevertheless, it is limited in their ability to represent the vertical dimension and complexity of the real world. With the increasing availability of 3D GIS and BIM, there has been a growing interest in developing 3D cadastre that could provide a more realistic and accurate representation of properties and property boundaries in order to implement a cadastre ecosystem. However, the current LOD concept in 3D GIS cannot define a complex 3D cadastre representation with both legal and geometrical levels of detail.

Therefore, in this paper, we proposed the concept of Cadastral Level of Detail (CLOD) and its classifications from CLOD0 to CLOD4 (2D in CLOD0, and 3D in CLOD1 to CLOD4). There are two aspects in the concept CLOD: legal and geometry specification. The legal level-of-detail specification corresponds to the LADM standard in order to represent legal information in associated relationships hierarchically, and meanwhile the geometric level-of-detail specification refers to but is different from LOD in 3D GIS to represent cadastral geometric granularity for satisfying practical needs from different cadastral actors/stakeholders.

In summary, the CLOD concept is primarily used to describe the levels of detail of the cadastral geometry and legal information to ensure that 3D cadastral models are accurate, complete, and useful throughout the lifecycle cadastral management. The main contribution is to provide a basic prerequisite to develop a link between different datasets and pathways to implement the Cadastre Ecosystem. It is a potential key factor in determining the accuracy and level of detail of 3D cadastral models used in the cadastre domain. In other words, the content of the 3D cadastral models could be represented through well-defined CLODs for property units including detailed information of legal and geometric attributes for multi purposes such as visualization, registration system, digital building permit, 3D digital detailed plans, urban planning, taxation and digital twins.

The paper is based on the previous research of cadastre ecosystem and the ongoing project "Testbed for Smart planning, construction, management and use processes over the entire life cycle (III) - tests in new processes" funded by the Smart Built Environment. In future work, we will specify the proposed five classifications of CLODs. Moreover, further research will focus on implementing the concept CLOD and its classifications in practical 3D cadastral models with a case study. The concept of CLOD for infrastructure will be refined in future work as well.

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