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Towards Investigation of Integrating LADM, BIM, and CityGML of 3D Condominium Rights for Cadastral Purposes: The Case of Turkish Cadastral System

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Key words: 3D Cadastre, LADM, BIM/IFC, CityGML.

SUMMARY

Four basic concepts form the basis of a modern land management system: Land Tenure, Land Value, Land Use, and Land Development. Cadastral studies are seen as the cornerstone of these four basic concepts. Especially, complex buildings located underground and above ground form the basis of 3D cadastral studies. In addition, international research has been conducted on developing future cadastral systems due to the increasing pressure on urban land use by locating various complex structures (multi-storey buildings, tunnels, subway networks, bridges, etc.) above and below ground. In light of these studies, a 3D cadastre is defined as a system in which owners' rights, restrictions, responsibilities correspond to advanced policies and standards. In this sense, having a well-formed and sustainable 3D cadastre will benefit many other applications such as urban planning, real estate valuation, construction activities. Nevertheless, the same objects are created in different data standards and formats for different applications. Thus, data exchange between different institutions and disciplines becomes difficult. In this sense, the open data standards (e.g. CityGML and Industry Foundation Classes (IFC)) have a vital role in enabling interoperability between different domains such as Architecture, Engineering, and Construction (AEC). Besides, Land Administration (LA) Standards representing legal and physical attributes such as LADM, CityGML and, IFC have been developed especially for buildings, which are the main objects of the 3D cadastre system. While LADM represents the legal side of cadastral objects, CityGML and IFC are not as successful as LADM in representing Rights, Restrictions, and Responsibilities (RRR) between real estate and its owner cadastral system. Therefore, the scope of CityGML, IFC and, LADM are slightly different concepts of representing building elements, but they could also be related to each other, primarily representing 3D condominium rights in the 3D cadastral applications. Unlike LADM, IFC and, CityGML are used to model physical objects. In particular, BIM applications focus on all building elements and technical details of the building at the scale of a building, while CityGML is used for a 3D city model or larger-scale applications. In this context, this paper aims to show the current situation and opportunities to efficaciously benefit from open data standards for the 3D condominium rights scope of the 3D cadastre. The examination of the paper concerns the cases for 3D condominium rights in the Turkish cadastral system. As a result, the study shows that the integration of LADM, CityGML, and the IFC schema model of condominium rights can benefit the general framework to transition to 3D LAS in Turkey.

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1. INTRODUCTION

Land management systems provide a comprehensive framework for designing and implementing effective policies and strategies associated with the planning and development of land in line with sustainable development goals (Rajabifard et al., 2018). Four basic concepts form the basis of a modern land management system: Land Tenure, Land Value, Land Use, and Land Development (Aien, 2013; Kitsakis et al., 2016; Rajabifard et al., 2018; Van Oosterom et al., 2018; Gürsoy Sürmeneli and Alkan 2021). Because of these four basic concepts, there is a growing interest worldwide in the production of three-dimensional (3D) city models. 3D city models support managers and decision-makers in many different areas, such as energy demand forecasting, disaster management and taxation, and real estate valuation (Biljecki et al., 2015). In connection with this situation, studies are carried out to represent many buildings in 3D to create digital city models. Building information modelling (BIM) and Geographic Information Systems (GIS) (CityGML) are most commonly used in the 3D representation of buildings. In particular, BIM applications focus on all building elements and technical details of the building at the scale of a building, while CityGML is used for a 3D city model or larger-scale applications. 3D city models and digital transformation that develop with urbanisation necessitate 3D real estate units of land management systems (Kalogianni et al., 2020). There are many studies in the literature on this subject (Aien et al., 2013; Ho et al., 2015; Rajabifard et al., 2018; Gürsoy Sürmeneli and Alkan, 2021). In this context, it becomes a necessity to digitally describe and register property rights in complex and multi-layered structures in detail. 3D cadastre should also be used to manage better lands and buildings in 3D city models (van Oosterom, 2018). In this context, open standards, which might be a conceptual or data standard, are crucial for making 3D city models and 3D cadastre databases (Eriksson et al., 2020). Putting into practice the 3D Cadastre requires the integration of different disciplines and stakeholders (Van Oosterom et al., 2020). The international standards that permit interoperability are therefore of significance. Accordingly, many studies concentrated on how to exploit these standards for 3D representation of ownership rights (van Oosterom, 2018). Some of these studies proposed to use the Land Administration Domain Model (LADM) (Kalogianni et al., 2021). Some scholars researched the integration of LADM with other standards such as CityGML (Li et al., 2016; Gürsoy Sürmeneli et al., 2020) and IndoorGML (Alattas et al., 2017) in order to better model legal rights and their physical counterparts. An ADE for CityGML that includes delineating condominium rights in Turkey is also proposed (Çağdas, 2013). With the growing interest in BIM, numerous researchers focused on the use of it in the context of 3D cadastre for different countries; for example, Sweden (Sun et al., 2019), Australia (Barzegar et al., 2020), and Serbia (Sladić et al., 2020). Recently, Atazadeh et al. (2021) proposed using the

IFC schema to model the features and attributes in LADM. Alattas et al. (2021) developed an approach that integrates IFC and LADM to represent the legal spaces in properties in Saudi Arabia. Çelik Şimsek and Uzun (2021) proposed calculating property valuations based on BIMs in Turkey's sense of condominium ownership. Guler and Yomralioglu (2021) suggested a conceptual framework for Turkey that integrates digital building permitting and 3D representation of condominium rights in terms of the use of BIMs.

Currently, integrating the standards mentioned above is challenging due to the difference in data formats used for these standards, hence the lack of interoperability between them (Kang and Li, 2017). In light of this information, the objective of this paper is to show the 3D delineation of condominium rights in Turkey, based on LADM and the integration of the IFC and CityGML schema. The study aims to bridge the gap by focusing on benefiting from open standards in the framework that integrates 3D delineation of condominium rights scopes of 3D cadastre. It was recently proposed for Turkey by the authors of the integrated model by using CityGML and LADM for 3D cadastre. In this sense, this paper first proposes a conceptual model for 3D delineation of condominium rights based on LADM, and then it shows an example by matching the features and attributes in this model with the IFC and CityGML schema. This paper also provides a general framework for the 3D cadastre in Turkey with an integrated model using LADM, IFC, and CityGML that makes possible the 3D depiction of condominium rights. The rest of the paper is structured as follows: Section 2 presents brief information about Turkey's current RRR registration. Section 3 presents an overview of open data standards and previous work on the IFC and CityGML semantic integration. Section 4 present the result(s) of integrating the open data standards for 3D registration of condominia in Turkey. Section 5 is the conclusion.

2. CURRENT STATE IN TURKEY

Turkish cadastral systems include two main parts. First is the land registry representing the legal relationship between people and real properties. The second part is the cadastral maps. Cadastral maps define geometry data and annotations; also contain the land use. Furthermore, it keeps all of the temporal information about the land registry records. The use and registration of lands in Turkey are regulated according to the constitution. All these transactions are carried out by the General Directorate of Land Registry and Cadastre (GDLRC). In Article 704 of the Turkish Civil Code, the following elements are stated as the subject of real estate property;

- Land,
- Permanent and independent rights recorded (RRR) on a separate page in the land registry,
- Independent sections are registered in the condominium book.

Therefore, the independent sections are an essential structure within the scope of the 3D cadastre among the real estate subject to registration in the Turkish cadastral system. The third dimension is not sufficiently covered in the constitution. However, there are several rights set out in the Turkish constitution concerning the third dimension (e.g., easement right, usufruct, right of passage). Several of these rights represent 3D descriptions, but they are in writing

registered to the book of land registry in the current situation. Also, several responsibilities that indicate the liabilities, such as taxation, repair, and maintenance, are defined in Turkish Civil Law. The legal interests currently registered in Turkey's 2D cadastral system are Parcel, Right, Restriction, Responsibility, Registration object, Building, Condominium, Annex, Boundary, Points, and Documents. These interests can be classified into three categories: a Cadastral object, Source, and RRR (Table 1). Cadastral objects are parcel, registration object, building, condominium, and annex. Sources are boundaries, points, and documents. RRRs are right, restrictions, responsibilities. It can be seen from the table that legal interests relating to properties are considered and registered in the Turkish land registry system.

Table 1. Definition of legal interests related with a condominium in Turkish cadastral system

Legal Interests	
Cadastral Objects	
Name	***In Turkish***
Parcel	*Parsel*
Registration object	*Tescil nesne*
Building	*Bina*
Condominium	*Bağımsız Bölüm*
Annex	*Eklenti*
RRR	
Right	
Name	***In Turkish***
Property Right	*Mülkiyet Hakkı*
Right of Usufruct	*Intifa Hakkı*
Joint Property Right	*Paylı Mülkiyet Hakkı*
Right of Residence	*Oturma Hakkı*
Co-Property Right	*Elbirligi Mülkiyeti*
Right of Superficies	*Üst Hakkı*
Property Ownership	*Kat Mülkiyeti Hakkı*
Right of Passage	*Geçit Hakkı*
Easement	*İrtifak Hakkı*
Right of Spring	*Kaynak Hakkı*
Rental Right	*Kiralama Hakkı*
Water Way Right	*Su Geçit Hakkı*
Restriction	
Name	***In Turkish***
Annotation	*Şerh*
Right to Purchase	*Geri Alım Hakkı*
Right of Pre-Emption	*Ön Alım Hakkı*
Lien	*Rehin*
Mortgage	*İpotek*
Zoning Status	*İmar Durumu*
Representation	*Beyan*

Responsibility	
Name	***In Turkish***
Right of Encumbrance	*Taşınmaz Yükü*
Possession	*Zilyetlik*
Real Estate Tax	*Emlak Vergisi*
Sources	
Name	***In Turkish***
Boundary	*Sınır*
Points	*Ölçüm Noktası (Koordinat)*
Documents	*Belgeler (Kroki, Plan, Tapu vb.)*

Nevertheless, this information is stored independently from the geometry as a separate attribute. A two-dimensional graphic representation of most rights and restrictions is possible. The rights and restrictions regarding the third dimension are recorded as textual (annotated to the title), although the presentation of the presentation is shown as right (e.g., right of passage) as a restriction (usually in large engineering projects: Metro route, pipelines, etc.) not shown in the cadastral maps.

Turkey conducted some projects to provide a modern cadastral system under the leadership of the GDLRC. The most notable of them occurred the INSPIRE Directive implementation, which made it necessary to create a conceptual model for Turkish cadastral data. One of these projects is the Turkey National Geographic Information System (TUCBS) which adopted the INSPIRE (EC, 2007) directive. It is an e-government project aiming to establish GIS infrastructure following the technological developments at the national level and create a web portal by public institutions and organisations to provide geographic information (Polat et al. 2020). The new project is 3D City Models and Cadastre that started in 2018. The project aims to produce 3D models of buildings and individual units with legal information. The ongoing project was produced detail of 3D models with sample titles and started integrating the models with the GDLRC information system would continue (Döner and Şirin, 2020).

3. OVERVIEW OF THE OPEN STANDARDS

3.1 Land Administration Domain Model (LADM)

LADM is developed to contribute to Land Administration Systems (LAS). It aims to establish a common ontology for rights, RRR affecting the land administration and its geometric components. Thus, it will enable communication between related parties or between different countries (Atazadeh, 2017). ISO/TC211 has established the LADM to standardise geographical information and geo-characteristics (van Oosterom et al., 2006; Gürsoy Sürmeneli and Alkan, 2021). LADM has three main packages and one sub-package. These are LA_Party (Party package), LA_AdministrativePackage (Management package) and LA_SpatialUnitPackage (Spatial Unit package) and LA_SurveyingAndRepresentation (Lemmen et al. 2015).

The Party package is described as entities about different land administration actors (LA_Party) and their roles for modelling information. The Administrative package covers two distinct main concepts: RRR (LA_RRR) and basic administrative unit (LA_BAUnit). The RRR class is composed three subclasses into "LA_Right", "LA_Restriction", and "LA_Responsibility". These subclasses are used for modelling various types of rights, restrictions, and responsibilities, respectively. The other administrative package concept is the basic administrative unit adopted in LADM to arrange and combine spatial units with the same or homogeneous RRR. Also, the Spatial Unit package and its Surveying and Representation subpackage are used to model legal objects' spatial dimensions. The central entity in this package is "LA_SpatialUnit" which is used for modelling the concept of spatial units (Lemmen et al. 2015; Atazadeh, 2017).

It also supports the time component of the Land Administration Basic Model. The most important feature of the model is a flexible model that can be expanded within specified standards. It is possible to associate with external classes such as Valuation, Address, and the Landcover as the model feature requires (Alkan et al., 2020). Although LADMs current version provides an international framework for LAS, it is limited to support 3D cadastre since it lacks geometric or topologic representations (Kalogianni et al., 2020). The second edition of the LADM (LADM II) aims to extend the conceptual model's initial scope, such as valuation information, spatial planning/zoning, linkage of legal objects with physical ones, and support of other legal spaces: mining, archaeology, utilities, etc. Furthermore, the current conceptual model is being improved, including formal semantics/ontology for the LADM Code Lists, more detailed 3D+time profiles, a comprehensive survey, and legal models. (Kalogianni et al., 2020).

3.2 Industry Foundation Classes (IFC)

BuildingSMART has developed the Industry Foundation Classes (IFC) standard. This organisation promotes BIM as an open and vendor-neutral data model to facilitate interoperability across multiple BIM platforms. It is also possible to share and exchange software applications in Architecture, Engineering and Construction (AEC) and Facilities Management (FM) through BIM platforms. (ISO16739, 2013). It has also been adapted as the ISO 16739 international standard (ISO, 2013). The standard that includes relevant constructs for various disciplines uses cases and processes associated with the construction and geometric representation of typical construction elements and their relationships. The IFC standard has represented spatial hierarchy with "IfcProduct" the most abstract superclass. It has two subclasses, namely "IfcElement" and "IfcSpatialElement". The former is the superclass of IFC entities used to model physically existing elements such as building elements (IfcBuildingElement) and geographic elements (IfcGeographicElement). The latter is the superclass of two entities defining the spatial arrangements within an IFC file. The first one is "IfcSpatialStructureElement". It is a generalisation of the elements, which include the site (IfcSite), buildings (IfcBuilding), building storeys (IfcBuildingStorey), and internal spaces (IfcSpace), defining the spatial structure of a building project. The second entity is "IfcExternalSpatialStructureElement". The abstract superclass for "IfcExternalSpatialElement" models various external spaces, regions, and volumes.

3.3 CityGML

CityGML is the most comprehensive semantic information model represented in an XML-based format to facilitate the exchange, sharing, storage, and maintenance of the virtual 3D city models. It is an application schema for the GML. It has two versions: the official version 2.0 and the proposed version 3.0. Also, the CityGML is an extendable international open standard for spatial data exchange issued by the OGC. 3D city models in terms of their geometry, topology, semantics, and appearance are represented with basic entities, attributes, and relations by CityGML (Rönsdorf et al., 2014; Zadef et al., 2019). CityGML data model has two modules: the core module and the thematic extension modules. The core module defines the abstract base classes of the CityGML data model, in which thematic classes are derived. The thematic module of CityGML provides specific thematic fields of the virtual 3D city model such as Appearance, Bridge, Building, CityFurniture, CityObjectGroup, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, WaterBody, and TexturedSurface (OGC, 2012). CityGML is mostly utilised to structure and represent physical parts such as walls, roofs, curbs or vegetation objects. Moreover, it is possible to store building properties such as year of construction (yearOfConstruction), year of demolition (yearOfDemolition), type of roof (roofType). In contrast, the representation of legal extents is not explicitly mentioned in the standard but can be implemented using Application Domain Extensions (ADEs) (Zadef et al., 2019). There is an extension mechanism in CityGML known as the ADE applied for CityGML adaptation to non-standard requirements of specific application areas. Besides the definition of new feature types, attributes, geometries, and associations, existing feature types can be enriched by incorporating new geometries, attributes and associations (Groger et al., 2012; Rajabifard et al., 2018). Furthermore, CityGML allows multiple representations of the city objects into semantic surfaces based on five different level-of-details (LOD). LOD1 provides the block model without any roof structures. LOD2 is the block model with roof structures, texture and larger building installations. LOD3 provides detailed architectural models. Finally, LOD4 enriches LOD3 by adding interior structure objects (OGC, 2012).

3.4 Related Works

Integrated information models are designed for city objects that consider physical elements, in addition to legal spaces, as part of some legal interests. The combination of legal and physical objects is possible at a representation level. Also, an integrated information model can be developed by defining semantic connections, when it is required, between legal objects and their physical components. Generally, there are two methods for developing integrated information models. The former is enriching physical information models with legal information. The latter defines an external relationship between legal and physical information models (Rajabifard et al., 2018). Various investigations integrate legal and physical information models for cadastral purposes. The integration of CityGML and LADM concepts has two methods. The first alternative is to create a profile of LADM for a particular country and then design a new ADE for the CityGML standard based on that profile. The second one is designing an ADE for the CityGML standard according to the general legal concepts defined in LADM. A few researchers suggest an extension of CityGML with legal

concepts found in the Land Administration Domain Model (LADM) by using buildings and condominia for cadastral purposes (Dsilva, 2009; Li et al., 2016; Gózdz et al., 2014; Rönsdorf et al., 2014; Gürsoy Sürmeneli et al., 2021). Çağdaş (2013) proposed an ADE adapted for immovable property taxation, taking into account the legal and administrative aspects which CityGML does not cover. Sun et al. (2019) worked on modelling cadastral data building and city level. In the study, several requirements are identified considering organisational, legal, and technical aspects. They formulate these requirements and then develop a framework for integrating 3D cadastre and 3D digital models. This paper aims to organisations dealing with cadastral information (LADM) BIM models (architecture, engineering, and construction companies).

The three steps are necessary to perform for matching IFC and CityGML schemas. The first step is which attributes and entities correspond to each other, the second is the different semantic meaning of objects, and the last one is the loss of information due to direct transformation (El-Mekawy et al., 2012). In line with these three steps, the integration of IFC and CityGML has been researched and presented with different methodologies by different researchers (El-Mekawy et al.,2012; Donkers., 2016; Ohori et al., 2018; Sun et al., 2019; Sani et al., 2022). Several authors from previous studies noted that the unidirectional approach leads to semantic loss. Therefore, the authors emphasise a bidirectional approach is needed to solve the problem of missing information due to the semantic integration of BIM and GIS.

4. RESULTS

This paper's result proposes a vision of the general framework for integrating 3D registration of condominium concepts of 3D cadastre with open data standards. There is an increasing interest in integrating open data standards for cadastral purposes. While CityGML and LADM are integrated within the scope of 3D cadastre by researchers, CityGML and BIM, so-called GeoBIM, are mostly integrated within the scope of 3D city models. The integration of both models is used to register 3D condominium rights within the scope of the 3D cadastre. CityGML is standardised by OGC and focuses more on city objects, while ISO has standardised LADM, which focuses on cadastral objects. IFC is the most widely used open data standard in the BIM domain, and CityGML has a similar characteristic in the 3D-GIS domain. Because 3D city models are created using CityGML in a widespread manner in Turkey, the increasing use of IFC data in building models necessitates the integration of the two standards. However, BIM and GIS are different due to the use of different technology, standards, and syntax descriptions. On the other hand, LADM is completely different from the other two standards, as it was developed for modelling the registration of legal rights (RRR) of cadastral objects such as independent sections. The availability of 3D representation of ownership rights will be clearly seen to be efficient for various land administration applications, such as property valuation. Open standards are, of course, pivotal for discovering the 3D registration of condominium rights as they provide the integration between different organisations and enable the interoperability for other processes that are needed the same data.

4.1 Integrating the Open Data Standards for 3D Registration of Condominium in Turkey

This proposed model focuses on the 3D registration of condominium rights by integrating the relevant international standards for the case of Turkey. Based on the model, 3D registration of condominium RRRs are represented by LADM, and physical sections are represented in CityGML and IFC. For this, first of all, a condominium in LADM and subclasses to represent RRR on it were created. TR_RegistrationObjects, TR_SpatialUnit, TR_Parcel, TR_Building, TR_CondominiumUnit, TR_Annex, TR_RRR (yellow colours in figure 1) (TR is means Turkey Republic in the proposed model). The TR_RRR describes the rights, restrictions, and responsibilities over real estate. Rights, Restrictions, and Responsibility are a package in which real or legal persons can represent relationships status on a real estate. The right class represents property rights and limited rights. The property right is the right of the owner or legal persons to make all kinds of operations, such as the use of property, purchase, sale, and rent. The limited real rights class represents mortgage and easement. The restriction class is the part of the information that restricts limited real rights in the title registration, where the restriction information is registered, and the information is determined. The responsibility class show some obligations such as paying the tax on the real estate, maintenance, repair, and easement according to real estate type. There may be one or more types of obligations. TR_SpatialUnit Package describes spatial units (e.g. parcel, building, condominium unit). The TR_ RegistrationObject class represents a basic administrative unit, a set of rights, restrictions, and responsibilities of one or more real properties.

The SpatialUnit class is the parent class, where all cadastral objects are represented and associated with the other classes. The SpatialUnit class comprises parcel sub-classes, buildings, and independent sections. The parcel class is obligatory for the cadastral system. The building class has a composition relation type with the parcel class. Therefore, every building has depended on only one parcel. The condominium is considered a spatial unit (related to one building). A building can have one or more independent parts. According to the Property Law, the Annex is outside of a condominium. Also, it is referred to directly as allocated to that section. The Annex cannot be registered alone in the land register. Therefore, the type of 0..* (0-lots) relationship is selected between the Condominium and Annex. Table 2 express the created new classes for 3D delineation of condominium rights based on an integrated model.

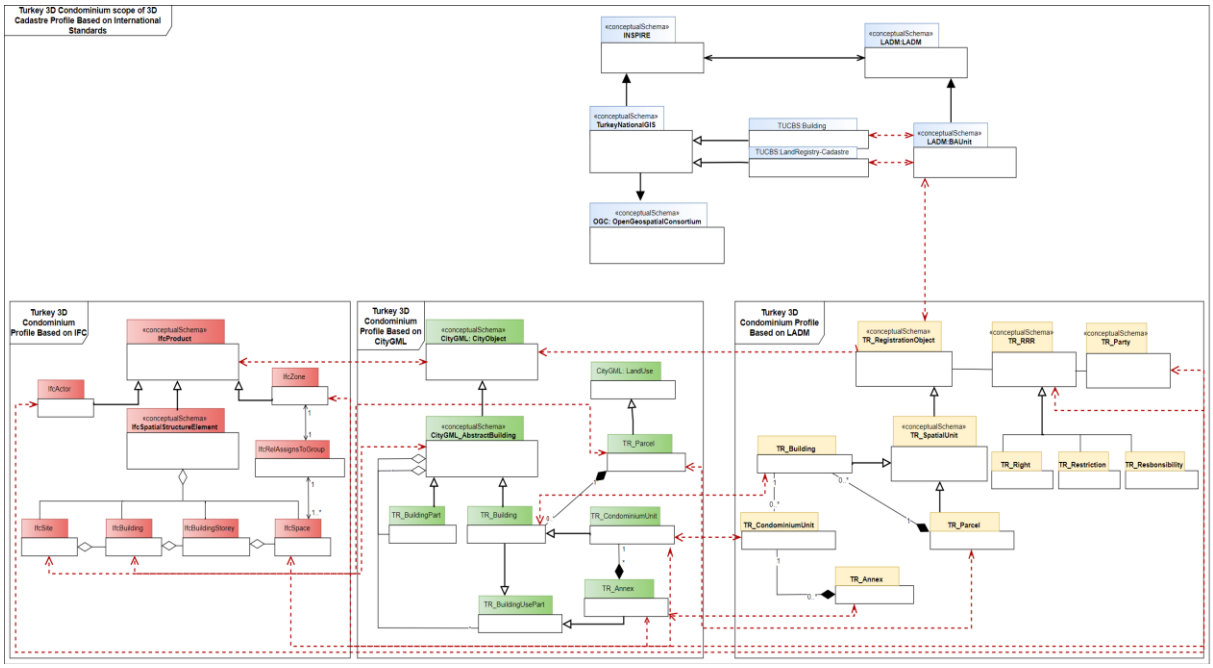

Figure 1. The relationship between the packages in the international standards developed for the registration of 3D condominium rights according to the legal system in Turkey. The proposed model was developed as the CityGML ADE extension of 3D condominium registration. Its legal aspects are represented by classes developed based on LADM. The relationship of the developed ADE with the classes in the IFC standard is shown. Red arrows indicate corresponding classes in each standard.

Table 2. Shows the newly created classes and their descriptions

Created new classes in the proposed model	Definition of the classes
TR_Party	*Expresses interest holder that has ownerships*
TR_RRR	*Shows the relevant attributes with respect to rights, restrictions, and responsibilities*
TR_RegistrationObjects	*Shows the relevant attributes with respect to rights, restrictions, and responsibilities*
TR_Parcel	*Definition the attributes related to the parcel*
TR_Building	*Definition of the attributes regarding the registered building*
TR_CondominiumUnit	*Represents the apartments in the building*
TR_Annex	*Uses the accessory parts in the building*
TR_BuildingUsePart	*Represent the common places in a building*

An integrated model is developed to enable better interoperability and 3D depiction of condominium rights (Figure 1). The proposed features adapted from LADM permit the 3D representation of ownership rights. In other words, BAUnit is used to compose RegistrationObject and linked to CityObject, which is CityGML class. The 3D Cadastre ADE

for Turkey by adding new classes and their attributes to the CityGML LandUse and AbstractBuilding feature classes are developed. In the developed ADE, five new feature classes, TR_CondominiumUnit, TR_Building, TR_Annex, and TR_BuildingUsePart were added to AbstractBuilding TR_Parcel is added to LandUse (green colours in the figure 1). The TR_RegistiritonObjects class and the CityObjects class are associated with each other. Also, since the attributes of each class were attached to the CityObject and LADM via the 'hook mechanism', the sub_classes inherit these attributes from the CityObject and LADM. However, as explained above, the Building, CondominiumUnit, Annex, and BuildingUsePart classes have already been specified as the AbstracBuilding class's subclasses. Likewise, the Parcel class is defined as a subclass of the LandUse class. The parcels are not clearly represented with CityGML, but the OGC specification states that the LandUse class represents parcels in 3D (OGC, 2012). Therefore, the parcel is a CityGML LandUse, and a new feature class is created. The parcel inherits all attributes and relations from the CityGML LandUse. The CityGML includes the BuildingPart class to represent the structural parts of buildings but does not have a class to identify the legal parts (i.e., condominium units, building use part, and annexes) of buildings required for cadastral purposes. This requirement is addressed in the developed ADE with the new class; condominium units, building use part, and annex (as shown in figure 1). The CondominiumUnit class represents individually owned building units, and it has composition relationships with Annex, which relate one condominium unit with one or more annexes. These classes inherit all attributes and relations from their superclass Building. The BuildingUsePart designates a relationship of many to many (*..*) between Building, CondominiumUnit, and Annex classes. One or more parcels contain zero or more buildings with several condominium units. In the UML class diagram (Figure 1), the Parcel and Building composition relationship indicate that several Parcel objects include zero or more Building objects. The aggregation relationship between the Building and Parcels reflects that a CondominiumUnit object is related to several parcels.

As shown in figure 1 (red colours parts), proposed features are linked with the IFC entities, namely IfcZone, IfcRelAssignsToGroup, IfcSite, IfcBuilding, IfcActor, and IfcSpace to provide integration with IFC. The approach that uses these entities is adapted from previous studies (Atazadeh et al., 2016; Atazadeh et al., 2019). IfcZone is an entity that enables a group of multiple spaces and has multiple IfcSpace instances that are used to depict the registration unit that might have both condominium unit and annex at the same time. IfcZone is linked with both RegistrationObject in LADM and CityObjects in CityGML to delineate condominium rights legal and physical spaces. In addition, the property sets related to TR_RRR can be added to the IfcZone entity. The property sets regarding TR_CondominiumUnit, TR_Annex, and TR_BuildingUsePart are linked with IfcSpace. The LandUse in CityGML and Parcel class in LADM are associated IfcSite. Another meaningful relationship is IfcBuilding which is linked AbstractBuilding in CityGML and TR_Building in LADM. IfcActor entity that expresses the person or organizations involved in a title system can be used to model TR_Party. Thus, spatial data that will be produced based on the proposed model can be integrated with IFC data. Figure 2 shows the CodeLists created within the proposed model.

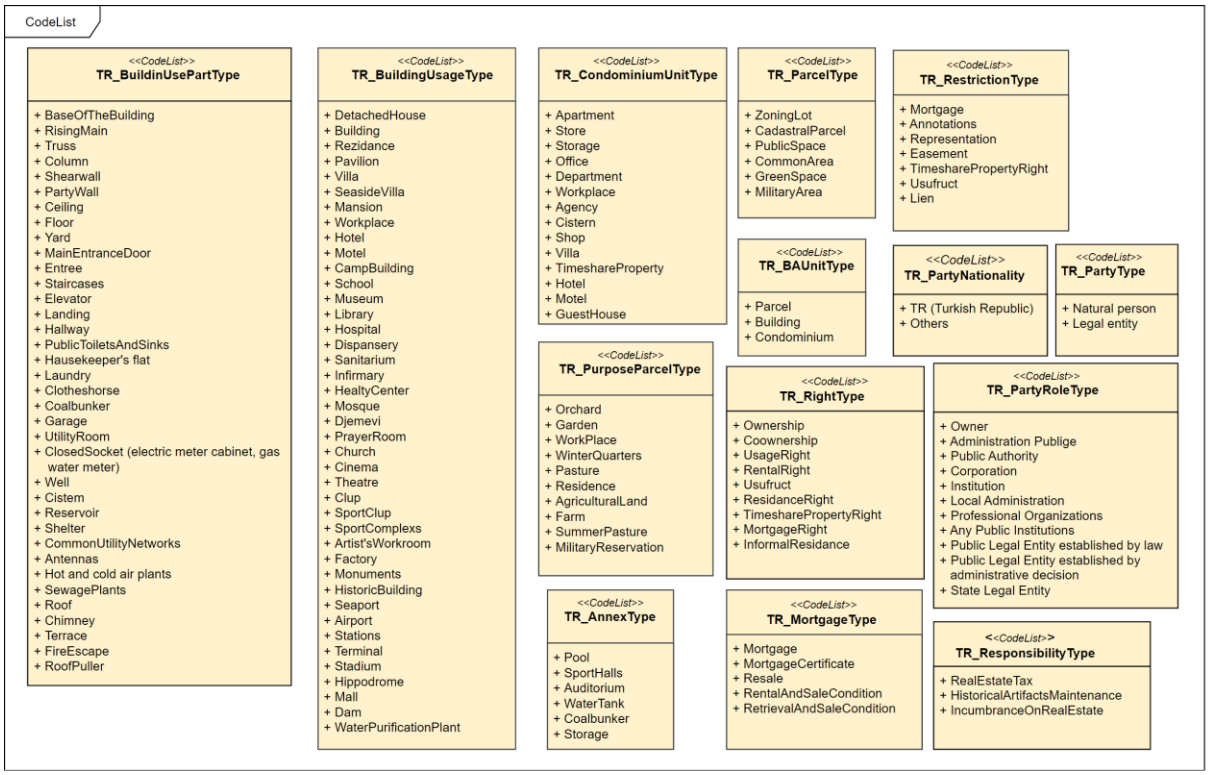

Figure 2. Description of the new code list of the proposed integrated 3D condominium rights data model.

Table 3 shows the general semantic mapping of IFC, CityGML, and LADM entities in the integrated model.

Table 3. The general semantic mapping of IFC, CityGML, and LADM entities in the proposed 3D condominium registration model

LADM	CityGML	IFC
RegistrationObjects	CityObjects	IfcZone
Building	AbstractBuilding	IfcBuilding
CondominiumUnit	CondominiumUnit	IfcSpace
Annex	Annex	IfcSpace
Parcel	LandUse	IfcSite
Party	-	IfcActor
RRR	-	IfcZone

5. CONCLUSION

This paper proposes a general framework for integrating cadastral information containing a 3D presentation of apartment rights and update of 3D city models, and with LADM on the legal objects and CityGML and IFC on physical objects. It proposes an integrated model for the 3D delineation of condominium rights scope of 3D cadastre in Turkey. Basic requirements for generating a 3D condominium rights scope of 3D cadastral model for Turkey are presented from current cadastral objects with legal and physical perspectives. 3D condominium rights which are registered in the cadastral system were defined in the framework of LADM (shown in table 1), and a legal model proposal was developed with the conceptual level for the Turkish cadastral system. The developed LADM model was connected to CityGML to generate an integrated 3D cadastral model at the conceptual level. It has also been linked to commonly used IFC standards for modelling physical objects updated to 3D city level. Table 2 shows the corresponding classes of these standards. It will also contribute to integrating data in a standard ontology into a general framework for management. We believe that we show how the data can be synchronised to the transition of 3D condominium rights from the current cadastral system to a 3D cadastre with CityGML, BIM, and GIS. It can be underlined that open standards provide a common basis, and countries can develop their model that fulfils the requirements specific to the country. Nevertheless, the fact that the model is still at the conceptual stage is seen as a study's shortcoming. However, further investigation is needed to show that the proposed model will focus on the applicability to fulfil the requirements and the general framework in practice.

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