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Integration of LADM and CityGML for 3D Cadastre of Turkey

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Key words: LADM, CityGML, 3D Cadastre, 3D City Database, SQL Query

SUMMARY

Representation of Right, Restriction, and Responsibility (RRR) in the 2D cadastral system falls short due to rapid urbanization causing complex infrastructures. Turkish cadastre, as in many other countries, faces difficulties in the daily recording of property transactions such as sales, donations among others. Therefore, it is highly recommended to represent the RRR in 3D Cadastre. The study elaborates on the current RRR in the cadastral system (2D) in Turkey and is proposing a new integrated data model using international standards as Land Administration Domain Model (LADM) and CityGML v2.0 (City Geography Markup Language). We propose an Application Domain Extension (ADE) that extends the LADM and CityGML data model's integration with the legal and administrative concepts defined in Turkish law for cadastral objects. To show the developed model operability, the data was managed in an open-source PostgreSQL database. This paper provides a detailed overview of the Turkish legal cadastral system with the newly developed integrated LADM and CityGML model providing both visualization and standardization within the scope of 3D cadastre and a proposal for its physical realization based on international standards.

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1. INTRODUCTION

Information regarding rights, restrictions, and responsibilities (RRR) on the cadastral parcel should be visualized on the cadastral maps (Kaufmann and Steudler, 1998; Stoter and Oosterom, 2007). However, although most legal systems enable the creation of property rights with 3D boundaries, they create cadastral maps that still mainly rely on 2D-based cadastral systems for current Land Administration Systems (LASs) (Ho et al., 2015; Atazadeh et al., 2016; Kalogianni et al., 2017; Rajabifard et al., 2018). Thus, RRR on the land cannot be adequately represented by LAS. For this reason, very detailed studies of 3D cadastres in a wide range of countries worldwide can be found in the International Federation of Surveyors (FIG) 3D cadastres' best practices book (Oosterom, 2018). In addition, the cadastre 2034 vision, published by ICSM in 2015, suggests that the basic services expected from the cadastre, such as knowing all RRRs, regarding real estate and the creation of the future cadastre in 3D with the policies, models, and standards should be developed (Aien, 2013; Alkan et al., 2020).

3D cadastre is defined as a system where RRRs (legal models) of buildings and properties correspond to their physical models (provision of registered rights above and below the 3D terrain surface) with advanced policies, standards, and models. (Aien, 2013; Alkan et al., 2020; Sürmeneli H.G. et al., 2020). The most efficient standardized model that represents RRR in the land administration system (LAS) field is the Land Administration Domain Model (LADM). It is an ISO standard in 2012; ISO19152:2012 (ISO, 2012), aims to establish a common ontology for RRR affecting land administration and its geometric components. 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 is to extend the initial scope of the conceptual model 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 explicit 3D+time profiles, an extended survey, and legal models. (Kalogianni et al., 2020). The 3D cadastre should include 3D spatial objects with their legal and physical 3D representation (Atazadeh et al., 2016; Sürmeneli H.G. et al., 2020). While a legal model is a real or virtual spatial unit with homogeneous RRRs that can be represented in different forms such as text, sketch, point, lines, surface, or 3D volume, a physical model is the structure of the permanent construction such as walls, ceilings, columns, windows, doors and similar architectural elements (Lemmen et al., 2010; Atazadeh et al., 2016; Kalogianni et al., 2020).

Thanks to the advance in technology in geographic information science, 3D cadastral developments have matured in terms of 3D visualization and analytical capabilities. (Kitsakis et al., 2016; Dimopoulou et al., 2018; Su et al., 2019; Kalogianni et al., 2020). Within the scope of these developments, Turkey has made improvements in its cadastral systems in comparison to 2014

(Stuedler, 2014) and 2034 (ICSM, 2015) visions such as in most countries. Turkish cadastre consists of two parts: land registry that represents the legal relationship between people and real properties, and cadastral maps based on 2D geometries with annotations for the concrete land use (Sürmeneli H.G. and Alkan 2018). However, this information is stored independently from the geometry as a separate attribute. There are three basic cadastral objects in the cadastral system: the parcel, the building, and the independent section of buildings (condominium). Registration of the individual units is subject to the Condominium Law, and the rights on the individual units are recorded in a condominium book (Sürmeneli H.G. and Alkan, 2020). Usually, every individual unit owner has full property rights for a part of the building (the condominium unit). Simultaneously, the shared areas (such as staircases and elevators) are held as co-property.

The legal interests currently registered in Turkey's 2D cadastral system are Parcel, Shared property, Right, Easement, Restriction, Registration object, Building, Condominium, Boundary, Survey, and Documents. Especially in the current cadastral system, RRRs are used for 3D representation. RRR represents all kinds of relationships on real estate to which real or legal persons are related. At the same time, there may be some restrictions on real estate. Therefore, the responsibility of the person against real estate is represented in law. So, the representation of RRRs in the 3D cadastre is very important. 3D cadastral work under various institutional projects has been carried out in Turkey. These studies and projects are the Turkish Land Register and Cadastre Information System (TAKBIS in Turkish), and Turkey's National Geographic Information System Project (TUCBS in Turkish). They contribute to the TUCBS project in the context of National Spatial Data Infrastructure (UKVA in Turkish). TUCBS results from technological developments at the national level and involves the creation of a web portal by public institutions and organizations for providing geographic information (Sürmeneli H.G. and Alkan, 2020).

The aim of the current research is to develop a database model that supports the regulation and analysis of 3D land rights, restrictions, and responsibilities for the Turkish Cadastral System. We use the ISO 19152 (ISO, 2012), Land Administration Domain Model (LADM) that represents RRR on the real estate, and the CityGML that represents the physical side of this object for the conceptual model. In addition, the PostgreSQL database development platform is used for the 3D database. The remaining of this paper covers the methodology of the study followed by results, discussion, and conclusion.

2. METHODOLOGY

The methods used in this research combine the two open standards LADM for cadastral information and the CityGML v2.0 for physical models. PostgreSQL is used to develop the 3D databases. Thus, the scope is dedicated to RRRs applications and includes temporal queries for real estate. The methodology that is used for the current research is shown in Figure1.

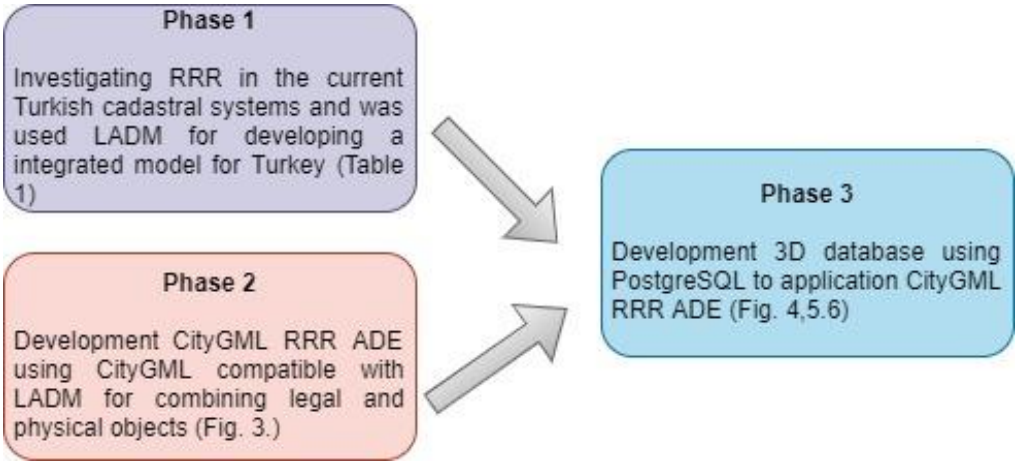

Figure 1. The process steps in the study

2.1 Land Administration Domain Model (LADM, ISO 19152)

LADM that aims to establish a common ontology for rights, restrictions, and responsibilities (RRR) is developed to contribute to Land Administration Systems (LAS). ISO/TC211 has established the LADM intending to standardize geographical information and geo-characteristics (van Oosterom et al., 2006; Sürmeneli H.G. and Alkan, 2020). Thanks to the common ontology of LADM, it enables the communication between related parties within a country or between different countries (Atazadeh, 2017). LADM has three main packages and one sub-package: LA_Party (Party package), LA_AdministrativePackage (Management package), and LA_SpatialUnitPackage (Spatial Unit package), and LA_SurveyingAndRepresentation (Lemmen et al. 2015) (Figure 2).

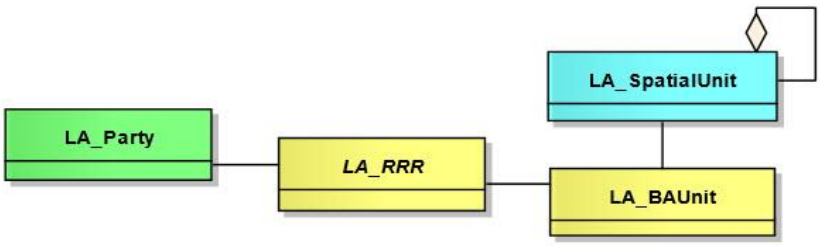

Figure 2. Basic packages of LADM (ISO19152)

It also supports the time component of the Land Administration Basic Model. The most important feature of the model is that it is a flexible model and can be expanded within specified standards. It is possible to associate with external classes such as Valuation, Address, and the Landcover as required by the model feature.

2.2 A General Overview of CityGML

The City Geography Markup Language (CityGML) is an XML-based format, and an open data model for data storage, sharing and maintenance of the virtual 3D city models. It has enabled the exchange of different hierarchies of geographical, topological, and semantic information for 3D representations, and issued by Open Geospatial Consortium (OGC). (Agugiaro et al., 2018). 3D city models in terms of their geometry, topology, semantics, and appearance are represented with basic entities, attributes, and relations by CityGML (Sürmeneli H.G. et al., 2020). CityGML v2.0 provides substantial coverage at the urban scale of buildings, utility networks, energy, and hydrology. Also, it has 10 thematic modules such as Bridge, Tunnel, CityObjects, etc. In addition,

CityGML can be extended by the user community for more specialist domains through the Application Domain Extension (ADE) mechanism.

2.3 3D Database Management System (DBMS)

3D DBMS (database management system) offers spatial data types and spatial functions are used to store the 3D data, which is important and necessary for 3D models with large data volume and various data sources. Storing spatial data and performing spatial can be completed with SQL queries. DBMS use widely Oracle Spatial and PostGIS for 3D geometric. The 3D objects can be stored in three forms such as 3D polygon, 3D multi-polygon, and 3D solid (Ying et al., 2020).

The 3D City Database (3DCityDB) has been developed as an Open Source to 3D geo-database solution for CityGML based 3D city models. It has been developed as a platform-independent software suite to facilitate the development and deployment of 3D city model applications. It uses relational database management systems (ORACLE Spatial or PostgreSQL/PostGIS) to import, manage, analyze, visualize, and export virtual 3D city models according to the CityGML standard (Yao et al., 2018).

3. RESULT

3.1 RRRs Profile based on LADM in Turkish Cadastral System

Turkish cadastral system consists of two basic units, including land registration and cadastral mapping (Sürmeneli H.G. and Alkan 2018). Although the use of parcels is volumetric, land parcels and cadastral objects like a building are represented as 2D. The use of volume parcels is provided by the real rights determined in the Turkish Civil Code (TMK, 2001). Also, although the horizontal boundaries of the cadastral parcel are clearly expressed in the law, the definition of the vertical boundary is not sufficient. However, there are several rights set out in the Turkish constitution concerning the third dimension (e.g., easement right) such as RRRs are used to determine the boundary. In Turkey, there are some rights under the constitution relating to the implementation of the third dimension. These rights are classified as easement rights, real servitude rights, and private easement. Types of real servitude, right is right of passage, the right of superficies, right of the source and another easement. Types of private easement rights are the right of usufruct, superficies (residence), the right of construction (construction), a right of resource and other rights. These rights defined in laws are classified in accordance with LADM (Table 1). The rights defined by laws have been classified and adapted to LADM standards. These rights correspond to the RRR package in LADM.

The TR_RRR package is based on the LADM. TR_RRR is an abstract class in which the rights, restrictions, and responsibilities set out in the Civil Code are represented to represent the 3rd dimension. The TR_RRR package has three sub-classes TR_Right, TR_Restriction, and TR_Responsibility (Fig. 3).

The right to property is the right of the owner or legal person to make all kinds of operations, such as the use of property, purchase, sale, rent, etc. The TR_Right class is divided into two sub_classes as mortgage and easement. The easement right is a type of right that gives the right holder the right to use and benefit from that real estate. The type of easement right can be one of the rights types

specified in the RightType code list. The mortgage is both a type of right and restriction. Some rights and restrictions may overlap, such as the mortgage.

These restrictions are subdivided into representations (Beyanlar in Turkish), rights and liability (Hak ve yükümlülükler in Turkish), annotations (Şerhler in Turkish), and mortgages in the land register. The representations are recorded in the land register with the topic, which is a transaction, the page number of the land register, and the document number. The mortgage class is the class of information required for the collateral of real estate for a possible debt. The annotation class is part of the disclosure of rights on real estate. It is the class in the declaration class that contains information about any situation related to real estate. The Rights and Liabilities class is the part where the rights such as easement, usufruct, right of access, timeshare property rights are registered to the land register.

The "representation" class contains the attributes necessary for the fulfillment of responsibilities such as tax and maintenance on real estate. There may be at least one or more types of responsibility on real estate.

Table 1 Definitions of the RRRs in the Turkish cadastral system according to LADM

RRR	Definition
Rights	It is the state of being able to make all kinds of transactions on real estate. The person has the Property right and Limited Real Rights on the real estate. The limited real rights are divided into two as Mortgage and Easement.
Restrictions	It is the part where the information is restricting the use of limited real rights in the land register. These restrictions can be listed as representations, rights, and liabilities, annotations, mortgages and easement.
Responsibilities	These are the obligations that an interest holder must fulfill on the real estate.

3.2 Integration of LADM and CityGML for RRR in Turkish Cadastral System

CityGML is standardized by OGC and focuses more on city objects, while ISO has standardized LADM, which focuses on cadastral objects. Both CityGML and LADM were modelled in the Universal Modelling Language (UML). It is more common to see two options for constructing an LADM-based ADE for the CityGML standard. The first option is to create a specific profile of LADM and then implement this profile of LADM as an ADE of CityGML. The second one is to directly implement the fundamental concepts of LADM (Rönsdorff et al., 2014; Gózdz et al. 2014; Li et al. 2016; Çağdaş, 2013).

We used the first option for CityGML RRR ADE. CityGML ADE extension is used to represent the RRR on the physically cadastral objects. Thus, the developed new ADE model, which represents RRR on the integrated both legal side and physical side, was done (Figure 3).

So, in the proposed ADE, seven new feature classes and eight sub_classes were added. These classes are TR_Parcel, TR_Building, TR_Condominium, TR_Annex, TR_BuildingUsePart (in green color in Figure 3), TR_SpatialUnit (in blue color in Figure 3) and TR_RRR (in yellow color in Figure 3). The sub_classes are TR_Right, TR_Restriction, TR_Responsibility, TR_Mortgage,

TR_Easment, TR_Representation, TR_Annotation, TR_RightAndLiability (in yellow color in Figure 3).

The TR_Party package maintains the basic relationships of LADM as in figure 2. TR_Party package is a class of ownership that corresponds to the LADM Party class in Turkey's Cadastral System. TR_Party class contains the ownership information about the owner of the real estate. Figure 3 shows only the relationship between LADM's administrative package and CityGML ADE.

The SpatialUnit class (in blue color in Figure 3) is the parent class in which all cadastral objects (parcel, building, and condominium) are represented and associated with the other classes (RRR etc.). The TR_SpatialUnit class comprises TR_Parcel, TR_Buildings, and TR_CondominiumUnit. The TR_Parcel are not clearly represented with CityGML, but the OGC specification states that the LandUse class can be used to represent cadastral parcels in 3D (OGC, 2012). The TR_Parcel class is a sub_class of both LADM SpatialUnit, and CityGML LandUse. The TR_Parcel inherits all attributes and relations from the CityGML and LADM. Moreover, it applies to the TR_Bulding class in the same way. 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.

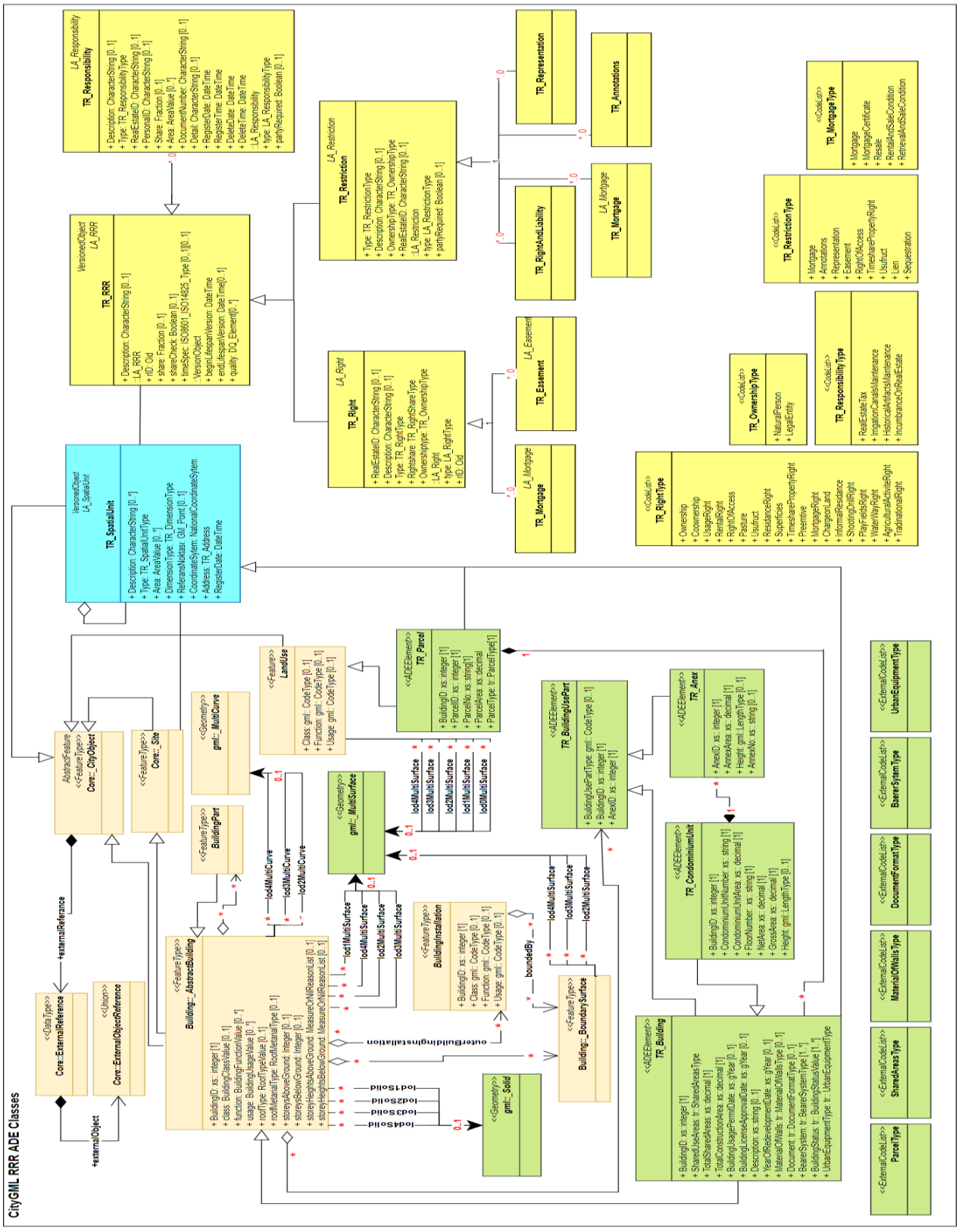

Figure 3. New proposed model for the Turkish cadastral system using, LADM and CityGML combining legal and physical model

TR_RRR (Rights, Responsibility, and Restrictions) is a package in which real or legal persons can represent relationship status on a real estate (Figure 3). TR_Right class represents the right of the owner or legal persons to make all kinds of operations, such as the use of property, purchase, sale, rent, etc. The TR_ Right class is divided into two sub-classes as mortgage and easement. The TR_Restriction class is the part of the information that restricts the use of limited real rights in the title registration, where the restriction information is registered and the information is determined. TR_Restrictions class has four sub_classes; TR_Representations, TR_RightsAndLiability, TR_Annotations, and TR_Mortgages in the land register. The TR_Responsibility class person's obligations are represented. These obligations include paying the tax on the real estate, maintenance, repair, easement according to the type of real estate. There may be one or more types of obligations.

This section has explained the development of an ADE to CityGML for the 3D RRR on cadastral objects for Turkey. The CityGML provides a flexible conceptual model which can easily be adapted to administrative and physical requirements. The research reveals that the CityGML ADE data model, which is supported with legal concepts (RRR) has the potential to be a national data model for 3D cadastre in Turkey.

3.3 3D RRR Queries in a PostgreSQL Environment

CityGML data of 8 real estates from the Sincan region in Ankara were obtained from Sincan municipality for the case study. Then, we integrated data of CityGML and LADM in the PostgreSQL version 13. database. Figure 4 shows the overview of the 3D database procedure packages.

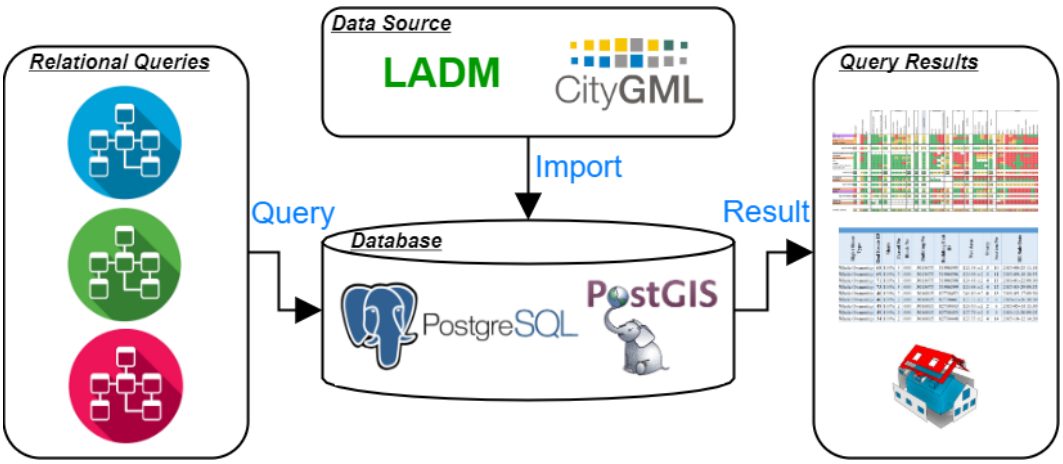

Figure 4. The overview of the 3D database procedure packages

Then, 2 SQL queries were made to test the CityGML RRR ADE model.

Query 1): Showing the mortgaged independent sections between years 2012-2020: The following is the SQL code written to show the mortgaged independent sections within the specified date range.

```
SELECT MT."MortgageTypeText" AS "Mortgage Type",
       M."RealEstateID" AS "Real Estate ID",
```

```
        (100 * M."Share" / M."ShareTotal") || '%' AS "Share",
        P."FirstName" || ' ' || P."LastName" AS "Payer",
        PRT."PayeeRoleTypeText" AS "Payee Role Type",
        PC."ParcelNo" AS "Parcel No",
        PC."BlockNo" AS "Block No",
        B."BuildingNo" AS "Building No",
        BU."TakbisPropertyIdentityNumber" AS "Building Unit ID",
        BU."NetArea" || ' ' || BU."AreaUnit" AS "Net Area",
        CG."StoreyNumber" AS "Storey",
        BU."IndependentSectionNumber" AS "Section No",
        M."RegisterDate" AS "Mortgage Start Date",
        M."DeleteDate" AS "Mortgage End Date"
FROM "TR_RightPackage"."TR_Mortgage" M
        INNER JOIN "TR"."TR_MortgageType" MT
              ON M."MortgageTypeID" = MT."MortgageTypeID"
        INNER JOIN "TR_PartyPackage"."TR_Party" P
              ON M."PayerID" = P."PartyID"
        INNER JOIN "TR_RightPackage"."TR_PayeeRoleType" PRT
              ON PRT."PayeeRoleTypeID" = M."PayeeRoleTypeID"
        INNER JOIN "TR_SpatialUnitPackage"."TR_SpatialUnit" SU
              ON M."RealEstateID" = SU."RealEstateID"
        INNER JOIN "TR_SpatialUnitPackage"."TR_BuildingUnit" BU
              ON SU."SpatialUnitID" = BU."SpatialUnitID"
        INNER JOIN "CityGMLPackage"."CityObjectGroup" CG
              ON BU."ParentCityObjectID" = CG."CityObjectGroupID"
        INNER JOIN "TR_SpatialUnitPackage"."TR_Building" B
              ON CG."ParentCityObjectID" = B."BuildingID"
        INNER JOIN "TR_SpatialUnitPackage"."TR_Parcel" PC
              ON B."ParcelID" = PC."ParcelID"
WHERE M."RegisterDate" >= '2012-01-01' AND M."DeleteDate" < '2021-01-01'
```

The above SQL code shows how to write the query to achieve query 1, While fig. 5 shows the result of the query in the TR_Mortgage table.

Mortgage Type	Real Estate ID	Share	Payer	Payee Role Type	Parcel No	Block No	Building No	Building Unit ID	Net Area	Storey	Section No	Mortgage Start Date	Mortgage End Date
Mortgage	64	1	FN015 LN015	İşbankası	3	600	3013675	51906591	124.38 m2	2	6	2013-05-16 16:00	2019-05-17 11:00
Mortgage	71	1	FN013 LN013	Garanti Bankası	3	600	3013675	51906598	124.48 m2	4	13	2012-12-12 12:00	2020-12-14 09:00
Mortgage	73	1	FN011 LN011	Garanti Bankası	3	600	3013675	51906599	120.88 m2	4	15	2012-12-03 12:00	2020-08-03 09:00
Mortgage	80	1	FN022 LN022	Ziraat Bankası	1	1100	3018678	3354122	23.37 m2	1	22	2015-06-05 10:00	2020-07-05 10:00
Mortgage	87	1	FN025 LN025	Garanti Bankası	1	1100	3018678	3354050	83.55 m2	2	5	2014-03-02 11:00	2020-03-02 11:00
Mortgage	94	1	FN016 LN016	HalkBank	1	1100	3018678	3253059	82.76 m2	4	12	2014-07-14 11:00	2020-07-14 11:00
Mortgage	139	1	FN021 LN021	YapıKredi Bankası	3	1100	3157372	5333375	89.71 m2	2	7	2012-06-21 14:00	2020-04-21 14:00
Mortgage	140	1	FN007 LN007	İşbankası	3	1100	3157372	5333376	89.71 m2	2	8	2012-03-15 13:00	2020-01-15 13:00

Figure 5. Data query TR_Mortgage table using QGIS, there are mortgages in 8 real estates

Query 2): Showing the sold real estates with an area of more than 120 m2 between the years of 2015-2021: In query 2, both the real estate sold within a certain date range (2015-2021) and those real estates are requested to be larger than 120 m^2.

```
SELECT RST."RightShareTypeText" AS "Right Share Type",
       RR."RealEstateID" AS "Real Estate ID",
       (100 * RR."Share" / RR."ShareTotal") || '%' AS "Share",
       PC."ParcelNo" AS "Parcel No",
       PC."BlockNo" AS "Block No",
       B."BuildingNo" AS "Building No",
       BU."TakbisPropertyIdentityNumber" AS "Building Unit ID",
       BU."NetArea" || ' ' || BU."AreaUnit" AS "Net Area",
       CG."StoreyNumber" AS "Storey",
       BU."IndependentSectionNumber" AS "Section No",
       RR."RegisterDate" AS "RE Sale Date"
FROM "TR_RightPackage"."TR_RealRight" RR
       INNER JOIN "TR_RightPackage"."TR_RightType" RT
             ON RR."RightTypeID" = RT."RightTypeID"
       INNER JOIN "TR_RightPackage"."TR_RightShareType" RST
             ON RR."RightShareTypeID" = RST."RightShareTypeID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_SpatialUnit" SU
             ON RR."RealEstateID" = SU."RealEstateID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_BuildingUnit" BU
             ON SU."SpatialUnitID" = BU."SpatialUnitID"
       INNER JOIN "CityGMLPackage"."CityObjectGroup" CG
             ON BU."ParentCityObjectID" = CG."CityObjectGroupID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_Building" B
             ON CG."ParentCityObjectID" = B."BuildingID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_Parcel" PC
             ON B."ParcelID" = PC."ParcelID"
WHERE RR."RegisterDate" BETWEEN '2015-01-01' AND '2021-12-31 23:59:59'
      AND RR."Description" = 'Satış'
      AND BU."NetArea" > 120
```

The real estates that respond to the requirements as a result of query 2 and their information are shown in the result table.

Right Share Type	Real Estate ID	Share	Parcel No	Block No	Building No	Building Unit ID	Net Area	Storey	Section No	RE Sale Date
Whole Ownership	68	1	3	600	3013675	51906595	124.38 m2	3	10	2015-08-25 11:18
Whole Ownership	69	1	3	600	3013675	51906596	120.88 m2	3	11	2015-09-18 10:55
Whole Ownership	71	1	3	600	3013675	51906598	124.48 m2	4	13	2016-01-22 09:30
Whole Ownership	73	1	3	600	3013675	51906599	120.88 m2	4	15	2015-03-29 09:55
Whole Ownership	40	1	2	600	3016815	82738452	246.10 m2	0	18	2018-05-17 09:30
Whole Ownership	46	1	2	600	3016815	82738441	123.33 m2	2	6	2018-11-26 10:30
Whole Ownership	48	1	2	600	3016815	82738443	129.40 m2	2	8	2015-05-14 15:30
Whole Ownership	49	1	2	600	3016815	82738453	127.79 m2	3	9	2016-12-20 09:25
Whole Ownership	54	1	2	600	3016815	82738448	123.33 m2	4	14	2015-10-12 14:20

Figure 6. Data query result table using QGIS, there are 9 real estate that has an area of more than 120 m^2

4. DISCUSSION AND CONCLUSION

The cadastral system should introduce the 3D definition of cadastral objects in Law Regulations, establishing legal instruments to subdivide, consolidate and manage a 3D real property where needed. Cadastral procedures should be defined for the coordination and relationship between involved parties and RRR using international standards such as LADM. It is challenging to represent RRR on the real property completely by 3D cadastral models. To generate a 3D cadastral model profile is necessary to store and integrate cadastral data with physical models at the conceptual level and the geometric level visualising in 3D. When modelling a legal interest (RRR), two points should be considered: the legal interests spatial structure and its attributes. An integrated model should be used to represent the physical provisions of legal interests. The LADM is used to create 3D terminology and establish a common ontology for the legal side. Thus, it enabled introduction to the Turkish cadastral system in national and international platforms during the transition to 3D cadastre with its legal aspects.

The most important factor in choosing CityGML instead of BIM (Building Information Model) in this study is the creation and storage of cadastral objects in CityGML format within the scope of digitalization studies in Turkey. Objects which can be subject to cadastre (energy transmission lines, transportation, utility, etc.) produced by different institutions are also created in CityGML format. There are overlapping attributes when matching LADM and CityGML packages in the study. We preferred physical attributes to be represented in CityGML packages instead of LADM packages. Because the physical properties of objects produced by different institutions are stored in CityGML format. Thus, it is easy to integrate all objects and share data with each other from different institutions. Also, CityGML data from the study area were created according to TAKBIS (Turkish Land Registry and Cadastre Information System) and TUCBS (Turkish National Geographic Information System) standards that are national projects. Thus, the proposed ADE is at a level that can be integrated into national projects. The data of the integrated model created was stored in the open-source PostgreSQL database. With the help of the integrated data, RRRs on real estate can be queried spatially by SQL querying. In this context, two important outputs were developed for this study. The first one is the development of the 3D RRR conceptual model for the Turkish cadastral system using, LADM and CityGML combining legal and physical and the second one is the development of a 3D database design that allows editing and querying of RRR.

This study proposes a general framework for integrating cadastral information with LADM on the legal objects and CityGML on physical objects. Basic requirements for generating a 3D RRR for Turkey are presented from current cadastral objects with legal and physical perspectives. From the Turkish cadastral system, a case study was used to implement and evaluate the use of 3D digital models to represent cadastral boundaries and RRR on the 3D property units. The LADM model was connected to CityGML to generate an integrated 3D cadastral model at the conceptual level. Then, database design was carried out with PostgreSQL based on the conceptual model. This study's main contributions are the modelling of the requirements from legal and physical perspectives and the general framework and application for integrating LADM and CityGML for 3D cadastral models to support these requirements. Furthermore, the newly developed CityGML RRR ADE is valuable for the Turkish cadastral system and can be used as the basis for a 3D national data standard.

REFERENCES

Aien, A., (2013). 3D Cadastral Data Modelling. PhD Thesis, Melbourne University, Victoria, Australia.

Alkan, M., Sürmeneli H.G. and Polat Z. A. (2020). Design and development 3D RRR model for Turkish cadastral system using international standards. Survey Review, 1, 1-14.

Agugiaro, G., Benner, J., Cipriano, P., Nouvel, R. (2018). The energy application domain extension for CityGML: enhancing interoperability for urban energy simulations. Open Geospatial Data, Softw. Stand. 3, 2.

Atazadeh, B., Kalantari, M., Rajabifard, A., Champion, T. and Ho, S. (2016). Harnessing BIM for 3D Digital Management of Stratified Ownership Rights in Buildings. FIG Working Week 2016: Recovery from Disaster, Christchurch, New Zealand 2-6 May.

Atazadeh, B., Rajabifard, A. and Kalantari, M. (2017). Assessing performance of three BIM based views of buildings for communication and management of vertically stratified legal interests. ISPRS Int. J. Geoinf. (6), 198.

Dimopoulou, E., Karki, S., Roić, M., de Almeida, J.P.D., Griffith-Charles, C., Thompson, R., Ying, S., Paasch, J. and Van Oosterom, P.J.M. (2018). Initial Registration of 3D Parcels. (Chapter 2 - FIG Publication (2018) 3D Cadastres Best Practices – Extended Version, Editor: Van Oosterom, P.J.M.).

Çağdaş, V. (2013). An application domain extension to CityGML for immovable property taxation: A Turkish case study. International Journal of Applied Earth Observation and Geoinformation, 21 (1), 545-555. doi:10.1016/j.jag.2012.07.013.

Gózdz, K., Pachelski, W., Van Oosterom, P.J.M., and Coors, V. (2014). The Possibilities of Using CityGML for 3D Representation of Buildings in the Cadastre. In: Proceedings 4th International Workshop on 3D Cadastres, 9-11 November 2014, Dubai, United Arab Emirates. International Federation of Surveyors (FIG), 339–362.

Ho, S., Rajabifard, A. and Kalantari, M. (2015). Invisible constraints on 3D innovation in land administration: A case study on city of Melbourne. Land Use Policy, 42, 412-425.

ISO/TC211, 2012. ISO/TC 211 geographic information – Land Administration Domain Model (LADM). ISO/FDIS 19152 (final draft international standard).

Kaufmann, J. and Steudler, D. (1998). FIG. Cadastre 2014, A Vision for a Future Cadastral System. Technical report, Federation International des Geometers, Commission 7.

Kalogianni, E., Dimopoulou, E., Quak, W., Germann, M., Jenni, L., van Oosterom, P.J.M. (2017). INTERLIS language for modelling legal 3D spaces and physical 3D objects by including formalized implementable constraints and meaningful code lists. ISPRS Int. J. Geoinf. 6 (10), 319 Special Issue: Research and Development Progress in 3D Cadastral Systems.

Kalogiannia, E., Dimopouloub, E., Thompsona, R.J., Lemmen, C., Ying, S., Van Oosterome, P. (2020). Development of 3D spatial profiles to support the full lifecycle of 3D objects. Land Use Policy, 98, 10417.

Kitsakis, D., Apostolou, C. and Dimopoulou, E. (2016). Three dimensional cadastre modelling of customary real estate rights. Survey Review. doi: 10.1080/00396265.2016.1252518.

ICSM (2015). A Vision for Cadastre 2034.

Lemmen, C.H.J., Van Oosterom, P.J.M., Thompson, R.J., Hespanha, J.P., Uitermark, H.T. (2010). The Modelling of Spatial Units (Parcels) in the Land Administration Domain Model (LADM). FIG Congress, Sydney, Australia, 11-16 April.

Lemmen, C., Van Oosterom, P. and Bennett, R. (2015). The land administration domain model. Land Use Policy, 49, 535–545.

Sun, J., Mi, S., Olsson, P., Paulsson, J. and Harrie, L. (2019). Utilizing BIM and GIS for representation and visualization of 3D cadastre. ISPRS Int. J. Geo-Inf., 8, 503. doi:10.3390/ijgi8110503.

Sürmeneli, H.G., Koeva, M.N., Zevenbergen, J., Alkan, M. (2020). Towards Integration of LADM and CityGML for the Cadastral System of Turkey, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLIII-B4-2020, 691–698. https://doi.org/10.5194/isprs-archives-XLIII-B4-2020-691-2020.

Sürmeneli, H.G. and Alkan, M. (2018). Design and Determine 3D Cadastral Systems: A Case Study of Turkey. 6th International FIG 3D Cadastre Workshop, Delth, Netherlands, 447-464, 2-4 October.

Sürmeneli, H.G. and Alkan, M. (2020). Towards standardisation of Turkish cadastral system using LADM with 3D cadastre. Survey Review. doi: 10.1080/00396265.2020.1855700.

Stuedler, D. (2014). Cadastre 2014 and Beyond.

Li, L., Wu, J., Zhu, H., Duan, X., and Luo, F. (2016). 3D modeling of the ownership structure of condominium units. Computers, Environment and Urban Systems, 59, 50–63.

OGC (2012). City Geography Markup Language (CityGML) En-coding Standard.

Rajabifard, A., Atazadeh, B. and Kalantari, M. (2018). A critical evaluation of 3D spatial information models for managing legal arrangements of multiowned developments in Victoria, Australia. International Journal of Geographical Information Science, 32(10), 2098-2122.

Rönsdorf, C., Wilson, D. and Stoter, J. (2014). Integration of Land Administration Domain Model with CityGML for 3D Cadastre. 4th International Workshop on 3D Cadastres 9-11 November, Dubai, United Arab Emirates.

TMK (2001). Turkish Civil Code.

Van Oosterom, P. J. M., Lemmen, C., Ingvarsson, T., van der Molen, P., Ploeger, H., Quak,W., Stoter, J. and Zevenbergen, J. (2006). The core cadastral domain model. Computers, Environment and Urban Systems, 30, 627–60.

Van Oosterom, P. (ed.) (2018). Best Practices 3D Cadastres, Extended version. FIG Publication, Copenhagen,
http://www.fig.net/resources/publications/figpub/FIG_3DCad/FIG_3DCad-final.pdf
(Accessed August 7, 2018).

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