The LADM Valuation Information Model and its application to the Turkey case

Kara, Abdullah; Çağdaş, Volkan; Isikdag, Umit; van Oosterom, Peter; Lemmen, Christiaan; Stubkjaer, Erik

DOI
10.1016/j.landusepol.2021.105307

Publication date
2021

Document Version
Final published version

Published in
Land Use Policy

Land Use Policy 104 (2021) 105307

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

The LADM Valuation Information Model and its application to the Turkey case

Abdullah Kara[a,b,*], Volkan Çağdaş[b], Umit Isikdag[c], Peter van Oosterom[a], Christiaan Lemmen[d,e], Erik Stubkjaer[f]

[a] Delft University of Technology, Julianalaan 134 2628 BL, Delft, The Netherlands
[b] Yildiz Technical University, Department of Surveying Engineering, 34220, Istanbul, Turkey
[c] Department of Informatics, Mimar Sinan Fine Arts University, Istanbul, 34427, Turkey
[d] Dutch Cadastre, Land Registry and Mapping Agency, Apeldoorn, P.O. Box 9046, 7300 GH, Apeldoorn, The Netherlands
[e] University of Twente, Faculty ITC, P. O. Box 217, 7500 AE, Enschede, The Netherlands
[f] Aalborg University, Department of Planning, Fibigerstræde 11, 32, DK-9220, Aalborg Ø, Denmark

ARTICLE INFO

Keywords:
LADM Valuation Information Model
ISO 19152
Land Administration Domain Model
LADM
Property valuation
LADM implementation

ABSTRACT

Spatial data in a Land Administration (LA) establish a fundamental geospatial data theme (see UN GGIM, 2018) and the integrated geospatial information framework for any Spatial Data Infrastructure (SDI). Domain-specific standards, an integral component of the SDI, play an essential role to represent the semantics of domains, specify links between distributed registries and databases, and stimulate the development and implementation for Land Administration Systems (LAS). As an international descriptive standard providing an abstract conceptual schema, the ISO 19152:2012 Land Administration Domain Model (LADM) has been used and is being used as a reference for the implementation of LAS. Various approaches have been used for the LADM implementation that includes elaborating (via a country profile) and realizing a technical model suitable for the implementation (van Oosterom and Lemmen, 2015).

LADM focuses on a specific function of LA that is interested in Rights, Responsibilities and Restrictions (RRR) affecting land, and the geometrical components thereof. The land value function of LA is considered outside the scope in the first edition. Recently, for extending the flexible and modular basis of the LADM, a valuation information model is developed for the specification of valuation information maintained by public authorities. It identifies the links between property valuation and the other LA registries and databases (e.g., cadastre, land registry, building and dwelling registries) that may enable interoperability across systems. The conceptual schema of the model provides a common basis to direct the development of local and national valuation databases and information technology products and services, following an approach similar to the LADM implementation. The proposed LADM Valuation Information Model is on the agenda of the development of the second edition of LADM within ISO/TC211.

The operability of the newly proposed conceptual model needs to be evaluated through technical implementation. This paper describes the development of a prototype for the implementation of the LADM Valuation Information Model and assesses its operability through a case study for Turkey. The primary aim of the paper is to test the capabilities of the LADM Valuation Information Model using the required and produced data in recurrent valuation processes, but not to build a specific information management system for Turkey. As the implementation of a LADM compliant prototype initially requires the development of a country profile at conceptual level, methodologies applied for LADM profile development are examined and then a Turkish LADM Valuation Information Model country profile is proposed using the Conceptual Schema Languages (CSL) of the Unified Modelling Language (UML) and INTERLIS. INTERLIS is a formal language as well as a set of software tools that support LADM implementations. Subsequently, approaches and tools used in the LADM implementation are investigated and utilized for the automated transformations from the country profile to several technical models. In this context, the article presents the experiences gained during the implementations. Moreover, strategies for implementing and managing property valuation information more efficiently (e.g. bi-

* Corresponding author at: Delft University of Technology Julianalaan 134 2628 BL, Delft, The Netherlands
E-mail addresses: A.Kara@tudelft.nl (A. Kara), volkan@yildiz.edu.tr (V. Çağdaş), umit.isikdag@msgsu.edu.tr (U. Isikdag), P.J.M.vanOosterom@tudelft.nl (P. van Oosterom), Chrit.Lemmen@kadaster.nl, c.h.j.lemmen@utwente.nl (C. Lemmen), est@land.aau.dk (E. Stubkjaer).

https://doi.org/10.1016/j.landusepol.2021.105307
Received 15 July 2020; Received in revised form 23 December 2020; Accepted 21 January 2021
Available online 23 February 2021

temporal aspects of valuation information management) are also studied and applied to the implementation. The generated technical models are then populated with sample datasets related to recurrent property valuation including the geometries of valuation units, as well as valuation information covering several years. The developed prototype is then tested through a number of queries to assess whether the LADM Valuation Information Model fulfils information management needs of recurrent valuations. The main contribution of this paper is to provide a holistic approach on how to develop an LADM conformant prototype for managing property valuation information.

1. Introduction

Property valuation is a process of forming an opinion of value of immovable property in exchange under certain assumptions (Wyatt, 2013, p. 49). It is performed by public and private sector actors for several LA processes, such as property taxation, compensation on expropriation, land readjustment, land consolidation, insurance assessment, real estate financing, and property transactions. Guiding references of the United Nations (UN) explicitly indicate that land management and therefore property valuation are the important domains in support to achievement of the Sustainable Development Goals (SDGs). The Voluntary Guidelines on the Responsible Governance of Tenure (VGGT) prepared by the Committee on World Food Security (CFS), and Food and Agriculture Organization of the United Nations (FAO) (2012) remarks that appropriate systems are required for fair and timely valuation of tenure rights in order to promote broader social, economic, environmental and sustainable development objectives (cf. Clause 18). Furthermore, the New Urban Agenda, which was adopted at the UN Conference on Housing and Sustainable Urban Development (Habitat III) as a guideline for sustainable development of urban areas, states that relevant stakeholders are supported in developing and using basic land inventory information, such as cadastral, valuation, and land and housing price records needed to assess changes in values (cf. Clause 104) (UN, 2016, p. 14). Additionally, it also points out that the use of geospatial information systems for sharing and exchanging information including standardization and dissemination of timely and reliable data are promoted (cf. Clause 156, 157, and 159) (UN, 2016, pp. 20–21).

Uniform and accurate valuation of property units require correct, complete, and up-to-date property data (International Association of Assessing Officers (IAAO, 2013). The fundamental element underpinning immovable property valuation are public registries, which accommodate regular data maintenance and updating of property characteristics, ownership details and transaction information (Tang et al., 2011, p. 5). Traditional cadastral systems generally provide two-dimensional (2D) boundaries of property units and legal information over them, whereas today's valuation practices also require three-dimensional (3D) spatial units (e.g. building units) together with the detailed physical, locational and environmental characteristics (Isikdag et al., 2014, 2015; Atazadeh et al., 2017). It is also noted that the basic registration unit of cadastral systems (e.g. cadastral parcel) may also differ from the basic valuation units (e.g. building, condominium unit) (Çağdaş et al., 2016). These situations reveal a need for the development of valuation registries by relevant authorities to store legal, spatial, physical and environmental characteristics of property units, in conjunction with the transaction prices and sales statistics, on the purpose of a more accurate and reliable property valuation practice (Çağdaş et al., 2016; Kara et al., 2020).

A valuation registry is considered as one of the core registries in land administration. Since land administration is the process recording and disseminating information about the ownership, value and use of land and its associated resources (UNECE, 1996, p. 14), it is anticipated from an efficient land administration infrastructure to link valuation registries with the other distributed public registries such as cadastre, land registry, address, and building and dwelling registries (Çağdaş et al., 2016). Standardization is supportive and helpful in the design, development, and further linking of land administration systems. In this context, domain-specific standardization is needed to capture the semantics of the land administration domain on top of the agreed foundation of basic standards (Lemmen et al., 2015). There are numerous international, domain-specific standards, which are somehow related with property valuation domain, such as procedural valuation standards (e.g. TEGoVA (2016), IVSC (2017), IAAO (2017, 2018)) and property measurement standards (e.g. ISO, 9836:, 2017; RICS Property Measurement, 2018; International Property Measurement Standards (IPMS, 2014, 2016). Despite the existence of these standards, there is no international standard or information model defining the semantics of process of valuation, and semantic relationships of valuation registries with other public inventories or registries (Çağdaş et al., 2016; Kara et al., 2018b).

The ISO, 19152:, 2012 Land Administration Domain Model (LADM) focuses on the tenure function of LA (see Enemark, 2005). The LADM includes Rights, Restrictions, and Responsibilities (RRRs) affecting land and the geometrical components thereof (Lemmen et al., 2015), but considers out of scope the specifications of valuation registries or inventories. It defines external links to other public inventories including property valuation, taxation, physical building and land use but does not specify the semantics of them. Nevertheless, its generic and modular structure provides a flexible framework for the extensions, specifications and further country-specific information models.

A valuation information model has recently been developed for the specification of valuation information maintained by public authorities (Çağdaş et al., 2016; Kara et al., 2018b, 2020). The rights to be valued are the fundamental and indispensable information for property valuation (International Association of Assessing Officers (IAAO, 2014). The LADM and the OGC's Land and Infrastructure Conceptual Model Standard (OGC LandInfra, 2016) are the only standards that elaborate legal concepts over immovable properties. As the LADM is a standard for LA domain that includes property valuation processes as an important component, and enables the extensions for the refinement of country-specific situations, LADM has been taken as the basis for the development of the valuation information model (Çağdaş et al., 2016; Kara et al., 2017, 2018b). The valuation information model is designed to facilitate all stages of administrative property valuation, namely identification of properties, assessment of properties through single or mass appraisal procedures, recording transaction prices, generation and representation of sales statistics, and dealing with appeals. It is supposed that LADM Valuation Information Model (LADM_VM) will provide public bodies a common basis for the development of local and/or national information models and databases, enabling the integration of valuation databases with land administration databases, and can act as a guide for the private sector (Open Geospatial Consortium (OGC, 2019).

The public authorities require appropriate systems for effectively and efficiently managing input and output data in valuation processes and thus carrying out fair and timely valuations. Developing a new information management system by each of the authorities is a time-consuming process and may cause lack of harmony and interoperability between the systems. The objectives of this paper are to present a holistic approach on how to develop a LADM_VM based prototype (a land administration system – LAS) for managing property valuation information, and to assess the operability of the prototype and therefore LADM_VM with its application to the Turkey case.

This research is based on the methodology as illustrated in Fig. 1, where each of the colors indicates a separate section in the paper. As the implementation of an LADM compliant prototype initially requires the development of a country profile at conceptual level, the methodologies applied in relevant studies are examined with the focus to the Conceptual Schema Languages (CSL) of Unified Modelling Language (UML) and to INTERLIS. Subsequently, the approaches and tools (e.g. tools of INTERLIS, ShapeChange) that can be used to derive technical models from LADM country profiles are also investigated in Section 2. A brief overview of the LADM Valuation Information Model is given in Section 3. The current state of recurrent property valuation in Turkey, especially conducted for the purpose of taxation, is analyzed, and the Turkish LADM Valuation Information Model Country Profile is designed according to the analysis results in Section 4. Section 5 firstly focuses on converting the country profile to the database schema of PostgreSQL/PostGIS, using different tools. In this stage, strategies for implementing and managing property valuation information more efficiently (e.g. temporal data management, implementing generalization relationship) are also studied and applied to the implementations. After that, the profile is also converted into several data exchange formats (i.e. GML, RDF, GeoJSON), in line with the results of the technical models/encodings working group of the seventh Land Administration Domain Model Workshop (FIG, 2018). The generated technical models are then populated with sample datasets related to recurrent property valuation, namely 3D geometries of valuation units (i.e. building) as well as valuation information covering several years in Fatih District, İstanbul, Turkey. Following the technical implementation, a number of queries are performed and visualized to assess whether it fulfills the information management needs of valuation processes in Section 6. Moreover, an assessment and discussion on the implementation is presented in the same section. The last section concludes the paper and suggests future research directions.

2. Literature review

As an international standard, the LADM may stimulate and accelerate the implementation of land administration systems (Lemmen et al., 2015). Implementation of the LADM enables Geographical Information Systems (GIS) and Database Management Systems (DBMS) providers and/or open source communities to develop and maintain products and applications for land administration in a more efficient, effective and sustainable way (Lemmen et al., 2015; Van Oosterom and Lemmen, 2015; Open Geospatial Consortium (OGC, 2019). The LADM is already utilized in various applications and implementations.

The LADM implementation includes elaboration to a country profile (e.g. UML application schema), realization of this profile with a physical (technical) model suitable for implementation: a database schema (Data Definition Language –DDL– schema of an intended database), a data exchange format (GML, GeoJSON, RDF) and a user interface for edit and dissemination (Lemmen et al., 2015; van Oosterom et al., 2019).

The LADM specifies a conceptual schema. To develop a LADM-compliant prototype, an application schema is required. An application schema defines the possible content and structure of the data with a Conceptual Schema Language (CSL) that is utilised as the basis for implementing application-schema-specific data structures for local storage of data (ISO19118, 2011). Country profiles can be used for customizing the LADM with adding user-defined classes, characteristics and associations to meet regional or country-specific needs and situations (International Organization for Standardization (ISO, 2012). The LADM Edition-I does not provide a strict methodology for creation of a country profile, however, it is indicated that a generic methodology for the development of country profiles will be available in the LADM Edition II (Lemmen et al., 2019). On the other hand, the steps that can be followed to develop a country profile are proposed by several studies (Kalantari et al., 2015; Bydłosz, 2015; Jenni et al., 2017; Janečka et al., 2018; Govedarica et al., 2018; Kalantari and Kalogianni, 2018; Kalogianni et al., 2019). These steps may be distilled as follows: (a) definition of purpose and scope of the country profile, (b) analysis of the requirements and the current land information systems, (c) creation of a conceptual model, (d) evaluation and test the proposed model.

Before designing a country profile, its purpose function should be explicitly determined. According to the aim and scope of the profile to be developed, an investigation can be carried out ranging from the organisational and institutional structure to the legislative framework and the regulations related the domain of LA in the relevant jurisdiction (Kalantari et al., 2015; Jenni et al., 2017; Kalantari and Kalogianni, 2018; Kalogianni et al., 2019). Moreover, current LASs should be analyzed in detail as their data models and concepts should be considered in designing a LADM profile (Kalantari et al., 2015; Kalogianni

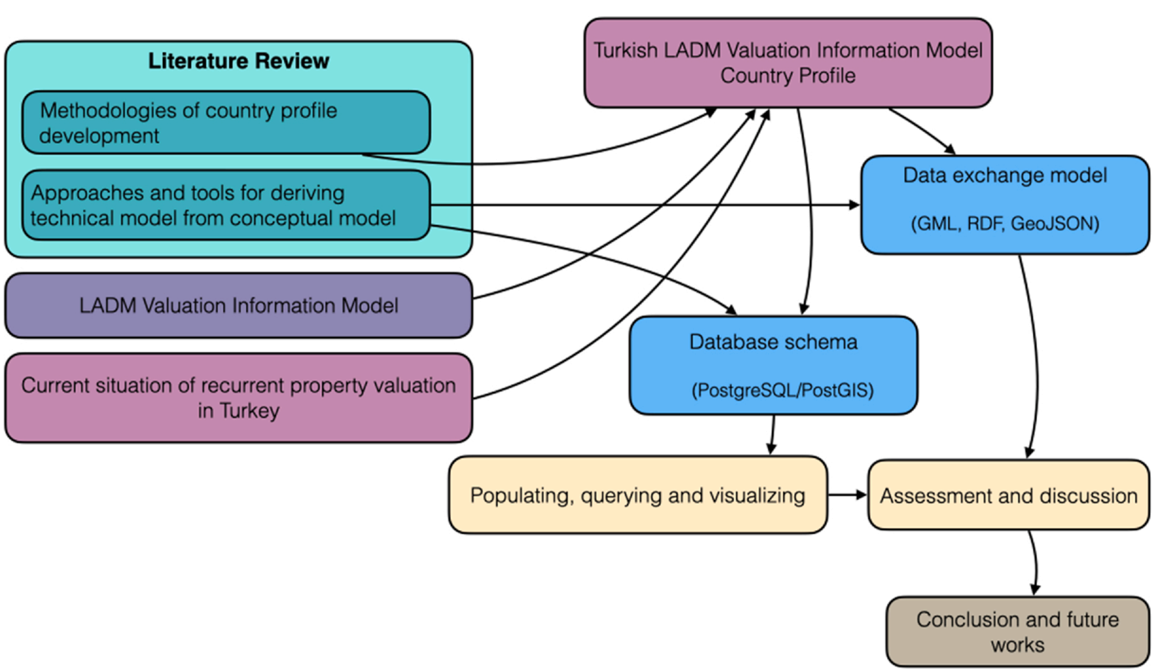

Fig. 1. The overview of the research methodology.

et al., 2019). Following the requirement analyses, a conceptual modelling process can start with mapping the concepts and elements of the existing LAS model(s) with LADM (Janečka et al., 2018; Kalantari and Kalogianni, 2018; Kalogianni et al., 2019; Janečka and Souček, 2017). A number of proposals that can guide conceptual modelling: (a) use LADM classes or inherit from LADM classes using a prefix denoting the country, (b) create new classes only when concepts do not fit to the LADM or the concepts are not captured by LADM, (c) add new characteristics to classes and add new values to existing code lists, if needed, (d) adjust multiplicities and cardinalities according to national legislations, and (e) define relevant constraints, if needed (Kalantari et al., 2015; Kalogianni et al., 2019; Janečka and Souček, 2017; Paasch et al., 2015). Several workshops can be held in analyses and modelling stages as done in Jenni et al. (2017) to ensure the involvement and approval of all relevant stakeholders in the design of a country profile.

A proposed country profile should be tested with real-world use cases. One way is to create UML instance-level diagrams as done in Annex C of the LADM (International Organization for Standardization (ISO, 2012). To make a solid and comprehensive implementation, a country profile can be designed and developed with a physical (technical) model. As with the LADM, the LADM Valuation Information Model and derived country profiles are based on the Model Driven Architecture (MDA), therefore the conceptual schemas of them that are expressed in a CSL can be utilised to derive a technical model automatically (Lemmen et al., 2015). One of the options is to derive a database schema (e.g. in PostgreSQL/PostGIS or Oracle) based on a CSL in which a country profile is modelled. The main advantage of database implementation is to detect inconsistencies in the conceptual model and duplicated characteristics as well as missing or incorrectly defined associations between classes. Several studies utilised UML application schema as CSL for deriving a database schema from a LADM country profile (Hespanha et al., 2008; van Bennekom-Minnema, 2008; Hespanha, 2012; Andrade et al., 2013; Budisusanto et al., 2013; Zulkifli et al., 2014; Kuria et al., 2016; Rajabifard et al., 2018; Alattas et al., 2018; Kara et al., 2018c; Yan et al., 2019; Zulkifli et al., 2019). They utilised various tools including certainly a UML tool (e.g. Enterprise Architect, Visual Paradigm, Dia), which was employed to design a LADM country profile as Platform Independent Model (PIM) and then transforming it into a Platform-Specific Model (PSM). This transformation is based on MDA transformation rules, resulting in a Data Definition Language (DDL) schema, which can be used to set up a Structured Query Language (SQL) database (Hespanha et al., 2008). Besides the UML tools, ShapeChange, an open-source Java tool that takes UML application schemas constructed according to the ISO 19109 standard and derives implementation representations (Interactive Instruments, 2019), can also be used to transform UML application schemas to SQL DDL schema of an intended database. On the other hand, some researchers state that automated implementations have limitations and manual fine-tuning is required in the output. For instance, it is reported that some of the 3D geometry types cannot be automatically transformed into SQL DDL schema (Alattas et al., 2018). Additionally, transforming code lists to SQL DLL expressions is not possible (Psomadaki et al., 2016).

INTERLIS, another CSL that is based on MDA and can be used for developing a LADM country profile, is a Swiss standard (SN 612030) (Germann et al., 2018; INTERLIS, 2016). It is being used to precisely define data models and has some advantages over other modelling languages (e.g. UML), for example, easy to read text files, rigid computer processable syntax, tools to generate a database schema and data exchange format, and built-in geometric data types (Germann et al., 2015). INTERLIS provides a set of tools that can be used in different stages of implementation, ranging from conceptual modelling to technical implementation. The INTERLIS UML editor is used to create and visualize INTERLIS data models (*.ili) similar to UML class diagram, while the INTERLIS Compiler (ili2c) checks the syntactic correctness of a newly created INTERLIS data model. Moreover, several INTERLIS tools enable the automatic translation of the INTERLIS data models to several database schemas (e.g. ili2ora for Oracle, ili2pg for PostGIS). These tools also enable importing and exporting INTERLIS data into and from databases (Kalogianni et al., 2017; Germann et al., 2015). Some of the ISO191xx base models and the LADM Edition I were already expressed in CSL of INTERLIS (Kalogianni et al., 2017; Germann et al., 2015). Furthermore, several LADM country profiles have been designed and implemented with INTERLIS tools (Jenni et al., 2017; Kalogianni et al., 2017; Kara et al., 2018d). It is worth noting that INTERLIS 3.0 is a work in progress and it will have full 3D support including solid geometries (Germann et al., 2018).

An alternative to the database implementation is to develop a data exchange format (e.g. GML, GeoJSON, RDF). Effective exchange of structured data between systems can be supported using this implementation approach. A suitable data exchange format can be selected according to the requirements of an application. For example, due to its acceptance as standard by various organizations and having been supported by many software products, GML can be selected. Moreover, GeoJSON can be chosen for displaying vectors in web applications as it is based on JavaScript object notation, and RDF can be chosen to develop linked data applications. Several tools have automated the conversion from conceptual model to data exchange formats. The ShapeChange has been used to convert UML conceptual models to GML application schemas by various studies (Góźdź et al., 2014; Eriksson et al., 2018; Kutzner et al., 2020), including creating GML application schemas of INSPIRE themes (INSPIRE, 2020). It can also be employed to create RDF and JSON based encodings, for example, van den Brink et al. (2014) extended ShapeChange to enable conversion UML and GML to RDF/XML. Some other tools also enable creating a data exchange format from a conceptual model. For instance, the INTERLIS Compiler can also be used to create GML application schemas from conceptual models based on INTERLIS CSL, while GML and RDF encodings of a UML conceptual schema can be derived using the software Enterprise Architect (EA) (Sparx Systems, 2020). It is worth indicating at this point that it is possible to convert from a source dataset to a target dataset in different exchange formats. The transformation of a data exchange model to another can be performed with the help of some GDAL libraries (GDAL/OGR, 2020) and Extract, Transform, Load (ETL) tools, such as the open-source Humboldt Alignment Editor (HALE) (Wetransform, 2020) and the Feature Manipulating Engine (FME, 2020). Lastly, it should be noted that encodings / technical models are proposed to be available in the LADM Edition II to facilitate the LADM implementations (Lemmen et al., 2019).

3. The LADM valuation information model

This section gives brief overview of the LADM_VM. The readers are referred to (Çağdaş et al., 2016; Kara et al., 2018b, 2020) for detailed information about the creation methodology.

The LADM_VM aims to specify the characteristics and semantics of valuation registries maintained by public authorities and to reveal the interrelations between valuation registries and other land administration registries, such as cadastre, building and dwelling register, etc. The LADM_VM is a conceptual schema. Its implementation enables the recording of data concerning objects of valuation (i.e. valuation units), parties involved in the valuation practices, input and output data used and produced through single or mass appraisal processes, transaction prices and sales statistics (Çağdaş et al., 2016; Kara et al., 2018b). Developing an information model on valuation and assessment of immovable properties for recurrent taxation is the initial purpose, however, it has capabilities to represent other purposes of valuations (e.g. sporadic valuations), as well.

The LADM_VM is proposed as a package in the second edition of LADM that is under development. The classes of it receive a prefix VM, short for ‘Valuation Module’. The main classes (featureTypes) of the model are shown in Fig. 2. The spatial part of the LADM Valuation Information Model includes the classes *VM_ValuationUnit*, *VM_SpatialUnit*,

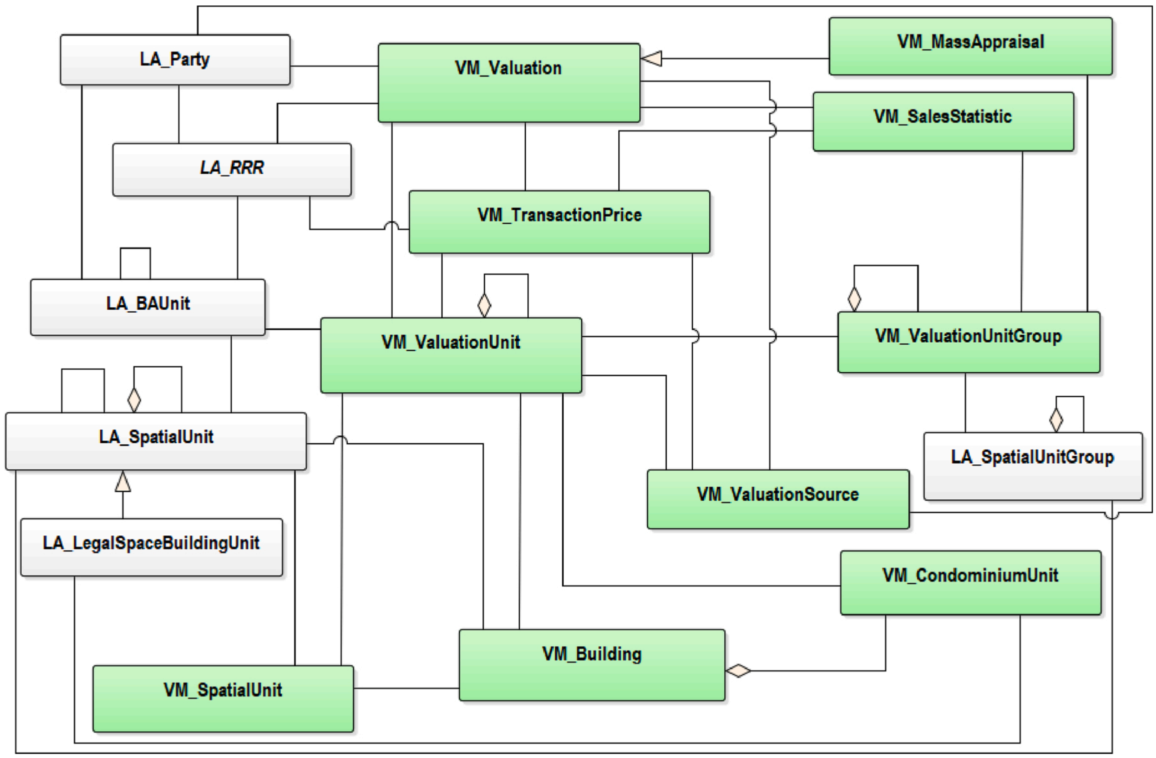

Fig. 2. The main classes of LADM Valuation Information Model.

VM_Building, *VM_CondominiumUnit*, *VM_ValuationUnitGroup*. Those classes represent objects of valuation and their characteristics that were already introduced in Kara et al. (2020), therefore they are not discussed here in detail. The *VM_ValuationUnit* class represents the basic recording units in valuation registries, such as land and improvements (e.g. only building, land and improvements together as condominium property). The *VM_SpatialUnit* class represents land as a subject of valuation, for instance, a cadastral parcel. The *VM_Building* and *VM_CondominiumUnit* classes represent the physical characteristics of buildings, building parts and condominium units that are required in a valuation process, while the *VM_ValuationUnitGroup* class is proposed for grouping or zoning valuation units (e.g. administrative, economic, function). As these classes have relationships with the spatial representation package of LADM, the valuation units can be represented in either 2D or 3D (Çağdaş et al., 2016; Kara et al., 2018b).

The VM_Valuation class, as a counterpart of the *ExtValuation* external class of LADM, specifies output data produced within a valuation process, such as date of valuation, type of value, valuation approach, assessed value, and status of possible appeals to valuation. As each approach in valuation (i.e. sales comparison, cost and income methods) has its own characteristics, different classes are proposed for elaborating them. For example, while *VM_SalesComparisonApproach* includes comparable valuation units' identifiers, the *VM_CostApproach* covers cost type (e.g. replacement or reproduction cost), chronological and effective age of improvements, and the *VM_IncomeApproach* contains income (e.g. gross, effective, net), operating expenses, capitalization rates, and gross rent multipliers characteristics (Çağdaş et al., 2016; Kara et al., 2018b).

The LADM_VM also enables the representation of mass appraisal-related information through the class *VM_MassAppraisal*, which is a specialization class of the *VM_Valuation* class. It describes mathematical models and mass appraisal analysis types (e.g., cluster, multiple regression, time series), and the sample size of the analysis. It also has a performance indicator characteristics, detailed in the class *VM_MassAppraisalPerformance*, which specifies the date of performance analysis, sample size, appraisal level, measures for appraisal level (e.g., mean), the measure of appraisal uniformity (e.g. coefficient of dispersion), and appraisal uniformity (Çağdaş et al., 2016; Kara et al., 2018b).

Valuation processes are benefiting from property transaction information recorded in a land registry or a database, which is created and updated regularly by information provided from contracts or declarations submitted by the parties (e.g. buyer and/or seller) involved in transactions. The class VM_*TransactionPrice* characterizes the information related to transactions, including the date of contract or declaration, the transaction price, and the type of transaction (e.g., sale, heritage, forced sale, and rent prices) (Çağdaş et al., 2016; Kara et al., 2018b).

The model also proposes the class *VM_SalesStatistic*, to represent sales statistics produced through the analysis of transaction prices for monitoring price trends. Such an analysis can be based on spatial (e.g. condominiums in a municipality) or thematic clusters (e.g. condominiums used for residential purposes). The class *VM_SalesStatistic* has characteristics that indicate calculated average transaction prices per square meter of valuation units, price index value, base price index value and their exact dates (Çağdaş et al., 2016; Kara et al., 2018b).

In principle, property valuation is documented with a source. The class *VM_ValuationSource* is proposed to record the type of valuation sources (e.g. valuation report, sale contract, rental contract, declaration). This class inherits from the class *LA_Source*, which includes acceptance and life span stamp characteristics, representing real-world time (valid time) of the source. The LADM_VM also includes several temporal characteristics related to real-world time, for example, the date of valuation characteristic in the class *VM_Valuation* represents the exact legal time of valuation. Additionally, the date of mass appraisal analysis, transaction price and price index are some of the other real-world time characteristics, distributed over the different classes of the model. Exceptionally, the *VM_ValuationSource* is the only class that does not inherit from the *VersionedObject* class of LADM, similar to the class *LA_Source*. The superclass *VersionedObject* specifies the begin life span and end life span characteristics, which are used when objects are recorded, changed and removed from a land registry or a database (system or transaction time) (International Organization for Standardization (ISO, 2012). Therefore, it can be stated that the LADM potentially invites bi-temporal support (Thompson and van Oosterom, 2019). In addition to that, in the Working Draft (WD) of LADM Edition II, Part 1: Fundamentals, there is a new proposal for a standard bi-temporal support for all classes inherited from *VersionedObject* except *LA_Source* (Thompson and van Oosterom, 2019). All the classes of the LADM_VM are also designed as a subclass of *VersionedObject* (except *VM_ValuationSource*), in line with the core LADM design approach, for efficient management of temporal and dynamic aspects of valuation information in a database.

Person or organization that plays a role in LA are represented within the class *LA_Party*. The roles of parties are specified with a code list, *LA_PartyRoleType*. To represent parties related to property valuation in the LADM_VM, the modelling approach proposed by Paasch et al. (2015) is followed, namely if the concept is captured by an LADM code list; use that existing code list to add new values. Therefore, the *LA_PartyRoleType* code list is extended with valuation-related roles (e.g. certified valuer), specified in the Property Valuation Thesaurus (Çağdaş et al., 2017). The LADM_VM only covers the roles of parties involved in valuations, although it is proposed to include some extra information on parties related to valuation (e.g. identifier for valuers, rating for valuers) (Kobasa et al., 2018).

The LADM_VM is firstly represented in CSL of the UML class diagram (Çağdaş et al., 2016; Kara et al., 2018b, 2020). Due to some advantages of INTERLIS over UML, the INTERLIS language is also applied to the LADM_VM. Fig. 3 shows a fragment from UML and INTERLIS representations of the LADM_VM. In order to derive an INTERLIS description of the LADM_VM, the INTERLIS files of the data models (e.g. ISO 19152, ISO 19107, and ISO 19111) to be used as basis are initially imported into the INTERLIS UML editor. After that, all the classes, characteristics and relationships of LADM_VM are manually described and then converted to the computer processable INTERLIS data modelling language (Kara et al., 2018d). As the INTERLIS UML editor only supports importing XMI Rational Rose format (Kalogianni et al., 2017), this is achieved manually instead of importing the UML class diagram definitions of the LADM_VM to the INTERLIS UML editor. The details related to the INTERLIS description of LADM_VM are given in Kara et al. (2018d).

4. Property valuation in Turkey

In Turkey, public and private sector actors have responsibilities in carrying out the property valuation. Valuation data are required for various LA practices, including property taxation (e.g. periodic and sporadic), expropriation, and property transactions. The legislations related to public practices (e.g. recurrent property taxation, expropriation) specify particular rules and principles for the determination of values of properties (e.g. tax value, expropriation value). This paper only investigates the administrative (public) valuations related to recurrent property (real estate) taxation. Using the outputs of this investigation given in Section 4.1, the Turkish LADM Valuation Information Model Country Profile is proposed in Section 4.2.

4.1. The recurrent property valuation in Turkey

The main principles concerning the valuations related to recurrent property taxes are regulated in the Tax Procedure Law (Vergi Usul Kanunu) No. 213, dated 1961 and the Property Tax Law (Emlak Vergisi Kanunu) No. 1319, dated 1970. The rules regarding assessment procedures of immovable properties are detailed in the Tax Assessment Statute (Emlak Vergine Matrah Olacak Vergi Değerlerinin Takdirine İlişkin Tüzük) No. 7/3995, dated 1972.

Fundamentally, there are two types of recurrent taxes on immovable properties: ‘unimproved’ property tax (i.e. land tax) and improved property tax (i.e. building tax). The subject of ‘unimproved’ property tax is the land parcels in rural and urban areas, while the subject of improved property tax covers land parcel and improvements together as a property (e.g. building or condominium). The improvements mean all permanent buildings erected on land and water, namely both ‘legal buildings’ that have an occupancy permit which legally documents that the building is suitable for occupancy and’ illegal buildings’ that cover structures that were not constructed in compliance with relevant legislation (Çağdaş, 2013).

The unimproved and improved property taxes are levied according to the ‘tax value’ of the properties. The Tax Assessment Statute states that the tax value is the market value of immovable properties that are subject to the property tax. However, in practice, tax value is generally lower than the market value. The tax value of the urban and rural land parcels are assessed on basis of a unit value of a parcel that is determined by local valuation commissions every four years, for each street in urban areas and each district in rural areas. The ‘land parcel unit value per square meter’ is publicly shared via the website of the central e-government and/or of the relevant municipality. The building tax values are generally assessed with a cost approach based on the ‘reproduction cost of building per square meter’ that is determined by the Ministry of Treasury and Finance and the Ministry of Environment and Urbanization. The reproduction cost refers to the estimated cost to construct a replica of a building using same materials at current prices. These tax values are updated between the reassessment periods by the half of revaluation rate, which indicates an annual changing rate in the Wholesale Price Indices calculated and published by the Ministry of

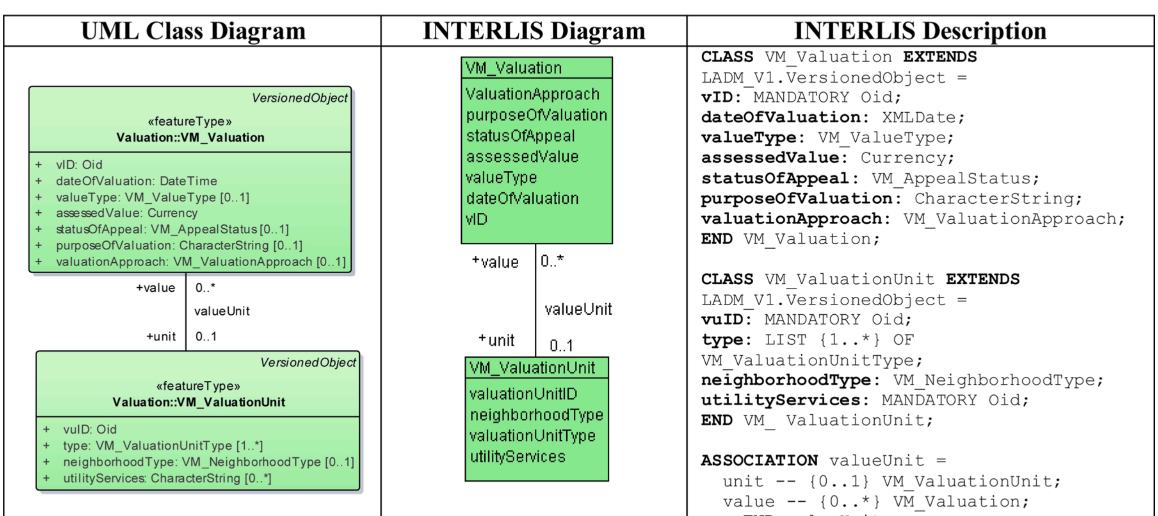

Fig. 3. A fragment of the different representations of the LADM Valuation Information Model.

Treasury and Finance.

The Tax Assessment Statute determines different approaches and data requirements for the assessment of three taxation objects, which are the improved property, unimproved property located in urban areas, and unimproved property located in rural areas. For example, tax values for improved properties should be determined via the sales comparison approach, if sufficient amount of sales data is available, otherwise the cost approach or the income approach is used. Although the Tax Assessment Statute specifies the methods and required property characteristics to be observed separately for each of the mentioned approaches (see Kara et al., 2018a), most of the determined characteristics are not used in practice. In other words, although the statute is in force, the tax values of properties are determined according to the official statements of the Property Tax Law issued by the Revenue Administration of the Ministry of Finance (Kara et al., 2018a; Revenue Administration, 2019).

The official statements regarding the Property Tax Law are published every year, covering the information on how the tax values of unimproved and improved properties have to be calculated. The characteristics used to determine tax values of improved properties, and unimproved properties located in urban and rural areas, specified by the official statements are presented in Table 1. The more complete coverage of property types are represented in Kara et al. (2018a).

Briefly, tax values of improved and unimproved properties are currently calculated with equations 2.1 and 2.2 according to the Property Tax Law and the official statements issued by the Ministry of Treasury and Finance. In the Eqs. (2.1) and (2.2), $V_{imp.\ pro.}$ and $V_{unimp.\ pro}$ represent tax value of improved and unimproved properties; A_{impr} denotes for the gross floor area of building or condominium unit; A_{parcel} represents parcel area or, if there is a co-ownership share, the parcel area per co-ownership share; V_{Parcel} stands for the unit value per square meter of parcels; C_{impr} represents the reproduction cost of building per square meter; o, e, h stand for physical obsolescence of improvements, availability of elevator and heating/air conditioning in improvements, respectively. Co-ownership shares have to be taken into account when calculating tax value of a condominium unit. More specifically, when calculating tax value of a condominium unit, the tax value of a building calculated with the Eq. (2.1) has to be multiplied with co-ownership share of that condominium unit.

$$V_{imp.\ pro.} = \left[\left(A_{impr} \times C_{impr}\right) \times (1-o) \times (1+(e+h)\right] + (A_{parcel} \times V_{Parcel}) \tag{2.1}$$

$$V_{unimp.\ pro} = A_{parcel} \times V_{Parcel} \tag{2.2}$$

Table 1
Required characteristics for valuation of improved and unimproved properties according to the official statements of the Property Tax Law.

Improved property characteristics	Definitions and value types
Reproduction cost of building per square meter	This is determined by the Ministry of Finance and the Ministry of Environment and Urbanization every year based on building construction type, use and construction quality type.
Building (condominium) use type	The type of building usage defined in Turkish Property Tax Law (e.g. residential, office, other specific building).
Building construction type	The type of construction defined in the Tax Assessment Statute (e.g. steel framework, concrete framework, stone, stone frame, timber, shanty, sundried or mud brick).
Building quality type	Construction class of buildings defined in the Tax Assessment Statute (i.e. luxury, first class, second class, third class, simple construction).
Gross floor area	The total floor area of building/condominium unit (dwelling) including outer walls.
Physical obsolescence	The loss of value due to age, physical deterioration. It is calculated by a scheme given in the Tax Assessment Statute.
Elevator	Existence of the elevator.
Heating/air conditioning	Existence of the heating and/or air conditioning.
Unimproved urban property characteristics in urban area	
Land parcel area	Area of land parcel.
Parcel unit value per square meter	This is determined local valuation commissions every four years and these values are updated between the assessment periods by the half of the revaluation rate.
Unimproved urban property characteristics in rural area	
Land parcel area	Area of land parcel.
Parcel unit value per square meter	This is determined local valuation commissions every four years and these values are updated between the assessment periods by the half of the revaluation rate.
Rural parcel type	Type of rural parcel defined in the Tax Assessment Statute (i.e. barren land, bottomland, and wetland).

4.2. Turkish LADM valuation information model country profile

The Turkish country profile is specified in compliance with the official statements of Property Tax Law and other related regulations, outlined in the previous subsection, and the development steps of a country profile, mentioned in Section 2. It is expressed in CSL of both UML and INTERLIS. As the UML is the most preferred CSL, when developing a LADM country profile, the UML-based profile is described more detailed than the INTERLIS profile.

Fig. 4 shows the classes of the country profile for the valuations regarding recurrent property taxation. The turquoise, green and grey colored UML classes present the Turkish country profile, LADM_VM, and core LADM, respectively. The proposed country profile is a combination of LADM_VM and the core LADM Edition I. It represents recurrent property valuations related to annual taxation, and covers the associations between the valuation information and the cadastral system, which provides information for valuation process, for example, owners of properties, land parcel areas, gross floor areas and share in common places (i.e. share of joint facilities or co-ownership share) for a condominium. Considering the aim and scope of the profile, some classes of LADM and LADM_VM (e.g. *LA_LegalSpaceUtilityNetwork*, *VM_SalesStatistic*) are not included in the proposed profile.

The Turkish LADM _VM Country Profile reveals the valuations conducted for annually levied recurrent taxes (i.e. unimproved and improved property tax). Moreover, it covers spatial aspects and physical characteristics of valuation units (e.g. parcel, building), valuation-unit groups, parties involved in valuation practices, and information on recurrent taxes in Turkey. It also includes relevant values for the code lists that detail administrative valuations in relation to property tax assessments in Turkey.

In the profile, 'TR' prefix is added to the all covered classes of both LADM and LADM_VM (e.g. *TR_LA_SpatialUnit*, *TR_VM_Valuation*) to avoid possible confusions with the classes of the original models.

Table 1 shows the required characteristics for the valuations. Some of the characteristics have already been included in the LADM_VM. The parcel area and floor area of a condominium unit are specified in the classes *LA_SpatialUnit* and *VM_CondominiumUnit*, respectively. Moreover, the physical obsolescence and the reproduction cost of building characteristics required for the valuation of buildings are included in the class *VM_CostApproach*. Nevertheless, the model still needs to be extended with new characteristics for a complete representation of the recurrent valuations. Therefore, *TR_VM_Valuation*, *TR_VM_MassAppraisal* *TR_VM_ValuationUnit*, *TR_VM_ValuationUnitGroup*, *TR_VM_Parcel*, *TR_VM_Building* and *TR_VM_CondominiumUnit* are inherited from the relevant classes of the LADM_VM. The inherited classes are then extended with the characteristics, given in Table 1. No new (feature) classes are created for the profile, as the LADM_VM classes (concepts) conforms to the valuations conducted in Turkey; however, a few new code lists are created.

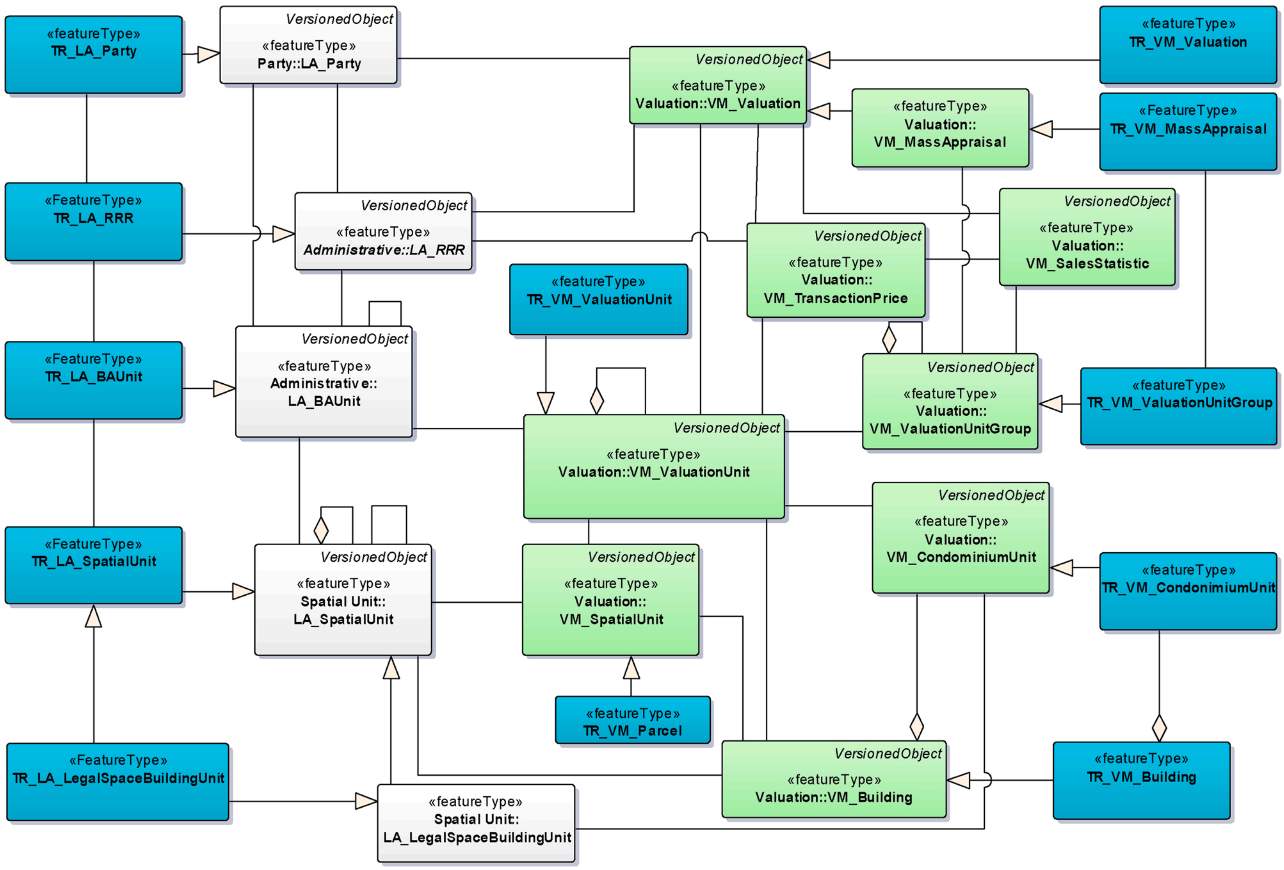

Fig. 4. The main classes of Turkish Country Profile (turquoise, TR_ prefix) and its basic relations with LADM Valuation Information Model (green, VM_prefix) and core LADM classes (grey, LA_ prefix) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Fig. 5 represents the main classes of Turkish LADM _VM Country Profile, its characteristics and the associations with the core LADM classes, while Fig. 6 shows the code lists of the country profile.

The types of valuation unit, namely unimproved (parcel) and improved (building or condominium) property, are represented in *TR_VM_ValuationUnit, which* has associations with the parcel, building, condominium unit and basic administrative unit classes. As the 'parcel unit value per square meter' is determined considering the parcel use type, the class *TR_VM_Parcel* includes the parcel type characteristic. The construction type and quality type are included in the class *TR_VM_Building* since the 'reproduction cost of building per square meter' is specified according to those characteristics of the building. Furthermore, the building area, date of construction, elevator and heating/air conditioning characteristics are included in the class *TR_VM_Building* as they are required when calculating tax values of improved properties (see Eq. (2.1)). The legal status of the building is also added to the profile in order to distinguish legal buildings from illegal buildings. On the other hand, the use type (e.g. residential, office, retail) and accessory part type (e.g. coal cellar, garage) are included as informative characteristics in the class *TR_VM_CondominiumUnit*. As share in common places and condominium floor area are variables that may be used in calculating tax values, the class *TR_VM_CondominiumUnit* also contains these characteristics. It is noted that the condominium floor area can be derived from and related to the definition of total floor area (gross floor area) in ISO, 9836:, 2017. The building (condominium) area size and area type characteristics are represented in the *TR_VM_AreaValue*. The geometric representation of parcels and buildings is addressed by the classes *TR_LA_SpatialUnit*, *TR_LA_LegalSpaceBuildingUnit*, and their associated geometry classes. The class *TR_VM_ValuationUnitGroup* is required in the profile as the 'land parcel unit value per square meter' and is determined per street or district. The class *TR_VM_ValuationUnitGroup* represents the valuation group types (e.g. street in urban or district in rural) and their geometries through an association with the class *TR_LA_SpatialUnit*.

The class *TR_VM_Valuation* covers the valuation-related information. In the profile, the initial value for valuation and the value type is specified as taxation and tax value, respectively. The assessment value, date of valuation and the valuation identifier are also included in the class *TR_VM_Valuation*. The country profile covers both tax values of unimproved and improved properties. The tax value of an improved property (see Eq. (2.1)) is simply the sum of values of parcel value and building (or condominium). Since the cost approach is used when calculating the building part of the tax value of improved properties, details regarding this approach are specified in the *TR_VM_CostType* (see Fig. 5), in conjunction with the approach characteristic of *TR_VM_Valuation*. The reproduction cost of building per square meter, date of cost price, estimated value by cost approach, and total obsolescence of building are the characteristics included in the *TR_VM_CostType*. Valuation of parcel can be considered as a type of mass appraisal, however, it is noted that no mathematical model and performance analysis is conducted when determining tax values of parcels. Nevertheless, *TR_VM_MassAppraisal* class is created to represent parcel value related characteristics, for example, valuation unit group-based value, date of group-based value, date of revaluation, date of revaluation rate and revaluation rate characteristics.

When the initial design is completed, the multiplicity of associations are adjusted, considering the national regulations (see Fig. 5). After that, the code list and their values are specified. A new code list is created, if there is no a suitable code list to add value in the LADM_VM (i.e. *TR_BuildingQualityType*, *TR_ParcelUseType* and *TR_LegalStatusType*). The rest of the code lists in the country profile, which can be seen Fig. 6, is designed as an extension of the code lists of LADM_VM. UML code lists

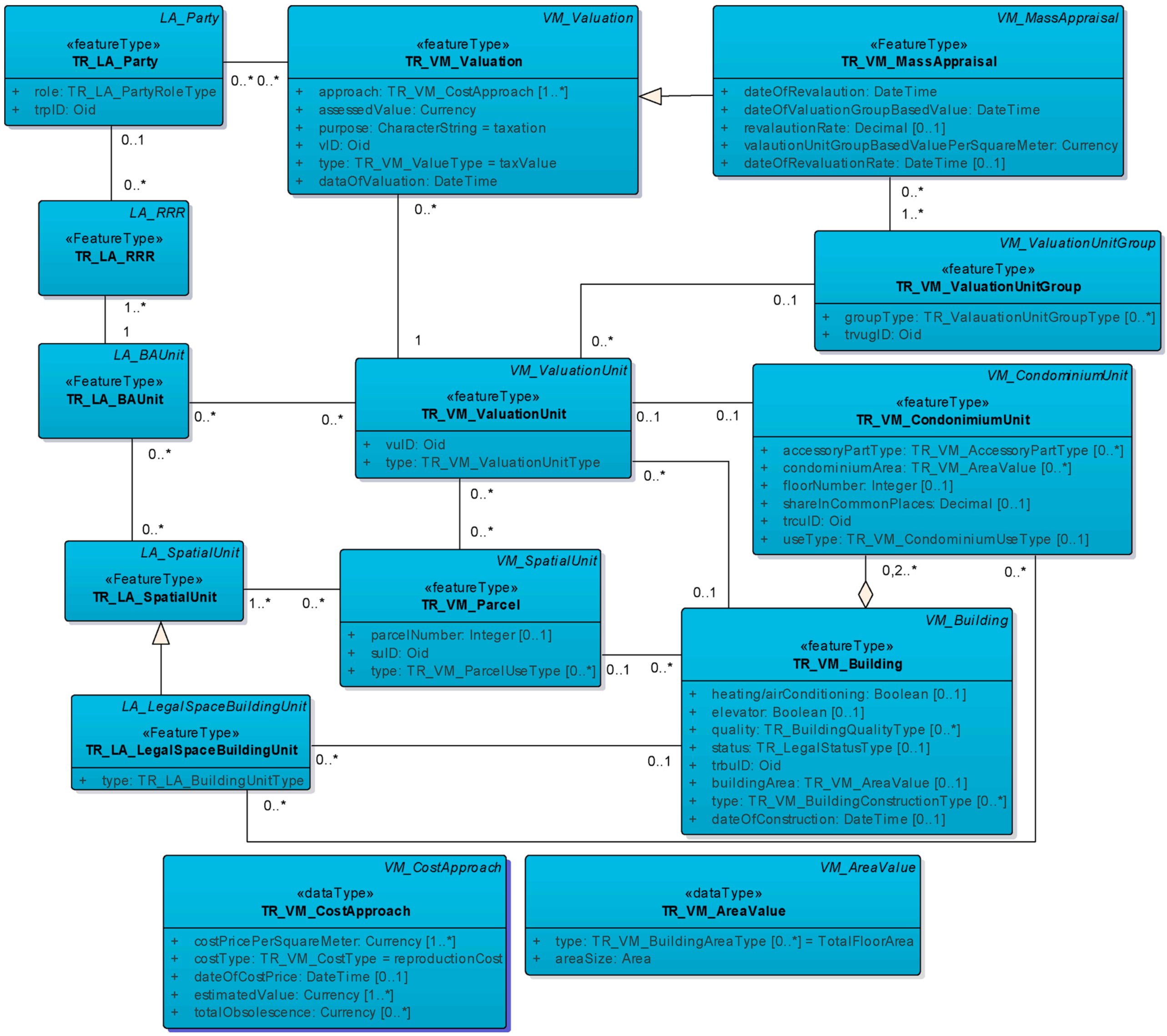

Fig. 5. The main classes of the Turkish LADM Valuation Information Model Country Profile.

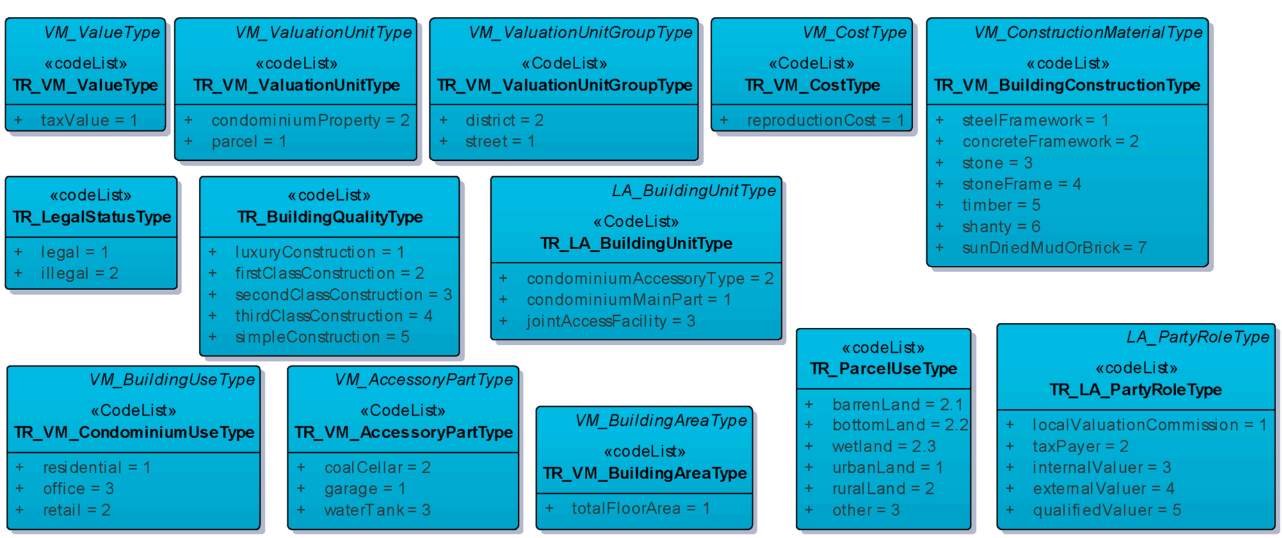

Fig. 6. The code lists of Turkish LADM Valuation Information Model Country Profile.

are just lists of values without any (hierarchical) structure. To present simple relations between code list values, a hierarchical numbering approach is used in the Turkish country profile as seen in *TR_ParcelUseType* in Fig. 6. Alternatively, a note can be added to the relevant code list to show hierarchical relations. It is worth noting that the knowledge organization systems (e.g. taxonomy, thesauri and ontologies) supported by the semantic technologies (e.g. SKOS, RDF, OWL) can provide more comprehensive structures for the specification of semantic relations between code list values (Lemmen et al., 2015; Paasch et al., 2015; Stubkjær et al., 2018).

The temporal aspects of valuation are also considered when developing the Turkish Country Profile. As *VM_ValuationSource*, a subclass of *LA_Source*, is not a part of this country profile, real-world time-related issues are modelled at characteristics level. More specifically, five different real-world times are described in the country profile, namely date of revaluation, date of valuation group-based value, date of valuation, date of revaluation rate and date of cost price determination. It can be stated that the country profile provides bi-temporal support since it also includes the system (database) time characteristics. As all the classes of the country profile somehow inherit from *VersionedObject*, they all include begin and end life span characteristics (note that the inherited characteristics are not displayed in Fig. 5).

Once the UML description of the country profile is completed, it is also expressed in CSL of INTERLIS, following a similar development approach to LADM_VM as described in Section 3. Firstly, the INTERLIS descriptions of the data models of the ISO standards (see Fig. 7) that are indispensable for developing the Turkish Country Profile were imported to the INTERLIS/UML-editor. The classes, characteristics and code lists required for the profile were then manually specified in the editor. After that, INTERLIS description of the profile, the INTERLIS (*.ili) file, was exported (Kara et al., 2018d). This INTERLIS file was then used to implement the country profile as presented in the next section. The INTERLIS description (*.ili files) of the LADM _VM and its Turkish Country Profile are presented in Kara et al. (2018d) in detail.

The next section investigates different approaches and tools for the automated conversion from the conceptual country profile to a number of technical models, together with the implementation decision taken and experience gained during the processes.

5. Technical implementation

An application schema (i.e. Turkish LADM_VM country profile) can be realized with various technical (physical) models using different tools, approaches and strategies. In this study, the UML application schema of the country profile is created with Enterprise Architect (EA), which also provides an opportunity to create DLL schema for various relational databases (e.g. PostgreSQL, Oracle, SQL Server, SQLite, Firebird and MySQL). An application schema prepared according to the ISO 19109 – Rules for Application Schema cannot be directly converted into an intended database schema with this software (version 12). Specifically, EA Database Model representation of the intended database

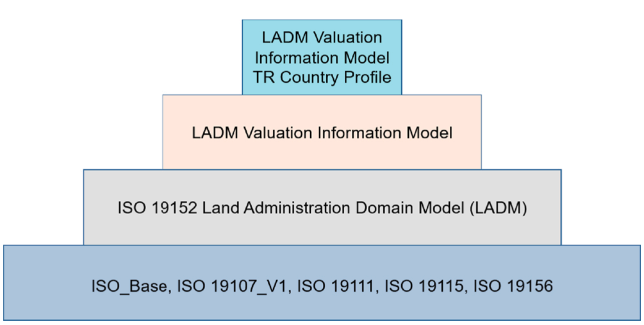

Fig. 7. The INTERLIS models used to describe the LADM Valuation Model and Turkish Country Profile.

schema has to be created for an automatic conversion (Sparx Systems, 2016). In this case, the MDA transformation rules should be specified individually by the user. In other words, corresponding data types and associations defined in the country profile have to be mapped manually with the EA Database Model. For example, the generalization association is not included in the EA Database Model; therefore, a decision should be taken when implementing it. There are a few options to implement the generalization and the remarkable ones for this study are the following: (i) only implement subclass(s) and inherit all characteristics of the superclass to it, (ii) implement both subclass(s) and superclass, and associate them with a foreign key (a foreign key for each subclass(s) or optional foreign key(s) for superclass). The association between the classes *TR_VM_Valuation* and *TR_VM_MassAppraisal* is an example of a generalization in the country profile. As the mentioned classes of the country profile represent separate concepts for the recurrent valuation, the second option is selected in the implementation. It is noted that this choice may change depending on the purpose of the application. On the other hand, since the implementation aims to cover the temporal aspect of recurrent valuation, the system (transaction) time characteristics (e.g. begin and end life span version) that are inherited from the class *VersionedObject* by all classes of the country profile are included in the EA Database Model, together with the valid time characteristics (e.g. date of valuation). Another issue is the code list implementation. For each code list a unique identifier, and begin and end life span characteristics are manually specified in the EA Database Model in order to manage the temporal aspects of values in code lists effectively. After creating the EA Database Model for PostgreSQL/PostGIS, this was used to derive the SQL DLL schema, automatically. All associations and data types including geometry types were properly converted to the PostgreSQL/PostGIS schema using this tool.

ShapeChange is another tool that can be used to automatically derive SQL DDL schema for PostgreSQL/PostGIS as well as other databases (e.g. Oracle, SQLServer, SQLite). One of the advantages of this tool is the ability to derive several technical models from ISO 19109 compliant (and platform-independent) UML application schemas. It can directly access EA UML conceptual models to perform this conversion (Interactive Instruments, 2019). ShapeChange provides an XML-based configuration file (e.g. MDA transformation rules) that can be used to specify the correspondence of each element (classes, data types and association) defined in a conceptual model, instead of defining them manually. In this tool, a number of flattening rules are provided that can be used to implement the generalization association with different options indicated above. As for converting the country profile to the database schema, the standard SQL map entries for PostgreSQL/PostGIS were employed within the configuration file. ShapeChange also provides an opportunity to create an EA database model representation of the schema, together with the database schema (Interactive Instruments, 2019). Similar to EA implementation, a database schema suitable the needs was obtained with this tool.

The INTERLIS tools also provide opportunities to automatically convert INTERLIS data models into several database schemas (e.g. PostgreSQL/PostGIS, Oracle, SQLServer, Geopackage). To derive the database schema from the Turkish Country Profile expressed in CSL of INTERLIS, the structural correctness of it is firstly checked with the INTERLIS Compiler (version 4.7.3). The INTERLIS loader for PostgreSQL/PostGIS (i.e. *ili2pg* version 3.11.1), which has an automated way to deploy mappings from ISO 19109 compliant conceptual models to database schemas, is then employed. Initially, an empty database schema was created in PostgreSQL/PostGIS and then a connection between the database and the loader tool was established. After that, all the required INTERLIS data models (see Fig. 7) were imported to the database one by one, starting from the higher-level models. The loader tool does not provide alternatives for implementing the generalization association and the only option is to create all classes with inherited characteristics automatically. On the other hand, the direct transformation from ISO 19109 compliant conceptual models to database schemas without an extra step, namely without running a SQL DDL script, may be considered as an advantage of the INTERLIS loader tool.

Instead of automatically realizing the country profile with a database schema, a data exchange format can also be derived. A GML encoding is one of the most preferred implementations of geographical data models. In this study, the first tool used to create a GML representation of the country profile is EA software. It should be noted that each class in the country profile was elaborately populated with appropriate tagged values (e.g. namespaces) in order to obtain a proper GML output (Sparx Systems, 2020). The INTERLIS compiler, which has the ability to convert INTERLIS models into a GML schema, was also used to derive the GML schema. The last tool used to derive a GML schema is ShapeChange. Similar to the database schema derivation, it uses EA conceptual model of the country profile and configuration file to make this conversion. This tool is also used to derive GeoJSON representation of the country profile. It was only managed to derive separate JSON files for each class in the profile without any characteristics. Lastly, the UML country profile was automatically converted to a RDF schema with ShapeChange, based on the conversion rules documented in OWS-8 Encoding Rules (Hobona and Brackin, 2011), which was also utilised by van den Brink et al. (2014) to derive RDF/OWL vocabularies. EA also provides the opportunity to convert UML models into RDF but it is not utilized for this purpose within the study.

In the next section, the technical models that were derived in this section are populated with sample dataset and then the populated database is queried in order to assess its operability.

6. Assessment and discussion

One way to evaluate a newly created technical model is to examine it with queries. In order to make an assessment of the operability of Turkish LADM_VM Country Profile, a sample dataset was loaded into the technical models. The PostgreSQL/PostGIS database schema was initially populated with a dataset obtained from the General Directorate of Land Registry and Cadastre (GDLRC) and a dataset derived from a base map. The obtained dataset from GDLRC is collected in the context of the valuation modernization project supported by the World Bank for performing the mass appraisal pilot applications in selected municipalities and preparing the guidelines related to the mass valuation processes (World Bank, 2020). One of the pilot application areas is the Fatih District, İstanbul. Since there is not enough data recorded in the registries to perform a mass valuation, data about randomly selected condominium units in Fatih, were collected within the scope of the modernization project (Yildiz et al., 2015). For the present investigation, a small part of the project area was selected as study area, see Fig. 8. The study area is an old settlement and all its properties are improved properties, namely condominium property (land and improvements as a whole). It covers 59 streets with 4293 parcels and 2040 buildings. The dataset derived from a photogrammetric base map includes building-related characteristics, such as the number of floors and footprint area as well as municipal data such as address, building age and construction materials. The other dataset includes characteristics of condominium units, such as gross floor area and co-ownership shares. However, the data about condominium units are not available for the entire study area. More specifically, the gross floor area and co-ownership shares characteristics are only available for 1351 condominium units located in 125 different buildings in the study area. Fig. 8 shows parcels (light green) and building (green and red) footprints in the study area, visualized with QGIS. The colors of building footprints represent data availability on condominium unit level, specifically no characteristics of condominium units are available for the green ones. For the 1351 condominium units in the study area, the tax values were calculated using the Eq. (2.1) (see Section 4), for the last seven years, namely between 2014 and 2020. Moreover, for all the improved properties (i.e. parcel and building as a whole) in the study area, tax values for the last seven years were calculated using the same equation.

Fig. 8. The selected study area, Fatih District, İstanbul.

In order to convert the datasets into the database, the ETL tool FME was utilized. A connection between FME workspace and the database was initially established. Then its user interface was used to create a mapping from the source datasets to the database schema. After setting up the mappings, all tables were populated with the relevant datasets. This conversion can be also done with other ETL tools. HALE software, for example, was also used for loading the dataset into the database schema and the same result was achieved. The ETL tools can also be utilised to populate data exchange schemas (e.g. GML and GeoJSON) using the features read and write. Both FME and HALE can read and write in GML and GeoJSON formats. In this study, the structured data in the database was utilized as source data and mapping was established between the source data and the generated technical schemas of GML and GeoJSON. It is also possible to convert the populated database into an intended data exchange format using the ETL tools. In the previous section, the country profile was also converted to the RDF schema. However, the RDF schema could not be populated with the datasets as the ETL tools utilized in this study do not provide read and write features for RDF.

Table 2 presents a snippet of the GML (XML) and GeoJSON (JSON) encoding for the class *TR_VM_Valuation*. The snippet includes information on the 2014 tax value of the condominium unit with the identifier, 22597697. It should be emphasized that the valid time (i.e. data of valuation) and transaction (system) time (i.e. begin and end life span version) characteristics indicate the bi-temporal functionality of the technical models. The end life span characteristic was set to last second of 2014, indicating that the tax value of 2014 for the condominium unit cannot be updated after that date.

In order to assess the operability of the implementation of the Turkish LADM_VM Country Profile, SQL queries were performed to the populated database. It should be noted that the height of each storey of the buildings is assumed to be 3 m. Using this assumption and the number of floors above ground level, the building footprints were extruded and recorded into the database to visualize the query results with the buildings in 3D using CesiumJS.

In the first query, it was aimed to assess the associations between the classes *TR_VM_ValuationUnit*, *TR_VM_Building*, *TR_VM_ValuationUnitGroup* and *TR_VM_SpatialUnit*. Buildings that have similar footprint area (between 180 and 200 square meters), date of construction (1970–1980) and number of floors (5-storey) were selected in each streets. Fig. 9 shows the selected 20 buildings with identifiers on them in 20 streets.

The tax values of the improved properties were calculated using the Eq. (2.1) (see Section 4) for the last 7 years and recorded into the database. Using the obtained result from the first query, the time series

Table 2

A snippet of GML (XML) and GeoJSON (JSON) for the class *TR_VM_Valuation*.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<gml:FeatureCollection
xmlns:ladm_vm="http://isoladm.org/gml/ladm_vm">
<gml:featureMember>
<ladm_vm:LADMVM.TR_VM_VALUATION   gml:id="idec853c2f-
c16e-4dac-a40c-4e16b30bc52c">
<ladm_vm:VID>val289</ladm_vm:VID>
<ladm_vm:VUID>22597697</ladm_vm:VUID>
<ladm_vm:ASSESSEDVALUE>66842.7006</ladm_vm:ASSESSEDVA
LUE>
<ladm_vm:DATEOFVALUATION>20140101000000</ladm_vm:DATE
OFVALUATION>
<ladm_vm:VALUETYPE>taxValue</ladm_vm:VALUETYPE>
<ladm_vm:BEGINLIFESPANVERSION>20140115105217</ladm_vm
:BEGINLIFESPANVERSION>
<ladm_vm:ENDLIFESPANVERSION>20141231235959</ladm_vm:E
NDLIFESPANVERSION>
</ladm_vm:LADMVALTR.TR_VALUATION>
</gml:featureMember>
```

```json
{
   "type" : "FeatureCollection",
   "geometry" : null,
   "name" : "LADMVM.TR_VM_VALUATION",
   "features" : [
      {
         "type" : "Feature",
         "properties" : {
            "VID" : "val289",
            "VUID" : "22597697",
            "ASSESSEDVALUE" : 66842.7006,
            "DATEOFVALUATION" : "20140101000000",
            "VALUETYPE" : "taxValue",
            "BEGINLIFESPANVERSION"                :
"20140115105217",
            "ENDLIFESPANVERSION"                  :
"20141231235959"
                              }
                  }
```


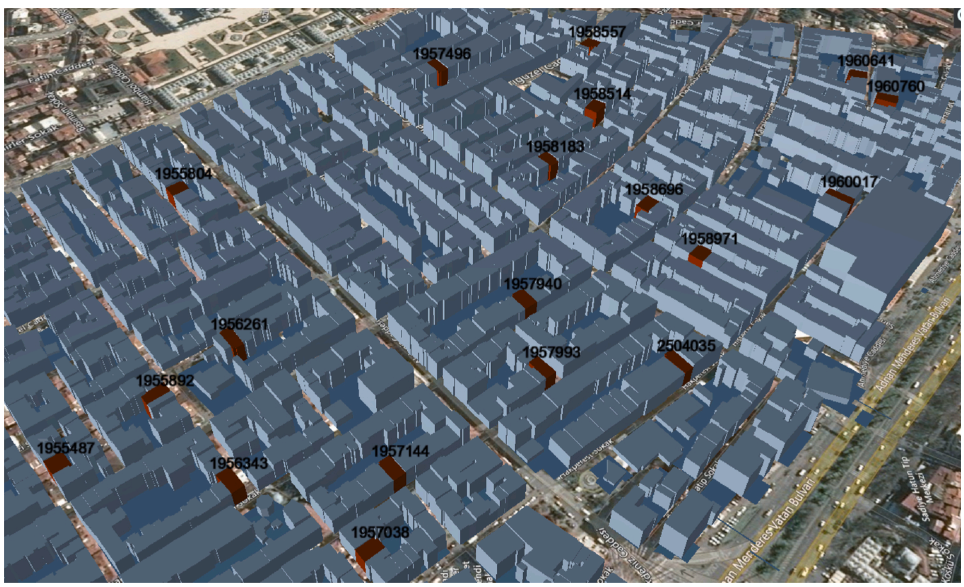

Fig. 9. The buildings that have similar characteristics in the study area.

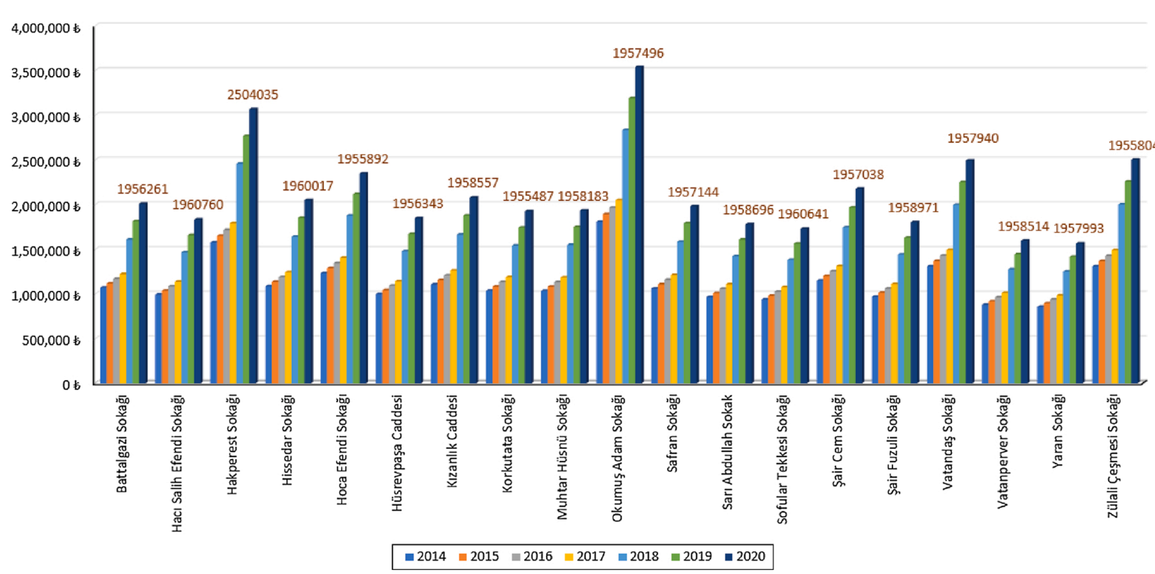

Fig. 10. The time series of the tax values of the improved properties with similar characteristics in different streets.

of tax values of the selected improved properties were calculated for 7 years, see Fig. 10. It can be stated that the difference in tax values of the selected improved properties are mostly originated from the parcel area and the street-level parcel values as the buildings share almost the same characteristics.

Fig. 11 shows the buildings colored according to the 2020 tax values of improved properties. The calculated tax values vary between 134,000 and 48,988,000 TRY, and 99 % of the tax values are between 200,000 and 16,000,000 TRY. The last query conducted is based on the 1351 condominium units recorded in the database, aiming to select the building that includes the highest valued condominium property in 2020. In Fig. 11, the building marked with a green circle contains the condominium unit with the highest tax value in the study area.

As indicated in Section 4, the street-level parcel unit values are only reassessed once every four years (e.g. 2014, 2018), and the determined values are updated by the half of the revaluation rate between the assessment periods. The database implementation includes the street-based parcel unit values (*TR_VM_ValuationUnitGroup* and *TR_VM_MassAppraisal*) for the last 7 years, those are used to calculate the rate of increase in tax values of parcel unit values from 2014 to 2018 for 59 streets. The results are rather interesting since 51 of 59 streets in the study share the same increase rate of 1,69. This may be considered as normal, as the Fatih District is an old settlement. On the other hand, it can be indicated that the local valuation commission mostly applies the highest rate allowed by the regulations in most streets. This may imply that the recurrent property valuation system needs to be modernized.

As for deriving technical models automatically, it may be indicated that ShapeChange has superiorities over utilised other tools. It provides well documented, XML-based and UML application schema independent configuration files for conversion to a wide variety of technical models. Moreover, it provides various options for different implementation strategies. For example, a relation (associative) table can be created for representing many-to-many multiplicity. Furthermore, it covers all options for the implementation of generalization association. These makes the tool more compatible for deriving technical models using different approaches.

7. Conclusion and future work

Property valuation is related to several processes in LA, and effective and efficient information management systems is required for fair, equitable, timely and sustainable valuations. The use of an appropriate system for managing and analyzing property valuation information should lead to improvements in the levels of performance and service provided by relevant authorities, particularly with regard to the accuracy and speed with which valuations can be undertaken (cf. United Nations Economic Commission for Europe (UNECE, 1996).

In this paper, the LADM_VM, which provides a common basis to develop a holistic management system for property valuation information, is firstly introduced. The LADM_VM can be implemented for several purposes, namely recording input and output data in valuation processes carried out for different purposes, assessing changes in transaction prices and values, and sharing and exchanging valuation information. In order to prove that a LAS developed based on LADM_VM works effectively for managing property valuation information maintained by public authorities, an approach is described that covers the conceptual modelling of recurrent valuations in Turkey and the implementation of this conceptual model (i.e. country profile) with several technical models, and populating and querying the database.

The use of existing standards and a shared terminology minimizes the interoperability problem between systems and organizations and increases the quality of communication between users. As the ISO 19152 LADM provides a solid base for extension with property valuation processes, the LADM was used as the basis for developing LADM_VM. Similar to LADM, the implementation of LADM_VM requires a country profile. In this study, the methodologies for developing a country profile were therefore investigated and the obtained results applied to a Turkish LADM_VM Country Profile about the recurrent property valuations conducted by local authorities. To develop the country profile, the regulations related to recurrent valuations were examined, and the required characteristics were determined. The LADM_VM was extended with a few new characteristics (e.g. street-level parcel value) and code lists (e.g. building quality type) to cover all country-specific situations. No new concept (e.g. feature class) was added to the LADM_VM to develop the country profile, therefore it could be stated that the LADM_VM proposal is almost complete for representing recurrent valuations in Turkey. On the other hand, it should be indicated that an updated or a second country profile might be needed in future, as there is an ongoing modernization project for the application of mass appraisal in Turkey.

The country profile was expressed in both CSL of UML and INTERLIS as they provide different advantages in technical implementation. As UML is a long accepted language and used in several applications, the tools that are used to convert a UML conceptual model into a technical model are steadier and more user-friendly. On the other hand, INTERLIS tools form an integrated environment covering the whole implementation process that can be considered as the main advantage of INTERLIS. According to the requirements of an application, a different technical implementation approach may be preferred. This study examined approaches for implementing the generalization association and adopted one of the approaches suitable to the application needs. Furthermore, different technical models (PostgreSQL/PostGIS, GML, GeoJSON) were derived from the country profile. These implementations can be utilized by different applications, for example, a JSON implementation of the

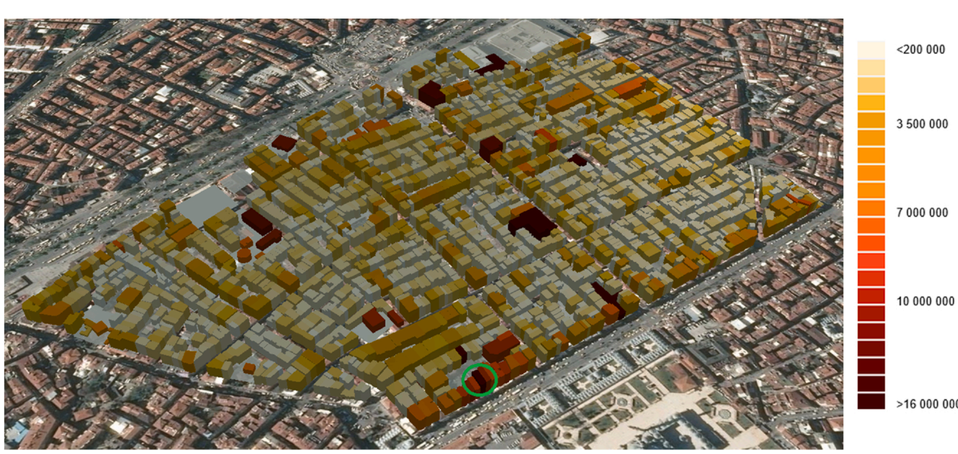

Fig. 11. The buildings colored according to 2020 tax values of improved properties.

profile can be directly consumed by web-based applications, while GML can be used in data exchange between property valuation related organizations.

In this study, a real database implementation was used to assess the operability of the technical implementation of the country profile based on a series of queries. The overall assessment of the database implementation performance is satisfactory and encouraging. Considering the assessment, it can be concluded that both the LADM_VM as well as its Turkish Country Profile can be considered feasible in terms of managing and querying property valuation-related information. On the other hand, different aspects of LADM_VM should be further tested in future implementations. For example, the mass valuation part of the model should be evaluated with a comprehensive and detailed dataset including mass appraisal performance indicators. The coverage of the model is not limited to valuations, also transaction prices and sales statistics can be represented with it. A future implementation of the LADM_VM can include sales statistics using time series of transaction prices. The bi-temporal aspect of property valuation processes is also introduced in this paper and it is demonstrated that the concept of bi-temporal data management is critical for the management of property valuation information. This requires further investigations on the applicability of a tri-temporal modelling approach to LADM_VM. Additionally, the advantages of implementing and/or integrating LADM_VM with different models (e.g. CityGML, LandInfra/InfraGML, BIM) should be further researched. Lastly, the possibilities of creating a 3D visualization and dissemination prototype in condominium unit level for the valuation information represented in LADM_VM should be examined, in the context of more transparent and trusted property valuation system.

CRediT authorship contribution statement

Abdullah Kara: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Volkan Çağdaş:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Umit Isikdag:** Methodology, Writing - original draft, Writing - review & editing. **Peter van Oosterom:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Christiaan Lemmen:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Erik Stubkjaer:** Methodology, Writing - original draft, Writing - review & editing.

References

Alattas, A., van Oosterom, P., Zlatanova, S., Diakite, A.A., Yan, J., van Oosterom, P., Dubbeling, D., 2018. Developing a database for the LADM-IndoorGML model. In: Proceedings of the 7th International FIG Workshop on the Land Administration Domain Model. Delft, The Netherlands, 2–4 October.

Andrade, A.J., Carneiro, A.F., Santos, J.C., 2013. LADM specification of a relational database for the republic of Cape Verde. In: Proceedings of the 5th Land Administration Domain Model Workshop, 24–25 September. Kuala Lumpur, Malaysia.

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S., Ngo, T., 2017. Building information modelling for high-rise land administration. Trans. GIS 21 (1), 91–113.

Budisusanto, Y., Aditya, T., Muryamto, R., 2013. LADM implementation prototype for 3D cadastre information system of multi-level apartment in Indonesia. In: Proceedings of the 5th Land Administration Domain Model Workshop, 24–25 September. Kuala Lumpur, Malaysia.

Bydłosz, J., 2015. The application of the Land Administration Domain Model in building a country profile for the Polish cadastre. Land Use Policy 49, 598–605.

Çağdaş, V., 2013. An application domain extension to CityGML for immovable property taxation: a Turkish case study. Int. J. Appl. Earth Obs. Geoinf. 21, 545–555.

Çağdaş, V., Kara, A., Van Oosterom, P., Lemmen, C., Işıkdağ, Ü., Kathmann, R., Stubkjær, E., 2016. An initial design of ISO 19152: 2012 LADM based valuation and taxation data model. ISPRS J. Photogramm. Remote Sens. 4, 145–154.

Çağdaş, V., Kara, A., Işıkdağ, Ü., Van Oosterom, P.J.M., Lemmen, C., Stubkjær, E., 2017. A Knowledge Organization System for the Development of an ISO 19152: 2012 LADM Valuation Module. FIG Working Week 2017, Surveying the World of Tomorrow - From Digitalisation to Augmented Reality. Helsinki, Finland, May 29–June 2, 2017.

Committee on World Food Security (CFS), and Food and Agriculture Organization of the United Nations (FAO), 2012. Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (VGGT), Rome. ISBN 978-92-5-107277-6.

Enemark, S., 2005. Understanding the land management paradigm. In: FIG Commission 7 Symposium on Innovative Technologies for Land Administration, 19–25 June. Madison, Wisconsin, USA.

Eriksson, H., Harrie, L., Paasch, J.M., Persson, A., 2018. Techniques for and consequences of using INSPIRE extensions: a case study with Swedish hydrological data. Int. J. Spat. Data Infrastruct. Res. 13, 172–201.

European Group of Valuers' Associations (TEGoVA), 2016. European Valuation Standards (EVS), Gillis: Belgium, 8th edition. ISBN 978-90-819060-819061-2. Available online: https://www.tegova.org/data/bin/a5738793c0c61b_EVS_2016.pdf, Last accessed 15 May 2020.

FIG, the 7th Land Administration Domain Model Workshop, 2018. Working Session Group 2: Technical models/encodings. The LADM 2018 Workshop, Zagreb, Croatia, 11-13 April. Available online: https://wiki.tudelft.nl/pub/Research/ISO19152/LADM2018Workshop/pres_22b.pdf, Last accessed 15 May 2020.

GDAL/OGR, 2020. GDAL/OGR Geospatial Data Abstraction Software Library. Open Source Geospatial Foundation. URL https://gdal.org, Last accessed 15 May 2020.

Germann, M., Kaufmann, J., Steudler, D., Lemmen, C., Van Oosterom, P., De Zeeuw, K., 2015. The LADM based on INTERLIS. Proceedings of the FIG Working Week 2015 from the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17–21 May.

Germann, M., Lüthy, J., van Oosterom, P., Dubbeling, D., 2018. INTERLIS 3 developments with 3D data types and better constraint support for 3D Cadastres. In: Proceedings of the 6th International FIG 3D Cadastre Workshop. Delft, The Netherlands, 2-4 October.

Govedarica, M., Radulović, A., Sladić, D., Popović, D., 2018. LADM – experiences and challenges in implementation. In: Proceedings of the 7th International FIG Workshop on the Land Administration Domain Model. Delft, The Netherlands, 2–4 October.

Góźdź, K., Pachelski, W., Van Oosterom, P., Coors, V., 2014. The possibilities of using CityGML for 3D representation of buildings in the cadastre. In: 4th International Workshop "3D Cadastres". Dubai, United Arab Emirates, 9–11 November.

Hespanha, J.P., 2012. Development Methodology for an Integrated Legal Cadastre. Ph.D. Thesis. Delft University of Technology, Deft, The Netherlands.

Hespanha, J., van Bennekom-Minnema, J., van Oosterom, P., Lemmen, C., 2008. The model driven architecture approach applied to the Land administration domain model version 1.1 - with focus on constraints specified in the object constraint language. In: Proceedings of the Integrating Generations, FIG Working Week. Stockholm, Sweden, 14–19 June.

Hobona, G., Brackin, R., 2011. Open Geospatial Consortium (OGC) OWS-8 Cross Community Interoperability (CCI) Semantic Mediation Engineering Report. OGC 11-063r6, 11-23. URL: https://portal.opengeospatial.org/files/?artifact_id=46342, Last access: 15.05.2020.

INSPIRE, 2020. Infrastructure for Spatial Information in Europe (INSPIRE) Data Specifications. https://inspire.ec.europa.eu/Themes/Data-Specifications/2892.

Interactive Instruments, 2019. Shapechange. Last Accessed 15 May 2020. https://shapechange.net/.

INTERLIS, 2016. eCH-0031, Swiss E-Government Standards, INTERLIS 2.4 Reference Manual. Available online: https://www.ech.ch/vechweb/page?p=dossier&documentNumber=eCH0031&documentVersion=2.0, Last accessed 15 May 2020.

International Association of Assessing Officers (IAAO), 2013. Standard on Mass Appraisal of Real Property, Kansas City, Missouri, Approved April. ISBN 978-0-88329-207-5; Available online: https://www.iaao.org/media/standards/MARP_2013.pdf, Last Accessed 15 May 2020.

International Association of Assessing Officers (IAAO), 2014. Guidance on International Mass Appraisal and Related Tax Policy, Kansas City, Missouri, Approved January. ISBN 978-0-88329-213-6, Available online. https://www.iaao.org/media/Standards/International_Guidance.pdf.

International Association of Assessing Officers (IAAO), 2017. Mass Appraisal of Real Property, Kansas City, Missouri, Approved July. Available online: https://www.iaao.org/media/standards/MARP_2013.pdf, Last Accessed 15 May 2020.

International Association of Assessing Officers (IAAO), 2018. Standard on Automated Valuation Models (AVMs), Kansas City, Missouri, Approved July. Available online: https://www.iaao.org/media/standards/AVM_STANDARD_2018.pdf, Last Accessed 15 May 2020.

International Organization for Standardization, 2011. ISO 19118, Geographic Information – Encoding, Ed. 2 (ISO 19118:2011). Available online. ISO, Geneva, Switzerland. https://www.iso.org/standard/44212.html.

International Organization for Standardization (ISO), 2012. ISO 19152, Geographic Information–Land Administration Domain Model (LADM), 1st ed. ISO, Geneva, Switzerland.

International Organization for Standardization (ISO), 2017. ISO 9836:2017 Performance Standards in Building—Definition and Calculation of Area and Space Indicators. Available online. https://www.iso.org/standard/73149.html.

International Property Measurement Standards (IPMS), 2014. International Property Measurement Standards: Office Buildings. ISBN 978-1-78321-062-6, Available online: https://fastedit.files.wordpress.com/2014/11/ipms-office-buildings-november-20141.pdf, Last Accessed 15 May 2020.

International Property Measurement Standards (IPMS), 2016. International Property Measurement Standards: IPMS Residential Buildings. ISBN 978-1-78321-166-1, Available online: https://fastedit.files.wordpress.com/2016/09/ipms-residential-buildings-sept-2016.pdf, Last Accessed 15 May 2020.

International Valuation Standards Council (IVSC), 2017. International Valuation Standards (IVS), London, United Kingdom. ISBN 978-0-9931513-0-9.

Isikdag, U., Horhammer, M., Zlatanova, S., Kathmann, R., van Oosterom, P., 2014. Semantically rich 3D building and cadastral models for valuation. In: Proceedings of the 4th International Workshop on 3D Cadastres, 9–11 November. Dubai, United Arab Emirates.

Isikdag, U., Horhammer, M., Zlatanova, S., Kathmann, R., van Oosterom, P., 2015. Utilizing 3D building and 3D cadastre geometries for better valuation of existing real estate. Proceedings of the FIG Working Week 2015, From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17–21 May.

Janečka, K., Souček, P., 2017. A country profile of the Czech Republic based on an LADM for the development of a 3D cadastre. ISPRS Int. J. Geoinf. 6 (5), 143.

Janečka, K., Bydłosz, J., Radulović, A., Vučić, N., Sladić, D., Govedarica, M., 2018. Lessons learned from the creation of the LADM based country profiles. In: Proceedings of the 7th International FIG Workshop on the Land Administration Domain Model. Delft, The Netherlands, 2–4 October.

Jenni, L., Germann, M., Eisenhut, C., Guarín, L.A., Bajo, M., 2017. LADM implementation in Colombia- process, methodology and tools developed and applied. In: Proceedings of the FIG Working Week 2017, Surveying the World of Tomorrow - From Digitalisation to Augmented Reality. Helsinki, Finland, May 29–June 2.

Kalantari, M., Kalogianni, E., 2018. Towards LADM Victoria country profile – modelling the spatial information. In: Proceedings of the 6th International FIG 3D Cadastre Workshop. Delft, The Netherlands, 2–4 October.

Kalantari, M., Dinsmore, K., Urban-Karr, J., Rajabifard, A., 2015. A roadmap to adopt the Land Administration Domain Model in cadastral information systems. Land Use Policy 49, 552–564.

Kalogianni, E., Dimopoulou, E., Quak, W., Germann, M., Jenni, L., van Oosterom, P., 2017. INTERLIS Language for Modelling Legal 3D Spaces and Physical 3D Objects by Including Formalized Implementable Constraints and Meaningful Code Lists. ISPRS International Journal of Geo-Information 6 (10). https://doi.org/10.3390/ijgi6100319.

Kalogianni, E., Kalantari, M., Dimopoulou, E., van Oosterom, P., 2019. LADM country profiles development: aspects to be reflected and considered. In: Proceedings of the 8th International FIG Workshop on the Land Administration Domain Model, 1–3 October. Kuala Lumpur, Malaysia. ISBN 978-87-92853-92-99.

Kara, A., Çağdaş, V., Isikdag, U., van Oosterom, P., Lemmen, C., Stubkjær, E., 2017. Towards an international data standard for immovable property valuation. FIG Working Week 2017, Surveying the World of Tomorrow - From Digitalisation to Augmented Reality. Helsinki, Finland, May 29–June 2.

Kara, A., Çağdaş, V., Işıkdağ, Ü., van Oosterom, P.J.M., Lemmen, C.H.J., Stubkjær, E., 2018a. Towards Turkish LADM valuation information model country profile. XXVI FIG Congress 2018: Embracing Our Smart World Where the Continents Connect: Enhancing the Geospatial Maturity of Societies.

Kara, A., Çağdaş, V., Lemmen, C., Işikdağ, Ü., van Oosterom, P., Stubkjær, E., 2018b. Supporting fiscal aspect of land administration through a LADM-based valuation information model. In: 19th Annual World Bank Conference on Land and Poverty Proceedings: Land Governance in an Interconnected World, March, 2018. Washington, USA.

Kara, A., Işıkdağ, Ü., Çağdaş, V., van Oosterom, P., Lemmen, C., Stubkjær, E., 2018c. A database implementation of LADM valuation information model in Turkish case study. In: Proceedings of the 7th International FIG Workshop on the Land Administration Domain Model. Delft, The Netherlands, 2–4 October 2018.

Kara, A., Çağdaş, V., Işıkdağ, Ü., van Oosterom, P., Lemmen, C., Stubkjær, E., 2018d. The LADM valuation information model based on INTERLIS. In: Proceedings of the 7th International FIG Workshop on the Land Administration Domain Model. Delft, The Netherlands, 2–4 October 2018.

Kara, A., van Oosterom, P., Çağdaş, V., Işıkdağ, Ü., Lemmen, C., 2020. 3 Dimensional data research for property valuation in the context of the LADM Valuation Information Model. Land Use Policy, 104179.

Kobasa, M., Shavrov, S., Batura, O., 2018. ISO19152 standard: role of LA_ExtValuation class for land administration. FIG Congress 2018, Embracing Our Smart World Where the Continents Connect: Enhancing the Geospatial Maturity of Societies, Istanbul, Turkey, May 6–11.

Kuria, D., Ngigi, M., Gikwa, C., Mundia, C., Macharia, M., 2016. A web-based pilot implementation of the africanized land administration domain model for Kenya—a case study of Nyeri County. J. Geogr. Inf. Syst. 8, 171–183.

Kutzner, T., Chaturvedi, K., Kolbe, T.H., 2020. CityGML 3.0: New Functions Open Up New Applications. PFG. https://doi.org/10.1007/s41064-020-00095-z.

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

Lemmen, C., van Oosterom, P., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., Alattas, A., 2019. The scope of LADM revision is shaping-up. In: Proceedings of the 8th International FIG Workshop on the Land Administration Domain Model, 1-3 October. Kuala Lumpur, Malaysia.

Open Geospatial Consortium (OGC), 2016. Land and Infrastructure Conceptual Model Standard (LandInfra), Version 1.0, Publication Date: 2016-12-20, Editor: Paul Scarponcini, Contributors: Hans Christoph Gruler (Survey), Erik Stubkjær (Land), Peter Axelsson, Lars Wikstrom (Rail). Available online: http://docs.opengeospatial.org/is/15-111r1/15-111r1.html, Last Accessed 15 May 2020.

Open Geospatial Consortium (OGC), 2019. OGC White paper on land administration. Editor: Christiaan Lemmen, Peter van Oosterom, Mohsen Kalantari, Eva-Maria Unger and Cornelis de Zeeuw. Available online: http://docs.opengeospatial.org/wp/18-008r1/18-008r1.html#_extended_scope_of_conceptual_model, Last Accessed 15 May 2020.

Paasch, J.M., van Oosterom, P., Lemmen, C., Paulsson, J., 2015. Further modelling of LADM's rights, restrictions and responsibilities (RRRs). Land Use Policy 49, 680–689.

Psomadaki, S., Dimopoulou, E., van Oosterom, P., 2016. Model driven architecture engineered land administration in conformance with international standards – illustrated with the Hellenic Cadastre. Open Geospatial Data, Software and Standards 1. https://doi.org/10.1186/s40965-016-0002-3.

Rajabifard, A., Agunbiade, A., Kalantari, M., Yip, K.M., Atazadeh, B., Badiee, F., Isa, D.M.N., Adimin, M.K., Chan, K.L., Aien, A., Olfat, H., Shojaei, D., Anaraki, M.R., 2018. An LADM-based approach for developing and implementing a national 3D cadastre – a case study of Malaysia. In: Proceedings of the 7th International FIG Workshop on the Land Administration Domain Model. Zagreb, Croatia, 11–13 April.

Revenue Administration (RA), 2019. Emlak Vergisi Kanunu Genel Tebliğleri. Available online: https://www.gib.gov.tr/en/emlak-vergisi-kanunu-genel-tebligleri, Last access: 15.05.2020..

Royal Institution of Chartered Surveyors (RICS), 2018. RICS Property Measurement, Professional Statement, Global, 2nd edition. Standard, London, UK, Available online: https://www.rics.org/north-america/upholding-professional-standards/sector-standards/real-estate/rics-property-measurement-2nd-edition/, Last accessed 15 May 2020.

Sparx Systems, 2016. Database Models. Available online: https://www.sparxsystems.fr/resources/user-guides/model-domains/database-models.pdf, Last accessed 15 May 2020.

Sparx Systems, 2020. Enterprise Architect. Available online: http://www.sparxsystems.com/, Last accessed 15 May 2020.

Tang, B., Wong, S., Liu, S., 2011. Institutions, property taxation and local government finance in China. Urban Stud. 48 (5), 847–875.

Thompson, R., van Oosterom, P., 2019. A suggested terminology for point-like entities in a bi-temporal representation of 2D and 3D land administration. In: 8th International FIG Workshop on the Land Administration Domain Model, 1–3 October. Kuala Lumpur, Malaysia.

United Nations (UN), 2016. New Urban Agenda. Endorsed by the United Nations General Assembly at its Sixty-Eighth Plenary Meeting of the Seventy-First Session on 23 December. ISBN: 978-92-1-132731-1.

United Nations Economic Commission for Europe (UNECE), 1996. Land Administration Guidelines: With Special Reference to Countries in Transition. United Nations, New York and Geneva. ISBN 92-1-116644-116646.

United Nations Global Geospatial Informaton Management (UN-GGIM), 2018. Determination of Global Fundamental Geospatial Data Themes. Committee of Experts on Global Geospatial Information Management, E/C.20/2018/7/Add.1. Available online: http://ggim.un.org/meetings/GGIM-committee/8th-Session/documents/E-C20-2018-7-Add_1-Global-fundamental-geospatial-data-themes.pdf, Last accessed 15 May 2020.

Van Bennekom-Minnema, J., 2008. The Land Administration Domain Model "Survey Package" and Model Driven Architecture, Joint Programme in Geographical Information Management and Applications. Master's Thesis. Utrecht University, Utrecht, The Netherlands, University of Twente/ITC Enschede, Enschede, The Netherlands, TU Delft, Deft, The Netherlands, Wageningen University, Wageningen, The Netherlands.

Van den Brink, L., Janssen, P., Quak, W., Stoter, J., 2014. Linking spatial data: automated conversion of geo-information models and GML data to RDF. Int. J. Spat. Data Infrastruct. Res. 9, 59–85.

Van Oosterom, P., Lemmen, C., 2015. The land administration domain model (LADM): motivation, standardisation, application and further development. Land Use Policy 49, 527–534.

Van Oosterom, P., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., Alattas, A., Lemmen, C., 2019. Joint ISO/TC211 and OGC revision of the LADM: valuation information, spatial planning information, SDG land indicators, refined survey model, links to BIM, support of LA processes, technical encodings, and much more on their way. In: Proceedings of the FIG Working Week 2019, Geospatial Information for a Smarter Life and Environmental Resilience. Hanoi, Vietnam, April 22–26.

Wetransform, 2020. The HUMBOLDT Alignment Editor (HALE). Available online: https://www.wetransform.to/products/halestudio/, Last accessed 15 May 2020.

World Bank, 2020. Land Registration and Cadastre Modernization Project. Available online: https://projects.worldbank.org/en/projects-operations/project-detail/P106284, Last accessed 15 May 2020.

Wyatt, P., 2013. Property Valuation, 2nd ed. John Wiley & Sons, New York City, United States. ISBN: 978-1-119-96865-96868.

Yan, Y., Soon, K.H., Jaw, S.W., Schrotter, G., 2019. An LADM-based 3D underground utility data model: a case study of Singapore. In: Proceedings of the 8th International FIG Workshop on the Land Administration Domain Model. Kuala Lumpur, Malaysia, 1–3 October.

Yildiz, Ü., Güneş, T., Eser, Ö., Yildirim, S., Buçan, N., Güzel, G., Uzer, E., 2015. Mass Valuation Activities Conducted by General Directorate of Land Registry and Cadastre in Turkey. FIG Working Week, Sofia, Bulgaria, pp. 17–21.

Zulkifli, N.A., Rahman, A.A., Jamil, H., Hua, T.C., 2014. Development of a prototype for the assessment of the Malaysian LADM Country profile. In: Proceedings of the FIG Congress 2014, Engaging the Challenges – Enhancing the Relevance. Kuala Lumpur, Malaysia, 16–21 June.

Zulkifli, N.A., Rahman, A.A., Siew, C.B., 2019. Database design and development of 3D cadastral registration based on LADM. In: Proceedings of the 8th International FIG Workshop on the Land Administration Domain Model. Kuala Lumpur, Malaysia, 1–3 October.