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Design of the new structure and capabilities of LADM edition II including 3D aspects

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ABSTRACT

The decision to refine the existing content and to extend the scope of Edition I of the ISO 19152:2012 Land Administration Domain Model (LADM) is a response to requests from the international Land Administration (LA) community. This response has to be formally organised in accordance with ISO guidelines. This begins with gathering feedback from ISO/TC 211 Member States on the need for updated and enhanced capabilities of the LADM. In addition, several proposals have been made to extend the scope of the LADM Edition I. After analysing the feedback received, it was proposed to develop the LADM Edition II as a multi-part standard: Part 1 — Generic conceptual model, Part 2 — Land registration, Part 3 — Marine georegulation, Part 4 — Valuation information, Part 5 — Spatial plan information and Part 6 — Implementation aspects. In other words, Edition I focuses on land tenure, while the design and development of Edition II is based on the inclusion of rights, restrictions and responsibilities (RRRs) concerning marine georegulation, valuation information, spatial plan information as well as LADM implementation. 3D representations are relevant for all parts.

This paper focuses on the design of the new structure of the second edition of the LADM and on the (operational) capabilities of this new edition in relation to the LA issues in Parts (standards addressing a specific part of the scope) and Packages (groups of conceptually close classes), with a particular attention to the requirements and design related decisions taken in the revision process. The parts 1, 2, 4 and 5 are the parts in which the authors are currently involved. Part 1 will be a high-level umbrella standard; Part 2 is largely based on LADM Edition I and focuses on land registration, with an enhanced support on the surveying functionality, including new subclasses of spatial unit, and extended 3D spatial profiles. Part 3 harmonises the description of RRRs and aligns land concepts with marine aspects from the marine domain based on the International Hydrographic Organisation (IHO) S121 Maritime Limits and Boundaries Product Specification. Part 4 deals with valuation information used and produced in the context of land administration, while Part 5 deals with spatial planning information and includes the planned use of the land (zoning), resulting in RRRs. Lastly, Part 6 is planned to be about implementation of the LADM and will be developed in close collaboration with the Open Geospatial Consortium (OGC).

1. Introduction

The Land Administration Domain Model (LADM) provides a shared ontology, defining a common terminology for Land Administration (LA) (Lemmen et al., 2015). The Edition I includes both support for 3D representations of spatial units and a seamless integration of 2D and 3D spatial units (Lemmen et al., 2010).

The Land Administration Guidelines by the United Nations Economic Commission for Europe (UNECE) include a widely accepted definition of land administration: "*the processes of recording and disseminating information about the ownership, value and use of land and its associated resources*" (UNECE, 1996). Based on this definition the LADM standard defines land administration as the "*process of determining, recording and disseminating information about the relation between people and land*". Land

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is defined in the LADM Edition II as the "*spatial extent to be covered by rights, restrictions and responsibilities and encompass the wet and dry parts of the Earth surface, including all space above and below*". Inclusion of the marine georegulation, land value information, as well as spatial plan information is well aligned to those definitions. From these definitions it can be seen that LA is a broad field with several functions, as introduced by Enemark (2006). In all these extensions the 3D representations play an important role.

The development of the LADM Edition I (ISO, 2012) was proposed by the International Federation of Surveyors (FIG) (Lemmen, 2012). The LADM and the Social Tenure Domain Model (STDM), a specialisation of the LADM (Augustinus et al., 2006; Augustinus, 2010; Lemmen, 2010), are currently under implementation in several countries around the world, see FIG (2017, 2018a, 2019, 2021a, 2022), Kalogianni et al. (2021), (Lemmen et al., 2020). Kalogianni et al. (2021) provides an overview of around fifty LADM-based country profiles, developed for various purposes from different parties (academia, governmental organisations, etc.). From those, approximately ten are under production, where most of the times with participation from the industry. Examples where LADM is the foundation for software development can be found in Land Equity International/Millenium Challenge Cooperation (LEI/MCC, 2020), (see also Lemmen, 2012), Morales et al. (2021), Govedarica et al. (2021) and Smyth (2021). Lastly, the LADM provides a wider context for the 'INSPIRE Cadastral Parcels' Data Specification (INSPIRE, 2014), playing a strong role on the standardisation, also at European level.

The 3D capabilities of LADM have been used in many projects, from visualising and querying 3D properties through a 3D platform, to BIM-based applications for 3D LA and 3D property valuation (Ying et al., 2011; Karki et al., 2011; Jeong et al., 2012; Felus et al., 2014; Zulkifli et al., 2015; Dimopoulou et al., 2017; Shnaidman et al., 2019b; Kalogianni et al., 2020b and 2020c, Alattas et al., 2021). Fig. 1 shows a web-based 3D cadastral prototype developed by Cemellini et al. (2020).

The LADM and the Social Tenure Domain Model (STDM) are applicable in relation to the implementation of relevant parts of international guiding documents such as the New Urban Agenda (UN, 2017), the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security from the Food and Agriculture Organisation of the United Nations (FAO) (FAO, 2012), the Continuum of Land Rights (UN-HABITAT, 2008; Teo and Lemmen, 2013), the Fit-For-Purpose Land Administration: Guiding principles for country implementation (UN-Habitat/GLTN/Kadaster, 2016; FIG/World Bank, 2014) and the Framework for Effective Land Administration: A reference for developing, reforming, renewing, strengthening, modernising, and monitoring land administration from the Expert Group on Land Administration and Management of the UN-GGIM (UN-GGIM, 2020). All of these fit well into the context of the implementation of the Sustainable Development Goals (SDGs). It is noted that there are nine strategic pathways identified in United Nations Integrated Geospatial Information Framework (UN-IGIF). Standardisation is one the identified pathways which clearly means that standardisation is a trend not a hype (UN-IGIF, 2023). Also, other United Nations and World Bank organisations support the use of standards.

The decision to enhance the current content and to extend the scope of LADM Edition I is in response to requests from the international LA community, see Section 2. In this sense, feedback from experts has been provided and having analysed it, several questions have arisen: How can the current content of LADM Edition I be refined? What capabilities can be included in Edition II? What are the requirements that should be included in Edition II? How can the structure of Edition II be optimised?

This paper focuses on the requirements and the structure of the second edition of the standard and its operational capabilities in Parts 1, 2, 4 and 5 (where the authors are involved), while also providing insight into the decisions taken during the revision process. The purpose of this paper is not to provide a literature review on LA, 3D cadastre or LADM, which may have prompted the LA community to request a revision and extension of LADM. It is to present how LADM Edition II is being designed, refined and improved. Therefore, the scope of this paper is limited to the revision of LADM Edition II. On the other hand, it is worth noting that the following references to 3D cadastre and LA have most likely been taken into account in the development of LADM Edition II: 3D Cadastre special issues in Computers, Environment and Urban Systems (Van Oosterom, 2013) and Land Use Policy (Van Oosterom et al., 2020); Fig. 3D Cadastre Best Practices (FIG, 2018b), Fig. 3D Cadastre Workshops (FIG, 2014, 2016, 2018c, 2021b) and so on.

This contribution to the Article Collection on the Special Issue '3D Land Administration' aims to report the current stage of the LADM revision. To mention the topics that are out of the scope of this paper; Part 6 refers to the implementation aspects as it is currently in its early stage of development. In parallel, Part 3, which refers directly to the International Hydrographic Organisation (IHO) S-100 Universal Hydrographic Data Model and S-121 Maritime Limits and Boundaries product specification (IHO, 2019), is not included in this paper. See Beaupré et al. (2022) for an overview of the adaptation of the ISO 19152 data model during the development of this specification.

The remainder of the paper is organised as follows: First, background information and the methodology followed are presented in Section 2. The proposed requirements and package structure of LADM Edition II are presented in Section 3. The developments and associated discussions of the four parts of Edition II (Part 1, 2, 4 and 5) are then presented in Sections 4–7. Finally, conclusions are presented in the last section.

2. Background and methodology

Although the LADM Edition I is extensively used (Kalogianni et al., 2021) and is applicable for various use cases and purposes, ISO rules prescribe periodic review. This starts by the collection of responses from ISO/TC 211 Member States concerning the needs for updated and extended capabilities of the standard. During the meeting of the UN-GGIM Expert Group on Land Administration and Management that was held in 2017, in Delft, The Netherlands, it was concluded that a revision of the LADM Edition I is required in order to provide better tools in support to tenure security with better coverage of LA. As a result of the voting on the systematic review of ISO 19152:2012 (March 2018) it became clear that the majority of the ISO/TC 211 P-members expressed their wish for the revision. Therefore, the ISO Stage 0 project started in May 2018 during the 46th Plenary Meeting Week of ISO/TC 211 in Copenhagen, Denmark.

In order to revise LADM Edition I, several FIG LADM Workshops were organised,[1] where options for improvement and extensions were discussed among experts; see further inputs (needs) for Edition II in FIG (2018b), (Lemmen et al., 2019), (Lemmen et al., 2020) and (Lemmen et al., 2021). From those, the integration of valuation information and spatial plan information within the LADM has been considered appropriate, together with the provision of LA in 3D (below, on and above the surface of the earth) on land as well as at sea. In addition, the need for further information exchange mechanisms, improved interoperability with other standards, refinement of Rights, Restrictions and Responsibilities (RRRs), refined survey model, semantically enriched code list values, new subclasses for spatial units, a set of possible representations of spatial units in 2D, 3D or mixed dimension, identifying legal spaces in buildings, refined legal profiles and so on have been considered.

In the 48th Plenary Meeting Week of ISO/TC 211 (June 2019), Standards Council of Canada (SCC) proposed LADM Edition II as multi-part. The following structure for the multi-part option (as multiple

[1] One in Delft, the Netherlands, in March 2017 (FIG, 2017), one in Zagreb, Croatia in April 2018 (FIG, 2018a), one in Kuala Lumpur, Malaysia in October 2019 (FIG, 2019), one online in June 2021 (FIG, 2021a), one in Dubrovnik, Croatia in March/April 2022 (FIG, 2022) and one in Gävle, Sweden in October 2023 (FIG, 2023).

Fig. 1. 3D cadastre prototype in Brisbane, Queensland, from http://pakhuis.tudelft.nl:8080/edu/Caesium-1.43/Apps/3dcad.

coherent packages with every part in separate standard) has been agreed:

- Part 1 – Generic conceptual model
- Part 2 – Land registration
- Part 3 – Marine georegulation
- Part 4 – Valuation information
- Part 5 – Spatial plan information
- Part 6 – Implementation aspects

It is noted that Part 1 was earlier called 'Fundamentals' and Part 3 'Marine Space Georegulation' and the names have been updated during the revision process.

The experts involved in the revision are from academia, industry, national standardisation bodies and professional organisations. Specifically, collaboration has been or will be organised between the International Standardization Organisation (ISO), the International Federation of Surveyors (FIG), the Open Geospatial Consortium (OGC), UN-Habitat, the UN Committee of Experts on Global Geospatial Information Management (UN-GGIM), the Global Land Tool Network (GLTN), the International Hydrographic Organisation (IHO) and the Royal Institute of Chartered Surveyors (RICS), and so on. The cooperation between OGC and ISO is expected to contribute to effective implementation and developments. In this scene, a White Paper on Land Administration has been prepared by the Domain Working Group Land Administration of the OGC (OGC, 2019), highlighting the operationalisation of the LADM.

The decision to publish LADM Edition II as a multi-part series has resulted in the development of six standards that are backward compatible with Edition I, with each part being a standard in itself and following the standardisation process for each. Therefore, a New Work Item Proposal (NWIP) has to be formulated for each part. In a multi-part approach, each professional group involved in the LA processes (e.g., surveyors and registrars, valuers, planners, etc.) can be better organised in developing the standard. In addition, it may be easier to collaborate with the relevant organisations, for example, FIG Commission 3 (Spatial Information Management) and Commission 7 (Cadastre and Land Management) for Part 2, Commission 8 (Spatial Planning and Development for Part 5, and Commission 9 (Valuation and the Management of Real Estate) for Part 4, as it can facilitate experts to review the standards in a focused way. The multi-part approach also has an advantage for future revisions, as one part may need to be revised and the other may not. Furthermore, taking into account the functions of the LA paradigm (see Fig. 2), the parts and their basic content were agreed. The scope of LADM Edition I is limited to the land tenure component of the LA paradigm (see the grey arrow and circle in Fig. 2), whereas LADM Edition II aims to extend the scope of Edition I to include land value, land use and land development (see the red arrow and circle in Fig. 2).

The methodology used in this paper is the design research methodology (Peffers et al., 2007; Hevner et al., 2010), which is consistent with the ISO methodology for developing standards.[2] To mention the most important steps of the ISO methodology, starting with the fact that standards should include a set of requirements that form the basis of the scope of the standard, and which are further used to specify an abstract test suite. In addition, the code list values of each class of the standard should have a description and, where appropriate, references to the source of these definitions shall be added. These ISO steps were not followed when developing the LADM Edition I, and therefore, they directly affect the design and the structure of all parts of Edition II. On the other hand, the ISO standard development process consists of several stages (i.e., proposal, preparatory, committee, enquiry approval and publication), and at each stage the proposal is evaluated and reviewed by domain experts. Each stage mentioned here has been applied to each part of LADM Edition II.

The steps in the methodology used to develop the LADM Edition II are shown in Fig. 3. It should be noted that the design science research approach as described by Hevner et al. (2010) was also carried out during the design process of each part of the LADM Edition II.

As the main purpose of this paper is to inform the international community on how the LADM Edition II is being developed, what operational functionalities are included, and how the parts of the standard are structured; the paper also outlines how the various packages

[2] ISO standard development process: https://www.iso.org/stages-and-resources-for-standards-development.html

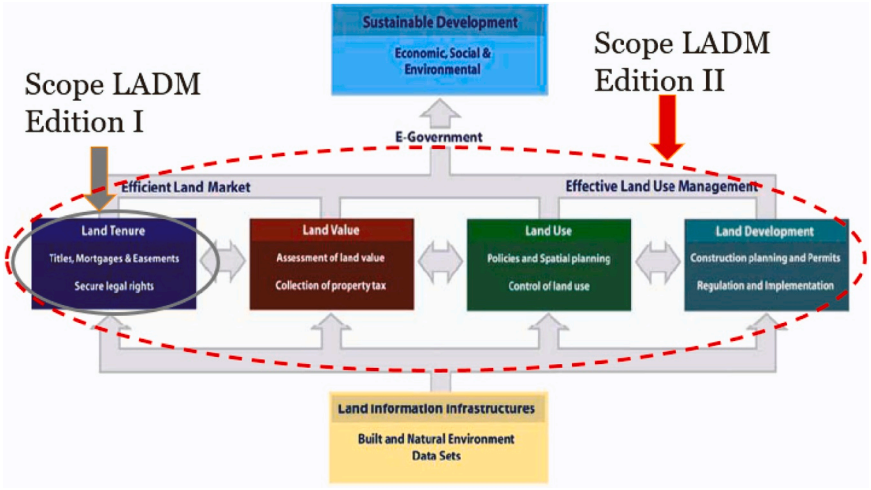

Fig. 2. Land Administration paradigm and LADM scope (adapted from Enemark, 2006).

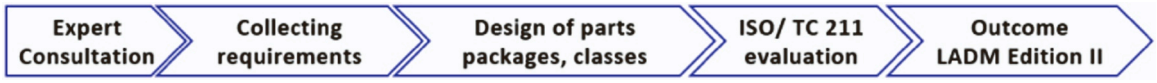

Fig. 3. Methodology used to develop LADM Edition II.

(based on the below requirements) were designed, how they relate to each other, and in which part of the new edition of LADM they are included. A special attention is given to the 3D aspects for each of the documented parts of the LADM Edition II.

3. Requirements' specification and LADM edition II parts' and packages' design

The LA paradigm has been around for years (see UNECE, 1996; Enemark, 2006), but there was not a detailed model to support the development and refinement of LA functions. In this context, LADM Edition II aims to fill this gap by extending the scope of the first Edition with land value, use and development. The novelty of this paper lies in the design of the Edition II packages through the harmonisation of the requirements distilled from the comments of the ISO TC/211 member states, the workshops and the other meetings as presented in Section 2.

The distilled requirements used to design the packages are shown in Tables 1–4. The requirements were initially collected, distilled, and proposed by the editors of the LADM revision and reviewed by the member state experts of ISO/TC 211. The requirements in the tables are coloured using the colours shown in Fig. 4. The requirements specified in Part 1 apply also at the other parts (i.e., Parts 2, 3, 4 and 5) as they are all based on the definitions in Part 1. Regarding the colouring of the table and Fig. 4, green colour is chosen for the Party package, while yellow and turquoise are chosen for the Administrative and Spatial Unit packages respectively, as well as light pink is used for the Surveying and Representation sub-package (in-line with the colouring of the respective classes of LADM Edition I). For the parts introduced in Edition II, different colours are used; the packages of Part 3 are coloured in grey, while Part 4 and Part 5 are coloured orange and light blue respectively.

The requirements in Table 1 and Table 2 are implicitly included in Lemmen (2012), ISO (2012) and Lemmen et al. (2015).

The first eight requirements in Table 2 are not coloured, as they are general requirements that apply to all packages in Part 2.

Fig. 4 depicts the package structure of LADM Edition II, designed in a way that meet the requirements. The "Party", "Administrative" and "Spatial Unit" packages are common packages in Part 1 as well as in Part 2. The newly added packages in Part 3 are "Party Group" and "Source

Table 1
The proposed and reviewed requirements for LADM edition II - part 1.

Requirement	Requirement name / Solution	Description
LADM-based systems can be designed based on core LADM classes.	Requirement 1–1 'Core Class Conformant'	The description, development and refinement of efficient and effective land administration/georegulation systems using this part of ISO 19152 shall be compatible with the classes described in Clause 5 (Party, Administrative and Spatial Unit Packages), and the classes and attributes described in Clause 6 (LA_Source and VersionedObject).
All people-to-land relationships can be managed.	Requirement 1–2 'Triplet Structure Present'	The three, possible compound, elements 1. LA_Party – 2. LA_RRR and/or LA_AdministrativeSource – 3. LA_BAUnit/LA_SpatialUnit provide the common pattern for land administration/georegulation and form the basic structure. A land administration/georegulation system shall be constructed using groupings of LA_SpatialUnit, LA_BAUnit and/or LA_Party classes.
Compatibility between the versions	Requirement 1–3 'Backwards Compatible'	Any country profile established using the elements defined in conformance with ISO 19152:2012 shall remain conformant with this version of the standard.
Maintenance of history should be supported	Requirement 1–4 'Versioned Objects'	All land administration/ georegulation systems shall support (bi-) temporal data management by inheritance from LA_VersionedObject.
All subjects, sources, objects etc. can be identified	Requirement 1–5 'Oid Present'	The local object identifier (Oid) shall be unique within the namespace.
Reference to source documents should be supported	Requirement 1–6 'Source Document Present'	All land administration/ georegulation systems shall make use of the LA_Source class to support references to source documents.

Table 2
The proposed requirements for LADM edition II - part 2.

Requirement	Requirement name / Solution	Description
All requirements in Part 1 apply to Part 2.	Requirement 2–1 'Based on General Conceptual Model'	This part of the standard is based on Part 1 – Generic Conceptual Model. All requirements contained in 19152–1 shall apply to this part of the standard.
All rights should be specified in a seamless way, not only real rights, also customary and personal rights.	Requirement 2–2 'Continuum of Rights'	The continuum of land rights shall be supported. This includes the recognising, recording, administering a variety of appropriate and legitimate land tenure forms, such as registered freehold, lease, group tenure, adverse possession, occupancy, customary.
Grouping people and land	Requirement 2–3 'Grouping People Land'	Groupings of people and land shall be supported. The flexibility of LA model can be based on the recognition that people to land relationships appear in many different ways, depending on local tradition, culture, religion and behaviour.
Distributed environment	Requirement 2–4 'Different Organisations'	Land administration data can be maintained by different organisations. And within one organisation at many sites. Administrative territories for organisations can be completely different. The LADM based systems shall be implemented as a distributed set of (geo-) information systems, each supporting the maintenance processes (transactions in land rights, establishment of rights, restrictions and responsibilities) and the information supply of parts of the data set, represented in this model.
No duplications unless something has different meanings in different models (roles)	Requirement 2–5 'Keep Data to Source'	Land administration data shall be kept to the source within Spatial Data Infrastructure (SDI). Today all data (spatial and thematic) can be stored in a Data Base Management System (DBMS). Information products are becoming flexible combinations of digital data components and additional facilities and services. This can replace the exchange of copies of data sets between organisations. Multi source information products require avoidance of redundancy and good standardisation protocols.
Continuous source updates maintenance; see also Requirement 1–6	Requirement 2–6 'Authentic Source Documents'	Inclusion of new data and data updates shall be documented. This concerns legal administrative data, spatial data and/or technical data.
Transparency in history management and updates	Requirement 2–7 'Transparency'	All updates shall be traceable in LADM compliant LASs.
Responsible person should be part of source data	Requirement 2–8 'Responsible Person'	The names of persons responsible for transactions shall be part of the source data set (conveyors, surveyors, registrars, etc.). This is one reason for management of history and for documentation of all updates.
All right holders should be clearly identified	Requirement 2–9 'Continuum of Right Parties'	Efficient and effective LAS using this part of ISO 19152 LADM shall support all types of parties. Parties can be persons, or groups of persons, or non-natural persons, that compose an identifiable single entity. A non-natural person may be a tribe, a family, a village, a company, a municipality, the state, a farmer's community/co-operation, a slum dwellers group/ organisation, a religious community, and so on. This list may be extended, and it can be adapted to local situations, based on community needs.
Spatial units that have the same right should be grouped together	Requirement 2–10 'Basic Administrative Unit'	In combination to the Triple (1. LA_Party – 2. LA_RRR and/or LA_AdministrativeSource – 3. LA_BAUnit/LA_SpatialUnit) the constellation of basic administrative units shall be supported. The purpose of a BAUnit is the grouping of spatial units, which have the same rights, etc. attached. A BAUnit can play the role of a party: a BAUnit may be owned by one or more other BAUnit.
Shares in right should be supported	Requirement 2–11 'Shares In RRR'	Holding shares in rights, restrictions, responsibilities shall be supported.
All spatial units should be specified in a seamless way	Requirement 2–12 'Continuum of Spatial Units'	Representation of a broad range of spatial units, with a clear quality indication, shall be supported by an LADM compliant LAS. Spatial units are the areas of land (or water – e.g., water rights and the marine environment) where the rights and social tenure relationships apply. Spatial units can be represented as a text ("from this tree to that river"), as a sketch, as a single point, as a set of unstructured lines, as a surface, or as a 3D volume.
All spatial units should have a unique identifier	Requirement 2–13 'Spatial Unit Identifiers'	Spatial units shall have a unique identifier. A key component in LASs is the spatial unit identifier, the parcel identifier or the unique parcel reference number. This acts as a link between the parcel itself and all record related to it. It facilitates data input and data exchange. There can be a need to change identifiers during data collection.
Cadastral maps should be based on surveys.	Requirement 2–14 'Spatial Source Based Maps'	Cadastral maps shall be based on spatial sources, such as surveys, design sources, topographic maps, etc.
Different data acquisition methods can be used to identify boundaries of spatial unit	Requirement 2–15 'Data Acquisition Methods'	Surveying of boundaries shall be supported. Surveys may concern the identification of boundaries of spatial units on a photograph, an image, or a topographic map. Surveys can be conventional land surveys, based on hand-held GPS. In all cases the representation of 'legal' reality is differentiated from the 'physical' reality. There may be sketch maps drawn up locally. Depending on the local situation, different registrations or recordings of land rights are possible.

(*continued on next page*)

Table 2 (*continued*)

Requirement	Requirement name / Solution	Description
Cadastral surveys should be represented in a reference system	Requirement 2–16 'Cadastral Reference System'	Efficient LASs compliant with this part of LADM shall be capable of producing co-ordinates, forming an essential component of cadastral systems. Provisions may be made to accommodate future changes in the reference system that may occur as a result of technical improvements. These may affect all co-ordinate-based systems. Imagery can be used depending on the user requirements, cost, and timing among other factors. It can be possible to include all documentation on data collected as evidence from the field.
Quality of cadastral data should be specified	Requirement 2–17 'Data Quality'	The cadastral information shall be as complete as possible, reliable (which means ready when required), and rapidly accessible. Users of cadastral information need clarity, simplicity and speed in the registration process. Consistency between spatial and legal administrative data is important. Topology integrated with geometry and other attributes is relevant. The system must be ready to keep the information up to date. Data quality of spatial data may be improved in a later stage of development of a LAS, this has to be documented. For combined data products from different sources the quality descriptions and meta data related to the original data are relevant in relation to liability and information assurance.

Group", in Part 4 the "Valuation information" package is introduced, while in Part 5 the "Spatial plan information" package.

For the common packages, in Part 1 the terms defined in these packages are only introduced, while the detailed description of these packages is included in Part 2. The "Generic conceptual model" package, which contains the basic requirements on which each part of Edition II is based, is included in Part 1, while the "Survey and representation" sub-package is specified in Part 2. Part 4 and 5 have been designed as a single package, both based on the definitions in Part 1 and 2. Part 1 and Part 2 together form an application schema as well as Parts 1, 2, 3, 4 and 5.

4. LADM edition II part 1 - generic conceptual model

The Part 1 will be a high-level umbrella standard that supports all the other parts of the LADM Edition II. Part 1 will include the fundamental notions and will define the basic components and relations shared by all objects created by land administration and provides an overview of all parts. Part 1 is based on the conceptual framework of the Cadastre 2014 principles (Kaufmann and Steudler, 1998) and its geospatial aspects follow the ISO/TC 211 conceptual model (see Kara et al., 2023) for further discovery of LADM's links to international standards, guidelines and frameworks). The Part 1 will not only be backward compatible with the previous version of the LADM but also with the IHO S-121 Maritime Limits and Boundaries standard (IHO, 2016), which is being used as a basis for the development of Part 3 of LADM Edition II.

Part 1 of Edition II provides terms, definitions, a general overview of the model in its individual packages and a more detailed overview of the

Table 3
The proposed requirement for LADM edition II - part 4.

Requirement	Requirement name / Solution	Description
A land administration system specifically designed for valuation information should be based at least on the ISO/TC 211 set of standards	Requirement 4–1 'Core LADM Conformant'	Efficient and effective land administration system for valuation information compatible with this part of ISO 19152 LADM shall be modelled using or extending the core LADM concepts, namely party, RRR, BAUnit, spatial unit, versioned object, which are all based on source documents. This statement also implicitly implies that it is also modelled in accordance with ISO standards including ISO 19107 — Spatial schema, ISO 4217 — Currency codes and so on.
Effective systems are needed to manage valuation information	Requirement 4–2 'Valuation Information Management'	Appropriate valuation information management systems (e.g., a registry or a database) using this part of ISO 19152 LADM can be developed by public authorities (e.g., municipality, local governments, State) for fair and timely valuation of tenure rights in order to promote broader social, economic, environmental, and sustainable development objectives. Input (e.g., legal, locational, physical, environmental characteristics of valuation units, and transaction prices) and output (e.g., value and valuation procedures) data in property valuation processes shall be identified, compiled, recorded, managed and maintained in such systems for effective valuations.
Valuation registry should be linked to the distributed registries needed in the valuation processes	Requirement 4–3 'Linked Public Registries'	Uniform and accurate valuation of property units requires correct, complete, and up-to-date property data. The fundamental element underpinning property valuation are public registries, which accommodate regular data maintenance and updating of property characteristics, ownership details and transaction information. An efficient land administration infrastructure shall link valuation registries to the other distributed public registries such as cadastre, land registry, property price registry, address, spatial planning, topographic, and building and dwelling registries.
Valuation units should be clearly specified	Requirement 4–4 'Valuation Unit Registration'	Effective valuation information management shall support the registration of each valuation unit and their required characteristics. The classification of valuation units and the required characteristics of each valuation unit need to be explicitly specified for each valuation process. The required characteristics may be obtained through (1) an existing registry

(*continued on next page*)

Table 3 (*continued*)

Requirement	Requirement name / Solution	Description
		or (2) valuation information registry, itself. A valuation information registry may be developed at the local, regional or national level.
Valuation procedures should be transparently shared	Requirement 4–5 'Valuation Procedure'	Valuation information management systems compatible with this part of ISO 19152 LADM shall support the determination of value of each valuation unit in accordance with published procedures, where possible based on market values and computer-assisted mass appraisal systems.
Efficient information systems for valuation requires to record transaction prices, and to publish indices related to the prices	Requirement 4–6 'Transaction Prices and Statistics'	Efficient land administration system for valuation information management compatible with this part of ISO 19152 LADM shall support the registration of transaction prices and the publication of sales statistics regularly.
Reference to valuation source should be supported	Requirement 4–7 'Valuation Source Document'	All valuation information management systems shall support make use of the VM_ValuationSource class to support references to source documents (e.g., sale contracts, valuation reports).
Property values should be open, and processes should be transparently shared with public	Requirement 4–8 'Value Dissemination'	Valuation procedures, processes and results shall be transparently shared with general public. Timely and effective dissemination of property values as well as input information related to valuation processes to general public is an essential part of a transparent and efficient valuation system. For this purpose web-map based dissemination is the preferred, and in case of stratified ownership (e.g., apartments), the 3D web-maps may be preferred.

LA_Source, with the addition of a backward-compatible integrated administrative and spatial source (the detail of spatial source is given in Part 2) (see the requirement 1–6 in Table 1). Also, *VersionedObject* class is included, in Edition II with standardised support for the bi-temporal model with intervals for both system and real-world times (see the requirement 1–4 in Table 1) (Thompson and van Oosterom, 2021). The requirements of Part 1 are given in Table 1.

In LADM Edition I, the term 'land administration' is used in the broad sense, including geographical spaces covering water and land, and elements above and below the surface of the earth. Considering the comment submitted by the Standards Council of Canada (SCC), a new term with a wider meaning is introduced 'georegulation', which can be defined as "*activity to delimit and assert control over geographical spaces through regulations*". Some of the geometry and spatial unit related definitions included in the LADM Edition I will not be defined in the Part 1 of Edition II since they are not applicable for the certain other parts (e.g., marine space). These definitions are boundary, boundary face, boundary face string, face, level and liminal spatial unit. In addition, the definition of right is changed to '*formal or informal entitlement to own or perform an action*', similar to restriction ('*formal or informal obligation on the land owner to refrain from performing an action*') and responsibility ('*formal or informal obligation on the land owner to allow or perform an action*') in order to provide more rigorous and precise definitions. It is noted that

Table 4
The proposed requirement for LADM edition II - part 5.

Requirement	Requirement name / Solution	Description
A land administration system specifically designed for spatial plan information should be based at least on the ISO/TC 211 set of standards	Requirement 5–1 'Core LADM Conformant'	Effective and efficient land administration systems for spatial plan information compatible with this part of ISO 19152 LADM shall be based on LADM core, namely Party, RRR, BAUnit, SpatialUnit, 2D/3D representations (from 19107), VersionedObject, and all of these are based on source documents.
Spatial plan information should be visualised and disseminated	Requirement 5–2 'Plan Information Dissemination'	Spatial plan information systems using this part of LADM shall allow open dissemination and clear visualisation (2D/3D) plan information.
Participatory spatial plan information monitoring should be supported	Requirement 5–3 'Plan Information Monitoring'	Spatial plan information systems shall support participatory plan monitoring to detect challenges and evaluate alternative scenarios for intervention making as well as achieving SDGs.
Spatial plans can be organised with plan units (homogenous, smallest planning unit) and blocks	Requirement 5–4 'Plan Unit and Block Relationship'	Spatial plan information compatible with this part of LADM shall organise plan units (plan zones) in plan block, as accepted plans by the relevant authorities for specified time interval.
All functions and subfunctions should be supported	Requirement 5–5 'Spatial Subfunction'	Effective land administration systems for spatial plan information compatible with this part of ISO 19152 LADM shall provide extensible code list for the spatial (sub) functions of plan units and plan blocks according to national/local regulations.
Spatial planning hierarchy should be supported	Requirement 5–6 'Plan Group Hierarchy'	Spatial plan information shall support the planning hierarchy (from national to local) via hierarchical plan groups.
Permit registration should be supported	Requirement 5–7 'Permit Registration'	Efficient and effective spatial plan information management system using this part of ISO 19152 LADM shall support permit registration and relating this to the relevant plan unit.

georegulation cover rights and restrictions and responsibilities.

The LADM is organised as a set of application schemas; see Fig. 5. Each application schema has its own namespace and is organised into a set of packages and (sub)packages. A (sub)package is a group of classes, with a certain degree of cohesion that facilitates the maintenance of different data sets by various organisations. Different organisations have their own responsibilities in data maintenance and supply, but may communicate on the basis of standardised administrative and technical update processes.

The Surveying and representation sub-package of the LADM Edition I will not be included in the main text of the Part 1 since it is not applicable for Marine georegulation, but is included in Part 2. As Part 1 is designed as a high-level standard, not all the classes of these packages are included. For example, LA_Mortgage from the Administrative Package and LA_LegalSpaceBuildingUnit and LA_LegalSpaceUtilityNetwork from the Spatial Unit Package are not included in the main text of the Part 1. It should be

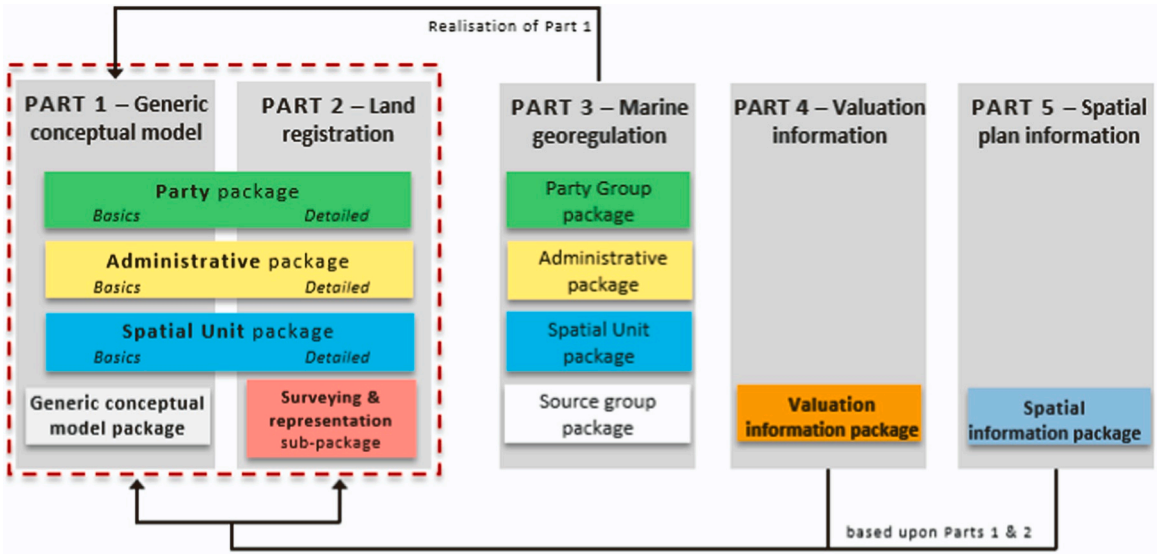

Fig. 4. Packages of LADM Edition II Parts.

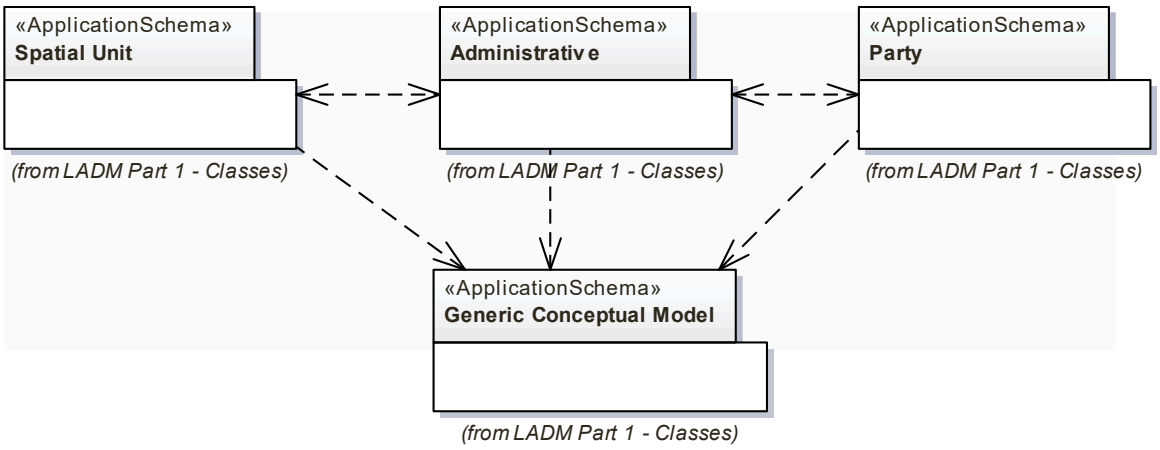

Fig. 5. (Sub)Packages of the core LADM.

noted that Part 1 will not contain any information about the attributes of any classes, except for the Generic conceptual model package (VersionedObject, LA_Source, Oid, Fraction) (see below).

Part 1 of ISO 19152 defines the high-level structure (global view) for the LA/ georegulation. The generic conceptual model of the LADM is based on six basic classes, all inheriting from VersionedObject (and associated to LA_Source) (see Fig. 6 and Fig. 10):

- Class LA_Party. Instances of this class are parties.
- Class LA_RRR. Instances of subclasses of LA_RRR are rights, restrictions or responsibilities.
- Class LA_BAUnit. Instances of this class are basic administrative units.
- Class LA_SpatialUnit. Instances of this class are spatial units.
- Class VersionedObject. This class is an abstract class.
- Class LA_Source. Instances of this class are sources, e.g., administrative source.

The main class of the Party Package is the basic class LA_Party. LA_Party has a specialisation: LA_GroupParty. Between LA_Party and LA_GroupParty there is an optional association class: LA_PartyMember., see Fig. 7.

The main classes of the administrative package are basic classes LA_RRR and LA_BAUnit. See Fig. 8. LA_RRR is an abstract class with three specialisation classes: LA_Right, LA_Restriction and LA_Responsibility. The type of right, restriction and responsibility depends upon the application area and will be described in more detail in each of the other parts of this standard.

Instances of class LA_BAUnit are basic administrative units (abbreviated as BAUnits). The BAUnit is one of the core classes of the model and defines the elements upon which RRRs apply. In principle, all RRRs

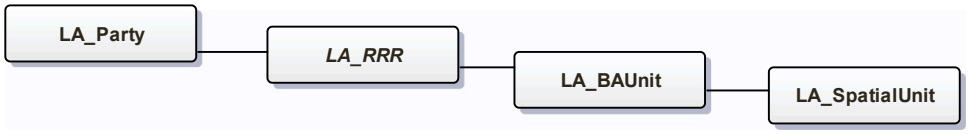

Fig. 6. Generic conceptual model- basic classes of the LADM without LA_Source and VersionedObject.

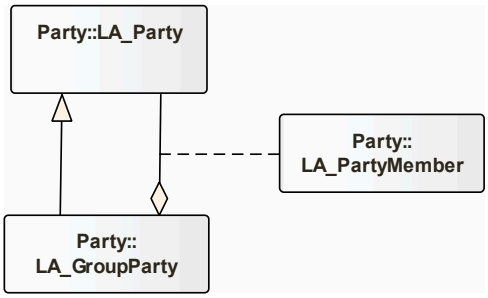

Fig. 7. Classes of Part package.

are based on an administrative source, as instances from class LA_AdministrativeSource.

The class LA_RequiredRelationshipBAUnit allows for creating instances of relationships between baunits. The Administrative package is partly introduced in Part 2 – Land registration. This concerns the class LA_Mortgage.

The main class of the Spatial Unit Package is the basic class LA_SpatialUnit, see Fig. 9. Spatial units may be grouped into two forms. First as spatial unit groups, second, as sub-spatial units (i.e., sub-parcels), that is a grouping of a spatial unit into its parts. This is realised by an aggregation relationship of LA_SpatialUnit onto itself, (Fig. 9). Parts, in their turn, may be grouped into subparts (subsubparcels), and so on. A level is a collection of spatial units with a geometric and/or topologic and/or thematic coherence, which is another approach that allows grouping of spatial units. Required relationships are explicit spatial relationships between spatial units, and instances of class LA_RequiredRelationshipSpatialUnit.

Part 1 provides a general overview of the model in its packages as indicated above and a more detailed description of the VersionedObject and LA_Source classes (see Fig. 10). VersionedObject is an abstract class and provides (optional) begin and (optional) end lifespan and real-world timestamps (optional) to the inheriting classes (see Fig. 11). The class VersionedObject is used in the LADM to manage and maintain historical data in the database (ISO, 2012). History requires that inserted and superseded data, are given a timestamp. All LADM classes inherit from VersionedObject (except for LA_Source). In this way, the contents of the database can be reconstructed, as they were at any historical moment (Thompson and Oosterom, 2021). There is one difference between the VersionedObject class of Editions I and II: the cardinality of the beginLifeSpanVersion changed from mandatory (1) to optional (0.1) and value type for this characteristic is defined as 'real_world_time'.

The LA_Source class is introduced in Part 1 in order to support any kind of source. This class represents the event causing the changes in the registration (ISO, 2012). All the dates and times are system (or database) time, corresponding to the moment where the event was processed and stored in the system (Thompson and Van Oosterom, 2021). With the associations between VersionedObject and LA_Source, instances of sources can now be versioned, unlike the previous version of the LADM (see the requirement 1–4 in Table 1). Constraints assure correspondence of dates and times in VersionedObject and LA_Source (Fig. 11). In addition, VersionedObject and LA_Source have a second set of optional temporal attributes (beginValidLifespanVersion, endValidLifespanVersion, and acceptance), representing to the corresponding valid times in the real world (see the requirement 1–6 in Table 1) (Thompson and Van Oosterom, 2021).

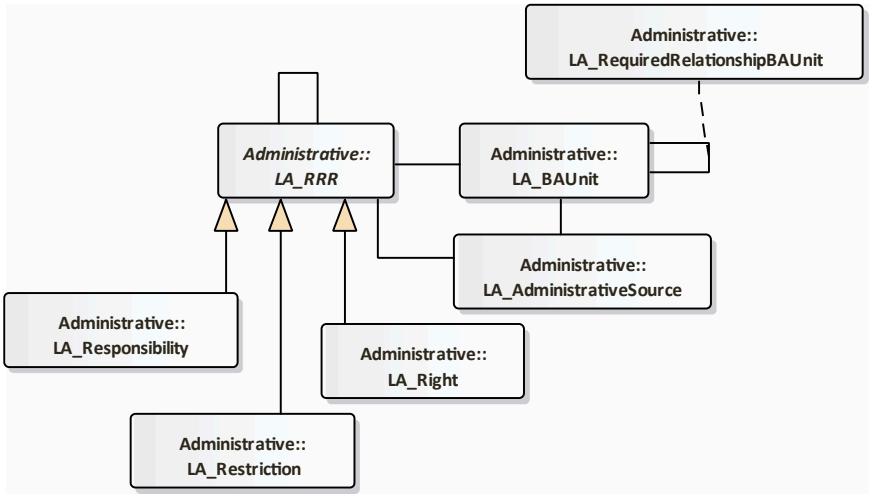

Fig. 8. Classes of Administrative package.

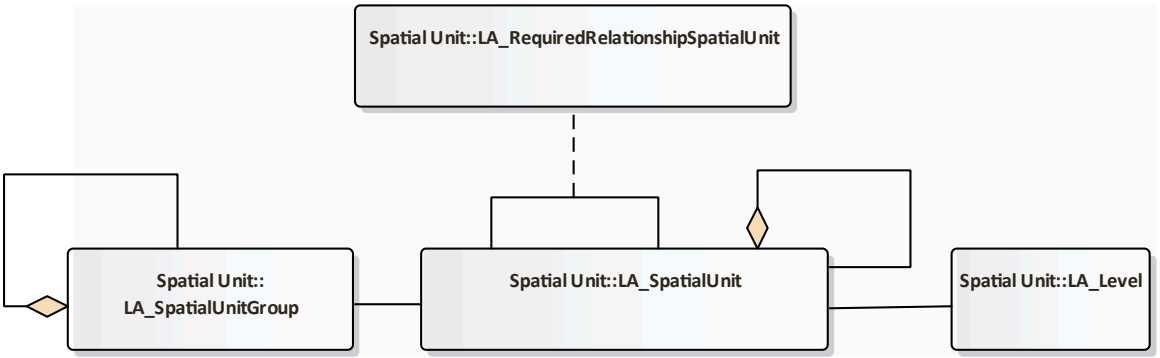

Fig. 9. Classes of Spatial Unit package.

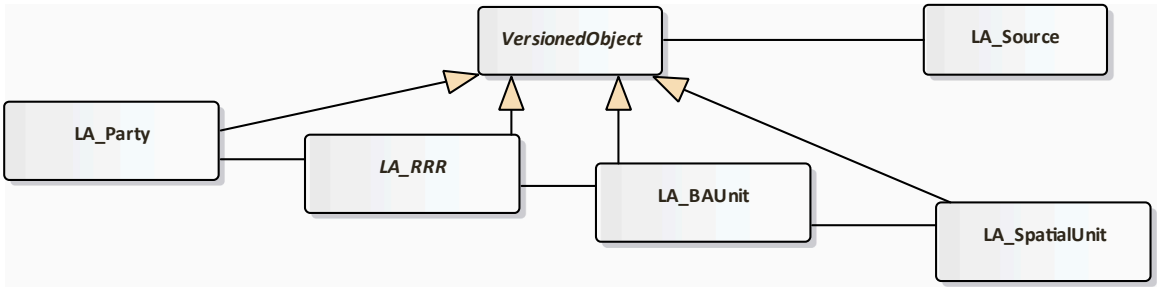

Fig. 10. Basic classes of the core LADM.

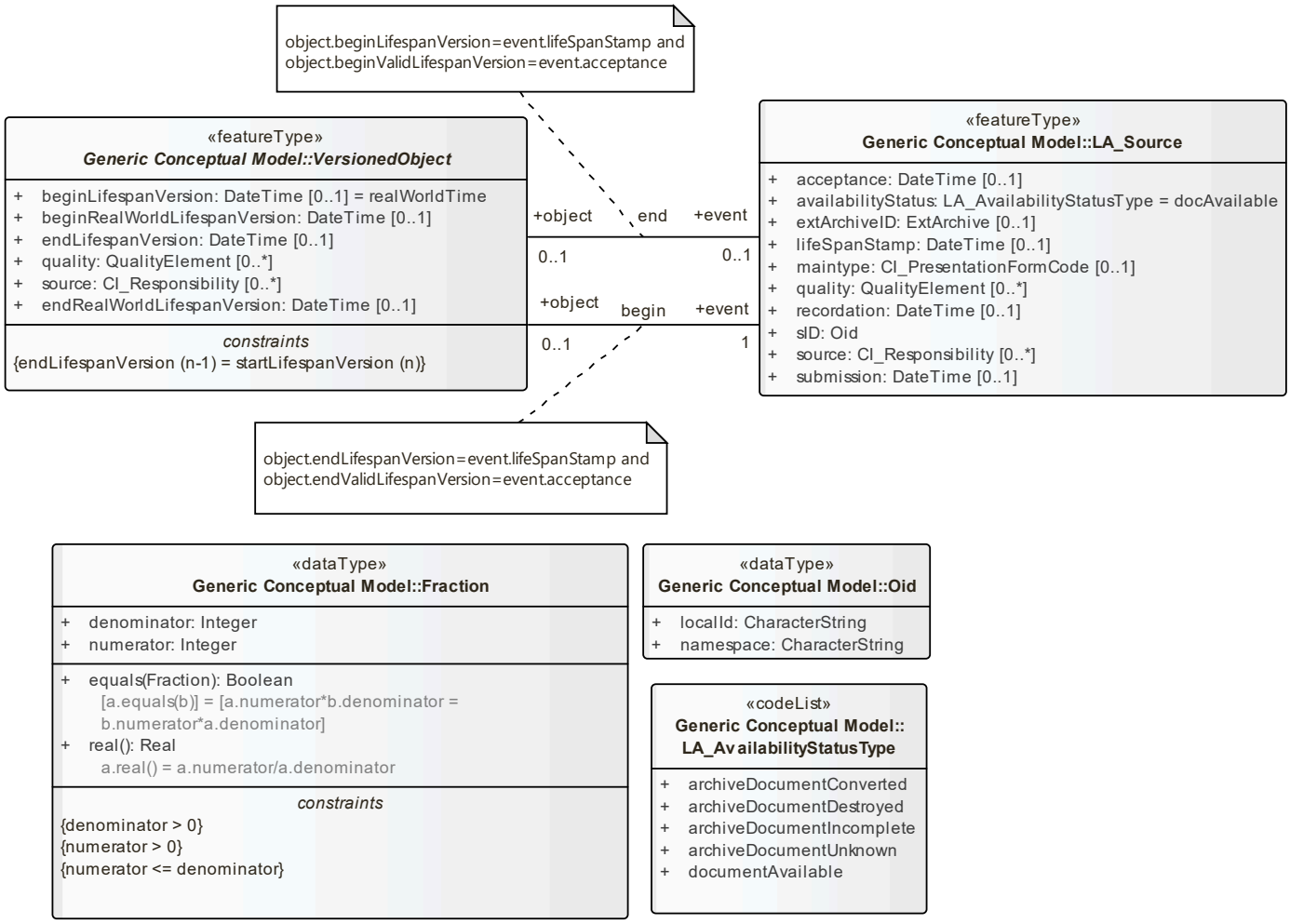

Fig. 11. Generic conceptual model package classes - Source, Versioned Object, Fraction and Oid.

Moreover, Part 1 introduces two more generic data types: Fraction and Oid (see Fig. 11). The former one provides support for fractions (e.g., ½ or ¾), written as a pair of numbers, numerator and denominator, and the latter one provides support for object identifiers (see the requirement 1–5 in Table 1) (ISO, 2012).

Part 1 plays a special role by providing the common basis relevant for all parts but also giving in the Annex B a synchronised overview, that is the model at class level, of the parts 2 to 5.

5. LADM edition II part 2 – land registration

The LADM Edition I concentrated on land registration, which will now be addressed in the Part 2 of the LADM Edition II. Some of the existing parts of LADM Edition I are being refined in Part 2. The goal is that these refinements will add more semantics to the LADM. Similar to Part 1, Part 2 is based on the Cadastre 2014 conceptual framework (Kaufmann and Steudler, 1998) and follows the ISO/TC 211 conceptual model. The continuum of land rights (UN-HABITAT, 2008) is also followed in the design of this part.

The proposed requirements for Part 2 are listed in Table 2. The first eight requirements are general requirements, while requirement nine relates to the Part 2 Party package.

In addition to the classes introduced in Part 1, as introduced in Section 4, Part 2 contains the LA_Mortgage subclass of LA Restriction and the LA_Mortgage is associated to the LA_Right on which it rests; see Fig. 12. This is the administrative package from Edition I. Requirements

2.10 and 2.11 in Table 2 refer to the administrative package.

Spatial units, feature type related to land administration/georegulation with associated spatial and thematic attributes, are refined into four specialisations (Fig. 13) in the Spatial Unit package (see the requirements 2.12 and 2.13 in Table 2) in Part 2:

- parcel. A parcel concerns legal space of parcel;
- utility networks. A utility network concerns legal space, which does not necessarily coincide with the physical space of a utility network;
- building units. A building unit concerns legal space not the physical space of a building;
- infrastructure. An infrastructure concerns legal space not the physical space of an infrastructure.

The LA_SpatialSource class as defined in LADM Edition I, is proposed to be further developed, see Fig. 14. There are many types of sources (see for example OGC, 2016, Aditya et al., 2021). LA_SpatialSource has two subclasses: LA_SurveySource and LA_DesignSource. A survey is documented with survey sources Sometimes, several documents are the result of a single survey. A design document (e.g., BIM/IFC, DXF) is documented with design sources. A spatial source (survey or design) may be official, or not (i.e., a registered survey plan, or an aerial photograph). Paper based documents (which may be scanned) can be considered as an integral part of the LA system (see the requirements 2–5–2–8 in Table 2).

The subclasses of the LA_SurveySource relate to the various survey acquisition methods that could be used during a survey, specifically: distance observations, angular observations, level observations, image-based methods, GPS, GNSS and/or using Galileo High Accuracy Services, classic total station and point-clouds observations.

Coordinates themselves either come from points or are captured as linear geometry. Points, lines, surfaces and volumes can be acquired in the field (with classical topographic surveys, or with satellite navigation systems), in an office (reusing input from design), or compiled from various sources, for example using forms, field sketches or orthophotos. The acquisition of points, lines, surfaces or volumes (through a topographic survey) may concern the identification of spatial units on a photograph, on an image (orthophoto), or on a topographic map; while cycloramas or pictometry methods (multiple images from different angles) may also be used for that purpose. 2D and 3D representations of spatial units use boundary face strings as instances of class, and boundary faces as instances.

The individual points are associated to LA_SpatialSource. While it is not required that the complete spatial unit is represented, a spatial source may be associated to several points. Geodetic control points, including multiple sets of coordinates for points, and with multiple reference systems, are all supported in the LADM.

The survey model is refined (see Shnaidman et al., 2019a and Kalogianni et al., 2020c) with various measurement types based on the OGC's LandInfra/InfraGML standard (see the requirements 2–14 to 2–17 in Table 2). Fig. 15 also shows the global overview of the Surveying and representation sub-package in Part 2.

Legal space is proposed to be linkable to physical objects in Edition II – by identifiers or re-use of descriptions of space. An IndoorGML-LADM model is one example of linking physical and legal objects one to another. In Part 2 of LADM Edition II, the combined use of IndoorGML and LADM is proposed to be used in order to define the accessibility of the indoor spaces based on the ownership and/or the functional right for use (Alattas et al., 2017; Alattas, 2022) (see needs identified in Section 2).

In LADM Edition I, the Spatial Unit package and the Spatial representation and surveying sub-package allows a set of possible representations of spatial units in 2D, 3D or mixed dimension (integrated 2D and 3D), ranging from "text based" spatial unit to the "topology based" level encoding, providing a framework for categorisation of spatial units (see needs identified in Section 2). After an inventory study concerning the 3D aspects in the revision of LADM (Kalogianni et al., 2018), Part 2 of the LADM Edition II will include refined 3D spatial profiles to support the full lifecycle of 3D objects (see Thompson et al., 2015, 2016; FIG, 2018b; Kalogianni et al., 2020b). Fig. 16 shows how in 3D, a general boundary approach can be used by referring to ExtPhysicalBuildingUnit, which could be a BIM/IFC designed model of a building, see also (Alattas et al., 2021).

The LADM supports the increasing use of 3D representations of spatial units, without putting an additional burden on the existing 2D representations. Another feature of the spatial representation within the LADM is that there is no mismatch between spatial units that are represented in 2D and spatial units that are represented in 3D.

Intense exploitation of land in the vertical direction has brought up complex legal relations between different types of spatial units with various characteristics (e.g., land, marine, air, underground parcels, and infrastructure objects). For this reason, the use of 3D models is not only required to clearly represent real property and associated rights but also 3D representations of restrictions and responsibilities, deriving both from private and public law (Kitsakis et al., 2021). Moreover, LADM is designed to provide efficient support for the title and deed registration systems (as others e.g., in socialist environment), as well as a possibility on modelling restrictions and responsibilities as rights' relationships between an owning and a benefitting party (see needs identified in Section 2) (Kalogianni et al., 2022).

More attention is given to provide semantically enriched, structured (thesaurus/ontology) and versioned code list in Part 2. Paasch et al. (2015) and Stubkjær et al. (2018) propose code lists as a mean of internationalisation by which the classes of the LADM may be related to

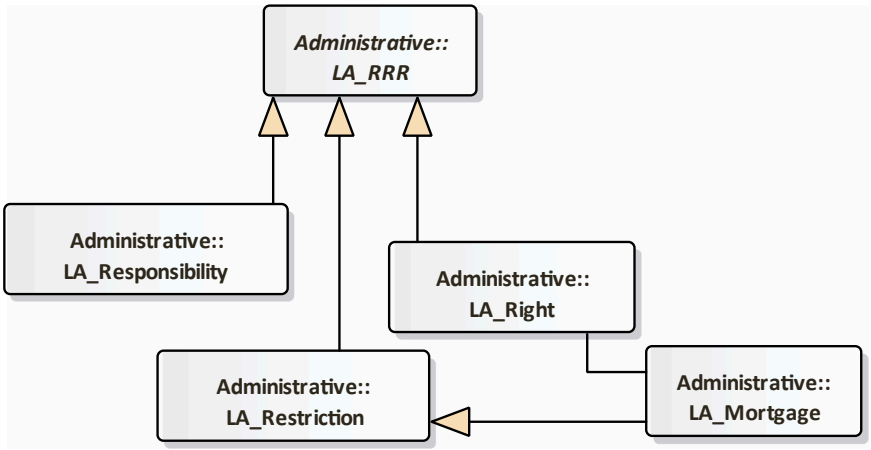

Fig. 12. LA_Mortgage as part of the Administrative Package in Part 2 of Edition II: Land registration.

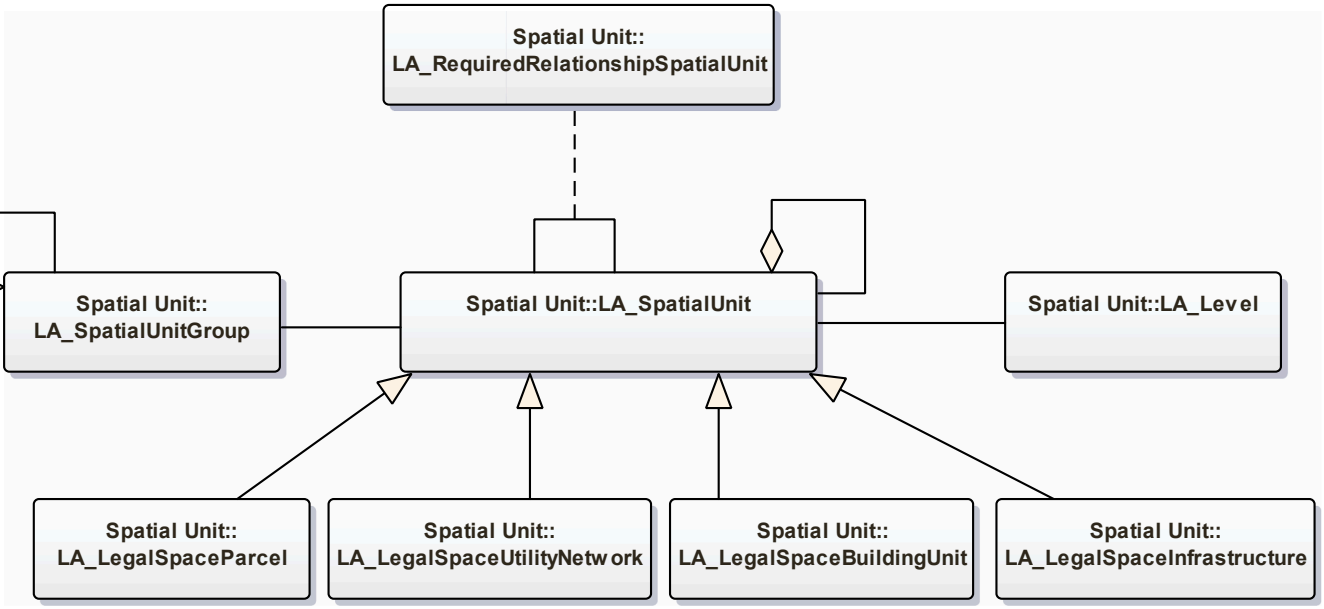

Fig. 13. The four subclasses of LA_SpatialUnit in the Spatial Unit package in Part 2, Land registration.

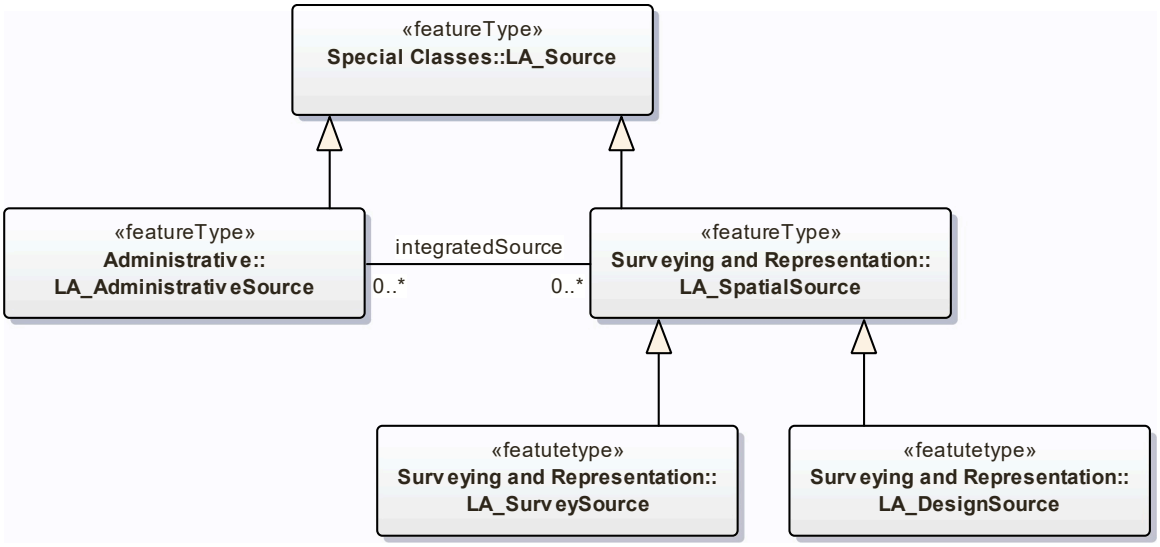

Fig. 14. Class LA_Source, with subclasses.

a particular jurisdiction. In this context, a metamodel is created to describe the necessary components for the design of semantically enriched code list values (see, Stubkjær et al., 2019; Stubkjær and Çağdaş, 2021; Kara et al., 2022b).

6. LADM edition II part 4 – valuation information

The valuation information package (VM) specifies the characteristics and semantics of valuation registries maintained by public authorities (Kara et al., 2018, 2020, 2021). Part 4 is based on the principles of Cadastre 2014 (Kaufmann and Steudler, 1998) and follows the ISO/TC 211 conceptual model. The terms and definitions in Part 4 are taken as far as possible from international valuation standards published by bodies such as the International Association of Assessing Officers (IAAO), the International Valuation Standards Council (IVSC) and the Royal Institution of Chartered Surveyors (RICS). The main classes of the valuation information package are VM_ValuationUnit, VM_ValuationUnitGroup, VM_SpatialUnit, VM_Building, VM_CondominiumUnit, VM_Valuation, VM_MassAppraisal VM_TransactionPrice, VM_SalesStatistic, and VM_ValuationSource, see Fig. 16. The requirements of Part 4 are specified in Table 3, and the first two requirements are general requirements.

Valuation units, the basic recording units of valuation registries, are realised by an aggregation relationship of VM_ValuationUnit onto itself, see Fig. 17. The object of valuation may be (a) only a land parcel, (b) only a building, (c) land parcel(s) with/without building(s) together as land property, (d) condominium unit consisting of building part(s) (e.g., condominium main part, condominium accessory part, joint access facility) and (e) a share in land parcel(s).

Valuation unit groups are realised by an aggregation relationship of VM_ValuationUnitGroup onto itself. A valuation unit group may be a grouping of other valuation unit groups. Examples of valuation units may be grouped according to zones (e.g., administrative divisions, market zones) that have similar environmental and economic characteristics, or functions of valuation units (e.g., commercial, residential, agricultural) that have similar characteristics.

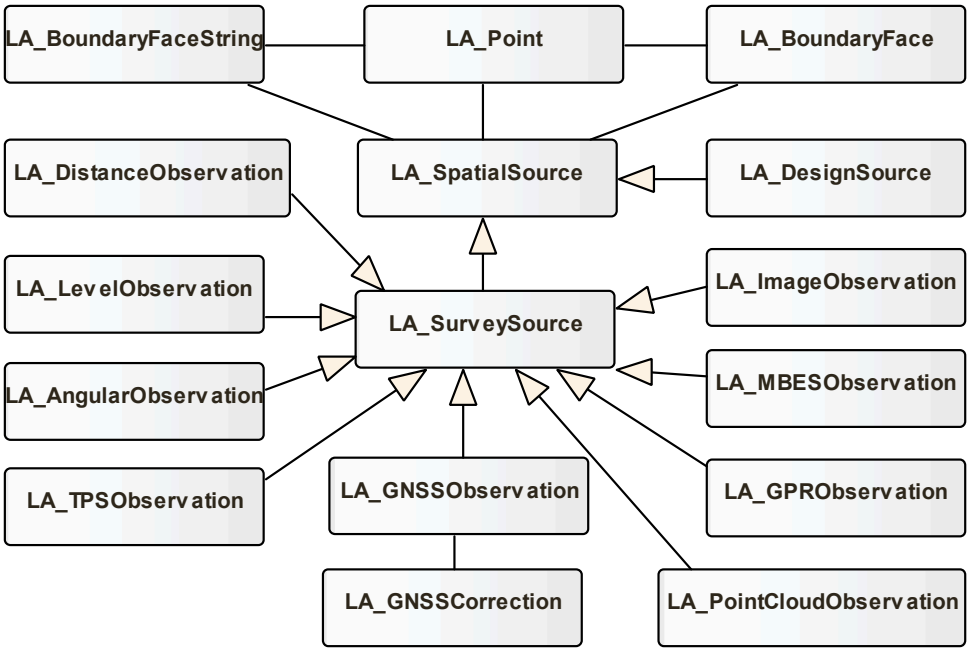

Fig. 15. Surveying and representation sub-package - new measurement types.

Class VM_SpatialUnit represents land parcel(s) (e.g., cadastral parcel and sub-parcel) that are subject to valuation. Class VM_Building includes the building characteristics required in valuation processes (e.g., date of construction, energy performance, use type). A building may be considered as a complementary part of parcel(s) (VM_SpatialUnit), but may be valued separately from the parcels on which it is located. A building may represents a condominium building, which consists of (i) condominium units (e.g. apartments, shops); (ii) accessory parts assigned for exclusive use (e.g. garages, storage areas); (iii) and joint facilities covering parcel, structural components (e.g. foundations, roofs), accession areas (e.g. entrance halls, spaces), and other remaining areas of buildings (e.g. staircases, heating rooms) (see OGC's Land and Infrastructure Conceptual Model Standard). Condominium units as instances of class VM_CondominiumUnit. A condominium unit is for the exclusive use of the individual condominium owner and shares a condominium building (see the requirement 4–3 in Table 3).

Class VM_Valuation specifies output data produced within valuation processes, especially for administrative valuations including property tax assessment. It concerns date of valuation, value type, valuation approach, and assessed value of valuation units. Class VM_Valuation has mass appraisal class as specialisation. Mass appraisal is a process of valuing a group of valuation units using standardised procedures at a given date. Class VM_MassAppraisal describes mathematical models, mass appraisal analysis types (e.g., multiple regression analysis), and the sample size of the analysis (see the requirements 4–4 and 4–5 in Table 3).

Class VM_TransactionPrice characterises the information content of transaction contractor declarations, including the date of contract or declaration, transaction price, date and type of transaction (e.g., sale, heritage, forced sale, and rent prices).

VM_SalesStatistic, with sales statistics as instances. It represents sales statistics produced through the analysis of transaction prices. VM_TransactionPrice and VM_SalesStatistic serve valuation activities for different requirements, e.g., estimating property values for property taxation, expropriations, and monitoring price trends (see the requirement 4–6 in Table 3).

Valuation sources as instances of class VM_ValuationSource. In principle, property valuation is based on a valuation source (e.g., valuation report, sale contract, rental contract, declaration), as instances from class LA_ValuationSource (see the requirement 4–7 in Table 3).

Fig. 18 presents the core classes of the LADM valuation information package and its relations with the core LADM, namely 19152–1 and 19152–2.

The relationships of Part 4 with Part 2 and Part 5 are illustrated in Fig. 19. The 2D (LA_BoundaryFaceString) and 3D (LA_BoundaryFace) representations as detailed in Part 2 are reused in Part 4 to avoid duplication. The geometric and topological model (see ISO 19107) is common for 19152–2, 19152–4 and 19152–5, however the instances of these parts do not need to be shared. Moreover, a valuation unit is associated with zero or more instances of plan units defined in Part 5.

Valuation has many relationships with 3D representation, as height is a part of the property location, has big influence on possible view (see Fig. 20 left), and also some relation to other factors such as noise, safety and routing. It is therefore expected that LADM valuation information package implementation will use the 3D possibilities of the LADM core. Kara et al., (2020, 2021, 2022a) did develop an initial prototype with cases from Turkey and the Netherlands (see Fig. 20 right) (see the requirement 4–8 in Table 3).

7. LADM edition II part 5 – spatial plan information

The spatial plan information package (SP) includes planned land use (zoning) to be converted into RRRs (Indrajit et al., 2020; Indrajit, 2021). Similar to the other parts, Part 5 is based on the conceptual framework of Cadastre 2014 (Kaufmann and Steudler, 1998) and follows the ISO/TC 211 conceptual model. In addition, the conceptual framework of Plan4all (Cerba, 2010) and the Land Use data theme of INSPIRE (INSPIRE, 2012) are also taken into account in the development of Part 5. This package has five classes: SP_PlanBlock, SP_PlanUnit, SP_PlanGroup, SP_PlanUnitGroup and SP_Permit, see Fig. 21. Table 4 presents the requirement statements for Part 5, and the first requirement is a general requirement.

SP_PlanUnit represents spaces of zoning plan and their characteristics in zoning plan activities. It represents homogenous area/space (2D/3D/4D) with assigned function/purpose, e.g., office, education, or retail (see the requirement 5–5 in Table 4). Each of zoning plan in SP_PlanUnit has specific RRRs derived from spatial planning processes. A land or space in zoning plan may share boundaries or not.

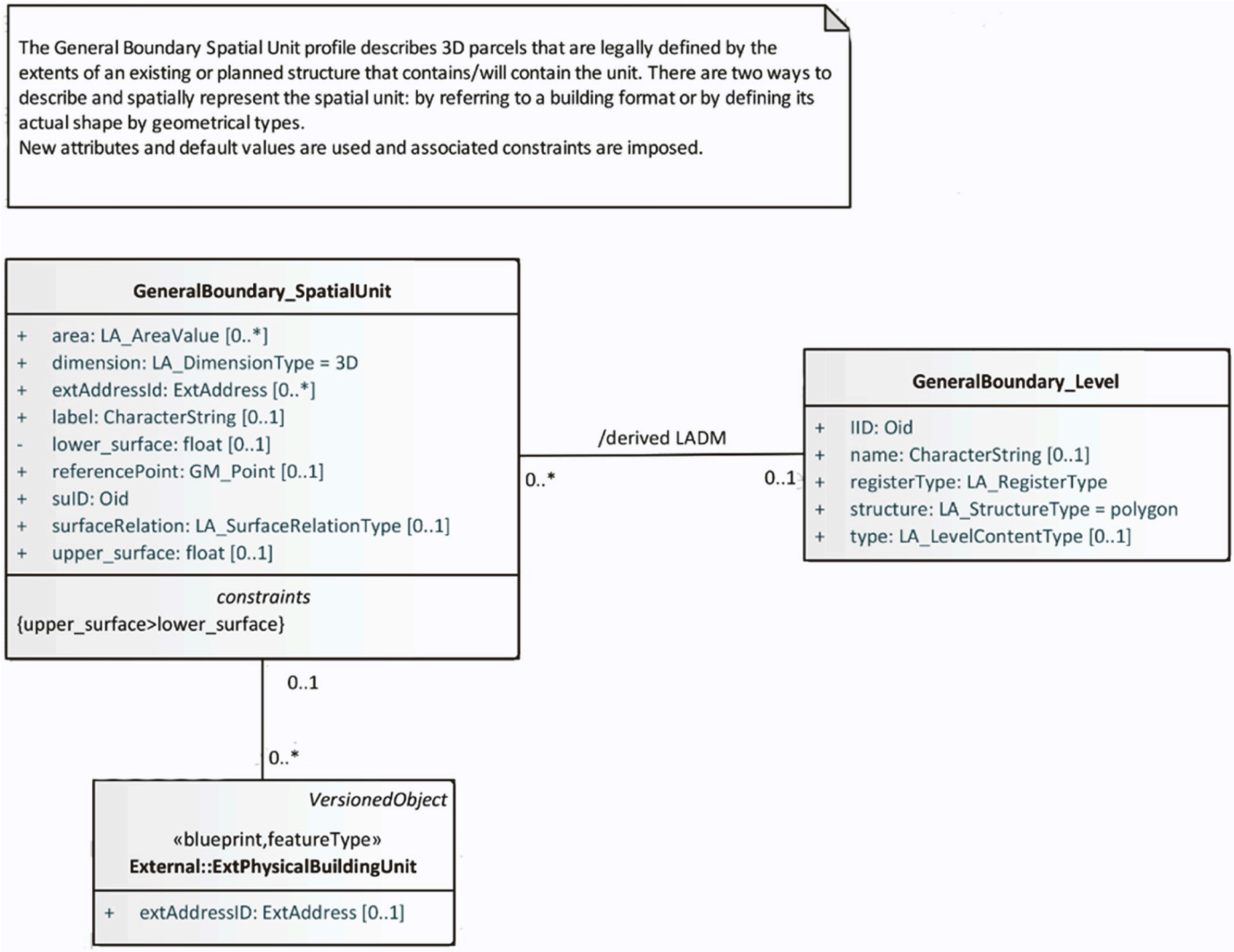

Fig. 16. Proposed spatial profile for building/construction format spatial units (Kalogianni et al., 2018).

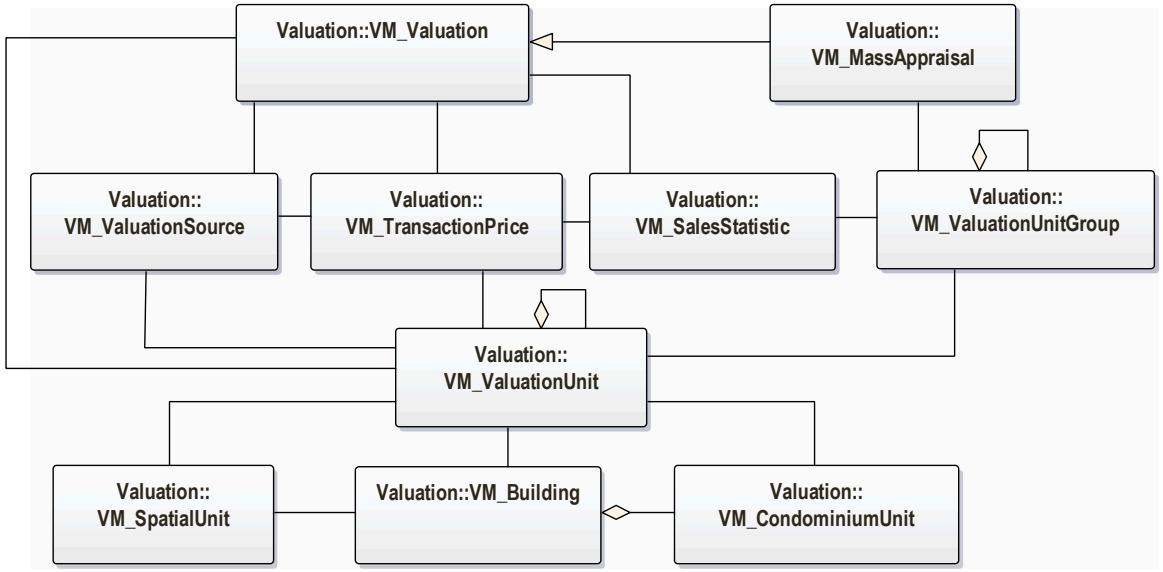

Fig. 17. Classes of the Valuation information package, Kara et al., (2020, 2021).

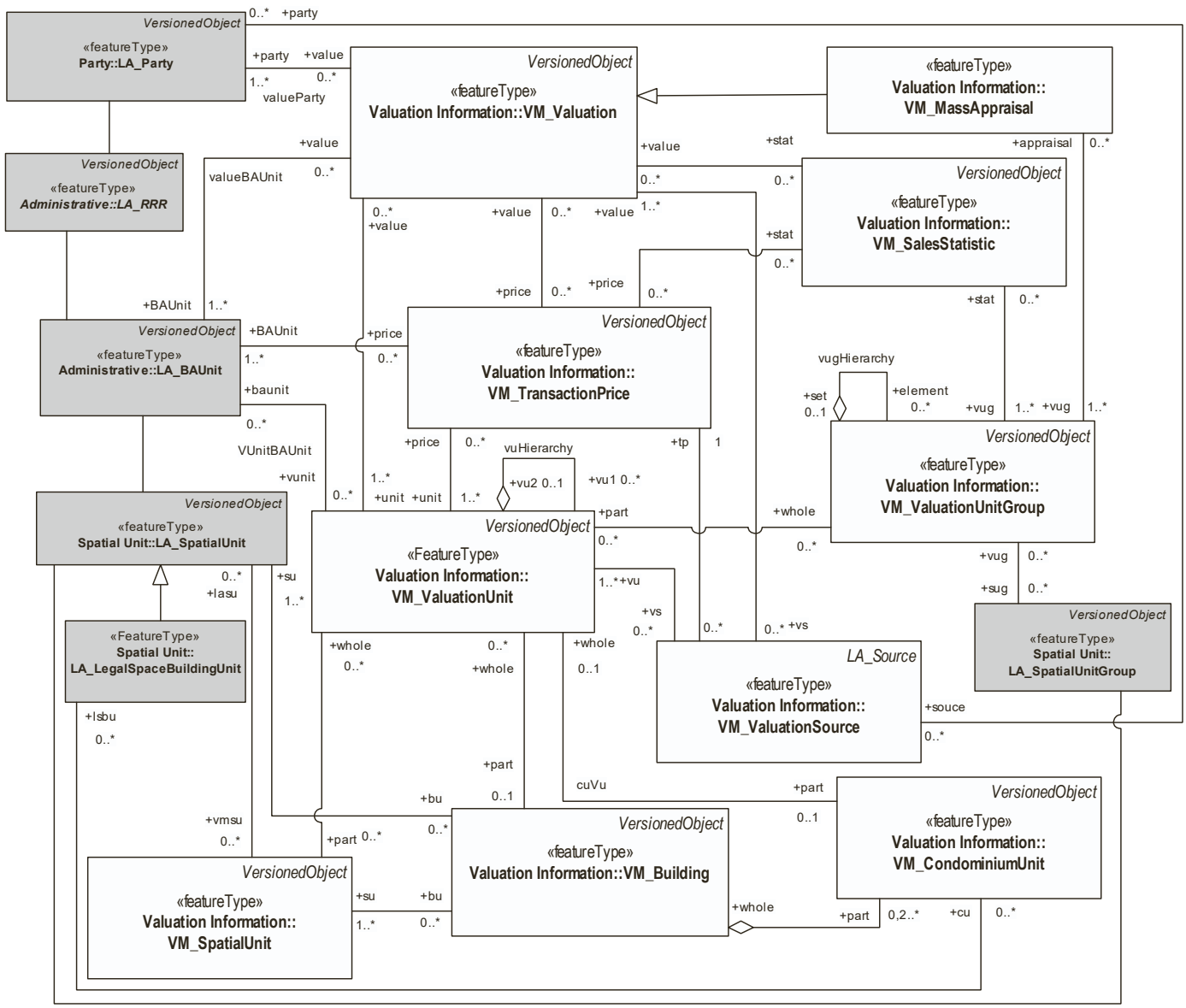

Fig. 18. Part 4 and its relations with core LADM.

SP_PlanUnit is used to register a detailed spatial planning zoning unit or a neighbourhood plan that contains RRRs. In principle, RRRs derived from spatial planning processes are based on an administrative source. This requires a separate process where the synchronisation is managed based on two datasets (cadastral map and spatial plan datasets).

SP_PlanBlock contains a recommendation or an expected land use with deontic expressions (i.e., permissible-impermissible, obligatory-omissible, optional, and ought) for an activity or use or physical development imposed on a spatial unit accommodated in SP_PlanUnit. The SP_PlanUnit contains detailed prescriptions or specifications of an activity and physical development at spatial unit level (see the requirement 5–4 in Table 4).

SP_PlanUnitGroup has an aggregation relationship with SP_PlanGroup (see Fig. 19). The plan unit groups are the areas corresponding to the higher planning levels with related boundaries and space function as sketched by the higher plan level authorities.

The class SP_PlanGroup is to accommodate hierarchy in spatial planning, such as: (a) regional-wide (e.g., European regions), (b) country-wide (e.g., Indonesia, the Netherlands, so forth), (c) island, (d) state or province, (e) municipality or city, and (f) urban or rural (see the requirement 5–6 in Table 4).

The class SP_Permit contains permit related information as issued by authorities to parties fitting in the relevant plan unit. A permit is an explicit proof of a right (to perform an action) granted by authorities and granted to parties fitting within the relevant plan unit, that is, the object having the correct function for the requested location (see the requirement 5–7 in Table 4).

The Spatial plan information package (Indrajit et al., 2020) reuses core LADM classes from the party package, and administrative package to represent the parties in spatial planning processes. This package models parties involved in providing legal aspects (RRRs) from spatial planning processes using classes of Party package in Part 2. Fig. 22 illustrates the LA_SubSpatialUnit (see ISO 19152–1) as an intermediate class in order to accommodate sub-parcel division from land administration to spatial planning processes. Subspatial units, or subparcels, can be used for grouping to a spatial unit. This is realised by a composition relationship of LA_SpatialUnit onto itself where LA_SubSpatialUnit may be used to integrate a plan unit with multiple functions and spatial units. If there is a hierarchy between subspatial units then the term spatial unit can be used in an interchangeable way. In addition, LA_AdministrativeSource (ISO 19152–1) and LA_SpatialSource (ISO 19152–2) classes from the core LADM are utilised to represent instances of sources

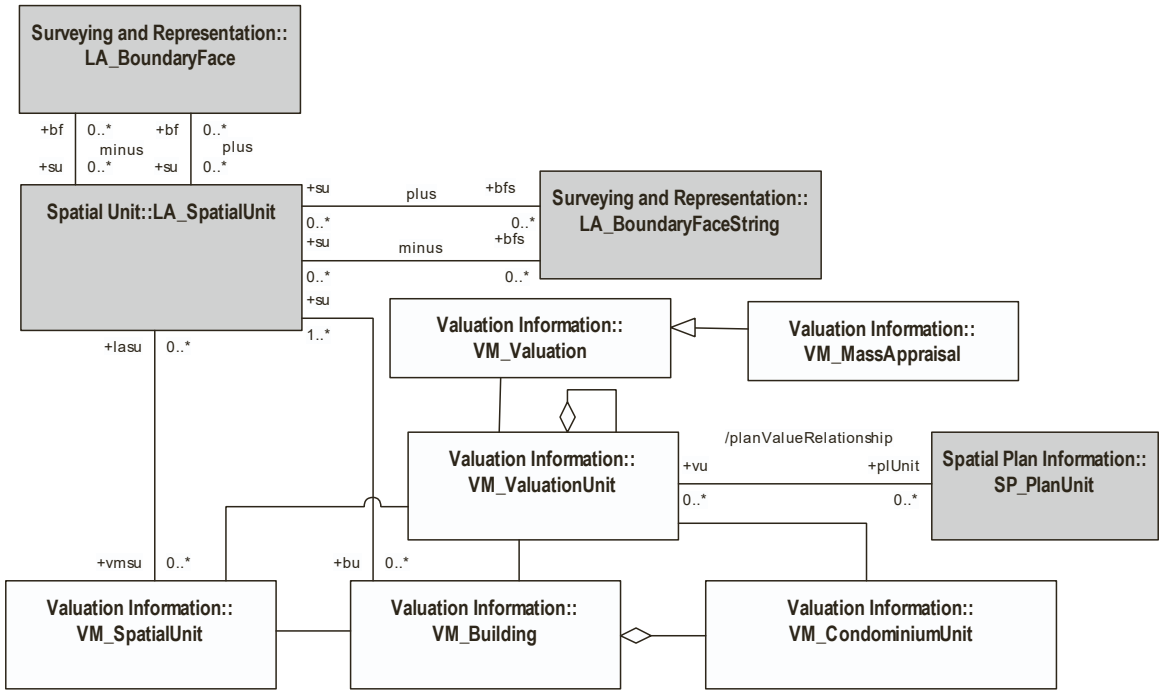

Fig. 19. Part 4 relationships with the other parts of LADM.

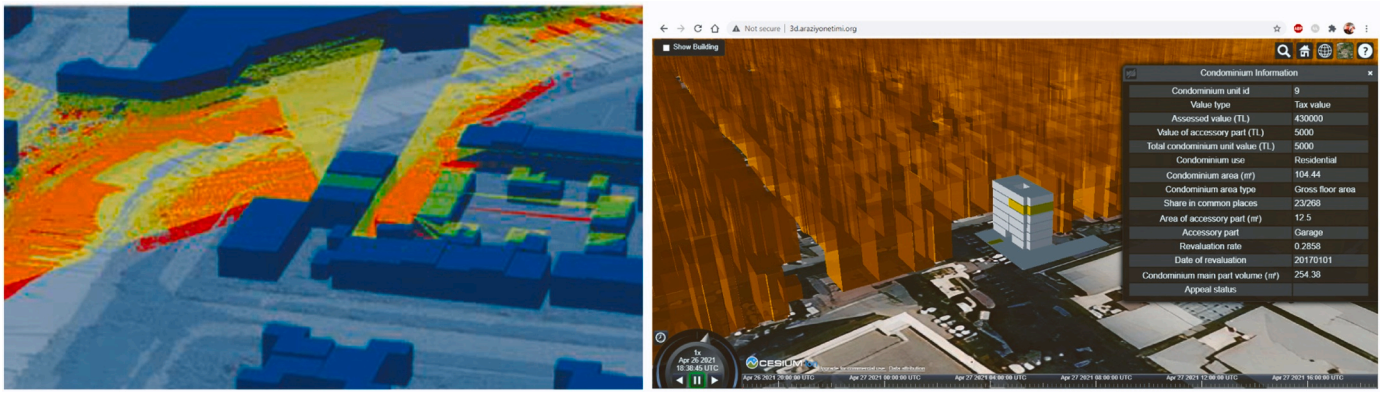

Fig. 20. (left) Viewshed polygons for two levels: yellow area is only visible top floor, red area is only visible at one level lower and orange area is visible by both top floor and floor below (from light blue part of building), (right) LADM Valuation information model-based prototype for dissemination.

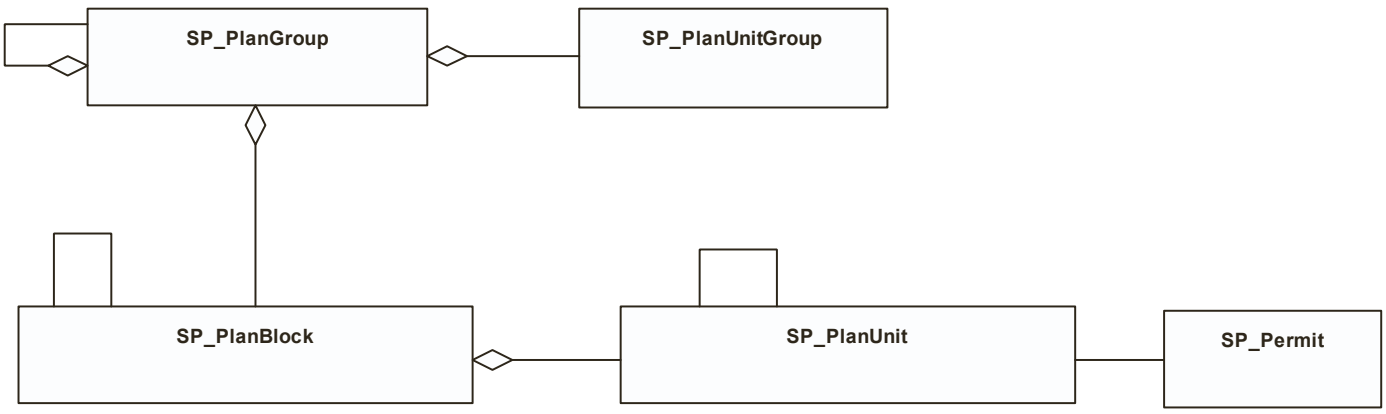

Fig. 21. Classes of the Spatial plan information package.

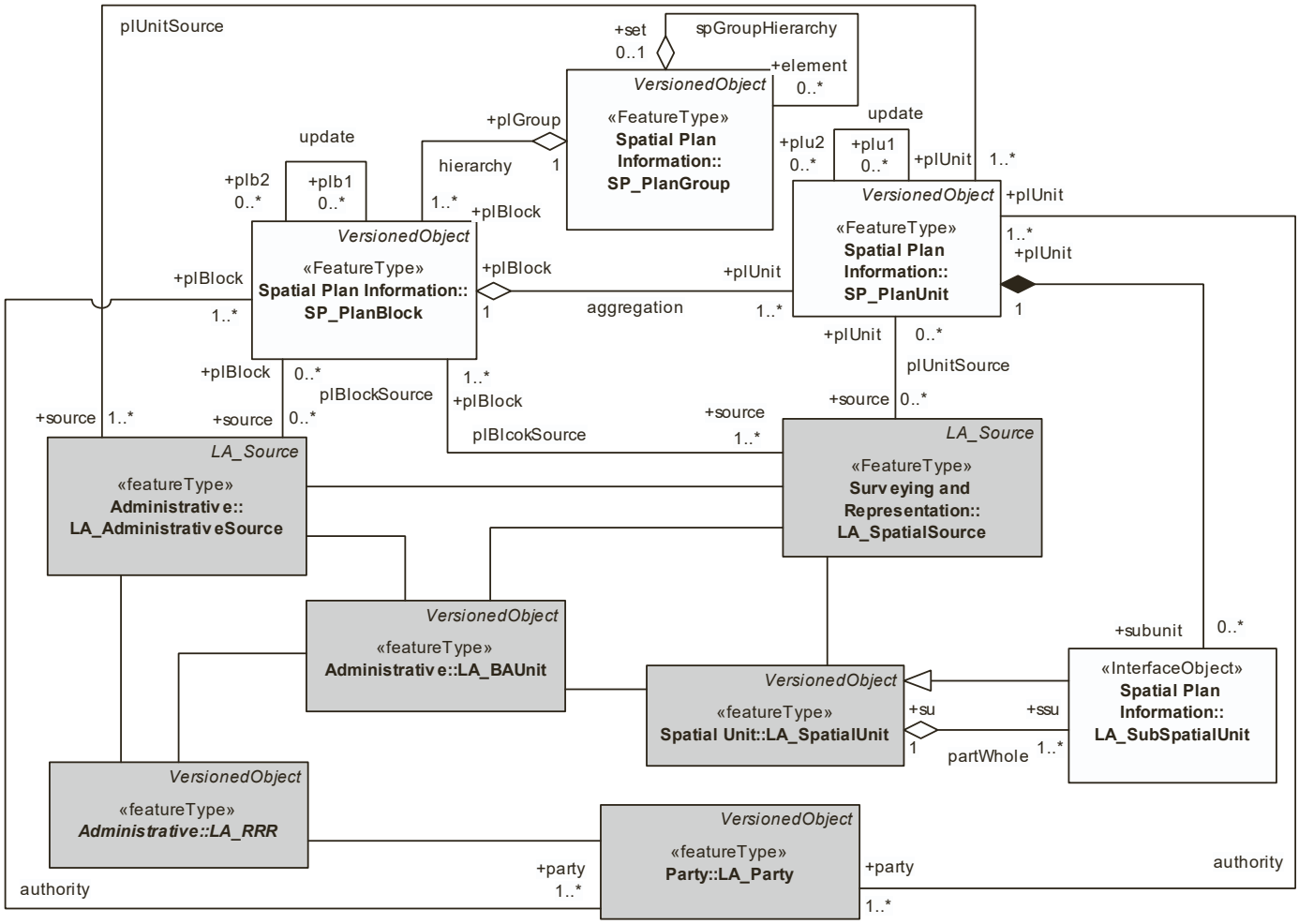

Fig. 22. Part 5 relationships with Part 2.

related to the spatial plan processes.

Fig. 23 shows the relationships between parties and permits. Two association relationships are specified between the classes SP_Permit and LA_Party: grantedBy and grantedTo. SP_Permit is also associated to one or more instance(s) of LA_Source.

Similar to the other part, there is a strong development that spatial plan information described more and more in 3D. Indrajit et al. (2021) developed a prototype for web-based dissemination system for 3D spatial plans in Indonesia for the cities of Jakarta and Bandung. Next to the spatial plans it was also possible to show 3D building and compare them to the spatial plans; see Fig. 24 (see the requirements 5–2 and 5–3 in Table 4).

Kalogianni et al. (2020a) and (2020b) claim that the relationships between people and land in vertical space can no longer be unambiguously represented in 2D. The current societal demand for sustainability in a collaborative environment and a lifecycle-thinking, is driving the need to integrate independent systems with standalone databases and methodologies, associated with different aspects of the Spatial Development lifeCycle (SDC). In this context it should be considered that financial, building/construction permit, occupancy, maintenance historical process and other information are vital aspects of an object's lifecycle and should be maintained and exchanged between its various phases in interaction with information from different databases.

8. Discussion

Developing a land administration framework is a complex task due to the need to accommodate a diverse range of regulatory and policy requirements. Ensuring interoperability between various technologies and systems is crucial in ensuring the necessary adaptability. There is a growing need to assist developing nations in implementing cost-effective, interoperable land administration systems, to modernise current manual processes, and to introduce automated solutions that can be easily adapted to new data sources and technologies. The success of a proposed land administration framework lies in its ability to support the unique regulatory and policy environments that exist in different jurisdictions and nations (OGC, 2019).

With the extended scope, LADM Edition II can support the development of interoperable systems in the context of land administration. Fig. 25 shows the class diagram of LADM Edition II parts 1, 2, 4 and 5 and their (inter)relationships. Some of the relationships are not visible for readability purposes. The VersionedObject class and its relationships, LA_Party, LA_BoundaryFaceString, LA_BoundaryFace and some of the relationships of LA_Source and its subclasses, are not shown in the diagram. The same colours for LADM classes are used in Fig. 25 as in Table 1.

9. Conclusion

The operationalisation of the LADM Edition I creates opportunities for LA service providers and vendors of Geographic Information Systems (GIS), Document Management Systems (DMS) and Database Management Systems (DBMS) to offer innovative products, services and applications for LA. This in turn enhances the ability of land registry and cadastral organisations to design, develop, implement and maintain

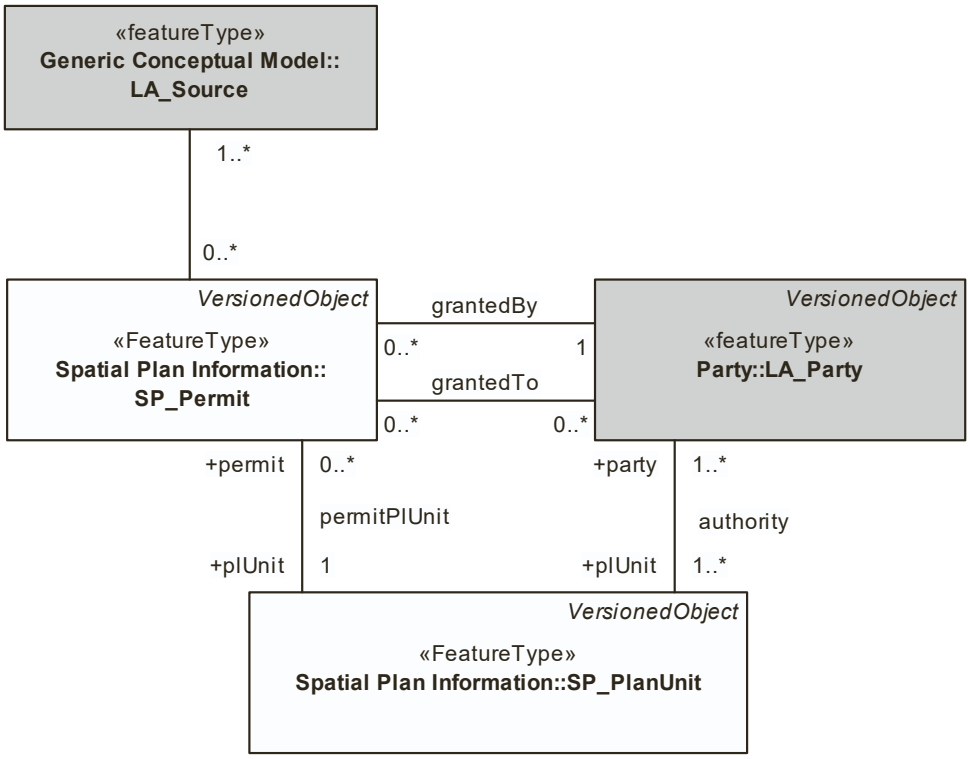

Fig. 23. SP_Permit and its relationships with plan unit and core LADM.

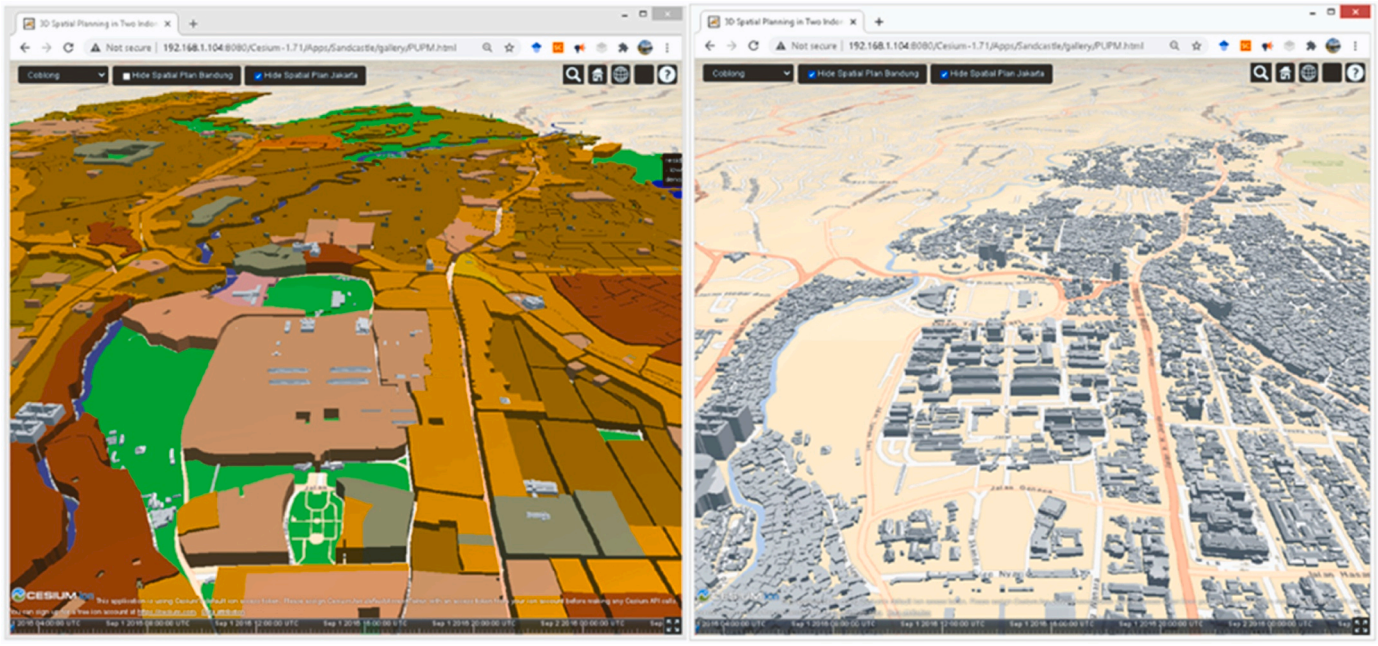

Fig. 24. 3D spatial plans, left spatial plans and buildings (sometimes extending outside the plans), right all buildings (from http://pakhuis.tudelft.nl:8080/edu/cesium74/pupm/).

their systems with greater efficiency. Specifically, the GIS and database industry has already begun to adopt LADM functionality. For example, ESRI's ArcGIS Parcel Fabric, which provides a framework for managing, manipulating and sharing parcel data, is designed with LADM in mind (Bar-Maor, 2022), and LADM and STDM are used in Trimble's Fit-for-Purpose (FFP) land management solutions. Furthermore, several countries have developed a country profile (see Kalogianni et al., 2021) to improve their land administration systems. The data structure of the Solutions for Open Land Administration (SOLA) software[3] developed for responsible governance of tenure by FAO is based on LADM, while the database model of the Mapping Approaches for Securing Tenure (MAST) application developed by United States Agency for International

[3] FAO Solutions for Open Land Administration (SOLA): https://www.fao.org/tenure/sola-suite/about/ru/

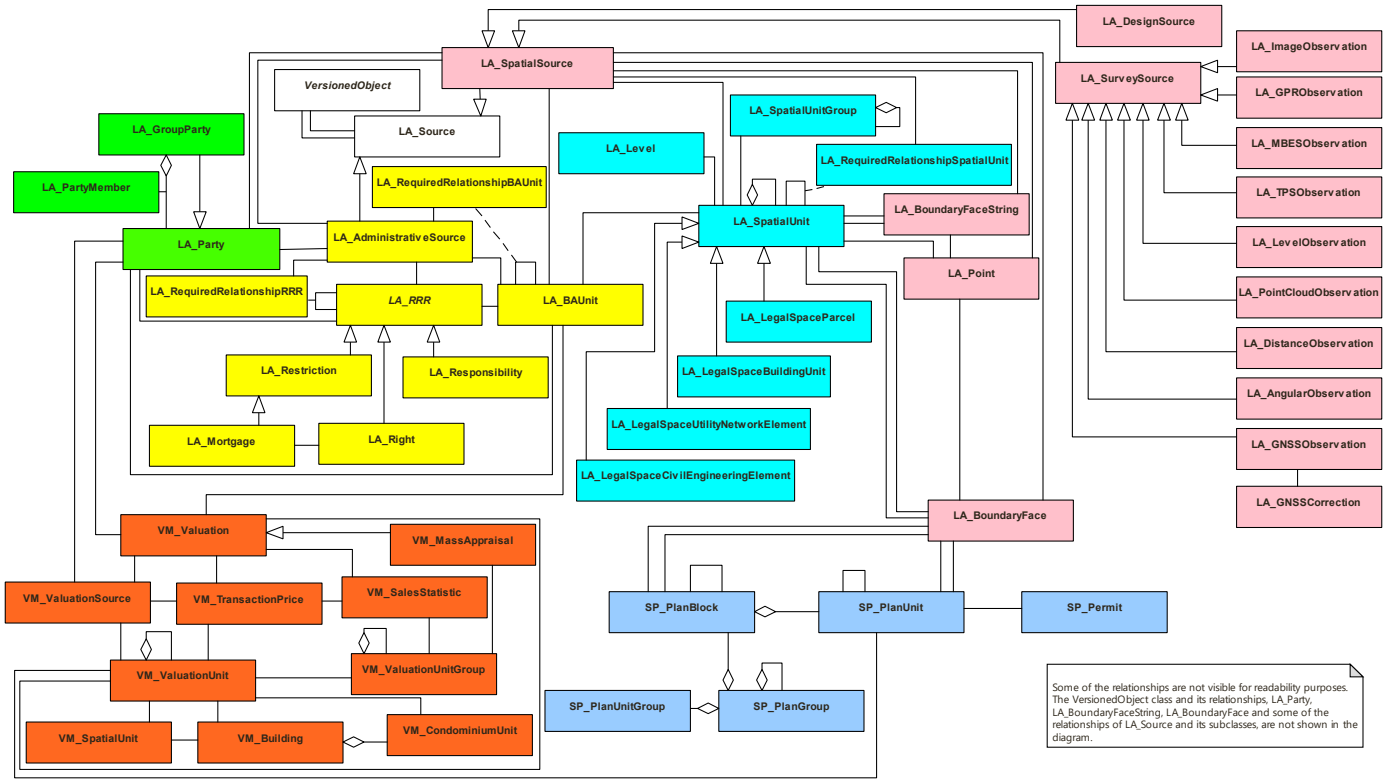

Fig. 25. LADM Edition II parts 1, 2, 4 and 5 and their relationships (no more changes expected in further development).

Development (USAID)[4] for helping communities manage, document, and secure their land and resource rights is developed complaint with LADM (USAID, 2018).

LADM Edition II extends this capability to marine georegulation, valuation and spatial planning organisations. In addition, 3D aspects are further supported by new developments (e.g., refined survey model, new types of spatial units, 3D spatial profiles, BIM/IFC as design source). It should be noted that other parts (parts 4 and 5) also support 3D in all aspects. With these new extensions, LADM Edition II now provides a harmonised data model covering all land administration functions that can lead to the development of interoperable land administration systems. In fact, the new functionalities of LADM Edition II have already started to be used by researchers, e.g., several country profiles have been developed using Part 4 (e.g. Kara et al., 2021; Tomić et al., 2021; Buuveibaatar et al., 2023; Demetriades et al., 2023; Sladic et al., 2023) for effective management of valuation information. Similar observations can be made for Part 5 (e.g. Indrajit et al., 2020; Indrajit, 2021) for conversion of planned land use information into RRRs. Furthermore, with the extended scope LADM Edition II can support several SDGs, see Unger et al. (2023) and Chen et al. (2023). According to the assessment of ISO/TC 211,[5] LADM Edition II may contribute to the SDGs 1 (no poverty), 2 (zero hunger), 5 (gender equality), 8 (decent work and economic growth), 9 (industry, innovation, and infrastructure), 11 (sustainable cities and communities), 14 (life below water), and 15 (life on land).

This paper provides an overview of the structure of LADM Edition II and its capabilities in support to land administration. The six parts of LADM Edition II are briefly described, and their maturity on the ISO revision process is presented.

The structure, refinements and new content proposed by editors are evaluated, commented on, and improved by the LA experts by means of ISO validation mechanism. According to the voting results in the NWIP stage for the Parts 1–5, all parts received a positive vote, see Fig. 26. This shows that the ISO/TC 211 P-members have evaluated and approved the proposed package structure, refinements and new content.

LADM Edition II adds capabilities to support marine space georegulation (not presented in this paper), valuation information, spatial plan information (supporting spatial development) and is closer to implementation (also technical models and processes). This makes LADM Edition II's coverage of land administration/georegulation more complete, which is important if the aim is to harmonise models from these closely related LA sub-domains. The votes received on the parts may indicate that the international LA community is satisfied with the proposed refinements and developments.

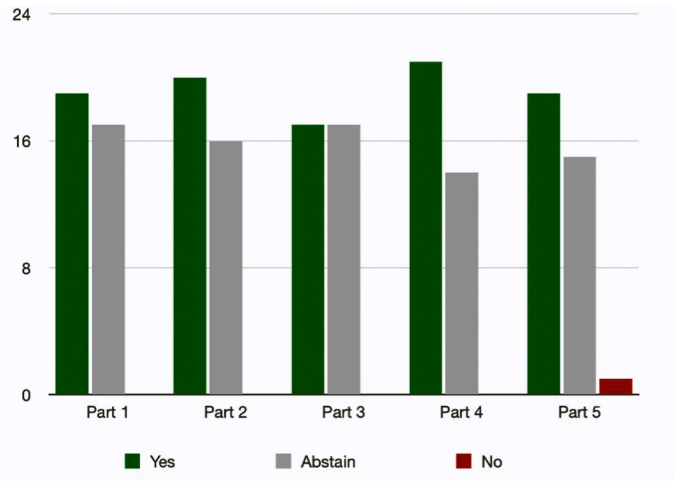

Fig. 26. NWIP voting results for the Parts 1–5.

[4] MAST USAID: https://www.land-links.org/tool-resource/mapping-approaches-for-securing-tenure-mast-learning-platform/ and https://github.com/MASTUSAID

[5] https://www.iso.org/standard/51206.html?browse=tc

Part 6 is planned to cover a methodology for developing an LADM country profile, an abstract framework for representing LA workflows (processes), a metamodel for structuring and managing semantically enriched code list values, and support for different encodings (e.g., GML, INTERLIS, RDF, GeoJSON, etc.). In addition, Part 6 is expected to include the OGC API family of standards-compliant recommendations for the development of interoperable LADM schema-based information systems. Furthermore, the relationships between the LADM and the instruction guidelines for property measurement, such as the International Property Measurement Standards (IPMS) and the International Land Measurement Standard (ILMS), is planned to be included in the processes section of Part 6.

CRediT authorship contribution statement

Kara Abdullah: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **Lemmen Christiaan:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Van Oosterom Peter:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Conceptualization. **Kalogianni Eftychia:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Alattas Abdullah:** Writing – review & editing, Writing – original draft, Conceptualization. **Indrajit Agung:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Christiaan Lemmen reports financial support was provided by University of Twente. Christiaan Lemmen reports a relationship with University of Twente that includes: non-financial support. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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