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The Land Administration Domain Model

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ABSTRACT

Societal drivers including poverty eradication, gender equality, indigenous recognition, adequate housing, sustainable agriculture, food security, climate change response, and good governance, influence contemporary land administration design. Equally, the opportunities provided by technological development also influence design approaches. The Land Administration Domain Model (LADM) attempts to align both: the data model provides a standardised global vocabulary for land administration. As an international standard it can stimulate the development of software applications and may accelerate the implementation of land administration systems that support sustainability objectives. The LADM covers basic information-related components of land administration including those over land, in water, below the surface, and above the ground. The standard is an abstract, conceptual model with three packages related to: parties (people and organisations); basic administrative units, rights, responsibilities, and restrictions (ownership rights); spatial units (parcels, and the legal space of buildings and utility networks) with a sub package for surveying, and representation (geometry and topology). This paper examines the motivation, requirements and goals for developing LADM. Further, the standard itself is described and potential future maintenance. Despite being a very young standard, 'born' on 1st December 2012, it is already possible to observe some of the impact of LADM: examples are provided.

Introduction

The work described in this paper is the first successful attempt to create an accepted international standard in the land administration domain.

Land administration is a large field; the focus of the LADM is on that part of land administration that is interested in rights, responsibilities and restrictions affecting land (or water), and the geometrical (geospatial) components thereof. The LADM is a conceptual model, and not a data product specification. The LADM is a descriptive standard, not a prescriptive standard. Domain specific standardisation is needed to capture the semantics of the land administration domain on top of the agreed foundation of basic standards for geometry, temporal aspects, metadata and also observations and measurements from the field. The standard for the Land Administration Domain serves the following goals:

- establishment of a shared ontology implied by the model. This allows enabling communication between involved persons (information managers, professionals, and researchers) within one country and between different countries. This is relevant in the determination of required attributes and in setting responsibilities on maintenance of data sets in case of implementation of Land Administration in a distributed environment with different organisations involved. This is also in support of the development of land administration systems as core in Spatial Data Infrastructure, SDI, or: Geo Information Infrastructures (GII). One more issue is globalisation; there are already ideas for and approaches to international transactions, e.g. within the European Union. Also in relation to carbon credits registration,
- support for the development of the application software for land administration. The data model is the core here. Support in the development of land administration systems means provision of an extendable and adaptable fundament for efficient and effective development based on a Model Driven Architecture (MDA). This approach offers automatic conversions from models to implementation, where local details can be added to the conceptual model first,
- facilitation of cadastral data exchange with and from a distributed land administration. Within SDI (GII) combinations of

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land administration data with other data sources should be possible. For example legal data related to cadastral objects with data from other sources describing physical objects as roads, buildings or utilities. Exchange can be between cadastres, land registries and municipalities and between countries in a federal state or between countries; etc., and:
- support for data quality management in land administration. Use of standards contributes to the avoidance of inconsistencies between data maintained in different organisations because data duplication can be avoided as much as possible. It should be noted here that a standardised data model, which will be implemented, can be supportive in the detection of existing inconsistencies. Quality labels are important for all attributes.

A specialisation, or perhaps arguably a generalisation of LADM, is the Social Tenure Domain Model (STDM); see (Augustinus et al., 2006; Augustinus, 2010; FIG, 2010). Developed in parallel to LADM, it broadens the scope of land administration. It provides a land information management framework that integrates state based and non-state based land systems. It also integrates administrative and spatial components. Doing so, the model describes relationships between people and land in an unconventional manner: it has the power to tackle land administration needs in communities, such as people in non-state recognised settlements and customary areas. The emphasis is on social tenure relationships as embedded in the continuum of the land rights concept promoted by the Global Land Tool Network and by UN-Habitat (UN-Habitat, 2008).

In this paper the Land Administration Domain Model (LADM) and its design and development are presented. The paper has synthesises progressive developments outlined in earlier works (Lemmen, 2012; Lemmen et al., 2013a,b). First, the motivation, background and goals of LADM are provided in "LADM motivation, background and goals". LADM supports land administration system development. Land administration and land administration systems support the implementation of the contemporary societal demands, embodied in land policies (cf. UN/ECE, 1996). That is, the land administration design should align with the societal requirements as described in Byamugisha (2013), CheeHai (2012), Enemark (2012), FAO (2012), FIG (2010), and UN-Habitat (2003, 2004, 2008, 2012). An efficient means for achieving this alignment is through the development and utilisation of a land administration standard. In other words: a standard can bridge the gap between land policies and information management opportunities. In this regard, LADM must be broadly accepted: it should be adaptable to local situations (Lemmen, 2012). An overview of LADM requirements is given in "LADM requirements". The LADM as available in the International Standard ISO 19152 is presented in "The LADM (ISO 19152)", is based on the common pattern of 'people–land' relationships. The model should cover the basic data related components of land administration (legal/administrative, mapping and surveying) and it should satisfy diverse user requirements. The domain model in its implementation can be distributed over different organisations with different tasks and responsibilities. A very first overview of LADM impact and future developments are discussed in "Impact of LADM and future developments" and "Conclusions and recommendations" are presented.

LADM motivation, background and goals

Contemporary political objectives including poverty eradication, gender equality, indigenous recognition, adequate housing, sustainable agriculture, food security, climate change response, and good governance, substantially relate to access to land, and to land-related opportunities. How governments commence dealing with issues relating to land access and use, is often defined as land policy (UN/ECE, 1996). However, a robust land policy is one thing, having the tools to enforce the policy is another altogether: the well-regarded land policies of Kenya and Namibia, amongst others, provide testament. Consequently, governments need instruments like regulations and administrative procedures to support land tenure security, land markets, land use planning and controls, land taxation, and the management of natural resources. It is within this context that the function of land administration systems can be identified: a supporting tool to facilitate the implementation of a land policy in the broadest sense.

Even in contemporary times, most countries (states or provinces) develop their own unique land administration systems. Some countries operate a deed registration, while other operates a title registration. Some systems are centralised, and others decentralised. Some systems are primarily based on a general boundaries approach, others on fixed boundaries approach. Some land administration systems have a fiscal background, others a legal one (Bogaerts and Zevenbergen, 2001; UN/ECE, 1996). However, organisational structures with distributed responsibilities and ever-changing system requirements make the separate implementation and maintenance of land administration neither cheap nor efficient. Furthermore, different implementations of land administration systems complicate cross-jurisdiction system interoperability (e.g. in an international context such as within Europe or in a national context (e.g. in a less developed country) where it may happen that different partners in development co-operation on design and provide different land administration systems without co-ordination).

Standardisation is supportive and helpful in design and (further) development of land administration systems. It is relevant to keep data and process models separate, this means that (inter-organisational) processes can be changed independent from the data sets to be maintained. The data model can be designed in such a way that transparency can be supported: this implies inclusion of source documents and inclusion of the names of persons with roles and responsibilities in the maintenance processes of the data model.

Standardisation is a well-known subject in the field of land administration. Standardisation concerns a prescribed approach to the identification of parcels, documents, persons, control points and many other issues. It concerns the repeatable organisation of tables in the registration and references from those tables to other components (e.g. source documents and maps) including archives. It concerns agreed methods for coding and use of abbreviations, (e.g. for administrative areas). It also concerns set workflows. All this is valid for both paper based and for digital land administration systems.

LADM requirements

Internationally, the demand for a widely accepted standardised domain model in land administration emerged in the early 2000s, partly as a result of Cadastre 2014 (Kaufmann and Steudler, 1998) and more generally from discussions regarding technological opportunity and societal demands embedded in land policies. This wish was supported by the International Federation of Surveyors (FIG) and UN-Habitat and also by the Food and Agricultural Organisation (FAO) of the United Nations (UN).

It was required that the data model should be able to function as the core of any land administration system. The standard had to be flexible, widely applicable and function as a gathering point of a state-of-the-art international knowledge base on this theme. After an extensive design and development procedure, starting in 2002 within the FIG and from 2008 within ISO TC211, and involving many stakeholders from UN Habitat, EU/Joint Research Centre,

Table 1
LADM requirements.

No.	Requirement	Impact
1	A continuum of land rights	The Triple Object (Spatial Unit) – Right (RRR) – Subject (Party) is the common pattern for land administration and is the basic structure (Lemmen, 2012). Groupings of objects or subjects should be supported. The flexibility of the model should be based on the recognition that people's land relationships appear in many different ways, depending on local tradition, culture, religion and behaviour. It should be possible to merge formal and informal tenure systems in one environment. *Land rights* may be formal ownership, apartment right, usufruct, freehold, leasehold, or state land. It may be social tenure relationships like occupation, tenancy, non-formal and informal rights, customary rights (which can be of many different types with specific names), indigenous rights, religious rights, possession, or: *no land rights (no access to land).* There may be overlapping tenures, claims, disagreement and conflict situations. This is an extensible list to be filled in with local tenancies – flexible and extensible coding of types of rights and restrictions, etc. is needed. People–land relationships can be expressed in terms of *parties having (social) tenure relationships to spatial units*. This is in support to access land for all (UN-Habitat, 2008). It is in support to LA requirements as in (FAO, 2012).
2	A continuum of land use right claimants (subjects or 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. It should be noticed that a person can hold a *share* in a right, e.g. in case of marriage, or groups of persons holding rights. Women's access to land can be organised by registration or recordation of shares in rights.
3	A continuum of spatial units (objects)	Representation of a broad range of spatial units, with a clear quality indication, should be possible. *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 – see for example Fourie (1998) and Fourie and Nino-Fluck (2000). See also the 'axes of variation' in Larsson (1991).
4	A basic administrative units (or Basic Property Unit)	In combination to the Triple Object – Right – Subject the constellation of basic property units should be supported. The purpose of a basic administrative unit is the grouping of spatial units, which have the same rights, etc. attached. A basic property unit can have a unique identifier – meaning that all spatial units belonging to this basic property unit have the same identifier). A property unit can play the role of a Party: a property unit may be owned by one or more other property units. To get a generic terminology the BPU should be called 'Basic Administrative Unit'.
5	A range of data acquisition methods	Surveying should be supported; boundary should be included in relation to 'Object' in this Triple. 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 should be distincted 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. In rural areas there can be spatial units covering customary areas. Those spatial units can be recorded as 'text based' spatial units, where boundaries are described in words. Or as 'line based' spatial units, drawn on low accurate satellite images. The tribe may be represented by its chief. Formal property based spatial units can concern formally registered ownership with a related owner and with identified boundaries by accurate field surveys. The (social) tenure relationship to the spatial units may be represented by points collected with (hand-held) GPS instruments – source documents may be printed from websites providing spatial data. Spatial units in urban business districts can be conventional parcels with high accurate boundaries. Spatial units in residential areas can be derived from aerial photographs. Or total stations, radar detection, recording, cyclomedia, Pictometry, or other sensors can be used. Digital video or voice recording are also possible; see Barry (2005). Data quality of spatial data may be improved in a later stage of development. *Note: Person identification is not a primary responsibility of cadastre and land registry, but might be of relevance in LA processes. It can be observed that biometric approaches are coming more and more available; in passports, in access to countries. Identification documents can be 'time-line' disrupted when new documents are provided. It should be possible to link fingerprints to points (co-ordinates).*
6	A range of authentic source documents	Inclusion of new data and data updates should be documented. This concerns legal administrative data, spatial data and technical data. Updating in one organisation may need updating in another organisation.
7	Transparency	The names of persons responsible for transactions are part of the data set (conveyors, surveyors, registrars, etc.). All updates should be traceable. This is one reason for management of history and for documentation of all updates.
8	History	Distributed systems or users may not only be interested at the current state of objects, but they may need a historic version of these objects. It may be that the organisation responsible for the maintenance of the objects is not interested in history; the distributed use may require this. Deed based systems require maintenance of history, title based systems may require maintenance of history, e.g. in case of distributed systems.
9	Different organisations	In FIG (1999) it is highlighted that the *flow* of information relating to land and property between different government agencies and between these agencies and the public must be encouraged. Whilst access to data, its collection, custody and updating should be facilitated at a *local level*, the overall land information infrastructure should be recognised as belonging to a *national* uniform service to promote sharing within and between nations. See also Williamson and Ting (2001). 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 is expected to 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 (diagram), thereby using other parts of the model. *Note*: this implies that it must be possible to use data in data infrastructures – where data are produced by different organisations. There are opportunities for greater cost effectiveness in areas such as subcontracting work to the private sector; increasing cost recovery through higher fees, sales of information, and taxes; and by linking the existing land administration records with a wider range of land information. See also Bogaerts and Zevenbergen (2001) and Fourie (1998). Organisations are becoming more dependent of each other and are in fact forced to openness (of systems) and exchange (of data). Developments such as chain orientation, digitisation and new technologies are leading to the fading of physical product concepts.
10	Keep data to the source (within 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.

Table 1 (*Continued*)

No.	Requirement	Impact
11	Existing standards	Existing ISO and OGC standards should be followed, particularly the ISO 191XX *geographic information* standards. Furthermore, LADM should be based on the conceptual framework of 'Cadastre 2014' (Kaufmann and Steudler, 1998). The layers of the Cadastre 2014 Model map well to GIS layers, each layer has associations with non-spatial tables, the layer set-up has to be flexible, and geometry can be based on ISO geometry and ISO topology. A remark related to the Cadastre 2014 principle of legal independence is that it should be possible to include *explicit relations* between different themes, e.g. rights and restrictions. Overlays are not accurate enough in many cases.
12	Reference system	Provisions must also be made to accommodate future changes in the network that may occur as a result of technical improvements. These may affect all co-ordinate based systems. If co-ordinates are an essential component of the cadastral system than the survey technique must be capable of producing these. Imagery can be used depending on the user requirements, cost, and timing among other factors. It should be possible to include all documentation on data collected as evidence from the field.
13	Identifiers	A key component in LASs is the spatial unit identifier (UN/ECE, 2004), 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. Identifications should be free of semantics, there is a need for 'identification' providers, e.g. for parcels, areas, names, rights, restrictions, taxation, mortgage, land use, survey and document.
14	Quality	Users of cadastral information need clarity, simplicity and speed in the registration process. The information must be as complete as possible, reliable (which means ready when required), and rapidly accessible. 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. Generic versioning and quality labelling for all contents of LADM is needed.

International Federation of Surveyors and representatives from South Africa, The Netherlands, Canada, Japan, Kenya, South Korea, USA, Finland, Sweden, Germany, France, Hungary, Malaysia, Thailand, Denmark, Australia and Spain. This standard was now published by the International Organisation for Standardisation ISO in December 2012.

The development of LADM is based on user needs: a comprehensive overview of requirements for the Land Administration Domain is available in (Lemmen, 2012; Table 1). Open markets and globalisation require a shared ontology allowing enabling communication between involved persons within one country and between different countries. Effective and efficient system development and maintenance of flexible (generic) systems ask for further standardisation. A standardised land administration domain model should be as simple as possible, in order to be useful in practice. Additionally, it should be adaptable and adoptable to local situations. Moreover, the technology adopted should be sufficiently flexible to meet future needs and to permit system growth and change.

The LADM (ISO 19152)

A common denominator, or the pattern can be observed in global land administration systems: legal/administrative data, party/person/organisation data, spatial unit (parcel)/immovable object data, data on surveying or object identification and geometric/topological data are all included (Lemmen, 2012). Along with the requirements and drivers discussed above, these were the initial basis for LADM design. Subsequently, the design of the LADM occurred incrementally. After preparatory works of almost six years the LADM was submitted to the ISO and parallel to CEN, this is the Comité Européen de Normalisation.

The Draft International Standard, published by ISO as ISO 19152, covers basic information related to components of land administration (including water and elements above and below the earth's surface). It includes agreements on data about administrative and spatial units, land rights in a broad sense and source documents (e.g. deeds or surveys). The rights may include real and personal, formal rights as well as indigenous, customary and informal rights. All types of restrictions and responsibilities can be represented. The draft standard can be extended and adapted to local situations; in this way it is argued that most, if not all, people–land relationships may be represented.

The UML class diagram is represented in Fig. 1. The three main packages of the LADM consist of the Party package (green), the Administrative package (yellow) and the Spatial Unit package (blue) with its sub package Representation and Survey (red).

The main class of the party package (see Fig. 2) of LADM is class LA_Party with its specialisation LA_GroupParty. There is an optional association class LA_Party-Member. A Party is a person or organisation that plays a role in a rights transaction. An organisation can be a company, a municipality, the state, or a church community. A 'group party' is any number of parties, forming together a distinct entity. A 'party member' is a party registered and identified as a constituent of a group party. This allows documentation of information to membership (holding shares in rights).

The administrative package (see Fig. 3) concerns the abstract class LA_RRR (with its three concrete subclasses LA_Right, LA_Restriction and LA_Responsibility), and class LA_BAUnit (Basic Administrative Unit). A 'right' is an action, activity or class of actions that a system participant may perform on or using an associated resource. Examples are: ownership right, tenancy right, possession, customary right or an informal right. A right can be a use right. Rights may be overlapping or may be in disagreement. A 'restriction' is a state based or non-state based entitlement to refrain from doing something; e.g. it is not allowed to build within 200 m of a fuel station; or servitude or a mortgage (class LA_Mortgage) as a restriction to the ownership right. A 'responsibility' is a formal or informal obligation to do something. A 'ba unit' (an abbreviation for 'basic administrative unit') is an administrative entity consisting of zero or more spatial units (parcels) against which one or more unique and homogeneous rights (e.g. an ownership right or a land use right), responsibilities or restrictions are associated to the whole entity as included in the land administration system. An example of a 'ba unit' is a basic property unit with two spatial units (e.g. an apartment or a garage). A 'basic administrative unit' may play the role of a 'party' because it may hold a right of easement over another, usually neighbouring, spatial unit. There may be relationships between BAUnits.

The spatial unit package (see Fig. 4) concerns the classes LA_SpatialUnit, LA_SpatialUnitGroup, LA_Level, LA_LegalSpace Network, LA_LegalSpace-BuildingUnit and LA_Required RelationshipSpatialUnit (this class is not represented in Fig. 4). A 'spatial unit' can be represented as a text ("from this tree to that river"), a point (or multi-point), a line (or multi-line),

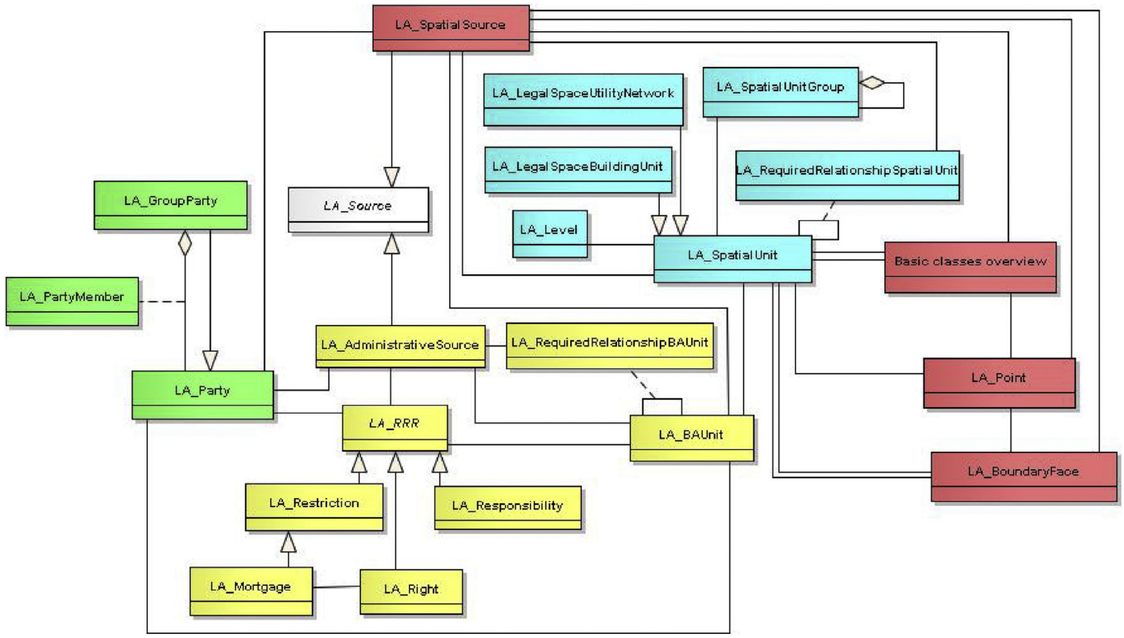

Fig. 1. The Land Administration Domain Model. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

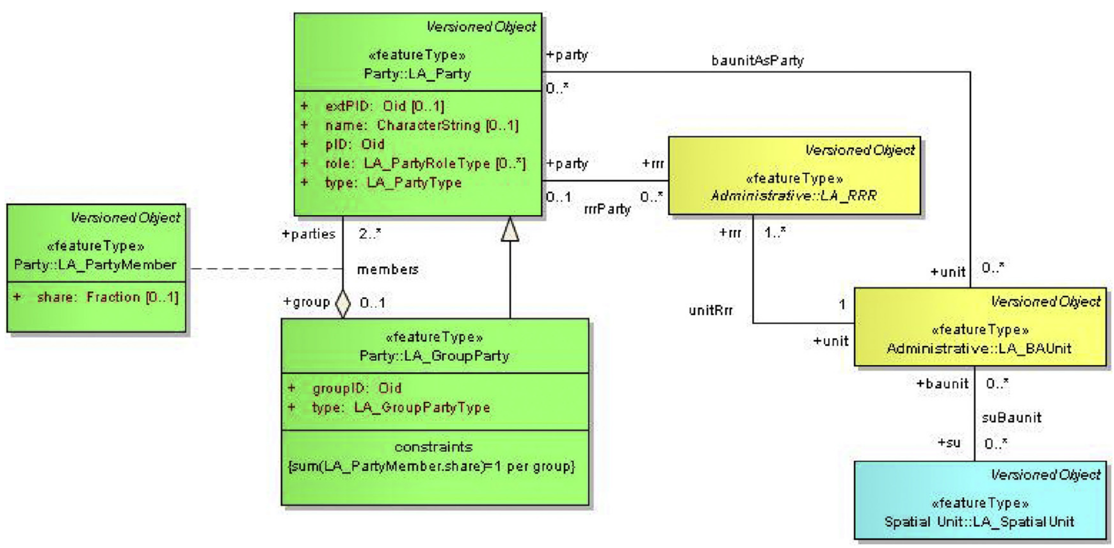

Fig. 2. Party Package (classes, with attributes, constraints, and operations).

representing a single area (or multiple areas) of land (or water) or, more specifically, a single volume of space (or multiple volumes of space). Single areas are the general case and multiple areas the exception. Spatial units are structured in a way to support the creation and management of basic administrative units. A 'spatial unit group' is a group of spatial units; e.g.: spatial units within an administrative zone (e.g. a section, a canton, a municipality, a department, a province or a country) or within a planning area. A 'level' is a collection of spatial units with a geometric and/or topologic and/or thematic coherence.

The Spatial Unit Package has one Surveying and Representation Sub-package with classes such as LA_SpatialSource, LA_Point, LA_BoundaryFaceString and LA_BoundaryFace. Points can be acquired in the field by classical surveys or with images. A survey is documented with spatial sources. A set of measurements with observations (distances, bearings, etc.) of points, is an attribute of LA_SpatialSource. The individual points are instances of class LA_Point, which is associated to LA_SpatialSource. 2D and 3D representations of spatial units use boundary face string (2D boundaries implying vertical faces forming a part of the outside of a spatial unit) and boundary faces (faces used in 3D representation of a boundary of a spatial unit). Co-ordinates themselves either come from points or are captured as linear geometry.

All classes (except LA_Source) inherit from VersionedObject (VersionedObject is not represented in the figures). VersionedObject contains quality labels and attributes for history management. In the LADM, administrative sources and spatial sources are modelled, starting with an abstract class LA_Source. LA_Source has two subclasses: LA_AdministrativeSource, and LA_SpatialSource.

Implementation of the LADM can be performed in a flexible way; the draft standard can be extended and adapted to local situations. External links to other databases (supporting information infrastructure type of deployment), e.g. addresses, are included (see Fig. 5). Legal implications that interfere with (national) land administration laws are outside the scope of the LADM.

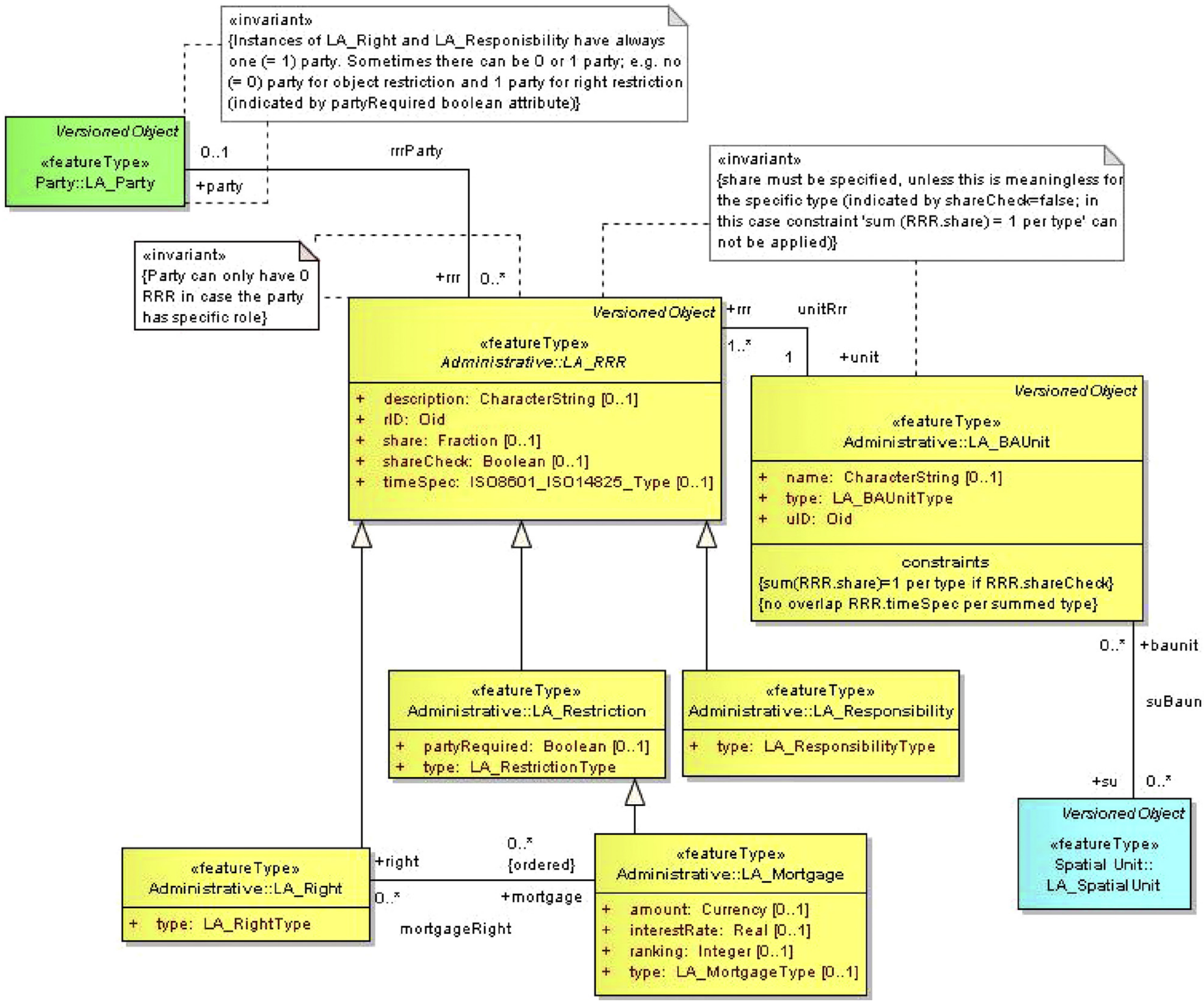

Fig. 3. Administrative package (classes, with attributes, constraints, and operations).

The LADM is organised into several packages as explained. It is likely that more packages will be developed. Besides being able to present/document the model in comprehensive parts, another advantage of using packages is that it is possible to develop and maintain these packages in a more or less independent way. LA modelling depends a lot on the scope of the models; e.g. if one Land Administration model includes a person registration and the other model just refers to a person, then the two models may look different, but the intentions are the same. Only the system boundary of the involved models is different. However, the boundary of the LADM is arbitrary in a certain sense. Perhaps, also (some of the) current packages of the model should be considered as separate models outside the LADM; or more models inside the LADM may be needed. The following is a list of classes, or packages of classes that are related to, but outside LADM:

- spatial (coordinate) reference system. It should be noted that the physical implementation of a reference system is part of conventional cadastral systems. There can be more then one reference system for different parts of the territories where such systems are implemented; e.g. one local coordinate system per village. Spatial reference systems are the basis for getting nationwide cadastral spatial data available. In LADM the Spatial Reference System (SRS) appear via the GM_Point attribute in the LA_Point, LA_Spatial Unit and LA_SpatialUnitGroup; via the GM_Curve attribute in LA_BoundayFace and via the GM_Surface attribute in LA_BoundayFace classes. In fact those attributes are re-used from ISO 19111, spatial referencing by co-ordinates; and ISO 19107 spatial schema – GM_point and GM_MultiCurve and GM_Surface are defined here. For this reason spatial reference systems are excluded from LADM, as well feature types for spatial data,
- ortho photos, satellite imagery, and Lidar and elevation models. Here it should be noted that ortho photo's and satellite imagery may be very well used as basis for data acquisition in the field of cadastral boundary data (Lemmen and Zevenbergen, 2010). The cadastral boundaries can be identified in the field on top of such images. The imagery source can be described in attributes in the LA_SpatialSource class, and in the DQ_Element attribute which is part of the LA_VersionedObject class. The images itself may included in LADM using LA_SpatialSouce,
- topography (planimetry). Again this is considered to be a domain in it itself. Topographic maps (or databases with topographic data) may be used as a basis for cadastral boundary data acquisition and maintenance; the topographic maps/data can be used as spatial source (as evidence from the field).
- geology, geo-technical and soil information. This is relevant information in relation to mining and land use (agricultural) management – those are domains in itself. The LADM supports the inclusion of attributes as results of data collection processes on

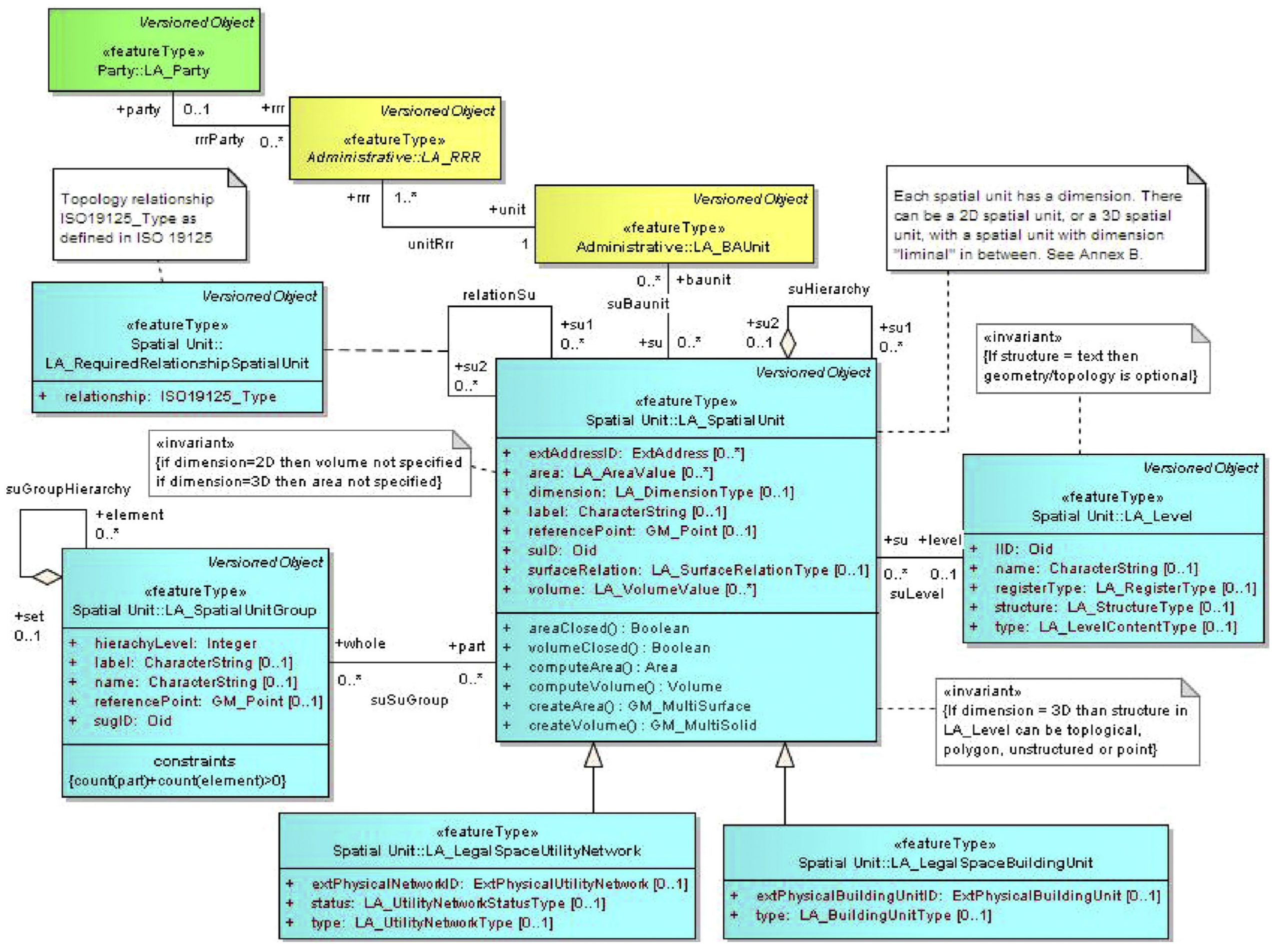

Fig. 4. Spatial unit package (classes, with attributes, constraints, and operations).

geology, soil, etc. In this way a Land Administration for mining may be built up; this would include concessions and exploration companies as parties,

- (dangerous) pipelines and cable registration. This concerns the physical registration of cables and pipelines – good external references are possible here using the extPhysicalUtilityNetworkID attribute under LA_LegalSpaceUtilityNetwork as subclass from LA_SpatialUnit. LADM is about legal space in 3D. This includes of course the registration of access to utilities as restrictions to other land rights of other parties (rights of way, encumbrances, and servitudes). It is very important to recognise that legal space around a utility cable or pipeline does not necessarily coincide with the physical space of a cable or pipeline in a network. Utilities can be invisible – antennas should "see" each other for signal transmissions. For all utilities a 3D partition of space is very helpful in representation. This may also include access to, e.g. airports,
- address registration (including postal codes). Standards for addresses are under development as ISO 19160. Addresses in LADM concern spatial unit addresses ("object" addresses) but of course parties can have addresses ("subject" addresses) – but in LADM those addresses are considered to be available via extParty class: this is the population register, or the company register. Of course the external address class as introduced here below can be included in a LADM implementation,
- building registration, both (3D) geometry and attributes (permits), this concerns the physical registration. The registration of legal space in 3D is included in LADM. Legal space does not necessarily coincide with the physical space of a building,
- natural person registration – the authentic person data are considered to be in the population register: name, date of birth, person address, sex, etc.,
- non-natural person (company, institution) registration. Same for typical attributes of non natural persons, e.g. companies,
- polluted area registration. This may be subject of registration. In fact the responsibilities as a consequence from such pollution or the restrictions following from it can be included in LADM. This domain of polluted area registration could be an extension in the future. Something similar may be valid for energy labels for buildings, mining right registration,
- cultural history, (religious) monuments registration. This can be included using local attributes defined for this purpose,
- ship- and aeroplane (and car) registration. Even car registration comes in here in case of distinction between movables and immovable's. But ships and airplanes may be defined as immovable – because there can be a mortgage established.

Most of the registration related issues identified here can be included in LADM using its basic structure and options of local extensions. In all cases the processes will not be the subject of modelling, only the outcomes of processes (steps) can be included in such extended local versions of LADM.

The (Draft) International Standard (ISO, 2011, 2012) and has been developed on the basis of a set of user requirements derived from existing literature, from experience from practise, both personal and from experts from many different countries and earlier publications on LADM, including earlier versions published within ISO (ISO/TC211, 2008a,b, 2009).

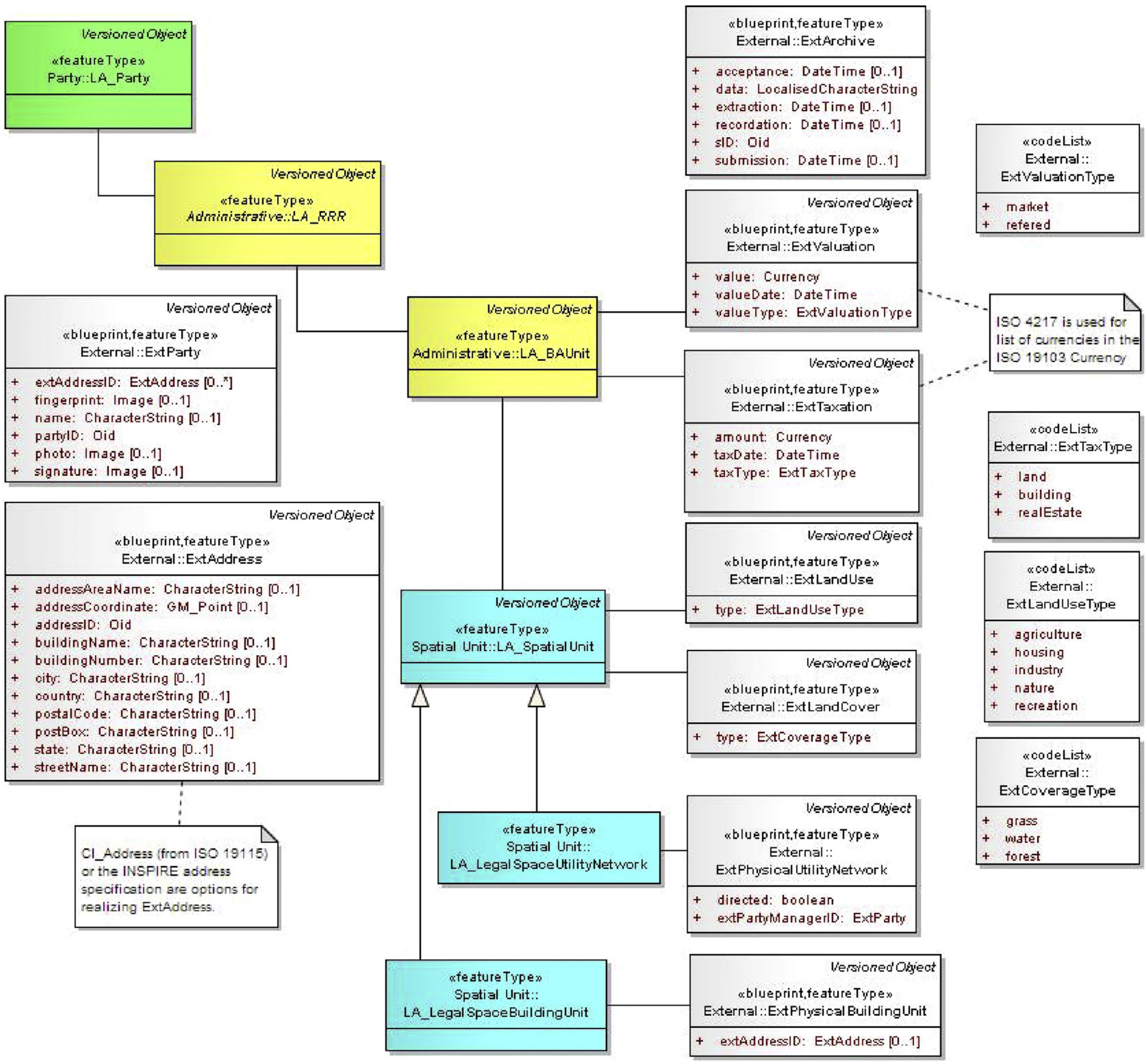

Fig. 5. External classes.

All requirements from "LADM requirements" are supported in LADM. Code lists for party type, group party type, and party role type allow for flexibility is the representation and extensibility of parties (including parties with responsibilities in transactions. Code lists for right type, restriction type, responsibility type, mortgage type, baunit type, source type allow the flexible implementation of the continuum of land rights (combined with the associations between classes). Similar code lists are available for spatial units and for area management.

LADM is maintained by ISO/TC211. Relevant existing international standards[1] have been re-used in LADM. Those data standards are accepted in the world of the Geographical Information Systems and Data Base Management Systems – and maintained by ISO TC211.

LADM is a conceptual model and is already in use as such (country profiles, integration in the data specification of cadastral parcels in INSPIRE (INSPIRE, 2009) and the Land Parcel Identification System of the European Union (ISO, 2012), basis for software development initiatives at FAO (FAO, 2011) and UN Habitat (FIG, 2010), etc., (see also Lemmen, 2012), the next steps include elaborating (via a country profile) and realizing a technical model suitable for implementation: database schema (SQL DDL), exchange format (XML/GML), and user interface for edit and dissemination. A good option for this is the collaboration between FIG and OGC to standardise this technical model (with options such as CityGML or LandXML).

Impact of LADM and future developments

LADM allows for the implementation of a rich functionality over distributed environment. Some of the offered options still have to be discovered, for example during pilots. A LADM community is developing. So far workshops have been organised in 2003,

[1] *For example*: ISO/IEC 13240:2001, Information technology — Document description and processing languages — Interchange Standard for Multimedia Interactive Documents (ISMID); ISO 19107:2003, Geographic Information — Spatial schema; ISO 19108:2002, Geographic Information — Temporal schema; ISO 19111:2007, Geographic Information — Spatial referencing by coordinate; ISO 19115:2003, Geographic information — Metadata; ISO 19125-2:2004, Geographic information — Simple feature access — Part 2: SQL option; ISO 19156:2011, Geographic information — Observations and measurements.

Enschede, the Netherlands, in 2004, in Bamberg, Germany, in 2009, Quebec City, Canada and in 2012 in Rotterdam, the Netherland, and 2013 in Kuala Lumpur, Malaysia.

The major impact of LADM will be through its recognition as an ISO standard for the domain of land administration. ISO standardisation is a comprehensive, extensive, formal process with continuous peer reviews and iterations based on experience of earlier implementations. For LADM this (creative) approach resulted in finding common denominators in land administration. The innovation is in the availability of the LADM as a basis for structuring and organising of representations of people to land related information, in databases, in a generic way. This means that the LADM is one of the tools (or better: conditions) for a wide range of organisational and societal activities. LADM has been designed in such a way that it can easily be changed depending on local demands. Use of the standard is far away from 'dogmatic implementations' with fixed rules; on the contrary the approach is as flexible as possible. It offers a common language for LA that enables mutual understanding. ISO has a standard update cycle for revisions of standards.

With regards to practical implementation, at the international level, LADM functionality supports emerging land administration design philosophies. LADM supports the Global Land Tool Network's (GLTN) the continuum of land rights (management of different tenures in one environment), the continuum of approaches, the continuum of recordation, the continuum of spatial units and subjects. LADM opens options now to bridge gaps between cultures where People to Land relationships are concerned, definitively not only in support of globalisation, but also with a strong attention to bring support in the protection of land rights (tenure security) for all. In this regard, UN-Habitat, the lead GLTN agency, promoted the development of STDM (FIG/UN Habitat, 2010). The STDM is a sub-version of the LADM that presents a generic and inclusive solution as a way forward for building flexible land administration systems. The STDM software and source code were released simultaneously at the 2014 FIG Congress in Kuala Lumpur, Malaysia (FIG, 2014a). As of December 2013, pilots in Kenya, Columbia, and Haiti had been undertaken. Scaled rollout was occurring in parts of Uganda. Meanwhile, capacity development programmes regarding STDM had been delivered to professionals in Namibia, Lesotho, South Africa, Botswana, Mozambique, Zimbabwe, Tanzania, Kenya, Malawi, North Sudan, South Sudan, Nigeria, Ghana, Burkina Faso, India, Thailand, Malaysia, Philippines, Indonesia, Jamaica, and Trinidad and Tobago (and other Caribbean Islands). Meanwhile, further rollouts were planned for DRC, Zambia and Fiji (Augustinus, 2014).

The Organisation of Eastern Caribbean States (OECS) provides a specific example of application. It is developing regional land policy guidelines addressing the critical land issues (Griffith-Charles et al., 2013). These guidelines are to represent an integrated approach to land policy development as the basis for land administration frameworks for the member states. Land agencies of the member states are mandated to participate in the initiative and have thus created a project-based momentum upon which the development of the STDM (Social Tenure Domain Model) can derive stakeholder support. In this context a reasonable goal of STDM implementation is its integration with or updating of the formal land administration systems. To achieve this, all data must be collected using the same structure: Party – Social Tenure Relationship – Spatial Unit. It must also be determined in advance whether the 'Party' would be a natural person, a household, or family. The social tenure relationships are defined in a code list, which is a universal set of all the possible instances in the OECS (Griffith-Charles et al., 2013).

In parallel to GLTN developments, FAO maintains land tool development programmes – also influenced by LADM. SOLA is an open source software tool developed since 2011. The aim is to provide a low cost land administration alternative for land agencies in developing countries – and subsequently support adherence to the FAO/CFS 'Voluntary Guidelines on the Responsible Governance of Tenure' (FAO, 2012). The guidelines deal extensively with the role of land administration systems in supporting land tenure security. Pilots of the software were conducted in Samoa, Nepal, and Ghana. In Lesotho, the software has also been implemented as part of ongoing land administration development efforts. Meanwhile, the recently released cloud based version of the SOLA, 'Open Tenure Community Server', whilst not yet public, is based upon the LADM.

Also at the international level, LADM supports implementation of FIGs 'Fit-for-purpose Land Administration' approach (Enemark et al., 2014). Fit-for-purpose means that the land administration systems – and especially the underlying spatial framework of large scale mapping – should be designed for the purpose of managing current land issues within a specific country or region – rather than simply following more advanced technical standards. The fit-for-purpose approach is participatory and inclusive. Benefits relate to the opportunity of building appropriate land administration systems within a relatively short time and for relatively low and affordable costs. The fit-for-purpose approach is a realistic approach that is scalable and could make a significant difference in the intermediate timeframe, and the flexibility in LADM supports the philosophy. Indeed, via FIG the original ISO proposal was submitted. At regional level, LADM has also influences developments, specifically within the European Commission's INSPIRE initiative. The directive aims at establishing a European-wide SDI. Cadastral parcels are a recognised layer. INSPIRE and LADM developed in parallel, however, developments regarding the INSPIRE cadastral parcels are tailored to align with the LADM approach. It should be noted that the Land Administration Domain Model (LADM) provides a wider context for the INSPIRE cadastral parcels because LADM includes additional information on rights (bound to national legislation) and owners, which are outside the direct scope of INSPIRE (INSPIRE, 2009).

Meanwhile, within national and state based land administration agencies, LADM can support system design and development, with coverage of all tenure types. LADM can operate in formal and informal environments ("self made land administration"). LADM describes the data contents of land administration in general. Implementation of the LADM can be performed in a flexible way; the standard can be extended and adapted to local situations. Already available published works from various contexts include: Paixão et al. (2013), Choon and Seng (2013), Shin and Kwak (2013), Zhuo et al. (2013), and Zulkifli et al. (2013). Meanwhile, other countries already expressing initial interest in terms of alignment or development include: Malaysia (Zulkifli et al., 2013), Zimbabwe (Paradzayi et al., 2014), Belize, Brazil (Paixão et al., 2013), Trinidad and Tobago (FIG, 2014b), Cyprus, Portugal, Lesotho, Honduras, Canada, Indonesia, Uganda, Senegal, Vietnam, China, Zambia, Albania and South Korea (http://isoladm.org). Further evidence for the potential utilisation of LADM in system development is provided in Annex A of the ISO standard. Six country profiles and spatial and legal profiles are included, in respectively Annex D, Annex E and Annex F. Beyond system development, LADM can also support the quality upgrading of existing (not properly maintained) datasets (consistency building and validation) (see Mađer et al., 2013), and the management of a wide range of documentation. The latter point concerns evidence from the field and legal, transactional, and administrative documents, land administration development. In LA organisations, LADM can also be linked to workflow management. Processes are not integrated in LADM, linking is possible by role types, versioning, quality labels and exchange of data between involved organisations. Soon (2013) demonstrated the formalisation of domain ontology from natural language for Land Administration. In order to build the domain ontology to emphasise user roles, additional classes and relationships have been added. The ontology attempts to support land administration systems that aim to serve customers more proactively for land administration routine processes such as registrations of land titles and submissions of survey plans.

Between agencies and organisations dealing with spatial data, LADM supports structuring and organising database interoperability. Databases can be implemented in a distributed environment in different organisations with different responsibilities in Land Administration and population registration. In short, LADM is usable within a Spatial Data Infrastructure (SDI). This concerns the data exchange between organisations involved in land administration. The LADM "packages" have been introduced for improved representation of tasks and responsibilities (which can be in different organisations). LADM can be a basis for combining data from different LASs; e.g. LASs with datasets on formal and informal People to Land relationships. The International Standard includes informative example cases with People to Land relationships demonstrating the flexibility of the standard. For implementation in SDI the links to external classes in other registrations are important.

For software and database developers, LADM provides the preferred stable (but extensible) standards as a starting point for a development. LADM allows a flexible, step-by-step approaches in the development of a Land Administration system based on the needs, priorities and requirements of users and the society. This can be combined, in a natural way, with organisational development with proper alignment to ICT development, see Gilroy (2013). In 2014, ESRI, one of the world's largest suppliers of GIS software, commenced measures to incorporate LADM into its software offerings (ESRI, 2013). In addition, Bentley Systems, another major provider of GIS software, undertook steps to align product offerings with LADM.

Within the land administration research community, LADM impacts upon several other developments. For example, when considering the complete development life cycle of rural and, in particular, urban areas, many related activities should often also support 3D representations (and not just the cadastral registration of the 3D spatial units associated with the correct RRRs and parties). The exact naming of these activities differs from country to country, and their order of execution may differ. However, in some form or another, the following steps performed by various public and private actors, which are all somehow related to cadastral registration, are recognised: develop and register zoning plans, design new spatial units/objects; acquire appropriate land/space; request and provide (after check) permits, etc. Several of the activities and their information flows need to be structurally upgraded from 2D to 3D representations. Because this chain of activities requires good information flows between the various actors, it is crucial that the meaning of this information is well defined – an important role for standardisation. Important are ISO 19152 (LADM) and ISO 19156 (Observations and Measurements), and very related and partially overlapping is the scope of the new OGC's Land Development – Standards Working Group (LD-SWG), with more of a focus on civil engineering information, e.g., the planned revision of LandXML (to be aligned with LADM). This phenomenon is especially true for 3D cadastral registration because it is being tested and practiced in an increasing number of countries. For example, for buildings (above/below/on the surface or constructions such as tunnels and bridges), and (utility) networks, this overlap is clear. LADM is focusing on the spatial/legal side, which could be complemented by civil engineering physical (model) extensions. It is important to reuse existing standards as a foundation and to continue from that point to ensure interoperability in the domain in our developing environment.

Finally, LADM will provide a structured approach to maintaining global standards and discourse in the land administration domain. ISO guarantees maintenance of the standard – future developments in the domain can be included in this way. The standard has been developed by experts from all over the world: UN Habitat Land Tenure Section with its comprehensive knowledge on customary tenure systems, EU Joint Research Centre with a broad knowledge base on INSPIRE and LPIS, the United Nations School for Land Administration Studies with many alumni on top positions in land administration organisations in many countries and representatives from Land Administration organisations, universities and normalisation institutes collaborated in the development.

Conclusions and recommendations

LADM, an international standard for the domain of land administration, is intended to assist the alignment of land administration design with societal demands embedded in national and state land polices. Fundamentally, the model is built upon and adheres to the concepts of the continuum of land rights when describing land interests. It covers basic information related to components of land administration: land administration includes water and elements above and below the earth's surface (ISO, 2012), and people. Those components concern: party related data; data on RRRs and the basic administrative units where RRRs apply to; data on spatial units and on surveying and topology/geometry. The data sets in those components are represented in UML packages and class diagrams. All data in a land administration are supposed to be documented in (authentic) source documents. Those source documents are the basis for building up a trusted and reliable land administration, as basis for transactions and for the establishment of new land rights in a land administration, see for example (Uitermark et al., 2010).

LADM is capable of supporting the progressive improvement of cadastres, including both the geographic and other elements and of supporting fit-for-purpose cadastral requirements. LADM can potentially be used to support organisational integration, for example, between often disparate land registry and cadastral agencies. LADM can help to reconcile superfluous government databases and reduce the large amount of data redundancy that currently exists.

Finally, regarding future recommendations, the following statements, echoing participant sentiment from the 5th LADM Workshop in Malaysia, are made. First, LADM requires maintenance, otherwise, it will disappear. This means the 'use' of the standard requires ongoing monitoring (i.e. number of downloads from ISO). Second, investigation on LADM can be integrated, and should be integrated, with other geo-information standards (e.g. to link legal spaces to their physical counter part represented in cityGML, landXML, BIM/IFC) should be undertaken. Third, how LADM code lists could provide the basis for establishing a complete catalogue of global land people relationships – if such a database is deemed necessary (registries would be needed for managing the content: code list values and their definitions) could also be undertaken. Fourth, whilst ISO maintains its own maintenance approach, another form of governance structure – potentially a reference group – is needed to further progress the refinement and maintenance of the standard (e.g. code lists, new items). Fifth, The LADM user community should make all efforts to interact on an annual or biannual basis to further share and develop the standard. Sixth, to ensure the global relevance and application of the standard, it is recommended to apply further research on the need for exploration of whether, and how, LADM can contribute to the Post-2015 global development agenda.

References

Augustinus, C., Lemmen, C.H.J., Van Oosterom, P.J.M., 2006. Social tenure domain model: requirements from the perspective of pro poor land management. In: Proceedings of 5th Regional Conference on Promoting Land Administration and Good Government in Accra, Ghana, p. 2006.

Augustinus, C., 2010. Social Tenure Domain Model: what it can mean for the land industry and the poor. In: Proceedings of the XXIV FIG International Congress 2010, Sydney, Australia.

Augustinus, C., 2014. Finding solutions to global challenges: the role of the land profession. In: FIG Congress 2014, Kuala Lumpur, Malaysia 16–21, June.

Barry, M., 2005. Talking titler multimedia land management system. In: Proceedings of the 5th FIG Regional Conference, Land Administration and Good Governance, Accra, Ghana, March 8–11, 2006.

Bogaerts, T., Zevenbergen, J.A., 2001. Cadastral systems – alternatives." Computers. Environ. Urban Syst. 25 (4–5), 325–337.

Byamugisha, F.K., 2013. Securing Africa's Land for Shared Prosperity: A Program to Scale Up Reforms and Investments. International Bank for Reconstruction and Development/The World Bank, A copublication of the Agence Française de Développement and the World Bank.

CheeHai, T., 2012. Improving land governance on a broad basis. In: Presented at World Bank Conference on Land and Poverty, Washington DC, USA (April).

Choon, T.L., Seng, L.K., 2013. Towards malaysian multipurpose 3D cadastre base on Land Administration Domain Model (LADM) – an empirical study. In: Proceedings of the LADM Wokshop, Kuala Lumpur, Malaysia, September.

Enemark, S., 2012. Sustainable land governance: spatially enabled, fit for purpose and supporting the global agenda. In: World Bank Conference on Land and Poverty, Washington DC, US, April.

Enemark, S., Bell, K.C., Lemmen, C.H.J., McLaren, R., 2014. Fit for Purpose Land Administration. International Federation of Surveyors, Copenhagen, Denmark, FIG Publication No. 60.

ESRI, 2013. ArcGIS and Land Administration – An Esri White Paper, December, United States.

FAO, 2011. FAO FLOSS SOLA Data Dictionary for the SOLA Desktop Development Snapshot, version 1.0 (Prepared by Elton Manoku, Matthew Boafo and Neil Pullar. Version 1.0, August 24, 2011).

FAO, 2012. Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security. FAO, Rome, Italy, ISBN 978-92-5-107277-6.

FIG, 1999. The Bathurst Declaration on Land Administration for Sustainable Development. International Federation of Surveyors (FIG), Copenhagen, Denmark.

FIG, 2010. The Social Tenure Domain Model, A Pro Poor Land Tool. FIG Publication 52, ISBN 978-87-90907-83-9.

FIG/UN Habitat, 2010. The Social Tenure Domain Model. FIG Publication 52, FIG Office, Copenhagen, Denmark.

FIG, 2014a. Fit-for-Purpose Land Administration. FIG Publication 60, Copenhagen, Denmark.

FIG. 2014b. STDM source codes to be released at FIG Congress 2014 in Kuala Lumpur Malaysia, June 2014. http://www.fig.net/news/news_2014/stdm_launch.htm (accessed 18·09.2014).

Fourie, C., 1998. An integrated geo-information system with emphasis on cadastre and land information systems for decision makers in Africa. In: Working Document for the Expert Group Meeting held at United Nations Economic Commission for Africa, Addis Ababa, Ethiopia, 23–26 November.

Fourie, C., Nino-Fluck, O., 2000. Cadastre and land information systems for decision makers in the developing world. In: Paper presented at the UN-FIG Conference on Land Tenure and Cadastral Infrastructures for Sustainable Development, Melbourne, Australia, October 25–27, 1999, Paper published in Geomatica, 54 (2000), pp. 335–342.

Gilroy, S., 2013. LADM: a blueprint for enterprise level land administration systems. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

Griffith-Charles, C., Lalloo, S., Browne:, J., 2013. Key considerations for the adaptation of the STDM for the OECS member states. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

INSPIRE, 2009. D2.8.I.6 INSPIRE Data Specification on Cadastral Parcels – Guidelines. INSPIRE, 2009-09-07.

ISO, 2011. ISO 19152, Draft International Standard (DIS). In: Geographic Information – Land Administration Domain Model (LADM). ISO, Lysaker, Norway, pp. 118.

ISO, 2012. ISO 19152:2012, Geographic Information – Land Administration Domain Model, edition 1. ISO, Geneva, Switzerland, 118 p.

ISO/TC211, 2008a. ISO 19152 New Work Item Proposal (NWIP), Geographic information – Land Administration Domain Model (LADM). ISO, Lysaker, Norway.

ISO/TC211, 2008b. ISO 19152 Working Draft 3 (WD3), Geographic information — Land Administration Domain Model (LADM). ISO, Lysaker, Norway.

ISO/TC211, 2009. ISO 19152. Committee Draft (CD), Geographic information — Land Administration Domain Model (LADM). ISO, Lysaker, Norway.

Kaufmann, J., Steudler, D., 1998. Cadastre 2014. A vision for a future cadastral system. In: FIG XXI International Congress, Brighton, United Kingdom.

Larsson, G., 1991. Land Registration and Cadastral Systems. Tools for Land Information and Management. Longman Scientific and Technical.

Lemmen, C.H.J., 2012. A Domain Model for Land Administration. Netherlands Geodetic Commission, Delft, Publications on Geodesy 72, 244 p. ISBN: 978-90-6132-336-5.

Lemmen, C.H.J., Zevenbergen, J.A., 2010. First experiences with a high resolution imagery based adjudication appoach in Etiopia. In: Deininger, K., Augustinus, C., Enemark, S., Munro-Faure, P. (Eds.), Innovations in land rights recognition, administration and governance. The World Bank, Washington D.C., pp. 96–104.

Lemmen, C.H.J., Van Oosterom, P.J.M., Uitermark, H.T., De Zeeuw, C.J.,2013a. Land administration domain model is an ISO standard now. In: Annual World Bank Conference on Land and Poverty. The World Bank, Washington, DC, April 8–11.

Lemmen, C.H.J., Van Oosterom, P.J.M., Van der Molen, P., 2013b. A Domain Model for Land Administration. Annual Report Netherlands Geodetic Commission.

Mađer, M., Matijević, H., Roić, M., 2013. Linking land registers and other official registers in the Republic of Croatia based on LADM. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

Paixão, S., Hespanha, J.P., Ghawana, T., Carneiro, A., Zevenbergen, J.A., 2013. Modelling Brazilian indigenous tribes land rights with ISO 19152 LADM. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

Paradzayi, C., Mapamula, R., Mtariswa, T., 2014. Investigating the conformity of the Zimbabwe Land Administration System to the Land Administration Domain Model Standard (ISO 19152). In: FIG Congress 2014, Kuala Lumpur, Malaysia 16–21 June.

Shin, Y., Kwak, B.-Y., 2013. A review of Korean LADM based on the Cadastre Reform Project. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

Soon, K.H., 2013. Representing roles in formalizing domain ontology for land administration. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

Uitermark, H.T., Van Oosterom, P.J.M., Zevenbergen, J.A., Lemmen, C.H.J., 2010. From LADM/STDM to a spatially enabled society: a vision for 2025. In: The World Bank Annual Bank Conference on Land Policy and Administration, Washington, DC.

UN-Habitat, 2003. Handbook on Best Practices, Security of Tenure and Access to Land. United Nations Human Settlements Programme, Nairobi, Kenya, 117 p., unedited version.

UN-Habitat, 2004. Pro Poor Land Management, HS/728/04E , Nairobi, Kenya.

UN-Habitat, 2008. Secure Land Rights for All. United Nations Human Settlements Programme, Nairobi, Kenya, 40 p.

UN-Habitat, 2012. Handling Land: Innovative Tools for Land Governance and Secure Tenure. United Nations Human Settlements Programme, 152 p.

UN/ECE, 1996. Land Administration Guidelines. With Special Reference to Countries in Transition. United Nations/Economic Commission for Europe, Geneva, Switzerland, 112 p.

UN/ECE, 2004. Guidelines on Real Property Units and Identifiers. United Nations/Economic commission for Europe, Geneva, Switzerland, 82 p.

Williamson, I.P., Ting, L., 2001. Land administration and cadastral trends – a framework for re-engineering. Comput. Environ. Urban Syst. 25 (4–5), Elsevier Science, New York, USA.

Zhuo, Y., Ma, Z., Lemmen, C.H.J., Bennett, R., 2013. Integration of land and housing in China: first analysis of legal requirements for LADM compliance. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September.

Zulkifli, N.A., Rahman, A.A., Van Oosterom, P.J.M., 2013. Developing 2D and 3D Cadastral Registration System based on LADM: illustrated with Malaysian cases. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September, There is a LADM wiki available: http://isoladm.org