A Domain Model for Land Administration

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A Domain Model for Land Administration

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Preface

For some people on this planet cadastral modelling can be a life time job. I'm amongst them and I'm happy to know quite a few from my own and from other countries. It is the generation heavily involved in bringing the cadastral maps and registers from analogue to computerised environments. A unique event with unique knowledge built up for that purpose. Cadastral maps required extra attention in computerisation in order to keep the spatial data consistent and accessible.

After conversion the data have been harmonised in many countries using extended or linked data models; the data quality has been improved; complete archives have been scanned and digital workflows have been introduced. Today products and services can be offered to users in society from complete digital cadastres. Data integration continues. Harmonisation of spatial data is a policy in the European Union in support to the implementation of environmental policies. The cadastral parcel is a core element here: a High Tea for cadastral data modellers. New, user dominated, applications appear with the introduction of all kind of mobile devices and social networks. The next generation can work and live now with all the created digital data sets. This generation does not (want to) have a notion about paper maps or registers based on conventions on maintenance and use from another century.

For many so-called less developed countries worldwide all this is not yet the case. My experiences in land administration in the less developed world learned that most 'people to land relationships' on land use and land ownership are not registered, nor recorded in some way, nor spatially referenced at all. In case data exist its quality is most often far from optimal, data are incomplete, not up-to-date and do not represent the situation in the field in a reliable way. This is valid for the analogue data sets and also for eventual computerised data sets. Newly created data are often not properly maintained.

There is an urgent need for cadastral maps and land registries worldwide – but I also learned that it is very complex to find simple solutions for the introduction or improvement of land administration systems. Those systems are worldwide recognised as being important for governance. Governments need information to govern. Accessible information on 'people to land relationships' is crucial here; for sustainable economic and infrastructural development and interrelated spatial planning, for resource and environmental management, for disaster management. All this is about today's challenges as change in climate, problems with draught and access to water, unequal access to land and lacking social justice, food shortage and a growing urban population with a complex urban–rural interface.

Given all this it is not so nice to see that in so many less developed countries there are so few people who can design the required data models, develop the required applications and implement the required systems. Tools are urgently needed here allowing taking advantage from modern land administration systems in support to good governance.

One of the most relevant tools is a software application built on top of a data model. The data model is the core. What to include and how to structure this? One other lesson from my experience comes in here: it is far more difficult to start from scratch than starting with a model that can be adapted to the local situation.

Providing a generic data model for land administration based on common grounds, widely accepted and being useful for many people is worth making efforts for. To find that it is possible to use it in so-called informal and customary environments. To look for a basis to apply the model for support equal land rights for all. To support in avoidance of land grabbing by mapping the existing situation fast and with unconventional approaches as point cadastres, satellite images, boundary drawing instead of measuring, with participatory approaches, accepting errors and with the intention to improve quality later.

I hope this domain model is useful indeed in many places where land administration and its improvement or implementation is under discussion and decision.

Christiaan Lemmen

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1 Introduction

The focus in this research is on the design of a Domain Model for Land Administration. In this chapter the research will be introduced: motivation, background, problem definition, research objective, research questions and research methodology.

First the motivation and background of this research is provided in Section 1.1: avoid re-inventing the wheel again and again when developing and implementing Land Administration Systems (LASs) There are several definitions of Land Administration (LA) and LASs, Section 1.2 gives a brief overview. Then the problem definition of LA Domain Modelling is discussed in Section 1.3. Research objective and questions are presented in Section 1.4; the methodology in Section 1.5. The incremental design approach of the Land Administration Domain Model (LADM), as made during the last ten years, is given in Section 1.6. Scope and limits is subject of Section 1.7. The thesis overview is in Section 1.8.

1.1 Motivation and Background

In many global documents land is considered as an issue of utmost importance, see for example Agenda 21, a comprehensive plan of action that was adopted by more than 178 governments at the United Nations Conference on Environment and Development (UNCED, 2002). Main political objectives such as poverty eradication, sustainable housing and agriculture, strengthening the role of vulnerable groups (e.g. indigenous people and women), are in many ways related to access to land, and to land-related opportunities. How governments deal with the land issue, could be defined as land policy, and part of the governmental policy on promoting objectives including environment sustainability, economic development, social justice and equity, and political stability. Having a policy is one thing, having the instruments to enforce this policy is another. Therefore governments need instruments like regulations concerning land tenure security, land market, land use planning and control, land taxation, and the management of natural resources. It is within this context that the function of LASs can be identified: a supporting tool to facilitate the implementation of a proper land policy in the broadest sense (UNECE, 1996[1], see also Van der Molen, 2006; Van der Molen and Lemmen, 2004a).

Until today most countries (states or provinces) have developed their own LAS. Some countries operate a deed registration, while other operate a title registration. Some systems are centralised, and others decentralised. Some systems are based on a general boundaries approach, others on fixed boundaries approach. Some LASs have a fiscal background, others a legal one (Bogaerts and Zevenbergen, 2001; UNECE, 1996). However, organisational structures with distributed responsibilities and ever-

[1] The United Nations Economic Commission for Europe, Land Administration Guidelines.

changing system requirements make the separate implementation and maintenance of LASs neither cheap nor efficient (UNECE, 1996). Furthermore, different implementations of LASs do not make meaningful communication very easy, e.g. in an international context such as within Europe or in a national context (for example in a less developed country) where it may happen that different partners in development co-operation design and provide different LASs without co-ordination.

Personal experience learns that it is very easy to make LASs very complex and that it is really complex to make it easy. Standardisation is supportive and helpful in design and (further) development of LASs. It is relevant to keep data and process models separated, this means (inter-organisational) processes can change 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 into the data model. A further lesson learnt is that the number of attributes is preferred to be minimal; during the design of the data model there may be lack of awareness that there is something like a “multiplier”: depending on the number of objects and subjects each attribute can have millions of instances. The LA organisation is responsible for the quality of all those data. There is impact if the number of attributes can be reduced with one.

Standardisation is a well-known subject since the establishment of LASs. Standardisation concerns identification of parcels, documents, persons, control points and many other issues. It concerns the organisation of tables in the registration and references from those tables to other components, e.g. source documents and maps; this includes efficient access to archives. It concerns coding and use of abbreviations, e.g. for administrative areas. It concerns workflows, etc. It should be observed that all this is valid for paper based and for digital LASs. During analogue to digital conversions (many) inconsistencies built up in a paper based system can appear: there can be parcels in the registry which are not on the map and the other way around. Such errors should be *impossible*, because a real right is always related to a person and to a piece of land in reality. The same is valid for the representation of this reality in a register and on a map. This type of inconsistencies should be impossible, but they exist. Measures have to be taken to avoid this in the future after computerisation.

Many countries perform efforts in the development of LASs. Just to mention a few: Zevenbergen (1998) talks about ‘promising’ results on computerising in a pilot land administration project in Ghana. Nabil Nassif (2002) describes the cadastral survey process in Egypt. A database design for land administration is included in this paper. Opadeyi (2002) explains problems related to storage, access, duplications, lacking unique identifier, etc. resulting in delays in processing in Trinidad and Tobago. Land administration agencies should take advantage of developments in information technology, by adopting computer tools for efficient storage and efficient retrieval. These tools would facilitate the exchange of data and ensure a more compact storage environment. Liou (2002) discusses the risks of economic exclusion presented by a lack of ICT and the internet enabling the poor to look after better place of shelter and good information on job opportunity. This is related to land information systems. Fares (2002) analyses types of cadastral systems and suggests the use of a Unified and International Form of LIS while respecting all Local Real Estate Laws and Regulations. Poyraz and Ercan (2002) introduce the new system in Turkey. Goal of the TAKBİS project is to create a "Land Registry and Cadastre Information System" throughout the country. See also the paper from Cete et al (2006) about analysing the Turkish cadastral system according to the land administration concept, with a reference to standards in Germany. Zhang Ning and Tuladhar (2006) discuss Modelling Spatio-Temporal Aspects for Cadastral System in China. Adeoye and Mensah (2008) explain the importance of GIS for land administration in Nigeria. Weldegiorgis (2009) talks about a cadastral system at infant stage in Eritrea, many steps have to be done, computerisation is amongst them. It is observed that human capacity is a problem. Arko-Atjei et al (2009) (see also Arko-Adjei (2011)) sees a big problem in the inability of land administrations to deal with the dynamic aspect of land tenure, for example, where several interests exist on the same piece of land. Also in Indonesia customary tenure is not included in the formal land administration, see for example Ary Sucaya (2009). He highlights the need for standardisation in land administration in Indonesia. The National Land Agency[2] is under a process of decentralisation. Standardisation is a requirement now to support the development of a National Land Information System.

What can go wrong if you don't have a standard for the Land Administration Domain? What goes wrong if you don't have standards? Many things went well before standards were introduced. Greenway (2005) gives some examples of standards: the format of telephone and banking cards; the internationally standardised freight container; the number of businesses implementing ISO 9000[3] (quality management) and ISO 14000 (environmental management); the universal system of measurement known as SI[4]; ISO codes for country names, currencies and languages; paper sizes and so on. He states that this list points to the ubiquity of standards, but also begins to indicate the economic benefits that they provide. That is the confidence that things will work and will fit together. He quotes key findings from a NASA[5] report (NASA, 2005): 'Standards lower transaction costs for sharing geospatial data when semantic agreement can be reached between the parties', and: 'Standards lower transaction costs for sharing geospatial information when interfaces are standardised and can facilitate machine-to-machine exchange'. So, standards are, amongst other things, widely used because of efficiency and because of support in communications based on common terminology. One more issue is the LAS development. As highlighted above many countries are working on this. The data model is the core. Starting from scratch in data modelling generally means the introduction of complexity (which has to be reduced later), it means creating a mix between really required data and process data (those are the data needed for data production and management; processes are subject to change, e.g. when new technologies are introduced). It often means software which cannot be easily extended for future needs[6] and it often means insufficient attention to *informal* relationships between people and land (because informalities are not recognised and seen as 'illegal'). In

[2] Badan Pertanahan Nasional.
[3] ISO is the International Organization for Standardization.
[4] Système international d'Unités.
[5] National Aeronautics and Space Administration.
[6] Larsson already observed in 1975: *"It is impossible to predict all possible uses of a system of this type (Land Data Bank). But we can be rather sure that, as time goes on, more and more registers will be built up, more and more information will be integrated in the data system and the possibilities of combinations between different types of Data Systems will increase"* (Larsson, 1975).

many countries this type of software is and will be developed, see the examples above. Examples are known from countries where different software has been developed without co-ordination. This happens for example under development co-operation with different donor countries. All the time the wheel is re-invented and the same functionality is re-implemented over and over again. It should not be forgotten that in many countries insufficient capacity is available. It often happens that experts get better salaries elsewhere after being involved in LAS automation for some time; this has huge impact on the continuity of development and maintenance and operation of LASs (in many cases insufficiently documented). A standardised LADM (adapted to the local situation) supports in knowledge sharing. One more issue in relation to the importance of standards is in the support to Spatial Data Infrastructure (SDI).

Van Oosterom et al (2009), based on and inspired by Nolan (1979), show how standardisation is contributing to the fact that Land Administration (LA) is considered more and more *the* cornerstone of the SDI, or, perhaps even more general: the cornerstone of the information infrastructure as it also involves (relationships to/with) non-spatial registrations. A model is used to specify different levels of maturity. Growth in maturity will follow the four levels. The model forms a kind of ladder where every step gives higher value and efficiency. Every level can be met after finishing the previous one. In almost every situation no level can be omitted as the subsequent level builds on the previous one.

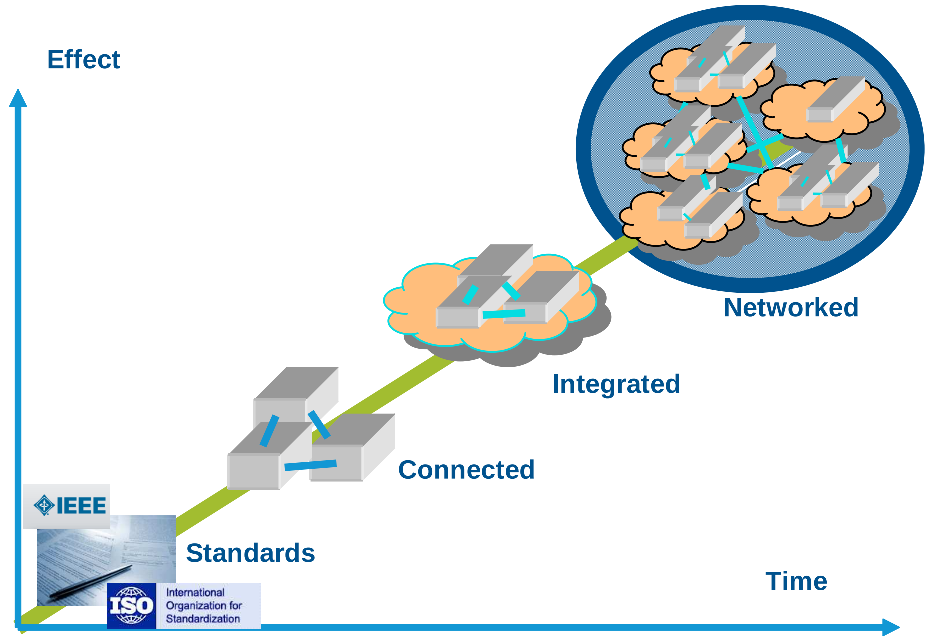

Figure 1 Land Administration Maturity Model (Van Oosterom et al, 2009).

The model has four stages: Standards, Connectivity, Integration and Network; see Figure 1. Once standards are clear, different organisations, or countries can start to make a connection. A point to point connection creates possibilities to exchange Land Administration information, both geographic and administrative. After being connected they start acting as a whole. This will form a kind of Land Administration Information Infrastructure; the spatial information “hang-out” for all related users. According to them the ultimate level ‘network’ implies a mind shift and has the biggest effect. The focus will shift from the Land Administration or Spatial Information Infrastructure towards higher level social themes. It will place the Spatial Information Infrastructure in the context of current relevant social themes, e.g. public safety, environmental issues, spatial planning, water management and poverty reduction. Within these themes many different players (stakeholders) and sectors and also information sets as such must work together to face the social challenges. This will require semantic translations of the information in order to be useful in a different context than the original production purposes. First steps are made in the European Union; see for example INSPIRE[7] (2009). The case from Indonesia here above is another example: at one side decentralisation is in support to registration of local land rights, this possibility is the main reason for the decentralisation, but at the other side a national SDI requires standards.

One more issue is that standards are in support to quality of data by avoiding inconsistencies.

A standard for the Land Administration Domain can serve the following goals.

1. *Establishment of a shared ontology implied by the model*. This allows enabling communication between involved persons[8] within one country and between different countries. This is relevant in the determination of required attributes and in setting responsibilities on maintenance in case of implementation in a distributed environment with different organisations involved. This is also in support of the development of LASs as core in SDI. One more issue is the globalisation; there are already ideas for and approaches to international transactions, e.g. within the European Union. Also in relation to carbon credits registration. See Van der Molen (2009) or Mitchel et al (2011).
2. *Support to the development of the application software for LA.* The data model is the core here. Support in the development of a LAS means provision of an extendable and adaptable fundament for efficient and effective LAS development based on a *Model Driven Architecture* (*MDA*), as promoted by the Object Management Group (Siegel, 2001). This approach offers automatic conversions from models to implementation, where local details can be added to the conceptual model first.
3. *Facilitation of cadastral data exchange with and from a distributed LAS.* This can be between cadastres, land registries and municipalities and between countries in a federal state or between countries.
4. *Support to data quality management in LA.* Use of standards contributes to the avoidance of inconsistencies between data maintained in different organisations

[7] Infrastructure for Spatial Information in Europe (INSPIRE, 2007).
[8] E.g.: information managers, prossionals, and researchers.

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.

1.2 Cadastre, Land Administration and Land Administration Systems

In this section definitions of land, land registration, land administration, cadastre and LASs are further clarified.

Simpson (1976) describes cadastre[9] ('a word brought from France') as a 'public register of the quantity, value and ownership of the land (immovable property) in a country, compiled to serve as a basis for taxation'. A register of deeds is a 'public register in which documents affecting rights in land are copied or abstracted'. A register of title is 'an official record of rights in defined units of land as vested for the time being in some particular person or body, and of the limitations, if any, to which these rights are subject'. In Henssen (1981) the following observations are placed in relation to deed and title registration: 'in case of registration of deeds the document (deed) containing the legal act with respect to a change in the legal status of the real estate is published in its entirety, which is not the case in registration of titles – than merely what is envisaged by parties is published (= legal consequences)'.

Henssen (1995) gives definitions for *land*, *cadastre* and *land registration.*

– *Land* is an area of the surface of the earth together with the water, soil, rocks, minerals and hydrocarbons beneath or upon it and the air above it. It embraces all things which are related to a fixed area or point of the surface of the earth, including the areas covered by water, including the sea.
– *Cadastre* is a methodically arranged public inventory of data concerning properties within a certain country or district, based on a survey of their boundaries. Such properties are systematically identified by means of some separate designation. The outlines of the property and the parcel identifier normally are shown on large-scale maps which, together with registers, may show for each separate property the nature, size; value and legal rights associated with the parcel (see also United Nations, 1985).
– *Land registration* is a process of official recording of rights in land through deeds or as title on properties. It means that there is an official record (land register) of rights on land or of deeds concerning changes in the legal situation of defined units of land.

FIG, in its Statement on the Cadastre (FIG, 1995) defines a cadastre as a register of land information: a cadastre is (normally) a parcel based and up-to-date land information system (LIS) containing a record of interests in land (i.e. rights,

[9] The derivation of the word cadastre (according to Simpson (1976), p. 4) used to be ascribed to the Latin word *capitastrum* was taken to be a contraction of capitum registrum, a register of capita, literally 'heads', and so by extension 'taxable land units'. Simpson adds that modern dictionaries derive 'cadastre' from the Greek word katastikhon (meaning literally 'line by line' and so a tax register).

restrictions and responsibilities). It usually includes a geometric description of land parcels[10] linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements. It may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (e.g. conveyancing), to assist in the management of land and land use (e.g. for planning and other administrative purposes), and to facilitate sustainable development and environmental protection. Such a system is usually managed by one or more government agencies.

Kaufmann and Steudler (1998) state that 'Cadastre 2014', see Figure 2[11], will be a complete documentation of public and private rights and restrictions for land owners and land users. It is further stated that 'Cadastre 2014' will be embedded in a broader LIS, fully co-ordinated and automated, without separation of land registration and cadastral mapping. Kaufmann and Steudler define Cadastre 2014 as a methodically arranged public inventory of data concerning all legal land objects in a certain country or district, based on a survey of their boundaries. Such legal land objects are systematically identified by means of some separate designation. They are defined either by private or by public law. The outlines of the property, the identifier together with descriptive data, may show for each separate land object the nature, size, value and legal rights or restrictions associated with the land object.

Figure 2 Cadastre 2014 a worldwide recognised vision on Cadastre (Kaufmann and Steudler, 1998).

[10] This means information is geographically referenced to unique, well-defined units of land.

[11] At the XX Congress 1994 of the International Federation of Surveyors (FIG) in Melbourne, Australia, FIG's Commission 7 on Cadastre and Land Management decided to produce a vision of where cadastral systems might be in twenty years, of the changes that might take place, of the means by which these changes can be achieved, and of the technology to be used to implement these changes. The vision 'Cadastre 2014' was presented at the XXI Congress of FIG, held in Brighton, United Kingdom, 1998. This publication of Kaufmann and Steudler found world-wide recognition and was translated into more than 30 languages.

Apart from Simpson there is a common agreement in the definitions above that a cadastre can be used for different purposes. Both a legal administrative component and a geometric component are included. The legal administrative component concerns a publication of formal land rights; this publication may include source documents. Land surveys are or can be needed for a geometric documentation. All the definitions are applicable in an automated environment or partial automated environment.

The term *Land Administration* (*LA*) is used, according to (UNECE, 1996), to refer to the processes of recording and disseminating information about the ownership, value and use of land and its associated resources. Such processes include the determination (known as the adjudication[12]) of rights and other attributes of the land, the survey and description of these, their detailed documentation and the provision of relevant information in support of land markets. In the document it is explained that stakeholders have different interests in the set-up of an organisation for LA. Further it is highlighted that it is important to adopt a unified LIS. And it is recognised that LA and LASs are state responsibilities, but there can be many areas where the private sector is involved.

Dale and McLaughlin (1999) define LA as ‘the processes of regulating land and property development and the use and the conservation of the land, the gathering of revenues from the land through sales, leasing, and taxation, and the resolving of conflicts concerning the ownership and use of the land.’

According to Van der Molen (2006) the definition of UNECE (1996) stands firmly, especially when the concepts of ‘ownership’, value’ and ‘use’ are interpreted in a broad sense. The concept of ‘ownership’ should, in the view of Van der Molen, be understood as a relationship between people concerning land within any jurisdiction, so the mode in which rights to land are held, and therefore based on statutory law, common law and customary traditions.

Enemark et al (2005) argue that ‘LASs historically reflect their jurisdictions of origin. Understanding how LASs were created and changed over time in response to political, social and technical pressures is important. However, management of the processes of change requires collective and international understanding of an LA model capable of servicing national and global needs’.

Williamson et al (2010) see land administration as the process run by the government using public or private sector agencies related to land tenure, land value, land use and land development. A LAS in their view is an infrastructure for implementation of land policies and land management strategies in support of sustainable development. The infrastructure includes institutional arrangements, a legal framework, processes, standards, land information, management and dissemination systems, and technologies required to support allocation, land markets, valuation, control of use and developments of interests in land. They explain that LA comprises an extensive range of systems and processes to manage.

1. *Land tenure*: the process and institutions related to securing access to land and inventing commodities in land and their allocation, recording and security; cadastral mapping and legal surveys to determine parcel boundaries; creation of

[12] The process whereby the ownership and rights in land are officially determined, UN ECE (1996).

new properties or alteration of existing properties; the transfer of property or use from one party to another through sale, lease or credit security and the management and adjudication of doubts and disputes regarding land rights and parcel boundaries.
2. *Land value*: the process and institutions related to assessment of the value of land and properties; the calculation and gathering of revenues through taxation; and the management and adjudication of land valuation and taxation disputes.
3. *Land use*: the process and institutions related to the control of land use through adoption of planning policies and land use regulations at national, regional and local level; the enforcement of land use regulations; and the management and adjudication of land-use conflicts.
4. *Land development*: the process and institutions related to building of new physical infrastructure and utilities; the implementation of construction planning; public acquisition of land; expropriation; change of land use through granting of planning permissions, and building and land-use permits; and the distribution of development costs. See also Enemark and Williamson (2004).

Zevenbergen in his inaugural address notes that the term *Land Administration Systems* has become much used since the transitions in Central and Eastern Europe in the early 1990s. An important reason he says is the need for a common term to bring together the cadastral and land registration functions (Zevenbergen, 2009). According to him the term “system” in land administration systems means much more than just the ICT (Information and Communication Technology) component, however important that part may be. A system can be described as “a set of elements together with relationships between the elements and between their attributes related to each other and to their environment so as to form a whole that aims to reach a certain goal” (Zevenbergen, 2002). A system is thus a combination of elements at a useful level that together fulfil a certain goal. In brief, in terms of a LAS that goal is to provide tenure security and to implement land policy. Zevenbergen highlights that it is of the greatest importance to remember that a LAS is a tool, or more precisely a number of tools, to be used to satisfy these goals.

In conclusion: it has to be emphasised that a LAS covers land registration and cadastre. The combined process is called land administration and a LAS is the environment in which this process takes place. Processes include adjudication (the juridical/administrative and technical procedures to document property, use and other land rights, which may be informal or customary), establishment of and transactions on land rights and information provision. Information provision can support in multiple purposes: taxation, legal or tenure security, support of land market and mortgage industry, support in spatial planning (land consolidation, re-allotment, re-adjustment and land reform) and other. Different organisations can be involved, public and private. Implementation can be centralised or decentralised. See also Bogaerts and Zevenbergen (2001), UNECE (1996).

The field of knowledge on land administration is called the *land administration domain* in this thesis.

1.3 Problem Definition of Land Administration Domain Modelling

One of the problems in the development of LASs based on proper data and process models is the representation of different responsibilities in LA over different organisations, e.g.: the office of the private surveyor, the cadastre or surveyor-general, the office of the valuation expert, the valuation department, the office of the conveyor or notary, registrar and also organisations responsible for determination of land use. See also (UNECE, 1996). Sometimes those organisations deal with different administrative territories of responsibility. Each organisation can have distributed responsibilities in itself again: central responsibilities (e.g. policy making and system design), regional (e.g. quality checking), local (e.g. data acquisition and maintenance); and with public or private roles. Those responsibilities are reflected in the 'ownership' and quality of the LA data sets: completeness, consistency; up-to-dateness and fitness for purpose.

In general it can be observed that organisations with tasks and responsibilities in Land Administration are confronted with rapid developments in technology, a technology push: internet, spatial data bases, modelling standards, open systems and Geographical Information Systems – GISs; as well with a growing demand for new services, a market pull: e-governance, electronic conveyance, integration of public data and systems; see Van Oosterom and Lemmen (2002a), Van Oosterom et al (2006b). Not all organisations can align their business of Land Administration with those developments yet. The distribution of responsibilities into different organisations and within organisations is a complicating factor in the provision of consistent and up-to-date land information.

In 2002, Van Oosterom and Lemmen observed that developments in Geo-ICT have important implications for the development of LASs in relation to SDI. The developments in Information and Communication Technology ICT in general, and specifically the Geo-ICT can improve the quality, cost effectiveness, performance and maintainability of LASs (Van Oosterom and Lemmen, 2002a). In their paper it was further observed that spatial data management was handled so far by GIS software outside the Data Base Management System (DBMS) or Geo-Database. As DBMSs are being spatially enabled (with spatial data types, operators, index systems, etc.), more and more GISs are or will soon migrate towards an integrated architecture: all data (spatial and thematic) are stored in the DBMS. This marks an important step forward that took many years of awareness creation and subsequent system development. Many organisations are currently in the process of migrating towards such architecture. A next logical step will be the creation of a common SDI for related organisations; the so-called information communities. This can replace the exchange of copies of data sets between organisations. It requires good protocols, standardisation such as the OpenGIS web mapping specification (Buehler and McKee, 1998). But also the role of the Geo-Database gets more important, because not a single organisation depends on it, but a whole community. Only the owner of the data should perform updates, others are only doing queries, data duplication should be avoided. This is difficult to organise.

The problem identified now is as follows:
In spite of the available basic standards (for modelling the Unified Modelling Language - UML), exchanging structured information (eXtended Markup Language: XML) and ISO generic geo-information standards, there is still one important aspect missing: a standard and accepted base model for the land administration domain[13].

There is a need for domain specific standardisation 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. This is required for communication between professionals, for system design, system development and system implementation purposes and for purposes of data exchange and data quality management. Such a standard will enable GIS and database providers and/or open source communities to develop products and applications. And in turn this will enable land registry and cadastral organisations to use these components to develop, implement and maintain systems in an even more efficient way.

1.4 Research Objective and Research Questions

Focus in this thesis is on the design of a standard for the domain of LA. It defines a LA Domain Model (LADM), covering the information related components of LA. This is the starting point for the research objective and the research questions, which are derived from this.

The research objective is to design a Land Administration Domain Model (LADM). It should be possible to use this model as a basis for LAS development. Such a LADM has to be accepted and it should be adaptable to local situations. It has to be usable to organise LA data within a SDI. The design is based on the pattern of 'people – land' relationships.

Principles for the design of the Land Administration Domain Model are:
1. it should be as simple *as possible*, in order to be useful in practice;
2. it should cover the basic data related components of land administration, see Section 2.2. This means a start from consolidated knowledge; a re-use of existing, widely recognised and accepted knowledge in order to achieve *generic* results. For the LA domain much attention has been paid to the development of the representation of all possible relationships between people and land, not only *formal* relationships like ownership but also *informal* relationships as proposed in UN-HABITATs[14] continuum of land rights (UN-HABITAT, 2008; see also UN-HABITAT 2003 and 2004). A similar continuum can be applied to the development of a range of parcels (*spatial units,* see also Fourie (1998) and Fourie and Nino-Fluck (1999)), persons and organisations (*parties*), and data acquisition methods, see also FIG (1996) and Section 2.4. See also the axes of variation in

[13] The Land Administration Domain Model as designed in this thesis was called the Core Cadastral Domain Model up to the version as presented during the XXIII Congress of the International Federation of Surveyors in Munich, 2006 (Lemmen and Van Oosterom, 2006). Later it was called the Land Administration Domain Model.
[14] UN-HABITAT is the United Nations Human Settlements Programme.

Section 2.3, based on Larsson (1991). Further the concepts of 'Cadastre 2014' of the FIG should be covered; see Kaufmann and Steudler (1998), later worked out in Kaufmann (2004), see Section 2.2 and 2.5 and the recommendations of Van der Molen (2003a), see Section 2.2;
3. user requirements see Section 3.1, 3.3 and 3.5.

Given the research objective, and a design of a LADM, the following questions are formulated:

1. what is the common pattern of 'people – land' relationships?
2. how can the model be used as a basis for LAS development?
3. is the design usable within a Spatial Data Infrastructure?
4. is the design accepted and supported by LA professionals and governments?
5. is the design adaptable to local situations?
6. is the design implementable and applicable in a real life situation?

1.5 Methodology of this Research

The design of the LADM took place in an incremental approach with a continuous expert reviewing from 2002 till 2006; see below and see Section 1.6. The final construction took place with Enterprise Architect software.

Then the design and development process for International Standards has been followed as a methodology for LADM design[15]. The first step in this process is to confirm that a particular International Standard is needed. A New Work Item Proposal (NWIP) is submitted for vote by the members of the Technical Committee (TC, in this case TC211. CEN 287 on Geographic information runs in parallel to TC211). The proposal is accepted if a majority of the participating members of the TC votes in favour and if at least five participating members want to take actively part in the project. At this stage a project leader is appointed. Then a working group of experts (the chairman (convener) is the project leader), is set up by the TC for the preparation of a working draft. Successive Working Drafts (WDs) may be considered. At this stage, the draft is forwarded to the TC for the consensus-building phase. As soon as a first Committee Draft (CD) is available, it is registered by the ISO Central Secretariat. It is distributed for comment and, if required, voting, by the participating members of the TC. Successive CDs may be considered until consensus is reached on the technical content. Once consensus has been attained, the text is finalised for submission as a Draft International Standard (DIS)[16]. The DIS is circulated to all ISO member bodies by the ISO Central Secretariat for voting and commenting within a period of five months. It is approved for submission as a Final Draft International Standard (FDIS) if a two-thirds majority of the P-members of the TC are in favour and not more than one-quarter of the total number of votes cast are negative[17]. If the approval criteria are not met, the text is returned to the originating TC for further

[15] See: http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.htm , last accessed December 2011.

[16] This is the last stage described in this thesis; this means the next stage, this is the Final Draft International Standard (FDIS), is not presented.

[17] A positive vote has been received on the DIS on June 27th 2011.

study and a revised document will again be circulated for voting and comment as a Draft International Standard. The FDIS is circulated to all ISO member bodies by the ISO Central Secretariat for a final Yes/No vote within a period of two months. If technical comments are received during this period, they are no longer considered at this stage, but registered for consideration during a future revision of the International Standard. The text is approved as an International Standard if a two-thirds majority of the P-members of the TC is in favour and not more than one-quarter of the total number of votes cast are negative. If these approval criteria are not met, the standard is referred back to the originating TC for reconsideration in light of the technical reasons submitted in support of the negative votes received.

In order to answer the research questions the following methodology is used.

1. *What is this common pattern of 'people – land' relationships?*
   To answer this question a literature review is performed on relevant papers related to this issue. This is described in Chapter 2. There is attention to informal people to land relationships. Documentation on land conflicts is included. Attention is paid to gender to land (shares in land). Social tenures are worked out in the so-called Social Tenure Domain Model (STDM); this is a specialisation of the LADM. A prototype has been developed to process collected data from the field. See Chapter 4. Finding the common pattern is relevant for the development of a generic model for the LA domain.
2. *How can the model be used as a basis for LAS development?*
   To answer this question a test has been performed in Honduras. A Model Driven Architecture provides a platform independent functionality. Standards, as provided by international standardisation bodies like the Object Management Group and ISO are identified with regard to MDA. See Section 5.3 with test case from Honduras.
3. *Is the design usable within a Spatial Data Infrastructure?*
   Domain models related to the LA domain do not yet exist. Related (future) domain models are considered to be "external", but can be linked in an information infrastructure See Chapter 3[18], Subsection 3.6.6. This is a design approach where well defined interfaces are recognised with an update mechanism to keep SDI consistent.
4. *Is the design accepted and supported by LA professionals and governments?*
   In their paper Van Oosterom and Lemmen (2002a) propose to join forces and start working on a standard and accepted cadastral base model. Such a model should be usable in (nearly) every country. The standardised cadastral domain model should be described in UML schemas and accepted by experts in LA modeling, by the proper international organisations and by software suppliers. The model has been designed and validated in an *incremental approach*, see Section 1.6. and the presented versions of the model in Chapter 3, Section 3.2, 3.4 and 3.6.
   An early review was related to the publication of a pre-version of the LADM, called the Core Cadastral Domain Model (Van Oosterom and Lemmen, 2002b).

[18] Given the definitions of Land Administration above it should be noted here that taxation, valuation and spatial planning processes are not included in the analyses behind the design of the Land Administration Domain Model in this thesis. Only the output of those processes (that is new or updated attributes) are considered to be relevant for the data model.

LADM versions (see Section 1.6) were not only discussed with LA professionals. Legal professionals, geodesists, anthropologists, land reformers and ICT professionals were all involved in the discussions and reviews.

After six years of discussions and developments FIG submitted a proposal (prepared by Lemmen and Van Oosterom) to develop an International Standard for the Land Administration Domain to the TC 211 (Technical Committee 211 on Geographic Information/Geomatics) of ISO, the International Organisation for Standardisation (ISO/TC 211, 2008a) in the beginning of 2008 and, in parallel, to CEN/TC287. The proposal received a positive vote from the TC 211 member countries. A project team started to work on the development of the standard. To date[19], after several Working Drafts (WDs), a Committee Draft (CD), a Draft International Standard (DIS), a Final Draft International Standard (FDIS) is under development. During the development of the standard those versions of the model have been reviewed by LA modelling experts, delegated by member countries and external liaisons (European Commission Joint Research Centre, FIG and UN-HABITAT) to the project team and later by the editorial committee within ISO/TC 211. Comments from those reviews are documented and have been accepted, partly accepted or have been rejected by the author of this thesis in his role as editor[20]. This methodology results in validation and acceptance of the model by means of voting of member countries of ISO/TC211. This methodology implies peer reviews by experts within the editorial committee of LADM within ISO/TC211. See ISO/TC211 (2008a), ISO/TC211 (2008b), ISO/TC211 (2009) and ISO/TC211 (2011c) and Section 3.6 and 3.7.

During the post-conference session at a World Bank Conference in Washington, D.C. USA in 2009 (World Bank, 2009a) the STDM as a means to improve security of tenure for vulnerable groups in developing countries, was subject of discussion. The discussion underscored a strong institutional and profession support for STDM (World Bank, 2009b). See also Lemmen (2010d) and Section 4.1 and 4.2.

In the Solutions for Open Land Administration (SOLA) from FAO the LADM DIS has been used as basis for data storage requirements although extensions and adjustments have been made to support the function requirements of SOLA (FAO, 2011b, FAO, 2011d). See Section 5.7.

5. *Is the design adaptable to local situations?*
   This is investigated in close co-operation with experts in modelling land administrations from different countries. Cyprus is worked out in detail in Section 5.2. and Honduras in Section 5.3. In Section 5.4 attention is paid to the developments in Portugal. One more case is INSPIRE, see Section 5.5. and further the Land Parcel Identification System as discussed in Section 5.6 of this thesis. See also the SOLA and LADM as discussed in Section 5.7.
6. *Is the design implementable and applicable in a real life situation?*
   This is tested by the development of a prototype of the STDM. See Chapter 4 for the experimental results with a first prototype version.

[19] May 2012.
[20] This activity has been performed in close co-operation with prof.dr Peter van Oosterom from Delft University of Technology and by dr Harry Uitermark from Twente University.

1.6 Incremental Design of the Land Administration Domain Model

As already mentioned above the announcement of the development of a standardised domain model was at the FIG Congress held in Washington DC, US in April 2002 in a paper (Van Oosterom and Lemmen, 2002a) analysing the impact of GeoICT developments. The paper highlighted that efficient design, development, testing and maintenance of LASs[21] allows the introduction of such systems within acceptable time and budgets. A basic condition is analysis of user requirements. The paper concluded that LASs are dynamic; they do have to develop continuously over time in order to support society in a sustainable manner because of changing user requirements with reference to UNECE (1996). This paper was the starting point of the development of the LADM - based on experience from building of a very large spatial database in the Netherlands, see the peer reviewed publication on this in Computers, Environment and Urban Systems: Van Oosterom and Lemmen (2001).

The version 0.1 was presented in September 2002 at a meeting of the Open GeoSpatial Consortium (OGC), organised in Noordwijk, the Netherlands, and also at a COST[22] Workshop in Delft, the Netherlands in November 2002 (Van Oosterom and Lemmen, 2002b).

A version 0.2 was presented (after expert reviews) at a workshop on Cadastral Data Modelling at the International Institute for Geo-Information Science and Earth Observation[23] (ITC) in Enschede, the Netherlands in March 2003 (Van Oosterom and Lemmen, 2003a); during the FIG Working Week, Paris, France, April 2003 (Lemmen and Van Oosterom, 2003a). Further several publications related to this have been made in GIM International (Lemmen and Van Oosterom, 2003b; Lemmens and Lemmen, 2003). In the latter feature in GIM International experts have been invited to give their opinion on a column written by the supervisor of the author of this thesis, prof.dr Peter van Oosterom (Van Oosterom, 2002d). Eight replies were received. Those replies concerned the environment of land administration, the dynamic processes in cadastre, country specific legislation and culture, and the many differences within countries. Further needs and user requirements were specified. These are included in the user requirements, see Chapter 3 of this thesis. One example here is from Enemark. He proposes to use the legal unit of ‘real property’ as the key unit, not the parcel. In this way, the model will enable the control of land as a legal, fiscal and physical object. This proposal was issue of debate during the developments of the LADM. Such a Basic Property Unit (BPU) is also included in the hierarchy in ownership as recognised in UNECE (2004) as discussed in Section 2.2 of this thesis. In the Draft International Standard (ISO, 2010) the BPU is included, but under another name: Basic Administrative Unit. Further specific requirements (boundary surveying) can be found in Wakker et al (2003). Attention to informal rights and communal rights was included in a presentation of an annual meeting of the FIG

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[21] In this paper, as in other papers, LASs are introduced as cadastral systems.

[22] CO-ordination in the field of Scientific and Technical Research - European Co-operation in Science and Technology.

[23] ITC is a Faculty of the University of Twente, the Netherlands, since 2010.

Commission 7 on Cadastre and Land Management held in Pretoria, South Africa, 2002 (Lemmen, 2002), but see also (FIG, 1996).

The version 0.3 of the model development has been presented during the Digital Earth, September 2003 in Brno, Czech Republic (Lemmen et al, 2003c); at the 2nd Cadastral Congress, held in Krakow, Poland (Van Oosterom et al, 2003b) and at the European Land Information Service (EULIS) Seminar on 'Land Information Systems and the Real Estate Industry', Lund, Sweden, April 2004. The version 0.3 included 3D extensions, new functionality for restrictions, and there was attention to the dynamic aspects, customary and informal tenure. There were refinements and more authors as domain specialists. The version 0.3 is based on the set of user requirements developed at the FIG Congress held in Washington DC, US in April 2002 in a paper (Van Oosterom and Lemmen, 2002a) and with inputs from the workshop in Enschede, the Netherlands. Also a paper from Van der Molen was an important input, (Van der Molen, 2003a). The version 0.3 can be seen as a 'mature' initial version of the LADM, at that time called the Core Cadastral Domain Model (CCDM), and will be presented (together with requirements) as a first step in the incremental development in Chapter 3 of this thesis: *LADM Version A*. Only major versions will be presented in this thesis, inclusion of all intermediate versions would not add value.

Input from the Expert Group Meeting on Secure Land Tenure, in Nairobi, Kenya, November 2004 was most relevant to better model and include customary tenure (Van der Molen and Lemmen, 2004a). The Nairobi meeting provided input from developing countries, which was worked out in the version of the model presented during the Second Workshop on Standardisation of the Cadastral Domain, held in the Auditorium of the University of Bamberg, Germany, 9-10 December 2004 (Van Oosterom et al, 2004). In this version 0.4, as presented in Bamberg, there has been attention to the system boundary and some other suggestions for further improvement have been included in the conclusions. In the event in Bamberg the version 0.3 has been used as a reference model to all presented papers during the workshop and as a reference paper for the discussions. See for the complete documentation (FIG and COST 2004) and the report of this event in Lemmen et al (2005).

The version 0.5 was presented at the FIG Working Week in Cairo, April 2005 (Lemmen et al, 2005). This version was mainly improved on the legal, administrative side of the model (based on the Bamberg workshop) and the model was made 100% compliant with the OGC and ISO/TC211 standards. This version included reflection on the Arab world cadastral registration at the FIG meeting in Jordan, September 2005. Version 0.6 was presented at the UN-HABITAT expert group meeting in Moscow, October 2005 (Van Oosterom and Lemmen, 2006a), and the FIG regional conference in Accra, Ghana, March 2006, including the third LADM workshop (Augustinus et al, 2006)[24].

After review of the version 0.5 the written, all very valid comments have been addressed in the version 0.6. The received comments resulted into the inclusion of a class Building in the model; improvements in relationships between rights and restrictions (often 'the positive and negative side of the same coin'); in a better explanation of the role of PartOfParcel and in a remark on the need of not only standardising the model but also possible information services. The version 0.6 was

[24] Earlier Fourie.

presented in a peer reviewed scientific journal and it was decided to present the whole model, instead of the increments only, because of reasons related to completeness and readability (Van Oosterom et al, 2006b).

Finally, the version 1.0 of the LADM was presented at the FIG Congress in Munich in October 2006 under the name of ‘version 1.0 of the FIG Core Cadastral Domain Model’ (Lemmen and Van Oosterom, 2006a). In this thesis this version is called *LADM Version B*.

In 2003 Lemmen, while working on the design of the LADM, also started the technical design of the STDM to address the challenges and fundament and concepts outlined in Fouries’ (1998) paper; see Lemmen et al, (2003b), further worked out in detail in Van Oosterom et al (2006b); Augustinus et al (2006), Lemmen et al (2007) and Lemmen (2010d).

After the FIG Congress in Munich in 2006 many cases and examples were worked through, including the initial filling of several code lists, which were until then not described with content. This document became the input for the ISO standardisation process (ISO/TC211, 2008a), over which was reported in (Lemmen et al, 2009a).

In the beginning of 2008, FIG submitted a proposal to develop an International Standard for the Land Administration (LA) domain to the ISO/TC 211 on Geographic Information of the International Organisation for Standardisation (ISO/TC211, 2008a) and parallel to CEN/TC287. The proposal received a positive vote and a project team started to work on the development of the standard.

Within TC 211, many issues and comments have been discussed during several meetings (in respectively May 2008, October 2008, December 2008, May 2009 and November 2009), held with a project team composed of 21 delegates from 17 countries. A significant contribution to the development of the standard has been provided by the research communities of the Faculty of Geo-Information Science and Earth Observation of the University of Twente (ITC) and Delft University of Technology, the Netherlands.

After positive results of voting on the so-called New Working Item Proposal (NWIP) in May 2008 (ISO/TC211, 2008a) and on the Committee Draft (CD) in October 2009 (ISO/TC211, 2009) the Draft International Standard (DIS) received a positive vote in June 2011 (ISO/TC211, 2011c); the stage of International Standard is expected in August 2012. The Draft International Standard is called *LADM Version C* in this thesis.

Each step in the developments within ISO includes reviews from the involved countries in the development process.

See for an implementation case from Cyprus a description in the peer reviewed Journal Survey Review (Elia et al, 2011).

During the development of the LADM many reviews have been performed resulting in new insights, improvements and proposals for extensions. All together the development took place from 2002-2012[25]. New ideas written in papers or books which could be used as possible input and/or requirements for the development of the LADM came available during the development of the standard.

Apart from the versions published during the development of the international standard within (and published by) ISO/TC211 (ISO/TC211, 2008a, ISO/TC211,

[25] ISO 19152 Land Administration Domain Model is expected to be an International Standard in July 2012.

2008b, ISO/TC211, 2009 and ISO/TC211, 2011c) there are publications in scientific journals related to the LADM (and its predecessor the CCDM). Table 1 gives an overview of those publications, combined with other core publications. In the column to the right there is a reference to the chapter and section in this thesis where the contents of these publications are included. All LADM publications are available at an LADM ISO 19152 Wiki[26]. The UML model is available at ISO/TC211 Harmonised Model Management Group (HMMG)[27].

Table 1 Overview of scientific publications related to this research.

Publication	**Reference to chapter and section in this thesis**
Lemmen, C.H.J. and Van Oosterom, P.J.M., (2001). Cadastral systems; editorial. Computers, Environment and Urban Systems, Volume 25, Issue 4-5, pp. 319-324.	In this first special issue on cadastral systems of CEUS the lack of a common terminology is highlighted. This is one of the motivations for this research; see Section 1.1.
Van Oosterom, P.J.M. and Lemmen, C.H.J., (2001). Spatial data management on a very large cadastral database. Computers, Environment and Urban Systems, Volume 25, Issue 4-5, pp. 509-528.	See Section 3.2, 3.4 and 3.5. The contents of this publication have been the basis for the requirement of integrated management of topology and geometry.
Van Oosterom, P.J.M. and Lemmen, C.H.J., (2002a). Impact analysis of recent Geo- ICT developments on cadastral systems. FIG XXII International Congress, Washington, D.C. USA, FIG.	The proposal on the development of the LADM is launched.
Lemmen, C.H.J., Van der Molen, P., Van Oosterom, P.J.M., Ploeger, H.D., Quak, C.W., Stoter, J.E. and Zevenbergen, J.A., (2003c). A modular standard for the cadastral domain. Digital Earth 2003.	This paper concerns the LADM Version A, see Section 3.2. This paper has also been used as a reference paper for the second Workshop on Standardisation in the Cadastral Domain (FIG and COST, 2003).
Lemmen, C.H.J. and Van Oosterom, P.J.M., (2006b) Cadastral systems IV: editorial. Computers, Environment and Urban Systems, Volume 30, Issue 5, pp. 523 -528.	The results of the second workshop on cadastral modelling, held in Bamberg, 2004 are reported. This sets direction for development of a standard for the land administration domain co-ordinated by FIG. This approach is described in Section 1.5 and 1.6 and Chapter 3.
Hespanha, J.P., Van Oosterom, P.J.M., Zevenbergen, J.A. and Paiva Dias, G., (2006) A modular standard for the cadastral domain: application to the Portuguese cadastre. Computers, Environment and Urban Systems. Volume 30, Issue 5, pp. 562-584.	An evaluation and adaption of the CCDM is worked out. See Section 5.4.
Van Oosterom, P.J.M., Lemmen, C.H.J., Ingvarsson, T., Van der Molen, P., Ploeger, H.D., Quak, C.W., Stoter, J.E. and	This publication has been extensively reviewed. This paper is basic input for LADM Version B presented in Section 3.4 in this

[26] http://wiki.tudelft.nl/bin/view/Research/ISO19152/WebHome
[27] http://www.isotc211.org/

Zevenbergen, J.A., (2006). The core cadastral domain model. Computers, Environment and Urban Systems, Volume 30, Issue 5, pp. 627-660.	thesis.
Lemmen, C.H.J. and Van Oosterom, P.J.M., (2006a). Version 1.0 of the FIG Core Cadastral Domain Model. XXIII FIG Congress. Munich, Germany.	This is the LADM Version B, see Section 3.4.
Lemmen, C.H.J., Augustinus, C., Van Oosterom, P.J.M. and Van der Molen, P. (2007). The social tenure domain model: design of a first draft model. FIG Working Week 2007. Hong Kong, China.	In this publication the Social Tenure Domain is presented in its first draft. See Chapter 4.
- ISO/TC 211, (2008a). ISO 19152 New work item proposal (NWIP), Geographic information - Land Administration Domain Model (LADM). - ISO/TC 211, (2008b). ISO 19152 Working Draft 3 (WD3), Geographic information - Land Administration Domain Model (LADM). - ISO/TC 211, (2009). ISO 19152. Committee Draft (CD), Geographic information - Land Administration Domain Model (LADM). - ISO/TC211, (2011c). ISO 19152, Draft International Standard (DIS), Geographic information - Land Administration Domain Model (LADM). Lysaker, Norway: ISO.	The NWIP has been prepared by the author together with his promoter prof.dr Peter van Oosterom. This document has been submitted by FIG to ISO/TC211 and (in parallel) to CEN/TC287. Comments and observations from a project team have been included in the WD. A CD was worked out by an Editorial Committee[28]. Remarks and observations to this document resulted in the DIS, presented as LADM Version C in this thesis. The ISO 19152 Working Draft, the Committee Draft and the Draft International Standard have been prepared by Lemmen as editor (and co-author) in close co-operation with his promotor prof.dr Peter van Oosterom and dr Harry Uitermark. The DIS is presented as version C in Section 3.6.
Van Oosterom, P.J.M., Groothedde, A., Lemmen, C.H.J., Van der Molen, P. and Uitermark, H.T., (2009). Land administration as a cornerstone in the global spatial information infrastructure. International Journal of Spatial Data Infrastructures Research 4: pp. 298-331.	This publication has a focus on the use of LADM and SDI. See Section 3.8.
Döner, F., Thompson, R., Stoter, J.E., Lemmen, C.H.J., Ploeger, H.D., Van Oosterom, P.J.M and Zlatanova, S., (2010). 4D cadastres: first analysis of legal, organisational, and technical impact—with a case study on utility networks. Land Use Policy, the international journal covering all aspects of land use, Volume 27, Issue 4.	See Subsection 3.6.6 for the description of the link to external physical utility networks

[28] Members of the Committee are: Danilo Antonio, replacing Solomon Haile (UN-HABITAT, Kenya); Wim Devos (Joint Research Centre of the EU, Italy); Antony Cooper (South Africa, chair); Paul Egesborg and Christian Lord (Canada); Tomohiko Hatori (Japan); TaikJin Kim (Korea); Christiaan Lemmen (the Netherlands, editor); Julie Binder Maitra (United States); Tarja Myllymäki (Finland); Peter van Oosterom (the Netherlands, co-editor), Jesper Paasch (Sweden); Markus Seifert (Germany); Harry Uitermark (the Netherlands, co-editor); Frédérique Williams (France).

Lemmen, C.H.J., Van Oosterom, P.J.M., Eisenhut, C., and Uitermark, H.T., (2010a). The modelling of rights, restrictions and responsibilities (RRR) in the Land Administration Domain Model (LADM). XXIV FIG International Congress 2010. Sydney, Australia.	Some relevant modelling decisions on RRRs for the LADM Version C are presented; see Section 3.6 and also Annex C.
Lemmen, C.H.J., Van Oosterom, P.J.M., Thompson, R.J., Hespanha, J. and Uitermark, H.T., (2010b). The modelling of spatial units (parcels) in the Land Administration Domain Model (LADM). XXIV FIG International Congress 2010. Sydney, Australia.	Some relevant modelling decisions on spatial units for the LADM Version C are presented and worked out.
Lemmen, C.H.J., (2010d). The Social Tenure Domain Model, A Pro poor land Tool. FIG Publication 52. ISBN 978-87-90907-83-9.	Presentation of the STDM as a pro poor land tool. See Chapter 4.
Elia, E.A., Zevenbergen, J.A., Lemmen, C.H.J. and Van Oosterom, P.J.M., (2011). The Land Administration Domain Model (LADM) as the reference model for the Cyprus Land Information System (CLIS), Article in Press, Survey Review.	See Section 5.2 for the adaption of LADM to the local LA Cyprus where implementation of LADM is considered

1.7 Scope and Limits of this Research

The scope of this research is on the data model behind Land Administration based on a common pattern where formal, informal and customary *people – land relationships* are considered. The data model in its implementation is assumed to be distributed over different organisations with different responsibilities in LA. It can be that a community maintains its own land administration, see for example the MSc thesis work of Moreno (2011) with an example from Bogotá, Colombia. This administration has been used for credits in communities. Lamba (2005) who gives example from Kenya in support of activities of slumlords. Those land administrations don't have a legal basis.

For a domain model it is necessary to draw a 'system boundary', to define what is inside the system and what is not, or what is inside this research and what is not, or more general what its limitations are. The scope of this research is on the data model behind Land Administration based on a common pattern: legal/administrative data, spatial data, survey data. The static part of the LA domain is the main subject. The dynamic part (initial data acquisition, maintenance and data provision processes) is seen as being needed to bring the LAS from one static situation into another; the dynamic part is outside the focus of this research.

This research does not focus on the legal, political, economic, institutional or financial aspects of land administration and land administration organisations; at least as far as those are not related to user requirements as worked out in Chapter 3. Strategic and operational planning within land administration organisation is neither a point of attention; the focus is on data modelling, not so much on primary (land transactions) and secondary (supporting financial and resource management, etc.)

workflows. Organisational aspects are not included in this research – as said: the Land Administration Domain is potentially to be implemented in a distributed environment; this implies that different organisations or different parts (centralised/decentralised) of one organisation can be involved in this. This is considered to be a starting point for modelling. Of course it can be just one organisation.

Taxation, valuation and land use are knowledge fields in itself and are not within the focus of this thesis.

1.8 Thesis Overview

Chapter 1, this chapter, gives an *introduction* to the subject of this research. Motivation and background, research objectives and questions, the methodology and the scope and limits are presented. This chapter also provides an overview of the incremental approach in the LADM design. Efforts have been made to present the model to FIG to get comments and reviews for improvements (2002-2007). Then the FIG submitted the LADM to ISO and CEN. Standardisation itself is a long process (2008: New Working Item Proposal – 2012: Final Draft International Standard, and International Standard expected in August 2012).

Chapter 2, *a review on existing work in LA domain modelling*, provides the results of a literature review on people to land relationships from modelling and land policy perspectives and comprises a discussion on common patterns in this relationship.

The *design and construction of the land administration domain model* in Chapter 3 will be discussed as follows on the basis of three ‘major’ versions of the model:

- the first set of user requirements and the initial version of the model (Lemmen and Van Oosterom, 2003c) as presented in Brno is the ‘mature initial version’ of the LADM: LADM Version A;
- the initial version 0.3 (as presented in Brno) has been used as a reference paper for the second workshop on Cadastral Modelling held in Bamberg, December 2004. Further developments were based on new insights from the EGM in Nairobi. All this resulted in a peer reviewed publication in Computers, Environment and Urban Systems (Van Oosterom et al, 2006b); finally worked out in the version 1.0 presented in Munich (Lemmen and Van Oosterom, 2006a). This is LADM Version B in this thesis;
- further developments in the ISO Technical Committee 211, up to the Draft International Standard (DIS) stage in January 2011 (ISO, 2011c). The Draft International Standard is LADM Version C in this thesis. No further versions are discussed; e.g. the current Final Draft International Standard (May 2012) will nor be introduced neither be discussed.

In Chapter 3 attention is given to *the basic packages of the LADM*. The packages are designed based on the assumption that the LADM can be implemented in a distributed environment where co-operation exists between organisations with different responsibilities. This is of course not necessary in case all responsibilities are under the umbrella of one organisation (for example within one community). But linking with SDI can appear. Linking to SDI is one more issue in Chapter 3 as is the ‘link’ to other ISO standards from the 19000 series on geographic data.

In Chapter 4 *new appraoches and experimental results* an explanation is given on the limitations of existing LASs: customary and informal tenures cannot be represented. A STDM prototype is presented based on Open Source software. This prototype has been introduced to the FIG Congress in Sydney, Australia, 2010. Specific attention is give to data acquisition in a field test in Ethiopia in Chapter 4 and to bridging the gaps between new appraoches and conventional systems.

Implementations: first Results of LADM will be discussed in Chapter 5 in relation to international attention in several countries. Special attention will be given to Cyprus, Honduras and Portugal where implementation is an actual point of consideration. The use of LADM in the context of INSPIRE and LPIS[29] will be highlighted as well as the use of LADM as basis for a Free and Libre Open Source Sotware (FLOSS) / Solutions for Open Land Administration (SOLA) within the FAO. *Conclusions* of this research and *proposed future work* can be found in Chapter 6.

The Appendices provide *LADM Class Names* for the different versions and can be found in Appendix A; an overview of *LADM Associations between Classes in the DIS* in Appendix B; *Instance Level Diagrams* in Appendix C and *Terms and Definitions used in the DIS* in Appendix D.

[29] Land Parcel Identification System of the European Union. LPIS is used for agricultural purposes (subsidies).

2 A Review of Existing Work on LA Domain Modelling

In Chapter 1 the motivation and background, problem definition, research objectives, research questions and methodology are presented. This thesis is a design thesis focussing on a generic data model for land administration. It is important to keep in mind that there can be different purposes behind a land registry and cadastre, see the definitions in Chapter 1.

In this chapter first a set of guidelines or starting points for LA modelling from global organisations is provided in Section 2.1. Than, in Section 2.2, relevant existing work on LA modelling (based on the so-called Object – Right – Subject 'view') is presented. Section 2.3 presents the 'axes of variation' as introduced by Larsson. In 2.4 the 'continuum' of land rights from UN-HABITAT is explained, followed by Cadastre 2014 from FIG in Section 2.5. Those concepts can only be used in flexible LASs. In 2.6 attention is paid to 3D Cadastres, in 2.7 to Marine Cadastres. In Section 2.8 an existing cadastral standard from the United States is discussed. Section 2.9 deals with open source cadastre and registry tools. In 2.10 the contents of this chapter are discussed and evaluated. One issue is the common pattern in people – land relationships that will be the basis for formulation of requirements for the LADM.

2.1 Some Guidelines from Global Organisations

The statement on the Cadastre of the FIG highlights, from an international perspective, the importance of the Cadastre (LIS) for social and economic development (FIG, 1995): the development of such systems should be promoted internationally, with attention to the needs and demands of societies with customary and informal tenures.

In the FIG Bogor Declaration (FIG, 1996) the different needs from different countries are underlined: a simple low cost manual cadastre recording only private ownership rights may be appropriate for one country, while a sophisticated and relatively expensive fully computerised cadastre recording a wide range of ownership and land use rights may be appropriate for another country. The infrastructure can support a vast array of legal, technical, administrative and institutional options in designing and establishing an appropriate cadastral system, providing a *continuum of forms of cadastre* ranging from the very simple to the very sophisticated. Such flexibility allows cadastres to record a *continuum of land tenure arrangements* (Section 4.5 of the Bogor Declaration) from private and individual land rights through to communal land rights, as well as having the ability to accommodate traditional or customary land rights. In field operations there is a range of technologies from GPS to the plane table. Work may commence with large scale photomaps for planning and adjudication purposes.

The Food and Agriculture Organisation of the United Nations, see FAO (2002), defines land tenure as the relationship, whether legal or customary, among people as individuals or as a group, with respect to land – where "land" is used here to include other natural resources such as water and trees.

The United Nations Urban Settlements Programme (UN-HABITAT) issued in 2003 a handbook on best practices, security of tenure and access to land (UN-HABITAT, 2003). It is recommended to develop efficient LISs to supply geo-information to decision-makers. Land information should not be confined to cadastral or tax information, but should also include informal and customary land information and records. And the systems should be developed with attention to poverty alleviation and the supply of tenure security and land to the poor as major priorities.

In the book *Land policies for growth and poverty reduction* (World Bank, 2003) it is stated that land is a key component of the wealth of any nation. Well-defined, secure, and transferable rights to land are crucial to development efforts. Once secure in their land rights, rural households invest to increase productivity. Moreover, the use of land as a primary investment vehicle allows households to accumulate and transfer wealth between generations. The ability to use land rights as collateral for credit helps to create a stronger investment climate and land rights are thus, at the level of the economy, a pre-condition for the emergence and operation of financial markets. Property rights to land are one of the cornerstones for the functioning of modern economies.

According to UNECE (2004), policy goals can not be achieved unless there is an effective land administration infrastructure with modern information technology.

According to the Land Policy Guidelines of the European Union (EU Task Force on Land Tenure, 2004) a broad view of cadastral systems and titling methods is needed, in order to establish reliable and appropriate records of village, family or individual land rights, and to register broad sets of rights, at low cost.

The main objective of the Global Land Tool Network (GLTN) is to contribute to poverty alleviation and the Millennium Development Goals (MDGs) (UN, 2000) through land reform, improved land management and security of tenure (GLTN, 2010). The GLTN originates from requests to the United Nations Human Settlements Programme (UN-HABITAT, 2010), which initiated the network in co-operation with the Swedish International Development Co-operation Agency (Sida, 2010), the Norwegian Ministry of Foreign Affairs and the World Bank in 2006. GLTN aims: to establish a continuum of land rights, rather than just focus on individual land titling, and to improve and develop pro-poor land management, as well as land tenure tools.

The FAO Good Land Governance (2007) document is written for people who work in LA and all those with an interest in land, land tenure and their governance (FAO, 2007). Although much has been written about the importance of good governance in achieving development goals, there is comparatively little material on good governance in land tenure and administration. Failings in governance have adverse consequences for society as a whole. In contrast to good governance can help achieve economic development and the reduction of poverty.

The FIG Coastal Zone Declaration (FIG, 2008) looks more specifically at providing a pro-poor approach to manage the interests and rights in the coastal areas, and the role of the LA professionals in this regard. In order to reach a harmonious, sustainable and resilient development of the coastal zone there is a requirement to approach the issues holistically. Two of the key factors that will maximise the effective management of these areas are: the creation of a uniform Cadastre following the key guidelines in the FIG Cadastre 2014 declaration and the creation of, and implementation of, a LIS to bring together all information sets that impact the costal zones.

2.2 Object – Right – Subject Model

Henssen (1995) visualised the *Object – Right – Subject* model. See Figure 3 for the combination of these *tuples* to a single *Triple* '*Object* (parcel) – *Right* (stewardship) – *Subject* (man)'.

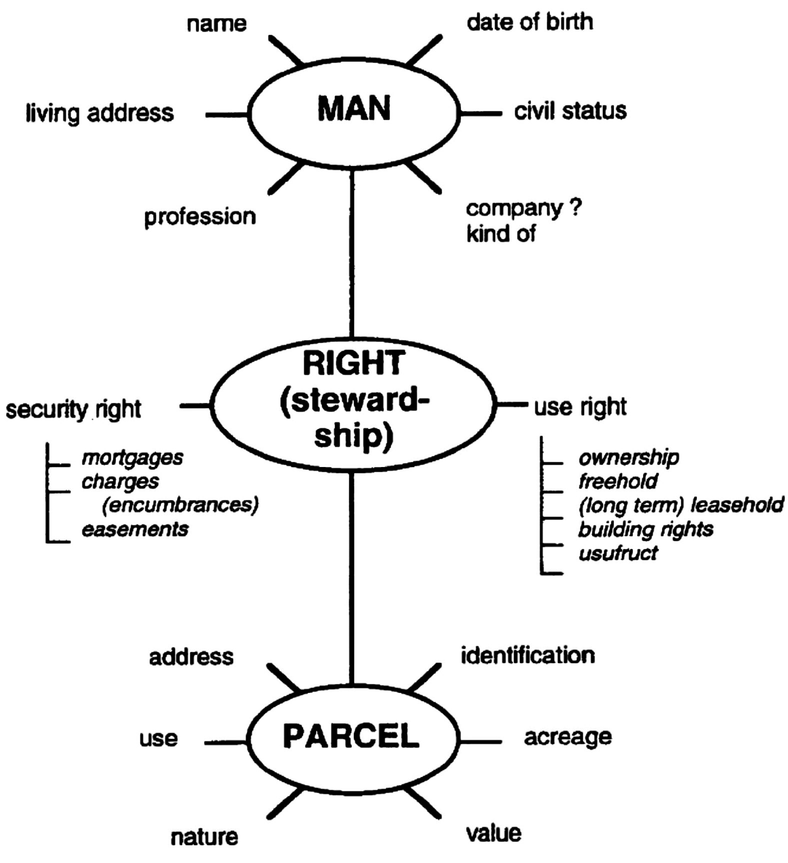

Figure 3 The Triple 'Object –Rright – Subject' (in Henssen, 1995).

Henssen explains that *land registration* and *cadastre* usually complement each other, and that land registration puts in principle the accent on the relationship *subject*

– *right*, whereas cadastre puts the accent on the relationship *object* – *right*. According to Henssen (1991) it is generally recognised that a land recording system should be *parcel based, not people based*, with the parcel being uniquely described on some form of map supported by a land survey system. Westerbeek (2000) and Tuladhar (2004) also use the object - right - subject approach in their work.

Simpson (1976), in his book in Section 3.1, also quoted by Larsson (1991) on p. 14 starts from the purpose of the land recordation system. The purpose should determine the unit of record. Simpson explains that in case of a fiscal system the unit of use (field which vary in size and quality and so in value) may be suitable. Fields together may form a unit of operation (a farm; this unit is appropriate where development is concerned). Two or more units of operation may form a unit of ownership, which may be a record. In this way of thinking the estate of the landowner may comprise several farms[30], each separately operated and containing several units of use. Larsson (1991) takes into account now that LISs are intended to serve many purposes. There may be different records, but there should be common units according to him; e.g. the parcel. Several parcels may be combined to form larger units of operation or ownership. The definition of a parcel by a UN Ad Hoc Group of Experts on Cadastral Surveying and Land Information Systems (UN, 1985) specified a parcel as a continuous tract of land within which unique tenure interests are recognised. The parcel must envelop a continuous area of land and a continuous interest in land. On the map a cadastral parcel is formed by a, in itself closed, line and has a unique identifier.

Dale and McLaughlin (1988) – (see also UNECE, 2004) – give a nice overview of alternative ways for parcel referencing: grantor/grantee index, title number, volume and folio, subdivision name and plot number, block and plot number, post office address, street index and parcel address, grid co-ordinate or geo-code. It should be noted here that some approaches are from the perspective of the person, other from the perspective of the land.

Also in UNECE (2004) a hierarchy of ownership is identified (see also Figure 4):
1. a portfolio of ownership:
2. the portfolio may consist of several proprietary units (commonly referred to as several properties);
3. the proprietary unit may consist of several Basic Property Units (BPUs) although often it is the same as a BPU;
4. the BPU may consist of several parcels;
5. each parcel may consist of several plots;
6. a plot is something that can be plotted on a map and is often identifiable by the way in which the land is used or managed.

[30] This sounds somewhat ‘colonial’ according to the author of this thesis. But this personal statement does of course not mean that Simpson’s view is not usefull. The ownership perspective is person based, the units of the operation perspective is land (parcel) based. See also Figure 4.

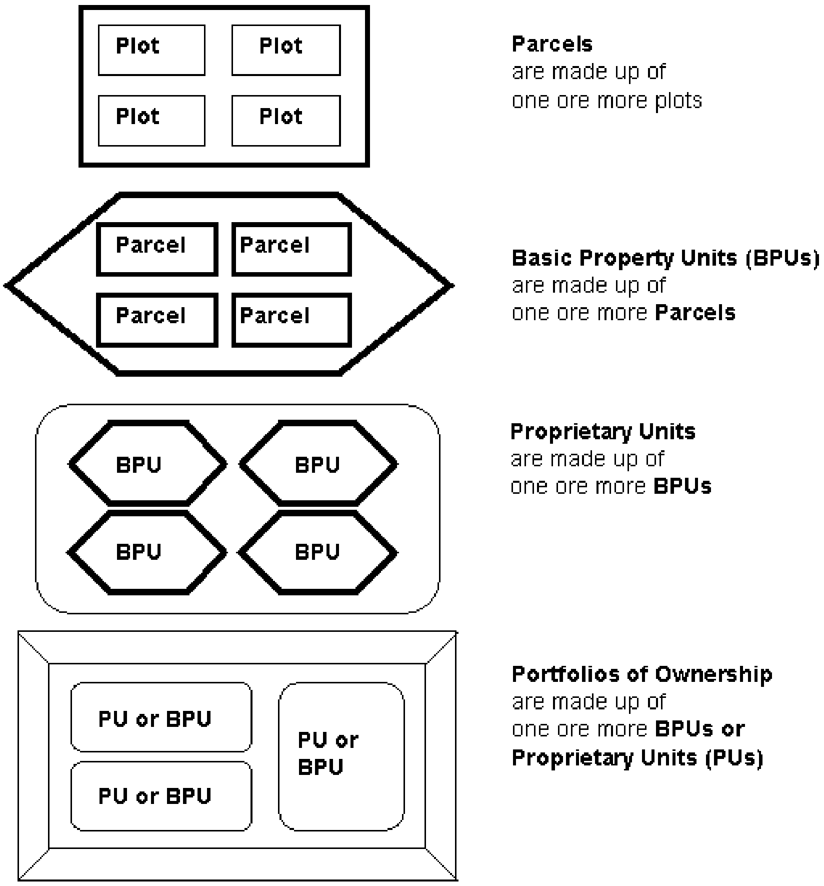

Figure 4 The hierarchy of ownership according to (UNECE, 2004, p 26).

This is based on the following definitions (quoted from UNECE, 2004):

- the term 'parcel' refers to the physical space that is identified in a cadastre. It is a closed polygon or more strictly a closed volume;
- a parcel is defined by uniform ownership and homogeneous real property rights. The parcel is the basic unit of area that is recorded in a cadastre;
- a parcel may consist of several plots, each of which belongs to one parcel;
- the plot is an area or volume that can be plotted on a map and is normally definable by the way in which the land is or may be used. It may or may not be identifiable in a cadastre;
- as a general rule, if an identifiable volume of space is or has been subject to a legal transaction, it is at least one parcel; if it is not or has not been subject to an independent transaction, it is a plot;
- a group of adjoining plots that belong to different owners but share the same characteristic may be regarded as a zone;

– a Basic Property Unit (BPU) is defined by ownership and homogeneous real property rights, and may be made up of several parcels. It is the basic unit of ownership that is recorded in the land books or land registers. A proprietary unit consists of one or more BPUs that can be regarded as one property within there are non-homogeneous real property rights. A proprietary unit arises where an original BPU may have been extended but where for historic or other reasons the additional components have not been amalgamated with the original. Consequently, there are different rights and the real property object is not homogeneous. In many cases, however, the proprietary unit and the BPU are the same thing;
– a portfolio of ownership is a collection of proprietary units and BPUs that are in the possession of one legal entity.

In practice, according to the guidelines, in many countries in Europe a BPU consists of only one parcel. Real property registration systems record BPUs and parcels (if they are not the same object). Only some countries identify the portfolio of ownership as a separate entity. Many countries do not register plots as separate parts of parcels.

About the land rights Simpson (1976) makes some statements comparing[31] *a bundle of sticks*. From time to time the sticks may vary in number (representing the number of rights), in thickness (representing the quantum of each right) and in length (representing the duration of each right). According to Simpson the whole bundle may be held by one person, a group of persons or a company. According to Simpson it very often may be the case very separate sticks are held by different persons. Sticks out of the bundle can be acquired in different ways and held for different periods, but according to Simpson the ownership itself is not one of the sticks – it is a container of the bundle. The owner has the right to give out the sticks. And[32] *"the transfer of the ownership is transfer of the container itself and leaves the transferor with no interest at all either present or future". Interests* may be enjoyed or exercised by persons other then the owner. Dale and McLaughlin (1988) speak also about land rights applied by groups of people or individuals; the protection of customary rights may be as important as the protection of those of the individual. Parcels are continuous area's (volumes)[33] of land in which unique, homogeneous interests are recognised (see also Henssen and McLaughlin, 1986). Attributes may be the name of the owner, the nature of the tenure (e.g. leasehold, freehold), the price paid for the land on transfer, any restrictions on the use of the parcel, any exclusions of rights to minerals, or any caveats or cautions. Overriding interests may be assumed to apply. Larsson (1991) sees a parcel based information system as important, because 'much of human life, human activities and human property have meaningful links with specific pieces of land'. According to Larsson this is obviously true in case of rights to land (ownership, occupancy, lease, mortgage, etc.), but there are other 'connections' as well: buildings, people, enterprises, property, building regulations, etc. Larsson further highlights possibilities of the use of parcel identifiers as geo-codes. This link was also recommended within the Netherlands Cadastre and Land Registry and Agency

[31] See Simpson (1976), 4.4, page 7: 'The collection of rights pertaining to any one land parcel may be linked to a bundle of sticks'.
[32] Simpson, 1974, 4.5, page 7.
[33] This definition of parcels may exist independent from a 2D or a 3D cadastre.

(Kadaster, 1980). In this report (in Dutch) it was recognised that parcel id and address can not completely replace each other: the National Post can not deliver letters using parcel ids and properties can in many cases not sufficiently be described using addresses. Both address and parcel ids can be geo-codes. See further Williamson et al (2010) for the significance of geo-codes and Holland et al (2009) for the use of geocodes and readiness for e-Government.[34]

Subsurface rights are included – with reference to Platt (1975) and Dale and McLaughlin (1988) speak about mineral, groundwater, timber, agricultural, development and air rights, see Figure 5. All those rights can be registered. If this really happens is another question.

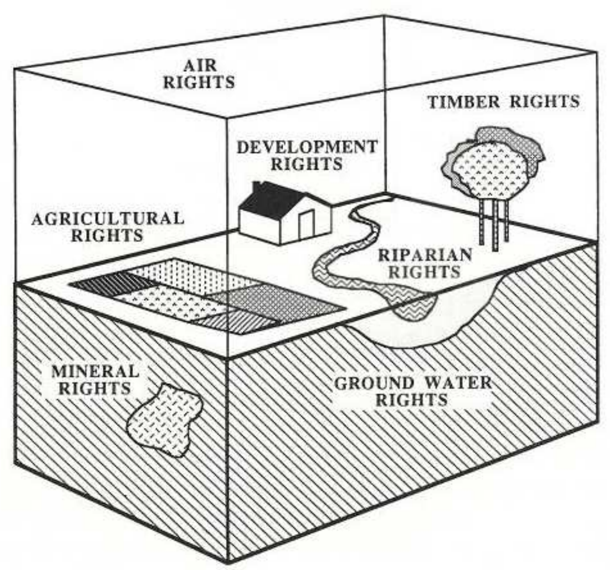

Figure 5 Type of rights in 3D space, based on Plat (1975).

Kaufmann and Steudler (1998) recognise the object – right – subject structure from Henssen, 1995. According to them in a deed system a rightful claimant[35] has 'in hand a document proving his/her right as the owner of a piece of land by describing the transfer of the rights referring to him/her. This document, the deed, becomes legally effective, when it is booked or registered in the official land register in relation to the rightful claimant. The deed system is 'man-related' (Kaufmann and Steudler, 1998) (see Figure 6 to the left). In a title system the right referring to the parcel, the title is registered together with the indications about the rightful claimant in relation to the land objects. The title system is land related (see Figure 6 to the right). Zevenbergen (2002) disagrees the adding of one-directional arrows as is done in Kaufmann and Steudler 1998. The 'deeds approach' as presented in Figure 6 to the left is in Zevenbergen's terminology a view from the legal aspect system. The alternative view in which the arrow points from parcel to person (Figure 6 to the

[34] There is a lot of literature on geo coding since the computerisation of land information started.
[35] In this thesis 'rightful claimant' and 'rightholder' is synonym.

right) takes according to Zevenbergen the point of view of (geo) information management (a part of the technical aspect system). Zevenbergen finds that view equally limited, since it might encourage seeing land registration (and the wider land administration) as an end in itself, without looking at its goals. If an arrow has to be added, it should be a bi-directional one according to Zevenbergen. He also introduces the organisational aspect system and highlights the importance of the interrelations between the different aspect systems as they constantly influence each other.

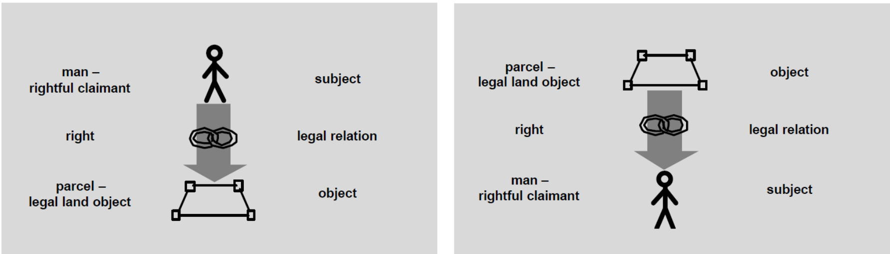

Figure 6 Left: relation man - land in a Deed System. Right: relation man - land in a Title System (Figure 3.16 and 3.17 in Kaufmann and Steudler 1998).

Deininger (1998) and Migot-Adholla (1999), also quoted by Quan (2000), speak about registration and adjudication of customary rights and on provision of titles on community basis. This was the result of an evolution of the World Bank's land policy after a long time of promoting formal land titling and abandonment of communual land tenure systems by the World Bank as a pre condition of modern development.

In (Van der Molen, 2003a) it is argued that when it is assumed that the world's community is sincerely of the opinion that appropriate LASs are required for the eradication of poverty, sustainable development and economic development then it will be evident that attention should be devoted primarily to LASs of developing countries. In these countries LASs will probably be very simple systems designed to make the appropriate contribution to the basic security of land tenure, basic land markets, and basic government land policy. Therefore, it will be necessary to adopt new concepts in the design of LASs in order to take more into account the dynamism of land tenure, the land market, and government intervention in private property rights. Traditional basic concepts (objects, subjects, and rights) are already affected in three ways with regard to:

1. objects: spatial units other than accurate and established units;
2. subjects: group ownership with non-defined membership;
3. rights: the recognition of types of non-formal and informal rights.

These new insights can now be incorporated in a modification of the Henssen diagram in Figure 3 of the three basic concepts of LASs. The modified diagram is shown in Figure 7.

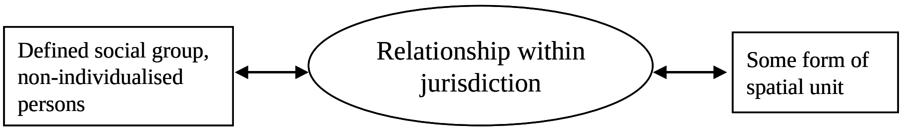

Figure 7 Modification of the Henssen diagram; after Van der Molen (2003a).

Van der Molen adds the following important remarks about groups and individual group members: the entity exercising the land rights is now defined as a community, i.e. a specified group of persons. However in this situation the individual members of that group are not specified (i.e. in terms of their membership of a tribe, a family, etc.). Their rights pertain to a relationship with the land that is in accordance with the standards and values of the relevant community, although these rights will need to be defined whether it is to be possible to provide third parties with meaningful information. In these situations the parcel of land, i.e. the object on which the rights are exercised, may be defined in a manner other than accurate land surveys and geometrical measurements. Furthermore, it is concluded that 'The adoption of an evolutionary approach to the implementation and development of LASs should guarantee the viability of these systems in developing societies.' See also FIG (1996). The object – right – subject model should be extendable to social tenure relationships: customary and informal rights. Examples of these relationships are village titles (Tanzania, Zimbabwe) (Lugoe, 1996), certificates of occupancy or rights of occupancy (Tanzania, Nigeria) (Sule, 2000), group ranches (Kenya) (Waiganjo, 2001), flexible titles (Namibia) (Juma and Christensen, 2001) and (De Vries, 2000), customary rights issued by Land Boards (Botswana, Uganda, Namibia) (Toulmin and Quan, 2000), communal titles for Community Property Associations (South Africa, which will probably be replaced by the customary common hold system) (Van den Berg, 2000), (Cousins, 2002) and (Durand-Lasserve and Royston, 2002).

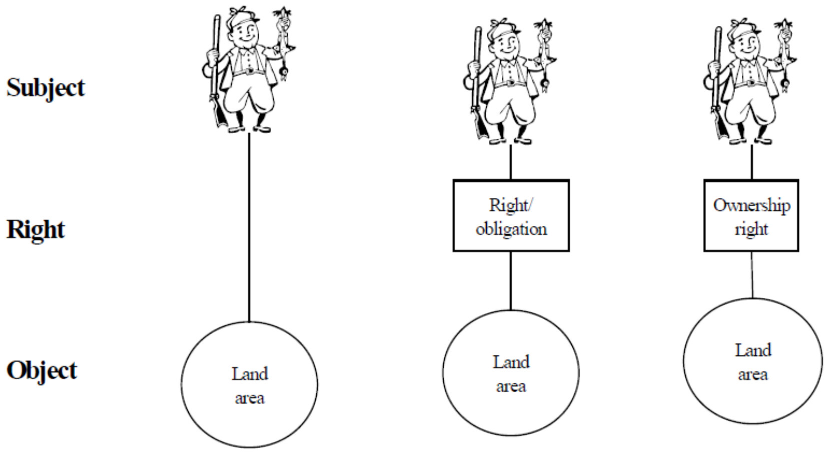

Figure 8 Theoretical connections between subjects and object (Mattsson, 2004).

Mattson (2004) presents the object – right – subject model as in Figure 8. There can be three categories with different theoretical connections between object (“man”) and subject (“object”): a direct connection between object and subject, a connection through right and obligation and a connection through ownership. See also Paasch (2004). In this thesis the example as given at the left in this version (the direct connection) does not exist. One does not ‘have’ the land, one has (a share in) ownership or use or another right to the land. Ownership is just one type of land right.

In the PhD research of Bennett (2007) a framework is developed for organising the management of ‘Rights, Restrictions and Responsibilities’ (‘RRRs’) in a way that enables the achievement of sustainable development objectives by citizens and governments. The framework consists of the ‘RRR Toolbox’, with in addition the concept of ‘Property Object’. The ‘RRR Toolbox’ includes eight *principles* (‘components’): land policy, legal, tenure, cadastral registration, institutional principles, spatial and ICT principles; human resource development and capacity building and emerging tools. The ‘Property Object’ is defined as an advanced descriptive framework of the five *attributes* that make up an individual property interest:

1. the objective attribute: the reasons for enacting the property object in legislation or contract;
2. the action attribute: the particular activities that the property object allows, with regard to land and natural resources;
3. the spatial extent attribute: the geographic area over which the interest applies;
4. the duration attribute: the period of time over which the property object applies;
5. the people impacted attribute: denotes the group of people affected by the property interest.

The work of Kalantari (2008a) was motivated by the fact that LA with its existing digital systems is not flexible enough (a) to accommodate new land related commodities and interests, and (b) to respond to the increasing need of clients for land information. New land related commodities and interests are *informal* and *customary* rights, 3D titles, water rights, biota rights, noise restrictions, or carbon credits. According to Kalantari LASs are not flexible enough for two reasons:

- a limited number of interests have historically been organised in cadastres, with parcel based data models providing the basic building block of LASs. Despite its relative success, it is now under pressure from the new land related commodities and interests. Parcel based indexing of interests in land cannot accommodate interests that are not necessarily equivalent to the extent of land parcels;
- many ICT based LASs are now outdated, and the maintenance of these systems is complex and expensive. Future LA requires a comprehensive view on the utilisation of ICT. Interoperability is a serious issue to be considered when enabling future LA by ICT.

Kalantari proposes to replace the data model based on the physical land parcel by a spatially-referenced data model based on the *legal property object* that is the unique combination of every interest and its spatial extent (see Figure 9).

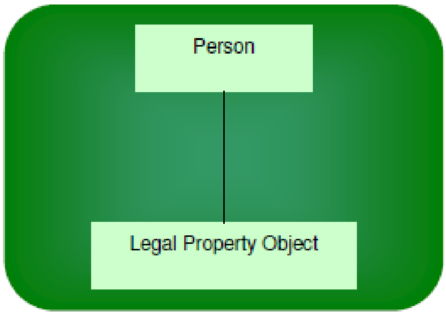

Figure 9 The legal property object model (from Kalantari, 2008a).

Consequently, the relation between interest and its spatial dimension is that they together are a unique entity in the real world. For purposes of spatial identification, any kind of interest, whether a right or a restriction has the same logical construction. This means RRRs are not seen as a separate entity or class. The author of this thesis disagrees with this way of modelling. RRRs are defined in legislation, there can be shares, and there can be different organisations with responsibilities in maintaining the attributes of a Legal Property Unit.

2.3 'Axes of Variation'

Larsson (1991) in his book 'Land registration and cadastral systems' presents 'axis of variation' in the (so-called progressive, see Fourie and Van Gysen (1995)) development of cadastral/land information systems. One can start at different levels; types of simplification can be seen as variations along a number of axes – which together determine information content. Most important axes are according to Larsson:

- *the land – unit division axis.* Larsson observes that for parcel based systems a division in land units is imperative. Variations can be found in size of the units – group (village), farm, parcel, etc. This fits to the vision of Simpson (1976) here above (units of use, operation, property). This fits for example also to the Land Use Division Survey of the Netherlands, see Bijkerk et al (1970): Lot, Compound Lot, Holding, Land Users District, Land Consolidation Block;
- *the location – determination axis.* Here Larsson observes that location of land can be indexed without maps, as in the Doomsday Book and in most ancient tax recordation's. Larsson explains that it can be also located by a point on an aerial photograph or map or as a co-ordinate. Larsson explains that if the boundaries of the units have been recorded on the ground, they can be recorded in a map or co-ordinate record with a varying degree of accuracy. This depends partly on whether ground survey, photo interpretation or photogrammetric methods are being used. Great variations in methods and results are possible. Also Dale and McLaughlin (1988) highlight that for many record management purposes a parcel identifier is the only spatial characteristic that is needed. In relation to spatial information many options are available. Survey of boundaries is expensive. Adjudication

followed by good monumentation can solve many problems in case of disputed boundaries by the local population. Centimetre accuracy of survey is rarely needed, if ever reconstruction of boundary points on cm level in the field will be needed for cadastral purposes. Dale and McLaughlin (1988) further discuss aerial photographs as basis for cadastral surveys. There are predictions on the major impact of the Global Positioning System (GPS) for cadastral surveys. There may be objections by licensed surveyors and because of problems with setting out afterwards. They may not be seen as evidence in court. In any case an aerial photograph is seen as a historical as well as a graphical document. Digital mapping and remote sensing can be sources as well. Fourie (1998) pays a lot of attention to identification of objects. As a result a range of identifiers has been proposed based on some innovative new concepts, see also Fourie and Nino-Fluck (1999): points, lines, sketch maps, text, list of names, non geo-referenced parcels, unique numbers, geo-referenced parcels, etc.:

- points, geo-codes (sometimes known as dots on plots), and lines (Latu, N.D.; Davies, 1998; Durand Lasserve, 1997; Home and Jackson (1997), in vector or raster format;
- polygons with fuzzy boundaries (Jackson, 1997);
- text, including lists of names (Ezigbalike and Benwell, 1994) and unique numbers;
- parcels - poorly surveyed, non geo-referenced (Törhönen and Goodwin, 1998) and geo-referenced;
- sketch maps (Törhönen and Goodwin, 1998), and photographs, in the absence of any better description (UNECA Expert Group meeting, 1998, see Fourie, 1998)

Aside from the property parcels of privately owned registered land, based on work by Davies (1998), Cowie (1999), Latu (N.D.), information in the form of thematic polygons of low accuracy should be created showing the location and approximate boundaries of the informal settlement and the customary areas. Lists of leaders (Ezigbalike and Benwell, 1994) in the informal settlement and/or customary areas should be attached to such thematic polygons for the purposes of identifying stakeholders and decision makers who should be involved in negotiating land use and/or land right changes. It is not possible to use the cadastral parcel as the only identifier:

– the *information – content axis.* Larsson explains here that to the primary land unit designation can be added various information connected to this unit. Such as area, land use, buildings, assessed value, owner, other rights, population, etc. Some of it may be contained in property or cadastral records, some in land or other registers connected by common identifiers. Larsson states that the system can be further extended by secondary records – again a wide scope of variation along this axes. In Annex II of UNECE, (2004) an example of information in a real property register is given. A remark is of course that the more attributes are included the more attributes have to be maintained – there is a multiplier for each new attribute related to e.g. object, right or subject;
– the *information – quality axis.* Here Larsson is very clear: practically included in a land information system may vary considerably in quality. Dale and McLaughlin (1988) ask a lot of attention for these issues. Where spatial data are concerned

they recognise that a major problem lies in reconciling data from various sources to different standards of accuracy and precision. This means that there are possible varieties in data acquisition and in existing data. In UN-HABITAT (2003) there is also attention to this issue. Instead of beginning with the accurate delineation of a parcel or plot, *geo-codes* against the site or *'dots on plots'* could be used (FIG and UNCHS, 1998). It is cost-effective to connect boundaries with *photo-grammetrically* derived dimensions, to existing cadastral boundaries, instead of using ground survey methods (Parker et al, 1998). The use of *visualisation* instead of relying on an accurate survey. A combination of *aerial photography and GPS* is very cost effective (Ericsson and Eriksson, 1998). Salzmann (2002) speaks about 'Do it your self determination of cadastral boundaries'[36];
- the *maintenance – axis.* Larsson says that the availability of up-to-date data is of strategic importance for land information systems. It may be included as a quality issue.

Finally Larsson identifies a spatial axis. This is about priority setting in order to determine which areas should be included. Today there is more and more discussion about complete global coverage, see for example (Bennet et al, 2010). There can be support in the avoidance of land grabbing with an overview of the complete set of existing people to land relationships. Knowledge on areas which are included in land registry and area's which are not included has a special value in this context.

2.4 The Continuum of Land Rights

In 1998 Fourie undertook a comprehensive review of the cadastre and land information in Africa for the United Nations Economic Commission for Africa. An overview is presented in this review as to what is required in terms of spatial units, identifiers, representation of varying accuracies, scales and qualities combined with persons and based on evidence (from the field) of how social tenures actually worked. The whole spectrum of tenure systems needs to be covered: formal, informal and customary systems, not neglecting land related disputes and conflicts. Focus in the design of systems should be on sustainable development – not on land transactions and mortgage. Design criteria for an information system are worked out in detail in this review – e.g. on the use of graphical reference frameworks; on the possible use of a range of instruments and data acquisition methods; on the contents of an information system where cadastre can be a linked system.

The importance of standards and national spatial frameworks was recognised, allowing decentral use of data for different purposes and for many different decision makers, combined with central use of data. Conventional LASs are parcel based. Fourie and Nino-Fluck propose ranges of technologies for data acquisition. Modelling: cadastral mapping using remotely sensed images, aerial photographs and GPS as source should be possible. According to Fourie and Nino-Fluck (1999) it should be possible to have flexible accuracy demands: it should accommodate, *"defined in Dale and McLaughlin (1988) terms"*, graphical (pictorial) data, geometric

[36] Nowadays this would probably be called 'crowd sourcing'

(measurement based) data and topological data. Illegal and informal lands and customary lands should be possible to include. A continuum of land rights is proposed in UN-HABITAT (2008).

LASs are not yet supporting all these requirements. This continuum of land rights was already discussed in UN-HABITAT, 2003: "*there are a range of land rights in most countries which occupy a continuum, with a number of such rights occurring on the same site or plot"*. And: "*there is a range of informal-formal (illegal-legal) types along a continuum, with some settlements being more illegal in comparison to others*". There is a reference to Payne (1997) who speaks about a useful strategy for policy makers "*...every step along the continuum from complete illegality to formal tenure and property rights as a move in the right direction, to be made on an incremental basis*".

In the FIG Bogor Declaration (FIG, 1996) a similar continuum is identified in relation to 'tenure arrangements' (see Section 4 in the Bogor Declaration): "*the cadastral infrastructure can support a vast array of legal, technical, administrative and institutional options in designing and establishing an appropriate cadastral system, providing a continuum of forms of cadastre ranging from the very simple to the very sophisticated. Such flexibility allows cadastres to record a continuum of land tenure arrangements from private and individual land rights through to customary land rights, as well as having the ability to accommodate traditional or customary land rights"*. See also Williamson (1997 and 1998).

Quan (2000) in Toulmin and Quan (2000) speaks about the introduction of simple systems for land rights documentation, boundary definition and support for the resolution of disputes at community level. Such systems for land rights management should be transparent. Quan also proposes simple approaches to formalise land market transactions (announcement of agreements at public meetings, providing facilities for written transactions, registration of contracts, and the witnessing of signatures. And: low cost survey and registration procedures. Further attention is paid to the recognition and integration of customary rights into the legislative framework and the extension of tenants rights.

UN-HABITAT (2008) views the various types of land right as existing along a continuum, with some settlements being more consistent with law than others. This view makes it possible to include the people with the weakest tenures in the idea of sufficient legal access (See Figure 10). See also Zoomers and Van der Haar (2000) and Augustinus et al (2006).

One more 'continuum' is at the subject side: FIG (1995) states that land units as parcels are defined by the formal or informal boundaries marking the extent of lands held for exclusive use by individuals and specific groups of individuals (e.g. families, corporations, and communal groups). Simpson (1976) speaks about family, clans or tribes as groups. Further there can be companies or governments at the subject side or farmer village, farmer co-operation, religious community, etc. Toulmin and Quan, 2000, speak about land shared by several groupings (e.g. wetlands, woodlands, grazing area's) and about fuzzy boundaries.

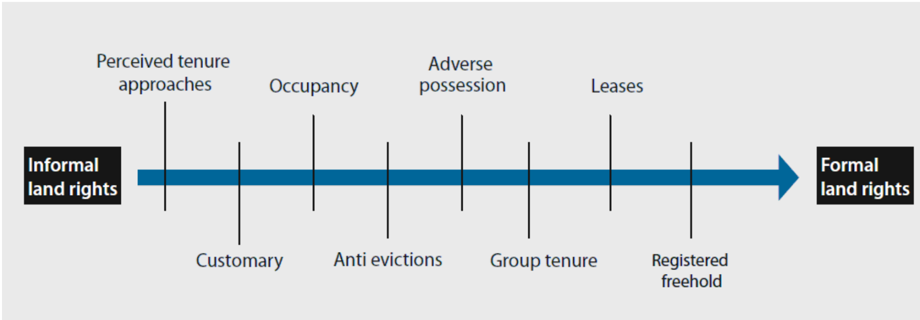

Figure 10 The continuum of land rights (from UN-HABITAT, 2008. There is an earlier version in UN-HABITAT, 2004).

2.5 Cadastre 2014

Kaufmann and Steudler (1998) presented characteristics of existing cadastral systems based on a research by a working group Vision 2014 from FIG's Commission 7. where questionnaires were send to FIG Commission 7 delegates. From 31 jurisdictions (with 7 states from Australia) responses were received. 23 Jurisdictions had a title based system, 5 a deed based system and 5 both. The cadastral unit is a parcel for 26 jurisdictions, a property for 4 and a name in 1 case. A mix of basic legal aspects of cadastre exists: positive or negative. There can be fixed boundaries based on surveys or general (approximate) boundaries. Legal value of boundaries can be on monuments in the field (19); cadastral maps (13); co-ordinates (14); measurements (16) or other 5 there can be monumentation of boundary vertices in the field or not. Interests in land may be rights (in 31 jurisdictions), restrictions (26); responsibilities (20); special rights (10); mortgages (4) and other (4). There can be a link between cadastral and topographic mapping on technical, legal or organisational level (25 cases) or not (6 cases). Cadastre can be complete or not – the latter means that there may be sporadic data acquisition approaches. In Zevenbergen (2002) the difference between positive and negative systems is explained: 'Under a positive system the registrar or his or her employer (usually the State) guarantees the titles that are registered. Whatever is in the registration is – by law– regarded correct. Damage caused by mistakes is settled (financially) by the State (or the registry). In a negative system there is no guarantee regarding the actual title. Only mistakes by keeping the registers are redeemed, not the (mainly private law based) problems that might not appear from the deeds, but still exist'.

All this implies a need for flexibility in the data model; parts of a LADM may be used in some cases and sometimes not. This is also valid for the organisation of land administration, many options are possible here. A LADM should cover this, see the requirements in Section 3.1.

Kaufmann and Steudler (1998) received a lot of attention for the idea that Cadastre 2014 will show the complete legal situation of land, including public rights and restrictions – using the concept of legal land objects; see Section 1.2. The principle of legal independence is a key item in the realisation of Cadastre 2014. This means that legal land objects, being subject to the same law and underlying a unique adjudication procedure, have to be arranged in one individual data layer; and for every adjudicative process defined by a certain law. Besides a special data layer for the legal land objects underlying this process has to be created. This is illustrated as follows in Figure 11.

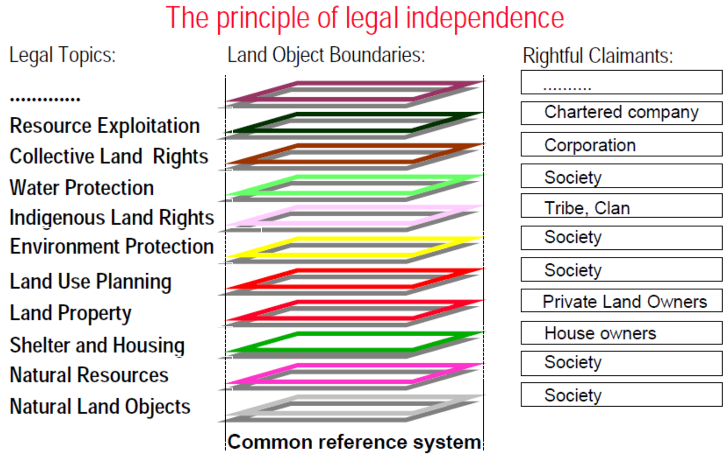

Figure 11 Structure of Cadastre 2014 according to the legal framework, (Source: Figure 16 in Kaufmann 2004 and Figure 3.18 in Kaufmann and Steudler 1998).

It is claimed in Cadastre 2014 that no linking between layers is needed. A model per layer is valid, e.g. as in Figure 12.

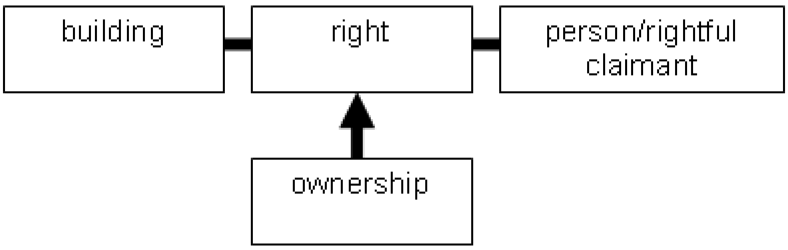

Figure 12 Models for Buildings as in Cadastre 2014. Parcels are in a separate layer, no links are needed, see Figure 8 in (Kaufmann, 2004).

According to Kalantari (2008a) the very close relationship between each interest and its spatial dimension in the real world should also be recognised in information systems. This means, they should be maintained together as a unique entity in a LAS. Kalantari further states that this unique entity must define both the interest and its spatial dimension. Spatial dimensions of the interests can include a variety of shapes, limited by the ability of computer systems to present them. The spatial dimensions can currently be presented in points, lines, polygons and volumes. The concept of the legal property object changes the current core data model from three components into two components: legal property object and person.

Kaufmann formulated design principles for Cadastre 2014[37]. (Kaufmann, 2004, see also Kaufmann and Steudler, 1998):

- principle of *spatial units*. The landownership parcel of traditional cadastres should be extended to include and administer all spatial units, which have some social, legal or economic relevance[38];
- principle of *the documentation of private and public rights, restrictions and responsibilities*. Not only ownership rights will be documented, but also the rights, restrictions and responsibilities established by different legislations having an impact on land shall be registered. See also FIG (1995);
- principle of *legal independence*. To be able to build a LAS, it is necessary to investigate the laws in a jurisdiction and to identify the ones with an effect on land. The different spatial units are to be arranged according to the laws by which they are defined. This structure allows the immediate adaptation of the land administration to the development of the legislation. It is not necessary to rearrange the information. New legal topics can simply be added by including a further information level. If a law is cancelled, the respective information level can be removed without reorganising the other levels. In this way it is possible to deal with facts which are not formally written down in a law. Such informal and customary rights exist where tribes or clans are obeying unwritten rules. These tribes or clans may have living, hunting and fishing rights within a defined territory from which the boundaries are known, but not documented formally. The rightful claimants (or: right holders) are certainly able to localise the outlines of their rights and the respective spatial unit can be included into the LAS. A form of 'occupation rights' exists in informal settlements in many areas of the world. Even when the occupation of the land may be contrary to the formal law, the rights of the involved settlers are informally defined by an unwritten code. The boundaries resulting from these informal arrangements can be localised and documented. So this principle can show overlapping rights and can serve to formalise the situation, to regulate transactions, to monitor and to improve ambiguous situations. Indigenous rights normally overlap with a formal ownership system. The rights and the boundaries where they are in effect are well-known and can be documented. The ideas of modelling informal and customary rights are also worked out in Lemmen et al (2003c) and Van Oosterom (2003b). There look up tables are proposed to manage the different types of customary, informal and formal rights; see also the description of the 'initial LADM' in Chapter 3 of this thesis. For the overlapping rights see also Van der Molen et al (2004b) and Van der Molen (2006);
- principle of *linking objects by geometry*. The realisation of the principle of legal independence results in a structure of independent topics. Spatial units are arranged in independent topics. There is no explicit link between spatial units in different topics, and links between spatial units are normally not stored in the

[37] Not all of the design principles from Cadastre 2014 are re-used in the LADM, e.g. the principle of title registration is not taken over. This would reduce the flexibility of the LADM; deeds registations exist in many places. This principle is not listed. Also the principle of IT application is not listed.
[38] Note: this is something else than the innovations proposed by Fourie and Nino-Fluck (2000): points, lines, sketch maps, etc., etc. in relation to the representation of space. But both principles are important for the design of the LADM.

system but may be created when needed with the help of a spatial overlaying technique[39];

- principle of *unified Cadastre and Land Registry*. Spatial units are linked directly with the information needed for registration. See also UNECE (1996): a single organisation has much merit. Dual systems (cadastre and land registry) can lead to duplication of efforts, additional costs, inconsistencies and, hence, inaccuracies in the data, and a danger of confusion resulting in taking wrong decisions;
- principle of *Land Administration Modelling*. The idea is to model objects in stead of thinking in graphical categories. Maps have no function as information repositories; their only purpose will be the visualisation of information.

In the LA domain the diversity of *formal, informal and customary land* rights; spatial units (e.g. parcels) and parties (e.g. natural or non-natural persons) has to be included.

2.6 3D Cadastre

The use of land is always related to a certain amount of 3D-space and spans as well as a certain amount of time[40], e.g. leasehold or time-shares. However, traditionally cadastres are based on a (projected) representation of the division of land in 2D on a certain moment in time (Williamson and Grant, 2002; Van der Molen, 2003b; Stoter, 2004; Van Oosterom et al, 2006c). Because of growing pressure on land, and rising land values, leading to more intensive and complex land use, we argue that there will be a growing need for 3D/4D information in cadastral registers[41]. The representation of the third dimension is especially relevant for apartment units and for physical objects that cross above or below land parcels, such as tunnels (Figure 13a), underground shopping malls and utility networks. In addition the time dimension is required to be able to record how the legal status of land is changing in time. In most cadastral registers, the time dimension is represented by a versioning of the objects (the state-based model) represented by time stamps that indicate the creation and deletion of represented objects in the cadastral system, see Figure 13b (Döner et al, 2011).

[39] Note: this does not work in many cases and may result in very small spatial references between objects in different layers. Also in case of using maps from different sources there may be problems. In the LADM this principle is not completely recognised for this reason, see the discussion at the end of this chapter and also Chapter 3.

[40] 3D + time, or 4D; see for example Döner et al (2010).

[41] This has been highlighted by (Kalantari et al, 2008b; Bennett et al, 2008): 2D representations have proven to be not suitable in all cases for organising and modelling the information of complex commodities and interests in land.

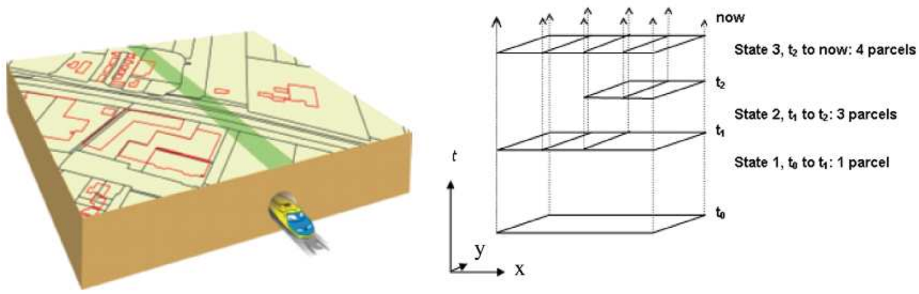

Figure 13 Illustration of 3D (a) railway tunnel crosses several land parcels and (b) temporal concept – changes of state of a subdivision – in a cadastral register (Döner et al, 2011).

In the short term a practical solution for the implementation of a full 3D Cadastre could be to use the 2D parcels as basis for the partition of space (with their implied column volumes) and to subtract from this the specific cases of volume parcels with a 3D description, e.g. in the form of a polyhedron. Because it can have major technical and legal implications when implementing such a ‘simplified’ full 3D Cadastre, and because it does change the land parcel based systems, Stoter (2004) concluded that a hybrid cadastre could be feasible in the short term.

The conceptual foundation of a 4D cadastre is again the partition concept: no overlaps or gaps in the registered rights (Van Oosterom et al, 2006). In this case it is not only space which is considered, but also the time dimension. So, every right is attached to a primitive in 4D space.

In Stoter (2004) three conceptual models for a 3D Cadastre are described:

- full 3D Cadastre. This can be a combination of ‘infinite parcel columns’ and ‘volume parcels’ (i.e. combined 2D/3D Cadastre), or only the support of parcels that are bounded in three dimensions (‘volume parcels’). Stoter explains that this means the introduction of the concept of property rights in 3D space;
- hybrid cadastre. This can be a registration of 2D parcels in all cases of real property registration and additional registration of 3D legal space in case of 3D property units. Or: a registration of 2D parcels in all cases of real property registration and additional registration of physical objects. According to Stoter this means preservation of the 2D cadastre and the integration of the registration of the situation in 3D by registering 3D situations integrated and being part of the 2D cadastral geographical data set.
- 3D tags linked to parcels in current cadastral registration. This means preservation of the 2D cadastre with external references to (digital or analogue) representation of 3D situations. Drawings (which can be digital) can only be examined per parcel in this set-up.

2.7 Marine Cadastre

A special case of 3D Cadastre lies in the *Marine Cadastre*: Ng'ang'a et al (2004), Sutherland (2005a) and Sutherland (2005b) a relatively new concept in the field of LA. Canada and the United States have been at the forefront of establishing Marine Cadastres and New Zealand has also worked on the concept, but there is no country yet which has completely setup a Marine Cadastre.

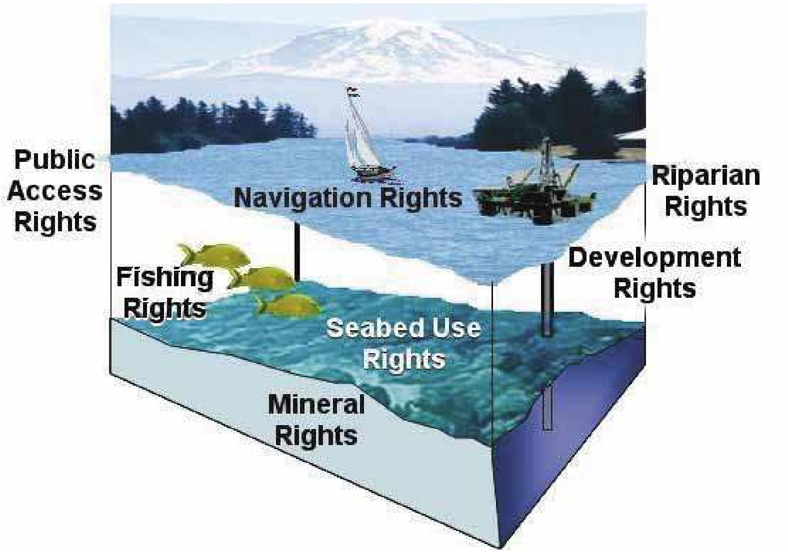

Figure 14 3D Perspective of marine rights (afterSutherland 2005a and Sutherland 2005b).

The Marine Cadastre poses a whole series of different issues to that of the "land cadastre". Issues relevant to this research are (after Widodo, 2003):

1. the marine environment is three dimensional–classical 2D simplifications are not adequate;
2. it is common that overlapping rights exist within a single locality;
3. rights can vary in time, adding a fourth dimension to the spatial data;
4. the baseline to which many maritime boundaries are related is ambulatory.

Sutherland (2005a, 2005b) visualises this model for marine rights in Figure 14. The figure visually supports the argument, that defining a land object, based on the surface area of the land it occupies, does not present an accurate view of every right that may exist in that land object. For example, the right to explore for minerals may have an impact on the surface of the land, but it will also affect a 3D cross-section of the parcel below the land's surface.

According to Ng'ang'a' et al (2004) few marine activities can said to take place on the "surface" of the water because everything marine activity actually takes place in a volume of water. Most marine rights, such as aquaculture, mining, fishing, and mooring and even navigation have an inherently 3D nature, which makes a 2D definition of these rights legally inadequate. A marine property model is presented in Figure 15.

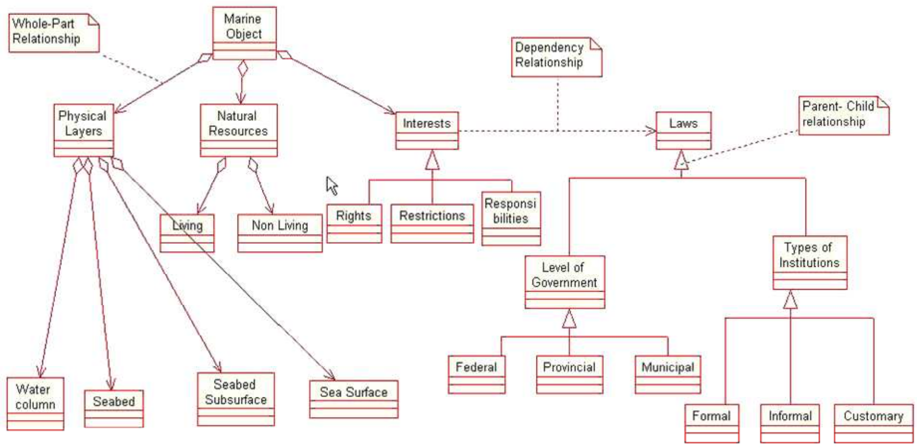

Figure 15 A marine property model (after Ng'ang'a et al 2004).

This marine property model, a 3D representation, presents a marine object in four physical layers: (1) sea surface, (2) water column, (3) seabed and (4) seabed subsurface. The marine object contains natural resources, which can be living or non-living. The marine object has certain interests associated to it – each physical layer that makes up the marine object can have a (legally recognised) right, restriction or responsibility associated to it. As an example, existing rights to fish certain species in the water column in a designated marine reserve may remain unaffected (although certain quotas might apply), while fishing activities that damage the seabed may be altogether forbidden. Interests can be categorised according to the type of laws that recognise their existence. Interests are based on laws, which can be formal (Fisheries Act) or informal (customary or aboriginal).

2.8 The USA Cadastral Data Content Standard

For the United States of America, a standard for cadastral data has been in development since 1990. The first version of this so-called Cadastral Data Content Standard (CDCS), under supervision of the Federal Geographic Data Committee (FGDC), appeared in 1996 (FGDC, 1996), with revisions in 1999, 2002, 2003 and 2008. See FGDC (2003) and FGDC (2008). It defines a standard, that provides semantic definitions of objects related to land surveying, land records, and landownership information, "which will facilitate data sharing at all levels of government and the private sector and will protect and enhance the investments in cadastral data at all levels of government and the private sector" (FGDC, 2003; FGDC, 2008). Cadastral data are defined as the geographic (spatial) extent of past, current, and future rights and interests in real property, including the spatial information, necessary to describe that geographic (spatial) extent. Rights and interests are defined as the benefits, or enjoyment, in real property, that can be conveyed, transferred, or otherwise allocated (FGDC, 2008). The CDCS forms the basis for automating the legal elements of cadastral data found in public records.

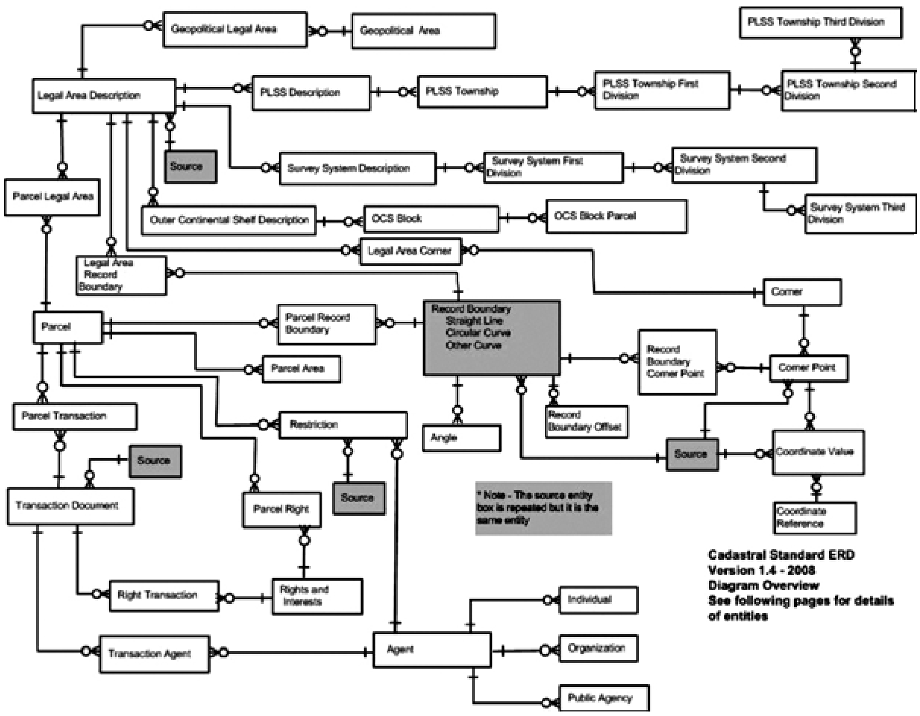

Figure 16 Cadastral Data Content Standard for the National Spatial Data Infrastructure - May 2008 – (Source: Version 1.4, Figure 3.1 FGDC, 2008).

The standard defines attributes, or elements, that are in landownership related documents. The standard does not contain the spatial and topological linkages and spatial features required to build and maintain a GIS (FGDC, 2008). The standard contains definitions of classes and attributes (with suggested domains of values) and relationships among attributes in the form of a logical data model. The Entity Relationship Diagram in Figure 16 illustrates the relationship among the attributes and classes.

The many classes and attributes of CDCS may be organised into generalised groups of classes, which is useful for a basic understanding of the model. One way of ‘logical grouping’ the classes is represented in Figure 17.

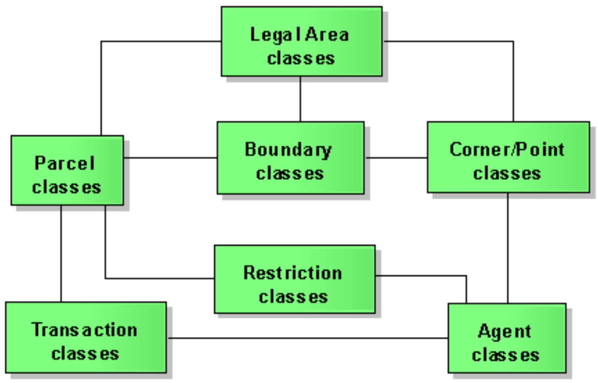

Figure 17 Logical Grouping of Classes (Source: Learning the Cadastral Data Content, Section 5[42]).

The ArcGIS parcel data model is an implementation (Von Meyer, 2003; Von Meyer, 2004). More information can be found in (Van Oosterom et al, 2003b) and (ESRI, 2009).

The standard in the US has been developed completely independent from the LADM. For this reason it is a good reference check. Some definitions are (quoted from FGDC, 2008): an *Agent* is an individual, organisation or public agency that holds rights, interests or restrictions in land, holds or files land records, or has established a land description, a co-ordinate value or a monument; a *Parcel* is a single cadastral unit, which is the spatial extend of the past, present and future rights in real property; a *Record Boundary* is the linear feature that represents the edge of a feature, which may be a parcel or a legal area. The *Record Boundary* is the information for each boundary segment. All boundary features come from the same source and have the same units of measure. A *Corner* is a legal location. It may mark the extremity of a *Parcel* or a *Parcel Legal Area*. A *Corner* may have multiple *Corner Points*, which serve as measures of markers for the location of the *Corner*. A *Corner Point* is a point feature, which marks the ends of *Record Boundaries* or the extremities of a legal area. A *Corner Point* may or may not be monumented and any representation of a *Corner*. *Restriction* captures information related to administrative, judicial, or other limitations or permissions for the use and enjoyment of land by the landright holder or rightful claimant. *Rights and Interests* are related to a parcel. *Rights and Interest* are benefits or enjoyments in real property that can be coveyed, passed, or otherwise allocated to another for economic remuneration. *Rights and Interests* can be below ground, such as mineral rights, simple ownership on the surface, an easement for hunting or grazing or an above right such as transferable development right. A *Right and Interest* is separable and can be conveyed, either permanently or temporarily such as in lease and

[42] http://www.fairview-industries.com/standardmodule/section5.htm last accessed on December, 3rd 2011.

is part of the chain of title. The *Right and Interest* is distinguishable from a *Restriction*, which is a limitation placed by a governing body and is not in the chain of title. A *Legal Area Description* provides the structure for assembling the components of a single legal area into one. The components of the *Legal Area Description* can be used to build legal descriptions based on areas. The *Transaction Agent* is any participant or party identified in a land record document or instrument. One attribute has a role here, e.g. grantor, grantee, leaser, lessee, trustee, mortgager, mortgagee, owner of record, recipient, lender and lendee. The *Transaction Document* is the record of the transfers of rights in land. *Transaction Documents* are often recorded in instruments, but it is not a requirement in most parts of the US that transactions should be written. Both parties in the transfer of rights must be legal parties who are capable of both delivering and receiving the rights being passed.

2.9 OSCAR - Open Source Cadastral and Registry Tool

OSCAR is an acronym for *O*pen *S*ource *C*adastral *A*nd *R*egistry tool. According to its website (OSCAR, 2009) the objective of OSCAR is to develop a cadastral application that uses the LADM. OSCAR externalises domain terms and concepts in the form of a domain ontology made up of resources that describe and link concepts and terms within the domain, using the so-called Resource Description Framework (W3C, 2009).

According to (Hall et al, 2008) the OSCAR data model and software architecture complement the approach proposed by the LA domain model in this thesis research, with the distinction that the OSCAR approach is *event-driven* rather than *state-based*. In the LA domain model in this thesis research *time stamps* are used to store event history. While this will work, Hall et al (2008) state that “it is not ideal in terms of accurately capturing LA workflow and processes. Nor is it ideal for queries on historical processes (such as winding back database events dynamically to reveal the state of the data at a specific point in time)”. Furthermore, it is stated that ”maintaining the integrity of an object’s state is also difficult especially where the historical state might be stored across various attributes in the system, i.e. since various objects may be involved in a single change in state, the time stamp is applied to all involved objects and this must be maintained with full integrity otherwise the system will fail. Hence, the relationship between versions of an object must be explicitly stored to allow the tracing of an object’s history since changes may involve the removal of an object from the active database”.

To overcome these state-oriented restrictions, a complementary, event-driven, data model for the management of cadastral records has been developed. Essentially, an *event* must be created whenever a change is made to an object (e.g. a parcel changes its ownership and/or its boundary locations and dimensions, or a new land title is issued for a parcel) and this event links the instrument of change to the object. In the case where several objects are changed by the same instrument, an event for each object is created. The event contains links to the new state which may be the new spatial extent of a parcel or polygon record, added spatial detail to the polygon record, or additional thematic attribute information added to the record.

The central feature of the OSCAR model is an ‘Instrument’, which is some kind of *document* of change associated with land registration administration and land surveying. OSCAR proposes that documents (which in OSCAR, are a digital representation of *Instruments*) be defined and implemented in a document repository, externally from software or database implementations. The external definition and management of *Instruments* effectively removes this aspect of land administration from the global data model and therefore removes the need to define these aspects before an implementation of database or software is attempted. In this case, users would define their own documents according to local conditions and data by inheriting base implementations from a shared repository.

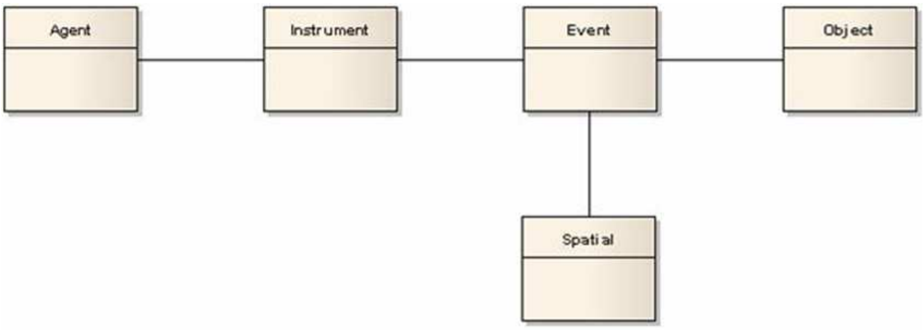

Figure 18 The OSCAR Data model (Hay and Hall, 2009).

The OSCAR data model is shown in Figure 18. The *Instrument* class links *agents* (such as people, banks, or government) to objects (such as a parcel of land or a building) via events or processes which implement the temporal aspects of land administration.

An *Instrument* also contains temporal information (such as valid time) and therefore details about an event that defines some kind of change to land and/or its relationship with agents. The use of an explicit event class models the temporal aspects of land administration in a way that it captures the history of objects (such as land). The history of an object is therefore its time ordered list of events/processes.

One more Open Souce Software Development concerns the FLOSS SOLA at FAO. This development is already based on an adapted version of the LADM. See Chapter 5, Section 7. Relevant documentation about opportunities and risks in the application of open source software is provided in (FAO and FIG, 2010).

2.10 Evaluation and Discussion

The spatial representation of pieces of land (spatial units) can be in points, lines, polygons, etc. as mentioned in Larsson, 1991 and in Fourie, (1998). All the representations are covered in the LADM, see Section 3.2, 3.4 and 3.6; including all types of restrictions (in the broad sense) with their own areas (see Van Oosterom et all 2006a, p. 648).

For indexing purposes, every land parcel or property recorded in a land registry or a cadastral information system must have an identifier. In fact identifiers are the most important linking data element in the land administration databases helping with interoperability.

Further elements needed are boundaries; boundary points, source documents for spatial and legal data, spatial reference system. Indexation and identification are important because of the amounts of data. In object identification different ways of identification are possible. A proposal for a basic model for maintenance exists (OSCAR, 2009). It is possible to mix parties responsible for maintenance and parties as rightful claimants in one database (as in the FGDC approach) or in several databases.

The FGDC (FGDC, 1996, FGDC, 2003 and FGDC, 2008) model contains both spatial and legal-administrative data about individuals, or organisations ('agents'); rights, or restrictions and parcels. Transaction documents are included. An 'agent' is an individual, organisation, or public agency that holds rights, interests, or restrictions in land, holds or files land records, or has established a land description, a co-ordinate value or a monument. This means attention is paid to the processes for data maintenance; agents can be rightful claimants (right holders) or parties with responsibilities in the process of data maintenance. Surveying is supported in the FGDC model. The FGDC model contains parcels and legal areas as spatial units. Rights and Interests are modelled between Agent and Parcel. Quite a few entities in the Entity/Relationship diagram as represented in Figure 16 are intersection entities. There are several entities describing administrative subdivions and subdivisions within subdivions.

Where the 3D/4D aspects are concerned Van Oosterom et al (2006c) conclude that the foundation for a generic LA domain model should be a 2D or 3D parcel (or spatial unit), with temporal attributes (so, actually the four dimensions should be represented), possibly with fuzzy boundaries (Lemmen and Van Oosterom, 2006a). This does not mean that every LAS should have 4D fuzzy parcels, but the model should offer the overall, general framework. An actual LAS is in a certain sense a 'special case' of this general model. 3D spatio-temporal parcels with possible fuzzy boundaries can be used to represent dynamic and temporal situations, such as: (long) lease, nomadic behaviour within a certain region or time pattern, time-sharing of certain real property (Monday-Friday: X, Saturday-Sunday: Y), fishing or hunting rights in certain regions during certain seasons.

Marine rights have a 3D nature and can be registered as such. Central in the model in is the 'marine object' class. This is an aggregation class and includes interests (rights, restrictions and responsibilities); this is similar to Kalantari's (2008) approach, see 2.1.7. Flexibility is needed to compose marine objects out of its smallest parts and objects in general. With some imagination the laws (formal or informal) can be seen as 'parties'; in fact the laws allow people to have interests in 'marine objects'. The interests are RRRs.

OSCAR models LA processes in a generic way. History has to be maintained and changes are based on documents. Event based modelling is used. So, the focus in OSCAR is on processes. History management is again a key issue, e.g. a state based approach (see Section 3.2.5). Such a generic view is of great relevance for the LADM development from data perspective.

According to the UNECE Land Administration Guidelines (UNECE 1996) there exists hierarchy in ownership reflected in hierarchy of spatial units, e.g. plots, parcels, proprietary units and portfolio's of ownership. Therefore it must be possible to "organise" spatial units in accordance to this hierarchy; this means the introduction of groups of spatial units as "land administration units".

The Triple '*Object (parcel) – Right – Subject (man)*' as introduced in Henssen (1995) has been the starting point for the LA domain model, since its inception in 2002 (Van Oosterom and Lemmen, 2002b). The distinction between security rights and use rights in Figure 3 represents in fact restrictions (such as mortgages, charges, or easements) to formal use rights. Henssen's model includes the results of valuation, and (parcel related) land use, which are also included in the UN Economic Commission for Europe definition of LA (UNECE, 1996) and by Dale and McLaughlin (1999).

The Triple *Object (parcel) – Right – Subject (man)* from Henssen is a good candidate for a common pattern for an LA model. This *pattern* is also used in Cadastre 2014 (Kaufmann and Steudler, 1998) as well as in (Van der Molen, 2003a) (FGDC, 2008) and in (Ng'ang'a et al, 2004). The views from Simpson, Larson, Fourie, UN-HABITAT fit very well to this. It should be repeated that a hierarchy is needed according to UNECE (2004); this concerns the organisation of the land information and is very much in support to generic aproaches. This implies that a kind of grouping of Spatial Units must be possible (this is related to the hierarchy of spatial units), this may require a fourth basic element between RRR and Spatial Unit[43]. There is a need for documentation of evidence in initial data collection and data maintenance. This allows for flexible representations of hierarchies and/or combinations of rights, restrictions and responsibilities. This will be a solid basis for the development of a standard. There should be no limitations in the types of relationships that can be included. The marine environment should be possible to include.

The solutions designed in the 1990s to administratively determine (for restrictions and responsibilities and other interests in land each effected parcel) is now considered to be obsolete, and GIS overlaying of the two types of spatial objects is more practical. If this is not possible, because of insufficient quality of spatial data, the parcel based method can still be (or must be) used of course. It is possible to 'link' two objects in two geometric layers which are "connected" in reality – but which cannot be connected by application of spatial overlay, e.g. a building and a parcel in two different layers from two different data sources. In this case an explicit link between the objects is needed. But in many cases different restrictions (determined by different social-economic and natural phenomena) have their own spatial object

[43] This was a requirement for *LADM version C*, see Section 3.5 and 3.6.

representing their sphere of effect. ‘Cadastre 2014’ was already foreseeing this (Kaufmann and Steudler, 1998). See also Van Oosterom (2006a) and further Kalantari et al (2008b). Kalantari et al introduce so-called ‘Legal Property Objects’[44] from a perspective of generic ‘interests in land’. ‘Interests in land’ as a generic term was also used in FIG (1995). Kalantari et al propose a close relationship between interests and the spatial dimension. Kalantari’s (2008a) Legal Property Object model is an interesting conceptual LA model, but in many legal systems however the ‘right of ownership’ and other real rights or land use rights is something else the object to which this right applies. This implies there is a need for distiction from modelling perspective. In practice there is a need for the separation between ‘RRR’ and parcel (or spatial unit): ‘RRR’ related data and ‘parcel’ or ‘spatial unit’ related data may be maintained by different organisations. These options should be available in an LA model. Furthermore a maximum flexibility is needed in options to group spatial units into administrative units. One more issue is the possibility to look completely from the perspective of a person or legal party. A person or legal party wants to know all RRRs which are valid for his or her property. It has to be repeated that this question can not always be answered in case of insufficient geometric accuracy of source data or in case the concept as proposed by Kalantari is not implemented. There are other good reasons not to implement the legal land objects: there can be restrictions to rights, to parcels servitude or there can be zones with specific restrictions as a result of spatial planning. The Triple Object – Right – Subject is a very nice concept in case of shareholders, e.g. a married couple or another group holding shares in one right. Compare the stock exchange: Shareholders – Share – Company (registered at the stock exchange). A final reason lies in the organisation of ‘RRR’ and ‘parcel’ in one object: in case there are many RRRs for one parcel it is difficult to manage the attributes: e.g. explosions in the number of attributes and repititions of attributes.

And: the Triple Object – Right – Subject is a very generic approach which can also be used in other interactions between government and citizen. E.g. for registration of other objects as cars, ships, trains, airplanes. Or the permission (to hold a shop) related to a (part of) a building. Or a permission to perform a certain activity by a certain person, e.g. based on a diploma. Or a permission to drive a car. This is something else then owning a car of course; the driver can be another person then the owner. In case of an accident or in case of violations in traffic (registered by cameras) both parties have different roles; e.g. in relation to insurance.

Such different roles are also relevant in Land Administration processes: can a conveyor support in a transaction of his or her own piece of land?

Persons with responsibilities in processes (conveyancing, surveying, registration, …) may be subject of registration themselves as a consequence of needed transparency: for complete transparency it is required to include the names of the responsible persons into the LAS. Van der Molen and Tuladhar highlighted the urgent need for attention to this issue; see Van der Molen and Tuladhar (2006) and Van der Molen (2007). Land Administration is the process of determing, recording and disseminating information between people and land. This may be done by different institutes. This concerns in most countries huge amounts of data, which moreover are

[44] Cadastre 2014 speaks about land objects.

of a very dynamic nature. The initial data acquisition, the maintenance process (updating) and the data provision process are not the scope of this thesis. But those processes may require adding of extra attributes: name of conveyor, date of transaction (submission, acceptance, registration), etc. The processes result in updates. All updates may be based on source documents which can be simple but authentic documents. The name of the person responsible for the transaction and the transaction itself should be traceable. This is needed because the responsible person may have lost his or her certificate or license or trust from community. Before and after updating the LAS is in a static situation. As said: data can be maintained by different communities, or organisations, for example the Municipality, the Planning Authority, the Private Surveyor, the Cadastre, the Conveyancer, or the Land Registry. The LADM will most likely be implemented as a distributed set of (geo-) information systems, each supporting the maintenance activities, and the information supply of parts of the data set, represented in this model (diagram), thereby using other parts of the model.

There are differences in tenures and rights. From legal perspective ownership in one country does not mean necessarily the same as ownership in another country.

If international standards (and the LADM may be such a standard as a result of this research and as a result of a co-operation with experts within ISO TC211) are introduced adaptations and extensions to local situations should be possible. A range of identification systems is in use; in many cases based on the administrative subdivision of a country. This is again a hierarchy, spatial units can be aggregated to zones and/or areas representing the administrative subdivision of a country. This can be specific for land administration. Other identification systems give evidence of the property as a whole even if it consists of several spatial units.

A main characteristic of land tenure is that it reflects a social relationship regarding rights to land, which means that in a certain jurisdiction the relationship between people and land is recognised as a legally valid (either formal or non-formal) by a community or a state (Van der Molen and Lemmen, 2004a; Thompson et al, 2010). These recognised rights are in principle eligible for registration, with the purpose to assign a certain legal meaning to the registered right (e.g. a title). Therefore LASs are not “just handling geographic information” as they represent a (lawfully or customary) meaningful relationship amongst people, and between people and land. Data recorded in a LAS have a social and legal meaning, and are based on accepted social concepts. That concerns both to persons/organisations involved, to rights (formal and informal) and land objects. It is not relevant whether these concepts are laid down in the law or in unwritten customs. In both cases the way how rights to land, the rightful claimants (or: right holders) and the land itself is understood by the people, determine the content and meaning of the LAS. These rules, constituting the basic principles for the system and justifying its existence, form the institutional context for land administration. Without rules land administration is not possible, as it will be without a societal and legal meaning[45]. By consequence it will be a meaningless activity, not worth to put any effort in. Also community based

[45] A start as a community based land information system, that can be linked with, and eventually incorporated into a formal system in the future, could be a good approach.

approaches in land administration will be based on agreements on which data to collect and how (Lemmen and Zevenbergen, 2010).

In this thesis the conceptual data model (expressed in UML[46] class diagrams) describing people land relationships is called the LADM. This model is claimed to be the representation of the common denominator in data models for land administration (classes and data attributes) which is stable over time and which can be adapted or extended to local purposes. LA can concern formal, informal or customary land rights; this means the focus of this research is on *data modelling for land administration* and on the knowledge behind it; independent from the level of formalisation of the people-land relationships. As Omar Razzaz, a lawyer, states, "property relations which are endowed with the protection of legal rights and duties are only a subset of the universe of property relations." (Razzaz, 1993). That is, the data modelling in this research is a search for a domain model that can be used for a LAS that can support the representation of all forms of land rights and claims, not only for formal registration of land rights; also for (informal) recordation of observed land rights.

The data model should be as simple as possible (*which still may be complex*), data on people's land relationships have to be multiplied by its appearances – which can be many millions in one territory. The land administration organisations are responsible for the quality of those data sets – which is more complex too manage if many attributes have to be maintained. For this reason the data model should be flexible in the way that it can be adapted or extended to local purposes. Here it should be observed that the way in which processes and transactions to collect the data are structured is very different in local environments. For this reason only the outcome of the maintenance processes (which are the newly created and updated data) are considered. This includes all data which are created and deleted under one transaction, or possible transaction step. The problem of LA domain modelling will be tackled by concentrating on the data, not the processes.

There is a need for a complete coverage of all land represented into LASs. There are many land conflicts because of unclear or not recognised land rights. LA is being recognised as fundamental for economic development, poverty eradication, and for protection of the environment, for protection of resources, for support of tenure security, taxation, planning and development, access to credit, access to land and water, management of carbon credits, etc. That is why a complete coverage does not only concern the registration of formal rights, and for the recordation of informal and customary rights. Also for managing of land value, the use of land, and land development plans, see Enemark and Williamson (2004). Complete coverage of all land in LASs is only possible with an extendable and flexible model. This implies that social tenure must be included apart from statutory tenure.

The basic elements Party, RRR, Spatial Unit for LASs can appear in different ways. There is a continuum of land rights, a continuum of parties (which can hold rights), a continuum of spatial units as representation of the reality, where the land rights are concerned. There is a range of data acquisition methods, where the

[46] A UML class diagram describes the types of objects and the various kinds of structural relationships that exist among them like associations and specializations. Furthermore the UML class diagrams show the attributes and operations of a class and the constraints that apply to the way objects are connected (Booch, Rumbaugh and Jacobson, 1999).

collection and maintenance of administrative, legal and spatial data is concerned, e.g. land survey, GPS aerial photos or satellite images for spatial data. Those methods are with different accuracies.

The need for 3D representation is identified. The next dimension is time: there is a need to include time to reconstruct history, to be integrable in SDI, to manage events in maintenance processes and to reflect reality in case of temporal rights. Spatial units with different accuracies, dimensions and representations should be possible to include. This implies a range of spatial units should be posible. One more reason to include the temporal dimension (3D + time) is the need for *information assurance* within SDI. Although the related objects, for example persons in case of a LAS, are not the primary purpose of the registration, the whole *LA production process* (both update and delivery of LA information) does depend on the availability and quality of the data at the remote server. Information assurance is needed to make sure that the primary process of the LA organisation is not harmed by disturbances elsewhere (e.g. one cannot simply update the LAS when this creates ‘dangling references’). In addition, remote (or 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 e.g. for taxation or valuation purposes. So even if the organisation responsible for the maintenance of the objects is not interested in history, the distributed use may require this (as a kind of ‘temporal availability assurance’). The total set of goals (goals can be distributed over organisations) has to be considered. In conclusion, an LA domain model needs the temporal dimension.

The common denominator, or the *pattern* that can be observed in land administration systems with *legal/administrative* data, *party/person/organisation* data, *spatial unit (parcel)/immovable object* data, data on *surveying* or *object identification* and *geometric/topological* data. See research question 1.

The task or challenge of LA domain modelling will be tackled by concentrating on the adaptation and extendibility to local situations with regard to *Parties*, a very wide range of *RRRs* and *Spatial Units*. This need in flexibility is very well recognised in FIG, 1996, Fourie, 1998 and Kaufmann and Steudler, 1998.

3 Design and Construction of an Land Administration Domain Model

Chapter 2 provided an overview of basic work in relation to LA Modelling. The Triple Object – Right – Subject is a common pattern in LA Models.

Chapter 3 presents the design and construction of a domain model for land administration based on an incremental approach: for the reader it would be complex to follow in detail all the steps which have been made during the LADM development 2002 – 2012. It may be confusing to present and discuss all intermediate versions. For this reason not all small steps and design decisions will be elaborated in detail.
Three versions of the LADM will be presented to demonstrate the development[47]:

– Version A: the 'mature initial version'. The user requirements for LADM Version A are presented in Section 3.1. LADM Version A (Lemmen and Van Oosterom, 2003c) can be found in Section 3.2 with an evaluation in Section 3.3;
– Version B: further developments were presented in (Van Oosterom et al, 2006b); finally worked out in the LADM version 1.0 (Lemmen and Van Oosterom, 2006a) presented at the FIG Congress in Munich, Germany, 2006. This is called the LADM Version B in this thesis. The user requirements are further developed based on the evaluation of Version A and are presented as part of this evaluation in Section 3.3. The LADM Version B is introduced in Section 3.4 with an evaluation in Section 3.5. The Version B has been used as basis for submission to ISO in a so-called New Working Item Proposal for ISO TC211 on Geographic Information, see Section 1.5 and 1.6;
– Version C: the Draft International Standard (ISO, 2011c). The evaluation of version B and many new insights from discussions in the ISO Technical Committee 211 resulted in extented user requirements, see Section 3.5. The Draft International Standard (DIS) has been submitted by FIG to ISO with a strong involvement of Lemmen, Van Oosterom and Uitermark. This is LADM Version C in this thesis, see Section 3.6. Section 3.6 further presents the special and external LADM classes in Version C and there is attention to importanted functionality from other ISO standards (re-use of existing standards in LADM). An evaluation of Version C can be found in Section 3.7.

In Section 3.8 a brief overview of the 'link' between LADM and SDI is presented. The chapter closes with a discussion in Section 3.9.

[47] During the development the naming of classes has been changed several times – after discussions with reviewers and within ISO committees. An overview of naming conventions for the three versions as mentioned here above is presented in the table in Appendix A.

3.1 User Requirements

The UNECE Land Administration Guidelines (UNECE, 1996), the FIG Bogor Declaration (FIG, 1996) and the FIG Bathurst Declaration (FIG, 1999) highlight the importance of continuously addressing user requirements. In FIG (1999) the importance of ICT for the development of LASs is underlined. Information technology will play an increasingly important role both in constructing the necessary infrastructure and in providing effective citizen's access to information. This is a general recommendation for many countries still today. This is also valid in collecting data.

LADM user requirements deal with the general requirements for standardisation as expressed in Section 1.1: ontology and support in system development and data exchange. Building upon consolidated knowledge and existing standards is relevant; e.g. Cadastre 2014, ISO standards.

From the beginning LADM has been developed based on a set of user requirements. These requirements have been in alignment with possibilities in Information and Communication Technology. The UNECE Land Administration Guidelines (UNECE, 1996) and the FIG Bogor Declaration (FIG, 1996) highlight the importance of continuously addressing user requirements. The UNECE Guidelines state that users can be anyone who is interested in land matters. The assessment of user needs should be made not only at the outset of the development of a new LAS, but also throughout its lifetime: *anticipate future needs*. This implies flexibility and extensibility. A wide variety of user communities will need to be consulted in order to understand their requirements and the constraints under which they currently operate. Naylor (1996) relates this to the market oriented approach applied to land information. New data acquisition methods are highlighted in the UNECE Guidelines in relation to co-ordinate systems. The importance of unique parcel identification is addressed. Data protection is mentioned.

Then a workshop on cadastral modelling was organised at the International Institute for Geo-Information Science and Earth Observation (ITC), in Enschede, the Netherlands in March 2003. This workshop was organised in co-operation between FIG, ESRI and ITC in Enschede, the Netherlands. More than 30 cadastral data modelling experts from around the world gathered to share their expertise and project experience helping to define the core data model requirements. The goal of the workshop was to refine the initial Cadastre 2014 data model to support key requirements, which include the management of multiple property rights and restrictions by cadastral agencies[48]. Specialised working group meetings on property rights, survey/topography, and land registry were conducted. During the discussions in this 3 day workshop requirements were formulated (Van Oosterom and Lemmen, 2003a and Van Oosterom et al, 2003b). There was also input from other papers, e.g. from Van der Molen (2003a) and Lemmen et al, (2003c).

The results from the first workshop on Cadastral Modelling, included the following (Van Oosterom and Lemmen, 2003a): the need for an object oriented

[48] The workshop was led by the author of this thesis together with Steve Grisé from Esri. The workshop was opened by prof. Paul van der Molen of ITC who shared his extensive international experience with various land management systems. Selected presentations followed from attendees who outlined the many issues involved in implementing cadastral systems in their respective organisations.

design approach. All object classes and attributes should be well defined. There should be the flexibility to include in implementation only those objects that will be maintained. FutureParcel may be included. Surveying needs to be worked out: 'Boundary' can be included in the model. Data maintained by different organisations (e.g. cadastre and land registry) have to be integrated in the model, and maintenance of historical data should be possible, to be supported by a robust version of the database management system. The requirements are worked out in Table 2.

See further the inputs from Chapter 2 of this thesis in the development of user requirements, this is the triple object – right – subject, shares in rights, support to different titling sytems, temporal aspects, 3D Cadastre, Marine Cadastre (also mentioned in FIG, 1999), exchange of data between organisations, process independent approach, flexibililty, maintenance of historical data, UML based ('object oriented'), etc. Furthermore the relevance of LA to SDI is important: avoidance of data redundancy and keeping data to the source.

Table 2 User Requirements for LADM Version A.

Code	Requirement	Impact
A01	*General*	The development should be based on user needs. There is a need for standardisation. 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. And: it should be adaptable and adoptable to local situations.
A02	*Anticipate future needs*	The technology adopted should be sufficiently flexible to meet *anticipated future needs* and to permit system growth and change. In this context, a framework for re-engineering LASs is given by Williamson and Ting (2001). For LADM it means that design tools should be flexible enough to support MDA. If a database is generated and new demands result in new classes or attributes there will be impact on the architecture.
A03	*Object – Right – Subject; survey and topology/ geometry*	The Triple Object – Right – Subject is the common pattern for Land Administration and is the basic structure. Groupings of objects or subjects should be supported. Relevant attributes could be value, area's, land use, geographic description, person name, dates, type (…), interest, transaction, conveyor, geodetic control point, etc. Surveying should be supported, boundary should be included in relation to 'Object' in this Triple. The common denominator, or the *pattern* that can be observed in land administration systems with *legal/administrative* data, *party/person/organisation* data, *spatial unit (parcel) /immovable object* data, data on *surveying* or *object identification* and *geometric/topological* data.

A04	*Shares in Rights*	Holding shares in rights must be supported.
A05	*Authenticity*	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. E.g. in an environment with use of distributed data there may be no disturbances elsewhere (e.g. one cannot simply update the LAS when this creates 'dangling references').
A06	*Different titling systems*	Both deed and title based systems should be supported and documented. This condition implies the maintenance of history.
A07	*History - temporal dimension*	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.
A08	*3D Cadastre*	Are strata titles (relating to the ownership of apartments, etc.) to be recognised? This subject has been discussed in a FIG workshop on 3D Cadastres (FIG, 2001), organised in Delft, the Netherlands. The 3D representation of cadastral data is a typical example of a future need for certain areas in the world. A 3D object should possibly have references to documents/images/3D models and to 3D geometry[49].
A09	*Implementation over different organisations*	The model should be implementable as a distributed data set with inter-organisational workflows. See FIG, (1999). Data packages have to be defined with links to organisation and responsibilities and liabilities. E.g. Cadastre and Land Registry. There will be a need for co-operation over who collects and co-ordinates data other wise the model can not be implemented.
A10	*Exchange of data between organisations*	Magis observed in 1998: the use of information and communication technology for management, transactions and communication is becoming increasingly popular (Magis, 1998). Customers are taking up a much more directive role. 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.
A11	*Avoidance of redundancy: keep data to the source*	Today all data (spatial and thematic) can be stored in a DBMS. This marks an important step forward that took many years of awareness creation and subsequent system development. The next

[49] Meanwhile there has been a second Workshop on 3D Cadastres, also in Delft (November 2011).

	(within SDI)	step is the creation of a common SDI for related organisations; the so-called information communities. This can replace, in the long run, the exchange of copies of data sets between organisations. It requires good standardisation protocols, such as the OpenGIS web mapping specificatin (Buehler and McKee, 1998). But also the role of the Geo-DBMS gets more important, because not a single organisation depends on it, but a whole community. The main use will be query oriented (and less update oriented, only the owner of the data is doing updates, others are only doing queries). An important component is the network infrastructure (bandwidth) itself. The public must understand and accept the level of information that is placed in the public domain or else people will find ways to avoid information appearing in the registers. See also Van der Molen (1999) and Van der Molen (2001). LA data are authentic – but not all of its data. E.g. names of parties have its origin in population and company registers.
A12	*Process independent*	Important considerations during the design of the model were, that it should cover the common aspects of land administration, worldwide. This means it should be possible to represent all people – land relationships independent from regulations related to local approaches in adjudication, maintenance and data provision processes and also independent from local legislation, customary or informal rules. Further there should be no mix with management of workflows and financial processes. This means neither exclusion of important dates in a transaction (check in, observed in the field, accepted, verified, validated, etc.) nor the roles and the names of the responsible persons. Those attributes are transparancy related and should be published.
A13	*Multi source information products*	Information products are becoming flexible combinations of digital data components and additional facilities and services. In order to be able to operate as a supplier of information products in this changing environment in the long term, an organisation must understand the economic dynamics of information production (Magis, 1998).
A14	*Built upon existing standards, e.g. Cadastre 2014*	Existing ISO and OGC standards should be followed, particularly the ISO 191XX *geographic information* standards. See the references in (Van Oosterom and Lemmen, 2002a). Furthermore, it should be based on the conceptual framework of 'Cadastre 2014' (Kaufmann and Steudler, 1998); see Lemmen et al, 2003c. There should be collaborating systems (see also the requirement under 'flexible' ways to organise data sets), each with system boundaries based on legislation; this means that the principle of legal independence from Cadastre 2014 must be applicable (Kaufmann and Steudler, 1998). As a result from the workshop on cadastral modelling in 2003 it was clear that a spatial representation of (public) restrictions on land has to be included in the model. This means in other words that the parcel should not be 'overloaded', in principle public restrictions don't result in

		subdivisions of parcels. GIS technology makes the layer concept available for the Cadastre. The layers of the Cadastre 2014 Model (see Section 2.5) map well to GIS layers, each layer has associations with non-spatial tables, the layer set-up has to be flexible, geometry can be based on ISO geometry and ISO topology.
A15	*Data protection and 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 more reason for management of history and for documentation of all updates.
A16	*Data acquisition*	The application of new technologies, such as GPS, should be assessed from an economic rather than a technical perspective (UNECE). 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 either *directly or indirectly*. Orthophoto-maps, rectified photomaps, or planimetric maps can be used depending on the user requirements, cost, and timing among other factors. Inclusion of quality labels. Whilst more and more users require cadastral information that is frequently and quickly updated in real-time, the need to *secure data quality* should not be underestimated. It should be possible to include documentation on data collected from the field.
A17	*Identifiers*	A key component in LASs is the spatial unit, 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. See (UNECE, 2004). Fiedler and Vargas (2001) recognise a technical requirement for cadastral data collection: the need to change the parcel identifier during the data collection process (e.g. first related to aerial photographs, later related to the administrative subdivision of the country; or first related to surveyor). 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.
A18	*Flexible ways to organise LA data sets*	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). LA 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).
A19	*Marine Cadastres*	In order to ensure sustainable development of territorial oceans claimed under the UN Convention on the Law of the Sea, the UN Nations emphasise the need for claimant countries to develop their capability to support effective marine resource administration through the national SDI.
A20	*Products*	Information that is timely, up-to-date, reliable, complete, accurate, relevant, if necessary customised, well-integrated with other relevant data sets of other suppliers. In view of the specific business characteristics, an information supplier should aim for standards (of distribution, exchange and usage) and product flexibility.
A21	*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 adminsitrative data is important. Topology integrated with geometry and other attributes (Lemmen and Van Oosterom, 2001) is relevant. The system must be ready to keep the information up to date.

Those requirements have been the starting point for the design of LADM Version A.

3.2 LADM Version A[50]

The Unified Modelling Language (UML) has been used for the LADM design.

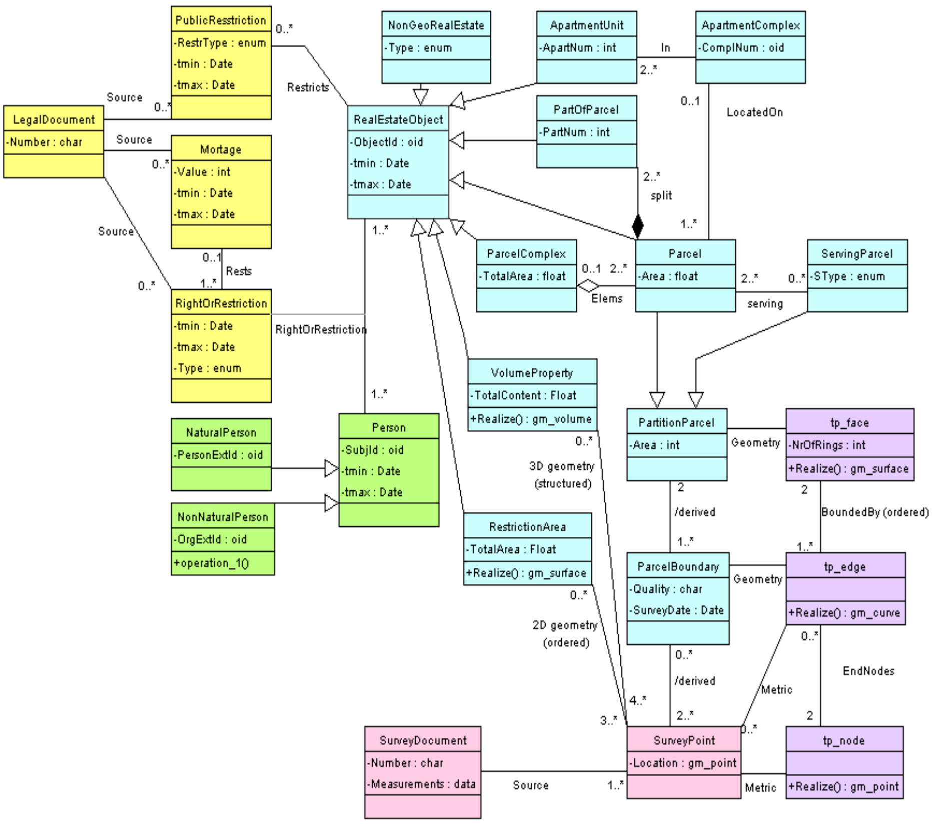

Figure 19 Version A of the LADM – earlier called CCDM (Lemmen et al, 2003c).

The LADM Version A, see Figure 19, is based on the paper 'A Modular Standard for the Cadastral Domain' (Lemmen et al, 2003c. See also Van Oosterom et al, 2003b). The core of the Land Administration Domain Model Version A as depicted in Figure 20, is the central part of the model as it was already presented at the FIG Working Week in April 2003, Paris (Lemmen and Van Oosterom 2003a).

The relationship between real estate objects (e.g. parcels) and persons (sometimes called 'subjects') via rights is the foundation of every land administration, see the introduction to object – right – subject in Section 2.2 and the discussion in Section 2.10. Besides rights, there can also be restrictions between the real estate objects and the persons. In Version A the class names for object – right – subject are now:

[50] Version A was published in September 2003 during Digital Earth in Brno, Czech Republic.

RealEstateObject – RightOrRestriction – Person. See also Appendix A where the LADM Class Names for Version A, B and C are presented.

Figure 20 shows the core of the LADM Version A. The RightOrRestriction is an association class between the classes Person and RealEstateObject. Note that this is an n-to-m relationship, with the conditions that every person should at least be associated with one RealEstateObject and vice versa every RealEstateObject should be associated with at least one Person (indicated in the UML diagram with the multiplicity of '1..*' at both ends of the association).

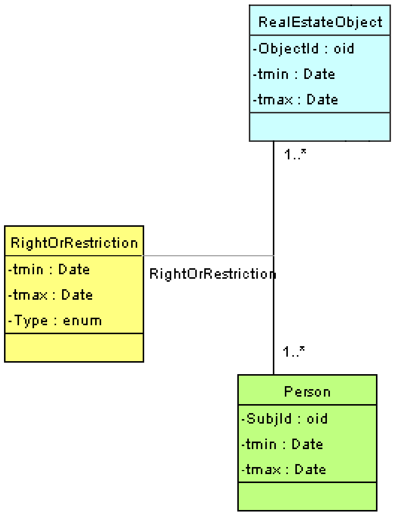

Figure 20 Core of Version A: Person, RightOrRestricton, RealEstateObject (Lemmen et al, 2003c).

The UML class diagram for the land administration domain contains both legal/administrative object classes like persons, rights and restrictions and the geographic description of real estate objects. This means in principle that data could be maintained by different organisations, e.g. Municipality, Planning Authority, Private Surveyor, Cadastre, Conveyancor and/or Land Registry. The model is built as a set of packages; one should not look at the whole model (all packages together as presented in Figure 19) at once as there are UML 'packages' or coherent parts of the model: legal/administrative aspects, real estate object specialisations and geometric/topological aspects. Besides being able to present/document the model in comprehensive parts, another advantage of using packages could be that it is possible to develop and maintain these packages in a more or less independent way[51]. The

[51] Domain experts from different countries could further develop each package. It is not the intention of the model that everything should be realised in one system. The true intention is that, if one needs the type of functionality covered by a certain package, than this package should be the foundation and thereby avoiding re-inventing (re-implementing) the wheel and making meaningful communication with other packages possible. Furthermore basic packages could be implemented by software suppliers, e.g. GIS suppliers.

different packages in Version A are presented in the following subsections in more detail.

3.2.1 RealEstateObject Classes

A RealEstateObject is an abstract class, that is, there are no object instances of this object class. However, it has specialisation classes (which have object instances), such as Parcel, ParcelComplex, PartOfParcel, VolumeProperty, RestrictionArea, ApartmentUnit, and NonGeoRealEstate. In a UML class diagram the specialisation classes point to the more generic class with an open headed arrow. The specialisations are mutual exclusive. The specialisations of the RealEstateObject class are represented in Figure 21. Also the other classes from the RealEstateObject package are represented there: ApartmentComplex, ServingParcel, PartitionParcel and ParcelBoundary.

All these specialisations of RealEstateObjects have associations with one or more Persons via the RightOrRestriction association. The Parcels are also part of a two dimensional partitioning of the surface (see Subsection 3.2.1), but not all these parts have this direct association with Persons. There are parts, called ServingParcels in the model, which only have direct associations with two or more (main) Parcels. This means that a ServingParcel 'serves' a number of other Parcels; e.g. a joint facility, such as a path or playground. A straight line in the UML class diagram depicts this association. It could be considered as some kind of joint ownership via the (main) Parcels. In the UML class diagram Parcel and ServingParcel are both specialisations of PartitionParcels, which altogether form the partition of the 2D domain. The PartitionParcel class, just as the RealEstateObject class, is an abstract class as there will never be instances of this class[52].

A ParcelComplex is an aggregation of Parcels. The fact that the multiplicity at the side ParcelComplex is 0..1 (in the association with Parcel) means that this is optional. A ParcelComplex situation might occur in a LAS where a set of Parcels – c ould be in one municipality or even in another administrative unit – has a legal/customary meaning, for instance being the object of one mortgage or spatial planning (e.g. land consolidation).

A Parcel can be subdivided into two or more PartOfParcels. This case could occur when 'preliminary' Parcels are created during a conveyance where the Parcel will be split and surveying is done afterwards. It could also be helpful to support planning processes, based on cadastral maps, where establishment of Parcels in the field is done later in time. Note that in the model a composite association is used, indication that the components (from the class PartOfParcel) have no meaning/right of existence without the aggregate class (Parcel), this in indicated with the closed 'diamond' in the UML diagram in Figure 21.

[52] Parcel is based on multiple inheritance (from RealEstateObject and PartitionParcel, both abstract classes).

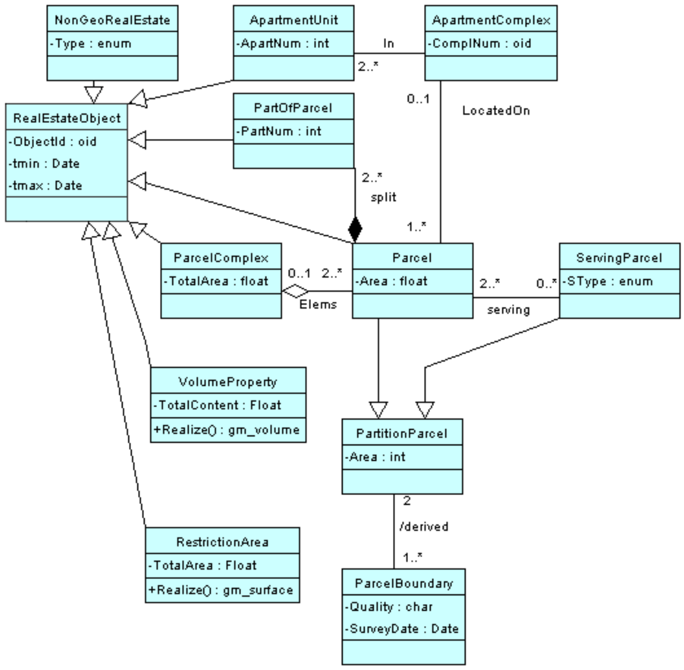

Figure 21 The RealEstateObject package in Version A (Lemmen et al, 2003c).

An ApartmentComplex is associated with one or more Parcels. There can be at most one ApartmentComplex located on a Parcel. There can be two or more ApartmentUnits in an ApartmentComplex. In case the multiplicity of a class in an association is one ('1'), then this is not explicitly shown in the UML class diagram as is the case at the site of the ApartmentComplex in the association between ApartmentUnit and ApartmentComplex[53].

Parcels are defined by ParcelBoundaries and have a geometric/topological description (Van Oosterom and Lemmen, 2001). The class ParcelBoundary always has two neighbour PartitionParcels, where territorial ParcelBoundaries have one 'zero-Parcel' as neighbour, representing the external territory. There can be more then one ParcelBoundary between two neighbour PartitionParcels, depending on attributes and the geometric configuration; e.g. there can be two ParcelBoundaries with different survey dates between two PartitionParcels. In reality this may look as just one boundary. Exclaves and enclaves from territorial perspective can be managed in this approach. In general this approach implies that individual PartitionParcels, and therefore also the derived classes Parcel and ServingParcel, are not explicitly represented as 'closed polygons'.

Attributes can be linked to individual boundaries; this allows for example classification of individual boundaries based on the administrative subdivision of the territory. In this way double, triple or multiple storage of the same boundary can be

[53] An ApartmentUnit is intended in the general sense, not only unit for living purposes, but also for other purposes, e.g. commercial. All building units with legal/registration significance are included here.

avoided, thus avoiding all kind of ‘gap and overlap’ problems, which don’t have a meaning in reality and would be confusing.

In most LASs a restriction is associated to a complete RealEstateObject (Parcel) and this is also reflected in the presented model: a Person can have a (RightOr)Restriction on a RealEstateObject (there are also PublicRestrictions; see Section 3.2.4). However, this may be inconvenient in some cases: one ‘thing’ may cause the restriction on many RealEstateObjects and in such a case this information has to be repeated many times (with all possibilities for inconsistencies). Further, a restriction might also cover/affect only a part of the RealEstateObject, but it is not (yet) registered which part this is. A better solution for this situation is to introduce a new layer (in addition of the planar partition of the PartitionParcels) with RestrictionAreas (comparable with ‘Cadastre 2014’, Kaufmann and Steudler (1998) and Kaul and Kaufman (2003). These can be considered as a kind of RealEstateObjects ‘overlapping’ other RealEstateObjects, from which they ‘carve out’ a part of the associated rights. In Lemmen et al (2003c) it is suggested to maintain only the ‘positive’ rights. For those ‘positive’ rights it is not explicitly stored (for one Person) that another Person has a part of the rights. Inspecting all rights associated with the RealEstateObject and the overlapping RestrictionAreas[54] is needed.

Because of the high pressure on the use of space, more and more situations occur which can best be modelled in three dimensions. Normally a (2D) Parcel represents the whole 3D column from the centre of the Earth, through the surface out into the sky. Explicit 3D VolumeProperties ‘carve out’ a part of this space in favour of another Person (the buyer of a 3D VolumeProperty). It is possible that one VolumeProperty overlaps with many Parcels (again this can be obtained via spatial overlay). In the same manner as proposed for RestrictionAreas, we suggest that it is best to register only the ‘positive’ side of the registration without redundancy. VolumeProperties are modelled without external topology, but with internal topology by referencing several times to the same SurveyPoint, when this is shared between the different faces of a polyhedron. VolumeProperties should not overlap in 3D space. However, their projection in 2D space may overlap. It is expected that it will not happen often that VolumeProperties will share faces with other explicit VolumeProperties (as is the case in 2D with the PartitionParcels). Might this assumption turn out to be wrong, then a 3D topological structured model should be introduced. More background and discussion on alternative 3D cadastral modelling can be found in Lemmen et al (2003c).

The class NonGeoRealEstate can be useful in case where a (complete) geometric description of the RealEstateObject does not (yet) exist. E.g. in case where only one co ordinate inside the RealEstateObject is observed, using Satellite Images or GPS. Or in case of a right to fish in a commonly held area (itself depicted as a ServingParcel), where the holder of the fishing right does not (or no longer) hold rights to a land parcel in the area.

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[54] RestrictionAreas are modelled as closed polygons (and obtain their co-ordinates from SurveyPoints, see section 3.2.3). There is no explicit topology between RestrictionArea, that is, they are allowed to overlap (and it is expected that they will not often share common boundaries as Parcels do).

3.2.2 Surveying Classes

Object classes related to surveying are SurveyDocument and SurveyPoint; see Figure 22. A cadastral survey is documented on a Survey Document, which is a (legal) source document made up in the field. Most importantly, this document contains signatures. In a full digital surrounding a field office may be required to support this under the condition that digital signatures have a legal support. Otherwise paper based documents should be considered as an integral part of the LAS. Files with terrestrial observations - distances, bearings, and referred geodetic control - on points are attributes of the SurveyDocument, the Measurements. Both ParcelBoundary and SurveyPoint are associated with the SurveyDocument. From the multiplicity it can be recognised that one SurveyDocument can be associated with several SurveyPoints. In case a SurveyPoint is observed at different moments in time there will be different SurveyDocuments. In case a SurveyPoint is observed from different positions during a measurement there is only one association with a SurveyDocument.

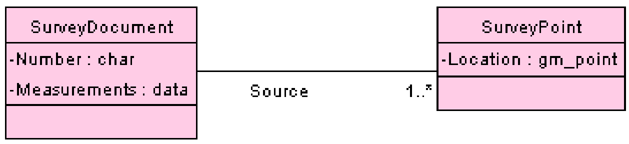

Figure 22 Survey Package in Version A (Lemmen et al, 2003c).

3.2.3 Geometry and Topology Classes

Object classes describing geometry and topology are tp_node, tp_edge and tp_face, see Figure 23 The Land Administration Domain Model is based on already accepted and available standards on geometry and topology published by ISO and OGC (ISO, 2003b, ISO, 2003c, OpenGIS Consortium OGC, 1999, OGC, 2006b, OGC, 2007a, OGC, 2007b, and OGC, 2010b).

Geometry in LADM is based on SurveyPoints (mostly after geo-referencing, depending on data collection mode: tape, total station, GPS, etc) and is associated with the classes tp_node (topology node) and tp_edge (topology edge) to describe intermediate ‘shape’ points between nodes, metrically based on SurveyPoints. The association between a ParcelBoundary and SurveyDocument is *derived* via the classes SurveyPoint, tp_node and tp_edge.

Parcels have a 2D geometric description. A Parcel corresponds one-to-one to the tp_face in a topological structure (as defined by ISO TC 211 and OpenGIS Consortium, see the references here above in this Subsection). A face is bounded by its edges in 2D. An edge is related one-to-one to a ParcelBoundary, which may contain non-geometric attributes. Every edge has exactly two end points, represented in tp_nodes. In addition, an edge may also have several intermediate points. Both intermediate points and nodes are associated with SurveyPoints. The topological primitives tp_face, tp_edge and tp_nodes, have all a method (‘operation’) called ‘Realize’ which can be used to obtain a full metric representation. There are two additional geometry layers in LADM Version A, which are not based on an explicit topological structure, these can be found in respectively the classes RestrictionArea and VolumeProperty. As in the topology/geometry layer of PartionParcel, co-ordinates are obtained from the SurveyPoints[55]. A VolumeProperty is defined by at least 4 non-planar SurveyPoints[56].

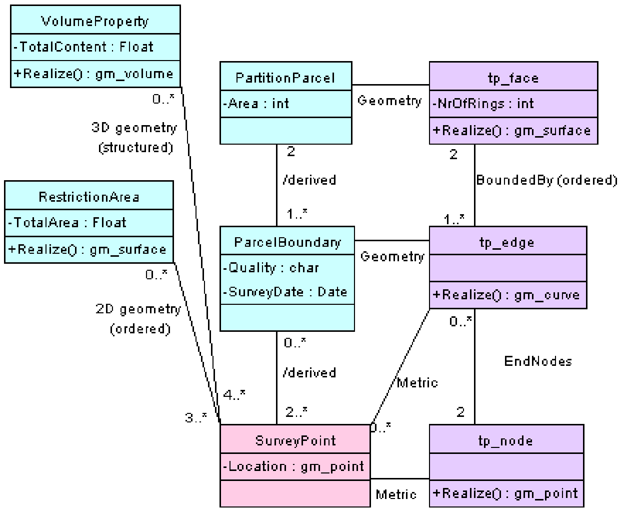

Figure 23 Geometry package in Version A (Lemmen et al, 2003c).

3.2.4 Legal/Administrative Classes

Object classes LegalDocument, Mortgage, PublicRestriction, Natural Person and NonNaturalPerson cover the refinements in the Legal/Administrative side (RightOrRestriction and Person); see Figure 24.

All updates associated to RightsOrRestrictions are based on LegalDocuments as source. In principle legal data will not be changed without provision of a LegalDocument.

The essential data of a LegalDocument are associated with (‘can be represented in’) the classes RightOrRestriction, Mortgage or PublicRestriction. A single legal document may be the source of multiple instances of these classes and may even create a mix of these three types. In the other direction, a RightOrRestriction, Mortgage or PublicRestriction is always associated with exactly one LegalDocument as its source.

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[55] There are also ‘Realise’ methods available within the RestrictionArea and VolumeProperty classes to return the complete and explicit geometry respectively gm_surface and gm_volume.
[56] This would result in a tetrahedron, the simplest 3D volume object. The RestrictionArea is defined by three or more SurveyPoints, which all have to locate in the same horizontal plane (of the earth’s surface).

Each jurisdiction has a different 'land tenure system', reflecting the social relationships regarding rights (and restrictions) to land. The variety of rights is a quite large within most jurisdictions and the meaning of similar rights differs considerably between jurisdictions. Usually one can distinguish between a number of categories:

a) firstly we have the strongest right available in a jurisdiction, called e.g. ownership, freehold or property;
b) secondly we have derived rights from the previous category where the claimant (or holder) of this derived right is allowed to use the land in its totality (often within the limits of a certain land use type, e.g. housing or animal farming);
c) thirdly we have minor rights that allow the claimant of it to some minor use of someone else's land, e.g. walking over it to the road. Such rights can be called servitude or easement, and also may include the right to prevent certain activities or constructions at some nearby land, e.g. freedom of view;
d) fourthly we have the so-called security rights, whereby certain of the previously mentioned rights can be used as collateral, mainly through bank loans, e.g. mortgage, lien.

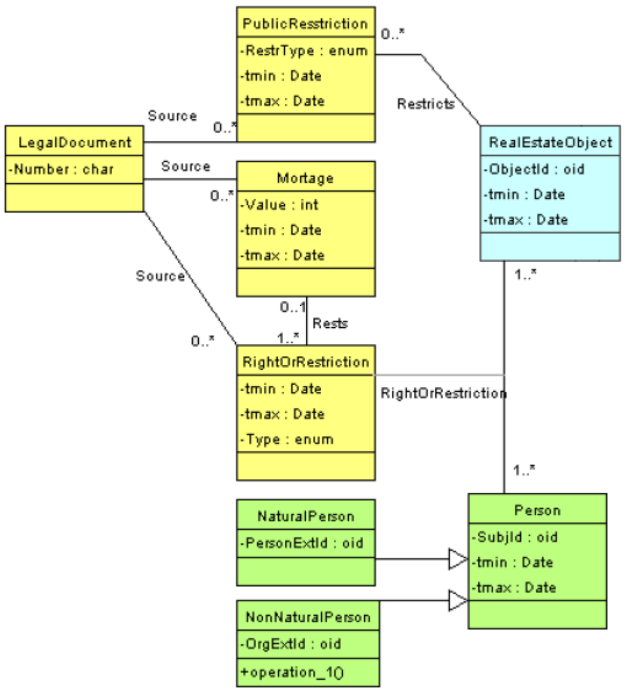

Figure 24 The Legal/Administrative classes in Version A and Person classes (Lemmen et al, 2003c).

The aforementioned rights are primarily in the domain of private law. Usually the rights are created after an agreement between the person getting the right and the person losing something (who sees his right restricted by the newly created right).

The rights and restrictions we are concerned with here usually remain valid, even if these persons change after the right was created (and registered). This is called a right *in rem* in many jurisdictions. There is a difference between legal systems and registration approaches in whether rights, other than under a), are formulated and recorded primarily as the right of the rightful claimant (right holder), as a restriction to the right (or object) they are 'carved' out from, or both.

Because property and ownership rights are based on (national) legislation, ‘look up tables’ with types of rights can support in this. E.g. the right of ‘ownership’ might be ‘Norwegian Ownership’, ‘Swedish Ownership’, etc., etc. ‘Customary Right’ related to a region or ‘Informal Right’ can be included; from modelling perspective this is not an item for big discussions. Of course, for the actual implementation of LADM in a country or region, this is very important.

In addition to those private law restrictions, many countries also have public law restrictions, which are usually imposed by a (local) government body. The ‘claimant’ of the right is abstract (either ‘the government’ or ‘society-as-a-whole’ ") and usually they are primarily seen as restrictions. Some of them apply to a specific RealEstateObject (or right therein) or a small group of them: e.g. most pre-emption rights, or the duty to pay a certain tax for improvements on the road, or the duty to repair damage or perform belated maintenance. Others have their own area of application, like whether there is soil pollution present, flood plains, (re-)zoning of areas (especially when urban development is made possible in a rural area).

Each restriction type has its own place in the Land Administration Domain Model. Public restrictions with their own areas can be recorded via the RestrictionArea class, not being linked to a specific claimant. Obviously the documents on which they are based need to be included. Public restrictions, which apply to RealEstateObjects, but have no clear beneficiary, are recorded as PublicRestrictions. Other restrictions should be recorded as well, if possible as rights in the name of the claimant, but in certain countries some types do not state the claimant (or the claimant is a neighbouring RealEstateObject, regardless who holds that RealEstateObject). In such cases the restriction as such is recorded on the RealEstateObject, often without a person connected to it. Nevertheless, the most vital rights are usually in the name of a person, like ownership, leasehold or usufruct. Security rights differ between jurisdictions. Sometimes the claimant of the right (e.g. a bank) is recorded. In other cases there is only a restriction recorded, informing others someone has already a security right on this RealEstateObject (often only a defined, and often recorded, amount of money is secured, and a second or third mortgage could be created). For every RightOrRestriction it is important that it is made clear how it is recorded. In all cases the relevant source LegalDocument(s) should be associated. One should finally be aware that in most jurisdictions certain use rights and certain security rights can exist totally outside the registration system. These so-called “overriding interests” are valid, also against third parties, without registration. Examples can be rent contracts for shorter periods, certain agricultural tenancy agreements, and ‘liens’ by tax authorities.

The abstract class ‘Person’ (that is again a class without object instances) has as specialisation classes NaturalPerson or NonNaturalPerson like organisations, companies, co-operations and other entities representing social structures. If a Person is a NaturalPerson it cannot be a NonNaturalPerson and the other way around. That is, NaturalPerson and NonNaturalPerson are mutual exclusive.

Right (a subset based on the type attribute in RightOrRestriction) is a compulsory association between RealEstateObject and Person in Version A, where this is not compulsory in case of restriction (the other subset in RightOrRestriction). For example a restriction like encumbrance is only associated with the land: the RealEstateObject.

3.2.5 History Aspects

There are two different approaches when modelling the result of dynamic systems (discrete changes in the state of the system): event and/or state based modelling:

– in event based modelling, transactions are represented as a separate entity within the system (with their own identity and set of attributes). When the start state is known and all events are known it is possible to reconstruct every state in the past via traversing the whole chain of events. It is also possible to represent the current state, and not keep the start state (and go back in time via the ‘reversal’ of events);
– in state based modelling, only the states (that is the results) are included explicitly: every object gets (at least) two dates/times, which indicates the time interval during which this object is valid. Via the comparison of two succeeding states it is possible to reconstruct what happened as result of one specific event. It is very easy to obtain the state at a given moment in time by just selecting the object based on their time interval (tmin-tmax).

In the Land Administration Domain Model a hybrid approach is introduced as both aspects of event and state based modelling can be found. The (legal and survey) documents can be considered as explicit representation of events (transactions). However, the effects of these events are kept in the states of the associated objects (which have tmin and tmax attributes). New inserted instances get a tmin, equal to the check-in/transaction time and a tmax equal to the maximal (integer) value. A deleted instance gets a tmax equal to its check-in/transaction time. In case of update of one or more attributes, a new instance will be created (as copy from the old instance with its new values for updated attributes) with a tmin equal to check-in/transaction time and a tmax equal to a maximum value. The old instance gets a tmax equal to check-in/ transaction time. This allows to query for the spatial representation of cadastral objects at any moment t back in time or to query for all updates between a moment t_1 and t_2 in the past. Apart from check-in/transaction times the real dates of observation in the field can be included to manage history.

Note that nearly every object inherits these tmin and tmax attributes via either RealEstateObject, RightOrRestriction or Person. It would have been possible to introduce a new object (TemporalObject with tmin and tmax) from which in turn these three mentioned classes would inherit their temporal attributes (mainly because of legitability this was not done).

In addition to the event and state modelling, it is also possible that the ‘parent/child’ associations between cadastral objects are modelled (lineage), e.g. in case of sub-division of a cadastral parcel. However, as these associations can also be derived from a spatio temporal overlay, it was decided in Version A not to further complicate the model with the explicit parent-child relationships.

Focus in this thesis is on the UML class diagram, that is, the structural aspect. This diagram can further be completed by diagrams covering dynamic aspects, e.g. via state (use case, sequence, collaboration, state or activity) diagrams. Activity diagrams show how processes are related to the information (data) and how one ‘flows’ from one to the other. The introduction of different ‘stages’ of a parcel, a right and a person could further reflect the dynamic nature of the system.

3.3 Evaluation of LADM Version A

In Lemmen et al (2003c) it was already observed that the dynamic nature of land tenure is a major challenge for cadastral modelling; see Chapter 2. In Subsection 3.2.5 some structural aspects of the dynamic LASs were discussed, mainly at an overview level in the model. In this section some more details and considerations are presented. In the first place there is variety of forms of tenure (Toulmin and Quan, 2000), (Zoomers and Van der Haar, 2000) and it is possible to switch between these forms, and ‘upgrade’ the right. See also the continuum of land rights in Section 2.4. This functionalilty has to be explicitly included in LADM Version B.

In Lemmen (2003c) it was mentioned that innovative concepts (Fourie et al, 2002) are observed for the geometric component of land administration, where a well-known guiding principle for the cadastre ‘specialty’, requires a good identification of the land parcel that is subject to the execution rights, normally by the survey of its boundaries. Apart from the dynamics of the land parcel as the result of the land market and land development (subdivision, consolidation, redistribution, restitution, etc.) alternative forms of identification are mentioned such as midpoint co-ordinates only, topographic visualisation (similar to the application of the general boundary rule in e.g. England and Wales). All these examples might provide some evidence that the creation of a Land Administration Domain Model is of a complex nature, and is a challenge. However the driver for the development of a land administration domain is the basic concept of a relationship between people and land, whatever right claimants (holders), whatever rights, and whatever land objects. The here presented dynamic aspects could be represented in the proposed model. Further research is required to verify this. See also Fourie (1998), Fourie and Nino-Fluck (1999)and Van der Molen (2003a) as discussed earlier in this thesis, see Sections 2.2 and 2.4. The related requirements are not yet sufficiently included in the LADM Version A.

UML is widely used for data modelling because of the support by the Object Management Group. A LADM based on UML diagrams can be adapted to local situations by the introduction of new attributes, codes, classes and associations.

History can be maintained in Version A by using time attributes (in the core classes, the class PublicRestriction and the class Mortgage; the time stamp attributes are inherited by all subclasses). Deed and title based systems can be supported using time stamps and LegalDocuments, where SurveyDocuments may be included. This can also guarantee authenticity (of course if implemented in a proper way with attention to access control, data security, privacy, etc.). In case of implementation in a distributed environment technical documents may be needed in case an instance is deleted in one database. This may have impact on references to another database. Maintenance of history data can be organised more efficient by the introduction of one TemporalObject from which all classes inherit.

The Object – Right – Subject Triple has been completely introduced in Version A, see Figure 20, RightOrRestriction is an associative class between Person and RealEstateObject. This means: if there is a RightOrRestriction there must be a Person and a RealEstateObject at the same time. This way of modelling is a logical impact of legislation, the right applies to an object and there is a right holder. But there have been comments on this from practise. It is known that there may be parcels on the map which are not known in the registers and/or the other way around in many land administrations. This type of error situations are in fact incorrect representations of reality. It must be possible to include such incorrect situation in LADM – in this way the inconsistencies can be managed and repaired. For this reason it is better to model the core classes with two separate associations: one association between RightOrRestriction and Person and one association between Rightor Restriction and RealEstateObject. One more reason is that the association class 'RightOrRestriction' does not allow multiple Right – Restriction – Responsibility (RRR) instances to be associated (e.g. one expressing ownership, and one expressing a certain responsibility). This can again be improved by the introduction of two associations between RightOrRestriction and Person and between RightOrRestriction and RealEstateObject. There are many types of Rights, Restrictions and Responisbilties. Therefore it should be possible to better represent this. This is in support to the inclusion of the continuum of land rights. RRRs are not yet really included in LADM Version A; this is a requirement from Cadasre 2014. See also Bennet (2007).

The class RightOrRestriction allows for the introduction of 'shares of rights' in case where a group of Persons holds a undivided part of a 'complete' right; this has to be included: a share in a Right is possible in Version A, but should be explicitly included as an attribute. Rights, Restrictions and Responsibilities should be specialisations of the RRR class; this allows for the introduction of separate attributes in subclasses.

Where Persons are concerned there could be special attention to those Persons with responsibilities (roles) in the data maintenance (conveyor, surveyor). It should be possible to include the names of those persons in the registration. The same is valid for moneylenders (banks).

For better modelling requirements from customary area's group persons (with members) are needed.

The Version A is organised into several packages. 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.

The set of specialisations of RealEstateObject include Parcels, ServingParcels, PartitionParcels, ParcelBoundaries, PartofParcels, ApartmentUnits, Apartment-Complexes, ParcelComplexes, VolumeProperties and RestrictionAreas. This implies that full topology is supported and in fact required in the implementation of the model. In case topology is incomplete this can be detected; from this perspective LADM can be used to detect and manage (and support the repairing of) inconsistencies in topology. Implementation of LADM Version A is based on the expectation that topologically well-structered polygons (PartitionParcels) will be represented in the model; no matter if systematic or sporadic titling (or another form of land administration) is applied.

Boundaries of Parcels are composed from SurveyPoints, the surveys are documented in SurveyDocuments.

In implementation of LAS it may happen that such well-structured polygon data are not available and even are not intended to be available. This became more and more clear during the LADM development, see examples in Chapter 2, Sections 2.2 and 2.3. Different types of spatial units need to be introduced into the model. E.g. no spatial units at all, text based spatial units, sketch based spatial units, point based units (see Lemmen, 2003c, with reference to Jackson, 2002), line based spatial units, polygon based spatial units; with labels for different accuracies (those labels are already included in the Version A). This also means that there can be areas with good spatial data which are well-structered or not structured. See also Augustinus (2006).

For apartments and apartment complexes there is a need to separate common areas (entrance, stairs, elevators, roof, etc.) and individual apartment units because of separation in ownership in buildings where apartments are located. This means the inclusion of building as a class.

SDI is supported by implementing packages in different organisations or by implementing the complete model in different organisations. E.g. one organisation responsible for the rights, another organisation for restrictions. This can support data sharing and avoidance of duplications in data storage.

Where Marine Cadastre (Ng'ang'a et al, 2001, Ng'ang'a et al, 2004; see Section 2.7) is concerned: the MarineObject corresponds with the RealEstateObject in LADM Version A, the Interest with RightOrRestriction in LADM Version A and the Law (read: institutions/organisations) corresponds with Person. The MarineObject is a composition of the physical environment (Water Columns, Seabed, Seabed-SubSurface and SeaSurface in PhysicalLayers); NaturalResources (Living and NonLiving) and Interests (Right, Restriction and Responsibilities). Interests depend on Laws (with Level of Government Federal, Provincial, Municipal) and with Institutions (Formal, Informal, Customary). It is expected that LADM can be used here; explicit layers to organise information are needed then.

The re-use and link to the existing ISO standards could be better highlighted, especially with attention to 3D representations (for 3D see also the MarineObject in Marine Cadastres).

Output may be modelled as interface classes, e.g. folios related to rights (ownership folio) or cadastral maps. This may be a better expression of the requirement for multi source information products.

In conclusion (see Table 2 for the references A01 – A21): the general requirement as under requirement A01 is met, but improvements in this version are needed. The model has been built in a flexible way, the model is easy extensible and the model is adaptable. This means growth and change (as mentioned under requirement A02) is possible, as it is proven by the development of the next versions. In practise this is related to a data conversion from data under one version to another version. This type of conversion can be easily organised by comparing the ontologies as provided in the UML models. The Triple Object – Right – Subject as in requirement A03 is the core of LADM Version A; it is implemented in the classes RealEstateObject, RightOrRestriction and Person. Surveying is supported, The required components surveying and geometry/topology are supported. Shares in rights are not yet really supported. GroupPersons are needed and methods to force that the sum of shares is equal to the whole. Authenticity (A05) is possible using source documents. In case of updating dangling ends should be avoidable: this requires versioned objects which can be related to workflows. Different titling systems (A06) can be organised – this is related to the functionality available under source documents. The history and temporal dimension (see 3.2.5) is supported by the time stamps, but versioned objects are needed. The 3D Cadastre (requirement A08) is not yet really supported where it concerns 3D objects; but strata tiles can be included. Implementation over different organisations as required from A09 is possible, but versioned objects and related workflows are needed to organise this in a proper way. A10, exchange between organisations needs to be specified and developed, but is supported under the principle using existing standards (e.g. GML). The principle of keeping data to the source (A11) can be very well supported; even if there are extensions to other databases founded on similar models in other environments. The model is process independent (A12), but process related data as names of persons responsible for transactions (see also A15) and dates in a transaction process have to be included. Multi source information products as required from A13 can be derived in case of implementation of the model in a distributed environment as intended. Interface classes could be helpful here. The model is built upon existing standards – the layers as in Cadastre 2014 – could be explicitly included. Data acquisition (A16) is supported by the option to use sources for spatial data and by the introduced class Point. Better versioning is used here to support conversions and adjustments. Identifiers free of semantics as required from A17 can be included (user based), but should be fully integrated. The flexible ways of organising data (A18) are supported by the different packages. Marine Cadastres are not really worked out, but the data model as presented in Figure 15 illustrates that the Triple is included: the 'MarineObject' can be seen as alias for RealEstateObject, the 'Interests'in Figure 15 cover the RightOrRestriction and 'Laws' can be seen as alias for Persons (normally this concerns a State).

The requirements on products are implementation related; as said: interface classes would be helpful. Where data quality is concerned (A21) it can be stated that this model supports data consistency (but further improvement is needed: e.g. versioned objects) and merging of data sets. Topology can be explicitly included. Main conclusion is that LADM Version A from 2003 is a very first version which needs further development. The evaluation above results in some re-formulated or new requirements, as presented in Table 3.

Table 3 User Requirements for LADM Version B.

Code	**Requirement**	**Impact Analyses**
B01	*Remaining requirements from LADM Version A*	This concerns the inclusion of explicit topology, identifiers without semantics, layers, interface classes for products and services, responsible persons in transactions (using roles), versioned objects and 3D Cadastre and Marine Cadastre.

B02	*Different tenures*	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. Inclusion of data in the LAS based on the model may not only be based on formal registration of formal land rights, but may also be based on observations in reality, resulting in recordation (not a formal registration) of informal land use rights[57].
B03	*All types of people's land relationships can be represented*	'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. Flexible and extensible coding of types of rights and restrictions, etc. is needed. Non-spatial data are closely linked to each other (UNECE, 1996).
B04	*An (extensible) continuum of land use right claimants (or parties) is included*	*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, …. 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.
B05	*A continuum of land rights can be represented*	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. There may be uncontrolled privatisation. Again, this is an extensible list to be filled in with local tenancies. A *restriction* is a formal or informal entitlement to refrain from doing something, e.g. it is not allowed to have ownership in indigenous areas. Or it may be a servitude or mortgage as a restriction to the ownership right. There may be a temporal dimension, e.g. in case of nomadic behaviour when pastoralists cross the land depending on the season. This temporal dimension has sometimes a fuzzy nature, e.g. "just after the end of the rainy season".

[57] Some of those requirements are implementation issues.

B06	*A continuum of spatial units can be represented*[58]	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) where the rights and social tenure relationships apply. Spatial units should possibly 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.
B07	*Integration of different recordation- and, registration- types*	This range of representations of spatial units and parties, combined with the continuum of land rights can cover community based LASs, or rural, or urban, or other types of formal LASs, like Marine Cadastres and 3D Cadastres. This is an implicit requirement. If all data are collected in the same structure than the integration with between informal recordation's and formal LAS should be possible.
B08	*A range of data acquisition methods resulting in (a range of) authentic source documentation can be applied for spatial and non spatial data. Quality upgrading of data is possible*	Surveys may concern the identification 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. (see Augustinus, 2006, Van der Molen and Lemmen, 2004a). A sketch map may be drawn on a wall, from which a photograph is taken. 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. Persons living in 'structures' in slum areas may be identified by fingerprints. 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 that there may be a serious need for accurate geo-data in slum areas: the value of land in slum areas near city centres can be very high. Person identification is not a primary responsibility of cadastre

[58] It should be possible to represent spatial data in different reference systems: local, regional or national, federal, continental or global reference systems.

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 is possible to link fingerprints to points (co-ordinates), see Lemmen (2010d).

3.4 LADM Version B[59]

LADM Version B is presented in (Lemmen and Van Oosterom, 2006a). This publication is strongly based on Van Oosterom et al (2006b), a peer reviewed publication – and is the basis for the content of this section.

The naming of some classes has been changed, see Appendix A.

3.4.1 RegisterObject Classes[60]

The core of the Version B is visualised in Figure 25[61]. In the model there is no direct relationship between Person and RegisterObject, but only via Class RRR[62] (Rights, Restrictions and Responsibilities).

In this version the idea of a registration authority for movable and immovable objects is included. RegisterObject has as subclasses Movable[63] and Immovable. The specialisations of the Immovable class are represented in Figure 26.

The different types of specialisations from Immovable include: RegisterParcel, SpaghettiParcel, PointParcel, TextParcel, ImmovableComplex[64], PartOfParcel. These classes can all have actual instances and these instances describe in a way a piece of land (2D) or space (3D). The other immovable register objects include: Building, Unit (with specialisations (SharedUnit and IndividualUnit), NonGeoRealEstate and OtherRegisterObject. All these specialisations of Immovable have associations with one or more Persons via the RRR class (see Figure 25).

Other RegisterObject classes are: AdminParcelSet, Parcel, ServingParcel and NPRegion.

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[59] The LADM Version B has been presented in October 2006 to the XXIII FIG Congress held in Munich, Germany.
[60] In LADM Version A RegisterObject is called RealEstateObject.
[61] Multiplicity is "1" if not represented. So, a RegisterObject can be associated to many RRRs, a Person can be assciated to may RRRs, a RRR can be associated to one Person or RegsiterObject.
[62] In LADM Version A RRR is called RightOrRestriction.
[63] This can be ship, plane, train or car. Reason to integrate those objects is that mortgage may be established, e.g. on a ship or a plane.
[64] In LADM Version A ImmovableComplex is called ParcelComplex.

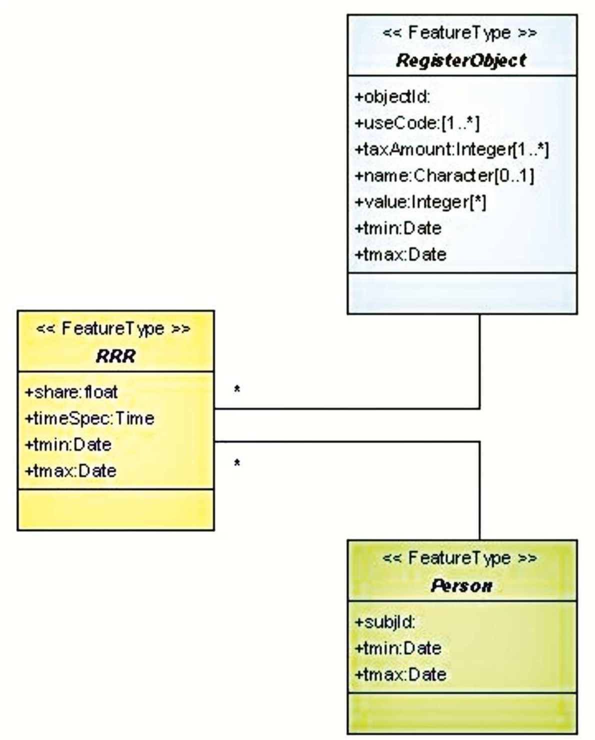

Figure 25 The core of LADM Version B: Person, RRR (Right, Restriction, Responsibility) and RegisterObject, see (Lemmen, and Van Oosterom 2006a, based on Van Oosterom et al, 2006b).

SurveyDocument and SurveyPoint in Figure 26 are survey classes. There are parts, called ServingParcels in the model, which only have direct associations with two or more RegisterParcels. Characteristic is that it serves a number of other RegisterParcels, and that it is held in joint ownership by the owners of those RegisterParcels.

Parcels can be aggregated to AdminParcelSets, e.g. a ‘section’, a polygon, a municipality or a planning area. This class contains a method for area calculation. An AdminParcelSet can be an aggregation of other AdminParcelSets. Implementations of the LADM can be related to identifiers of parcels or spatial units.

The UML class diagram RegisterParcel, ServingParcel and NPRegion[65] consists of specialisations of the topologically structured Parcel, which altogether form the partition (subdivision without gaps and overlaps) of the territory where land administration applies. The Parcel-family of classes (Immovable objects) is shown in Figure 26.

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[65] NonPlanarRegion, see explanation below.

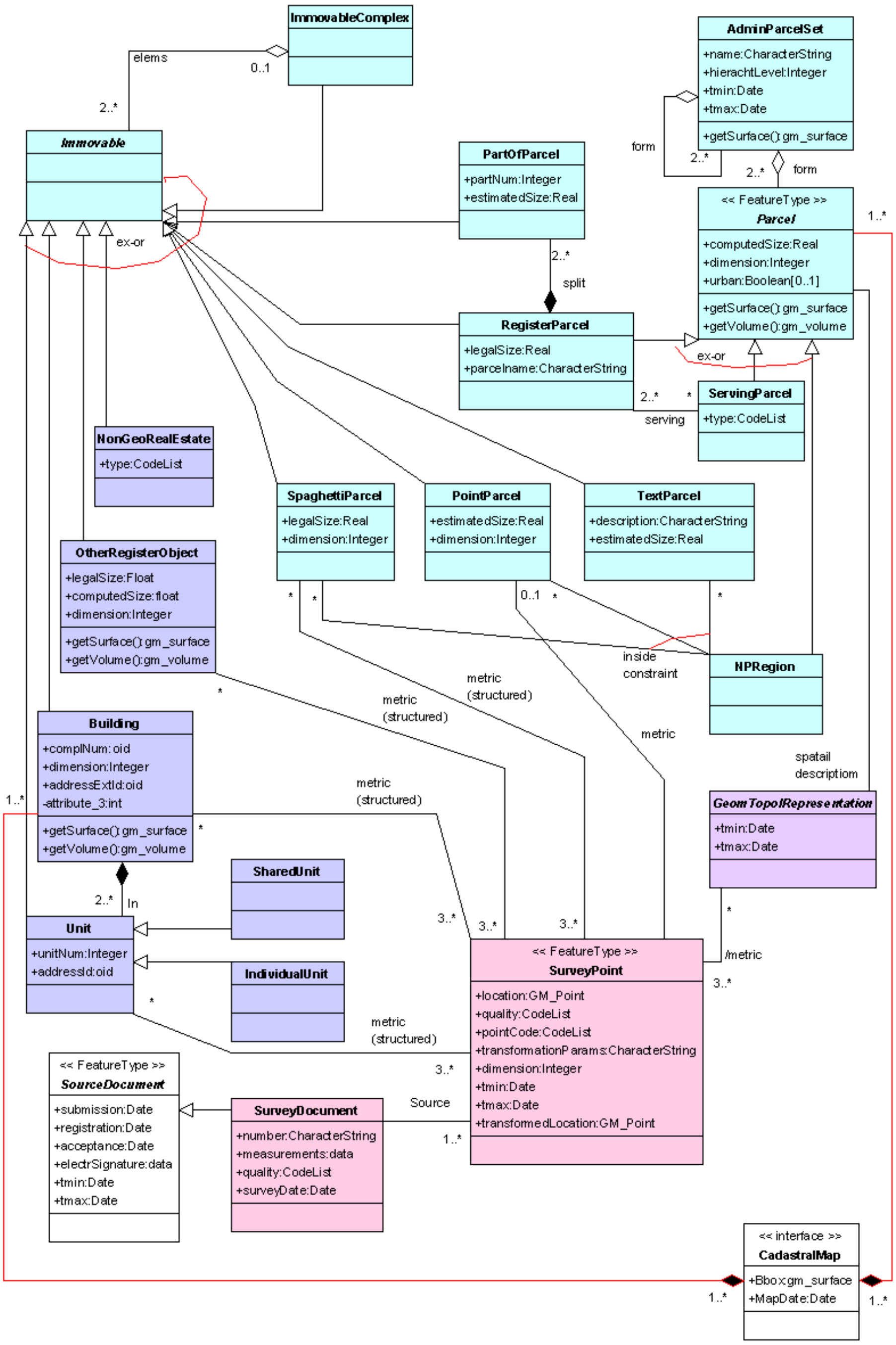

Figure 26 The different types of Immovable object classes in Version B, see Lemmen and Van Oosterom (2006a) based on Van Oosterom et al (2006b).

An ImmovableComplex[66] is an (optional) aggregation of Immovables. A ImmovableComplex situation might occur in a system where a set of Immovables (e.g. a Unit -see below-, a Building and a Parcel) has a legal/customary meaning. An ImmovableComplex is in itself an Immovable which can be related to a RRR.

A RegisterParcel can also be subdivided in two or more PartOfParcels. This case could occur when 'preliminary' RegisterParcels are created during a conveyance where the RegisterParcel will be split and surveying is done afterwards. It could also be helpful to support planning processes, based on cadastral maps, where establishment of RegisterParcels in the field is done later in time. Or in case where a RegisterParcel is determined from aerial or space imagery.

The Version B of the LADM offers the possibility to represent parcels not only based on a topological structure (in 2D or in 3D), that is a set of cells without overlaps and without gaps, but also in alternative ways. A land (or space) Immovable/RegisterObject could (initially) be represented with a textual description (label), a single point or a spaghetti polygon, which is not (yet) adjusted with its neighbour in a topological structure. Spaghetti polygons can overlap each other and can be identified. In this way a land administration 'territory' can be covered by two types of regions:

1. regions based on parcels with a topological structure, and
2. regions not (yet) based on parcels with a toplogical structure

Together these regions cover the whole territory; except the 'zero-Parcel' representing the external territory.

The object class Parcel is therefore also specialised into NonPlanarRegion (NPRegion). A NonPlanarRegion is a region without topological structured data. Note that the NPRegion itself does not have any associated Person (or RRR), that is it is not a RegisterObject. On the other hand, the land objects in Immovable class include the following specialisations: TextParcel, PointParcel and SpaghettiParcel. These three 'alternative' non-topology representations of a land object can only exist in NPRegion areas. A parcel may change its presentation over time from TextParcel (e.g. associated to Person or RRR later in time), to PointParcel to SpaghettiParcel to RegisterParcel. However, this does not need to be the case in the situation that the TextParcel, PointParcel or SpaghettiParcel fulfils the needs. Perhaps, the text, point and spaghetti representation of a parcel should be interpreted as a parcel description with a certain fuzziness (all 'fuzzy faces' belonging to the same 'conceptual' partition of the surface). A TextParcel may be a list of names of neighbours or other textwise description of boundaries.

One more option is 'SketchParcel'. This can be a rough or a detailed sketch of the parcel (or spatial unit). This type can be included as SurveyDocument; see Subsection 3.4.2. In that case there must be at least one point (SurveyPoint) for geo-referencing. Another option is to include Sketchparcel as LegalDocument (this may be needed because of a complete lacking geo-reference). Use of other media (voice and video, see Barry (2005)) require different data types under the description attribute of TextParcel, or may be included again under LegalDocument because of lacking geo-reference.

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[66] ImmovableComplex replaces ParcelComplex in earlier versions of the LADM Version B.

As mentioned above, the other immovable register objects, include: Building, Unit, NonGeoRealEstate and OtherRegisterObject; see Figure 26. In the Version B of the LADM there is no explicit association between Building and a Parcel as this can be derived from the geometry and topology structures. This also fits to the Cadastre 2014 approach; see Kaufmann and Steudler (1998). In case this would not be possible[67], for example because a TextParcel (without geometry) is involved, an explicit association could be added in that specific country or area. Unit and Building are specialisations of Immovable[68]. A Building is composed out of several Units[69].

ImmovableComplex allows to relate one right to e.g. a combination of apartment Unit, parking place and another Unit in the building.

A Unit has as specialisations SharedUnit and IndividualUnit. In such a way an apartment could be represented as an IndividualUnit, the common areas (threshold, stairs, corridors, elevator, roof,…) as a SharedUnit. A Unit is associated to SurveyPoint and so a link to 3D geometry is established. SharedUnit, Individual Unit and the association Unit and SurveyPoint are new functionalities in Version B.

In most LASs a restriction is associated to a complete RegisterObject (RegisterParcel) and this is also reflected in the presented model: a Person can have a Restriction (specialisation of RRR) on a RegisterObject. It should be observed here that OtherRegisterObjects are modelled as closed polygons in 2D or polyhedrons in 3D and there is no explicit topology between OtherRegisterObjects, that is they are allowed to overlap. Typical examples of OtherRegisterObjects are: geometry of an easement (such as 'right of way'), protected region (as a consequence of sustainable management of national resources or nature preservation), legal space around a utility object. In this way the functionality as available in Version A under class PublicRestriction is available again in Version B.

RegisterObject contains attributes required for valuation purposes: arrays of value attributes with linked dates (of observation) are included now[70].

The class NonGeoRealEstate can be useful in case where a geometric description of the RegisterObject does not (yet) exist. For example in case of a right to fish or hunt in a commonly held area (itself depicted as a ServingParcel), where the holder of the fishing right does not (or no longer) hold rights to a land parcel in the area.

3.4.2 Surveying Classes

Object classes related to surveying are SurveyDocument and SurveyPoint; see Figure 26, 27 and 28. A cadastral survey is documented on a SurveyDocument, which is a (legal) source document made up in the field. This document may contain signatures; in a full digital surrounding a field office may be required to support this under the condition that digital signatures have a legal support. Otherwise paper based documents (which can be scanned of course) should be considered as an integral part

[67] In Version C the option for explicit associations is re-introduced after discussions with experts from many countries in relation to the development of the LADM as an ISO standard. Re-introduction is needed because of inaccuracies in geometry (e.g. shifts) or because of the detection of very small overlaps in case of applications of polygon overlays in geographical information systems.

[68] This is new in version Version B of the LADM. In Version A Unit was associated to Building only.

[69] A Unit is intended in the general sense, not only unit for living purposes, but also for other purposes, e.g. commercial. In other words, all building units with legal/registration significance are included here.

[70] But valuation is outside ths scope of this thesis.

of the LAS. Files with terrestrial observations – distances, bearings, and referred geodetic control – on points are attributes of SurveyDocument, the Measurements. The individual SurveyPoints are associated with SurveyDocument, see Figures 26 and 27. One SurveyDocument can be associated with several SurveyPoints. The SurveyPoints form the metric foundation of both the topology-based objects and the non-topology-based objects.

In case a SurveyPoint is observed at different moments in time there will be different SurveyDocuments. In case a SurveyPoint is observed from different positions during a measurement there is only one association with a SurveyDocument. One of the attributes of a SurveyPoint is the pointCode, which indicates the type of SurveyPoint; this could for example be a Geodetic Control Point (GCP). If the ‘same point’ is (re-)surveyed several times and the location does change significantly then there are two options in the model: replace the old SurveyPoint with a new SurveyPoint (with a new id) and all associated classes (Building, but also Parcel node, edge, face) must be updated in order to refer to this new id.

An alternative is to make a new version of the old SurveyPoint (keeps same id, but gets different time stamps). The associated classes do not have to be updated, only the SurveyPoint itself: new time stamp, improved quality co-ordinate and association to new SurveyDocument. Previous locations of a specific SurveyPoint can be found via its id, which remains the same. In general the second option is preferred in case the location of the SurveyPoint is changed as this offers all the functionality with a relative small adjustment in the data set. Further, instead of a resurvey, there could also be other reasons for changing co-ordinates, for example map improvement or switching to a different co-ordinate reference system (or a new calculation of the same reference system). Note that in Version B indication of Geodetic Control Points, possible multiple co-ordinates for points, supporting multiple reference systems are supported.

3.4.3 Geometry and Topology Classes

Object classes describing the geometry and topology are GeomTopolRepresentation, TP_Face_2D, TP_Edge_2D, 2D_Node_2D[71], TP_Volume_3D, TP_Face_3D, TP_Edge_3D and TP_Node_3D; see Figure 27.

The Version B is based on already accepted and available standards on geometry and topology published by ISO and OGC (ISO, 2003b, ISO, 2003c, OGC 1999, OGC, 2006b, OGC, 2007a, OGC, 2007b and OGC, 2010b). Geometry itself is based on SurveyPoints (mostly after geo-referencing, depending on data collection mode: tape, total station, GPS, etc.) and is associated with the classes TP_Node_2D (topology node), TP_Edge_2D (topology edge) and TP_Node_3D, TP_Edge_3D and TP_Face_3D (topology face, only in 3D case) to describe intermediate ‘shapes’ points between nodes, metrically based on SurveyPoints.

[71] In the LADM Version A TP_Face_2D, TP_Edge_2D, 2D_Node_2D is called tp_face, tp_edge and tp_node.

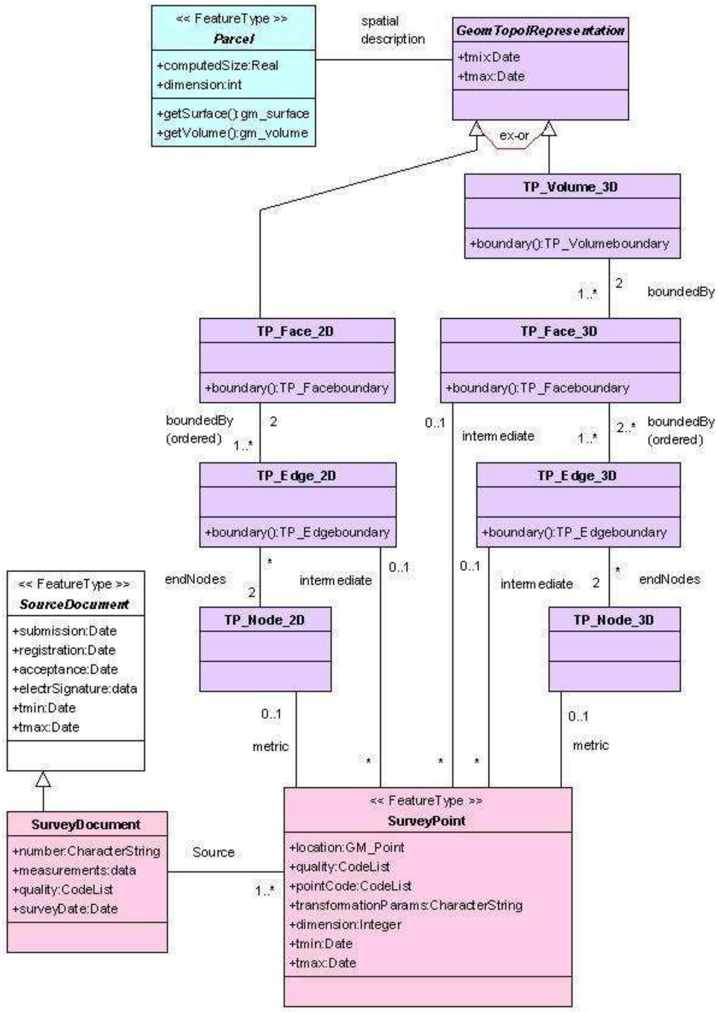

Figure 27 The Geometry, Topology and some related packages in Version B, see Lemmen, and Van Oosterom (2006a) based on Van Oosterom et al (2006b).

Parcels have a 2D or 3D geometric description. In 2D a geometry area is defined by at least 3 SurveyPoints, which all have to locate in the same horizontal plane (of the earth' s surface). In 3D a geometry volume is defined by at least 4 non-planar SurveyPoints; this would result in a tetrahedron, the simplest 3D volume object.
Parcels have a 2D or 3D geometric description. The 2D or 3D (ISO/OGC) topology structures are valid at every moment in time. There are never gaps or overlaps in the partition. However, two edges belonging to different time spans (defined by tmin-

tmax) may cross without a node. The temporal topology must also be maintained, that is no time gaps or overlaps in the representations. Therefore the structure is based on spatio-temporal topology.

LASs, based on 2D topological and geometrically described parcels, have shown limitations in providing insight in (the 2D and 3D) location of 3D constructions (e.g. pipelines, tunnels and building complexes) and in the vertical dimension (depth and height) of rights established for 3D constructions (Stoter and Ploeger, 2002; Stoter and Ploeger, 2003; Stoter, 2004). 2D and 3D are treated in the same manner throughout the model; not only for Parcels but for all types of Immovables. It is important to realise that there is a difference between the 3D physical object itself and the legal space related to this object. The LADM only covers the 'legal space'. That is, the space that is relevant for the registration and cadastre ('legal bounding box' of the object), which is usually larger than the physical extent of the object itself (for example including a safety zone).

3.4.4 Legal/Administrative Classes

'Person', see Figure 28, has as specialisation classes NaturalPerson or NonNaturalPerson like organisations, companies, co-operations and other entities representing social structures. Further there can be a third specialisation: GroupPerson. The difference between the NonNaturalPerson and the GroupPerson is that the first is intended to represent instances such as organisations, companies, government institutes (with no explicit relationships to other Persons), while the second is intended to represent communities, co-operations and other entities representing social structures (with possible explicit relationships to other Persons, optionally including their 'share' in the GroupPerson and associated RightsOrRestrictions to RegisterObjects). Note that a GroupPerson can consist of all kinds of persons: NaturalPersons, NonNaturalPersons, but also of other GroupPersons. In case of more informal situations the explicit association with the group member Persons is optional. Further, a Person can be a member of 0 or more GroupPersons. The composite association between GroupPerson and Person could be developed into an association class 'Members', in which for each Member certain attributes are maintained, e.g. the share in the group and the start and optionally end date of the membership.

The main class in the Legal/Administrative package (Figure 28) is the abstract class RRR with specialisations Rights, Restrictions and Responsibilities. In principle, all RRRs are based on a LegalDocument as source. The essential data of a LegalDocument can be represented as attributes in the classes RRR and Mortgage. In the other direction, a RRR or Mortgage is always associated with exactly one LegalDocument as its source. Of course it is possible to describe more than one Mortgage in one LegalDocument (even combined with one or more other RRRs).

Property and land use rights are based on (national) legislation, 'look up tables' can support in this. 'Customary Right' related to a region or 'Informal Right' can be included in those tables; from modelling perspective this is not an item for discussion. Of course, for the actual implementation in a given country or region, this is very important.

In addition to those private law restrictions, many countries also have public law restrictions, which are usually imposed by a (local) government body. The ‘holder’ or ‘claimant’ of the right is a Person (either ‘the government’ or ‘society-as-a-whole’) and usually they are primarily seen as restrictions. Some of them apply to a specific RegisterObject (or right therein) or a small group of them, for example most pre-emption rights, or the duty to pay a certain tax for improvements on the road, or the duty to repair damage or perform belated maintenance.

Each non-ownership Right by a third party (be it government or a private Person) causes a Restriction (to the ownership). These Restrictions have their own place in the LADM Version B: they are modelled as views. That is not intended to be stored, but to be derived on demand when needed.

Right (a specialisation of the abstract superclass RRR) is a compulsory association between RegisterObject and Person, where this is not compulsory in case of ‘Restriction’ and ‘Responsibility’ (the other specialisations of RRR); in case of a public restriction not allowing to do something (e.g. not to built within a certanin distance to a fuel station). The class RRR allows for the introduction of ‘shares of rights’ in case where more than one Person holds an undivided part of a ‘complete’ Right (or Restriction or Responsibility). There are some refinements in the Legal/Administrative side; see Figure 28.

The first refinement is the extension of the class RRR to explicitly include Responsibilities as well. In current thinking and literature on cadastral and land administration issues usually the three Rs of Rights, Restrictions and Responsibilities are used. A restriction means that you have to allow someone to do something or that you have to refrain from doing something yourself. Restrictions can both be within private law, especially in the form of servitudes, as within public law through zoning and other planning restrictions as well as environmental limitations. Responsibilities mean that one has to actively do something. Not all legal systems allow such mandated activities as property rights (rights *in rem*), and this will also effect the question if they can (and have to be) registered. Obviously their impact can be substantial and their registration makes sense.

The class RRR, is presented as an association between Person and RegisterObject in LADM Version A. In Version B of the model this has been replaced by a normal class RRR with associations to both Person (exactly one) and RegisterObject (exactly one) as suggested by (Zevenbergen (2004) and Paasch (2004). It is still possible that one RegisterObject is related to several Persons (via RRR associations) and reversibly that one Person is related to several RegisterObjects (again via RRR associations). There is always at least one instance of Right (subclass of RRR) in which the type of right represents the strongest (or primary) right, for instance customary or statutory ownership, freehold or leasehold. Connected to this strongest right certain interests can be added or subtracted from this ‘strongest’ right, see Subsection 3.2.4. A point of discussion is how to represent the subtractions (Restrictions) as they are already implied by a non-primary right of a third party. The fact a neighbour is allowed to walk over your Parcel is an additional Right (appurtenance, positive -side) to the ownership of the neighbour property, where it is a Restriction (encumbrance, negative side) to your property. In the present model both sides are represented. Zevenbergen suggests to include the positive side and derive (compute) the negative side when needed (compare Zevenbergen, 2004).

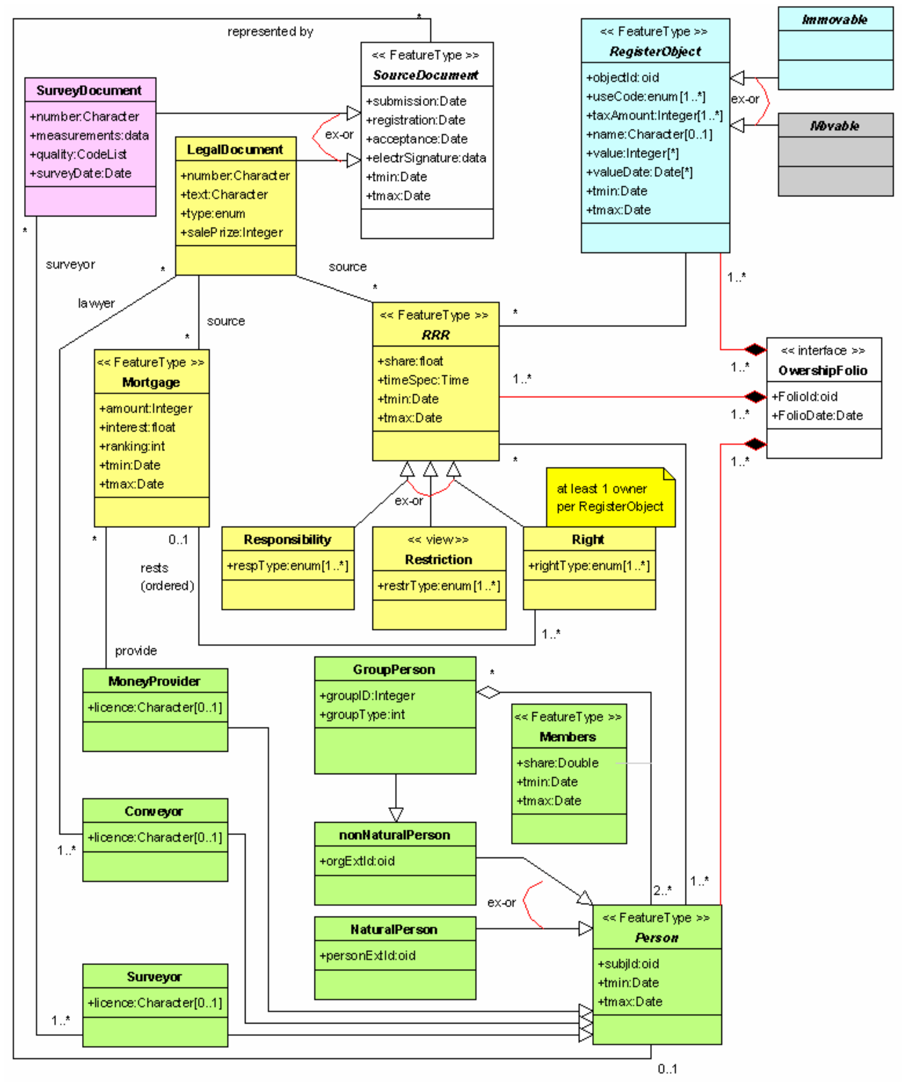

Figure 28 The Legal/Administrative and Person classes in Version B, see Lemmen, and Van Oosterom (2006a) based on Van Oosterom et al (2006b).

One or several mortgages are always vested on a (set of) Right(s) and should never be seen as a separate relation between Person and RegisterObject. On the other hand a Mortgage is usually vested as a collateral for a loan. Therefore the mortgagee is connected to the Mortgage as MoneyProvider; one specialisation of Person (see Figure 28). Mortgage is associated to a Right and not anymore on a RRR as in Version A of the LADM simply because a Mortgage on a Restriction or Responsibility has no meaning.

The fact that all the different (public law and private law) RRRs find their base in some kind of establishing or transacting document is represented by connecting them to LegalDocument which is a specialisation of the abstract class SourceDocument (as is SurveyDocument). The one responsible for drafting the document is connected to this as Conveyer.

LASs that have to underpin customary land tenure, informally arranged land use or conflicting claims to rights, and whose objects might not be clearly identifiable (fuzzy), not (yet) clearly identified or whose areas overlap are in need of other classes to allow for those type of situations (Van Oosterom et al, 2004). Often in such countries or jurisdictions both types of situations (strictly legal and formalised and more fuzzy and informal) are to be found in the same area, and should therefore be able to co-exist in the LAS, and thus in the Land Administration Domain Model.

3.5 Evaluation of LADM Version B

As mentioned earlier: a main characteristic of land tenure is that it reflects a social relationship regarding rights to land, which means that in a certain jurisdiction the relationship between people and land is recognised as a valid one (either formal or non-formal). LASs mostly only take into account conventional legal forms of evidence and are parcel based. This means that they only cover a portion of all forms of land tenure. Also they cannot accommodate all forms of tenures. See Augustinus and Lemmen, 2011. Globally there are many examples where the land use rights of informal settlement residents, slum dwellers, families and groups living under customary tenure, indigenous people, pastoralists, refugees, etc. are not capable of being integrated into a conventional LAS. The STDM has been designed to cover all types of tenures, conventional and other social tenures such as informal and customary tenures (Augustinus et al, 2006). It compliments the LADM and allows interoperability between the two systems. The STDM, with its own terminology, will be worked out in Chapter 4, prototype software has been developed to test the model; see Chapter 5.

After the presentation of the Land Administration Domain Model Version B to the FIG Congress in Munich. Germany, 2006, this version has been prepared as an ISO TC 211 New Working Item Proposal (NWIP), see ISO (2008a). This NWIP has been submitted to ISO TC 211 on Geographic Information. A template has been used for this purpose.

The main comments and observations received from the project group and editorial committee[72] during this development are presented here below. This concerns comments and observations to Version B from international experts in the TC 211 project team and also to later versions developed by the Editorial Committee

[72] In the editorial committee experts from the following countries are represented: Canada, Finland, France, Germany, Japan, Korea, the Netherlands, South Africa, Sweden and the United States. UN Habitat was represented as well as FIG and the Joint Research Centre from the European Union. All experts performed reviews on the Working Draft, Committee Draft and the Draft International Standard. It is a comprehensive, extensive and formal process with a continuous review and a continuous, creative approach to find common denominators in land administration systems and included data sets. Also with support of national expert groups.

for LADM within ISO TC 211; this concerns the Working Draft versions and Committee Draft version (see ISO, 2008b, ISO, 2009 and ISO, 2011c). There were hundreds of comments on the (lacking) definitions and terminology, especially on attributes in the NWIP. Some terms (layer, right) have already a definition within ISO. Can this be re-used – or is it better to use another term (which happened for 'layer', the term was replaced by 'level').

Also many comments on the representations in the UML diagrams, the contents of classes, the example cases, etc. Besides there were many minor comments on the organisation and structure of the document, spelling and grammar. All those comments are documented and have been discussed with the project team and later with the editorial committee.

From the reviews positive support was received: LADM as guide to land administration modelling and exchange of data. Also the LADM was recognised as being potentially very supportive in the design of new LASs.

On the other side there were critical remarks, especially from countries in the EU. This was related to the fact that the standard could get the status of mandatory norm (via CEN and national standardisation bodies and that this may cause change in the system or via INSPIRE[73]). Sometimes there was confusion about the proposed contents of the LADM, e.g. that it presupposes that a Cadastre and Land Registry are in the same institution, and that the act of registering a property in the Land Register is equivalent to register it in the Cadastre with legal implications. This is of course not the intention of the LADM. For this reason a clear scope has to be included to avoid this type of mis-understanding of legal impact.

From several countries there were remarks that there is too much emphasis on the 'spatial/surveying' part and too little on 'administrative/legal' aspects.

An interesting comment was that ISO/TC211 treats Geographic Information and not rights and duties. This was not accepted. LADM is a domain model. Therefore, its content is also non-geographic information, as in all other domains. Point information can be used for orientation (if the reference system is known), but lines on a map only have meaning with domains as reference behind it.

The 'overview' requirement B01 (see Table 3) includes some non-fulfilled requirements from LADM Version A. In LADM Version B topology is explicitly included now, a few identifiers without semantics are included – but a structural approach is needed as was discussed during the Development of the International Standard (this DIS is presented in the next Section 3.6 as LADM Version C), layers are more or less possible in LADM Version B (class based, again a structural approach is needed), interface classes for products and services are available, responsible persons in transactions (using roles) are included, RRRs are added, versioned objects could be more systematically included. Functionality for 3D Cadastre is basically there. Marine Cadastre is basically there (with an association between 'Interest' and 'Law' (read 'Institutions'). Requirements B02, B03 and B05 are included based on types of RRRs (look at RRR from a broad perspective: it can be formal, customary, etc.). A better management is possible using layers. B04: GroupPerson is included now, this extends the possible representations of land

[73] A mandatory implementation would be completely unacceptable and impossible for the countries with voting rights in TC211. To avoid misunderstanding a scope for the LADM was defined formulated in such a way that there could be no misinterpretation on this.

rightful claimants or right holders. New forms of spatial units are added, topology is not longer a requirement for point based, text based and spaghetti based immovables. This allows for overlaps with the toplogical structured area; this is a kind of introduction of layers, but insufficient. The functionality in support of surveys has been extended, e.g. transformations, quality code.

New requirements from the comments and observations provided by international experts are in Table 4.

Table 4 User Requirments for LADM Version C.

Code	**Requirement**	**Impact Analyses**
C01	*Remaining requirements from LADM Version B*	This concerns identifiers without semantics, layers and better support in surveying.
C02	*Better Representation of Basic Property Unit[74] needed*	The Triple Object – Right – Subject does not support the constellation of basic property units (see Figure 4), especially in cases where a basic property unit has a unique identifier (meaning that all spatial units belonging to this basic property unit have the same identifier). The purpose of a basic administrative unit is the grouping of spatial units, which have the same rights, etc. attached. A new core class is needed to represent this properly. This is a fundamental change because there is no direct association between RRR and Spatial Unit anymore. But it allows the inclusion of non-parcel based LASs, see also the BPUs in Section 2.2. Multiplicities in the associations between core classes should be as flexible as possible[75]. To get a generic terminology the BPU should be called 'Basic Administrative Unit'. This BAUnit does not include the word 'property'.

[74] Basic Property Unit may consist of several parcels, each of which may contain several plots. In many cases the plot, the parcel, the BPU, the proprietary unit and the protfolio will be the same thing (UN/ECE definition, Guidelines on Real Property Units and Identifiers, page 55 in UN/ECE, 2004). See also Figure 4. A basic property unit is defined by ownership and homogeneous real property rights and is made up of several parcels. It is the basic unit of ownership that is recorded in the land books or land registers (page 49). During the review process there was the suggestion to introduce Legal Land Object as a name for a new BPU, like core class.

[75] On the other side there were remarks that the main right for any land is the equivalent of freehold, which is either held by the state or an other party. All other rights derive from the main right. Leases cannot exist with only one party, there has to be a landlord and a tenant. Without the tenant all there is is a provisional lease, in effect an offer to potential tenants to negotiate. The same logic follows for all other lesser rights. This would mean a set of associations between core classes as in Version A. This can not be accepted, because roles are included, which means that there can be Parties (certified to perform in data maintenance) without RRRs. The multyiplicity issue was also discussed where RRR and documents are concerned: RRR can exist without any document. In the ideal case every LA_RRR must have at least one document, but the reality is that the reference to the document or maybe the whole document is missing (e.g. during war).

C03	*Basic Property Unit as Party*	A property unit (BPU in Figure 4) can play the role of a Party. E.g. in Scandinavian countries there can be two kinds of ownership. The most common is "personal" ownership. In addition to that a property unit may be owned by one or more other property units. This is often the situation within co-ownerships. The right then often follows the properties and not the owners. This may be parking areas or playgrounds that are owned by the properties in the neighbourhood.
C04	*Positive and negative side of restrictions*	The model has to cater for both positive and negative situations: if the negative side can be derived (computed), then only the positive side needs to be stored. Parcel based systems work very well (Tuladar, 2004), but BPUs are required.
C05	*Cadastre 2014[76] and the principle of legal independence not only by overlay, but also by explicit linking*	A remark related to the Cadastre 2014 principle of legal independence (which should be possible to be introduced as layers in LADM Version C), 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. This brings unreliable results. "RequiredRelationship" should be explicitly possible and always override implicit relationships established through spatial operations[77].
C06	*Re-use existing ISO Standards*	The standards to be re-used should be better described; e.g. the spatial description package. This observation concerns all the existing classes on geometry and topology (see Subsection 3.2.3 and 3.4.3) and should be referred to as extClasses[78]. Attention point here is on aspects of 3D Cadastre: do the existing standards[79] include 'unbounded objects'[80]. It should be possible to close volumes in all directions to form a bounded volume. Also for the Survey package there should be as much as possible re-use of standards on Observations and Measurements[81] (under development). On surveying itself there were remarks that also stereo plotting can be used as basis for acquisition of data on cadastral boundaries. This is supported of course and better worked out in the LADM Version B (e.g. lines without associations to points).

[76] The standardization process is not an authorisation of Cadastre 2014 to an ISO standard. In general references are not accepted as part of the normative text – this would imply the inclusion of the contents of that reference to the contents of the standard.
[77] When geometry overlay can be used and when not? What in reality means legal independency mentioned in Cadastre 2014? This is quite a key question which is not resolved yet. According the LADM geometry overlay seems to be the only way, but according to real world experiences in some countries it is not suitable in every case. Real world experiences should be taken into account better was one of the comments.
[78] This implies that the view of integrated management of topology and geometry and other attributes as in (Lemmen and Van Oosterom, 2001) is abandoned; topology is not modelled in an explicit way anymore.
[79] E.g. ISO 19107 Geographic Information, Spatial Schema (ISO, 2003b).
[80] A parcel is in some jurisdictions defined by a set of property rights. A parcel extends notionally from the centre of the earth to the infinite in the sky and as such should be regarded as a volume of space, see Dale and McLaughlin (1998). In fact this is an unbounded 3D object.
[81] ISO 19156.

C07	*Party members*	It should be indicated that by default, it is assumed that all members in a partygroup hold equal shares in the group. The use of class PartyMember is only required to manage party members in a Group party with unequal shares.
C08	*System boundary of LADM, external classes and information infrastructures*	There was discussion on the system boundary again. Which classes belong to the LADM and which don't. First of all there is re-use of existing standards as discussed above. But in an information infrastructure also data on persons, companies, addresses, land cover, land use, valuation, taxation and networks may be external. This is very relevant in relation to the development of information infrastructures for good governance. Such infrastructures do not only contain spatial data; many domains have to be covered. Goal is avoidance of data duplications and clear responsibilities on data maintenance. Archiving is proposed to be completely external, using existing standards. According to some experts documents can't be divided as spatial and non-spatial documents: this is an old-fashioned way of thinking. Nowadays (even more than earlier) one document can include every kind of data. See Subsection 3.6.6 for external classes in Version C.
C09	*Generic versioning and quality labels*	Generic versioning and quality labelling for all contents of LADM is requested. There was a remark that class SourceDocument does not provide sufficient information to manage event based history. It would be required to maintain the state before and after for each document to display the history. It needs to be demonstrated that event based modelling is supported.
C10	*Miscellaneous*	Values in code lists are informative, not normative, although there is the possibility to add national codes. There were also many remarks and comments on attributes: should purchase price be included?; should electronic signature or finger print be an attribute? Data types as multimedia should be included for documentation purposes. Regarding dimensions: a spatial unit can be represented by a line which would be 1D or by a point (centroid) which would be 0D. More flexibility with identifiers and general and generic introduction of identifiers is needed.

3.6 LADM Version C

The Land Administration Domain Model (LADM) has been published as a Draft International Standard by the International Organisation for Standardization (ISO), as ISO 19152 (ISO, 2011c). The Draft International Standard has also been submitted to CEN/TC 287. As explained in Sections 1.6 and 3.5 this development has been a substantial effort. The Draft International Standard is presented here now as version C of the LADM. Some class names changed, see Appendix A. For a complete overview of associations (relationships) between classes in Version C, see Appendix B. Terms and Definitions for LADM Version C can be found in Appendix D.

Of course, the scope of the LADM (or any other model) is limited and does not model the whole world. The scope of Version C (that is the ISO 19152 Draft International Standard) is described now in detail.

The standard (ISO, 2011c, p. 1):

- ‘defines a reference Land Administration Domain Model (LADM) covering basic information-related components of Land Administration (including those over water as well as land, and elements above and below the surface of the earth);
  - provides an abstract, conceptual schema with four basic packages related to:
  - parties (people and organisations);
  - basic administrative units, rights, responsibilities, and restrictions (ownership rights);
  - spatial units (parcels, buildings and utility networks);
  - spatial sources (surveying), and spatial representations (geometry and topology);
- provides a terminology for land administration, based on various national and international systems, that is as simple as possible in order to be useful in practice. The terminology allows a shared description of different formal or informal practices and procedures in various jurisdictions;
- provides a basis for national and regional profiles; and
- enables the combining of land administration information from different sources in a coherent manner.

The following is outside the scope of this International Standard:

- interference with (national) land administration laws that may have any legal implications;
- construction of external databases with party data, address data, valuation data, land use data, land cover data, physical utility network data, archive data and taxation data. However, LADM provides stereotype classes for these data sets, which indicate what data set elements LADM expects from these external sources, if available; and
- modelling of land administration processes.’

LADM Version C, as a product, is a conceptual schema. LADM Version C is organised into three packages, and one subpackage. (Sub)packages facilitate the maintenance of different data sets by different organisations, e.g. Land Registry or

Cadastre (each with their own responsibilities in data maintenance), operating at national, regional or local level.
The core LADM in Version C is based on four core classes, see Figure 29 (prefix LA is used now for each class)[82]:
1) Class LA_Party[83], parties;
2) Class LA_RRR, rights, restrictions or responsibilities;
3) Class LA_BAUnit, basic administrative unit[84];
4) Class LA_SpatialUnit[85], spatial units.

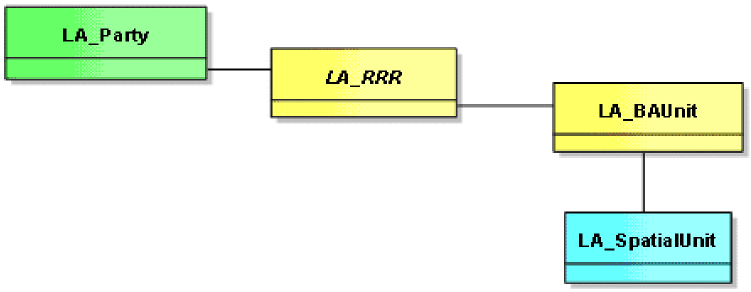

Figure 29 The four core classes of LADM (ISO 2011c).

The three packages are: Party Package, Legal/Administrative Package and Spatial Unit Package. The Surveying and Spatial Representation Subpackage is one subpackage of the Spatial Unit package. Figure 30 presents all Version C classes.

The four core classes of Version C are introduced in 3 packages (Party, Legal Administrative and Spatial Unit) and are described in the next subsections of this section. The sequence of presentation and the contents of the packages in this Section has been changed compared to the LADM Versions A and B in earlier sections. First the Party Package is introduced, then the Administrative Package with RRRs and Basic Administrative Units (BAUnits, a new core class, see Figure 29) and then the Spatial Units Package (which includes now the Surveying Classes and Spatial Representation Subpackage) are presented. This order of presentation is one of the outcomes of the discussions with international experts: first party and right should be known and then the objects (spatial unit) where the right applies to; for the model this sequence is not relevant. In this section there are further subsections for special classes (for object versioning) and a subsection where 'LADM – expected' contents of external classes is described. Finally the imported functionality from other ISO standards is presented (re-use of existing standards).

[82] Prefixes used in this thesis: Prefixes from ISO: CI Citation (ISO 19115), DQ Data quality (ISO 19115),, EX Extent (ISO 19115), GF General Feature (ISO 19109), GM Geometry (ISO 19107), LA Land Administration (ISO DIS 19152), MD Metadata (ISO 19115), OM Observation and Measurement (ISO DIS 19156), RS Reference System (ISO 19115), SC Spatial Coordinates (ISO 19111), TM Temporal (ISO 19108)
[83] In LADM Versions A and B LA_Party is called Person.
[84] Baunits are administrative units consisting of zero or more spatial units against which one or more RRRs are associated. See Subsection 3.6.2 for a further definition and description.
[85] In LADM Versions A and B LA_SpatialUnit is called Parcel or PartOfParcel.

Code lists are used to describe a more open and flexible enumeration. Code lists are useful for expressing a long list of potential values. The code lists included in the LADM aim to allow the use of local, regional or national terminology.

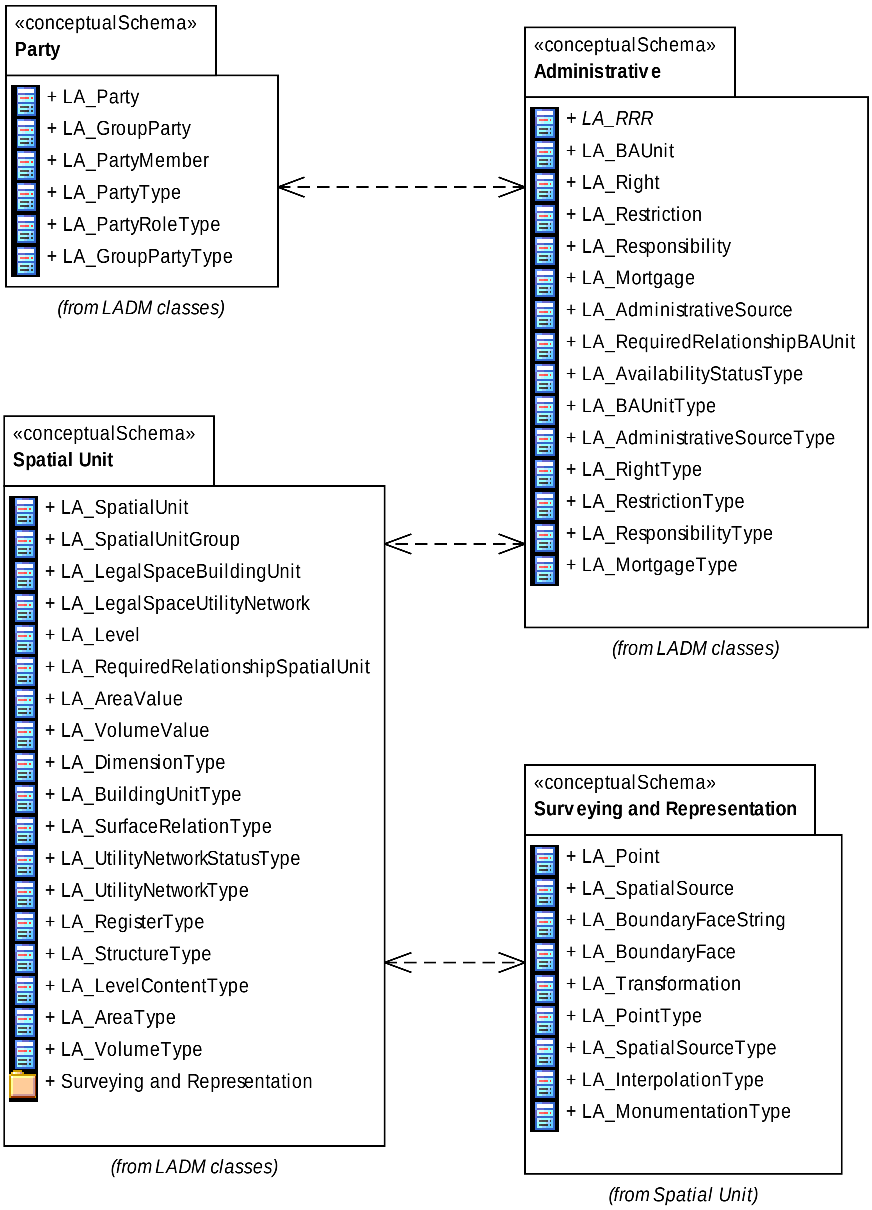

Figure 30 The LADM overview of (sub)packages in Version C, with their respective classes (ISO 2011c).

3.6.1 Party Classes

The main class of the Party Package (see Figure 31) is the class LA_Party with its specialisation LA_GroupParty[86]. A party is a person or organisation that plays a role in a rights transaction. Another class is LA_PartyMember[87].

There is an optional association class LA_PartyMember between LA_Party and LA_GroupParty. A group party is any number of parties, forming together a distinct entity; e.g. a village community or a tribe. A party member is a party registered (or recorded) and identified as a constituent of a group party.

There are external classes for Parties in Version C; those external classes have references from LA_Party. This is in support of implementations on information infrastructures (based on domain standards). The idea is to use only authentic data in such information infrastructures, e.g. to use data from population or company registers in case of Parties. The external classes indicate what data contents LADM is expecting from external resources. See Subsection 3.6.6 for an overview and expected contents of external classes in Version C of LADM.

In LADM Version B there are separate classes for role types (MoneyProvider, Conveyor and Surveyor). But facts related to persons with a specific role are mostly included in a separate database. This is implemented in Version C via an attribute for party role types combined with an identifier of the party with a specific role in an external database (extPID). In this way it is possible to refer, for example to an (external) database with certified conveyors to find out if a specific conveyor is still authorised in case a transaction is requested[88]. Something similar is valid for notaries, for certified or non-certified surveyors or for state administrators. If parties with a specific role in a transaction are in an external database it is needed that history is maintained in this external database. This is necessary because a party performing a specific transaction needs to be known and traceable for transparency reasons. This is also valid for transactions performed in the past (e.g. before a certificate was withdrawn). The need for transparency and transparent systems, and related to this the success of land administration, is discussed in Van der Molen and Tuladhar (2006b) and in Van der Molen (2007).

Conveyors and surveyors may also have different roles combined in one person. They can be rightful claimant or right holder and/or they can have a responsibility in the data acquisition and/or data maintenance process via transactions. Those responsibilities concern the authenticity and quality of the products which are delivered from their roles: survey documents, legal documents and mortgage deeds. It may be required to include the names of the responsible persons into the LAS with linked external databases.

Also user groups for information services as citizens, banks and parties involved in transactions (conveyors, etc.) have a role e.g. to organise authorisation or payment of services and products. Farmers may be included in a specific role e.g. because of subsidies for agriculture; see Section 5.6.

[86] In LADM Version B LA_GroupParty is called GroupPerson.
[87] In LADM Version B LA_PartyMember is called Member.
[88] This is in principle the responsibility of an external organisation and not of the LA organisation.

Attributes of LA_Party are (see Figure 29): the identifier of the party in an external registration (extPID); the name of the party; the identifier of the party (pID); the role of the party[89] in the data update and maintenance process and the type of the party[90].

Attributes of LA_GroupParty are: identifier of a group party (groupID) and type of a group party[91]. An attribute of LA_PartyMember is share, this is a fraction of the whole. The sum of shares must be equal to 1 (one); see the constraint in class LA_GroupParty in Figure 31.

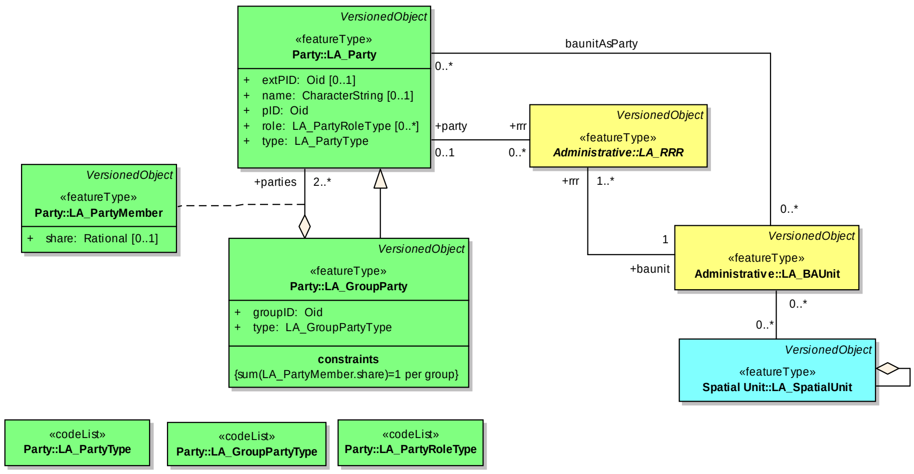

Figure 31 LADM Version C Party Package and associations to other core classes (ISO, 2011c).

3.6.2 *Legal Adminstrative Classes*

The main classes of the Administrative Package are core classes LA_RRR and LA_BAUnit. See Figure 32. LA_RRR has three classes as specialisations:

– LA_Right, this is an action, activity or class of actions that a system participant may perform on or using an associated resource. Rights are primarily in the domain of private or customary law. Ownership rights are generally based on (national) legislation, and code lists in LADM are in support of this, code tables are available for all “type attributes”; e.g.: ownership, possession or customary right. A right can be an (informal) use right. Rights may be overlapping, or may be in disagreement;

[89] LA_PartRoleType can be bank, certified surveyor, citizen, conveyor, employee, farmer, money provider, notary, state adminsitrator, surveyor, writer, etc.

[90] LA_PartyType, see Figure 31, can be a baunit, see Subsection 3.6.3, a group, a natural person or a non-natural person. Examples of non-natural persons are: a company, a municipality, the state, a tribe, a farmer co-operation, or a church community (with each juridical person represented by a delegate: a director, chief, CEO, etc.).

[91] LA_GroupPartyType can be: an association, a group of baunits, a family or a tribe. For baunits (basic administrative units), see Subsection 3.6.2).

- LA_Restriction, this is a formal or informal entitlement to refrain from doing something. E.g. it is not allowed to build within 200 meters of a fuel station. Or a servitude or mortgage as a restriction to the ownership right. Restrictions usually remain valid when the right to the land is transferred. A *mortgage* (LA_Mortgage) is a special restriction of the ownership right. A mortgage is in fact a security right to provide a maximum guarantee that (bank) loans for purchase of real estate are repaid;
- LA_Responsibility, this is a formal or informal obligation to do something, e.g. the responsibility to clean a ditch, to keep a snow-free pavement, to remove icicles from the roof during winter or to maintain a monument.

BAunits are administrative entities consisting of zero or more spatial units against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions are associated to the whole entity as included in a LAS.

By unique is meant that a right, restriction or responsibility is held by one or several parties (e.g. owners or users) for the whole basic administrative unit. By homogeneous is meant that a right, restriction or responsibility (e.g. ownership, use, social tenure, lease or easement) affects the whole basic administrative unit. It should be observed in relation to this that rights, restrictions and responsibilities may affect only a part of the spatial unit, with the geometric representation of that part missing. E.g. in case of a right of way: the location of the way may be unknown.

The class LA_BAUnit contains a constraint expressing that the sum of shares in a subclass of RRR must be equal to 1. This means parties can hold a share in a right, restriction or responsibility. A special attribute indicates whether this constraint is valid or not, as in some cases this constraint is meaningless.

LA_BAUnit allows the association of one right to a combination of spatial units (e.g. an apartment and a parking place); e.g. a ‘baunit’ is a basic property unit with three spatial units (e.g. an apartment, a garage and a rural parcel). A ‘baunit’ can be a group of spatial units under a zoning plan, which is under development or a group of spatial units as basis for taxation. A basis for taxation can be more than ownership in case lease is included: so a ‘baunit’ for taxation is not necessarily the same as a group of spatial units forming an ownership baunit. With class LA_BAUnit it is possible to register spatial units from different levels (sets of spatial units in themes) as one unit. If (parts of) spatial units are included or eliminated from the ‘baunit’, the identifier may remain the same, but with a different version. In this approach, a mortgage can only be established on the complete ‘baunit’, not on one or more of the included spatial units. A (group of) ‘baunits’ may be a party; this means a ‘baunit’ may own another ‘baunit’. This can be compared with serving parcels in Version B.

There may be required relationships between basic administrative units in absence of spatial units to describe the ‘baunits’ or in the presence of inaccurate geometry of spatial units to generate reliable implicit spatial relationship;. e.g. between a ‘baunit’ (a servitute) on one level and a ‘baunit’ (a basic property unit) on another level or between an ownership ‘baunit’ on one level and a ‘baunit’ for taxation on another level. For taxation purposes ‘baunits’ may be formed on the basis of factual land use (e.g. ‘ownership’ minus ‘leased to’ plus ‘leased from’ minus ‘given in use to’ plus ‘taken in use from’. Land ‘given in use to’ or ‘taken in use from’ exists within families or village communities). Something similar may be valid for land use based subsidies; e.g. subsidies for agriculture in Europe. Even if the geometry for spatial units does exist and is accurate there may be legal reasons to organise the data in this way. Instances of LA_RequiredRelationshipBAUnit override implicit relationships, established through geospatial overlaying techniques. Different life cycles of relationships between 'baunits' can be traced.

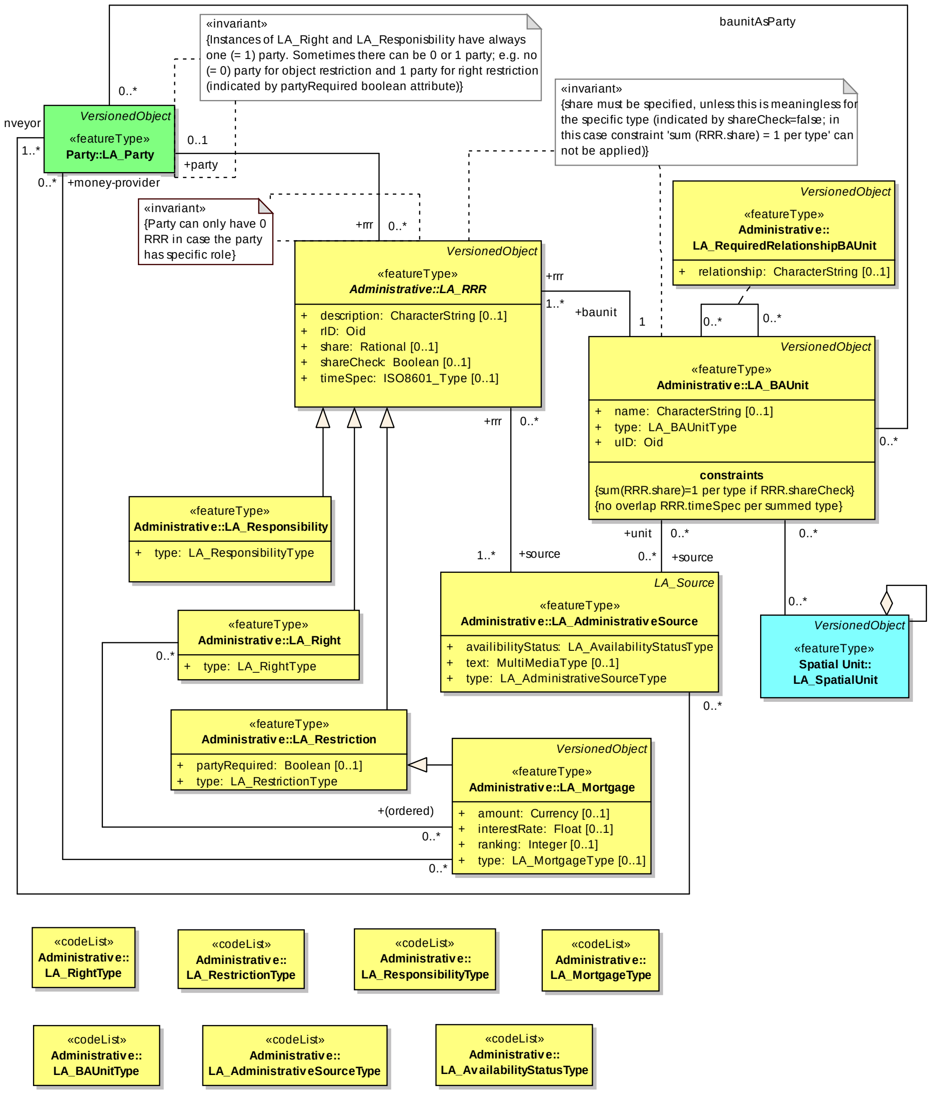

Figure 32 LADM Version C Administrative Package with associations to other core classes (ISO, 2011c).

In principle, all rights, restrictions and responsibilities are based on an administrative source. Class LA_RequiredRelationshipBAUnit allows creating instances of relationships between ‘baunits’. It allows maintaining explicit relationships between ‘baunits’ in the absence of spatial units to describe the ‘baunits’ or in the presence of inaccurate geometry of spatial units to generate reliable implicit spatial relationships; e.g. in case of ‘map conversion’ from a less accurate to a very accurate cadastral map.

Attributes of LA_RRR are (see Figure 32): a description regarding the right, restriction or responsibility; the RRR identifier (rID); a share in an instance of a subclass of LA_RRR (attribute shareCheck indicates whether the constraint in class LA_BAUnit is applicable) and timeSpec[92] (operational use of a right in time-sharing).

An attribute of LA_Right is the type of right[93]. Attributes of LA_Restriction are: the type of the restriction[94] and partyRequired (for specific parties may not be needed to exist) PartyRequired identifies if a party is needed or not. An attribute of LA_Responsibility is the type of responsibility[95]. Attributes of LA_BAUnit are: the name of the basic administrative unit; the type of the basic administrative unit[96] and the identifier of the basic administrative unit (uID). Attributes of LA_Mortgage are: the amount[97] of money of the mortgage; the interest rate of the mortgage (percentage)[98]; the ranking order (if more than one mortgage applies to a right(s)) and the type of the mortgage[99]. Attributes of LA_AdministrativeSource[100] are: the availability status of an administrative source[101]; the content of the document and the type of document[102] An attribute of LA_RequiredRelationship is the description of the required relationship.

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[92] Attribute timeSpec is capable of handling other temporal descriptions, such as recurring patterns (every weekend, every summer, etc.). This means, for example, that a party can hold a right to use an apartment each year in March, or that a group of pastoralists has the right to cross a field each summer (for fuzzy time range specifications see ISO (2004), Annex D; may be used instead of ISO 8601:2004). There is a constraint that no overlap is allowed between timeSpecs for the same RRR type and the same basic administrative unit.

[93] LA_RightType can be agricultural activity, common ownership, customary type (there are many), fire wood, fishing, grazing, informal occupation, lease, occupation, ownership, owneship assumed, superficies, tenancy, ususfruct, waterrights and Islamic rights (milk, miri, waqf).

[94] LA_RestrictionType may be administrative public servitude, monument, no building allowed, servitude, zone, etc.

[95] LA_ResponsibilityType can be monument maintenance, waterway maintenance, road maintenance, road cleaning, etc.

[96] BA_UnitType can be basic property unit, leased unit, taxation unit, etc.

[97] ISO (2008) should be used for the list of currencies

[98] This percentage may change after some years; in that case the question is if this should be included in the LAS.

[99] LA_MortgageType could be linear, microcredit, title at the bank, etc.

[100] In LADM Versions A and B LA_AdminsitrativeSource was called LegalDocument.

[101] LA_AvailabilityStatus can be archive converted (A/D), archive destroyed, archive incomplete, archive unknown (meaning not accessible because the location is unknown, e.g. after war), etc..

[102] LA_AdministrativeSourceType can be agri-consent, agri-lease, agri-notary statement, deed, mortgage, title, community statement, personal statement, etc.

3.6.3 Spatial Unit Classes

The main class of the Spatial Unit Package is core class LA_SpatialUnit, see Figure 33. A spatial unit is a single area (or multiple areas) of land and/or water, or a single volume (or multiple volumes) of space. A spatial unit can be a parcel. Spatial units are structured in a way to support the creation and management of basic administrative units.

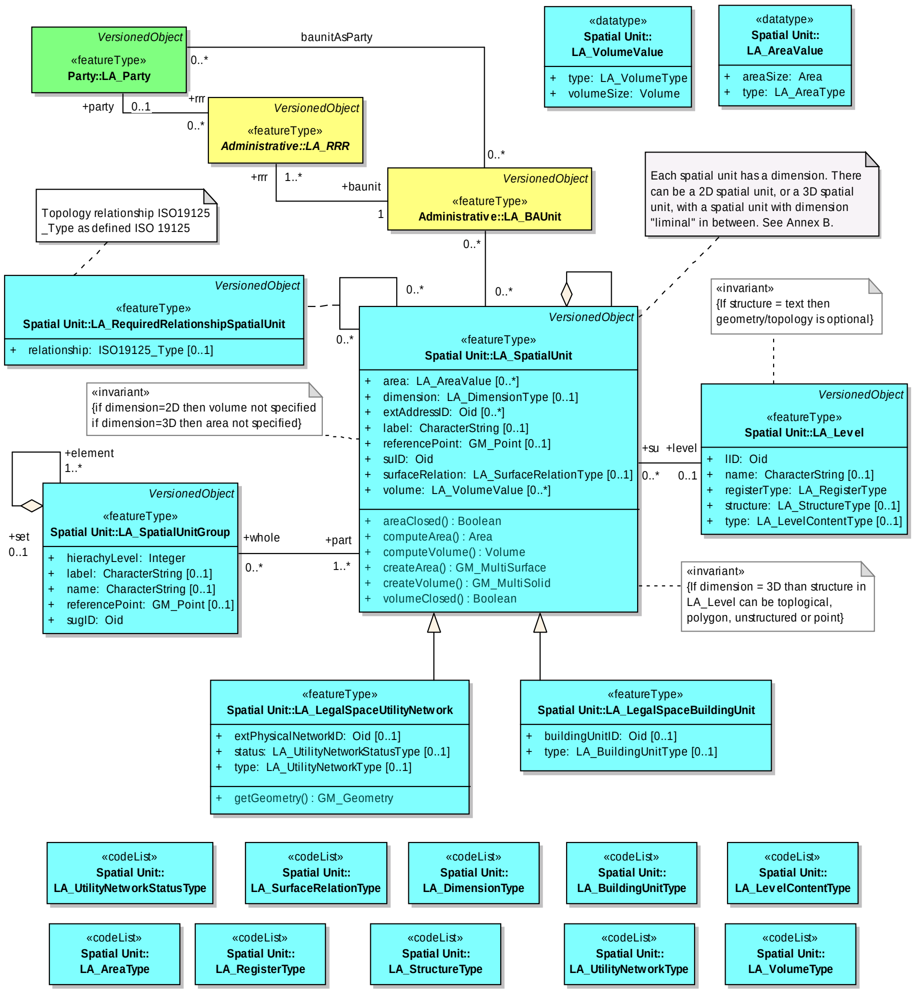

Figure 33 LADM Version C Spatial Unit Package with associations to other core classes (ISO, 2011c).

LADM Version C supports different types of spatial units as in Version B; see also Chapter 2 with reference to Larsson (1991) and Fourie (1998) for spatial profiles (see also Annex E in the DIS (ISO, 2011b):

- no spatial units (see Henssen, 1981). This does not mean that there is no object description. This means no map;
- a 'sketch based' spatial unit is used when a sketch (a quick draw of a group of spatial units) is available; e.g. sketch maps (Törhönen and Goodwin, 1998) and photographs, in the absence of any better identification,
- a 'text based' spatial unit is used when the definition of the spatial unit is entirely by descriptive text. This includes the 'metes and bounds' descriptions. Metes and bounds is a system or method of describing real property. The system has been used in England for many centuries, and is still used there in the definition of general boundaries. By custom, it was applied in the original thirteen colonies that became the United States and in many other land jurisdictions based on English common law (Cribbet et al, 2002). A typical description for a small parcel of land would be: "beginning with a corner at the intersection of two stone walls near an apple tree on the north side of Muddy Creek road one mile above the junction of Muddy and Indian Creeks, north for 150 rods to the end of the stone wall bordering the road, then northwest along a line to a large standing rock on the corner of John Smith's place, thence west 150 rods to the corner of a barn near a large oak tree, thence south to Muddy Creek road, thence down the side of the creek road to the starting point" (Wikipedia, 2010). There can be observations like distances and bearings (by compass) in a local system. This means there is no cadastral map;
- a 'point based' spatial unit is used when the only information about the location are the co-ordinates of a single point within its area (or volume). Jackson (1996), with references to several other authors, speaks about the 'midpoint concept'. In this concept the position of a land right is recorded, not its boundaries. Lester and Teversham (1995) refer to the concept as follows: "a single co-ordinate of the centre of the dwelling unit could positively identify that unit, and this may be sufficient for basic recording purposes where the limits of the landholding are for the time being unimportant". This concept is supported in LADM by 'point based' spatial units. Fourie and Van Gysen (1995) place the midpoint survey at an early stage in a system of progressive title improvement, ending in a standard freehold system. This is exactly what LADM supports in providing different options for the representations of spatial units;
- a 'line-based' (also known as 'unstructured' or 'spaghetti') spatial unit is used when the representation is allowed or the data storage is explictly used to have inconsistencies, such as hanging lines and incomplete boundaries. This may happen if data are collected over time with different data acquisition methods. Referring to Figure 34 it can be seen that, although the line work is of different quality and lineage, and in fact does not join in places (the circled points), a large number of the parcels are well defined. In fact, to a human user, the pattern of subdivision is clear. Further, adjacent parcels can be determined by inspection of the figure. The other side of this issue is that each piece of line work is uniquely identifiable, and can be marked with a quality statement. Using this statement, a set of criteria can be developed to allow many of the issues of hanging lines and

mismatches to be resolved. Different ‘levels’ may be used for storage of different qualities, as explained here below. This could imply that both line based and topology (or polygon) based spatial units are in us;

- a ‘polygon based’spatial unit is used when each spatial unit is recorded as a separate entity. This is applied in many GISs. There is no topological connection between neighbouring spatial units (and no boundaries shared), and so constraints enforcing a complete coverage must be applied by the sending and receiving software;
- a ‘topology based’ spatial unit is used when spatial units share boundary representations. A topological based spatial unit is encoded by reference to its boundaries, with the common boundary between two adjacent spatial units being stored once only. Thus there is a topological connection between neighbours.

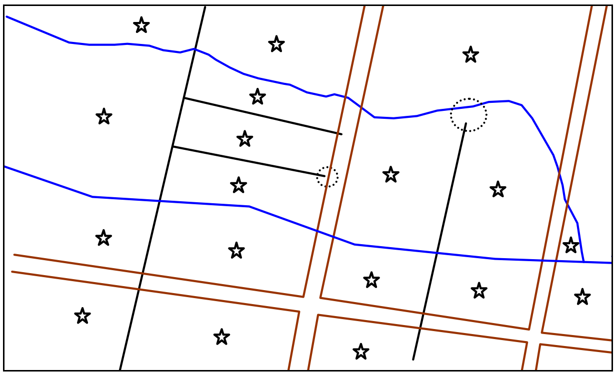

Figure 34 Line based spatial units (Lemmen et al, 2010b); figure designed and created by Rod Thompson.

LADM supports either 2-dimensional (2D), 3-dimensional (3D), or mixed (2D and 3D) representations of spatial units, which may be described in text (“from this tree to that river”) or based on a single point or represented as a set of unstructured lines or as a surface (with or without topology) or as a 3D volume (Lemmen et al, 2009a, Lemmen et al, 2010b). Independent from spatial units represented with a single point, text or a set of unstructured lines, a spatial unit may have an area equal to zero for administrative reasons; e.g. in case where a ‘mother parcel’ is subdivided into parcels which have been sold. Spatial units can be grouped in two forms:

1. as spatial unit groups (any number of spatial units, considered as an entity e.g. a municipality). This is realised by an aggregation relationship of LA_SpatialUnitGroup[103] onto itself, see Figure 33. A spatial unit group may be a grouping of other spatial unit groups. In implementations of LADM this is to enable the inclusion of spatial unit identifiers in hierarchical zones;
2. as sub spatial unit, that is a grouping of a spatial unit into its parts (recursive grouping of LA_SpatialUnit). This is realised by an aggregation relationship of LA_SpatialUnit onto itself, see Figure 33. Parts, in their turn, may be grouped into subparts and so on.

[103] In LADM Version B LA_SpatialUnitGroup is called AdminParcelSet.

Spatial units have two specialisations: building units, those are components of a building concerning the legal, recorded or informal space of the physical entity and utility networks, those are networks describing the topology of a utility; this can be modelled as a 'baunit'.

A level is a set of spatial units, with a geometric and/or topologic and/or thematic coherence. A 'level' is a collection of spatial units with a geometrical, topological or thematic coherence (class LA_Level in Figure 33) This concept is important for organising the spatial units in LADM. In this way, in relation to the principle of 'legal independance' (Kaufmann and Steudler 1998), there can be one level representing spatial units, reflecting the formal rights as described in e.g. the civil code. This may include freehold, leasehold and servitutes. If spatial units are based on local legislations (e.g. a municipal regulation) there can be another level for this; e.g. a level with restrictions or responsibilities. This may be valid for all municipalities in a territory. Further levels can be related to regulations developed by other governmental institutions. A further division may be based on the urban and rural subdivision and the related type of land registration which exist in many countries. There can also be a forest cadastre, a railway cadastre or an utility cadastre. There may be a need to represent a taxation and legal cadastre which can be separate organisations. A final division is in allocating levels for types of this. It is also possible to deal with facts which are not formally set down in a law. Such informal and customary rights exist where tribes or clans are obeying unwritten rules. These tribes or clans may have living, hunting and fishing rights within a defined territory from which the boundaries are known, but not documented formally. The rightful claimants are certainly able to localise the outlines of their rights and the respective spatial unit can be included into the LAS. A form of 'occupation rights' exist in informal settlements in many areas of the world. Even when the occupation of the land may be contrary to the formal law, the rights of the involved settlers are informally defined by an unwritten code. The boundaries resulting from these informal arrangements can be localised and documented. So this principle can show overlapping rights and serves to formalise the situation, to regulate transactions, to monitor and to improve ambiguous situations. Indigenous rights normally overlap with a formal ownership system. The rights and the boundaries where they are in effect are well-known and can be documented (Augustinus et al, 2006; Lemmen et al, 2007). Spatial units may be sketch based, text based, point based, line based, polygon based or topology based in this documentation.

The principle of legal independence; the type of land register (urban, rural, forest cadastre etc.) and different types of spatial units can be combined in one level using so-called code lists; this is worked out below. This allows for integrating data delivered by different organisations, with different (legal) mandates and for integrating data based on different spatial units as a basis for progressive title improvement Fourie and Van Gysen (1995), which could be ending in a standard freehold system.

According to the author of this thesis a progressive approach can also be applied in a way that results into re-established customary systems for different areas of a territory. A similar progressive approach can also be applied in relation to the quality of spatial data related to different qualities.

An example of quality improvement of the cadastral map in the Netherlands can be found in Salzmann (1996) and Salzmann et al (1997).[104] This renovation has a direct link with combining spatial data e.g. the information of the cadastral map with other geographic information (e.g. topographic base maps). Earlier inconsistencies between maps are noted and are difficult to understand for citizens.

Required relationships are explicit links between spatial units and instances of class LA_RequiredRelationshipSpatialUnit. In many cases there is a need for these links, when the geometry of the spatial units is not accurate enough to give reliable results, when applying spatial overlay techniques (e.g. a building, in reality inside a parcel, is reported to fall outside the parcel; the same applies to the geometry of a right e.g. an easement). Required relationships override implicit relationships established through spatial overlay techniques.

LA_SpatialUnit[105] has the following attributes (see Figure 33): area[106] (this is the area in case of a 2D spatial unit; there can be many different areas and areas can be of different types[107]); the dimension of the spatial unit[108]; a link to external address(es) of the spatial unit (this is useful in case spatial units have addresses); a label, this is a short textual description of the spatial unit which can be used for local purposes; a referencePoint, this is a co-ordinate set of a point inside the spatial unit; the spatial unit identifier (suID); the surfaceRelation[109] and the volume[110] in case of a 3D spatial unit. There can be many different volumes and types of volumes[111] similar to areas.

Attributes of LA_SpatialUnitGroup are: hierarchyLevel[112], this is the level in the hierarchy of an administrative or zoning subdivision; label, this is a short textual description of the spatial unit group; name, this is the name of the spatial unit group; the co-ordinates of a point within the spatial unit group and the identifier of the spatial unit group (sugID).

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[104] Quality improvement may have a huge impact on areas of spatial units. A criterium needs to be available on the allowed difference with legal area (as written in legal documents).

[105] The methods 'ComputeArea' and 'CreateArea' compute and return a geometric primitive GM_MultiSurface, which includes a geometric primitive GM_Surface. Similar methods are for 'ComputeVolume' and 'CreateVolume'. If dimension is 2D the volume is not specified, if dimension is 3D than the area is not specified. Condition is of course that the area or volume can be calculated: this requires well-structered topology.

[106] A special data type is created for area size: this includes both areaSize and LA_AreaType; see Figure 33 upper right.

[107] LA_AreaType can be surveyed, calculated, non-official and official. Areas may have versions after quality improvements of cadastral spatial data.

[108] LA_DimensionType. Each spatial unit has a dimension: 0D, 1D, 2D or 3D or liminal. There can be a 2D spatial unit, a 3D spatial unit and a spatial unit with dimension 'liminal' in between, see Section 3.6.4.

[109] LA_SurfaceRelation indicates whether a spatial unit is above or below the surface.

[110] A special data type is created for volume size: this includes both volumeSize and LA_VolumeType; see Figure 33 upper right.

[111] LA_VolumeType, for the volumes different values are possible similar to area: a volume may be surveyed, calculated, non-official or official.

[112] The highest level in the hierarchy of a subdivision (*country*) is 1; lower levels are incremented by 1. In many LASs this is the basis for identification of spatial units. A meaningless value as id may be a better appraoch, there can be serious implications because of changes in the boudaries of administrative hierachic units. This may mean re-indentification or even double (old and new) identification of spatial units.

Attributes of LA_LegalSpaceBuildingUnit[113]are: the identifier of the building unit. And the type of the building unit[114]. Attributes of LegalSpaceUtilityNetwork are: a reference to the physical (technical) description of the utility network; the status of the utility network[115]; the type of the utility network[116]. Attributes of LA_Level are: the identifier of the level (lID); the name of the level; the register type[117]; the structure of the level geometry[118]; type of the content of the level[119]. An attribute of LA_RequiredRelationship is the description of the required relationship as in ISO 19125-2 spatial type (ISO, 2004b).

3.6.4 Surveying Classes and Spatial Representation Classes

Spatial units are structured in a way to support the creation and management of basic administrative units. The Spatial Unit Package has one Surveying and Spatial Representation Subpackage (See Figure 35) with classes such as: LA_Point[120]; LA_BoundaryFace; LA_BoundaryFaceString[121]; LA_SpatialSource[122].

Points (0-dimensional geometric primitives) can be acquired in the field (with classical surveys or with GPS), in an office or compiled from various sources for example using forms, field sketches, ortho-images or orthophotos. The acquisition of points (a survey) may concern the identification of spatial units on a photograph, on an image or on a topographic map. Cycloramas or pictometry methods (multiple images from different angles) may also be used for that purpose.

A survey is documented with spatial sources. This is a spatial representation of one (part of) or more spatial units (as evidence from the field). This may be the final (sometimes formal) documents or all documents related to a survey. Sometimes, several documents are the result of a single survey. A spatial source 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 LAS. The document can be used as authentication for the agreement between neighbours and also for reconstruction of boundary points in case of disputes.

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. While it is not required that the complete spatial unit is represented, a spatial source may be associated with several points.

[113] So this concerns not the physical space but the legal space. In LADM Version A LA_LegalSpaceBuidinUnit is called ApartmentComplex or ApartmentUnit, in LADM Version B it is called Unit, SharedUnit or IndividualUnit.

[114] LA_BuildingUnitType: can be shared or individual.

[115] LA_UtilityNetworkStatusType can be in use or not; or planned.

[116] LA_UtilityNetworkType can be chemicals, electricity, gas, heating, oil, telecommunication, water, .etc.

[117] LA_Registertype can be all, forest, mining, public space, raral, urban, etc. Registers can be in levels per type.

[118] LA_StructureType can be point, polygon, text, topological, unstructured lines. Spatial units can be in levels per type .

[119] LA_LevelContentType can be building, customary, informal, mixed, network, primary right, responsibility, restriction, etc. Contents can be in levels per type.

[120] In LADM Versions A and B LA_Point is called SurveyPoint.

[121] In LADM Version A LA_BoundaryFaceString is called ParcelBoundary.

[122] In LADM Versios A and B LA_SpatialSource is called SurveyDocument.

Geodetic control points, including multiple sets of co-ordinates for points, and with multiple reference systems, are all supported in the LADM.

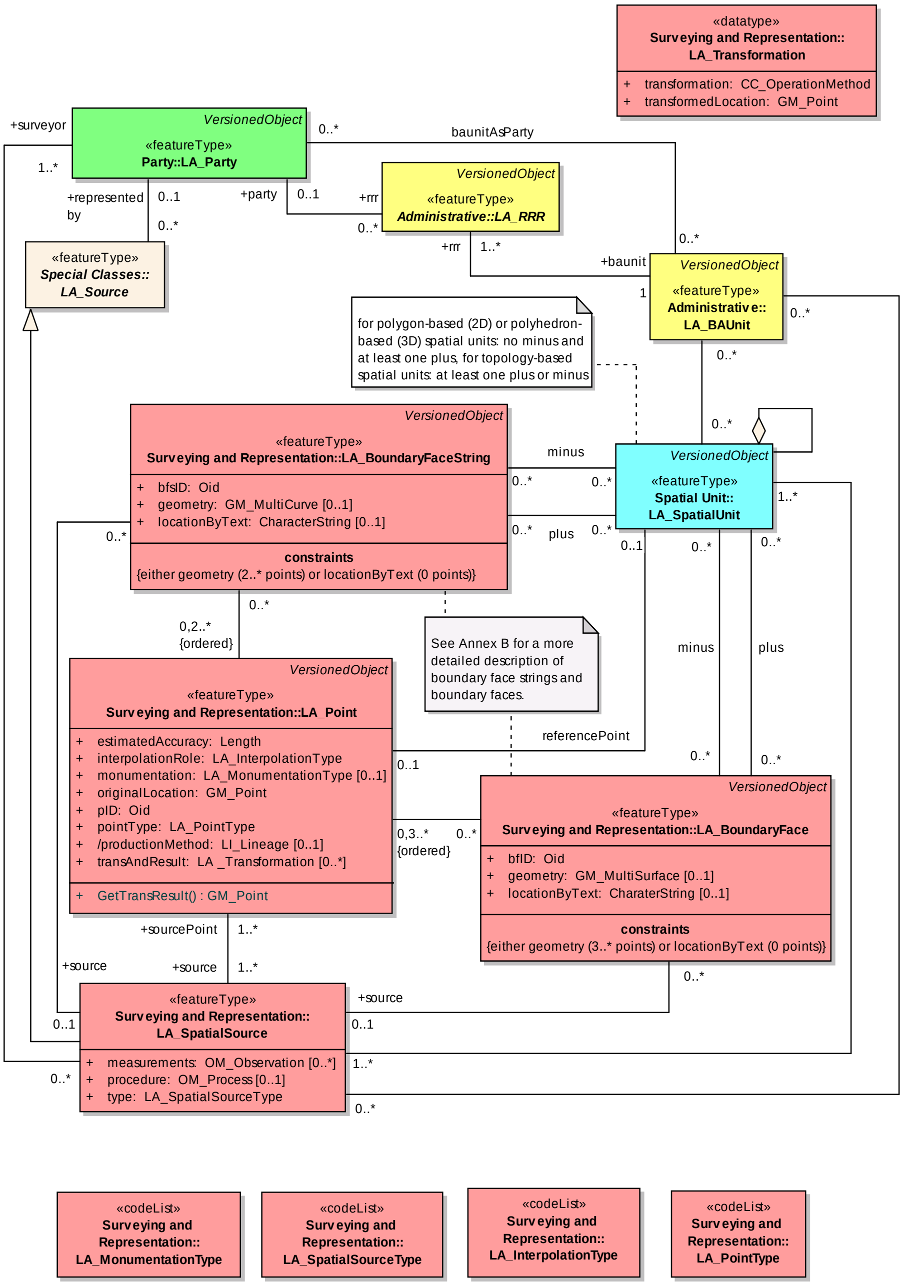
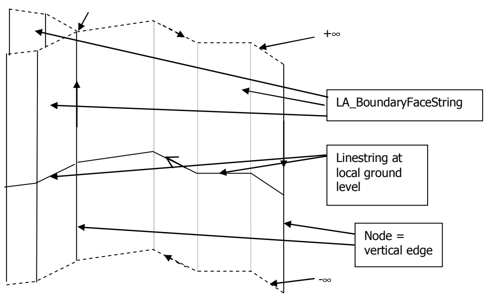


Figure 35 LADM Version C Surveying and Representation SubPackage with associations to core classes (ISO, 2011c).

2D and 3D representations of spatial units use boundary face strings, this is a boundary forming a part of the outside of a spatial unit, and boundary faces, and this is used in 3-dimensional representation of a boundary of a spatial unit. Co-ordinates themselves either come from points or are captured as linear geometry; e.g. in a photogrammetric workstation. Spatial units may share the same representation structure: existing 2D data, whether topologically structured or not or polygons or unstructured boundaries or simply point or textual descriptions can be included. LADM Version C 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 LADM is that there is no mismatch between spatial units that are represented in 2D and spatial units that are represented in 3D. 2D and 3D representations of spatial units use boundary face strings and boundary faces as key concepts, see Figure 35 and 36. In many countries, a 2D representation is interpreted as a 3D prismatic volume, with no upper and lower bound. Using this interpretation, 2D and 3D representations can be unified (ISO, 2011c, Annex B):

a) by boundary face strings, for 2D boundary representations with a GM_MultiCurve (linestring) for storage. Boundary face strings imply also a series of vertical virtual boundary faces, see Figure 36 left and right and
b) by boundary faces, for true 3D boundary representations with a GM_Surface (that may be curved) for storage. Boundary faces can also have non-vertical true 3D boundaries. This also allows for the representation of a volume, like an inverted cone, where the top is wider than the bottom.



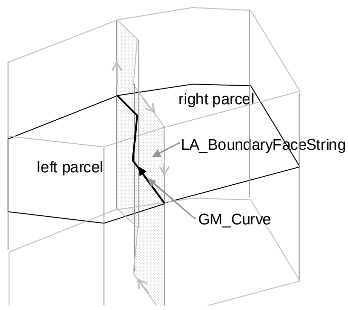


Figure 36 left: boundary face string concepts, right: spatial units defined by boundary face strings (Lemmen et al, 2009a); figure designed and created by Rod Thompson.

Liminal spatial units are on the threshold of 2D and 3D representations. These representations are a combination of boundary face strings and vertical boundary faces. The vertical boundary faces shall dissolve into boundary face strings (when common pairs of edges are removed). The boundary faces shall be completely defined from an (undefined) upper bound to an (undefined) lower bound, see Figure 36 left and right. This method is used for 2D spatial units which are adjacent to 3D spatial units with a split in the shared vertical boundary faces.

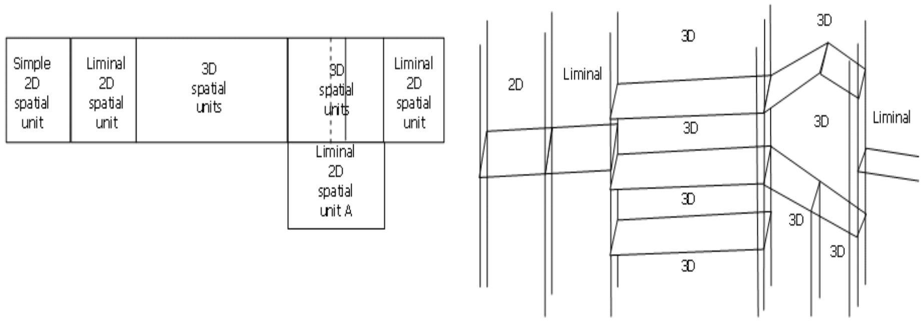


Figure 37 left: top view of mixed 2D/3D representations, right: side view showing the mixed use of boundary face strings and boundary faces to define both bounded and unbounded 3D volumes (Lemmen et al, 2009a); figure designed and created by Rod Thompson.

Class LA_Point includes the attributes (see Figure 35): point identifier (pID); the estimated accuracy; the interpolation role, this is the role of point in the structure of a straight line or a curve[123]; monumentation, this is the type of monumentation in the field[124]; originalLocation, this is of type GM_Point and concerns the calculated co-ordinates from original observations in a Co-ordinate Reference System CRS, explained in more detail in Subsection 3.6.7; point type[125]; productionMethod; transAndResult (transformation and transformed location, the transformed location is a new version of the point). Transformations include for example affine transformations but also mathematical computations such as least square adjustments. Note that there may be 0 or more transAndResult attribute values, implying that there are one (in orginalLocation) or more (in transAndResult) GM_Point values for every instance of a LA_Point object class.

LA_SpatialSource contains as attributes measurements, procedure and type[126]. See also ISO (2011b).

3.6.5 Special Classes

The Class VersionedObject is introduced in the LADM to manage and maintain historical data in the database. History requires, that inserted and superseded data, are given a time stamp. In this way, the contents of the database can be reconstructed, as they were at any historical moment. The generic data type Oid is introduced in the LADM to provide support for object identifiers; see Figure 38. Data type rational is

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[123] LA_InterpolationType can be end, isolated, mid, mid_arc,or start.
[124] LA_MonumentationType can be beacon, cornerstone, marker, not_marked.
[125] LA_PointType can be geodetic control points, or points with or without source documents.
[126] LA_SpatialSourceType can be fieldsketch, GNSS survey, orthophoto, relative measurement, topographic map, or even video (Barry, 2008). See also examples in (Lemmen et al, 2010b).

used for ‘share’ attributes; see Figure 31 and 32. Data type Oid for identification purposes; see Figure 31, 32, 33, 35, 38 and 40.

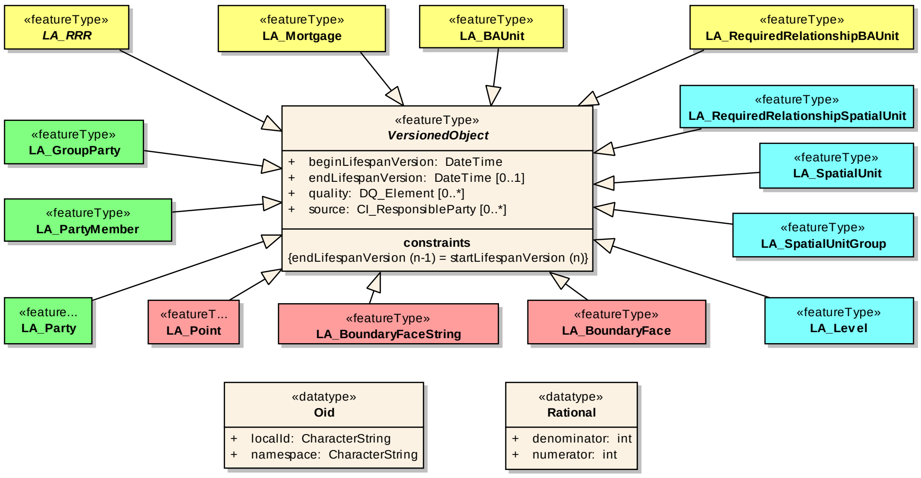

Figure 38 LADM Version C VersionedObject classes with subclasses and data types Oid and Rational (ISO, 2011c).

Classes LA_Party, LA_GroupParty, LA_PartyMember, LA_Mortgage, LA_RRR, LA_BAUnit, LA_SpatialUnit, LA_SpatialUnitGroup, LA_RequiredRelationshipSpatialUnit, LA_RequiredRelationshipBAUnit, LA_Level, LA_BoundaryFaceString, LA_BoundaryFace, and LA_Point are all subclasses of class VersionedObject, see Figure 38. Class VersionedObject has as attributes time stamps for history management; this is one attribute for the date and time of inserting into the model (the database) and one for the date of deletion; is this way the lifespan of all instances in subclasses are known. All this allows to reconstruct the database at one moment in the past or to retrieve all changes within a time span; also related to external databases. This is possible for the subclasses; LA_Source[127] is not a subclass of versioned object because it concerns authentic documents; but LA_Source has a lifeSpanStamp as attribute. Versioned object class has also quality and a responsible party as attributes. Those attributes are imported from other standards, see Figure 45 and 46 in Subsection 3.6.7.

In principle the updating of the database is based on authentic source documents, which can not be changed. Class LA_Source has as attributes submission (the date of submission of the source by a party); acceptance (the date of force of law of the source by an authority); and recordation (the date of registration – recordation – of the source by the registering authority); extArchiveID for identification of documents in external archives; lifeSpanStamp (history management –the moment that the event, represented by the instance of LA_Source, is further processed in the LAS (this is the moment of endLifespanVersion of old instances, and the moment of

[127] In LADM Version B LA_Source is called source document.

beginLifespanVersion of new instances of related objects in the database such as LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit; this is the “database time”, compare the time stamps in LA_VersionedObject); sourceIdentifier; mainType (the type of document according to ISO, 2003c); see Figure 39.

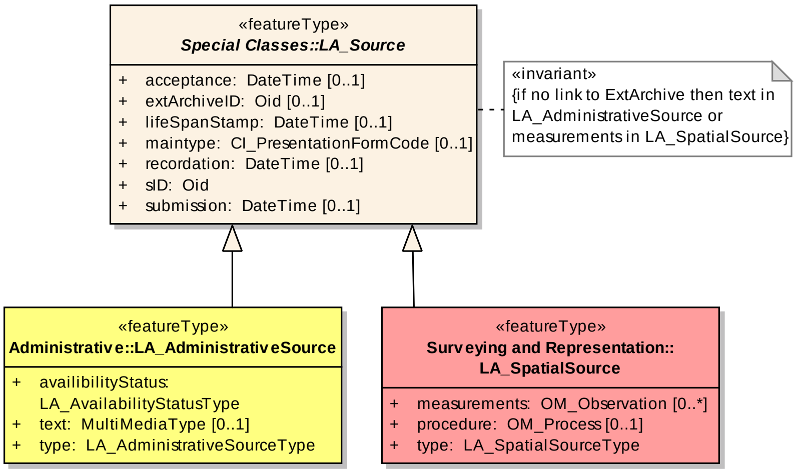

Figure 39 LADM Class LA_Source (with subclasses).

The abstract class LA_Source has two specialisations: LA_AdministrativeSource (see Figure 39 and also Figure 32 in Subsection 3.6.2) and LA_SpatialSource (see also Figure 35 and Subsection 3.6.4).

3.6.6 External Classes

The (external) databases with party data, address data, valuation data, land use data, land cover data, physical utility network data, archive data and taxation data is outside the scope of the LADM (see Annex K in ISO, 2011c). However, the LADM provides stereotype classes for these data sets, which indicate what data set elements the LADM expects from these external sources, if available. Figure 40 presents an overview of external classes in relation to the LADM core classes. The classes are briefly introduced here. Classes which are outside the scope of the LADM (e.g. ExtParty, ExtAddress, ExtLandUse, ExtLandCover, ExtValuation, ExtTaxation, ExtPhysicalUtilityNetwork and ExtArchive) are represented as <<blueprint>> stereotype classes. They do not have the ‘LA_’ prefix, but they do give an exact definition of what the LADM is expecting of these external classes.

The Class ExtParty is a class for an external registration of parties. This can be a link to a population register, or to a chamber of commerce with a company register or to external databases with certified Parties with a role in land transactions. The attributes of ExtParty are: extAddressID: this is the identifier, pointing to the external address; the fingerprint of the external party; the name of the external party, this is the identifier of the external party; the photo of the external party; the signature of the external party.

The LADM would need its own 'external database' for people living abroad. It may also be needed in case a population register or company register does not yet exist or is not linked in an electronic way.

Class ExtAddress is a class for external registration of addresses (an address being a direction for finding some location or deliver mail). The attributes of ExtAddress as proposed in Version C are: the address area name of the external address; the co-ordinates of the external address; the identifier of the external address; the building name of the external address; the building number of the external address; the city of the external address; the country of the external address; the postal code of the external address; the post box of the external address; the state of the external address; the street name of the external address.

The INSPIRE address specifications (INSPIRE, 2010) may also be used or an ISO standard on addresses. The ISO 19160 (ISO/TC211, 2011a) project team has documented well the review of existing addressing standards and provided the recommendations that describe the addressing standardisation requirements for ISO 19160 (ISO/TC211, 2011a). These include addressing terminology, conceptual models, address assignment schemes, quality management and rendering addresses on postal items, maps, graphic displays, etc.

Address co-ordinates can be used for geo coding services in combination with reference points and labels in spatial units and spatial unit groups and points. In the LADM there is a reference from spatial unit to external address: the object address and from Party to external address: the subject address. This is because the rightful claimant (or right holder) does not need to reside on the spatial unit (building or apartment).

Class ExtLandUse is a class for the external registration of land use data; land use is an arrangement, activity or input people undertake in a certain land cover type to produce, change or maintain it. ExtLandUse is associated to class LA_SpatialUnit. Like taxation it is normal that land use is integrated in Land Administration and Cadastre. A similar discussion took place for land use as for taxation. With a similar result. The attribute of ExtLandUse is the type of land use . The LADM is designed in such a way that the inclusion of land use can be integrated later. Class ExtLandCover is for the external registration of land cover data; land cover is the observed (bio)physical cover on the earth's surface. ExtLandCover is associated to class LA_SpatialUnit. The attribute of ExtLandCover is the type of land cover . See the remark on land use above – this is valid again for land cover – but here also the ISO 19144 Land Cover standard applies. Class ExtValuation is a class for the external registration of valuation data. ExtValuation is associated to class LA_BAUnit. The attributes of ExtValuation are: the value of the valuation; the date of the valuation and the valuation type . Again this is seen as an external process. The data resulting from this process can be linked to the LADM. Class ExtTaxation is a class for the external registration of taxation data. ExtTaxation is associated to class LA_BAUnit. The attributes of ExtTaxation are: the amount of taxation; the date of taxation and the tax type . It is common practice in some countries that taxation can be included in Land

Administration and Cadastre. The inclusion of taxation has been considered in the development of the LADM.

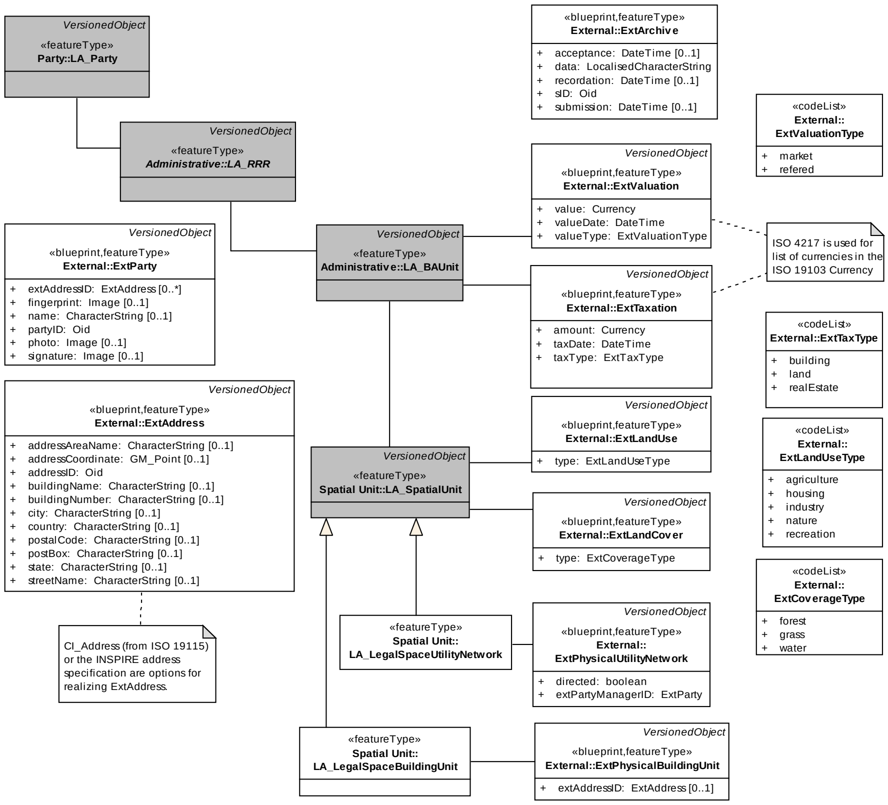

Figure 40 LADM Version C External classes ISO (2011c).

The conclusion was that the valuation and required spatial and non-spatial data and also the determination of tax values is a domain in itself and therefore outside the scope of the LADM. However, the LADM is designed in such a way that the (S)II based integration with taxation can be realised. Class ExtPhysicalUtilityNetwork is for the external registration of mapping data of utility networks. ExtPhysicalUtilityNetwork is associated to class LA_LegalSpaceUtility-Network. The attributes of ExtPhysicalUtilityNetwork are: the flow direction, fixed or not, and the organisation responsible for the utility network. Class ExtArchive is a for the external registration of sources. The attributes of ExtArchive are: the date of force of law of the source by the authority; the content of the source; recordation, this is the date of registration (recordation) of the source by the registering authority; the identifier of the source; the date of submission of the source by a party. Attributes submission, acceptance and recordation allow for links to workflows. This means that the status of a transaction can be followed. This is relevant to avoid double transactions.

3.6.7 Imported Functionality from other ISO Standards

In this Section, a number of concepts and classes from other ISO TC211 standards (as used in LADM) are investigated in more detail; e.g. GM_Point from ISO 19107 (ISO/TC211, 2003b), Co-ordinate Reference Systems from ISO 19111 (ISO/TC211, 2003a) OM_Observation from ISO 19156 (ISO/TC211, 2011b) and DQ_Element from ISO 19115 (ISO/TC211, 2003c). The class GM_Point may look simple at first sight, but it is the start of quite a larger part of the model where relevant cadastral functionality is available; including support of the embedded Co-ordinate Reference System (CRS). The GM_Point itself is a type (class) that inherits from the abstract class GM_Primitive, which in turn inherits from the abstract class GM_Object; see Figure 41.

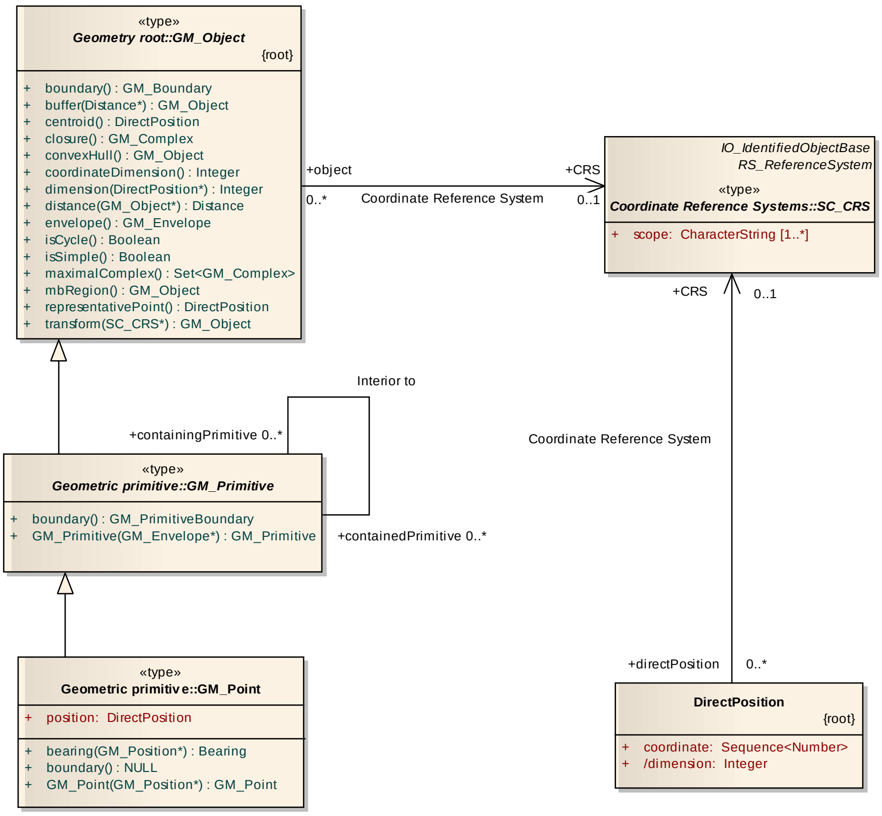

Figure 41 The GM_Point (ISO 19107, ISO/TC211, 2003b) itself is a type (class) that inherits from the abstract class GM_Primitive, which in turn inherits from the abstract class GM_Object.

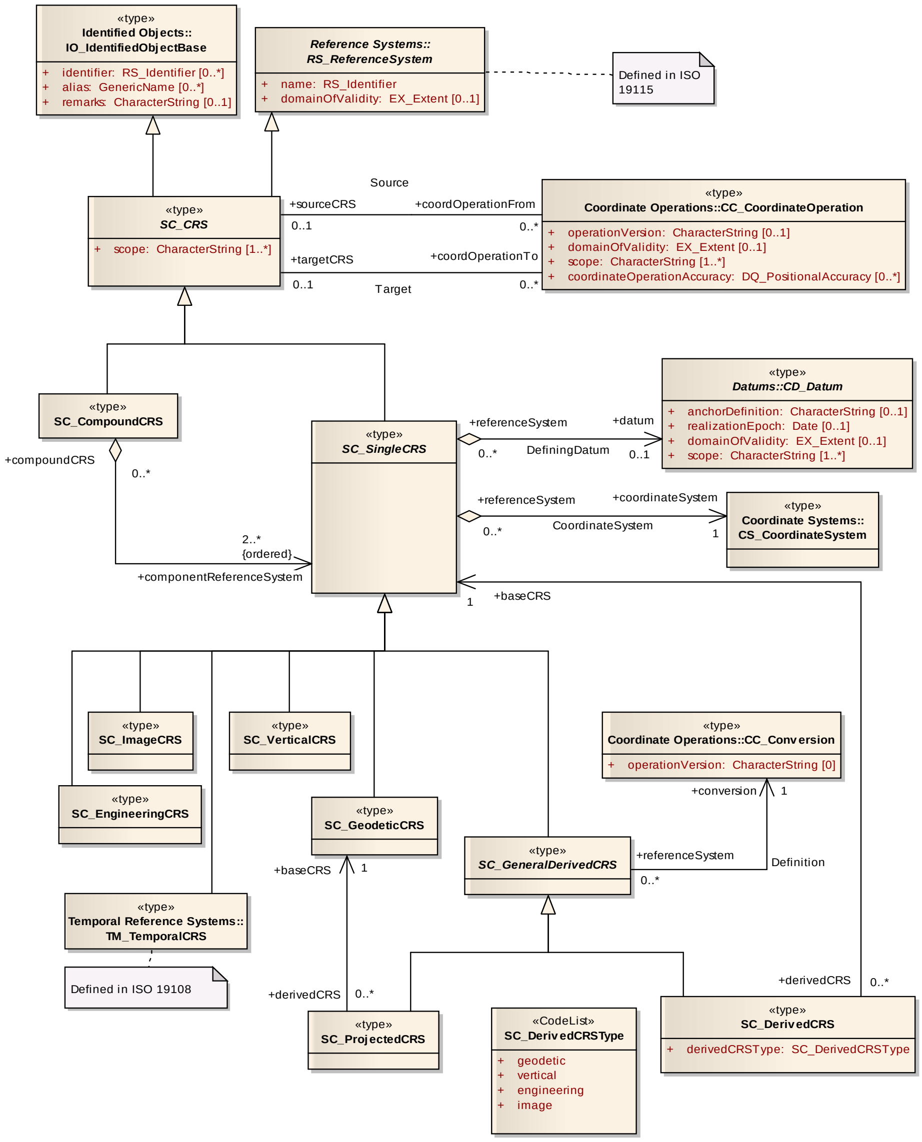

Figure 42 The abstract class SC_CRS (Co-ordinate Reference System) from ISO 19111, ISO/TC211 (2003a).

Out of these three classes only the class GM_Point has an attribute of type (class) DirectPosition. All three classes define several (generic) operations. The class DirectPosition has one attribute called co-ordinate of type Sequence<Number> and one derived attribute called dimension of type Integer. Both GM_Object and DirectPosition have an association to the class SC_CRS (Co-ordinate Reference

System) as defined in ISO 19111 Spatial referencing by Co-ordinates (ISO/TC211, 2003a). Both associations have multiplicity 0..1 at the side of SC_CRS.

The abstract class SC_CRS has two specialisations: the classes SC_SingleCRS (again abstract, with several concrete subclasses; e.g. SC_VerticalCRS, SC_GeodeticCRS, SC_ProjectedCRS) and SC_CompoundCRS (abstract, an aggregation of SC_SingleCRS); see Figure 42. A SC_SingleCRS is associated with one CS_Co-ordinateSystem, which has in turn one or more CS_Co-ordinateSystemAxis; see Figure 43. In summary, GM_Point and SC_CRS are part of a non-trivial model, which should be able to provide all the functionality needed in the context of the LADM and the Survey part: supporting various co-ordinate systems and transformations.

Another important ISO/TC211 standard used in the LADM is ISO DIS 19156 on Observations and Measurements (ISO, 2011b). The survey source data is modelled and stored in LA_SpatialSource. The attribute “measurements” is of type OM_Observation (as defined in ISO 19156) and contains the actual source survey data. The attribute “procedure” is of type OM_Process and documents the actual survey procedure. The class OM_Observation contains, in addition to the survey data, also attributes for documenting the temporal and quality aspects of the survey; see Figure 44.

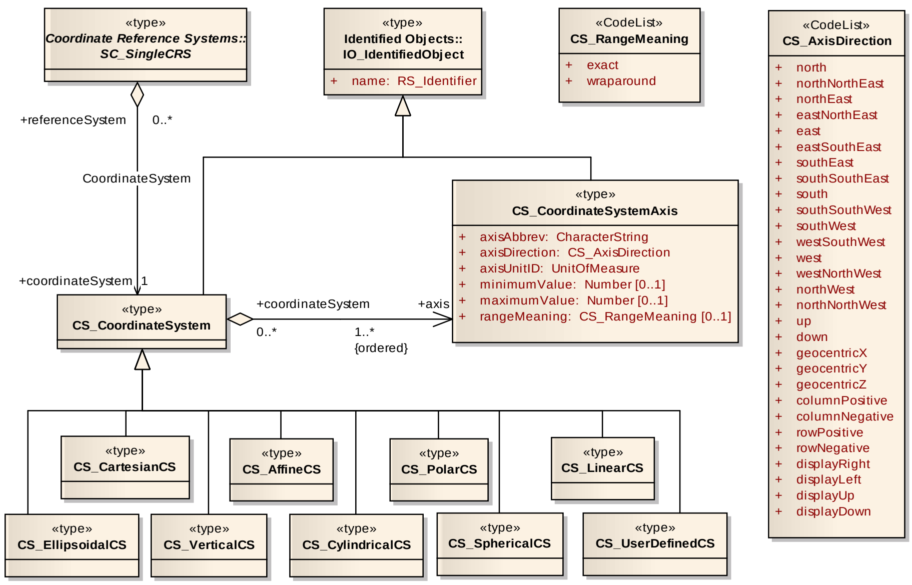

Figure 43 SC_Co-ordinateSystem from ISO 19111 (ISO/TC211, 2003a).

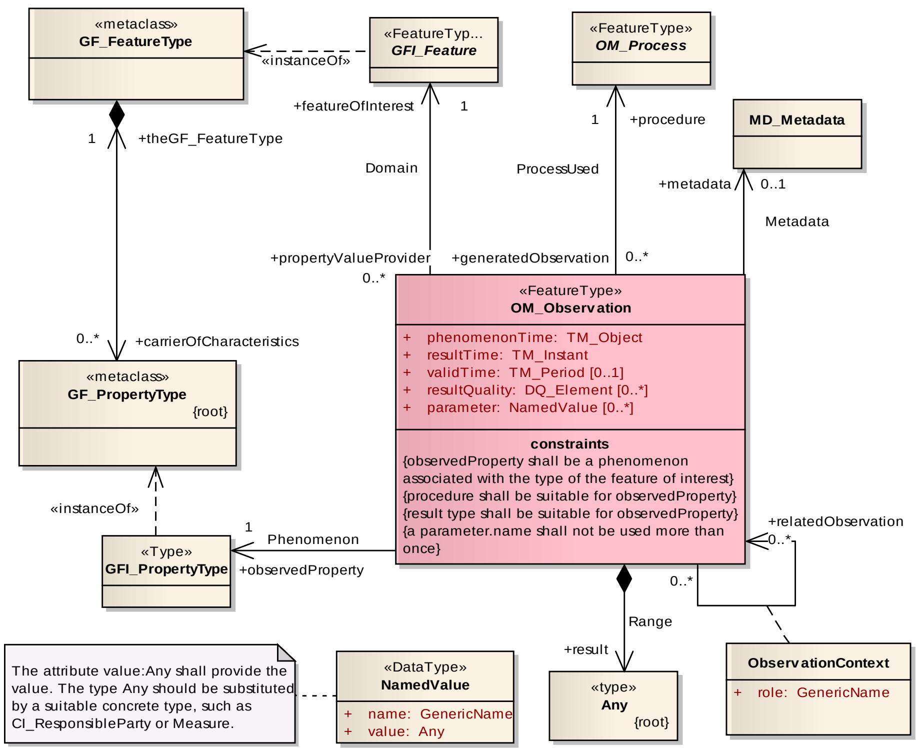

Figure 44 OM_Observation from ISO 19156 (ISO/TC211, 2011b). Note TM_Instant and TM_Period both from ISO 19108 (ISO/TC211, 2002)Temporal Schema.

The class LA_Point inherits of the abstract class VersionedObject. Besides temporal attributes this also provides attributes for quality (of type DQ_Element) and source (CI_ResponsibleParty, this is the responsible organisation of a specific instance version in the database). The quality attribute has multiplicity 0..* and so the various quality aspects as modelled via DQ_Element can be represented. DQ_Element is class from ISO 19115 on Metadata (ISO/TC211, 2003c). It is an abstract class with the following subclasses: DQ_Completeness, DQ_Logical-Consistency, DQ_ThematicAccuracy, DQ_TemporalAccuracy, and DQ_Positional-Accuracy; see Figure 45. The source attribute also has multiplicity 0..* and the class CI_ResponsibleParty is also from ISO 19115 on Metadata (ISO/TC211, 2003c). Besides a number of names (individual, organisation, positional) also the role and contact information of the responsible party is modelled; see Figure 46.

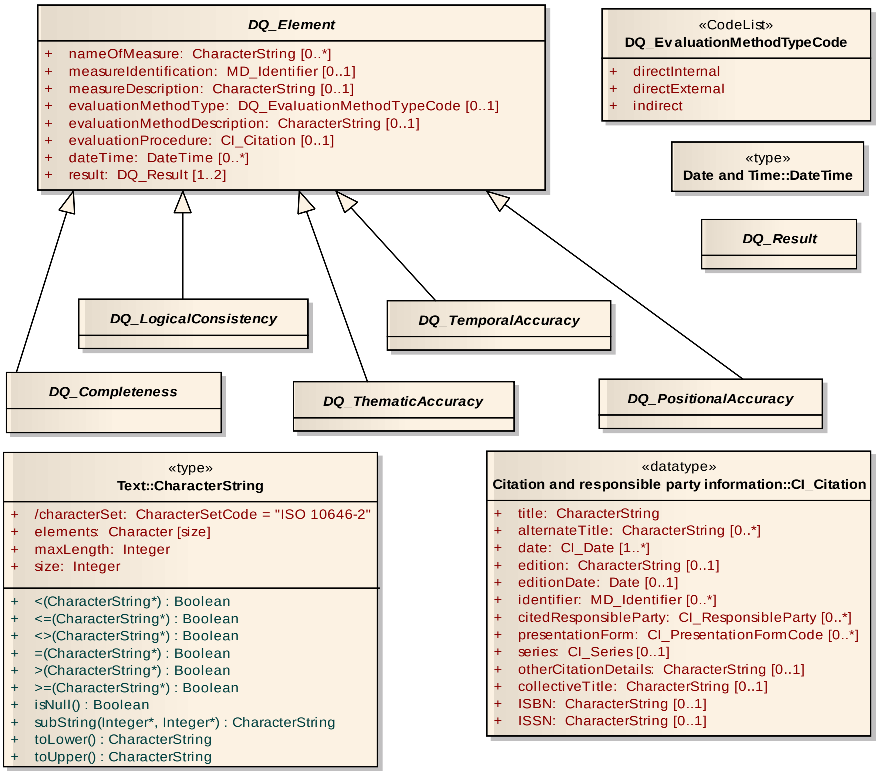

Figure 45 DQ_Element from ISO 19115 (ISO/TC211, 2003c).

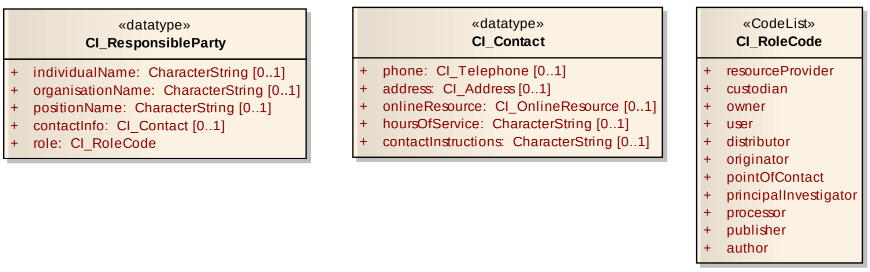

Figure 46 CI_ResponsibleParty from ISO 19115 (ISO/TC211, 2003c).

3.7 Evaluation of Version C

During the development of the LADM three 'core classes', 'Person', 'Right' and 'Parcel' (or 'RealEstateObject') were always included with the remark that the terminology changed (see Appendix A), not the meaning (see for an overview of definitions as used in the DIS Appendix D). This is the result of intensive discussions. The class name 'Person' changed into 'Party', the class name 'Right' changed into 'RRR' (Rights, Restrictions and Responsibilities) and the class name 'Parcel' into 'SpatialUnit'. The basic classes were derived from (Henssen, 1995); see Section 2.2. This appraoch fits very well to FIG's 'Cadastre 2014' (Kaufmann and Steudler, 1998).

In the Version A class diagram, the classes 'Person' and 'Parcel' (or 'RealEstateObject') were associated with class 'RRR', as an association class as represented in Figure 20.

The association class 'RightOrRestriction' from the initial version was in the version B replaced by two associations: (1) between class 'RegisterObject' and class 'RRR', and (2) between class 'Person' and class 'RRR'; see Figure 25. The main reason for this design decision was to make it possible that, for a unique combination of a specific 'Person' with a specific 'RegisterObject', multiple RRR instances can be associated (e.g. one expressing ownership, and one expressing a certain responsibility), which was not possible in the construction with the association class 'RightOrRestriction'.

Then, during the discussions in ISO/TC 211, it was agreed that there is a need for inclusion of a so-called 'Basic Administrative Unit' (UNECE, 1996 and 2004), located between the classes RRR and SpatialUnit. This allows for the introduction of the so-called 'Basic Property Unit'. A 'Basic Property Unit' is in the definition in UNECE (1996) "the extent of the land, that is one unit of ownership". It may consist of one, or more adjacent, or geographically separate parcels. A farm, for example, may have a number of fields that are in different locations, but together they constitute one BPU. Likewise, a house may have a garage on a separate piece of land".

The BPU is called Basic Administrative Unit (abbreviated as 'BAUnit') in the LADM. This is a more generic term, the LADM is not only about formal property rights, but also about other types of 'people – land' relationships; e.g. customary and informal types of land use. This resulted in four core classes (LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit); see Figure 29.

This allows for a separate introduction in the LADM of the 'legal/administrative part' (the registers), and of the 'spatial part' (the cadastral map), at different moments in time; e.g. first the building up of the registers, then of the map.

History is maintained in LADM, state based and event based approaches are available.The same is valid for the user requirements in general.

The functionality offered by extensible code lists, by levels, spatial units, parts (of parts) of spatial units, spatial unit groups, BAUnits, RRRs and parties supports in a very flexible way legal requirements for representing reality into LASs.
Existing standards are re-used as much as possible.

It can be concluded that the inclusion of explicit topology (see C01with reference to earlier versions from there) is completely based on existing standards in the LADM

Version C. This functionality is not included in the LADM 'itself' any more. See Annex O[128] of the DIS, ISO (2011b). A further requirement from C01 is on identifiers without semantics. This is implemented now by a separate data type Oid in the LADM Version C, see Figure 31, 32, 33, 35 and 38. The required layers from C01 are there now under the term 'level'. Interface classes for products and services are left to the user, so this is not further in use since the LADM Version B. Responsible persons in transactions are not included anymore as separate classes but as role types; this is included by code tables for LA_PartyRoleType, see Annex K[129]of the DIS. Versioned objects are included in the LADM Version C, all classes inherit from VerionedObject[130], see Figure 38, to support state based management of history. Support to 3D Cadastre is included in the LADM Version C. Marine Cadastre needs further review, some 'basics' are included in the LADM, see Section 3.5. The Basic Property Unit as required from C02 has been implemented as core class BAUnit. Multiplicities between core classes are vey flexible now. A Party can be without RRR (in case Party has a role and no RRR), RRR can have zero or more Parties (restrictions and responsibilities do not always have a Party), a RRR is associated to one BAUnit[131], a BAUnit can have one or more RRRs[132]. A BAUnit can be associated to zero or more SpatialUnits (in some land administrations there is no cadastral map); a SpatialUnit can be associated to zero or more BAUnits. BAUnit can be a Party; this means a BAUnit can be a rightful claimant or a right holder (see requirement C03). This means a spatial unit can be owner of an access right to that spatial unit, e.g. of a servitude at the neighbour spatial unit. Positive and negative sides for restrictions can be represented/calculated. This means requirement C04 is supported.

The introduction of LA_Level allows for all kind of combinations of data as demonstrated by the examples below:

- one level of spatial units to define basic administrative units associated with formal rights, a second level for spatial units to define basic administrative units associated with informal rights and a third level for spatial units to define basic administrative units associated with customary rights;
- one level of spatial units for an urban cadastre and another for spatial units for a rural cadastre;
- one level of spatial units to define basic administrative units associated with rights and another level of spatial units to define basic administrative units associated with restrictions. Rights or restrictions can be related to specific legislation;
- one level with point based spatial units, a second level with line based spatial units and a third level with polygon based spatial units.

This allows very flexible approaches including overlapping tenure systems. The Cadastre 2014 principle of legal independence in supported (Requirement C05).

[128] LADM and other ISO standards.
[129] Code lists.
[130] Except LA_Source, which is completely authentic.
[131] Only during implementation and conversion there may be a need to set this multiplicity even more flexible. there can be inconsistencies in the input data. Inconsistencies should be allowed in this phase until they are solved.
[132] See footnote 129.

Explicit relationships between SpatialUnits and BAUnits are also possible, needed in case of inaccurate spatial data. Polygon overlays would provide bad quality results. Existing standards are re-used. In the future this should also be possible for unbounded volumes (C06). See also the normative references in the ISI 19152 DIS (ISO, 2011b). Requirement C07 (shares, party members) is fulfilled. The system boundary (requirement C08) is very clear defined based on the introduced external classes in Annex K of the DIS. One external class is extParty. This could be a link to the population register or to a company register in an information infrastructure with key registers. Still the core class Party is needed in the LADM, e.g. to establish the link and to register names of people outside the territory of the population or company register (abroad). Event based modelling is included via source documents, see figure 39. Here are the attributes acceptance, recordation etc. which can be related to workflows. Administrative and spatial source documents are fully integrated in the LADM Version C in support to the documentation of all events (optional). Quality labels are included in a generic way via VersionedObjects, see requirement C09. Miscellaneous requirements got attention in ISO (2011b); e.g. purchase price is not included anymore, finger print and signature attributes are external (see annex K of the DIS in ISO (2011b)). Attributes multimedia are agreed (as all the issues above) and included for source documents, etc. See for further details on (grouping of) RRRs Lemmen (2010a) and (grouping of) spatial units Lemmen et al (2011b).

The level of acceptance of the LADM Version C can be derived from the voting results in ISO/TC211. In total 32 Participating members could vote; see Table 5.

Table 5 LADM Voting Results.

Stage	**New Working Item Proposal (NWIP)**	**Committee Draft (CD)**	**Draft International Standard (DIS)**
Date of voting:	May 2nd, 2008	October 12th, 2009	June 27th, 2011
Approved:	15	22	26
Disapproved:	6	3	2
Abstained:	4	4	4
Not voted:	7	3	0

3.8 LADM and SDI

Spatial data sets are most useful in the support of areas like decision making, management of space, performance of government or business processes, when they are integrated in governmental information infrastructures and architectures (Van Oosterom et al, 2009). The basic idea behind data infrastructures is that it provides for tools giving easy access to distributed databases to people who need those data for their own decision making processes (Van der Molen, 2005). Although data infrastructures have a substantial component of information technology, the most fundamental asset is the data itself, because without data there is nothing to have access to, to be shared or to be integrated. Last decade it was understood that the development of data infrastructures not only provided easy access to distributed databases, but also gave good opportunities for re-thinking the role of information supply for the performance of governments. Based on this starting point, the ‘Streamlining Key Data’ Programme of the Netherlands' government took the lead in the development and implementation of a strategy for restructuring government information in such a way that an electronic government evolves that (Van Duivenbode, 2003):

- inconveniences the public and the business community with request for data only when this is absolutely necessary;
- offers them a rapid and good service;
- can not be misled;
- instils the public and the industrial community with confidence;
- is provided at a cost that is not higher than strictly necessary.

This implies availability of well maintained links between spatial data sets and other ‘basic’ or ‘key’ data sets, e.g. on addresses, persons, companies, buildings or land rights. Integrated inter-organisational value chains and business process management with a reduction in administrative overhead can be realised based on good co-operation. In general, solving the problems in society requires more information than provided by one single data set. It is evident that this type of data provision is complex in case data is stored at a variety of locations and in data models specific to their applications. See Van Oosterom et al (2009).

LA has important relationships with other key registers in the (spatial) information infrastructure, some of which are spatial, e.g. topography or buildings, while others contain administrative information, like names of persons, addresses or names of companies. It is therefore important to have unambiguous definitions of the contents of these key registers in order to avoid overlap and to enable re-use of information. Further, due to continuous updating of these independent, but related, key registers care has to be taken to maintain consistency, not only within one database, but also between databases. By re-using basic standards (for geometry, temporal aspects, metadata, observations and measurements from the field), at least the semantics of these fundamental parts of the model are well defined and can be shared. What is needed in addition to this is domain specific standardisation to capture the semantics of the land adminsitration domain (as developed in this thesis) on top of this agreed foundation. See Van Oosterom et al (2009) and also Section 1.1. of this thesis. In this way information about land rights can be accessible from SDI. SDI can provide a platform for access to many other data sets; see for example Willamson et al (2010).

For each domain it should be clear what is included. Next an attempt to list classes that are proposed to be outside the Land Administration Domain Model with reasons:

1. spatial (co-ordinate) reference system. It should be noted that the physical implementation of a reference system is part of conventional cadastral systems. There can be more than one reference system for different parts of the territories where such systems are implemented; e.g. one local co-ordinate system per village. Spatial reference systems are the basis for getting nationwide cadastral spatial data available. In the LADM the Spatial Reference System (SRS) appears 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_MulitCurve and GM_Surface are defined here. For this reason spatial reference systems are excluded from the LADM, as well feature types for spatial data;

2. orthophotos, satellite imagery, and Lidar and elevation models. Here it should be noted that orthophotos and satellite imagery may be very well used as basis for data acquisition in the field of cadastral boundary data (Lemmen and Zevenbergen, 2010c). 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 be included in the LADM using LA_SpatialSouce;
3. topography (planimetry). Again this is considered to be a domain in 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);
4. geology, geo-technical and soil information. This is relevant information in relation to mining and land use (agricultural) management. This are domains in itself. The LADM supports the inclusion of attributes resulting from of data collection processes on geology, soil, etc. In this way a Land Administration for mining may be built up; this would include concessions and exploration companies as parties;
5. (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_LegalSpace-UtilityNetwork as subclass from LA_SpatialUnit. The LADM concerns 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, 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;
6. address registration (including postal codes). Standards for addresses are under development as in ISO 19160 (ISO/TC211, 2011a). Addresses in the LADM concern spatial unit addresses (“object” addresses), but of course parties can alsohave addresses (“subject” addresses). But in the 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;
7. building registration, both (3D) geometry and attributes (permits), concerns the physical registration. The registration of legal space in 3D is included in the LADM. Legal space does not necessarily coincide with the physical space of a building.

8. natural person registration – the authentic person data are considered to be in the population register: name, date of birth, person address, sex, etc.;
9. non-natural person (company, institution) registration. Same for typical attributes of non-natural persons, e.g. companies.

It is not easy to define the scope[133] of the LADM as nearly all topics mentioned above are related to the classes in the Land Administration Domain Model. The first four topics listed above are or can be used in the cadastral system for reference purposes (or support of data entry; e.g. of the RealEstateObjects). Other topics have a strong relationship in the sense that these (physical) objects may result in legal objects ('counterparts') in the cadastral registration. For example, the presence of cables or pipelines can also result in a restriction area (2D or 3D) in the cadastral registration. However, it is not the cable or pipeline itself that is represented in the cadastral system, it is the legal aspect and legal space[134] of this. Though strongly related, these are different aspects; compare this to a wall, fence or hedge in the terrain and the 'virtual' or 'invisible' parcel boundary.

The fact that these 'external' objects (or packages) are so closely related also implies that it is likely that some form of interoperability is needed. When the cables or pipelines are updated than both the physical and legal representations should be updated consistently (within a given amount of reasonable time). This requires some semantic agreement between the 'shared' concepts (or at least the interfaces and object identifiers). In other words these different, but related domain models need to be harmonised. As it is within one domain (such as the cadastral domain) already difficult to agree on the used concepts and their semantics, it will be even more difficult when we are dealing with other domains. However, we can not avoid this if a meaningful interoperable Geo Information Infrastructure has to be realised.

3.9 Discussion

The success of the Internet has shown the power of an open infrastructure. The open standards and the decentralised architecture are responsible for the many free and non-free services. Besides the network infrastructure (wired and mobile), the SDI can be seen as composed of three important and quite different types of ingredients (Van Oosterom et al, 2000, Groot and McLaughlin, 2000):

- geo-data sets in different domains, e.g. cadastres, but also coverage data; this is supported by the LADM with its external classes;
- geo-data services in general and the geo-DBMS specifically; this is supported by the LADM with facilities to generate services provided by different suppliers;
- interoperability standards are required to enable the integration of the different data sets and to combine the geo-data processing services; this is a main goal of the LADM.

[133] Version C, which has been developed in TC 211 on Geographic Information of ISO, has a very clear scope, see Section 3.6.
[134] The legal space is normally bigger then the physical space to allow access.

The standardised Land Administration Domain Model (LADM), covers land registration and cadastre in a broad sense (spatial and administrative components, source documentation included). Such a Land Administration Domain Model (ISO/TC211, 2011c) underpins existing conventional LASs.

These conventional systems take into account conventional legal forms of evidence and are in principle parcel based. This means that they only cover a portion of all forms of land tenure.

The work of Kalantari (2008a) was motivated by the fact that LA with its existing digital systems is not flexible enough (a) to accommodate new land related commodities and interests and (b) to respond to the increasing need of clients for land information. New land related commodities and interests are informal and customary rights, 3D titles, water rights, biota rights, noise restrictions or carbon credits. This fits very well to the LADM and Cadastre 2014 approach.

It can be observed now that the UML class diagram for the land administration domain contains both legal/administrative object classes like persons, rights and restrictions and the geographic description of real estate objects. This means in principle that data could be maintained by different organisations, e.g. Municipality, Planning Authority, Private Surveyor, Cadastre, Conveyancor and/or Land Registry in the same LADM environment. In practise this would require willingness to co-operate, which might be in conflict with the tradition and cultures of involved organisations. But with a growing world population, change in climate (see for the relations with LA Van der Molen (2009)), urbanisation, problems with access to food and water (see for an example a case related to ground water: Ghawana, 2010), problems with management of natural resources and land management and also disaster management there is an urgent need now to produce a global overview of who is using which piece of land, also for marine areas. Also to get an overview on disputed lands. Such overview is needed for policies supporting social equity (see for example: Secure land rights for all, UN- HABITAT (2008)), for proper planning and development, for protection of the environment and for food production in a sustainable way or to generate tax income for governments. Taxes paid by all, not only a few. All this means formalisation of societies, governments need information for this. In general governments need information to govern.

A cadastral map may look somewhat boring. It represents boundaries of ownership or land use rights, e.g. customary land rights. Or informal land rights as possession or occupation. It is in fact a map where it is (or can be) visualised that people agree on the boundaries of their properties (or living areas or environment). From this respect it can be seen as a social map. It can also be seen as a map representing legal certainty in relation to ownership or factual land use, which is in fact also a social issue. The map can be used as a basis for the calculation of land tax. Again a social issue in relation to the contribution of individuals, families or groups to building and maintaining society, of course if organised in a transparent way. An example of a cadastral map is given in Figure 47.

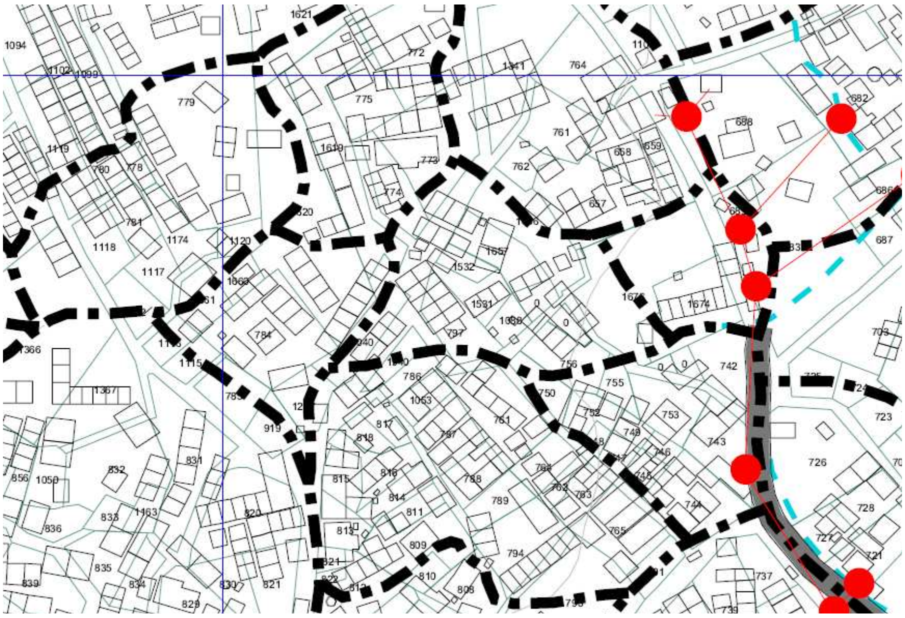

Figure 47 A cadastral map is a social map representing agreements between people; source of the map is Pomoja Trust, mapped in Kisumu, Kenya.

Often distinction is made between "general" and "fixed" boundaries, see (Henssen 1995 and also Bogaerts and Zevenbergen, 2001). Henssen relates this to data where can be relied on. He states that the English system mainly relies on physical boundary features, man made or natural. The precise position of the boundary within these physical features depends on the "general" land law of the country concerned. This system is called the "general boundary system". The LADM also provides functionality, for precise surveyed boundaries to be included as "fixed" boundaries if desired by the owners (or other claimants or right holders). Inclusion of the survey data in the Cadastre implies the boundary to be "legally fixed". In some LASs the location of the boundaries is guaranteed. The choice between "fixed" and "general" boundaries depends according to Henssen on the pace of creating or updating the system, the existence of physical feature, disputes to be expected, the amount of necessary security and costs. Important observation in the field may be to identify to whom the physical boundary belongs.

Fixed boundaries are based on surveys in the field. Cadastral boundary measurements are input for a cadastral mapping process resulting in co-ordinates, often published in combination with point identifiers, bearings (directions or azimuths) and distances between the points; see Figure 48.

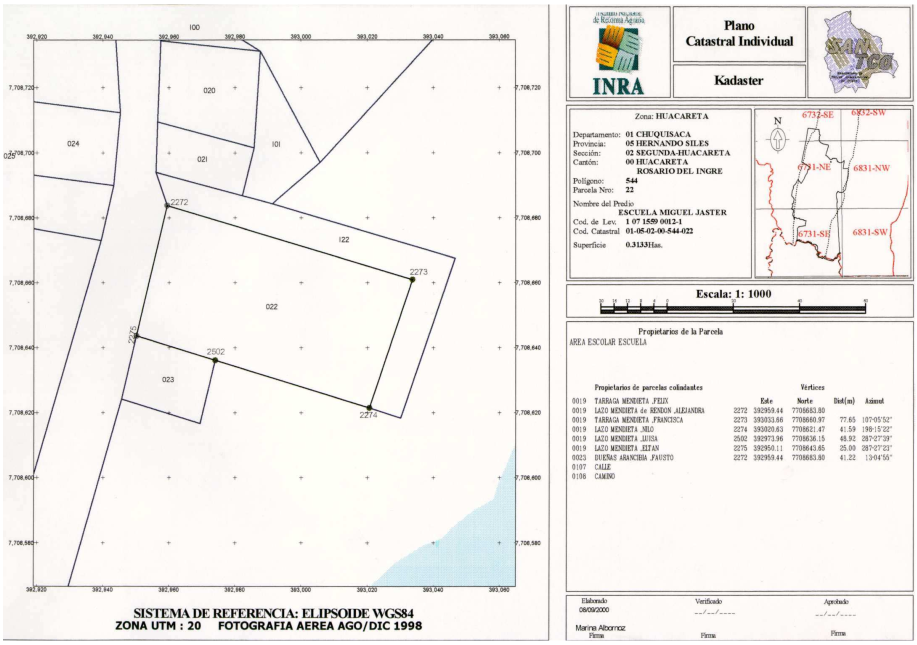

Figure 48 Fixed Boundaries with point identifiers, co-ordinates, distances between points and azimuths; source INRA, Bolivia.

A cadastral map can be seen as a social map as explained above. This means that land disputes can be visualised in relation to boundaries; see the example in Figure 49 (courtesy to the National Land Centre, Rwanda). An example map with disputed lands cannot be produced without boundary observations. A boundary between two spatial units (can be parcels) has (in principle) to be identified in the field. This is "collecting evidence from the field". Identification may be very well possible in a very accurate way in some cases (e.g. 10 cm accuracy). But in many cases this level of accuracy is not possible. This implies that the precision of identification of boundary vertexes can be "less accurate" than the precision of surveys. For this reason (and for reconstruction purposes) monuments can be placed (beacons, markers, other). Here it should be noted that monuments can be moved to another place. All this has to be documented: a cadastre is not only a LAS, it is also 'implemented' in the field. Boundaries must be 'reconstructable'. Surveying is an integral part of LASs, also in case this work is performed by private surveyors. Cadastre 2014 is missing this surveying component. Cadastre 2014 also expects to calculate spatial relations using overlay methods. In practice explicit links are needed in many cases.

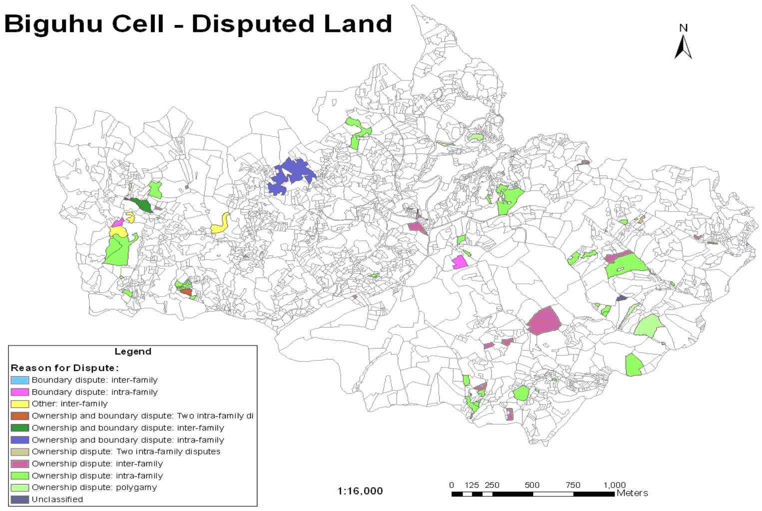

Figure 49 Disputes or overlapping claims on a cadastral map; source National Land Centre, Rwanda – Field trail period.

Apart from surveying (total station, GNSS based surveys, etc.) it should be observed that such boundaries may be identified in the field using aerial photos, satellite images (Lemmen et al, 2009) or existing topographic maps. In such cases boundaries are drawn using pens or digital pens. A digital pen "knows" its location on the printed aerial photo or satellite image because a pattern is printed on the photo which can be read by the pen. The pen is a device which can be connected to a computer where super imposition of the drawn boundaries with the image can be done. Of course it also possible to vectorise directly on top of the image if both neighbours are represented. Milindi Rugema (2011) identified the advantages of using digital pens for boundary drawing in the field on top of high resolution orthophotos (used as normal for drawing boundaries in Rwanda): easy for local people in Participatory-Mapping; boundaries direct geo-referenced on site; digital pen predictable for climate conditions; rechargeable after long time used and no loss of data when the battery is discharged. Examples of other data acquisition tools are mobile mapping tools, see for example Lemmens (2010c). Most relevant for the LADM are not the different approaches in data acquisition but the options to include the original source data with documentation of the results of data acquisitions (and processing of those data, because this processing implies different versions, e.g. different versions of co-ordinates).

Myllymäki and Pykälä (2010) observed that 'the result' of the LADM work will be an international standard. Currently the work is in the draft stage of an international standard. The data model has been changed a lot between the meetings due to a large number of comments. This shows something about the difficulty of the modelling. It is still possible that the model needs a few, new review cycles to provide a more stable result. In the LADM the academic freedom of modelling is limited, because land administration as a domain is related to legal aspects in such a large extent. On the other hand, the LADM is a conceptual model and therefore it can be seen in a positive way and accepted more easily than the INSPIRE model. The present stage of the LADM work shows that a common model is possible. Than again several unequal country profiles prove that a common model has not yet been achieved.

It is not the intention of the model that everything should be realised in one system. The true intention is that, if one needs the type of functionality covered by a certain package, than this package should be the foundation and thereby avoiding re-inventing (re-implementing) the wheel and making meaningful communications with others possible. Furthermore basic packages could be implemented by software suppliers, e.g. GIS suppliers and suppliers of database management software and data acquisition software.

According to the author of this thesis a progressive approach in land titling can also be applied in a way that results into formally recognised customary systems for different areas of a territory. This would be in support of policies where different tenures would be (re-)implemented for different areas using step by step (progressive) approaches based on a standardised LAS. This is establishement of tenures by spatial planning: e.g. large farms areas for food production, urban development and allocation of customary areas where freehold may not exist. This may be combined with corridors for pastoralists and development of infrastructure.

The LADM supports the representation of all people – land relationships – but a specialisation of the LADM is required. This specialisation needs its own terminology; terms as ‘cadastre’, ‘land registry’, ‘ownership’, etc. are too strong related to converntional LASs. Such an appraoch is worked out in Chapter 4 as STDM.

4 New Approaches and Experimental Results

In Chapter 3 the design and design process of the Land Administration Domain Model has been presented.

This chapter introduces the STDM in more detail. This STDM is a specialisation of the LADM. This model is based on first proposals from Fourie (later Augustinus), see Fourie (1998); later those proposals were worked out by the author of this thesis. Main reason is that the Land Administration Domain Model (Lemmen et al, 2003c; Lemmen and Van Oosterom, 2006a based on Van Oosterom et al 2006b; ISO, 2011c) underpins existing conventional LASs. The STDM has been designed as a specialisation of the LADM to cover all types of tenures, conventional and other social tenures such as informal and customary tenures (Augustinus et al, 2006; Lemmen et al, 2007; Augustinus, 2010; Lemmen, 2010d; Augustinus and Lemmen, 2011). The STDM has its own terminology and it complements the Land Administration Domain Model (LADM) and allows interoperability between the two models. Identified overlapping claims to land need to be included (see Fourie, 1998) as well as illegal and/or informal land uses or occupation of land. This means a complete map of the 'people – land' relationships (see also the discussion in Chapter 3) is needed with recognition of all social tenure relationships, i.e. personal, customary, informal and indigenous land use and property rights.

This chapter first explains in Section 4.1 why new land administration approaches are needed (see also Augustinus et al, 2006 and Augustinus and Lemmen, 2011). Those needs explain the need for pro poor land tools as STDM. Section 4.2 gives an overview of the STDM history. There are important contributions from Augustinus here: Fourie (1998); Augustinus et al (2006); Lemmen et al (2007); Augustinus and Lemmen (2011); Augustinus (2010); Lemmen (2010d); Augustinus and Lemmen (2011). In Section 4.3 the STDM prototype is introduced. This prototype is based on open source software. A field test for data collection has been done in 2009 in Ethiopia; see Section 4.4. Section 4.5 discusses how to bridge the gaps with conventional systems. The chapter is closed with a discussion in Section 4.6.

4.1 Why New Land Administration Approaches are needed

LASs provide the infrastructure for implementation of land polices and land management strategies in support of sustainable development. The infrastructure includes institutional arrangements, a legal framework, processes, standards, land information, management and dissemination systems and technologies required to support allocation, land markets, valuation, control of use and development of interests in land (Williamson et al, 2010).

Such infrastructure is only available with a nationwide coverage in about 20 to 30 countries. Most developing countries have less than 30 percent cadastral coverage; this means 70 percent of the land in many countries is generally outside the land administration. The security of tenure of people in these areas relies on forms of tenure different from individual freehold. Most of the registered rights and claims are based on social tenures. Formal land titling is important and necessary, but it is not enough in itself to deliver security of tenure to the majority of citizens in most developing countries. Customary tenure and informal settlement tenure are widespread (Fourie, 1998).

Further it can be observed that existing LASs have limitations because of the fact that informal and customary tenures cannot be included in these registrations. Generally, the LASs are not designed for this purpose. Land tenure types, also in terms of the continuum of land rights (UN-HABITAT, 2008), see also Section 2.4, which are not based on the cadastral parcel and are not registered require new forms of LASs, including land information management systems. Those systems should work differently from the conventional land information systems (Augustinus et al, 2006). That is, land administration systems are required for security of tenure and land management. Conventional systems do not cover the majority of developing countries either because they cannot go to scale and/or because they cannot accommodate the social tenures present in that country. A social tenure approach is needed to fill the gap. This is done via STDM, a specialisation of LADM; if STDM works than the whole range of tenures is covered.

It should be noted that recent innovations in LAS could better cover social tenure. E.g. Kalantari (2008a) is focussing on Legal Property Objects, where interests in land are attached to land as a condition to make it a legal entity. There is some (but limited) attention to customary and informal tenure in his thesis. Similar in Kaufmann and Steudler (1998). Customary tenure is covered in Cadastre 2014; but the data acquisition part and the 'wide range of spatial units' is missing – it is based on availability of quality spatial data – which is possible with GPS and satellite images indeed, but than still there is a need to combine those spatial data with already existing spatial data.

One of the main drivers behind the development of STDM is that many countries and areas are introducing new approaches to tenure which are not based either on registered rights and/or the cadastral parcel. Below we outline some of the innovations which are taking place around the world and require new forms of domain models. In Mozambique the new Land Act (1997) recognises customary rights in the form of co-titling, as well as the need to consult with the local communities as part of the authorisation process for new investments (Quadros, 2002). In Namibia there is a new Land Law that will address the broad issues of customary land reform by means of the creation of regional land boards for rural areas (Pohamba, 2002). A flexible land tenure system has been proposed by the Namibian government for the urban areas (Faurholm Cristensen, 2005). A similar approach can be recognised in Tanzania (Kironde and Lussaga, 2005) where residential licenses in urban areas exist, which are intended to be converted to full title later. In Ethiopia a certification in two phases has been instituted (Abebe-Haile, 2005). The case of Ethiopia, where – within a rather short time frame – about 6 million land use certificates were distributed, even though during the "first phase" no map or spatial reference ares included, is thus of potentially large interest for policy makers (Deininger et al, 2006). In Lesotho 3 forms of leases are under development: primary, demarcated and registerable (Selebalo, 2005).

Van den Berg (2000) states that under a new Act in South Africa customary titles can be granted to Customary Property Associations. Common properties can further be: indigenous or co-operations (Kirk et al, 1998). In Bolivia the INRA Act (1996/Ley Instituto Nacional Reforma Agraria) provides for the recognition of *Tierras Comunitarias de Origen* (TCOs), i.e. land belonging to indigenous groups (Zoomers, 2000).

There are many other innovations in land rights, especially in Africa. See for a comprehensive overview Van der Molen (2003).

Many different types of land use rights exist; e.g. usufruct, tenancy, lease, long lease, etc. Land rights can be religious; e.g. the *waqf* in Islamic land rights, apart from the *milk* (private) and *miri* (government) rights. Use of apartments can be formal or informal. It is even possible that apartments (the 'individual units' in an apartment block) have been formally privatised without related regulations for 'shared units' (threshold, stairs, roof, corridors, elevators, etc.). Also, state or public lands can be national, regional or municipal, and can be allocated for a public purpose, e.g. road, school or hospital (Lemmen et al, 2007).

The recognition of customary rights also devotes attention to rights of sheep and cattle farmers. In many countries there are serious conflicts between traditional nomadic sheep or cattle farmers and arable farmers about grazing and farming lands (such as Kenya, Tanzania and Rwanda). Related to this is the right of access. Most informal settlements do not have proper roads and access is across 'private property'. Access rights are formalised as servitudes in some systems. It can also concern access to water or agricultural or other lands (Lemmen, et al, 2007).

Tanzania's new village Land Act provides for the sharing of pastoral and agricultural land by sheep and cattle farmers and arable farmers on the basis of adjudication and mutual agreements (Mutakyamilwa, 2002). Even 'illegal relationships' between persons and land, e.g. in case of uncontrolled 'privatisation' (Trindade, 2003) exist (reflecting the reality of the real world in the system), as well as cases of 'disagreement', 'occupation' or 'conflict', resulting in overlapping claims to land. In this way a systematic record of conflicts on lands could support the realisation of solutions.

As indicated there are therefore a wide range of rights being developed which cannot be easily recorded in the conventional land administration and land information management systems, in addition to the wide range of social land tenures such as informal settlements, customary tenure and post conflict tenures which need to be managed. Hence there is the need to move from LADM to STDM to expand both security of tenure and land management capacity.

4.2 History and Background of STDM

The history and background of the STDM is documented in Augustinus and Lemmen (2011). In 2005 a number of organisations working with UN-HABITAT acknowledged that there is an insufficient focus on pro-poor tools and that these gaps have to be filled. This resulted in the formation of the Global Land Tool Network[135] in 2005/6. STDM was identified by partners as one of the technical gaps and it became part of the GLTN's agenda, which partners had agreed to work on jointly (Augustinus, 2005). With respect to STDM, the organisations concerned were the International Federation of Surveyors (FIG), ITC, UN-HABITAT and the World Bank. They worked together to develop the model, to register it as an ISO-standard, to develop the software, to do the technical design and to undertake piloting and scaling. Developments included[136]:

– design and prototype development in close co-operation between UN-HABITAT/GLTN and ITC[137]. ITC has been contracted by UN-HABITAT to develop the (detailed) concept, the technical specifications and the prototype software for testing on real world data. Further UN-HABITAT contracted FIG to review the development process and the outcome;
– the World Bank funded a project for piloting the STDM model in Ethiopia on certificated rural tenure. The results are documented in (Lemmen et al, 2009b, Lemmen and Zevenbergen, 2010c);.
– external peer review. FIG took the lead, but involved well-known land professionals/practitioners. The reviews are in support of the STDM development; STDM is important and could facilitate low cost recording of a wide range of rights. The use of open source software in the prototype development is in line with the expectations of the reviewers. See also (Steudler et al, 2010). It was mentioned that the statement of objectives could be bolder: "STDM will provide the ability to both register existing rights in the formal system and record other rights in a way that will support the development of improved policy and legal frameworks and the enhanced institutional and administrative arrangements that implement the frameworks", which is correct. Implementation of information and communication technology, reversibility to paper based systems and the introduction of work processes are identified as being of a complex nature; also for STDM[138];
– Social Tenure Domain Model: From Concept to Implementation. Launch at the XXIV FIG International Congress 2010, Sydney, Australia. See: http://www.fig.net/pub/fig2010/techprog.htm and http://www.unhabitat.org/-content.asp?cid=9085&catid=5&typeid=6&subMenuId=0;

[135] GLTN is facilitated by UN-HABITAT and funded by Norway and Sweden.
[136] http://www.itc.nl/Pub/services/Major-projects/Social-Tenure-Domain-Model-STDM.html.
[137] This is a coalition of international partners, including FIG (the International Federation of Surveyors), ITC (University of Twente, Faculty of Geo-information Science and Earth Observation, the Netherlands), and the World Bank (WB).
[138] See www.oicrf.org and type STDM as keyword to find the powerpoint presentations as presented at the Post-conference workshop on the Social Tenure Domain in March 2009 during the Conference on Land Governance in Support of the Millennium Development Goals: Responding to New Challenges, held at the World Bank. (Powerpoints by Enemark, Sietchiping, Burns, Törhönen, Allebachew and Bell).

- prototype release by ITC (August 2010);
- data testing of the prototype using data from Slum Dwellers International affiliate Pamoja Trust from Nairobi, Kenya;
- further refinements and development of an intermediate version built on the STDM prototype addressing the informal settlements issues (UN-HABITAT, currently under development);
- the Land Administration Domain Model (LADM) has been published as a Draft International Standard by the International Organisation for Standardization as ISO 19152 (ISO, 2011c). STDM is under development as a so-called “specialisation” of LADM. “Specialisation” here means that there are differences in terminology in LADM compared to STDM. For example, what a “real estate right” is in a formal system is considered a “social tenure relationship” in STDM. Note that a formal right is also a social tenure relationship, but not all social tenure relationships are formal land rights. The LADM itself, during its development to a (Draft) International Standard (DIS), includes already more and more of the STDM functionality; i.e. a range of spatial units and parties (parties, group parties, non natural persons, …). This makes the LADM more generic.
- a range of conference and academic papers has been published such as the World Bank special sessions on Land Administration and FIG events (See: Augustinus et al, 2006; Lemmen et al, 2007; Lemmen et al, 2009b; Augustinus, 2010; Lemmen and Zevenbergen, 2010c; Lengoiboni, et al, 2010; Steudler et al, 2010; Uitermark et al, 2010; Zevenbergen and Burns, 2010a, Zevenbergen and Haile, 2010b, Augustinus and Lemmen, 2011). See also Herbst and Wagner (2009). This concerns software based on the model that has been developed in Senegal. In their article Herbst and Wagner mention the LADM as a generic approach, but the STDM principles can be clearly identified. See further the papers from Payne et al (2009) and Zimmermann (2009), where STDM is mentioned as an innovative tool under development, MSc thesis work at ITC about the STDM approach and integration into a country profile of the LADM for Indonesia: Ary Sucaya, I.K.G. (2009) and Guspriadi, T. (2011). The latter thesis has a focus on customary tenure;
- UN-HABITAT led pilot projects with specifically developed functions (e.g. informal settlement) in Kenya, Uganda and the Caribbean (urban and rural) working with a range of potential partners who are bilateral and/or NGOs (under discussion to start in 2011). UN-HABITAT started piloting end 2011 in Uganda;
- other pilots – International Land Systems Inc (later Thomson reuters), ‘Open Title’ software based on the STDM model being piloted (ongoing). See: http://en.landsystems.com/content/section/2/21/;
- development of initial conceptual designs to use STDM for carbon sequestration (Mitchell et al, 2011).

GLTN partners have agreed that an open source version needs to exist to ensure that the poorest part of the population and poorest municipalities and governments can afford a LAS, given the costs of conventional software acquisition, licensing and upgrading fees. It should be noted here that in any case expertise is required to manage the software, computer systems and databases in an ‘open source environment’.

It is very encouraging to see that International Land System (later Thomson Reuters) is developing a STDM compliant software (Edmead, 2011) to work out affordable business product software based on it. These business products can be linked to on site support, which may be an important requirement in case of insufficient or lacking local ICT expertise within the land sector. The use of open source software and commercial software may be complimentary; this is one of the advantages of standards. ILS OpenTitle adheres to the STDM and configures the required data model entities (Persons, Non-Natural Persons, Social Tenure Relationships and Spatial Units and Mortgages) during software installation.

The steps outlined above show that a lot of careful work and reflection (by UN HABITAT and in co-operation between the author and UN-HABITAT) and funding (mostly by Norway and Sweden) has been required to move STDM forward and still more is required to be able to produce robust fully functional software, which is also open source, based on the STDM model. In fact the acceptance so far and the support in further development can be seen as a part of the validation.

4.3 The Prototype

The development of the prototype[139] software is based on four documents: a conceptual design (Lemmen, 2008a), a functional design (Lemmen and Alvarez, 2008b), a technical design (Lemmen and Van Bennekom, 2008c) and a software test report (Alvarez, 2009a). An application's users guide (Alvarez, 2009b) and an installation guide (Alvarez, 2009c) are also available.

The organisation of activities needed for data acquisition and data maintenance is not really included in this functional design; point of departure is that there is a need for a generic, process independent, solution based on forms per social tenure relationship. The data on parties and spatial units have to be collected and those data have to be linked together with source documents (forms and images, sketches, etc.).
Administrative data can be collected by the administrative data collector[140] using forms. Spatial data can be collected using imagery. After spatial data have been collected by the spatial data collector the party gets a small piece of paper with the spatial unit identifier (which has been drawn on the satellite image) and goes to the administrative data collector where the administrative data are written or typed. In this way the relation between people and land is managed in the field. Neighbours should be available on site. The following attributes are included in the data model of the prototype, see also Figure 50 (with an overview of STDM basic classes in Fugure 51) and Lemmen and Alvarez (2008b) and Alvarez (2009b):
Base imagery
– Administrative area: the administrative province/region subdivision of land (M).
– Spatial Reference System: can be given in WGS84 (M)[141] in ILWIS[142].

[139] Prototyping is the process of quickly putting together a working model.
[140] One of the roles in the design. Other roles are spatial data collector, data covertor person and information manager.
[141] If another reference system is needed for geo-referencing, that has to be adjusted.

Data Collector

- First and last name: the first and last name of the data collector (M).
- DataCollectorType[143]: type of collector depending how he/she is authorised to collect, modify,or delete (senior/junior, spatial/administrative data, conveyor) (M).
- Licence: professional license number of the data collector (if available).

Natural Person

- Person ID: official country ID of the person[144].
- GenderType: natural person’s gender [145](M).
- First Name: natural person’s first name (M).
- Last Name: natural person’s family name (M).
- Street: street name; this can be a description. A postal code can be included.
- City: name of city or region (M).
- Photograph: person’s photograph.
- Fingerprint: the scan of the person’s finger print.
- Signature: scan of the person’s signature.
- Date Of Birth: natural person’s date of birth.
- Validity/Until: date the record is inserted (M) - date not valid anymore.

Non-Natural Person:

- Name: name of the non-natural person (M).
- GroupType[146]: type of group (M).
- External ID: official ID of the non natural person.
- Street: street name or number of the non-natural person’s address.
- Postal code: postal code.
- City: name of city or region.
- Representing Person: the representing person of the group.
- Validity: date the record has been recordedut in the database (M).
- Until: date the record is not valid anymore.

Source Document

- Identification: identification code of the paper original source document (M).
- Source: address path where the scan of the source document is stored (M).
- Measurements: set of parcel measurements taken during the survey
- QualityType: quality type[147] (M).
- Social TenureInventoryType[148]: type of social tenure inventory (M).
- SpatialUnitInventoryType[149]: type of spatial unit inventory (M).

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[142] ILWIS is the Intergrated Land and Water Information System, one of the open source software components of the STDM. PostgrSQL is another component, this is the data base management system. The prototype has been developed on Java, ApacheTomcat supports Client/Server environment.

[143] DataCollectorType could be spatial data collector or administrative data collector or both.

[144] I.e. ‘burgerservicenummer’ in the Netherlands, Social Security Number SSN is the US, ‘Cédula de Ciudadanía’ in Colombia or ‘Carteira de identidade’ in Brasil (M).

[145] GenderType of natural person, male or female.

[146] GroupType may be farmers, indigenous, association, informal.

[147] QualityType could be terrestrial (an than there may be again options), satelite image, digitital, GPS, unknown.

[148] SocialTenureInventoryType may be paper, digital, etc.

[149] SpatialUnitInventoryType may be image, photograph, sketch, topo-map, planetable map, photo, etc.

- Data Collector: the name of the data collector that collected the information for this record (M).
- Recordation date: date on which the source document is recorded on the field (M).
- Acceptance date: date on which the competent parties formally accept the source document.
- Submission date: date on which the source document is submitted in the database after it has been formally accepted.
- Survey Date: date on which the survey took place.
- Comments: free-open field to make comments about the source document.
- Validity: date the record has been recorded in the database (M).
- Until: date the record is not valid anymore.

Spatial Unit

- Spatial Unit ID: identification number of the spatial unit (M).
- Field ID: identification number of the spatial unit given on the field and written on the paper source document (M).
- City: city or region where the spatial unit is located (M).
- Tax Amount: estimation of the tax that has to be paid for the spatial unit has to pay according to regulations of the country.
- Value: estimation of spatial unit value.
- Calculated Area: approximate area of the spatial unit.
- SpatialUnitType[150]: type of spatial unit (M).
- UseType[151]: type of use of the spatial unit.
- Data Source: address path where the data source for the spatial unit is stored (M).
- Photograph: scan or digital photograph of the spatial unit(s).
- Validity: date the record has beenput into the database (M).
- Until: date the record is not valid anymore.

Social Tenure Relation

- Person/Party: the party to be related to a spatial unit (M).
- SocialTenureRelationType[152]: type of social tenure relationship (M).
- Spatial Unit: spatial unit ID that is related to the selected person (M).
- Share: share in a social tenure relationship. The sum is 1.
- Data Sources: list of source documents/images existing for the social relationship.
- Validity: date the record has beenput into the database (M).
- Until: date the record is not valid anymore.

Survey Point (not yet implemented)

- DimensionType[153]: the number of dimensions.
- Location Origin: calculated co-ordinates, based on observations.
- Quality: survey point quality (look up table).
- Survey Point ID: identification number of the survey point.

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[150] SpatialUnitType may be point, line-based, text, sketch, topolgy.
[151] UseType could be agricultural, living (formal or informal), residential, industry, etc.
[152] SocialTenureRelationType may be informal tenure, customary tenure, co-operation, tenancy, possession, restriction, stateland, comfort, disagreement, milk, miri, waqf, conflict, occupation, network, fishing, hunting, common land, etc.
[153] DimensionType is 2D or 3D.

– Transformation Parameters: transformation used (from calculated co-ordinates in a local reference system to transformed co-ordinates).
– PointType[154]: type of point.

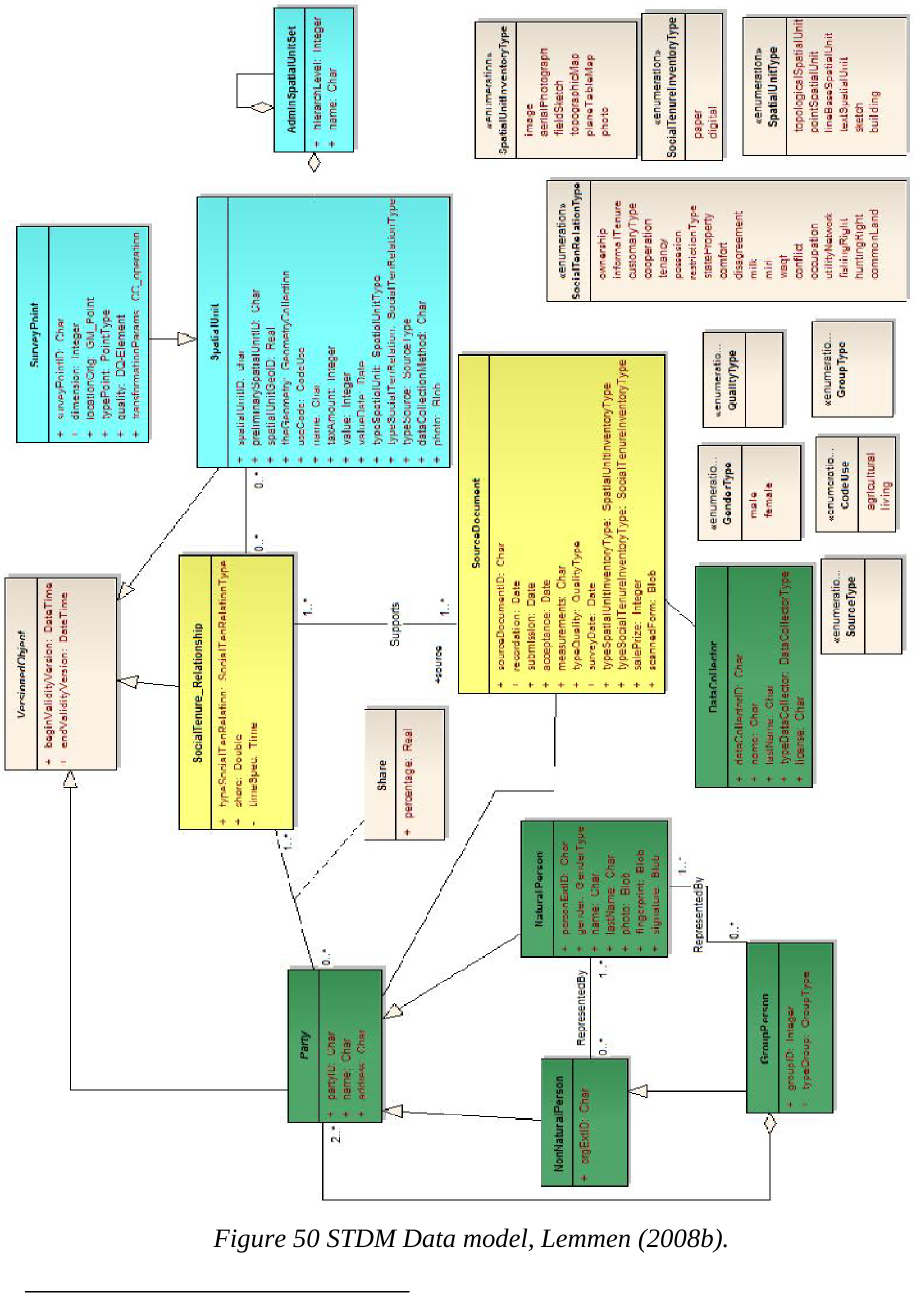

Figure 50 STDM Data model, Lemmen (2008b).

[154] PointType may be concrete post, bottle, metal pipe, nail, monument, wooden pile.

STDM is based on LADM Version A (Section 3.2) and uses a different terminology for some of the classes of LADM. For example, class RRR has been named Social-TenureRelationship. See Figure 51.

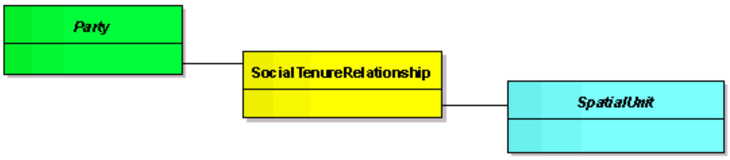

Figure 51 Basic classes of STDM: Party, SocialTenureRelationship and SpatialUnit.

The concept of BAUnit, as a basic property unit, is not present. Furthermore, SocialTenureRelationship has no subclasses (Right, Responsibility and Restriction), and therefore it is not an abstract class (Lemmen, 2010).

A specific social tenure relationship, including its parties and spatial units, may be collected on different source documents; e.g. one or more source document(s) for the administrative data and one (or more) for the spatial data. The source document for the spatial units may contain information about more than one spatial unit.

A source document contains all the attributes of Parties (Persons), Social Tenure Relationships and Spatial Units. It is possible that more than one data collector has the responsibility to fill in (part of the) forms in the field. It may happen that a sequence is needed for filling in the forms. This has to be organised by the data collectors.
According to the design a form can be analogue or digital[155]. Analogue forms to be used in the field can be printed by the STDM system. After printing the forms can be copied. Those forms can be filled in the field (using a pen) and the collected data can be inserted in the system later. The interface for inserting the data is the digital version of the form. It may happen that the data have been digitised but not yet committed to the database, e.g. because the data collection is not yet finished in a specific case.

A Spatial Unit can be linked to spatial data. The implementation of a Spatial Unit represented by point or polygon will be implemented by spatial columns of a table in PostgreSQL; this is the open source database selected for the STDM prototype.

4.4 Field Test

In 2008, a team[156] conducted a simple field test using high resolution imagery. On-site tests were performed to determine if Quickbird satellite imagery could be used to establish parcel index maps in selected villages. The data collection in the field was performed with the help of rightful claimants or land right holders and local officials.

[155] An iPad with GPS navigation and recordation of co-ordinates included would be very optimal for data collection. The only problem is that people can not "sit around the image" in that case. And this is very important for acceptance. An alternative is to collect data digital in the field and to project them on a big screen in the evening to discuss the results. People can very wel understand the contents of the images; see Lemmen et al (2009b) and Lemmen and Zevenbergen (2010c).

[156] Augustinus, Burns, Deiniger, Haille, Lemmen and Zevenbergen.

The image quality of the plots at a scale of 1:2000 was sufficiently high to allow the parties to easily understand the images and contribute input, making the process very participatory. Many rightful claimants or land right holders were not able to present their certificates, suggesting updating issues. Even though the test was not well prepared, it yielded useful experiences and data. This limited data set was processed initially with ArcGIS and later with the first prototype of the STDM based on open source software. Processing the limited graphical display of the boundaries was relatively easy, but trying to link the data to GPS co-ordinates (collected, at the same time, with hand-held GPS) was not immediately possible due to offsets caused by a number of reasons. Nevertheless, the approach seems very useful for lower land value areas where coverage is more important than (absolute) accuracy (Lemmen and Zevenbergen, 2010c).

Since the beginning of the 21st century, great progress has been made with rural land certification in Ethiopia. Several Ethiopian states have introduced land administration systems for rural areas aimed at issuing land use certificates at an affordable cost for all (sedentary) farmers in that state. Unlike many similar initiatives in other countries, the implementation of this quickly caught on in Ethiopia, and by 2005 data had been collected on about six million households, about half of which have actually received their “first phase” certificates.

These certificates identify the rightful claimants or the landholders (by name, etc. and with photographs), but are weak on the description of the land plots, which include neither a map nor any kind of spatial reference (except for a list of neighbouring landholders) and only give a roughly measured or estimated indication of acreage.

To gain more of the benefits that land administration can bring, graphical and/or geometrical data on the spatial units to which the landholders have their use rights need to be collected.

In early 2009, further testing was done by the Environmental Protection Land Administration and Use Authority (EPLAUA) in Amhara as part of the Cadastral Index Mapping piloting (Belay, 2009). Comparable work includes earlier doctoral research in Ethiopia (Haile, 2005), Pakistan (Zahir, 2009), as well as pilot projects in Rwanda (Sagashya and English, 2009) and Namibia (Kapitango and Meijs, 2009). Using satellite imagery for cadastral applications is not new; see the experiences from Kansu and Sezgin (2006); Konstantinos (2003); Paudyal and Subedi (2005); Tuladhar (2005); Ondulo and Kalande (2006) and Palm (2006)).

After field data collection the processing of the data involved (see Lemmen et al, 2009b; Lemmen and Zevenbergen, 2010c):

– scanning. This resulted in six analogue images, each containing the identified boundaries and parcel identifiers, which were scanned using a Cougar 36 scanner with 30 dpi resolution as a first step in transforming the field information into a digital environment. Scanning resulted in six raster data sets in JPEG format. Necessary corrections such as rotations were carried out in order to ease the following processes;
– geo-referencing, The six raster data sets contained undefined spatial references. Spatial references were defined by importing the co-ordinate system and projection of the original image. After defining the reference system, geo-referencing was then performed by identifying and matching the co-ordinates of

the new images (marked at the edges of each scanned image) with the original image. Control points such as road intersections and other identifiable features were also used. The same was done in the STDM prototype as soon as available, see Alvarez (2009a);

- Vectorising. Once the images were geo-referenced, on-screen digitising was performed, first in ArcGIS; later in the STDM prototype. Parcel boundaries were extracted by pointing and tracing the cursor along the parcel boundaries drawn on the image. Each parcel was created as a closed polygon. The polygons do not share boundaries with neighbouring parcels and are, therefore, independently identifiable. The digitising process tried as accurately as possible to avoid overlaps between boundaries, especially where parcels bordered each other. Two shape files were created: one from the test area Hanigodu-Megelta, and another from Alengu;
- a database containing administrative data about the attributes of the spatial units was created in Microsoft® Excel® (later the same exercise was done in PostgreSQL as soon as the STDM prototype was available, see Alvarez (2009a) and was exported and joined with the attribute table of the parcel's shape file. A shape file is a commonly used data format for GIS software that spatially describes features depicted on a digital map as geometric shapes (e.g. points for water wells, lines for roads, polygons for parcel boundaries). The result was that parcels (geometric data) now also contained administrative records, i.e., the names of the rightful claimants or land right holders of the parcels, their certificate identifications, the area and the names of neighbouring land right holders to the north, east, south, and west;
- GPS points consisting of survey points from the edges of various parcels in the field were uploaded and superimposed on the shape files. These offsets are likely caused by the fact that the images were not ortho-rectified and by errors introduced during scanning and geo-referencing processes, as well as by relief distortion resulting from the differences in elevation of the aerial images and the GPS observations as described above. A more comprehensive analysis for more and less mountainous areas has been recently undertaken in Pakistan (Zahir, 2009).

Uploading of the data collected by the field team into the STDM prototype was successful; see Alvarez (2009a) and Alvarez (2009b). This data set has been demonstrated during the FIG Congress in Sydney, 2010.

4.5 Bridging the Gaps with Conventional Systems

Van der Molen (2006a) states very clear that conventional, 'Western' ways of land administration being applied in less developed countries, e.g. titling programmes, are known as being too complicated, too accurate, too slowly, too expensive and too much in favour of middle and elite classes. Unconventional approaches are needed (World Bank, 2003; UN-HABITAT, 2004), also from the perspective of information management.

STDM is basically about people and is intended to broaden the scope of land administration by providing a land information management framework that would integrate formal, informal, and customary land systems, as well as integrating administrative and spatial components. The STDM makes this possible through tools that facilitate recording all forms of land rights, all types of right holders and all kinds of land and property objects/spatial units regardless of the level of formality. The thinking behind the STDM also goes beyond some established conventions. Traditional or conventional LASs, for example, relate names or addresses of persons to land parcels via rights. An alternative option is being provided by the STDM, which instead relates personal identifiers, such as fingerprints, to a co-ordinate point inside a plot of land through a social tenure relation such as tenancy. The STDM thus provides an extensible basis for an efficient and effective system of land rights recording (Augustinus and Lemmen, 2011). This extensible basis means (Augustinus and Lemmen, 2011):

- inclusion of the representation of all People to Land relationships – the continuum of land rights (UN-HABITAT, 2008) applied in a global setting. New types of relations can be easily included. The STDM describes relationships between people and land in an unconventional manner, tackling land administration needs in hitherto neglected communities, such as people in informal settlements and customary areas. It supports the development and maintenance of records in areas where regular or formal registration of land rights are not the rule. It focuses on land and property rights which are neither registered nor registerable, as well as overlapping claims that may have to be adjudicated in terms of "who", "where" and "what right". In other words, 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 (2008). During the workshop in Enschede (Van Oosterom and Lemmen, 2003a) there was a lot of attention to the inclusion of 'informal areas' into Cadastral Data Models. In the workshop in Bamberg (FIG and COST, 2004) 'Formal Ownership'; 'Customary Tenure'; 'Indigenous Tenancy'; 'Starter, Landhold, Freehold, Evolution'; 'Possession'; 'Mortgage, Usufruct, Long Lease, many Restriction Types'; 'State Lands'; 'Informal and Unknown People to Land Relationships'; 'Disagreement'; 'Occupation'; 'Uncontrolled privatisation (which is in fact a kind of transaction) and 'Conflict' were presented as a set of (extensible) relations between people and land (Van Oosterom et al, 2004). A first start in this approach with extensible code tables was presented in a paper to the FIG Working Week in Paris, France (Lemmen et al, 2003a and Lemmen et al, 2003b). In the LADM a range of spatial units was introduced based on the overview of Fourie, 1998;
- flexible representation of people and social structures. This means that a range of types of parties can be included, in principle without exceptions;
- flexible representation of units of land-use rights – a range of spatial units – Augustinus et al (2006) provides a comprehensive overview. See also Lemmen (2010d);
- a range of different field data acquisition methods can be applied resulting in (a range of types) of (authentic) source documentation for spatial and non-spatial data. Unconventional and participatory approaches in collecting evidence from the field; participation could mean the presentation of field collected data in the

evening to the community. Different data acquisition methods mean different data qualities; quality labels can be included. E.g. Hailu and Backstrom (2006) report from Ethiopia that, because of lack of equipment and electricity in most of the villages, traditional survey methods, compass and measuring tape (cord) were used. They mention surveying and mapping as being expensive. Moreover, for collecting data for around 20 million plots covering the whole of Ethiopia other methods are needed, such as ortophotos and satellite imagery. Those images have different geometric qualities. Mosaics are composed out of images with survey times; 'old' images may be used because they are cheaper (Lemmen and Zevenbergen, 2010c). Imprecise has to be accepted: insisting on expensive standards is not in the benefit of the poor and government as well. Insisting on expensive standards for data acquisition has been proven not to work. In general such proposals mean that there is insufficient attention for the scale LA implementations and also insufficient attention for the option to upgrade quality later. This does not mean that there should be no attention to the maintenance of LA data;

– promising is the use of the digital pen (Milindi Rugema, 2011 and Prastowo, 2011). Here a pattern is plotted on top of an (aerial or satellite) image. This pattern 'informs' the pen about its location on the image. This means the data collected in the field can be easily projected to the local people after reading the drawn lines into a PC or inclusion of video or sound (Barry, 2005);
– unconventional and participatory approaches in collecting evidence from the field means that overlapping claims can be identified as a spatial unit (as a type of 'right' with claimants included, a 'what to do list' for arbiters. This clarifies which areas are probably free of conflicts;
– if many attributes are collected than many attributes have to be maintained. This means there should be awareness for this 'multiplier' effect. In STDM there is a minimal set of attributes. Local extensions are possible; on the other side not all attributes may be needed. Local set-ups require database expertise;
– in STDM the dynamics in reality can be represented. Maintenance of non-spatial and spatial data is possible with a minimal number of attributes. The STDM has been designed in such a way that there is no real workflow management, nor 'controlled' process management. The user should (and can) easily understand what has to be done based on the use cases in the manual: retrieve/edit/delete person, group person, organisation, source document, spatial unit, social tenure relation and split and merge. Different sources can be combined. There is no need for cm or meter precision. This helps to combine and understand land administration information from different sources in a coherent way;
– for initial data collection the types of allowed spatial units, persons and social tenure relationships have to be set based on the STDM code lists as presented in Section 4.3[157] in Figure 50 and in attribute descriptions (footnotes to 'types');
– it should be possible to perform unconventional 'transactions': in general there can be new types of transactions along the dimensions 'right continuum' (based on

[157] SpatialUnitInventoryType; SocialTenureInventoryType; SpatialUnitType; SocialTenureRelationType; GroupType; GenderType; QualityType; UseType; DataCollectorType; PointType.

UN-HABITAT (2008), ‘party continuum’ and ‘spatial unit continuum’. The use of the LADM is most relevant with regard to the maintenance of the data to be able to provide up-to-date data on land rights. How to go from an informal social tenure relationship to a formal one and from a personal right of use to a formal one? The inventory of informal rights could be seen as a “what to do list”, after integrating the land data collected by the local community with data from a Land Administration Authority, maybe in co-operation with other institutions. Sometimes there are objections in recognising informal rights; the “informal rights” are called “illegal rights”. This is in fact neglecting what can be observed in reality. The officials know this: if it is “illegal” action should be taken; e.g. because of risks of land slides or inundations. People need a shelter somewhere and in many cases the government did observe informal areas, but did not interfere for a long time. How to move from a conflict situation (conflicting claims) to a formal one? Again a “what to do list” for the government (upgrade the rights or take other decisions based on the recordation of rights). Women’s access to land can be organised by registration of shares in rights.

Unconventional transactions and updates in the STDM may be:

- a transaction to *change or update* a social tenure relationship from ‘informal’ to, for example, ‘occupation’ and may be later to ‘free hold’. Or, in a way similar, from ‘starter’, to ‘land-hold’, to ‘freehold’;
- a transaction to *convert* from freehold back to ‘customary’ and from ‘individual person’ to ‘member’ of a ‘group person’. This could be a restitution after grabbing or after disaster (aids, tsunami, genocide) returning land rights to the children (this explain the urgent need for a complete coverage, e.g. point based related in land use with fingerprint or other biometric attributes. Do we need DNA here in the database necessary from a social perspective?;
- a transaction to *change* from a spatial unit under ‘conflict’ or ‘overlapping claim’ to ‘informal occupation’ and may be later to ‘leasehold’;
- all kind of transactions to support the *establishment* of unconventional restrictions: e.g. not allowing formal titles within a polygon or set of polygons. Or: the *establishment* of a planning and development area as a restriction; e.g. to avoid speculation; the *establishment* of a forest destruction restriction (e.g. no trees for biofuel, palm oil, etc.); the *establishment* of a corridor restriction (right to cross land via a corridor for pastoralists);
- a transaction supporting the *establishment* of occupation of land after disaster. If existing land rights are unknown land can be occupied and can be ‘consolidated’ later related to a bigger area where land rights are re-allocated;
- all kind of quality improvements can be seen as transactions: ‘*improve*’ geometric quality e.g. from point based to polygon based. This could mean introduction of land taxation to support in development or from text based/sketch based spatial units to polygon based spatial units. Geometric quality improvements lead to changed co-ordinates, this may have impact on areas of spatial units. For this reason formal and calculated areas may be represented;
- a transaction supporting ‘*inheritance*’ land use rights based on shares in accordance to local traditions to avoid loss of rights. Or: ‘*claiming*’ land use

rights in case of divorce; this claim can be recorded; this means a transaction from a share in a use right to an overlapping claim.

All together this implies that different approaches and different registries may be used in different areas. This includes different data acquisitions methods, and recognition of different Party types (range of persons), the allowance of different type of spatial units and the possible People to Land relationships. See Figure 52 and 53.

The quality demands in slum areas are different compared to residential areas, because of different policies and spatial developments. Slum dwellers may not pay taxes, but are looking for improvement of livelihood, e.g. based on microcredit. People in residential areas are looking for legal security, the same holds for the business centre. High land values in business centre may imply a high level accuracy demand, etc.

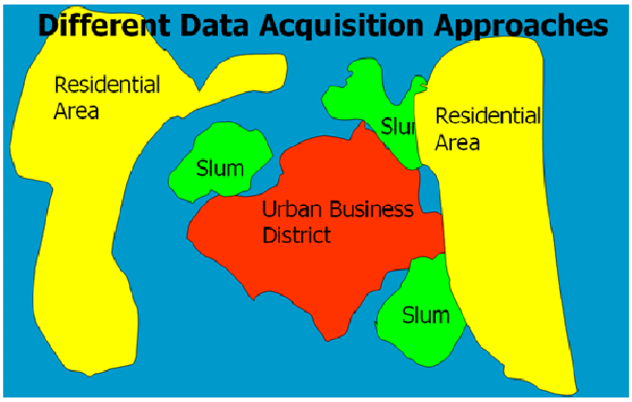

Figure 52 Different areas with different quality demands for Land Administration.

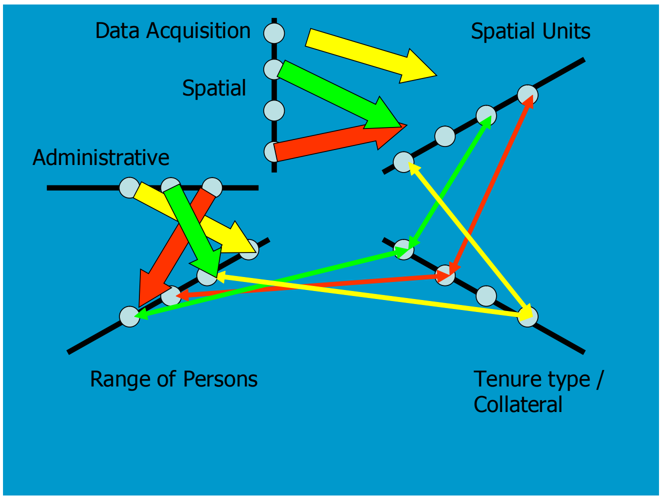

Figure 53 in different areas different approaches may be used.

4.6 Discussion

Up to the 1970s work on land at the country level in the developing world tended to be focused on conventional land titling. From the 1970s onwards extensive work was done by political and social scientists to show that most poor people, who were the majority of the population, lived under social forms of tenure. This social approach was validated by the seminal work of Deininger (2003) on land policies for growth and poverty reduction**.** The adoption by African governments of new forms of tenure, as described in Augustinus and Lemmen (2011), together with the overall global thinking about land, has brought an increased realisation that we need to use the framework of a continuum of land rights. This continuum of land rights has been widely adopted at the global level. However, the implication of adopting the continuum of rights meant that new tools would have to be designed, as the conventional land administration and land record systems could not accommodate the range of social tenures being discussed. Without new tools the social tenure form of thinking cannot be implemented. By 2005 the discussion within the land community meant that the LADM underpinning conventional approaches had to be re-thought taking also into account the social tenures, hence the development of STDM. However, we are not there yet. STDM has to date been used to interrogate our conventional systems, learn lessons and develop innovative approaches, but until we have a robust software modelled on the STDM, which delivers the approaches, concepts, framework and values outlined above, for free as well as within a business environment, we will not have filled the technical gap.

This means and implies that most People to Land relationships can be supported in recordation/registration using STDM as a specialisation of the LADM.

It should be noted that with the STDM we do not have the aim to represent 100% of all possible cases for all countries. It is likely that additional attributes, operators, associations, and perhaps even new classes, are needed for a specific country or region. Further it should be noted that it is possible to use a subset of the STDM classes for a specific implementation within a specific scope; there are many options, both at the class level and the attribute level.

A complete overview of who is living where, under which tenure conditions and for which areas requires generic standardised approaches that can be easily extended and adapted to local approaches. New and innovative approaches are needed in data acquisition and maintenance (community based mapping, participatory approaches, women’s access to land), with different levels of geometric accuracy. Policy, legal, organisational, human capacity building (formal and non-formal training) all need to be considered in the design of such an unconventional system.

There is a need for a specialisation which can be used in an informal environment. This is to avoid confusion and prejudice on implementation of the LADM in informal and customary areas (even if it would be technically possible)[158]. The fact has to be accepted, that more social tenure relationships exist than statutory land rights, especially at the political and higher administrative levels. This is best expressed by inclusion in a land policy. The relevant land agencies and involved private

[158] This means LADM for LASs in areas with formal land rights; STDM(with its own terminology) in areas with informal and customary land rights.

practitioners need to be willing to adapt their ways of working to allow for dealing with the concepts of STDM as compared to the 'conventional land administration' approach, including recognition of a range of rights and mechanisms to gather the data of these rights on a community based participatory approach.
It is well known by the author that getting the non-technical (institutional) issues right is far more complex than the technical issues; but in this thesis the focus is on the data model. This will be in support to software developers (GIS and DBMS). Professionals and scientists with different backgrounds and disciplines co-operated in the development of this model.

The STDM is a concept which makes it possible to bring the social element into land administration thinking by (Augustinus and Lemmen, 2011):

- acknowledging other non formal tenure arrangements;
- opening options for innovative and incremental approaches to improve tenure security;
- bridging the gap between informal systems and formal systems that emphasise titles;
- unpacking existing social tenures;
- giving a snap-shot of the People to Land relationship at any given time;
- informing the land administration authorities about the actual situation on the ground; this can be extended with all kind of attributes which can be associated with people

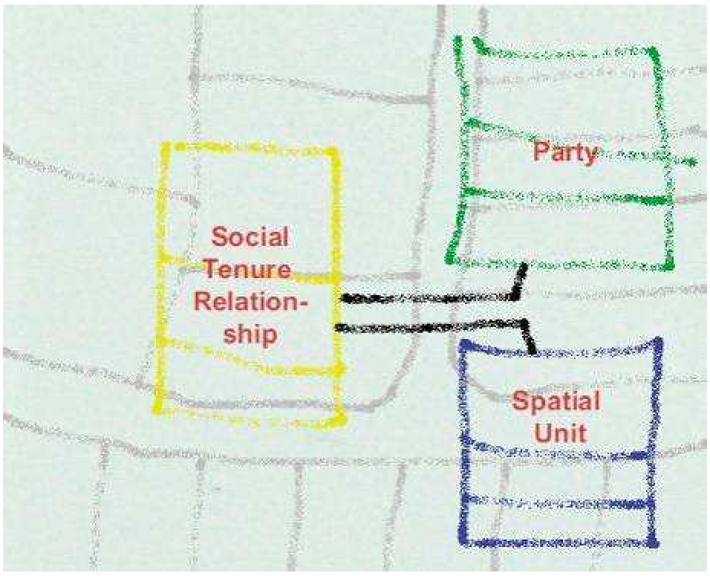

Figure 54 The STDM 'logo', based on the CCDM logo, designed by Axel Smits.

In conclusion, the flexibility of STDM (see Figure 54 for the STDM 'logo') is in the recognition that parties, spatial units and social tenure relationships may appear in many ways, depending on local tradition, culture and religion and behaviour.

Recordation in STDM is not only based on formal registration of formal land rights, but can also be based on observations in reality, resulting in recordation of informal land use rights. There may be many recordations in many places and also different registrations. Exchange of data is possible now because of standardisation.

In case of using open source software the support of an open source community is needed. Commercial software combined with open source software is very well possible; this is one of the further advantages of the standard and one of the reasons for the development of LADM.

The STDM is a conceptual schema like the LADM. If needed the schema can be changed; e.g. new codes in code lists. New attributes should be easy to implement using MDA and the same is valid for new classes. See Chapter 5.

5 Implementations: First Results

When the LADM is finalised as an International Standard it can be used as a basis for the design of LASs. Modelling facilitates appropriate system development (and re-engineering) and, in addition, it forms the basis for communication between different systems in different (parts of) organisations. This use of the LADM in practice means that now, finally, application design can be based on GIS and database technology. Of course there is no difference if open source, commercial GIS and/or database management platforms are used for this purpose. When using standards, information can be exchanged in heterogeneous (commercial and open source) and distributed environments.

There is international attention to the LADM/STDM developments, (see research question 4), see Section 5.1 for an overview including country profiles. Special attention will be given to Cyprus, where implementation is considerd, see Section 5.2. The same for Honduras, see Section 5.3. In Honduras MDA has been used to generate the database. In Section 5.4 attention is paid to the LADM developments in Portugal. Other model use is being conducted e.g. in relation to the INSPIRE Data Specification on Cadastral Parcels[159], see Section 5.5 and to the the Land Parcel Identification System, see Section 5.6. FAO[160] Solutions for Open Land Administration (SOLA) (via Free and Libre Open Source Software, FLOSS) and LADM will be briefly discussed in Section 5.7. The chapter ends with a discussion in Section 5.8.

5.1 Examples of Standard-LADM

LADM may be not complete for a particular country; local adaptions and extensions are possible. It should be expandable and it is likely that additional attributes, operators, associations, and perhaps new classes, will be needed for a specific region or country. Furthermore it may be so that specific attributes or even classes are not needed in a region or country. Country profiles can be used for customising the LADM to meet specific needs. An example is given here below in Figure 55 (this is the country profile of the Netherlands, see Annex D in the DIS 19152; ISO (2011c). There are further country profiles in Annex D of ISO (2011c) (Version C of the LADM in this thesis) from Portugal (see Hespanha et al, 2006 and Hespanha et al, 2009, see Section 5.4); Queensland, Australia; Indonesia (see also Ary Sucaya, 2009 and Guspriadi, 2011); Japan and Hungary (see also Iván et al, 2004). Profiles for Korea and Cyprus (see for Cyprus Elia et al, 2012, this paper in press is discussed in Section 5.2) are also available and may be included in the final version of the standard.

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159 The idea is that the LADM will be fully integrated in this specification after its acceptance.
160 Food and Agricultural Organization of the United Nations.

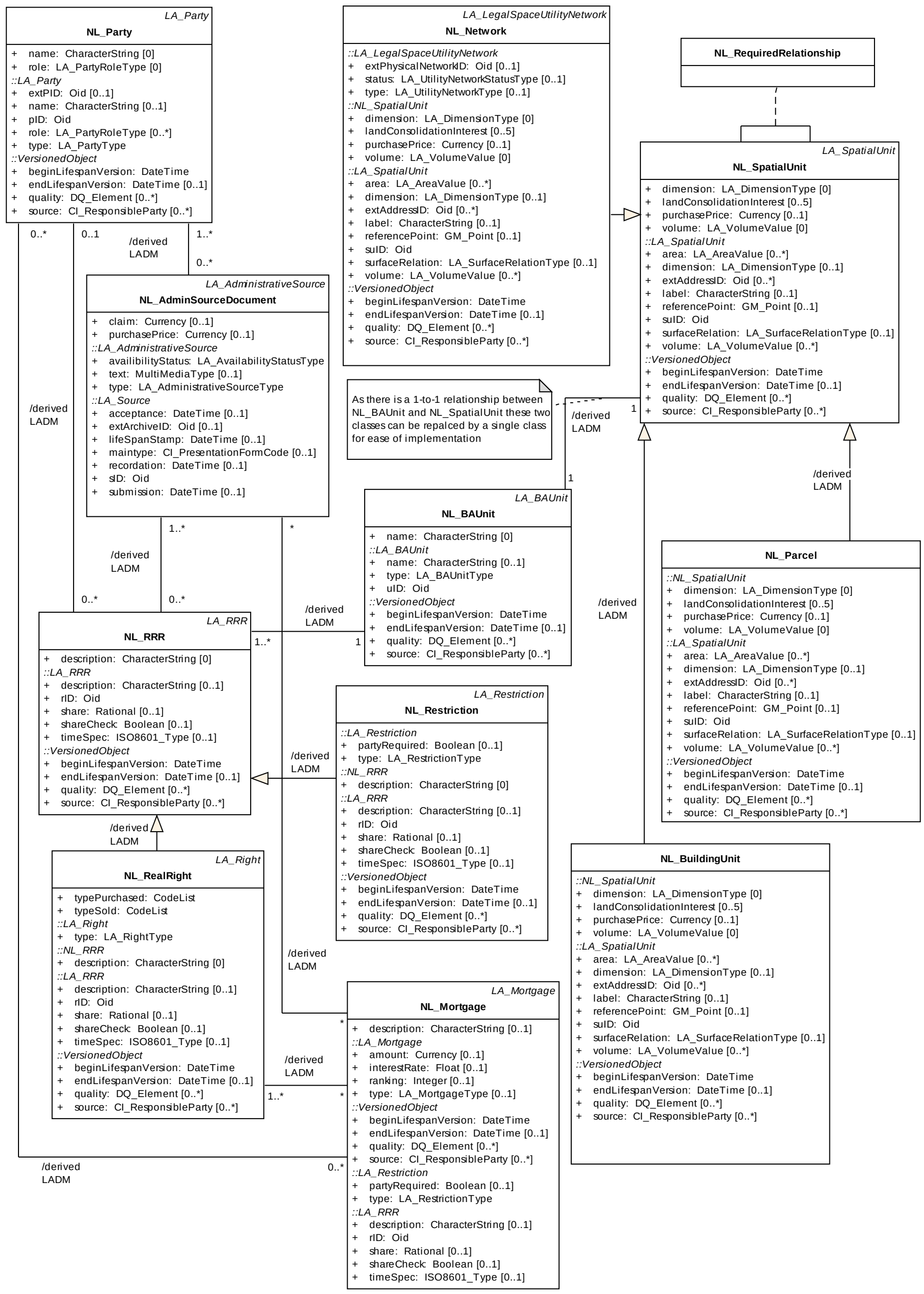

Figure 55 Country profile of the Netherlands (prefix NL for classes).

Ingvarsson (2005) investigated in what way the CCDM and open source software can benefit the development of cadastral registration in Iceland. He suggested not to make the CCDM universal, but to focus the development of the CCDM (compare the LADM Version A of this thesis) on homogenous cultural areas, like within the European Union. In the LADM Version C the approach of country profiles is integrated: the idea is that the country profile should not include different structures or solutions, where the LADM has standard provisions. This is, among other places, expressed in the normative Annex A, the Abstract Test Suite, of the standard.

The Netherlands' country profile is depicted in Figure 55. This profile has been designed by Van Osch and Lemmen from the Netherlands Kadaster based on their experience.

In Indonesia the management of customary land is transferred to local government (Ary Sucaya, 2009). That means to more than 400 districts. To prevent a variety of LASs, standardisation is needed. Hence the LADM was selected. While most user requirements for Indonesia are present in the LADM, some extensions are needed, for example for dispute information. See Figure 56. See also Guspriadi (2011).

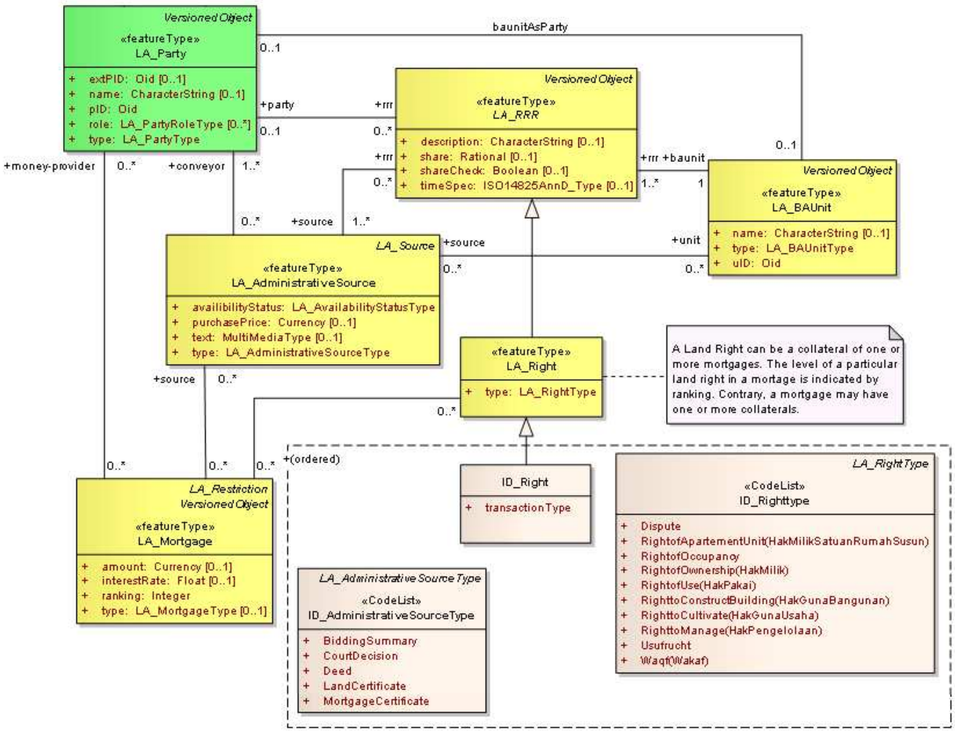

Figure 56 The Indonesian LADM country profile, with dispute information (within dashed lines, prefix ID for classes); prepared by Ary Sucaya and colleagues (Ary Sucaya, 2009).

Ary Sucaya (2009) in his MSc thesis concludes that a wide range of user requirements is accomodated by the LADM. Modification and adoption of code lists is indeed needed to adapt the LADM to localities. Comprehensive studies on localities will contribute to the enrichment of land data, empowering vulnerable groups and in line with the decentralisation spirit of the land administration in Indonesia. Sucaya sees the standardisation as a condition for decentralisation of BPN, the National Land Agency. Further he concludes that the adoption of the LADM is technically possible. The existing data model of Indonesia can be transformed to the LADM. The introduction of shares in RRRs is seen as a big advantage. Versioned object may be very supportive, e.g. in relation to the many land disputes in Indonesia. Quality labels can be used to manage the improvement of the quality of geometric data. Customary lands and gender access can be integrated. This is seen as a big advantage. Also state land can be included, e.g. to support environmental protection. There may be reduction in IT costs. Sacuya (2009) sees his work as a validation of the LADM. It would be good if similar validations would be available from other countries. He developed a prototype for validation pruposes, see Sacuya (2009).

Guspriadi (2011) in his MSc thesis sees the STDM approach as a possibility to accommodate customary rights in one level combined with formal rights in another. Using social tenure relationships is very representative. Assimilation is possible between customary and formal tenure environments and progressive approaches can de developed in two ways: from customary to formal and from formal to customary. Guspriadi (2011) sees his work as a STDM validation. In this MSc thesis he describes how to develop an assimilation approach that can accommodate customary tenure (*ulayat* land in a *minangkabau* community) within the Indonesian LAS. This approach concerns a process whereby the National Land Agency will recognise the customs and attitudes of the prevailing cultures and customs and related customary tenure concepts and principles through an integrated tool. The STDM has been used as a standard to develop this model. The model has been validated by doing some demonstrations. Some demonstrations verify that the model is valid to accommodate customary land tenure within the national LAS. A prototype has been built to simulate the provison of rights for building and cultivation; see Guspriadi (2011).

An example of a real case of customary tenure is presented in the instance level here below in Figure 57. This is based on inputs from Arko-Adjei; see also Arko-Adjei (2006) and Arko-Adjei (2011).

There has been an STDM field test in Ethiopia in 2008 and 2009 (Lemmen and Zevenbergen, 2010), in co-operation- with the World Bank and UN-HABITAT. The field tests were done with the use of high resolution satellite images. The data collection was performed together with the land right holders/claimants and local officials. The understanding of the images was high. This contributed to making the process a participatory process. See further Section 4.4.

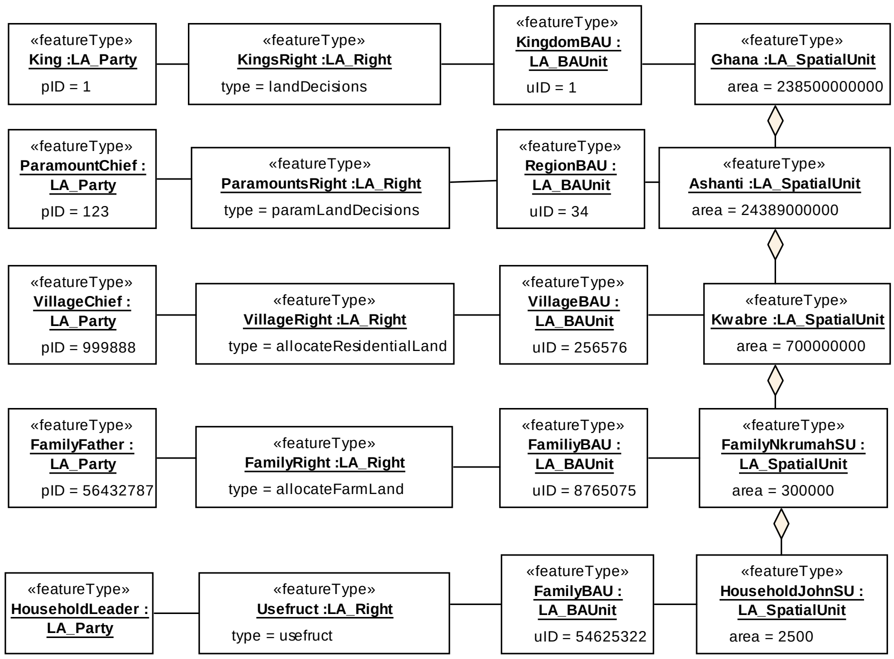

Figure 57 Customary tenure in Ghana, based on dicussions with Arko-Adjei see ISO (2011b), (DIS), Annex C, Instance Level cases, Figure C.37.

Another example is from Canada (Egesborg, 2009). Here 80,000 claims from Indian lands were reconciled and registered. The work has been completed in March 2010. When we look at the basic classes of the LAS used here, then it shows clearly its similarity with the LADM. See Figure 58.

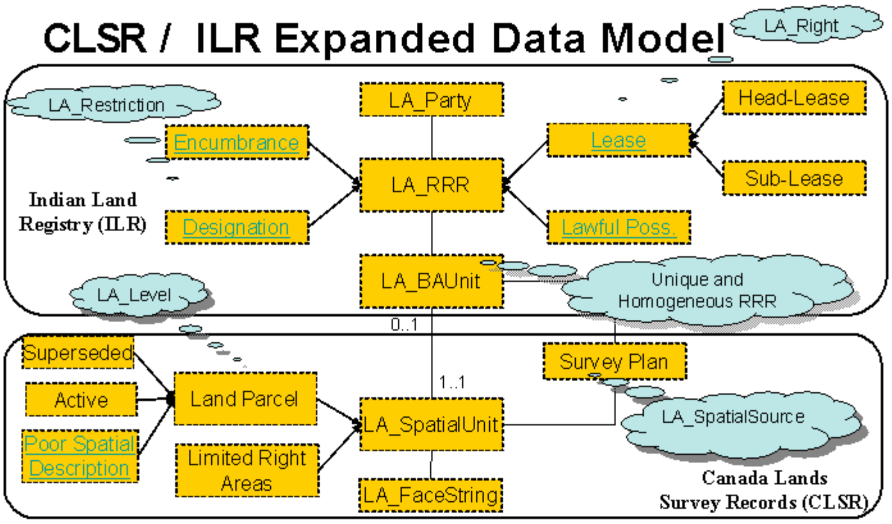

Figure 58 The Canadian LAS for registering Indian lands, Egesborg (2009).

Since 2008 a new LAS has been developed in Senegal, commissioned by the EU (Herbst and Wagner, 2009). The domain model was derived from ISO/ TC 211 (2008a).

Some changes to this domain model were made in order to fit the requirements in Senegal and to increase simplicity in order to fulfil the task of developing the application within the limited time frame. The RRR class (Rights, Restrictions and Responsibilities) was reduced to 'Tenure Relations'. Some other parts of the model were not implemented and some were simplified after discussions with the client.

Herbst and Wagner (2009) conclude that "the development of a domain model and data model is a long term process which is often in contradiction to development projects which are planned as short or medium term projects. The development of LASs in developing countries or countries in transition is no less complex than in the developed world. Often the unclear legal situation or the missing, poor or contradictory data available make the development of a LAS very complex and difficult (often more so than in developed countries)".

A system has been developed based on the STDM concept, see Figure 59. PostgreSQL/PostGIS was chosen as the DBMS. Together with the PostGIS extension it proved to be well featured and flexible enough for the implementation of the requirements defined in the domain model. The aim was to maintain validation, versions and history of objects as well as other behaviour exclusively within the database. Validated objects are treated differently and in order to validate an object, certain requirements must be met. Herbst and Wagner (2009) report that the validation was carried out mainly through trigger functions which ensure integrity of the database during insert, update and delete procedures.

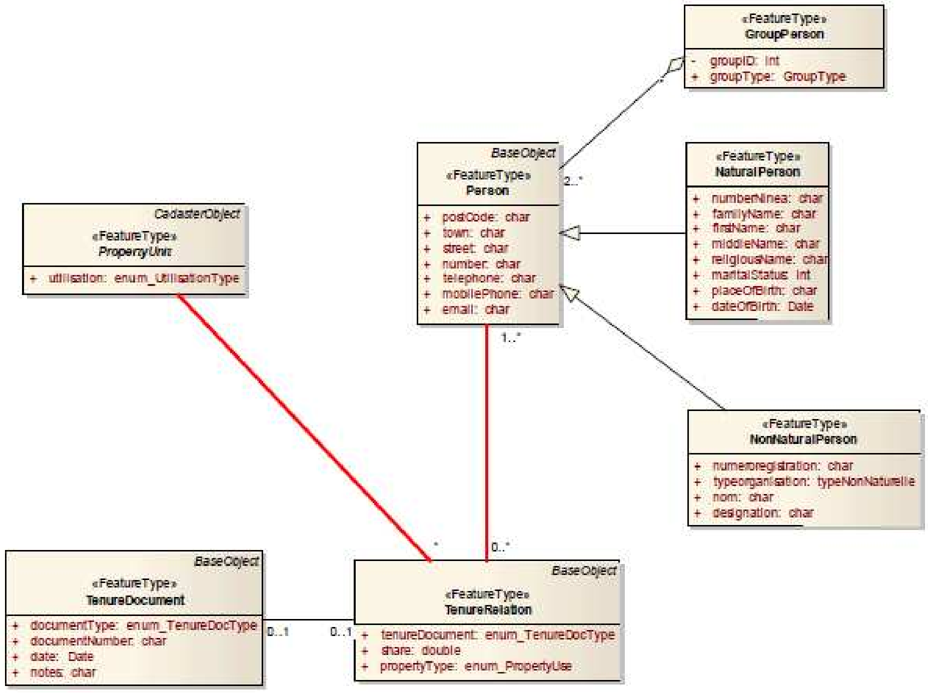

Figure 59 Part of the Class Diagram for the LAS development in Senegal based on LADM/STDM (Herbst and Wagner, 2009).

A topology as defined in ISO could not be implemented throughout the database as this would require the development of a special database extension for PostGIS, which was beyond the scope of their activities in the project (Herbst and Wagner (2009). However, the topology constraints defined in the domain model can be met by implementing verification routines in the database for individual spatial objects. One of the conclusions of the paper of Herbst and Wagner is: "*The development of a domain model and data model is a long term process which is often in contradiction to development projects which are planned as short or medium term projects. The development of LASs in developing countries or countries in transition is no less complex than in the developed world.*" It is one of the goals of the LADM to give support here. The work of Herbst and Wagner (2009) is an implementation effort of LADM.

5.2 Cyprus

In this section the enhancement of the data model of the Cyprus Land Information System (CLIS), with the adoption of the Land Administration Domain Model (LADM) is examined. The CLIS was established in 1999, within the Department of Lands and Surveys (DLS) to support the operation of the Cyprus cadastral system and has met the majority of its initial set goals. It is however now broadly accepted that the CLIS should be improved and upgraded. A new data model should be introduced to facilitate the manipulation and provision of data to internal and external users/customers in a more effective way. See: Elia, Zevenbergen, Lemmen and Van Oosterom (2012). The contents of this section are based on the paper ‘The Land Administration Domain Model (LADM) as the reference model for the Cyprus Land Information System (CLIS)’, article in Press, Survey Review.

The need to enhance the CLIS coincides with the introduction of the LADM (Elia et al, 2012). The adoption of LADM is a great opportunity for the DLS to introduce an ISO standard model, based on the Model Driven Architecture (MDA) and to gain all the benefits derived from such a movement. Such benefits include the improvement of the effectiveness and the efficiency of the current system and the expansion of the services provided by CLIS to the broader Land Administration System and to the Cyprus community. The new functionality includes better structuring of the rights, responsibilities and restrictions (and related source documents); better fitting in the information infrastructure, both national (e.g. valuation, taxation, building, address and person registrations) and international (e.g. INSPIRE cadastral parcels) and future capabilities for representing 3D spatial units (e.g. legal spaces related to apartment or utility infrastructure).

In the Cyprus Land Information System (CLIS), all data related to properties, ownerships and owners (legal bodies), attachments and valuation data are stored in the Property Database. The Property Database is a mirror of the contents of Land Register pages, and contains all the necessary information required to issue a legal Title Certificate of ownership, and reflects information on potential impediments. The property identification or the owner identification is the main entry point to the Property Database. Data stored in the Property Database can either be provisionally registered or fully registered. Fully registered data make up the bulk of the property database (DLS, 1996).

The *ownership* relation is used to record the owners of all properties recorded in the system. Ownership is recorded as fractions, if more than one owner is recorded for a property. The sum of the fractions for each property should be the equivalent of 1/1 (which means 100%) at any point in time, i.e. no fraction must be unrelated/non-existing.

Various restrictions (charges) may be recorded regarding properties, ownership and/or legal bodies. These are given the common name “*Agreements*”, see Figure 60. The existing categories of such contractual arrangements include property or personal easements, interests, restrictions, mortgages, contracts of sale, encumbrances and prohibitions. An example is when someone has bought an apartment which is still under construction. The apartment, because it is under construction, can not be registered in the DLS. For this reason, and to secure the purchase, the contract of sale is recorded at the DLS as a restriction on the parcel (lot). With this restriction, the developer can not sell the lot or the apartment under construction to somebody else, without approval of the purchaser. After the completion of the building, the apartment and its owner are registered and the title certificate is given. The contract of sale restriction is cancelled.

The primary purpose of the “*legal body*” within the CLIS is to serve as an identification of owners of immovable property, but also as an identification of other legal bodies used in the system as lawyers, mortgagees, employees, etc. The Legal Body is divided into two main groups: Persons and Organisations. This division is selected because the characteristics of each group are different. These two groups are further subdivided into "*persons*", "*foreigners and other persons*", "*companies*", "*cooperatives*" and "*other organisations*".

The *Property* (see Figure 60) is the central entity in the CLIS, as it contains an identification of all immovable properties in Cyprus. The Property Identification is used to record the ownership or lease of a property and also can be used as a recording of the persons liable to pay property tax. The "*Property*" entity does not hold much information in itself, but can be considered as an umbrella for a more detailed description of the property. The information that must always be recorded for a registered property can be summarised as: ownership, at least one subproperty, e.g. *parcel* or unit, the parcel on which the property is located.

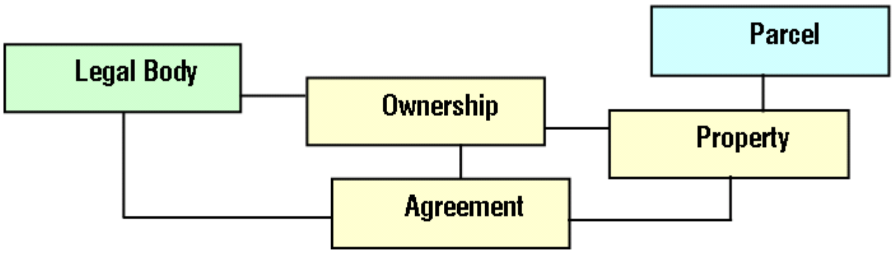

Figure 60 Cyprus Land Information System (CLIS) basic entities (Elia et al, 2011).

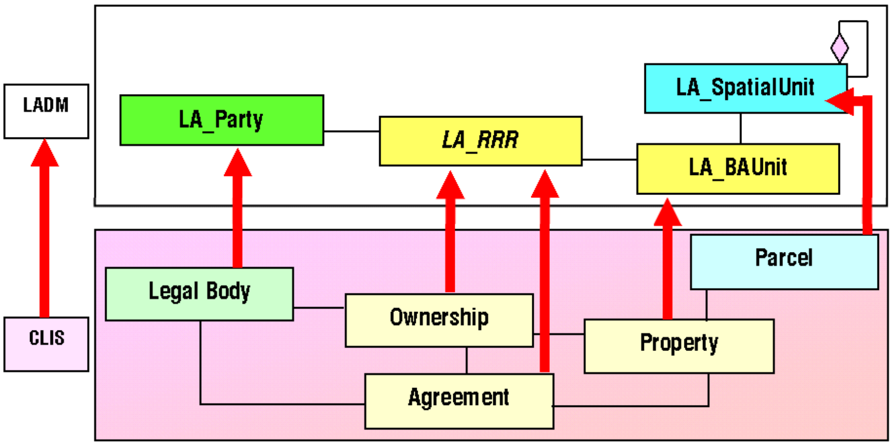

Figure 61 "Migration" of CLIS entities to LADM classes (Elia et al, 2011).

The current CLIS application does not handle efficiently the legal documents, which are circulated and stored in paper form. The "*administrative source*" class of

LADM, also resolves this problem and indicates the way of handling the legal paper documents, required for the operation of the Cyprus Land Administration System.
An enhancement of the existing CLIS model to comply with the LADM, requires the "*migration*" of CLIS entities to LADM classes. A detail examination of these entities/classes indicated that there is a direct relation between them, and the proposed migration is shown in Figure 61, see Elia (2010).

CY_Legal Body → LA_Party
The "*legal body*" entity should be converted to "*LA_Party*" class. The "*LA_Party*" could host all types of legal bodies stored in CLIS. Figure 62 shows the content of the Party class and associations to other basic classes in the proposed CLIS data model, based on the LADM. Examples of party types include natural persons contained in the external class of the Civil Registry, and non-natural persons, such as companies contained in the external class of the Companies Registry. The role of a party is activated in the data update and maintenance process.

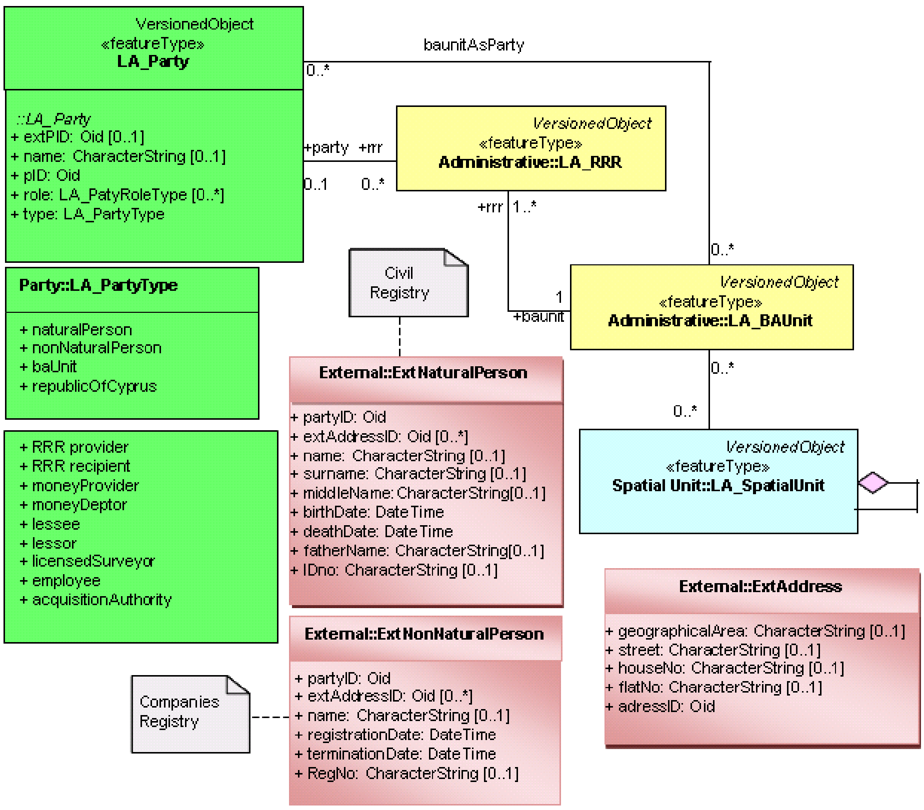

Figure 62 Content of the Party class in the proposed CLIS data model, based on the LADM (Elia, 2011).

CY_Ownership→*LA_RRR*, *CY_Agreement*→*LA_RRR*, *CY_Property* → *LA_BAUnit*
In CLIS, the "*ownership*" right is handled as a separate entity, while other rights, restrictions and responsibilities are recorded as "*agreement*" (contractual arrangements) entities. The "*ownership*" entity could constitute a type of "*LA_Right*" class and along with the "agreements" it should be migrated into LA_RRR classes, as a result of an upgrade of the CLIS and a restructuring of its data model. All "*agreements*", registered in the CLIS, could be types of "*LA_Rights*" or "LA_Restrictions". The "administrative source" class of LADM is expected to solve the problem of handling the huge amount of legal paper documents, required for the operation of the Cyprus Land Administration System. Paper documents should be converted in electronic forms for easy accessing, sharing and archiving. The "*property*" entity should be converted to "LA_BAUnit" class (Figure 63).

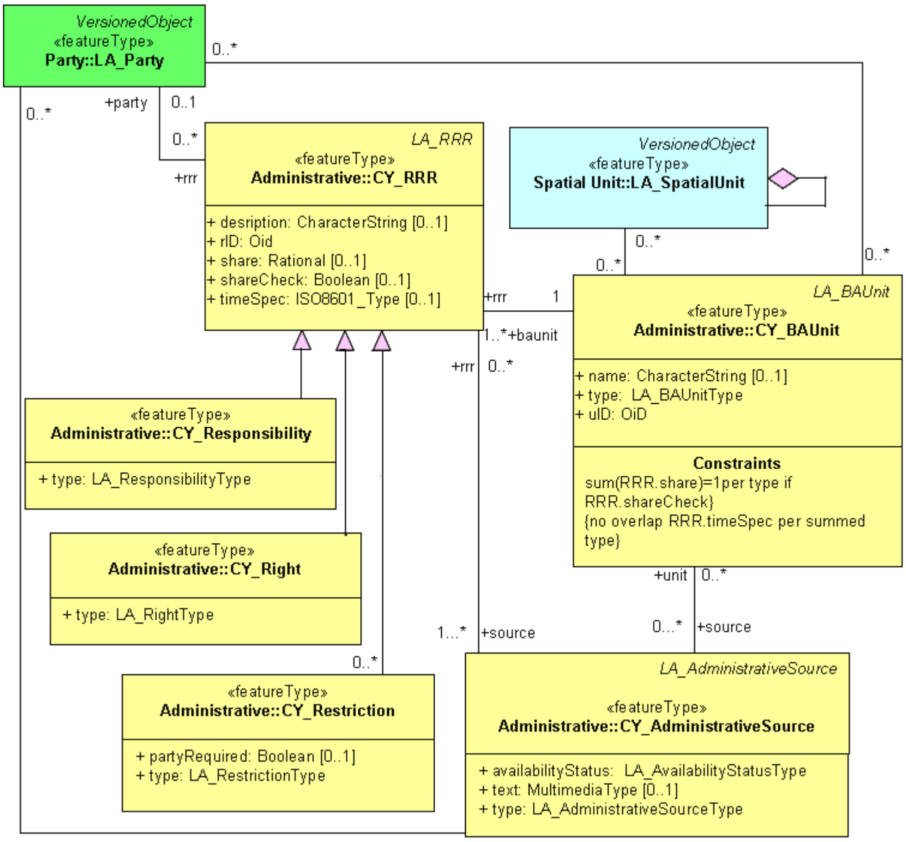

Figure 63 Content of administrative classes and associations to other basic classes (Prefix CY in classnames) (Elia et al, 2011).

Each jurisdiction has a different 'land tenure system', reflecting the social relationships regarding RRRs as regards land in that area. The variety of rights is quite large within most jurisdictions and the exact meaning of similar rights may differ considerably between jurisdictions (ISO/TC211, 2008b). In the existing CLIS, a big number of RRRs is registered or recorded, creating a multi-purpose cadastre. The recording of RRRs however is, in some cases, “unstructured”. A major advantage in adopting the LADM is the classification and structuring of RRRs. The RRRs should be classified and separated in various categories, see the code lists in Figure 64.

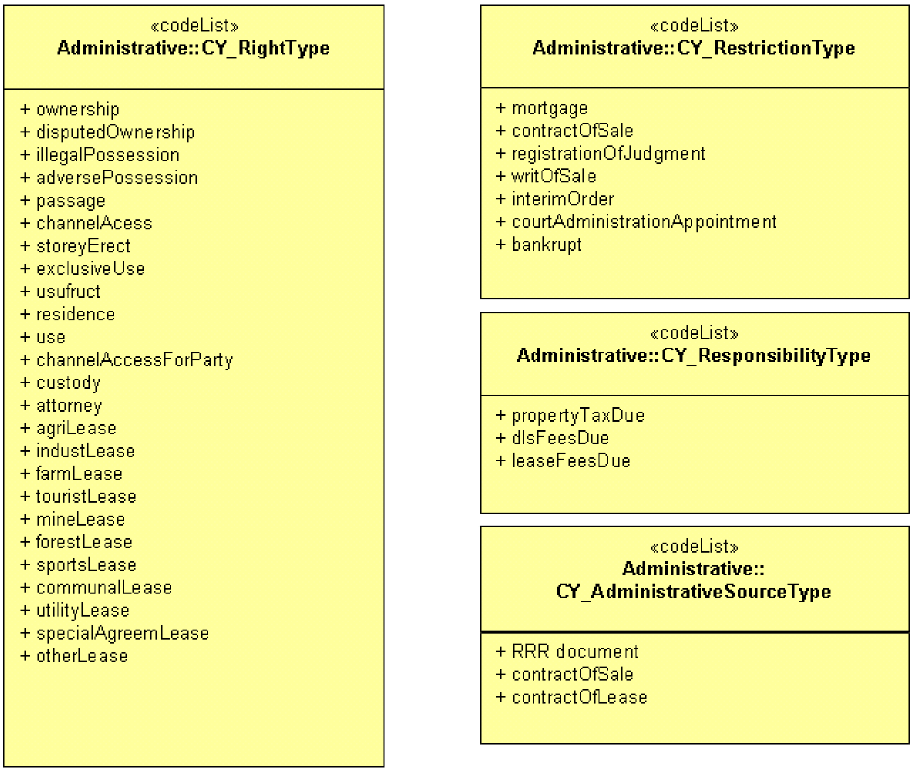

Figure 64 Code lists of the Cyprus proposed administrative package (Elia et al, 2011).

The rights are classified to: (i) rights related to ownership, which include the right of ownership, disputed ownership; illegal possession and adverse possession. (ii) easements and other rights attached to parcel units. They are real rights, meaning that the rights remain valid even when the ownership of the unit is transferred from one party to another and include the passage right, the channel access, the storey erect and the exclusive use right; (iii) easements and other rights attached to parties. Personal easements are rights which as long as they are valid, the consent of the beneficiary party is required for the transferring of the ownership right and for other property related transactions. These rights include usufruct, residence right, income, use, channel access for party. The custody is also a right attached to a party; finally (iv) the lease right, which, according to the purpose the lease is conducted to can be agriculture, industrial, farming, tourism, mining, forest, sports, communal, utility, or special agreement lease.

The restrictions are classified to: (i) restrictions attached to parcel units, as encumbrances. An encumbrance is a direct restriction (charge) upon an immovable property. It may be a voluntary charge (e.g. mortgage, contract of sale) or a result of court order (e.g. registration of judgment, writ of sale (contract)); (ii) restrictions attached to parties (prohibitions) which constitute an indirect restriction (charge) upon immovable property, resulting to the forbidding, prevention or interdiction of any person (party) from transferring or mortgaging all or any of his/her immovable property under the provisions of any law in force for the time being. The basic restrictions attached to parties, in the Cyprus Land Administration System, include the interim order, the court administration appointment and the bankrupt. In the Cyprus Land Administration System there are various responsibilities of parties related to spatial units. These responsibilities (obligations to do something) are enforced by different legislations, by the government, local authorities or other organisations. Examples of responsibilities enforced by DLS include the responsibility of property owners to pay the annual immovable property tax and in case of leases of state land the tenant has a responsibility to pay the annual rent.

CY_Parcel → LA_SpatialUnit

The "*parcel*" entity should be converted to "*LA_SpatialUnit*". LADM supports the increasing use of 3D representations of spatial units, without putting an additional burden on the existing 2D representations (ISO/TC211, 2008b). CLIS supports only 2D representations. There is, however, an increasing interest on 3D representations, see (Van Oosterom et al, 2011) and DLS could consider moving to a 3D Cadastre; this will be supported by the LADM country profile.

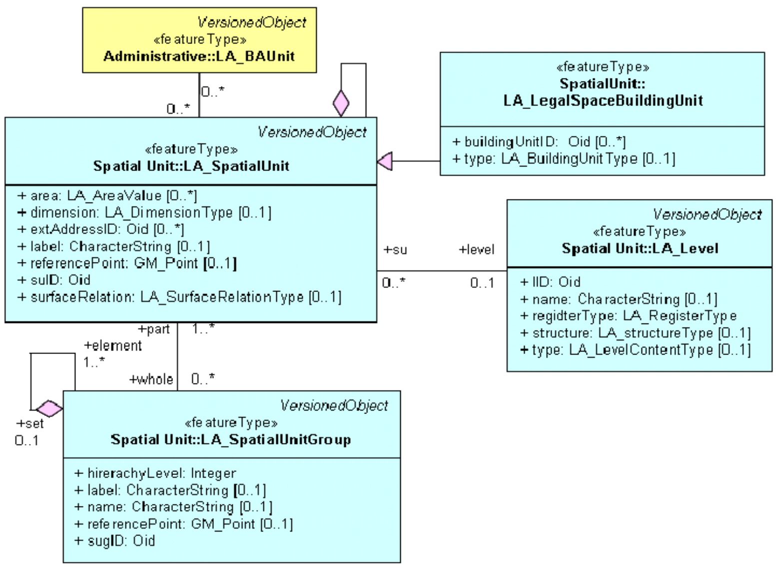

Figure 65 The spatial unit class and its association to LA_BAUnit in the proposed CLIS data model, based on the LADM (Elia et al, 2011).

Figure 65 illustrates the spatial unit class in the proposed CLIS data model, based on the LADM. For the time being, a 2D representation of spatial units is used, which could be extended to 3D in the future. The LA_SpatialUnitGroup can be used to define the level in the hierarchy of administrative subdivisions as well as for planning zoning. Cyprus is divided in districts, quarters and parcel blocks. The LA_LegalSpace-BuildingUnit can be used for the buildings registration.

It can be concluded that the work of Elias in Cyprus (in close co-operation with the co authors in Elia et al, 2011) is a real implementation effort for LADM.

5.3 Honduras

The European Commission, by means of its Agency Europe Aid, within the framework of the program URB-AL III[161] has granted financial aid for the project Integral Land Management in Puerto Barrios, Guatemala, in Omoa, Puerto Cortés and Tela in Honduras (Lemmen and Oukes, 2011).

Part of the project is the design and implementation of a municipal infrastructure for the management of geographic information in the (four) municipalities. The municipal infrastructure based on a system to be designed under the name SIGIT (Sistema de Información Gestion Integral de Tierras) has to be able to:

– maintain permanently the cadastral data;
– have permanent interchange of data between the municipal cadastral registration and the national registration, Sistema Unificado de Registros (SURE) in Honduras;
– have permanent interchange of data between the municipal cadastral registration and the municipal information systems for taxes maintain permanently the land use data;
– have permanent interchange of data between the municipal system for land use planning and the national system for land use planning, Registro Nacional de Normativas de Ordenamiento Territorial (RENOT) in Honduras;
– have permanent interchange of data between the municipal system for land use planning and the municipal systems for building permits, public services and other relevant systems and publish information online on the internet relevant for the Integral Land Management process at local level.

The SIGIT can be supportive to a situation where all citizens in a municipality *pay* the land tax and where land-possession *can be* converted to legal land ownership. This will be based on an up-to-date and complete data set in a transparent environment. The concept of SIGIT is depicted in Figure 66.

[161] URB-AL III.

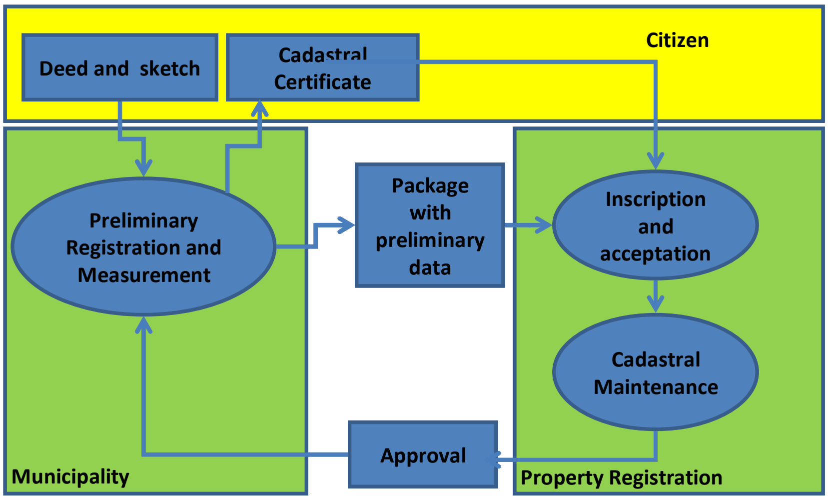

Figure 66 System concept of SIGIT (design by Koers).

SIGIT operates as a one-stop shop at the municipal side. Jan Koers, Christiaan Lemmen, and Rodimiro Espinal designed the SIGIT, based upon international standards to manage the cadastre (LADM), in a multi-user and business process oriented way with history and transaction support and with a 100% web user interface with internationalal support and open source technology programmed. The technologies used are shown in Figure 67.

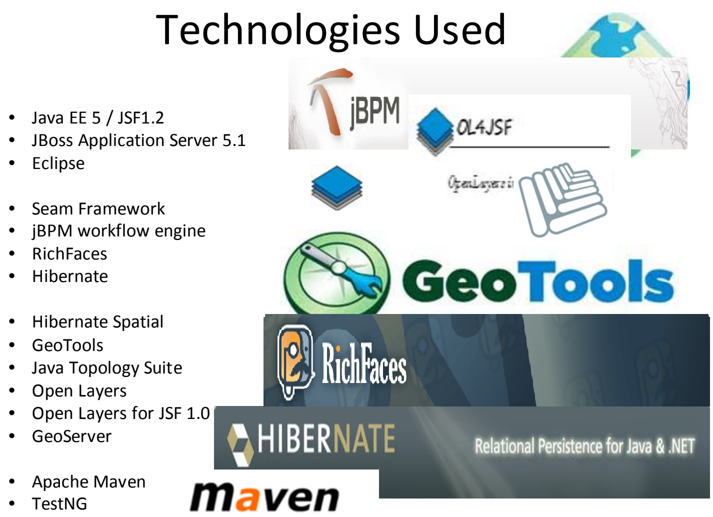

Figure 67 Technolgies used for the SIGIT design (design by Espinal).

LADM implementation was mapped using the Hibernate ORM mostly with standard JPA annotations: Entity-Relationship-Schema generated by Hibernate. The “Hibernate Spatial” extension was used to support geometry fields. Fields are represented by Java Topology Suite class objects. Classes with the HND_ prefix are used to represent information regarding Honduras.

Only generalisation associations are done from the LA-prefix classes to HND-prefix classes. During a transaction, data are copied to a Shadow. All the modifications are done there. When a transaction is complete, data are copied back to the LADM schema. Figure 68 shows the interface for property right mutation.

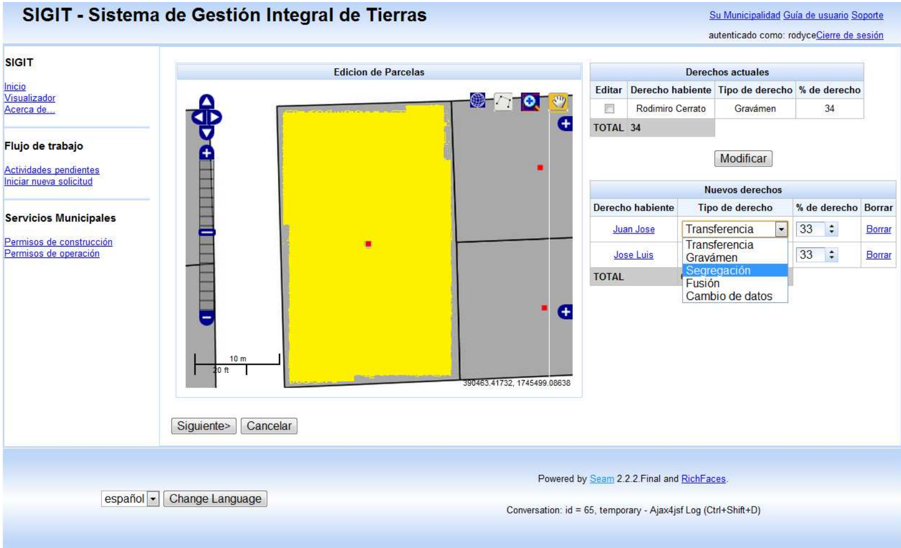

Figure 68 Interface for property right mutation (design by Espinal).

It can be concluded that this is a real implemtation effort based on LADM and MDA. See research question 2. In practice it became clear that the LADM conceptual schema was insufficient; an application schema (in UML) is needed to generate the database.

5.4 Portugal

In their paper Hespanha et al (2006) developed an object oriented, conceptual model for the Land Administration Domain adapted to the Portuguese Cadastre and the Portuguese Real Estate Register. After a brief description of the present Cadastral and Land Registration situation in Portugal, UML (Unified Modeling Language) literate modeling is used to describe the top level classes by using a structured mix of UML Class Diagrams and natural text. Important contributions in this paper are the evaluation of the CCDM by applying it to Portugal. It turns out that a limited number of the classes of the domain model (at that time still called Core Cadastral Domain model) are currently not needed (but some of them might be used in the future) and that other classes need to be added specifically for the situation in Portugal. This is anticipated use of the domin model and in case similar patterns occurs in several countries, the new version of the domain model should be adapted accordingly. Activity Diagrams were used to model dynamic behavior concerning a number of chosen Cadastral Update tasks.

In Lemmen et al (2010b) it is stated that the modelling of the LA domain, has evolved significantly during the transition to the new millennium, and this is reflected in the information technology frameworks from the previous specifications (IGP, 1996), to the latest specifications, which are UML based and ISO compliant (IGP, 2009).

One important change from the older to the current specifications, is the focus on just two of the three forms of property: (1) private ownership and (2) local community ownership, omitting thus public domain ownership. Also, specialised classes from LA_SpatialUnit, namely class LA_LegalSpaceBuildingUnit, will not be acquired anymore, given the new specifications. The final result is the absence of a strict view of a planar partition, once there will be gaps over the country territory. Furthermore, consideration of transitional areas, which are currently of an informal legal status, as the Deferred Cadastre or the Urban Areas of Illegal Genesis (AUGI, in Portuguese), will form areas that could overlap private ownership parcels.

The proposal is therefore to consider the Polygon Based Spatial Profile from the LADM (see Figure 69) as the geometry representation for the specific Portuguese spatial units. Within this profile, individual polygons are assembled by one or more GM_Multicurve geometry types. For implementation purposes, definitions contained in the Simple Features specifications (OGC, 2006a) will be considered, because they are largely adopted in current spatial DBMSs.

In this way, the constraints to be taken care of are the ones, that each instance of the LA_BoundaryFaceString forms a Linear Ring and that the boundary between adjacent polygons (which will be duplicated) do not create sliver polygons.

Considering the LA_LevelContentType code types used in the LA_Level class, one could group the Portuguese specialisations of the LA_SpatialUnit into two levels.

1. *Base Level*: comprising Real Property and Baldios (Customary Land) parcels, which fundamentally do not overlap, but will have gaps or even holes within them. The code type will be ‘primaryRight’, once it is determined by the basic ownership right as a maximum real right;
2. *EmptyAreas Level*: thus called in the Portuguese specifications. They comprise both AUGI areas, which can overlap other spatial units on the Base Level or the Deferred Cadastre areas, which, in spite of being (potentially) private Real Property, do not have a full legal status due to a number of reasons.

The boundary face strings and points (respectively from class LA_Boundary-FaceString and class LA_Point) are successively derived from a spatial source, although the surveying subpackage is presently absent from the specifications.

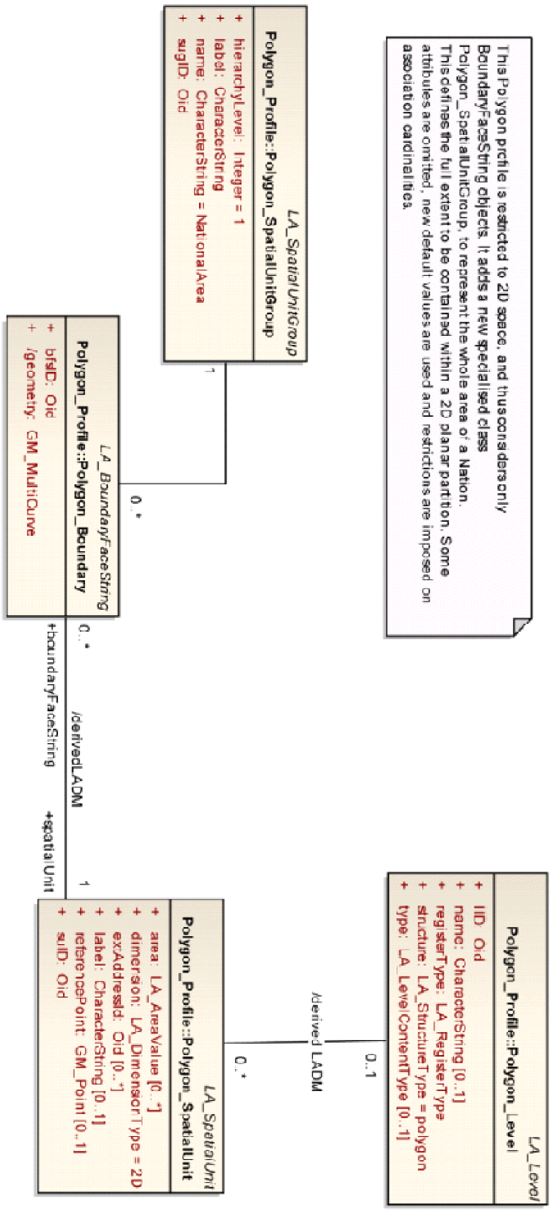

Figure 69 2D Polygon base spatial profile (ISO/TC211, 2011c).

5.5 INSPIRE

For cross-border access of geo-data, a European metadata profile, based on ISO standards, is under development using rules of implementation defined by the Infrastructure for Spatial Information in the European Community, INSPIRE (INSPIRE, 2007). For actual data exchange, the INSPIRE implementing rules will further define harmonised data specifications and network services. This is complemented with data access policies and monitoring and reporting on the use of INSPIRE. '*Cadastral parcels'* is one of the harmonised data sets (INSPIRE, 2009). Cadastral parcels in INSPIRE should serve the purpose of generic information locators for environmental applications, i.e. searching and linking other spatial information.

The INSPIRE Directive requires to take existing standards into account (article 7 of the Directive). Once adopted, the ISO 19152 standard should be taken into account if there are requirements and consensus to extend Data Specification for Cadastral Parcels. In the case of the LADM, there was an opportunity as both the INSPIRE Cadastral Parcels (CP) and the LADM where under development at the same time. Through joint work, between the INSPIRE Thematic Working Group CP and the LADM Project Team, this has been achieved. This ensured consistency between INSPIRE and LADM, and resulted in a matching of concepts and compatible definitions of common concepts. It must be remembered that there are differences in scope and targeted application areas; e.g. INSPIRE has strong focus on environmental users, while LADM has a multi-purpose character and is supporting both data producers and data users in these various application areas. Also, LADM has harmonisation solutions for rights and owners of 3D spatial units, which are currently also outside the scope of INSPIRE CP. However, through intensive co-operation, it is now made possible that a European country may be compliant both with INSPIRE and with LADM. Further, it is made possible through the use of LADM to extend INSPIRE specifications in future, if there are requirements and consensus to do so.

In order to 'prove' the compatibility, Figure 70 shows the LADM based version of INSPIRE Cadastral Parcels, explicitly indicating how the INSPIRE development fits within the LADM and that there are no inconsistencies. In selecting relevant classes from LADM, using inheritance, adding attributes and constraints it has been possible to express of the INSPIRE Cadastral Parcels data set consistent with LADM. In INSPIRE context, four classes are relevant:

- LA_SpatialUnit (with LA_Parcel as alias) as basis for CadastralParcel;
- LA_BAUnit as basis for BasicPropertyUnit;
- LA_BoundaryFaceString as basis for CadastralBoundary;
- LA_SpatialUnitGroup as basis for CadastralZoning.

The LADM attributes inherited by INSPIRE can have a more specific data type or cardinality in INSPIRE (compared to LADM). This has been included in the diagram. This implies that an optional LADM attribute [0..1], might not occur in INSPIRE as the cardinality can be set to 0; e.g. nationalVolume. This also implies that an optional LADM attribute [0..1], might be an obligatory attribute in INSPIRE; e.g. label. Further, INSPIRE specific attributes are added to the different classes. Figure 70 looks a bit more complicated as the normal INSPIRE CP UML class diagram, because it is showing the different LADM parent classes and the refinement of the different attribute types (but the resulting model is the same).

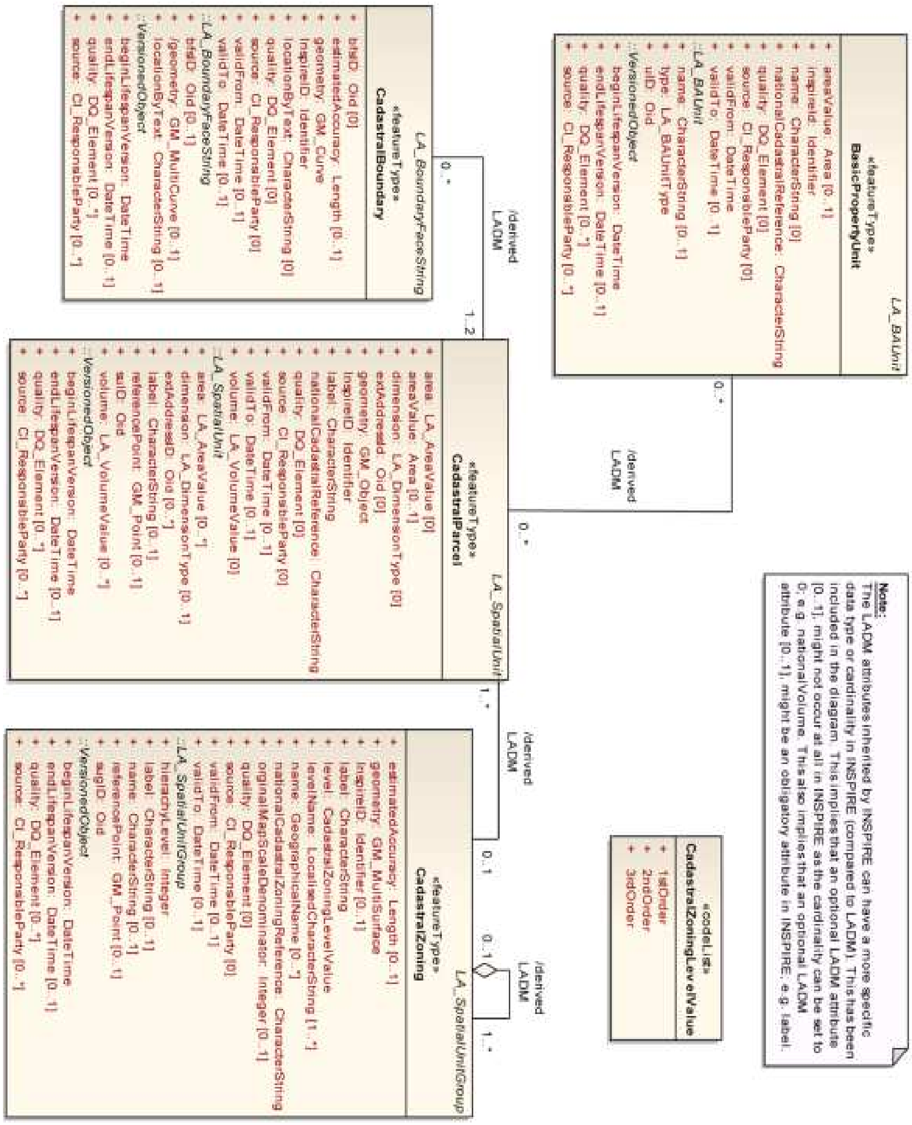

Figure 70 The INSPIRE Cadastral Parcel model derived from the LADM via inheritance (ISO, 2011c).

5.6 Land Parcel Identification System (LPIS)

One of the aspects of the Common Agricultural Policy (CAP) of the European Union is to focus on the management of subsidies to the farmers. For this purpose, member states have established Integrated Administration and Control Systems, including Land Parcel Identification Systems (LPISs) as the spatial component. The LPIS as a concept was developed already in 1992, when the need for identification of the agricultural parcels to support IACS emerged. At that time, the data model was purely alphanumerical without any geospatial reference. It was in the Council Reg. No 1593 (2000)[162] that the spatial LPIS based on a GIS was promoted. Five years have been given to the member states to establish LPIS in digital and geo-referenced format. Thus, the first year of operational GIS-based LPIS was 2005. Although the regulatory requirements were unique across the sector, the particular implementations were a subject of the member states. In fact, during the development stages of different LPISs in different member states, the use of Land Administration (LA) or Cadastre data, as well as large-scale topography data, were on the agenda for a considerable while (UNECE, 2004).

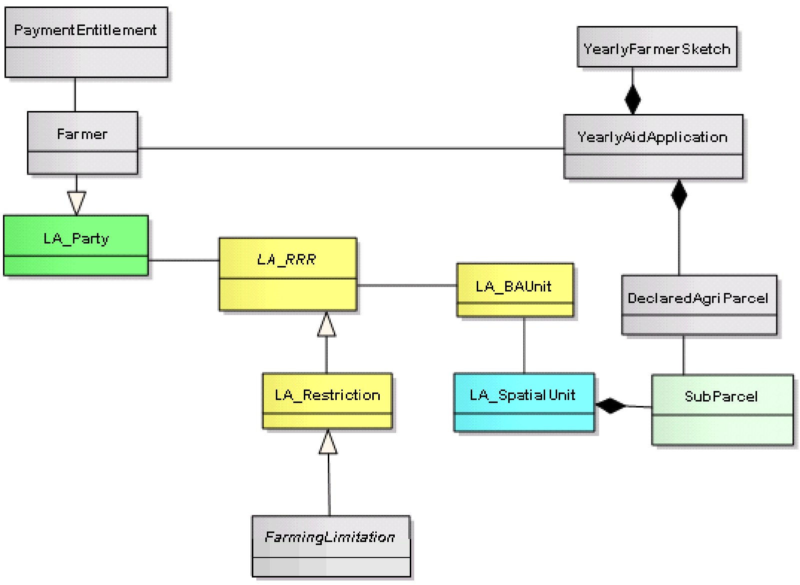

Figure 71 Integration of LADM and LPIS.

In Figure 71 a data model is designed, that implies the collaboration or integration of LADM and LPIS. The standardisation initiative in the area of LPIS (Sagris and Devos, 2008; CCM, 2009) by the Joint Research Centre (JRC) of the European

[162] COUNCIL REGULATION (EC) No 1593/2000 of 17 July 2000 amending Regulation (EEC) No 3508/92 establishing an integrated administration and control system for certain Community aid schemes

Commission is used in this example in order to represent potentials for integration/collaboration between LADM and LPIS. See also Inan et al, (2008).

5.7 FAO Solutions for the Open Land Administration

The FAO Solutions for the Open Land Administration (SOLA)[163] project will promote affordable IT-systems that enable improvements in transparency and equity of governance. Started in June 2010, SOLA is a three year trust fund project funded by the Government of Finland. Through the development and re-use of open source software, it aims to make computerised LASs more affordable and more sustainable in developing countries. Three countries (Samoa, Nepal and Ghana) have been identified for pilot implementation of the software. The LADM is being used as input for SOLA developments[164].

In the statement of requirements (FAO, 2011a) it can be learned that the geospatial components used and/or implemented by the system will support applicable OGC and ISO TC2115 standards as well as applicable INSPIRE6 guidelines, e.g. WFS, GML, LADM, etc.

The SOLA database is implemented in a PostgreSQL (FAO, 2011d) database and is a relational database implementation of an extended version of the LADM DIS. It has been necessary to extend DIS 19152 because of the operational needs of land administration agencies to incorporate case management and other features into any system that supports the processing of client service requests (for land information, registration and cadastre change requests and others) and the maintaining and updating rights and restrictions, ownership and property boundaries. The FLOSS SOLA software supports this range of land administration business processes and the FLOSS SOLA database is an integral part. It should be noted here that it was never the intention to include process or case management into the LADM, see principle 2 in Section 1.4. The FLOSS SOLA Data Dictionary (FAO, 2011d) gives some nice examples of the flexibility of LADM, see for example the values of the ‘administrativeSourceType’: ‘proclamation’, ‘courtOrder’, ‘agreement’, ‘contractForSale’, ‘will’, ‘powerOfAttorney’, ‘standardDocument’, ‘waiver’ and ‘idVerification’ are not included in LADM but could be very easily integrated in FLOSS SOLA from FAO.

The structure of the SOLA Database is based on the data storage requirements implied by the Land Administration Domain Model although extensions and adjustments have been included to support the function requirements of SOLA (FAO, 2011b). The database contains multiple schemas with the data in each schema managed and maintained by a primary SOLA EJB. The PostGIS Database provides support for storage and manipulation of spatial data. Use cases are documented in FAO, 2011e. User documentation for software development is available (FAO, 2011c).

See further FAO and FIG (2010), FAO, 2011a, FAO 2011b, FAO 2011c, FAO 2011d and FAO 2011e for a comprehensive description.

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[163] http://flossola.org/
[164] see www.flossola.org

5.8 Discussion

Real efforts for implementation are ongoing in Cyprus, Honduras and Senegal. There is attention to the LADM within the European Union for implementation in LPIS and INSPIRE (cadastral parcels). Furthermore attention is paid to the development in other countries; e.g Indonesia (where the LADM may be very supportive in the decentralisation of BPN) and Portugal. All this is ongoing even before the development of LADM within ISO has been finalised and resulting in an International Standard (IS). This is a good indication for the urgent need for and support to the standard.

The MDA has been applied in Honduras. From there it was observed that role names are not included everywhere in the scheme. This is because the LADM concerns a conceptual schema, navigability is considered to be integrated in the implementation.

6 Conclusions and Recommendations

This chapter provides conclusions and presents the main results from this research in Section 6.1 and an overview of possible future work in Section 6.2.

6.1 Conclusions

The research objective is:
"To design a Land Administration Domain Model (LADM). It should be possible to use this model as a basis for LAS development. Such an LADM has to be accepted and it should be adaptable to local situations. It has to be usable to organise LA data within a SDI. The design is based on the pattern of 'People to Land' relationships."

The Land Administration Domain Model (LADM) has been designed and published as a Draft International Standard (DIS) by the International Organization for Standardization (ISO, 2011c), as ISO 19152.

In Figure 72 an overview of all the diagrams of the DIS is depicted. The DIS has been developed on the basis of a set of user requirements derived from existing literature (see Chapter 2), from experience from practise, both personal and from experts from many different countries and earlier publications on LADM (see for an overview Section 1.6), including earlier versions published within ISO (ISO, 2008a, ISO, 2008b, ISO, 2009). These requirements are presented in Section 3.1, 3.3 and 3.5. The overview of requirements in Section 3.5 is derived from the comments and observations provided by a group of international experts involved in the development of the ISO 19152 standard on LADM.

The requirements presented in Section 3.1 have been used as basis for the design of LADM Version A, see Section 3.2. The next, extended, set of requirements as given in Section 3.3, has been used as input for the design of LADM Version B. This version is introduced in Section 3.4. Version B has been the basis for a new Working Item Proposal submitted (by FIG) to ISO. Further LADM developments took place under the ISO umbrella; the author is editor[165] in co-operation with co-editors Harry Uitermark and Peter van Oosterom.

The Draft International Standard (DIS)[166], in this thesis known as LADM Version C (see Section 3.6), covers basic information related to components of land administration (land administration includes water and elements above and below the earth's surface). 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

[165] The Editorial Committee has been drafting the ISO 19152 Land Administration Domain Model. The ISO 19152 DIS is presented in this thesis as LADM Version C..
[166] Legal implications that interfere with (national) land administration laws are outside the scope of the LADM.

in UML packages and class diagrams in this thesis. 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.

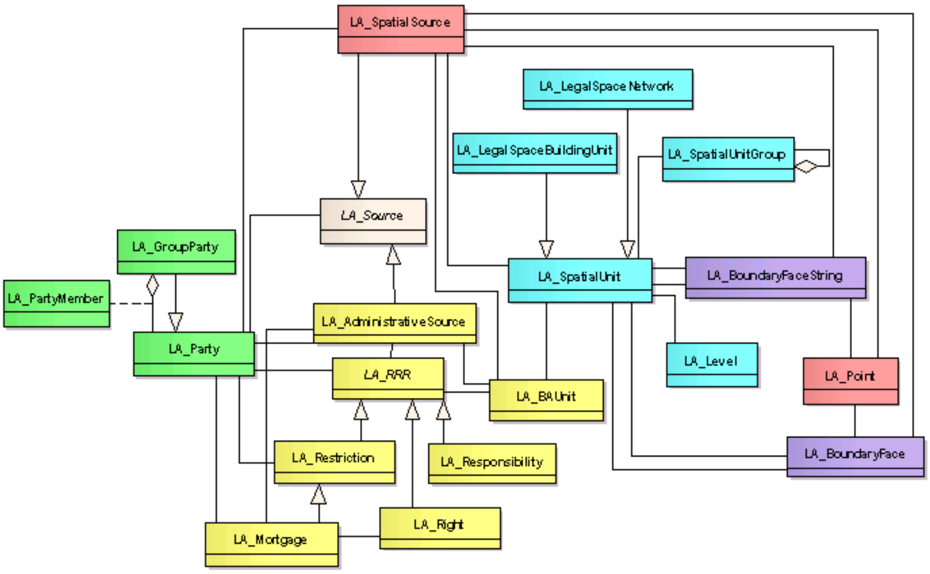

Figure 72 The LADM as Draft International Standard, figure designed by Harry Uitermark based on ISO/TC211 (2011c).

Rights may include real and personal, rights as well as indigenous, customary and informal rights. All types of restrictions and responsibilities can be represented. Overlapping claims to land may be included.

A set of research questions has been formulated in Section 1.4; the conclusions in relation to those questions are as follows.

1. What is this common pattern of ‘People to Land’ relationships?
   The common denominator or the *pattern* that can be observed in land administration systems is with a package of *party/person/organisation* data and *RRR/legal/administrative* data, *spatial unit (parcel)/immovable object* data. This can be derived from the existing work on Land Administration Domain Modelling, see Chapter 2. During the LADM design, as expressed in Chapter 3, it became more and more clear that the Triple ‘Subject – Right – Object’ (as introduced in Section 2.2 and further in Chapter 2) is insufficient to cover a group of existing LASs which is not ‘parcel or spatial unit based’ but ‘property based’. In those LASs all spatial units ‘belonging’ to the same basic property unit are seen as one single object. This implies the core classes Party, RRR and SpatialUnit have to be extended with one more class BAUnit: ‘Basic Administrative Unit’. The design steps are introduced in Chapter 3 of this thesis; cumulating in Section

3.6 where the BAUnit is introduced as a core class in the ISO 19152 LADM Draft International Standard. Conclusion: the common pattern can be represented in four core classes: Party, RRR, BAUnit and SpatialUnit.

2. How can the model be used as a basis for LAS development?
   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. Structuring and organising data may be in interaction with data in other databases. Databases can be implemented in a distributed environment in different organisations with different responsibilities in Land Administration. The MDA approach can support in generating database schemas. Exchange formats (XML) between organisations – in case of a distributed environment for implementation – are not illustrated in this thesis.
   See the approach for software development in Honduras as presented in Section 5.3. An application schema is needed for software development, but this can only be developed after the local demands are precisely known. The application schema can be built on the generic conceptual schema of the LADM (this is the UML Model from Version C of the LADM, see Section 3.6), combined with local needs. This is also demonstrated in FAO FLOSS SOLA (FAO, 2011d)[167]. Annex A of ISO 19152 provides a abstract test suite to check if a model is LADM compliant.
3. Is the design usable within a Spatial Data Infrastructure?
   This concerns firstly the data exchange between organisations involved in land administration, packages have been introduced in LADM for a proper representation of tasks and responsibilities. Secondly 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 Draft International Standard includes informative example cases with People to Land relationships demonstrating the flexibility of the draft standard in its Annex C. The 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 certainty) for all. Thirdly, for implementation in SDI the links to external classes in other registrations, as presented in Subsection 3.6.6, are important, see also Figure 73. The integration of LADM in SDI, and also in key registers, is discussed in Section 3.8.
4. Is the design accepted and supported by LA professionals and governments?
   There is support from professions, e.g. within FIG (FIG submitted the NWIP to ISO, LADM is ‘FIG Proof’), ISO/TC211 (an editorial committee with experts from about ten countries prepared the ISO 1952), UN-HABITAT (the development and implementation of STDM), EU (attention to LADM in relation to LPIS, INSPIRE), FAO (LADM as basis for FLOSS/SOLA) and countries

[167] Quote from this document: ‘*The SOLA database is implemented in a Postgres SQL database and is a relational database implementation of an extended version of the Land Administration Data Model (LADM) which is currently a Draft International Standard (DIS 19152). It has been necessary to extend DIS 19152 because of the operational needs of land administration agencies to incorporate case management and other features into any system that supports the processing of client service requests (for land information, registration and cadastre change requests and others) and the maintaining and updating of the record of rights and restrictions, ownership and property boundaries*’.

(Cyprus, Portugal and Honduras, see Chapter 5. Bahrein, Canada, Indonesia, Montenegro, Uganda, Senegal and South Korea) are adopting or interested.

5. Is the design adaptable to local situations?
   The draft standard can be extended and adapted to local situations; in this way all People to Land relationships may be represented. This can be supportive in the development of software applications built on database technology. 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. See example cases in Section 5.1[168], with country profiles, spatial profile, example of customary tenure representation; Section 5.2 with LADM as a case at Cyprus; Section 5.3 with a case in Honduras; Section 5.4 with a case in Portugal. The integration with the INSPIRE Cadastral Parcel Model (INSPIRE, 2009) is documented in Section 5.5 and with LPIS in Section 5.6. 3D Cadastres are covered in such a way that these seamlessly integrate with existing 2D registrations. External links to other databases, e.g. addresses, can be included, see Section 3.6.6. A very nice example of an extended and adapted version of the LADM is in FAO/FLOSSOLA, see Section 5.7.
6. Is the design implementable and applicable in a real life situation?
   Applications in real life situations can be concluded from: firstly the prototype based on STDM (see Section 4.1, 4.2 and 4.3) for processing of field work data for validation purposes. Secondly the case from Cyprus in Section 5.2, thirdly the case from Honduras in Section 5.3 and fourthly the case from Portugal in Section 5.4. For the use in the context of FLOSS SOLA, FAO, see Section 5.7. And more to follow.

In general it can be concluded that 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. FIG submitted the LADM as a NWIP to ISO/TC 211 in 2008. A main effort was in finding agreement between experts from different countries and in provision of balanced reactions to comments and observations made by experts. The standard 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 is a common language for LA enabling understanding each other. ISO has a standard update cycle for revisions of standards.

[168] Section 5.1 includes model validations from Senegal (Herbst and Wagner, 2009) and by two students at ITC during their MSc research (Guspriadi, 2011) and (Ary Sucaya, 2011).

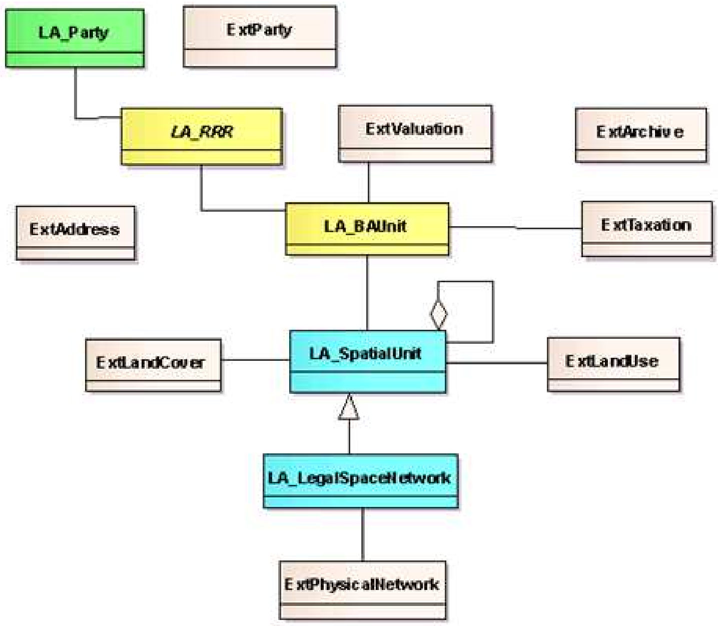

Figure 73 LADM and External classes, figure designed by Harry Uitermark based on ISO/TC211c, 2011.

The objective of this research has been achieved; the research questions have been answered. Validation has been performed. The fact that many experts have been involved in the LADM development – with a lot of experience in developments and implementations of LASs – is a solid basis. Their acceptance is very promising. Also developments in Cyprus and other countries and with FAO FLOSS SOLA are promising. Further implementation is ongoing; e.g. the STDM at UN-HABITAT. More testing is required. Data exchange requires further attention in LADM (XML encoding).

6.2 Future Work

With the official status of the LADM as an International Standard approaching, the question arises: what's next? The answer is of course *more implementation and use of the model in practice.* Already several country profiles have been designed and other model usage is being conducted; e.g. in the Solutions for Open Land Administration (SOLA) project and the development of the Social Tenure Domain Model as an Open Source software by UN-HABITAT. Those developments are promising and underline the need for a model as LADM. In the past, there have been more publications on the anticipated developments of Land Administration, see Kaufmann and Steudler (1998), Van der Molen (2003) and more recently Bennett et al (2010); Lemmens (2010a) and Lemmens (2010b).

The expected further requirements to LADM for the next decade have been discussed in Uitermark et al (2010). Those requirements concern: formalisation of current constraints, standardisation of processes, new RRRs, mature information infrastructures to serve society; 3D, 4D that is, space and time integrated in Land Administration; applications of augmented reality; spatial design applications; semantic web technologies; monitoring applications; and user dominance (this is a dynamic process model with acquisition/updating/participation by actors and community driven cadastral mapping – crowdsourcing). LADM is a requirement here from a modelling perspective. Below these are elaborated.

Formalisation of current constraints in LADM. Now the standard is documented for large parts in English where the constraints are concerned. Object Constraint Language (OCL) should be used here. More constraints should be added where appropriate; this means refinement of semantics.

Inclusion of processes. After the standardisation of the information model also process models may be considered to standardise. See in relation to this OSCAR (2009).

At leased guidelines can be developed for procedures/workflows based on best practise/experience as in Zevenbergen et al (2007).

New RRRs and mature information infrastructures. In general it can be expected that many types of public restrictions need to be included in Land Administration – as far as not yet there (Kaufmann and Steudler, 1998 and Williamson et al, 2010). This includes planning zones under design or under implementation. The same holds for taxation zones or benefiting areas, for fair payments by the real beneficiaries, or limitations in land use because of environmental conditions related to restrictions in land use. In other zones land use may be allowed to intensify. Permits may be required in specific zones.

LASs need the flexibility to easily introduce a range of new registrations. A characteristic of all these new registrations is that people, spatial objects or spatial phenomena (and the relationships between these) are important. Spatial phenomena can be existing, registered, situations or situations under design or development. Emerging examples of this are: registration of groundwater quota (note that this has clearly a 3D and temporal character) (Ghawana et al, 2010), carbon credit quota registration (as a tool to assist in taking measures to cope with global climate change) or rights of all kinds of natural resources (such as mining). But also the physical plans and the associated rights, restrictions and responsibilities they bring along, will belong to this category of 'new' registrations in LASs. Instead of unrelated registrations, in the next decade society will benefit from a harmonised system of registrations of all these spatial and temporal objects and the involved rights, restrictions and responsibilities. This can be combined with polygons and points from risk maps, areas effected by disasters, polygons representing areas with a lot of sunshine (solar panels require space) or wind (wind mills with restrictions around), areas defined in 112 centres, etc. Other attributes (e.g. energy labels for buildings, hazardous substances, anti-fire protection in buildings - via external building class) can also be introduced in an easy way in an LADM based environment in combination with mature information infrastructures. New RRRs are in support to the implementation of LADM/STDM.

The information society, which is currently in its infancy stage, will be more mature by the year 2025; with as a result several well established *domain standards*, enabling meaningful information exchange, but also at a national or local level, between different domains or disciplines. The LADM is one of the very first examples here. The information infrastructure will provide the environment for integrated and 'seamless' access to all these sources. Similar proposals can be found in Bennet et al (2010).

Information infrastructures will provide the environment in which data sources can be maintained in a consistent manner. Domains need links with other domains, which require that updates take care of consistency with related registrations. For LASs, as cornerstone of the information infrastructure, these links with other registrations are numerous, for example, persons, companies, addresses, buildings, rights, or topography. Besides 7*24 hours access over the network, this requires certain mechanisms to be in operation, like every registration must maintain history (in order to avoid 'dangling' references from outside, not aware of certain changes), update alert or notification systems must be established (in order to inform related registrations about changes, which may also need an update in the related registrations) and providing adequate solutions for performance and robustness, for example, via replicated, proxy servers.

Research is recommended on those areas: development of domain standards on buildings, addresses, buildings, topography, etc. See the LADM external classes in Subsection 3.6.6. Consistency issues are important in relation to this. One more important research area is in using MDAs – new 'versions' of standards will be available. This has impact on environments where earlier versions have been introduced.

3D, 4D Cadastres. The increasing complexity and flexibility of modern land use requires that LASs will need an improved capacity to manage the third dimension. As the world is by definition not static, there will be a need in relation to the representation of the temporal (fourth) dimension, either integrated with the spatial dimensions or as separate attribute(s). In the long term, an integrated 4D registration of all objects will be the most effective solution (Van Oosterom et al, 2006; Döner et al, 2010) in dense urban areas. The *4D integrated space/time paradigm*, as a partition of space and time without gaps and overlaps (in space and time), is a very generic and solid basis. Initially, this approach may seam overkill, and only to be applied for some more complex objects such as construction works and utility networks. However, by the year 2020, the technological challenges related to 4D registrations will be solved, and this will be the most effective base for registering all objects.

Augmented reality. Augmented reality applications, precise positioning and orientation: data must be accessible everywhere, all using authentic sources, but also for updating these sources by the community outside. Furthermore, mobile applications can read the successors of bar codes of id-cards to identify people, and digital fingerprints, or iris scans will be available in the field. These types of attributes are already included in the LADM. As with the development of crowd sourcing the development of augmented reality applications depend on the availability of domain standards to get generic functionality available in an open environment.

Spatial design. Today LA is mainly used in ‘registration’ mode: observations from reality are represented in the LAS. But it may also be well situated to be used in ‘design’ mode: objects created/designed in the system are being implemented in reality; e.g. as in land consolitation or re-allotment. This implies: participation in decision making of the areas involved (using many existing spatial data and creating many new spatial data at the same time (design means data creation)), participation in the design of zones where land use functions are to be allocated (requirements, wishes, agreements, complaints and acceptance by citizens) and involvement in the implementation of the zoning plan (with new and temporal restrictions and responsibilities, permits and maintenance issues). All this with mechanisms to avoid people losing land rights (also in customary areas or in areas where LA does not exist at this moment) and where governments can apply all kind of restrictions. In relation to carbon credits (see Van der Molen, 2009). LADM has the flexibility to bring support in management of data for spatial design. In designing new spatial units, the future information infrastructure will be heavily used as the design requirements are related to many other geo-information sources. Further research is needed to check if the requirements from spatial design on the level of spatial units (e.g. land consolidation and urban planning) are supported by the LADM.

Semantic Web Technology. Differences in (legal) concepts, terminology and languages, which are used in the different LASs in different countries, are today still limiting the access and understanding of LA data in an international context (compare the EULIS project; see Tiainen, 2004). However, legal concepts of different countries will be formalised using semantic web technology, similar to all other kinds of knowledge. These formalised semantics are used in the linking between the concepts and terminology from different countries, allowing the users to have access to all information in an unambiguous and understandable manner. The LADM structures, legal/administrative data and spatial data via country profiles into a standardised model. LADM is recommended to be used in research in this area. LADM could function as an intermediate between different ontologies.

Monitoring changes. Satellites can monitor changes in areas, which have been identified as world heritage sites: forest and nature, lakes, coast lines, glaciers and polar zones. But also land use (e.g. agriculture land) and phenomena as inundations and draughts can be monitored. This information can be linked to ‘RRR’ polygons and other GII layers for decision making in water and food provision with attention to flora and fauna. And for decision making on financial compensations (subsidies by governmental or other bodies, payment by insurance, etc.). This implies that both land users and land owners should be known. Monitoring land use can also be used in detection of illegal occupations or in case of overlapping claims; e.g. claims from indigenous people and claims from new farmers or mining companies. This is possible by comparing land usage today with earlier satellite images. All this is supported by the LADM in a flexible way; piloting is recommended to test this.

User dominance. The currently established update procedures in Land Administration are expected to be simplified in the near future and based on ubiquitous web access. For example, to split and sell a part of a parcel requires nowadays professionals, such as notaries, surveyors and registrars, each performing certain subtasks. Based on authenticated identification of persons and trusted reference material (e.g. high resolution and up-to-date geo-referenced imagery), seller and buyer will together, via web services, draw the new boundaries of the split part of the parcel and complete the transaction, including payment. Examples of required web services and protocols are already given in (Brentjes et al, 2004); e.g. WFS-T (Web Feature Service with Transaction capabilities; OGC (2010a). The role of the LA authorities will be to provide the required infrastructure, at least the LA part and the links to other parts of the Geo Information Infrastructure (GII), and perform quality control and validate transactions: “are all steps performed correctly?” Here new types of roles for responsible parties in relation to transactions come in as supported by the LADM. Examples of crowd sourcing for Land Administration are given in McLaren, 2011a and McLaren, 2011b. In the proposals from McLaren the use of Open Source software using Open Standards as STDM based on the LADM is highlighted. McLaren refers to the Solutions for Open Land Administration (SOLA) from FAO based on the LADM. He discusses Open toolkits for mobile phone platforms. He talks about LAS apps for non-literate users. This requires further research on how to integrate crowd sourcing for administration with LADM and Open toolkits.

On more relevant development here is OpenCadastreMap. This initiative by Laarakker and De Vries (2011), is currently exploring the possibilities and dilemmas of *participatory cadastral mapping* by asking for instance the following questions: what will happen if people start uploading their land claims to the internet if the formal statutory systems lag behind? What are the social, legal and technical dilemmas? What are the economic implications? OpenCadastreMap is also investigating the power of social media in relation to Land Administration. Dilemmas with privacy need further attention in this context and also impact on open data policies in general.

Co-operation with anthropologists and other disciplines in further research is required. Many organisations have attention to the registration of land rights, and there are networks, like the Indigenous Mapping Network. The mission of the Indigenous Mapping Network is to connect native communities with the tools needed to protect, preserve and enhance their way of life within the aboriginal territories. This endeavor often requires an amalgamation of traditional “mapping” practices and modern mapping technologies. Another network is the aboriginal network. According to Chapin et al (2005), the mapping of indigenous lands to secure tenure, to manage natural resources and to strengthen cultures, is a recent phenomenon, that started in Canada and Alaska in the 1960s (paper map based), and in other regions during the last decade and a half. They recognise that indigenous mapping has shown itself to be a powerful tool and it has spread rapidly throughout the world. Their review covers the genesis and evolution of indigenous mapping, the different methodologies and their objectives, the development of indigenous atlases and guidebooks for mapping indigenous lands and the often uneasy mix of participatory community approaches with technology. A recent workshop in Quebec, Canada on the Land Administration

Domain Model, pointed out that this issue is still most relevant in Canada (Egesborg, 2009).

Also slum mapping in relation to tenure is an issue of international attention; see for example the discussions at the latest World Urban Forum[169]. Key findings towards securing tenure, according to a research from Huchzermeyer (2009), include the importance of various forms of mobilisation, that accompany enumeration, and of the informal and formal knowledge generation, that results from the enumeration process. For a grassroots enumeration exercise to be successful, grassroots trust must be sustained for ongoing verification and updating of the enumeration data and the enumeration must link up effectively with the planning authorities.

Given the problems, related to urbanisation, environment, access to land, access to food and water of the world today, there is a need to get a complete overview of who is living where, under what tenure conditions and for which areas. Overlapping claims to land need to be included, illegal acquisition or occupation of land too. A continuous map of People to Land relationships' is needed. Research efforts are needed to find cheap, high tech solutions. LADM/STDM with its continuum in Parties, RRRs, SpatialUntis (and others, see the code tables) should be the core standardised data model behind.

Research and development (apps, etc) in this area of user dominance can be supported with the LADM as an open standard.

Further standardisation and LADM maintenance. The ISO approach for development of International Standards has been followed for the LADM. All International Standards are reviewed at least three years after publication and every five years after the first review by all the ISO member bodies. A majority of the P-members of the TC/SC decides whether an International Standard should be confirmed, revised or withdrawn. Results from research as recommended here above can be included in review processes and may lead to extensions of the LADM functionalities.

Land Administration is the key in the information infrastructure and is related to other registrations[170]. Within the LADM these other registrations are indicated in *external classes*, such as parties, addresses, valuation, taxation, land use, coverage, physical utility networks, etc. Within the EU, some of these domains are treated in INSPIRE, but certainly not all. Here lies an important research and development task for academia in co-operation with NGOs as FIG at a global scale and with ISO.

[169] http://www.unhabitat.org/categories.asp?catid=584.
[170] In INSPIRE the cadastral parcels are identified for serving the purpose of 'generic information locators'.

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Appendix A LADM Class Names

Table A-1 LADM Class Names.

Package	**Version A** Initial Version Lemmen and Van Oosterom (2003c)	**Version B** Version 1.0, FIG Munich Lemmen and Van Oosterom (2006a) based on Van Oosterom et al (2006b)	**Version C** Draft International Standard (DIS) ISO (2011)
Party			
	Person	Person	LA_Party
	NaturalPerson	NaturalPerson	
	NonNaturalPerson	NonNaturalPerson	
		GroupPerson	LA_GroupParty
		Members	LA_PartyMember
		MoneyProvider	
		Conveyor	
		Surveyor	
Administrative			
	RightOrRestriction	RRR	LA_RRR
	Mortgage	Mortgage	LA_Mortgage
	LegalDocument	LegalDocument	LA_AdministrativeSource
	PublicRestriction		
		Right	LA_Right
		Restriction	LA_Restriction
		Responsibility	LA_Responsibility
			LA_RequiredRelationshipBAUnit
Spatial Unit			
	RealEstateObject	RegisterObject	LA_BAUnit
		Movabale	
		Immovable	
	ParcelComplex	ImmovableComplex	
	Parcel	Parcel	LA_SpatialUnit
		ServingParcel	
		RegisterParcel	
		NPRegion	
		SpaghettiParcel	
		PointParcel	
		TextParcel	
	ParcelBoundary		LA_BoundaryFaceString
			LA_BoundaryFace
		AdminParcelSet	LA_SpatialUnitGroup
	PartOfParcel	PartofParcel	LA_SpatialUnit
	ApartmentComplex		LA_LegalSpaceBuildingUn

			it
		Unit	
	ApartmentUnit	SharedUnit	LA_LegalSpaceBuildingUnit
	ApartmentUnit	IndividualUnit	LA_LegalSpaceBuildingUnit
	NonGeoRealestate	NonGeoRealEstate	
		OtherRegisterObject	
			LA_LegalSpaceUtiliyNetwork
			LA_Level
			LA_RequiredRelatioship SpatialUnit
Survey			
	SurveyPoint	SurveyPoint	LA_Point
	SurveyDocument	SurveyDocument	LA_SpatialSource
Topological			
		GeomTopolRepresentation	
	tp_face	TP_Face_2D	
	tp_edge	TP_Edge_2D	
	tp_node	TP_Node_2D	
		TP_Volume_3D	
		TP_Face_3D	
		TP_Edge_3D	
		TP_Node_3D	
Special			
			VersionedObject
		SourceDocument	LA_Source
			Oid
Interface			
		CadastralMap	

Appendix B LADM Associations between Classes in the DIS

Table B-1: LADM: Associations between Classes in the Draft International Standard ISO 19152.

Class 1	**Class 2**	**Role name End 1**	**Multi-plicity**	**Role name End 2**	**Multi-plicity**
AdministrativeSource	BAUnit	source	0..*	unit	0..*
AdministrativeSource	Party	-	0..*	conveyor	1..*
AdministrativeSource	RRR	source	1..*	rrr	0..*
BAUnit	BAUnit	-	0..*	-	0..*
BAUnit	RRR	baunit	1	rrr	1..*
BoundaryFace	SpatialSource	-	0..*	source	0..1
BoundaryFace	SpatialUnit	-	0..*	-	0..*
BoundaryFaceString	Point	-	0..*	-	0,2..*
BoundaryFaceString	SpatialSource	-	0..*	source	0..1
BoundaryFaceString	SpatialUnit	-	0..*	-	0..*
Mortgage	Right	-	0..*	-	0..*
Party	BAUnit	-	0..1	-	0..1
Party	Mortgage	money-provider	0..*	-	0..*
Point	BoundaryFace	-	0,3..*	-	0..*
Point	BoundaryFaceString	-	0,2..*	-	0..*
RRR	Party	rrr	0..*	party	0..1
Source	Party	-	0..*	represented by	
SpatialSource	BAUnit	-	0..*	-	0..*
SpatialSource	Party	-	0..*	surveyor	1..*
SpatialSource	Point	source	1..*	sourcePoint	1..*
SpatialUnit	BAUnit	-	0..*	-	0..*
SpatialUnit	Level	su	0..*	level	0..1
SpatialUnit	Point	-	0..1	-	0..1
SpatialUnit	SpatialSource	-	1..*	-	1..*
SpatialUnit	SpatialUnit	element	1..*	Set	0..1
SpatialUnit	SpatialUnitGroup	part	1..*	Whole	0..*

Appendix C Instance Level Diagrams

In this appendix some instance level diagrams are represented. Examples are based on Lemmen et al (2010a). The examples are provides to show and demonstrate the richness of the LADM.

An easement without Geometry

The next three figures show how a single easement without geometry is represented

– Figure C-1 represents the easement, without indication who (party or parcel or 'baunit') is benefiting;
– Figure C-2 now a party is explicitly associated with the easement;
– alternatively, the parcel ('baunit') could play the role of a party: 'baunit as party'; see Figure C-3.

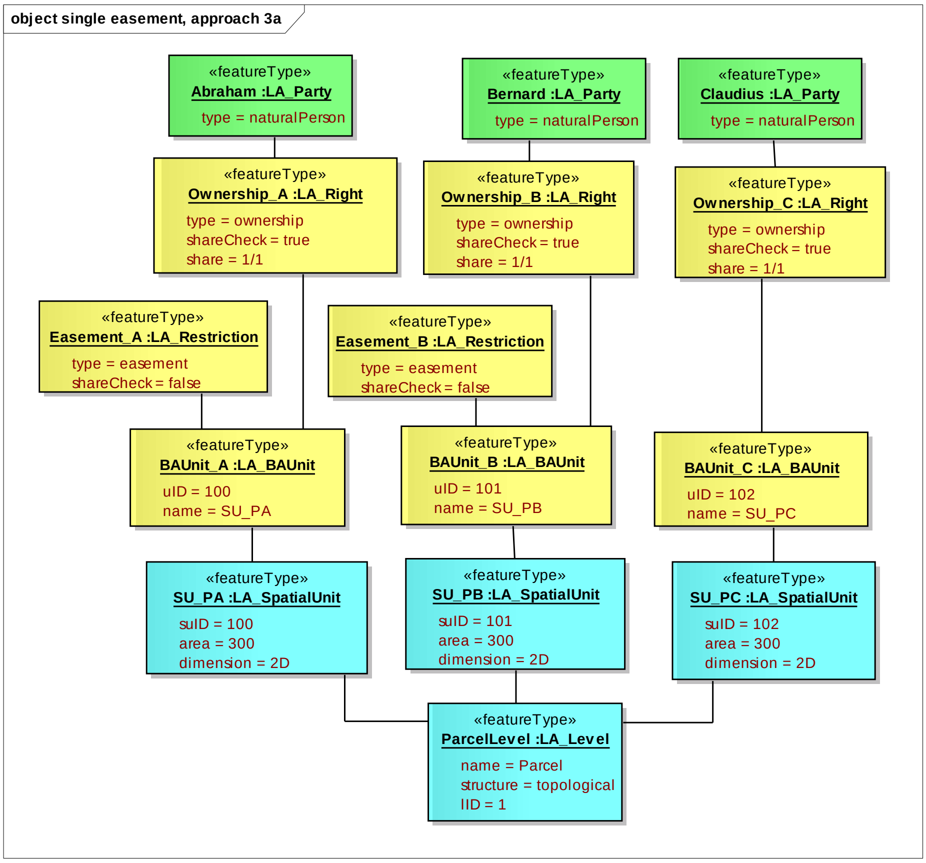

Figure C-1 LADM instance diagram: single easement with no geometry, no party.

Figure C-1 shows the simplest use of the model, but with the drawback that the (exact) easement location is unclear and that it is also unclear who is benefiting. In order to make clear who is benefiting, the LA_Party (as naturalPerson) can be attached to the LA_Restriction; see Figure C-2. In case multiple parties are benefiting this is represented by multiple LA_Restriction ‘shares’ (parts); e.g. Easement_A_forB and Easement_AforC.

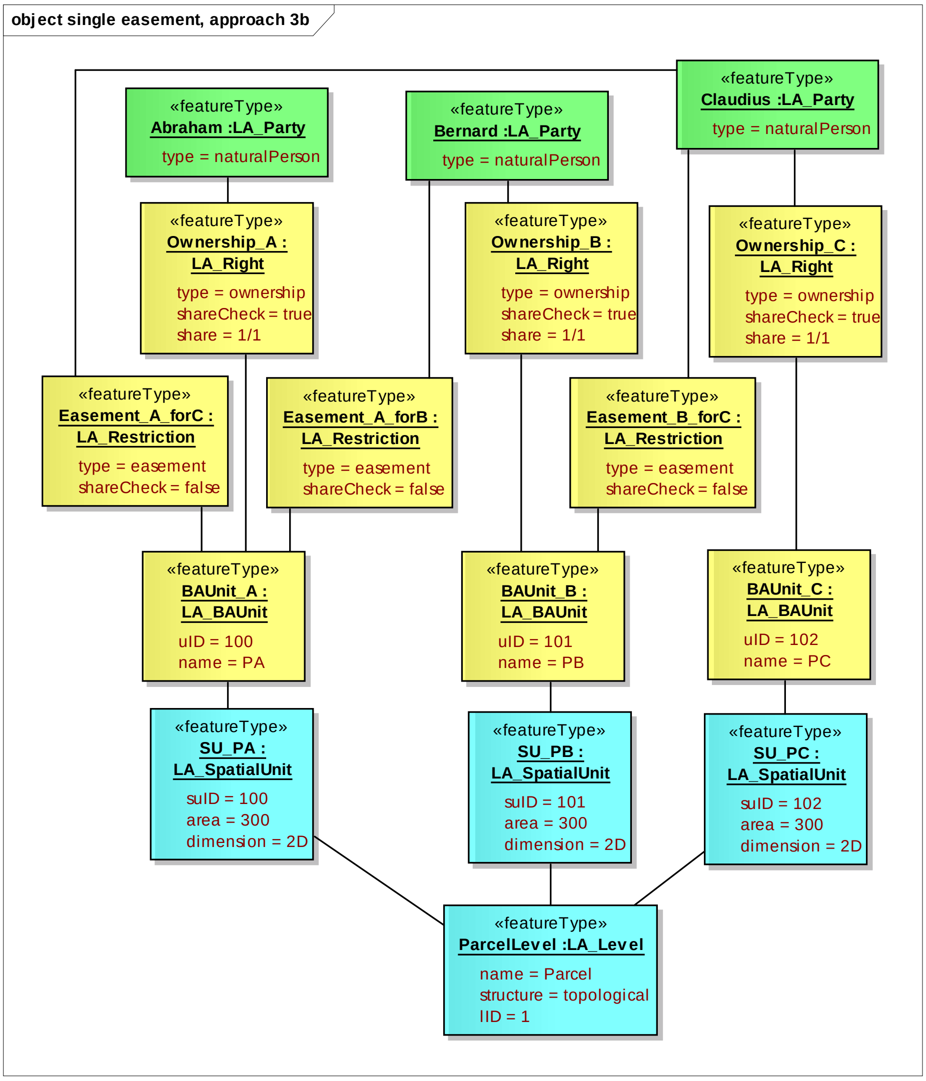

Figure C-2 LADM instance diagram: single easement with no geometry, normal party.

Perhaps a more elegant approach is to associate the easement not to a party but to the parcel ('baunit') that is benefiting (but as always, depending on national legislation and rules); see Figure C-3.

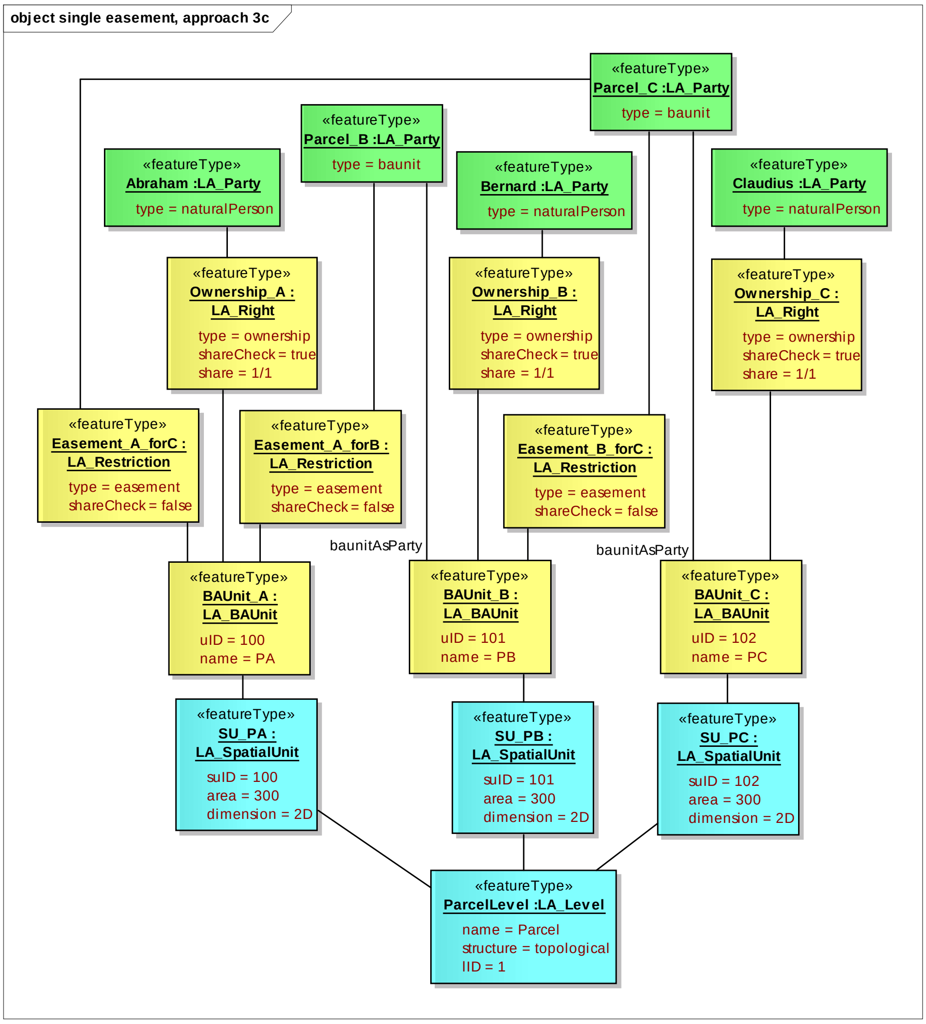

Figure C-3 LADM instance diagram: single easement with no geometry; 'baunit as party'.

An Easement with Two Levels

Figure C-4 shows how a single easement with its own geometry is represented (and with a normal party attached to LA_Restriction). Representations without a party, attached to the easement, or 'baunit as party', are quite similar to their counterparts in the previous section.

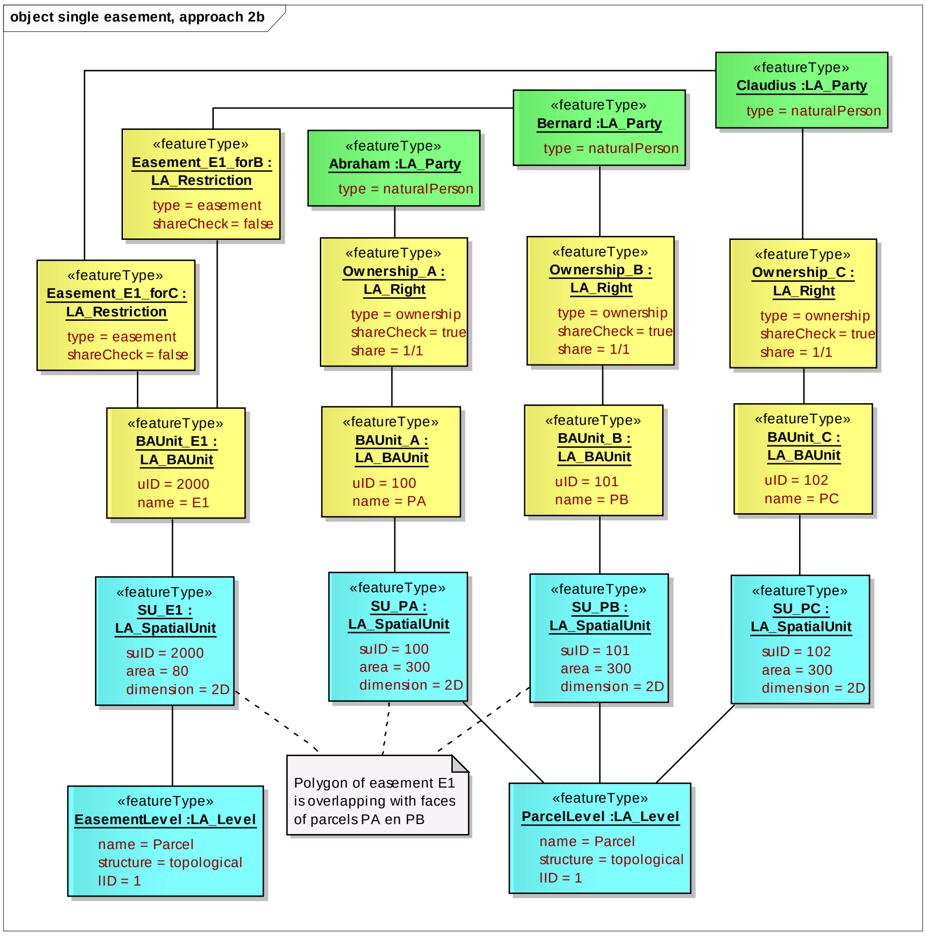

Figure C-4 LADM instance diagram: two levels (parcels and easements), normal party.

An Easement based on Subdivision

Figure C-5 shows how a single easement, with its own geometry, is used to subdivide the involved parcels in a single parcel layer, and a normal party attached to LA_Restriction. Note that this results in quite a fragmentation of the parcels, which is only partly compensated by their grouping in 'baunits'; e.g. SU_PA1 and SU_PA2 in BAUnit_A1_2.

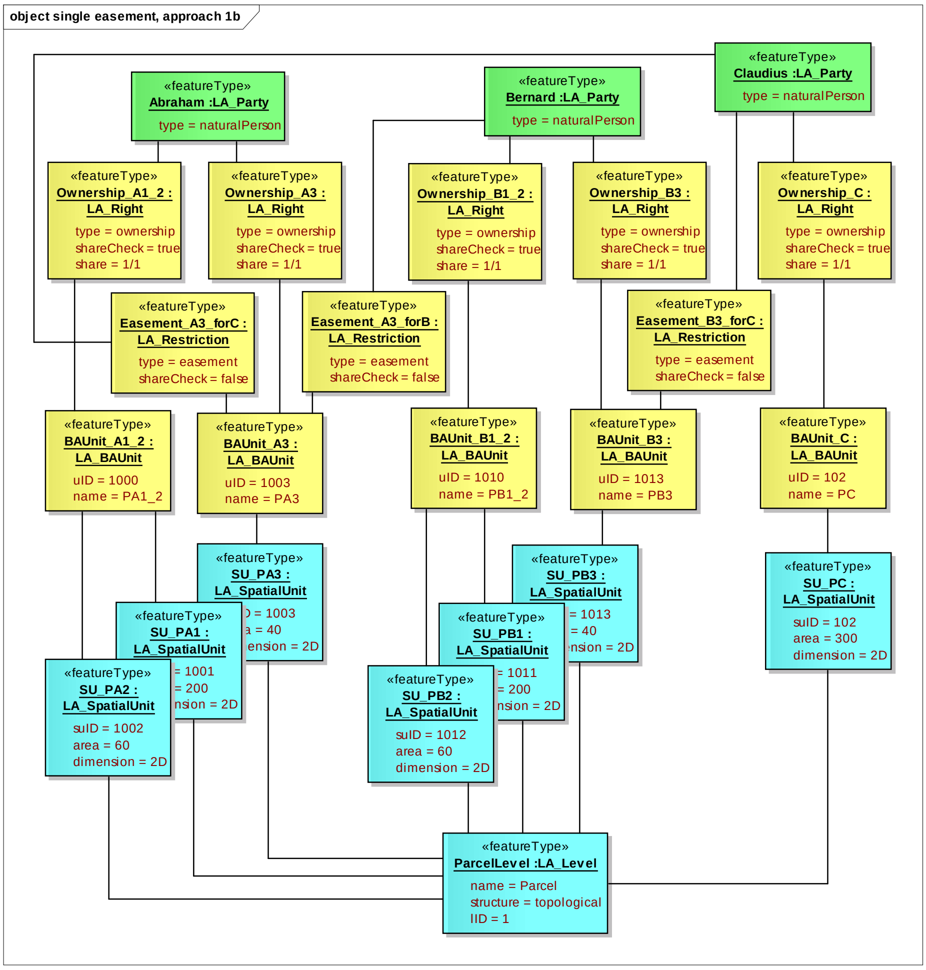

Figure C-5 LADM instance diagram: a single level (subdivision of parcels by easement geometry), normal party.

Appendix D Terms and Definitions used in the DIS

Tabel D-1 Terms and Definitions used in the Draft International Standard ISO 19152.

Term	Definition
administrative source	source with the administrative description (where applicable) of the parties involved, the rights, restrictions and responsibilities created and the basic administrative units affected
basic administrative unit (baunit)	administrative entity consisting of zero or more spatial units against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions are associated to the whole entity, as included in a Land Administration system
boundary	set that represents the limit of an entity [ISO 19107:2003, definition 4.4]
boundary face	face that is used in the 3-dimensional representation of a boundary of a spatial unit
boundary face string	boundary forming part of the outside of a spatial unit
building unit	component of building (the legal, recorded or informal space of the physical entity)
face	2-dimensional topological primitive [ISO 19107:2003, definition 4.38]
group party	any number of parties, forming together a distinct entity, with each party registered
land	the surface of the Earth, the materials beneath, the air above and all things fixed to the soil [UN/ECE, 2004]
land administration	process of determining, recording and disseminating information about the relationship between people and land
level	set of spatial units, with a geometric, and/or topologic, and/or thematic coherence

liminal spatial unit	spatial unit on the threshold between 2D and 3D representations
party	a person or organisation that plays a role in a rights transaction; ISO 19153 Geospatial Digital Rights Management Reference Model (GeoDRM RM) – to be published
party member	party registered and identified as a constituent of a group party
point	0-dimensional geometric primitive, representing a position [ISO 19107:2003]
profile	set of one or more base standards or subsets of base standards, and, where applicable, the identification of chosen clauses, classes, options and parameters of those base standards, that are necessary for accomplishing a particular function [ISO 19106:2004, definition 4.5]
required relationship	explicit association between either spatial units, or between basic administrative units
responsibility	formal or informal obligation to do something
restriction	formal or informal entitlement to refrain from doing something
right	action, activity or class of actions that a system participant may perform on or using an associated resource [ISO 19132:2007]
source	document providing facts
spatial source	source with the spatial representation of one (part of) or more spatial units
spatial unit	single area (or multiple areas) of land and/or water, or a single volume (or multiple volumes) of space
spatial unit group	any number of spatial units, considered as an entity
utility network	network describing the topology of a utility

Abbreviations

BPU	Basic Property Unit
CAP	Common Agricultural Policy
CCDM	Core Cadastral Domain Model
CEN	Comité Européen de Normalisation
CD	Committee Draft
CDCS	Cadastral Data Content Standard
CI	Citation
CLIS	Cyprus Land Information System
COST	CO-ordination in the field of Scientific and Technical Research
CP	Cadastral Parcel
CRS	Co-ordinate Reference System
DBMS	Data Base Management System
DIS	Draft International Standard
DQ	Data Quality
EJB	Enterprise Jave Beans
EU	European Union
EULIS	European Land Information Service
EX	Extent
FAO	Food and Agricultural Organization
FDIS	Final Draft International Standard
FGDC	Federal geographic Data Committee
FIG	Fédération Internationale des Géomètres (International Federation of Surveyors)
FLOSS	Free and Libre Open Source Software
GF	General Feature
GII	Geo Information Infrastructure
GIS	Geographical Information System
GLTN	Global Land Tool Network
GM	Geometry
GML	Geography Markup Language
GPS	Global Positioning System
HMMG	Harmonised Model Management Group (of ISO/TC211)
IACS	Integrated Administration and Control Systems
ICT	Information and Communication Technology
ITC	International Institute for Geo-Information Science and Earth Observation
INSPIRE	INfrastructure for Spatial Information
IS	International Standard
ISO	International Organization for Standardization
ITC	Faculty of Geo-Information Science and Earth Observation
LA	Land Administration
LADM	Land Administration Domain Model
LAS	Land Administration System
LIS	Land Information System
LPIS	Land Parcel Identification System

MD	Meta Data
MDA	Model Driven Architecture
MDG	Millennium Development Goal
NCG	Nederlandse Commissie voor Geodesie/Netherlands Geodetic Commission
NEN	Nederlands Normalisatie-instituut
NWIP	New Working Item Proposal
OCL	Object Contsraint Language
OGC	Open Geospatial Consortium
OM	Observations and Maesurments
OSCAR	Open-Source Cadastre and Registration
PU	Proprietary Unit
RRR	Rights, Restrictions, Responsibilities
RS	Reference System
SC	Spatial Coördinates
SDI	Spatial Data Infrastructure
SOLA	Solutions for Open Land Administration
STDM	Social Tenure Domain Model
TC	Technical Committee
TM	Temporal
UML	Unified Modelling Language
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNECE	United Nations Economic Commission for Europe
UN-HABITAT	United Nations Human Settlements Programme
WFS	Web Feature Service
WD	Working Draft
XML	Extensible Markup Language

Summary

A Domain Model for Land Administration

A Domain Model for Land Administration is designed in this thesis. There is a need for domain specific standardisation 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. A standard is required for communication between professionals, for system design, system development and system implementation purposes and for purposes of data exchange and data quality management. Such a standard will enable GIS and DBMS providers and/or open source communities to develop products and applications for Land Administration purposes. And in turn this will enable land registry and cadastral organisations to use the components of the standard to develop, implement and maintain systems in an even more efficient way. The research objective is to design a Land Administration Domain Model (LADM). It should be possible to use this model as a basis for Land Administration System (LAS) development. Such a LADM has to be broadly accepted and it should be adaptable to local situations. It has to be usable to organise Land Administration data within a Spatial Data Infrastructure (SDI). The design is based on the pattern of 'people – land' relationships. The model should be as simple as possible, it should cover the basic data related components of Land Administration (legal/administrative, mapping and surveying) and it should satisfy user requirements. The Domain Model in its implementation is can be distributed over different organisations with different tasks and responsibilities.

This research does not focus on the legal, political, economic, institutional or financial aspects of Land Administration and Land Administration organisations; at least as far as those are not related to user requirements for the model. Taxation, valuation and land use are knowledge fields in itself and are not within the focus of this thesis.

Chapter 1 gives an *introduction* to the subject of this research. Motivation and background, research objectives and questions, the methodology and the scope and limits are presented. Chapter 2, *a review of existing work in LA Modelling*, provides the results of a literature review on people to land relationships from modelling and land policy perspectives and comprises a discussion on common patterns in this relationship. The core of the thesis is in Chapter 3: the *design and construction of the land administration domain model*. Three main versions (A, B and C) are introduced with evolving and more and more refined user requirements included. In Chapter 4 *experimental results* are presented from prototype software. *Implementations: first Examples* of LADM are discussed in relation to international attention in several countries and within the INSPIRE and the (agricultural) Land Parcel Identification System of the European Union development in Chapter 5. Chapter 6 gives an overview of conclusions and future work.

The design of the LADM took place in an incremental approach. For the presented Versions A and B this concerns input from workshops, personal experience, other expertise and improvements from reviews of publications and for the Version C of the LADM the development process for International Standards. After preparatory works of almost six years the LADM has been submitted to the ISO and parallel to CEN. After positive results of voting on the so-called New Working Item Proposal (NWIP) in May 2008 and on the Committee Draft (CD) in October 2009 the Draft International Standard (DIS) received a positive vote in June 2011; the International Standard is expected in August 2012. The Draft International Standard is called *LADM Version C* in this thesis. The developments in ISO are a comprehensive, extensive, formal process with a continuous review and a continuous, creative approach to find common denominators in land administration systems, including data sets. Many comments and observations have been processed to bring the LADM to the required quality level needed for international acceptance.

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 all *people – land relationships* may be represented.

The three main packages of the LADM consist of the Party package, the Administrative package and the Spatial Unit package.

The main class of the party package 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.

The administrative package 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 an (informal) use right. Rights may be overlapping or may be in disagreement. A 'restriction' is a formal or informal entitlement to refrain from doing something; e.g. it is not allowed to build within 200 meters of a fuel station; or a servitude or a mortgage as a restriction to the ownership right. A 'responsibility' is a formal or informal obligation to do something; e.g. the responsibility to clean a ditch, to keep a snow-free pavement or to remove icicles from the roof during winter or to maintain a monument. A 'baunit' (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 'baunit' 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 neighboring, spatial unit.

The spatial unit package concerns the classes LA_SpatialUnit, LA_SpatialUnitGroup, LA_Level, LA_LegalSpaceNetwork, LA_LegalSpace-BuildingUnit and LA_RequiredRelationshipSpatialUnit. 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), 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 Spatial Representation Subpackage 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.

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 GII type of deployment), e.g. addresses, are included. Legal implications that interfere with (national) land administration laws *are outside the scope of the LADM.*

The objective of this research has been achieved; the research questions have been answered. Validation has been performed. The fact that many experts have been involved in the LADM development – with a lot of experience in developments and implementations of LASs – is a solid basis. Their acceptance is very promising. Also developments in Cyprus and with FLOSS SOLA, an OpenSource Software development at the Food and Agricultural Organisation and the development of the Social Tenure Domain Model (a LADM specialisation) at UN-HABITAT are promising. Relevant is the attention of commercial software suppliers to the LADM development. There are proposals for implementation of the LADM in several countries already, even before it has been published as an International Standard. More testing is required. Data exchange requires further attention in testing of the LADM.

Future work in relation to the LADM can be the development and inclusion of New RRRs, 3D and 4D Cadastre, linking into augmented reality applications, support in spatial design and support in monitoring spatial changes worldwide. Further standardisation (other domains and processes) and LADM maintenance is important, especially for the development of mature information infrastructures.

Samenvatting

Een Domein Model voor Land Administratie

In dit proefschrift is een Domein Model voor Land Administratie ontworpen. ‘Land Administratie’ kan gezien worden als Kadaster ‘in ruime zin’. Er is behoefte aan domein specifieke standaardisatie om de semantiek van Land Administratie vast te leggen op basis van al bestaande standaarden voor geometrie, tijd, metadata en voor waarnemingen en metingen uit het veld. Een standaard is nodig voor communicatie doeleiden, voor systeemontwerp, voor systeemontwikkeling, voor systeem-implementatie en ook voor uitwisseling van gegevens in de Land Administratie. Leveranciers van GIS en DBMS software en/of open source gemeenschappen worden zo in staat gesteld om op een relatief eenvoudige manier producten en toepassingen te ontwikkelen voor toepassing in de Land Administratie. En, op zijn beurt, zal het landregistratie- en kadasterorganisaties in staat stellen om de componenten van de standaard te gebruiken om systemen op een nog efficiëntere wijze te ontwikkelen, te implementeren en te onderhouden. De onderzoeksdoelstelling is het ontwerpen van een Land Administratie Domein Model (LADM). Om een dergelijk LADM breed geaccepteerd te krijgen moet het aan te passen zijn aan lokale omstandigheden. En het moet bruikbaar zijn om Land Administratie gegevens in te passen in zgn. ruimtelijke informatie infrastructuren. Het model is gebaseerd op het patroon van relaties tussen mensen en land. Er is steeds getracht het model zo simpel als mogelijk te houden, en het moet de basisgegevens gerelateerde componenten van Land Administratie bevatten (wettelijk/administratieve, landmeetkundige en topologische) en het moet voldoen aan eisen van gebruikers. Verondersteld wordt dat het Domein Model over meerdere organisaties wordt geïmplementeerd, waarbij iedere organisatie een eigen verantwoordelijkheid in de Land Administratie heeft.

Dit onderzoek richt zich niet op wettelijke, politieke, economische, institutionele of financiële aspecten van Land Administratie en Land Administratie organisaties, tenminste voor zover deze niet gekoppeld zijn aan de gebruikerseisen voor het model. Belastingheffing, waardebepaling en landgebruik zijn kennisvelden op zichzelf en vallen niet in het aandachtsgebied van deze dissertatie.

Hoofdstuk 1 geeft een inleiding op het onderwerp van dit onderzoek. Motivatie en achtergrond, onderzoeksdoelstellingen en vragen, de methodologie, de focus en beperkingen worden gepresenteerd. Hoofdstuk 2, geeft de resultaten van een literatuurstudie over relaties tussen mensen en grond vanuit het perspectief van modellering en het omvat een discussie over hat algemene patroon in deze relatie. De kern van de dissertatie is Hoofdstuk 3: ‘het ontwerp en de bouw van het Land Administratie Domein Model’. Drie hoofdversies (A, B en C) worden geïntroduceerd op basis van gebruikerseisen. In Hoofdstuk 4 worden de experimentele resultaten gepresenteerd van een prototype. Implementatievoorbeelden worden besproken in Hoofdstuk 5 in de context van internationale aandacht voor het model: vanuit verschillende landen, vanuit ontwikkelingen in INSPIRE en ook vanuit het Land

Perceel Identificatie Systeem van de Europese Unie. Hoofdstuk 6 geeft een overzicht van conclusies en mogelijk toekomstig werk.

Het LADM is stapsgewijs ontworpen. Ten behoeve van de gepresenteerde versies A en B gaat het om inbreng vanuit literatuurstudies, workshops en om verbeteringen op basis van beoordelingen van publicaties. Bij versie C staat de ontwikkeling van een Internationale Standaard centraal. Na voorbereidend werk gedurende ongeveer zes jaar is het LADM aan de Internationale Organisatie voor Standaardisatie voorgelegd. Na een positief resultaat van een de stemming van een‘New Working Item Proposal’ in mei 2008 en ook van de ‘Committee Draft’ in oktober 2009 kreeg de ‘Draft Internationale Standaard’ (DIS) een positieve beoordeling tijdens de stemming in juni 2011; de Internationale Standaard wordt verwacht in juli 2012. De ‘Draft International Standard’ wordt in deze dissertatie LADM Versie C genoemd. De ontwikkelingen binnen de ISO betreffen een veelomvattend, intensief, formeel proces met continue beoordelingen en een continue creatieve aanpakom de grootste gemene deler in land administratie systemen te vinden, inclusief gegevensbestanden. Heel veel commentaren en waarnemingen zijn verwerkt om het LADM op het vereiste kwaliteitsniveau voor internationale acceptatie te brengen.

De ‘Draft International Standard’, gepubliceerd door ISO als ISO 19152, betreft de basisinformatie gekoppeld aan componenten van Land Administratie (inclusief water en elementen boven en onder het aardoppervlak). Deze basisinformatie omvat overeenkomsten over administratieve en ruimtelijke eenheden, landrechten in de brede zin van het woord, alsook inheemse, gewoonte- en informele rechten. Alle typen beperkingen en verantwoordelijkheden kunnen worden afgebeeld. Overlappende aanspraken kunnen worden opgenomen. De ‘Draft International Standard’ kan worden uitgebreid naar en aangepast op lokale situaties; op deze wijze kunnen alle mens – landrelaties worden afgebeeld in het model.

De belangrijkste klasse uit het ‘party package’ van het LADM is de klasse ‘LA_Party’ met de specialisatie ‘LA_GroupParty’. Er is een optionele associatieklasse ‘LA_PartyMember’. Een ‘party’ is een persoon of organisatie die een rol speelt in de transactie in rechten. Een organisatie kan bij voorbeeld een bedrijf zijn of een gemeente, een coöperatie, of een Staat. Een ‘group party’ is een aantal ‘parties’, die samen een afzonderlijke eenheid vormt. Een ‘partymember’ is een ‘party’ die geregistreerd en geïdentificeerd is als een deel van de ‘group party’. Dit staat documentatie van gegevens van leden van een groep toe.

Het ‘administrative package’ betreft de abstracte klasse ‘LA_RRR’ (met drie concrete subklassen ‘LA_Right’, ‘LA_Restriction’ en ‘LA_Responsibility’) en de klasse ‘BAUnit’ (‘basis administratieve eenheid’). Een ‘right’ is een actie, activiteit of categorie van handelingen, die een systeemdeelnemer kan uitvoeren op of met behulp van een bijbehorende hulpbron. Voorbeelden zijn: eigendomsrecht, pachtrecht, bezit, gewoonterecht of een informeel recht. Een ‘right’ kan een (informeel) gebruiksrecht zijn. ‘Rights’ kunnen overlappend zijn of er kan overeenstemming ontbreken. Een ‘restriction’ is een formeel of informeel recht om iets te doen of zich te onthouden om iets te doen, bijvoorbeeld het is niet toegestaan om binnen een afstand van 200 meter van een benzinestation te bouwen of een erfdienstbaarheid of een hypotheek als beperking op een eigendomsrecht. Een ‘responsibility’ is een formele of informele verplichting om iets te doen, bijvoorbeeld om een sloot schoon te maken of om een pad sneeuw vrij te houden of om een monument te onderhouden. Een ‘baunit’ is een basis administratieve eenheid bestaande uit nul of meer ’spatial units’ (percelen), waarmee één of meer unieke en homogene ‘rights’ (bijvoorbeeld een eigendomsrecht en een gebruiksrecht) en/of ‘restrictions’ en/of ‘responsibilities’ zijn geassocieerd. Een voorbeeld van een ‘baunit’ is een eigendomseenheid met twee ’spatial units’ (bijvoorbeeld een appartement en een garage). Een ‘baunit’ kan een ‘party’ zijn, omdat een ‘baunit’ een erfdienstbaarheid kan houden over een andere, meestal aangrenzende, ‘spatial unit’.

Het ‘spatial unit package’ betreft de klasses ‘LA_SpatialUnit’, ‘LA_SpatialUnitGroup’, ‘LA_Level’, ‘LA_LegalSpaceNetwork’, ‘LA_LegalSpace-BuildingUnit’ en ‘LA_RequiredRelationshipSpatialUnit’. Een ‘spatial unit’ kan worden weergegeven als een tekst (“van deze boom tot die rivier”), een punt (of meerdere punten), een lijn (of een verzameling van lijnen), die een vlak (of meerdere vlakken) land (of water) of, meer specifiek, een volume ruimte (of meerdere volumes ruimte, ondergronds/bovengronds) afbeelden. ’Spatial units’ zijn gestructureerd op een wijze, die de creatie en het management van ‘baunits’ mogelijk maakt. ‘Spatial units’ betreffen een flexibel concept om de werkelijkheid weer te geven. Een ‘spatial unit group’ is een groep ‘spatial units’, bijvoorbeeld alle ‘spatial units’ binnen een administratieve zone (een sectie, een canton, een gemeente, een departement, een provincie of een land) of binnen een planning gebied. Een ‘level’ is een verzameling ’spatial units’ met een geometrische, topologische of thematische samenhang. Het ‘spatial unit package’ heeft een ‘surveying and spatial representation subpackage’ met klasses zoals ‘LA_SpatialSource’, ‘LA_Point’, ‘LA_BoundaryFaceString’ en ‘LA_BoundaryFace’. ‘Points’ kunnen worden ingewonnen in het veld met landmeetkundige metingen of met behulp van satellietbeelden of luchtfoto’s. Een meting wordt gedocumenteerd met ‘spatial sources’. Een verzameling landmeetkundige waarnemingen (afstanden, richtingen, etc.) is een attribuut van ‘LA_SpatialSource’. De individuele ‘points’ zijn instanties van de klasse ‘LA_Point’, die geassocieerd is met ‘LA_SpatialSource’. 2D en 3D weergaves van ruimtelijke eenheden gebruiken ‘boundary face strings’ (2D grenzen die een verticaal aanzicht impliceren dat een deel van de buitenkant van de ruimtelijke eenheid vormt) en ‘boundary faces’ (aanzichten gebruikt in 3D weergave van een grens van een ruimtelijke eenheid). Coördinaten zelf komen ofwel van punten ofwel als lineaire geometrie.

Implementatie van het LADM kan op een flexibele wijze worden uitgevoerd; de Draft International Standard kan worden uitgebreid naar en aangepast waar dat nodig is. Exerne koppelingen met andere gegevensbestanden, bijvoorbeeld adressen, zijn opgenomen. Juridische implicaties, die interfereren met nationale wetgeving op het gebied van Land Administratie, vallen buiten het bereik van het LADM.

De doelstelling van dit onderzoek is bereikt; de onderzoeksvragen zijn beantwoord. Validatie is uitgevoerd. Er is een groot aantal experts, met veel ervaring in de ontwikkeling van Land Administratie Systemen, betrokken geweest in de LADM-ontwikkeling. Hun acceptatie van het model is veelzeggend en veelbelovend. Ook ontwikkelingen in Cyprus en met FLOSS/SOLA, een open source software ontwikkeling bij de FAO, evenals de ontwikkeling van het STDM bij UN-HABITAT stemmen hoopvol. Relevant is ook de aandacht van commerciële software-ontwikkelaars voor het LADM. Er bestaan al voorstellen voor de implementatie van het LADM in verschillende landen, zodra deze gepubliceerd is als een Internationale

Standaard. Meer testen zijn noodzakelijk, vooral op het gebied van gegevensuitwisseling.

Toekomstig werk in relatie tot het LADM kan de ontwikkeling en inrichting van nieuwe RRRs (‘rechten’, ‘beperkingen’ en ‘verantwoordelijkheden’) noodzakelijk maken. Te denken valt aan 3D en 4D Kadaster, koppeling met applicaties voor ‘augmented reality’, ondersteuning bij ruimtelijk ontwerp, ontwikkeling naar semantisch web technologie en ondersteuning bij het controleren van ruimtelijke veranderingen wereldwijd. De invloed van gebruikers zal in toenemende mate relevant worden. Verdere standaardisatie (op andere domeinen) en onderhoud van het LADM zijn belangrijk, vooral in verband met de ontwikkeling van volwassen ruimtelijke infrastructuren.

Curriculum Vitae

Christiaan Herman Jacobus Lemmen was born on June, 3rd, 1956 in Venlo, province Limburg, the Netherlands. He obtained a diploma Atheneum from Blariacum College in Venlo-Blerick in 1974. He graduated from Delft University of Technology in 1983 with a MSc in Geodesy. Subject of his thesis was a re-allocation and adjustment system for land consolidation based on mixed integer programming algorithms.

In 1982 he started as a researcher at the Study Centre for Land Information at the Faculty of Geodesy, Delft University of Technology. Main focus of research was on the implementation options for the re-alloaction system for land consolidation.

In 1984 he joined the Netherlands Cadastre and Land Registry Agency where he had several positions as advisor and information manager in land consolidation and cadastral systems. He was involved in the design and development of core applications at the Netherlands Cadastre and Land Registry in those areas for many years; cadastre became his profession.

In 2000 he moved to Kadaster International, the international branch of the Netherlands Cadastre and Land Registry on part time basis. At the same time he started an academic carreer as assistant professor in cadastral systems at the International Institute for Geo-Information Science and Earth Observation in Enschede (ITC), the Netherlands.

As a senior geodetic advisor at Kadaster International he acts as an International Consultant in Cadastre and Land-management in aspects as data acquisition, land administration, cadastral systems, information and communication technology, strategy and organisational development, institutional development, evaluation and monitoring. He has experience from activities and projects in about 50 countries world wide.

As an assistant professor he is focussing on education and research in Land Adminsitration and Cadastral Systems at the Department of Urban and Regional Planning and Geo-information Management at ITC. ITC is a Faculty at the University of Twente since 2010. As an associated institution of the United Nations University (UNU), ITC contributes to the UNU mission, which is “to contribute, through research and capacity building, to efforts to resolve the pressing global problems that are the concern of the United Nations, its Peoples and Member States”.

Since 2000 he is contributing editor of GIM International, the Global Magazine for Geomatics.

He has an active role in Commission 7, Cadastre and Land Management of the International Federation of Surveyors since 2002. First as vice-chair administration (2002 – 2006), later as chair of the Working Group on Pro Poor Land Management of the Commission (since 2006). From this position he could co-operate with UN-HABITAT in the development of the Social Tenure Domain Model.

After serving as secretary from 2002 till 2010 he is director of the *Office International du Cadastre et du Régime Foncier*[172], OICRF. This is one of the permanent bodies of the International Federation of Suveyors. OICRF serves as a documentation and study centre for land administration.

Since 2008 he is chairing the committee drafting a international standard for the Land Administration Domain in the Technical Committee 211 on Geographic Information of the International Standardization Organization; since 2009 as editor.

[172] The International Office of Cadastre and Land Records hosted by the Netherlands Cadastre, Land Registry and Mapping Organisation.