# A modular standard for the Cadastral Domain

Christiaan LEMMEN[1], Paul VAN DER MOLEN[1], Peter VAN OOSTEROM[2], Hendrik PLOEGER[2], Wilko QUAK[2], Jantien STOTER[2], Jaap ZEVENBERGEN[2]

*[1] Dutch Cadastre, Apeldoorn, P.O. Box 9046, 7300 GH Apeldoorn, The Netherlands, Tel. +31 55 5285695*
*& International Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, 7514 AE Enschede, The Netherlands, Tel. +31 53 4874523, Fax + 31 53 4874575.*
*[2] Department of Geodesy, Delft University of Technology, Thijsseweg 11, 2629 JA Delft, The Netherlands, Tel +31 15 2786950, Fax +31 15 2782745*
*lemmen@itc.nl, oosterom@geo.tudelft.nl*

A standardized core cadastral domain model, covering land registration and cadastre in a broad sense (multipurpose cadastre), will serve at least two important goals: 1. avoid reinventing and re-implementing the same functionality over and over again, but provide a extensible basis for efficient and effective cadastral system development based on a model driven architecture, and 2. enable involved parties, both within one country and between different countries, to communicate based on the shared ontology implied by the model. The contributions of this paper consist of an improved and extended version of the existing cadastral domain model, and the introduction of a modular approach (packages). One of the main preconditions of the model development is to keep the model as transparent and simple as possible in order to be useful in practise.

## 1. Introduction

Until today most countries (or states or provinces) have developed their own cadastral system because there are supposed to be huge differences between the systems. The one operates deeds registration, the other title registration, some systems are centralized, and others decentralized. Some systems are based on a general boundaries approach, others on fixed boundaries. Some cadastres have a fiscal background, others a legal one. However, it is also obvious that the separate implementation and system's maintenance of a cadastral system are not cheap, especially if one considers the ever-changing requirements. Also, the different implementations (foundations) of the cadastral systems do not make meaningful communication very easy, e.g. in an international context such as within Europe. Looking at it from a little distance one can observe that the systems are in principle mainly the same: they are all based on the relationships between persons and land, via (property) rights and are in most countries influenced by developments in the Information and Communication Technology (ICT). The two main functions of every cadastral system are: 1. keeping the contents of this relationship up-to-date (based on legal transactions) and 2. providing information on this registration.

In many global documents (Agenda21, Habitat, Johannesburg) land is considered as being an important issue. Main political objectives such as poverty eradication, sustainable housing and agriculture, strengthening the role of vulnerable groups (indigenous, women), are one way or another related to access to land, and to land-related opportunities. This definitely impacts on the policy of donor agencies (e.g. the English policy on 'better livelihoods for people', the German policy on 'land tenure in development cooperation', and the Dutch policy on 'business against poverty'), and on Poverty Reduction Strategy Papers for the Worldbank. How with this respect governments deal with the land issue, could be defined as 'land policy'. Having a policy is one thing, having the instruments to enforce the policy is another. Therefore governments need instruments like the regulations concerning land tenure security, the land market, land use planning and control, land taxation and the management of natural resources. It is within this context that the function of land administration systems can be identified: a supporting tool to facilitate the implementation of a proper land policy in the broadest sense.

The UN Land Administration Guidelines (UN/ECE, 1996) speak about land administration as the 'process of determining, recording, and disseminating information on ownership, value and use of land when implementing land management policies'. If 'ownership' is understood as the mode in which rights to land are held, we could also speak about 'land tenure'. 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 one (either formal or non-formal). 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 land administration systems are not 'just handling only geographic information' as they represent a lawfully meaningful relationship amongst people, and between people and land. As the land administration activity on the one hand deals with huge amounts of data, which moreover are of a very dynamic nature, and on the other hand requires a continuous maintenance process, the role of information technology is of strategic importance. Without availability of information systems it is believed it will be difficult to guarantee good performance with respect to meeting changing customer demands. Organisations are now increasingly confronted with rapid developments in the technology, a technology push: internet, (geo)-databases, modelling standards, open systems, GIS, as well as a growing demand for new services, a market pull: e-governance, sustainable development, electronic conveyance, integration of public data and systems. Cadastral modelling is considered as a basic tool facilitating appropriate system development and re-engineering and in addition it forms the basis for meaningful communication between different (parts of the) systems.

Standardization is a well-known subject since the establishment of cadastral systems. In both paper based systems and computerized systems standards are required to identify objects, transactions, relations between real estate objects (e.g. parcels) and persons (also called subjects in some countries), classification of land use, land value, map representations of objects, etc. etc. Computerized systems ask for even further standardization when topology and identification of single boundaries are introduced (Van Oosterom, Lemmen, 2001). In existing cadastral systems standardization is limited to the territory or jurisdiction where the cadastral system is in operation. Open markets, globalisation, and effective and efficient development and maintenance of flexible (generic) systems ask for further standardization. In (Van Oosterom, Lemmen, 2003) an overview is given of the following initiatives and developments:

1. Land Title and Tenure SIG: first initiative of the OpenGIS Consortium (OGC) in 2000.
2. Several standardization initiatives and developments in Cadastral Organizations
    - Introduction of ISO Standards in Germany (Seifert, 2002)
    - US National Integrated Land System (FGDC, 1999, Meyer, von et al., 2001)
    - Initiatives from Australia and New Zeeland (LINZ, 2002, LandXML, 2002, ICSM 1999, 2002)
    - Initiative from Sweden: The EULIS project (Ollén, 2002)
3. COST Research Activity Statement
4. The International Federation of Surveyors, FIG (Greenway, 2002)

Further initiatives can be recognised in Europe: INSPIRE is "an initiative to support the availability of spatial information for the formulation, implementation and evaluation of Union policies" . 60 spatial data components, grouped around 17 theme's have been identified as important data-sets, among others topography, cadastral properties, geographical names administrative area's, postcodes, buildings and addresses, terrain elevation and orthophoto's. INSPIRE 'intends to set the legal framework for the gradual creation of a spatial information infrastructure'. INSPIRE can be considered as an outcome of the 6th Environmental Action Program 2001-2010 of the EU. (www.ec-gis.org/inspire).

After the 'false start in 2000', the OGC now seeks sponsors for Property and Land Initiative as announced in a press release of March 25, 2003: 'The Open GIS Consortium, Inc. (OGC) is issuing a Call for Sponsors for a Planning Activity that may support future development of an OGC Property and Land Information (PLI) Initiative. This planning activity will seek interested sponsors to provide input on technology requirements and concepts to foster development of next-generation interoperable networked architectures and capabilities to enable broader sharing and application of property data and land information between collaborating organizations'. And: 'The ultimate goal of the OGC Property and Land Information Initiative is to promote increased understanding of the application of OpenGIS® Specifications to the challenge of cross-organizational and cross jurisdictional access to critical information. The Initiative would seek to design, test and operationally validate open architectural frameworks for distributed property and land information networks. As part of the growing "Spatial Web", these networks will allow information to be easily exchanged between consumers, governments, and businesses for many different purposes. This information would be accessible online through OpenGIS Interface Specifications and other standards consistent with best practices defined as part of National and Global Spatial Data Infrastructures and E-Government initiatives. This initiative will demonstrate how standards-based distributed networks of databases and information services can help consumers and citizens to access vital data, businesses to offer premium customer services, and governments to provide more effective service to citizens'.

This paper continues in Section 2 with an overview of the progress made so far in the development of a standardized Cadastral Domain Model based on the geographic standards from ISO and OGC (OpenGIS). This cadastral model is developed in cooperation with the FIG, the research is also related to the framework of the COST (Co-ordination in the field of Scientific and Technical Research) Action G9: 'Modelling Real Property Transactions'. Alternatives for 3D Cadastral modelling are discussed in Section 3 and the dynamic nature of Cadastral systems is elaborated on Section 4. The main conclusions and future work are finally described in the last section.

## 2. Cadastral Domain Model

The core of the cadastral domain model as depicted in Figure 1 is the central part of the model as was already presented at the FIG working week in April 2003, Paris (Lemmen, Van Oosterom 2003). It shows the Unified Modeling Language (UML) class diagram, which represents the result of the previous work. The relationship between real estate objects (e.g. parcels) and persons (sometimes called 'subjects') via rights is the foundation of every land administration. Besides rights, there can also be restrictions between the real estate objects and the persons. The figure shows that RightOrRestriction is an association class between the classes Person and RealEstateObject. Note that this an n-to-m relationship, with the conditions that every persons should at least be associated with one RealEstateObject and vice versa every RealEstate object should be associated with at least one Person (indicated in the UML diagram with the multiplicity of '1..*' at both ends of the association).

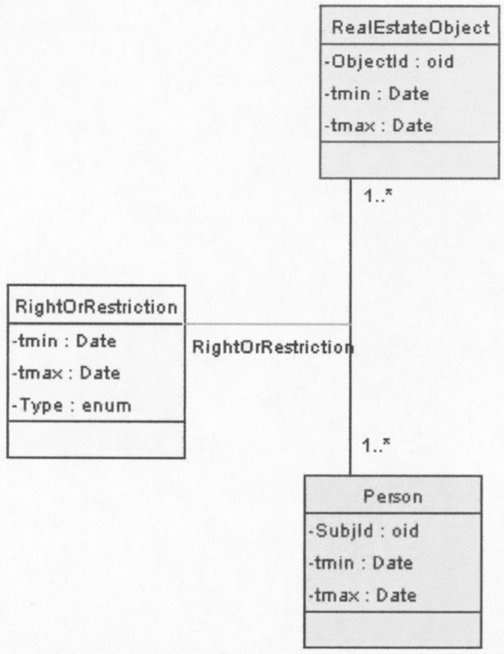


*Figure 1: Core of the Cadastral Domain Model: Person, RightOrRestricton, RealEstateObject*

When presenting or trying to describe a model, one always faces the question 'how to describe this model for domain experts (non-technical end-users, managers, but not modeling experts)?'. This question reappears in every context where models are developed. Textual descriptions alone are difficult to understand, as the model structure may not be visible. For this purpose all kinds of diagrams have been developed with 'boxes and arrows'. However, every time the 'boxes and arrows' did have a different meaning, which made general understanding, even by modeling specialists, difficult. Therefore, the Object Management Group (OMG, see Booch, Rumbaugh, Jacobson, 1999) standardized the main types of diagrams and the meaning of 'boxes and arrows'. In this paper we will mainly use UML class diagrams to describe the cadastral domain model. There are several other types of UML diagrams. Normally the modeling starts with the development of use case diagrams (for this work we refer to the COST Action G9 'Modeling Real Property Transactions'). In this paper we start with the class diagrams as these are the most 'stable' and independent of organizations and actors. UML class diagrams are reasonably well suited to describe a formal and structured set of concepts, that is an 'Ontology' (Gruber, 1993). This is one of the main results from our attempt to develop a Cadastral domain model. Experiences (in other domains) show that it is still not easy to read these diagrams. The solution used in this paper is to use 'Literate Modeling', that is UML diagrams embedded in text explaining the models. More details and discussion on Literate Modeling, with examples from British Airways, can be found in (Arlow, Emmerich and Quinn, 1998).

A UML class diagram describes the types of objects and the various kinds of structural relationships that exist among them like associations and subtypes. 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, Jacobson, 1999). The proposed UML class diagram for the cadastral domain contains both legal/administrative object classes like persons, rights and the geographic description of real estate objects. This means in principle that data could be maintained by different organizations, e.g. Municipality, Planning Authority, Private Surveyor, Cadastre, Conveyancor and/or Land Registry. The model 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 dataset represented in this model (diagram), thereby using other parts of the model. This underlines the relevance of this model; different organizations have their own responsibilities in data maintenance and supply and have to communicate on the basis of standardized processes in so called value adding production chains.

One should not look at the whole model (all packages together as presented at the end of this section) at once as the colours are representing UML 'packages' or coherent parts of the model: green and yellow: legal/administrative aspects, green and blue: real estate object specializations, blue, pink and purple: geometric/topological aspects. It is likely that more packages will be developed. Besides being able to present/document the model in comprehensive parts, another advantage of using packages could be that it is possible to develop and maintain these packages in a more or less independent way. Domain experts from different countries could further develop each package. It is not the intention of the model that everything should be realized in one system. The true intention is that, if one needs the type of functionality covered by a certain package, then this package should be the foundation and thereby avoiding reinventing (re-implementing) the wheel and making meaningful communications with others possible. Furthermore basic packages could be implemented by software suppliers, e.g. GIS suppliers like ESRI are providing models for several domains like agriculture, topographic mapping, biodiversity/conservation, defence, energy utilities, environmental regulated facilities, forestry, geology, historic preservation, hydrograpic/navigation, marine, petroleum, pipeline, system architecture, telecommunications, urban, water utilities, water resources. One domain of interest for ESRI is Cadastre 2014 (Kaufmann, Steudler, 1998). The principles op Cadastre 2014 are integrated in our approach. In the following subsections the different packages will be described in more detail.

## 2.1 Specializations of RealEstateObject: object detail classes

A RealEstateObject is an abstract class, that is, there are no object instances of this object class. However, it has specialization classes (which have object instances), such as Parcel, ParcelComplex, PartOfParcel, VolumeProperty, RestrictionArea, ApartmentUnit, and NonGeoRealEstate. In a UML class diagram the specialization classes point to the more generic class with an open headed arrow. The specializations are mutual exclusive. The specializations of the RealEstateObject class are represented in the 'blue' package; see Figure 2. 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 partioning of the surface (see section 2.4), but not all these parts have this direct association with Persons. There are parts, called ServingParcels in our model, which only have direct associations with two or more (main) Parcels (in Dutch mandeligheid). 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 specializations of PartitionParcels, which all-together 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. Note that Parcel is based on multiple inheritance (from RealEstateObject and PartitionParcel, both abstract classes).

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 system where a set of Parcels -could be in one municipality or even in another administrative unit- has a legal/customary meaning, for instance being the object of one mortgage. A Parcel can be subdivided in two or more PartOfParcel's. 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.

An ApartmentComplex is associated with one or more Parcel's. There can be at most one ApartmentComplex located on a Parcel. There can be two or more ApartmentUnit's 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. Note that an ApartmentUnit 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.

Parcel's are defined by ParcelBoundaries and have a geometric/topological description (Oosterom, van, Lemmen, 2001). The class ParcelBoundary always has two neighbour PartitionParcel's, where territorial ParcelBoundary's 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. 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 avoided, thus avoiding all kind of 'gap and overlap' problems, which don't have a meaning in reality.

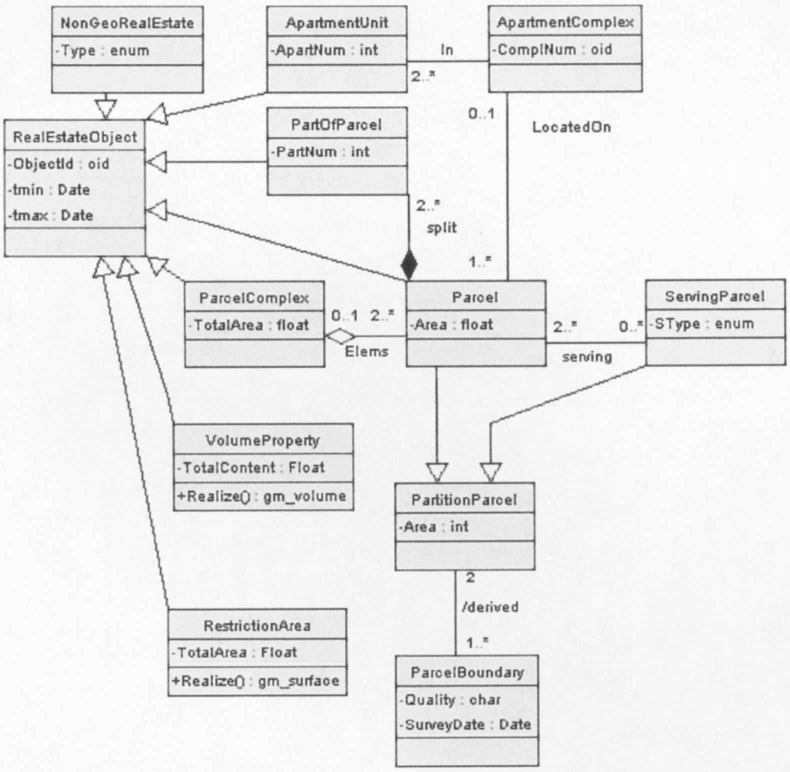


*Figure 2. The RealEstateObject package refined('blue'part)*

In most cadastral systems 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 2.5). 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, 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. We would suggest to maintain only the 'positive' rights, that is not explicitly store (for one Person) that another Person has a part of the rights, in the cases where the 'positive' right holder is known (see also section 2.4). This can be obtained via inspecting all rights associated with the RealEstateObject and the overlapping RestrictionArea's. Note that RestrictionArea's are modelled as closed polygons (and obtain their coordnates from SurveyPoint's, see section 2.3) and 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).

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 center of the Earth, trough 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 suggested for RestrictionAreas, we suggest that it is best only to register 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 VolumePropties (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 section 3.

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.

## 2.2 Surveying Classes

Object classes related to surveying are presented in pink colour; see Figure 3. 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 cadastral system. Files with terrestrial observations -distances, bearings, and referred geodetic control- on points are attributes of SurveyDocument, the Measurements. Both ParcelBoundary and SurveyPoint are associated with SurveyDocument. From the multiplicity it can be recognized 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.

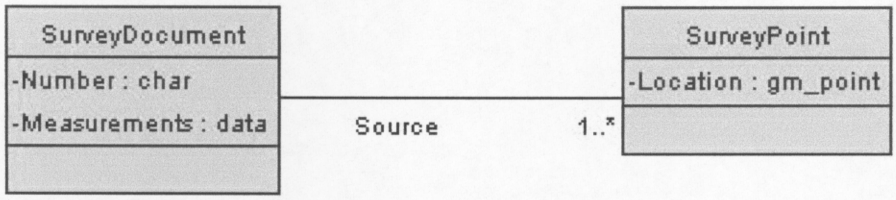


*Figure 3. The Survey Package, 'pink'*

## 2.3 Geometry and Topology: imported OpenGIS classes

Object classes describing geometry and topology are presented in purple; see Figure 4. The Cadastral Domain Model is based on already accepted and available standards on geometry and topology published by ISO and OGC (ISO, 1999a, 1999b, OpenGIS Consortium 1998, 2000a, 2000b, 2000c and 2000d). Geometry 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 'shapes' 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). 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 as explained in 6.2. 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, which are not based on explicit topology structure, these can be found in respectively the classes RestrictionArea and VolumeProperty. As in the topology/geometry layer of PartionParcel, all coordinates are obtained from the SurveyPoints. There are also 'Realize' methods available within the RestrictionArea and VolumeProperty classes to return the complete and explicit geometry respectively gm_surface and gm_volume. A VolumeProperty is defined by at least 4 non-planar SurveyPoints; this would result in a tetrahedron, the simplest 3D volume object. The RestrictionArea is defined by 3 or more SurveyPoints, which all have to locate in the same horizontal plane (of the earth surface).

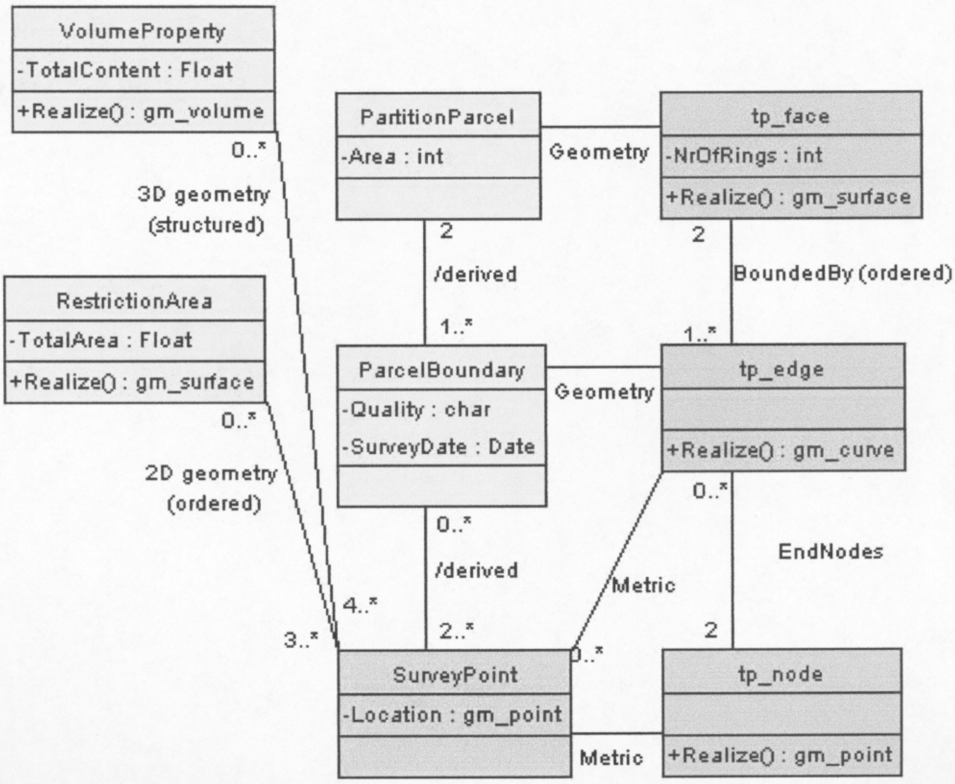


*Figure 4. The Geometry, Topology and some related packages, purple*

## 2.4 Legal/Administrative classes

Object classes presented in yellow cover the refinements in the Legal/Administrative side; see Figure 5. 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 of mix of these three types. In the other direction, a RightOrRestriction, Mortgage or PublicRestriction is always associated with exactly one LegalDocument as its source.

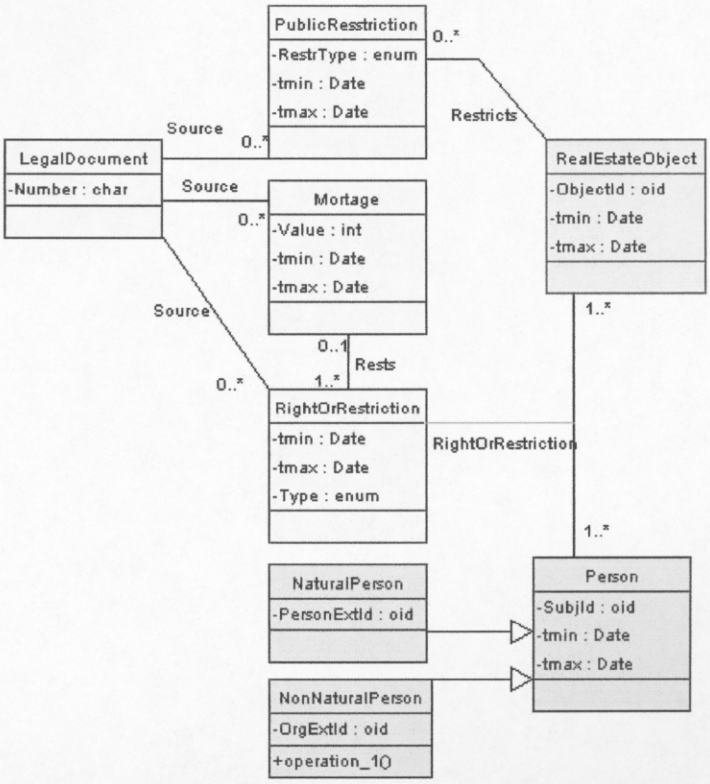


*Figure 5: The legal/administrative classes ( yellow) and person classes (green)*

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

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 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 holder of it to some minor use of someone else his 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 construction 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, hypothec, lien.

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 holder, as a restriction to the right (or object) they are 'carved' out from, or both. The last solution is of course risky from data management point of view, since inconsistencies can arise.

Because property and ownership rights are based on (national) legislation, 'lookup tables' 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 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' of the right is abstract (either "the government" or "society-at-large") 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 (esp. when urban development is made possible in a rural area).

Each restriction type has its own place in the cadastral domain model. Public restrictions with their own areas can be recorded via the RestrictionArea class, not being linked to a specific holder. Obviously the documents on which they are based need to be included. Public restrictions, which apply to RealEstateObject's but have no clear beneficiary, are recorded as PublicRestrictions. Other restrictions should be recorded as well as possible as rights in the name of the holder, but in certain countries some types do not state the holder (or the holder is a neighbouring RealEstateObject, regardless of 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 holder of the right (e.g. bank) is recorded, in other cases there is only a restriction recorded, informing others someone already has 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 compulsory association between RealEstateObject and Person, 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.

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.

### 2.5 History and dynamic 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 modelled 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 know 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 modelled explicitly: every object gets (at least) two dates/times, which indicate 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 our model we have introduced a hybrid approach 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 t1 and t2 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 to not further complicate the model with the explicit parent-child relationships.

Besides the data modelling aspect of the dynamic processes within the Cadastral Domain, one could question how are the functions and processes related to each other? Focus of the work until now has been on the UML class diagram, that is, the structural aspect. The UML class diagram should further be completed by diagrams covering other aspects, e.g. via state (use case, sequence, collaboration, state or activity) diagrams. Figure 6 shows a state diagram of the splitting of a parcel. Activity diagrams show how processes are related to the information (data) and how one 'flows' from on to the other. In all the other mentioned types of UML diagrams, actors or organizations play an important role and this may be quite dependent on that (national) set-up. The introduction of different 'stages' of a parcel (one-point, image, surveyed), a right (start, landhold, freehold) and a person could further reflect the dynamic nature of the system. More background discussion related to the dynamic aspects of a cadastral system can be found in section 4.

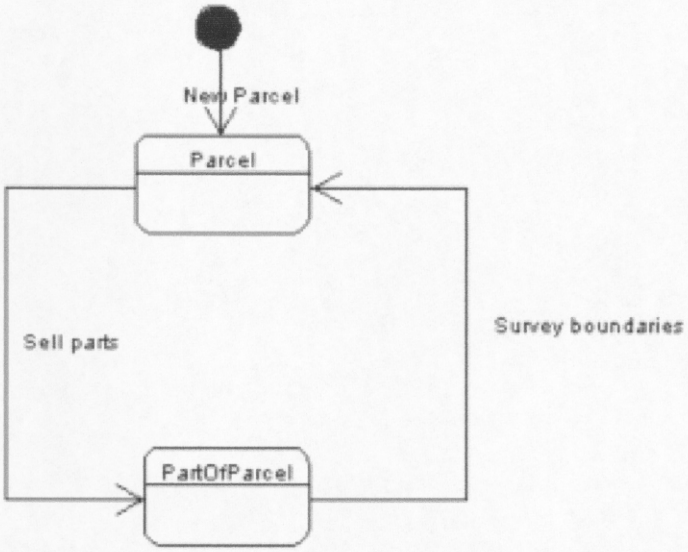


*Figure 6: State diagram of splitting a PartionParcel. If a part of a parcel is sold, the parcel is split into several PartOfParcels, which become regular parcels again only when their boundary is surveyed.*

## 2.6 Further developments

As indicated in the beginning of this section, the presented third version of the Core Cadastral Domain Model (see Figure 7) is just a proposal and a potential start for the final standardized model. Many more things have to be done (and perhaps modelled in additional packages or refinements). Potential further developments could be:

- GeodeticReferencePoints, could be a specialization of SurveyPoint. This will make SurveyPoint an abstract class with CadastralSurveyPoints and GeodeticReferencePoints as its specializations. Further specialization could be CadastralCentroidPoint, in case only one point of a Parcel or NonGeoRealEstate is observed, see Jackson 2002.
- Higher level administrative units (aggregations: sections, municipalities,...) and the relationship to the lower level units. If possible redundant storage of the geometric and topological data should be avoided.
- Land consolidation/reform, urban development, urban and rural cadastres
- Links to external registrations could include:
    1. Persons (e.g. via fiscal person identifier, or other approved identifiers)
    2. Companies/organizations (e.g. chamber of commerce)
    3. Addresses and zip codes, related to objects and subjects
    4. Buildings or more general, topographic data, in relation to core cadastral data.

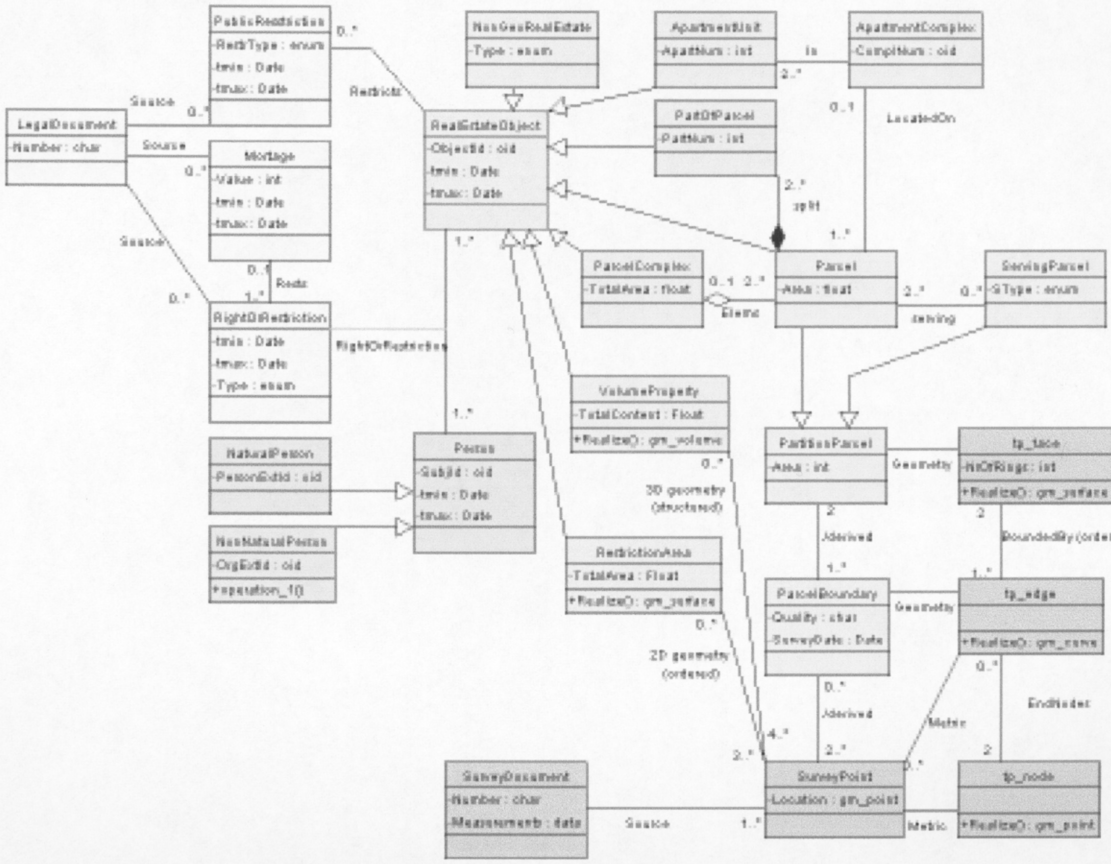


*Figure 7: the 'complete' cadastral core model, version 3.0*

## 3. Three dimensional alternatives/extensions

Current cadastral registration systems, 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, building complexes) and in the vertical dimension (depth and height) of rights established for 3D constructions (Stoter and Ploeger , 2002; Stoter and Ploeger, 2003). In the previous section the VolumentricProperty was introduced, but this requires a significant change in the legislation in most countries. Therefore in this section some alternatives (with less legal impact and based on the well known concept of the 2D parcel) for 3D situations are presented together with their UML class diagrams. In addition to the 3D legal volumes, the 3D constructions themselves cannot be queried in current cadastral registration systems, for example it is not possible to perform a query such as 'who is the owner of this tunnel?'. To overcome these limitations, the 3D aspect should be incorporated in the core cadastral data model. Two alternatives to the VolumetricProperty of the core cadastral data model have been introduced in the 3D cadastre research (Stoter and Ploeger, 2002; Stoter and Ploeger, 2003). These will be described in this section.

### 3.1 Registration of the 3D extension of rights

The first alternative is just a simple extension of the core model: the introduction of a 3D right-object. The 3D right-object is the 3D representation of a right that is established on a parcel for a 3D construction (Stoter and Ploeger, 2002). The 2D extent of a 3D right-object is the actual parcel-boundary. The upper and lower limits of the 3D right-object are the upper and lower limits of the space where the right applies (Stoter and Ploeger, 2002). The 3D right-object gives insight in the vertical dimension of the rights established. For example when a railway tunnel crosses a parcel and a right of superficies is established on the parcel, the 3D right-object is the 3D description of the space where the right applies. This example is illustrated in figure 9. For this example new (fictive) parcel boundaries were created in order to avoid that parts of parcels that do not overlap with the tunnel are affected with a right of superficies. With the 3D right-objects it is possible to see that the rights are established for an underground construction, also the depth and height of the construction is visible, which is not visible on conventional cadastral maps. The UML class diagram of 3D right-objects is shown in figure 8. For every right that is established on a parcel and that concerns a complex situation (one parcel is used by more than one person) a 3D right-object is maintained. This contains the 3D representation of the right, which is also maintained in the DBMS.

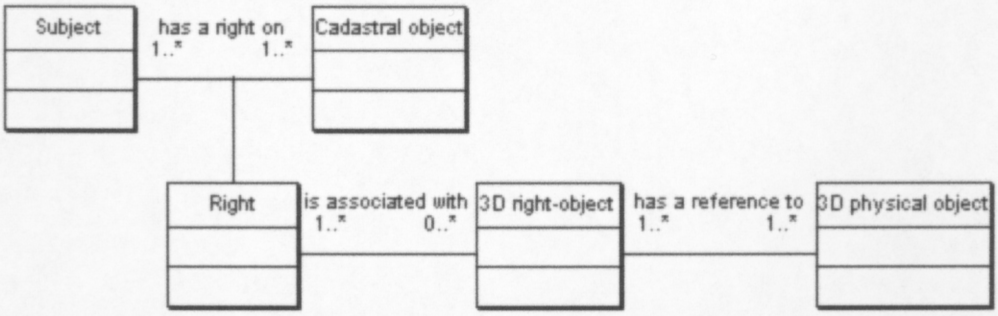


*Figure 8: UML class diagram of 3D right-objects*

One 3D right-object can be associated with more than one right, e.g. if a tunnel is held by two subjects. One 3D right-object can have a reference to more than one physical object. For example when two tunnels held by one subject cross a parcel and only one right is established for the two tunnels. All 3D right-objects belonging to one physical object can be found since they refer to the same 3D physical object. The factual ownership of a volume of space can be found by tracing the subject(s) that has/have the right that is associated with the 3D right-object. The data model needs some adjustment compared to the current cadastral model, but the principle of the 2D parcels as basic objects remains the same. The registration of a 3D right-object will not take place if only one subject has the complete right on a parcel. For the tunnel the registration of 3D right-objects will not take place, when the Ministry of Transport and Public Works owns the intersecting parcel. This leads to 'gaps' in the 3D registration. This is clearly illustrated in figures 9b and 9c. Figure 9b shows the situation when new parcels are created and some of these parcels are in full ownership with the Ministry. For those parcels a 3D right-object will not be created (the Ministry owns the whole parcel column). The situation is even less clear in figure 9c. This will be the case when both new parcels and the original undivided parcels are in full ownership.

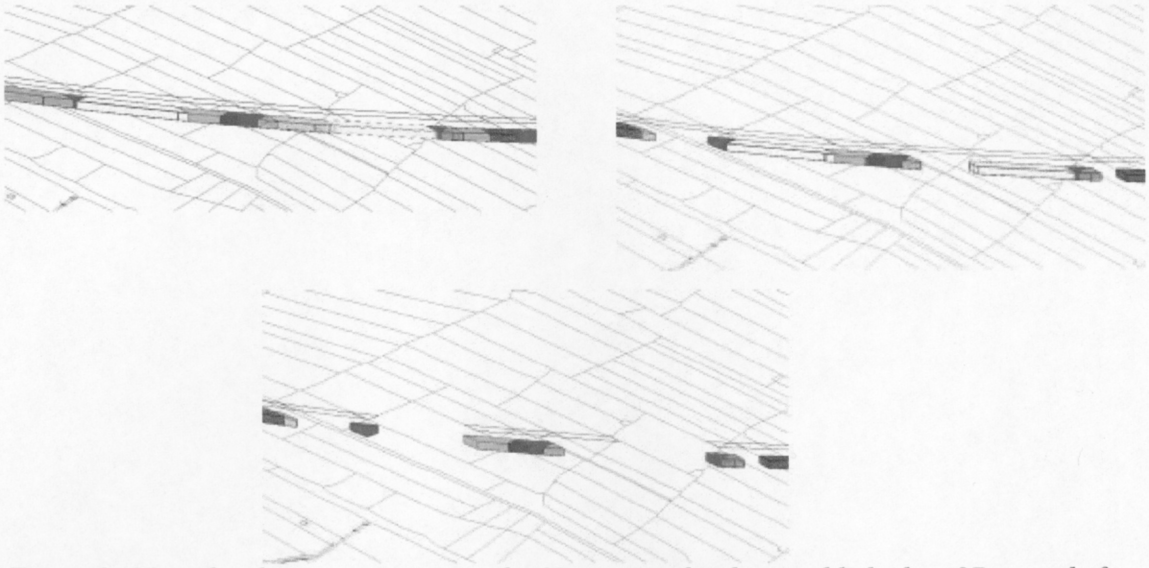

*Figure 9: 3D right-objects representing the 3D extent of rights established on 2D parcels for a railway tunnel owned by the Ministry. Figure a (top left): all the parcels are encumbered by right of superficies, new parcels are created for all intersecting parcels. Figure b (top right): as figure a, but now three newly created parcels are in full ownership of the Ministry. Figure c (bottom): three newly created parcels are in full ownership, two parcels that are not subdivided are in full ownership. All the other (new) parcels are encumbered with a right of superficies.*

### 3.2 Legal space of object is registered

How to know the actual location of the tunnel and to avoid the 'gaps' in the registration? The only solution is the registration of the complete construction itself, as is shown for the railway tunnel in figure 10. This would be the most optimal solution to register 3D situations and is the second alternative proposed: registering the 3D physical object itself together with a spatial description of the legal space of the object. The legal space is the space that is relevant for the cadastre (bounding envelope of the object), which is usually larger than the physical extent of the object itself (for example including a safety zone). Note that this solution does not introduce the possibility to register 3D physical objects as real-estate objects. The cadastral registration of the legal status of real estate is still based on 2D parcels.

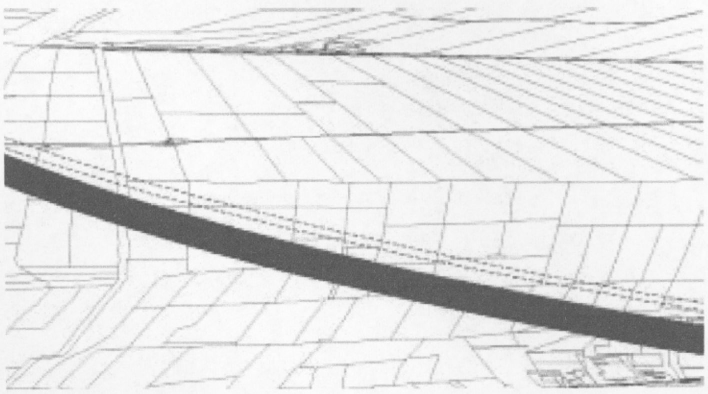

*Figure 10: Registration of the legal space of the railway tunnel. The dashed line is the projection of the tunnel on the surface. Note that the parcels are not divided into smaller parcels.*

The UML class diagram of this registration is shown in figure11. Apart from parcels (cadastral objects), 3D physical objects are also registered. The holder of the 3D physical object is a subject with a right on the intersecting parcels established for the 3D physical object (factual ownership, which is not the same as the juridical ownership). This can be right of superficies, but also complete ownership. In general the holder of a 3D physical object is the person or organization who is responsible for the 3D physical object, and uses the object as if he were the owner. Rights and limited rights are still registered on parcels. The only right that a person can get on a 3D physical object is that he can become the holder of this object. Therefore, a 3D physical object is not a subset of cadastral objects: 3D physical objects are maintained in addition to 2D parcels.

The juridical relationship between the legal space of the 3D object and the intersecting parcel(s) is stored implicitly, because the holder of a 3D physical object is maintained. This is the same (non-natural) person who has a right on the intersecting parcels. The solution of registering the legal space of 3D objects compensates many limitations of current cadastral registration. The intersecting parcels still need a right referring to a 3D construction, but the parcels need not to be divided into smaller parcels. The spatial relationships between parcels and the (legal space of the) 3D physical object can be maintained with spatial functions in the DBMS.

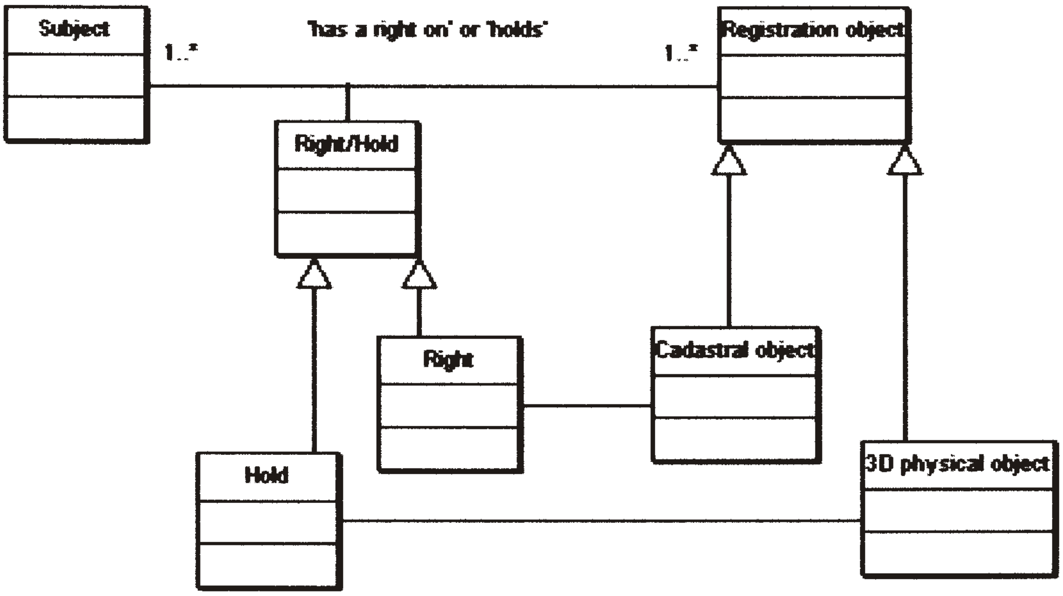


*Figure11: UML class diagram of 3D physical objects*

**4. Dynamic Aspects of the model**

The dynamic nature of land tenure is a major challenge for cadastral modelling. In section 2.5 we discussed some structural aspects of the dynamic cadastral systems, 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 & Quan, 2000), (Zoomers & Van Der Haar, 2000) and it is possible to switch between these forms, and 'upgrade' of the right. Regarding private tenure there are for example rights to land with an unlimited duration (like freehold, ownership, mulk), rights with limited duration (like leasehold and miri), condominium and strata title, rents, derived rights like usufruct, superficies, easements, mortgages, and forms of adverse possession. Regarding public forms of land tenure we observe crown lands, state lands, parastatal lands, and various forms of public interest in land (like encumbrances pertaining to land use regulations, pre-emptive rights, expropriation). Also land rights within the customary law and tradition are more and more considered as being 'legal' moreover it they are recognised explicitly by statutory law. Without such a recognition however one could assume they within the jurisdiction of the customary tradition they are as valid as written law. Various forms are tribal lands, collective lands, individual use rights, secondary rights (right to collect firewood, grazing after harvest, water rights, berry picking etc.), and pastoral rights (grazing lines, corridors, reserved grazing areas). The dynamic nature of land tenure does not pertain to the normal land market and land development (land reform) only, it reflects also the evolving rights to land in countries where adjudication and cadastral boundary survey that results in the issuing of full fletched titles to land (freehold) is considered as being much too expensive and too demanding. New right top land are evolving, such as native title (Australia, USA, Canada), Maori title (New Zealand), certificates of customary ownership and occupation certificates (e.g. Uganda), co-titling (e.g. Mozambique), starter and landhold title (e.g. Namibia), cadastral certificates (Albania), village titles (e.g. Tanzania), to name a few. Also quite a few countries are attempting to integrate their customary tenure in the statutory environment, such as the new land laws in Uganda (1998) and Mozambique (1998), Namibia (pending), South Africa Communal Property Bill (pending), Bolivia INRA-law (1996), Ghana Constitution (1992).

Similar 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 an 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.) new 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. in England and Wales) and alike (Jackson, 2002). All these examples might provide some evidence that the creation of core cadastral domain models might be of a complex nature, and is a challenge. However the driver for the development of a core cadastral domain is the basic concept of a relationship between people and land, whatever right holders, whatever rights, and whatever land object. The here presented dynamic aspects could be represented in the proposed model, further research is required to verify this.

## 5. Conclusion

A core cadastral data model should serve at least two purposes:

- Enable effective and efficient implementation of flexible (and generic) cadastral information systems based on a model driven architecture (as argued in this paper), and
- Provide the 'common ground' for data exchange between different systems in the cadastral domain.

The later one is a very important motivator to develop a core cadastral data model, which could be used in an international context; e.g. the EULIS project. The OpenGIS Consortium 'Property and Land Information Initiative', as announced in March 2003, underlines the relevance of standardisation. We would again like to emphasize that the current (third) version of the Core Cadastral Domain Model is just a proposal; it is incomplete and may even contain errors. We would like to encourage everybody to participate in the further development of this model in order to make this standardization effort really work. Worldwide many efforts can be recognized related to standardization in the cadastral domain. It is again proposed here to join forces between FIG and OpenGIS (ISO TC211) and to establish an OGC SIG for the Cadastral Domain. The activities of this SIG could be organized in close co-operation with the FIG. The introduction of a de facto standard on the cadastral domain, which is OpenGIS compliant, is a substantial effort. In any case there should be sufficient support world wide.

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