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The core cadastral domain model

Peter van Oosterom [a,*], Christiaan Lemmen [b,c,1], Tryggvi Ingvarsson [a], Paul van der Molen [b,c,1], Hendrik Ploeger [a], Wilko Quak [a], Jantien Stoter [c], Jaap Zevenbergen [a]

[a] *OTB Research Institute for Housing, Urban and Mobility Studies, Delft University of Technology, Jaffalaan 9, 2628 BX Delft, The Netherlands*
[b] *Dutch Cadastre, Apeldoorn, P.O. Box 9046, 7300 GH Apeldoorn, The Netherlands*
[c] *International Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, 7514 AE Enschede, The Netherlands*

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Abstract

A standardized core cadastral domain model (CCDM), covering land registration and cadastre in a broad sense (multipurpose cadastre), will serve at least two important goals: (1) Avoid re-inventing 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 (MDA), 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 second goal is very important for creating standardized information services in an international context, where land administration domain semantics have to be shared between countries (in order to enable needed translations). This paper presents an overview of the core cadastral domain model and its developments over the last 4 years. The model has been developed in a set of versions, which were each time adjusted based on the discussions at workshops with international experts and the experience from case studies in several countries of the world (Netherlands, El Salvador, Bolivia, Denmark, Sweden, Portugal, Greece, Australia, Nepal, Egypt, Iceland, and several African and Arab countries). Important conditions during the design of the model were and still are: should cover the common aspects of cadastral registrations all over the world, should be based on the conceptual framework of Cadastre 2014, should follow the international ISO and OGC standards, and at the same time the model should be as simple as possible in order to be useful in practise. Besides presenting the

* Corresponding author.
E-mail address: oosterom@geo.tudelft.nl (P. van Oosterom).
[1] Tel.: +31 55 5285695.

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CCDM itself this paper represents an important new wave in geo-information standardization: after the domain independent basic geo-information standards (current series of ISO and OGC standards), the new standards based on specific domains will now be developed. Due to historical differences between countries (and regions) similar domains, such as the cadastral domain, may be modeled differently and therefore non-trivial harmonisation has to be done first. The presented CCDM is a result of this harmonisation and one of the first presented examples of semantic geo-information domain standards.

Besides the three well-known concepts, Parcel, Person and Right, at the class level the model also includes immovables such as Building and OtherRegisterObject (geometry of easement, like a right of way, protected region, legal space around utility object, etc.) and the following concepts: SourceDocument such as SurveyDocument or LegalDocument (e.g. deed or title), Responsibilities, Restrictions (defined as Rights by other Person than the one having the ownership Right) and Mortgages. At the attribute level of the model the following aspects are included: SalePrize, UseCode, TaxAmount, Interest, Ranking, Share, Measurements, QualityLabel, LegalSize, EstimatedSize, ComputedSize, TransformationParams, PointCode, and several different date/times. The heart of the model is based on the three classes: (1) RegisterObject (including all kinds of immovables and movables), (2) RRR (right, restriction, responsibility), and (3) Person (natural, non-natural and group). The model supports the temporal aspects of the involved classes and offers several levels of Parcel fuzziness: Parcel (full topology), SpaghettiParcel (only geometry), PointParcel (single point), and TextParcel (no coordinate, just a description). The geometry and topology (2D and 3D) are based on the OGC and ISO/TC211 standard classes. The model is specified in UML class diagrams and it is indicated how this UML model can be converted into and XML schema, which can then be used for actual data exchange in our networked society (interoperability).

Keywords: Cadastre; Modeling; Standardization; Harmonization; Real property; UML; ISO; OGC

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 systems 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 these relationships up-to-date (based on legal transactions) in a cadastral registration system and (2) providing information on this registration.

The UN Land Administration Guidelines (UNECE, 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 that 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, modeling 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 modeling 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 system 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. 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 and 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, 1996; von Meyer, Oppmann, Grise, & Hewitt, 2001)
   - Initiatives from Australia and New Zealand (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". Sixty spatial data components, grouped around 31 themes have been identified as important data-sets, among others topography, *cadastral properties*, geographical names *administrative areas*, *postcodes*, *buildings and addresses*, terrain elevation and orthophotos. 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 works on the 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 methodology and the steps taken so far in the development of a standardized CCDM based on the geographic standards from ISO and OGC (OpenGIS). The CCDM 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: 'Modeling Real Property Transactions'. The CCDM itself is presented in Section 3, including specific aspects such as 3D Cadastral modeling and the dynamic nature of Cadastral systems. The main conclusions and future work are finally described in the last section.

2. Methodology and history of the model development

The CCDM is developed in an iterative manner based on an empirical approach. First, an initial CCDM proposal is made (based on literature, 'Cadastre 2014' among others, and experience of the involved authors/designers) and published via relevant symposia, workshops, conferences and their proceedings and websites. Next, international discussion took place based on the published model and is done in different manners: trying to apply the model to different countries (by local experts) and developing prototype systems and exchanging scientific arguments at specifically devoted meetings. The involved international experts do not only have a geographically different background, but also a professionally different background in order to make sure that all relevant aspects are covered: legal specialists, surveyors, ICT-specialists, etc. from different organisations (land registry and cadastral organisations, standardization institutes, industry and academia). Based on the outcome of these experiments and discussions the model is improved and refined (and hopefully) iterates towards more consensus. The currently presented version is version number six. Below a more detailed overview of the different versions, now first some remarks on the 'Cadastre 2014' (Kaufmann & Steudler, 1998) conceptual framework as the starting point for the CCDM development.

2.1. Cadastre 2014

The guidelines of Cadastre 2014 give an excellent modeling start, but it is a generic, or abstract, set of guidelines, which must be further refined into a more specific model. This is the aim of the CCDM. One could compare these two levels with the abstract and the implementation level of specification within Open Geospatial Consortium (OGC). The abstract level contains the most important knowledge, but this can be implemented in several different manners, which can all claim to be compliant (but the systems would not support automated interoperability). The CCDM goes one step further and specifies an implementation level of the model, which means that different systems adhering to the core cadastral model will be interoperable. Kaufmann and kaul (2004), in his paper on the assessment of the CCDM from 'Cadastre 2014' perspective, notes that in Cadastre 2014 the legal land object (instead of only the parcel) is in the centre. All legal land objects are handled in the same manner. Further he notes that cadastral surveying is not explicitly treated in Cadastre 2014, but this is to a certain extend within the CCDM. He concludes that the basic considerations made in the context of the CCDM and those behind Cadastre 2014 do not differ much. Kaufmann and Kaul further concludes that the CCDM initiative, trying to model existing occurrences of cadastres, is confronted in every step with new questions. The development of the CCDM shows that with every step more elements of Cadastre 2014 are included. A trend in direction of Cadastre 2014 can be identified. Cadastre 2014 was, when first presented, a totally new approach to cadastre. Including all legal land objects of a certain jurisdiction and according to its laws and handling them according to the proven and successful principles of the traditional cadastre, is a new approach made possible by the development of ICT. This new approach makes it necessary to throw overboard some traditional practises as the parcel-only-centric approach. Thinking in land objects is the future in modern cadastral systems. An important characteristic of Cadastre 2014 is that similar land objects are organized in independent layers. This is translated in the CCDM in different independent object classes, such as Parcel, Building, OtherRegisterObject (legal area of easements, utility infrastructure, specific land use or protection, etc.). All these classes of immovables share the characteristic that they are all somehow related to persons via (all kinds of) rights (restriction and responsibilities).

2.2. Summary of the CCDM history

The development of the CCDM has its history. During the FIG Congress in April 2002, held in Washington, US, a proposal was made by Lemmen/van Oosterom to develop the CCDM (van Oosterom & Lemmen, 2002a) a first version of this model, named '*Noordwijk'02*', was later on presented at a OGC meeting, organised in Noordwijk, the Netherlands, September 2002 and at a COST Workshop in Delft, the Netherlands in November 2002 (van Oosterom & Lemmen, 2002b). The second version of the Model, named '*Paris'03*', based on expert reviews has been presented at a workshop on Cadastral Data Modeling at the International Institute for Geo-Information Science and Earth Observation, ITC, in Enschede, the Netherlands in March 2003 (see www.oicrf.org) and during the FIG working week, Paris, April 2003 (Lemmen & van Oosterom, 2003). Several publications have been made in GIM International 2002–2003. The OGC announced in March 2003 the 'Property and Land Information Initiative' (LPI Initiative) and cooperation was established by exchanging the models and by OGC involvement in a subsequent workshop (Bamberg, see below).

A third version of the model (multi-purpose cadastre, 3D extensions, refinements and by more authors, domain specialists), named '*Brno'03*', has been presented at Digital Earth, September 2003, at the second Cadastral Congress in Kraków, Poland in September 2003 (Lemmen et al., 2003) and at the EULIS Seminar on 'Land Information Systems and the Real Estate Industry', Lund, Sweden, April 2004. During an Expert Group Meeting on Secure Land Tenure, Nairobi Kenya (see www.fig.net), November 2004 it came clear that customary tenure should be included. The Nairobi meeting provides input from developing countries, which was worked out in the fourth version of the model, named '*Bamberg'04*', presented during the second workshop on standardization of the cadastral domain, held in the Aula of the University of Bamberg, Germany, 9–10 December 2004 (van Oosterom, Lemmen, & van der Molen, 2004). In the paper presented in Bamberg there has been attention to the system boundary and some other suggestions for further improvement have been included in the conclusions.

The fifth version of the model, named '*Cairo'05*', was presented at the FIG working week in Cairo, April 2005. This version was mainly improved in the legal, administrative side of the model (based on the Bamberg workshop) and the model was made 100% compliant with the OGC and ISO TC 211 standards. The near future plans for the CCDM include reflection Arab world cadastral registration at FIG meeting (Jordan, September 2005), presentation at the UN Habit expert group meeting (Moscow, October 2005), and FIG regional conference Accra, Ghana, March 2006 (including the third CCDM workshop), and FIG main conference Munich October 2006 (with detailed report working trough many cases and examples in more detail and including initial filling of several code lists, which are until now only mentioned but not described with content). It is expected that the model is now quite mature and stable, but it will be an illusion to think the model itself is ever finished as the world around us will keep on changing and insights and knowledge keeps on evolving. Within Europe the CCDM will be proposed as basis for the cadastral data specification within INSPIRE as one of the authors, van Oosterom, is member of the INSPIRE data specification core drafting team. From European prospective, it can be expected that financial institutes like banks, mortgages and security and other users are the drivers for development of a CCDM, but who takes the leading role? Search continues for an authority that will drive development of CCDM further, e.g. the FIG or INSPIRE with their networks and supported by OGC. A co-ordinating group is needed who can further identify the driving force. The 'model boundaries' (what should not be included, what should be included) require further investigations; rights, restrictions, responsibilities related to land should be included and an extension of fiscal rights and responsibilities. Relationships to objects outside the CCDM model boundaries (and managed in other registrations) have to be organized within a GI. Again, within Europe INSPIRE should be designed to provide such 'registration linking' facilities.

This paper presents the current, sixth version, of the model and will be called '*Moscow'05*'. The 'Cairo'05' version of the model has also been submitted to ISO TC211 for comments and the written, all very valid, comments have been addressed in the current version. The comments were related to include a Building in the model, to better explain relationship between rights and restrictions (often 'the positive and negative side of the same coin'), better explain the role of PartOfParcel (yet unseparated area), and a remark on the need of not only standardizing the model but also the possible information services. In contrast to the previous, intermediate, versions of the model, not only the new aspects are incrementally presented, but also the whole model and history is recaptured. This is the first version that is presented in a scientific journal and it was decided to present the whole model, instead of the increments only. Mainly, because of reasons related to completeness and readability.

2.3. Boundary of the CCDM

Since the 'Brno'03' version of the model, the CCDM is organised into several packages. It is likely that more packages will be developed. Besides being able to present/document the model in comprehensive parts, another advantage of using packages is that it is possible to develop and maintain these packages in a more or less independent way. Domain experts from different countries could further develop each package. It is not the intention of the developers 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, then this package should be the foundation and thereby avoiding re-inventing (re-implementing) the wheel and making meaningful communications with others possible. It is very tempting to keep on adding more packages as (new) object classes are often related to classes in the current model (and this becomes more true when the model keeps on growing by adding more and more packages). Further, the result of comparing cadastral models depends a lot on the equal scope of the models; e.g. in one cadastral model includes a person registration (with all attributes and related classes to persons) and the other model just refers to a person (in another registration), then the two models may look different, but the intentions is the same. Only the system boundary of the involved models is different. However, the boundary of the cadastral domain model is quite arbitrary in a certain sense. Perhaps, also (some of the) current packages of the model should be considered as separate models outside the core cadastral model. It is therefore proposed to try to get some consensus on the model boundary by considering the current cadastral registration practice in different countries of the world. We propose everything (all packages except the imported ISO TC211 model for geometry and topology) in the Brno'03 version of the CCDM to be indeed within the boundary of the model. Next an attempt to list classes or packages of classes that are related to, but outside, the CCDM:

1. spatial (coordinate) reference system;
2. ortho photos, satellite imagery, and Lidar (height model);
3. topography (planimetry);
4. geology, geo-technical and soil information;
5. (dangerous) pipelines and cable registration;
6. address registration (incl. postal codes);
7. building registration, both (3D) geometry and attributes (permits);

8. natural person registration;
9. non-natural person (company, institution) registration;
10. polluted area registration;
11. mining right registration;
12. cultural history, (religious) monuments registration;
13. fishing/hunting/grazing right registration;
14. ship- and airplane (and car) registration;
15. …

Again it is stressed that it is very difficult define the scope of the CCDM as nearly all topics mentioned above are (sometimes strongly) related to the classes in CCDM. 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 Immovables). 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 utility 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 of this. Though strongly related, these are different aspects (compare this to a wall, fence or hedge in the terrain and the 'virtual' 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 then 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 already difficult within one domain (such as the cadastral world) to agree on the used concepts and their semantics, it will be even more difficult when we are dealing with other domains. However, we cannot avoid this if a meaningful interoperable geo-information infrastructure has to be realised. Some vendors (e.g. ESRI, Bentley, Intergraph) are quite active in supporting the model driven architecture and developing specific domain models and it can be expected that they will try to avoid overlap (and especially when this is inconsistent) between the different models: agriculture, topographic mapping, biodiversity/conservation, defence, energy utilities, environmental regulated facilities, forestry, geology, historic preservation, hydrotropic/navigation, marine, petroleum, pipeline, system architecture, telecommunications, urban, water utilities, water resources. It seams appropriate that also a more neural organisation plays a coordinating role in this harmonisation process; FIG, OGC, ISO, INSPIRE, CEN,…

In several countries of the world we see attempts to harmonise a number of domain model within one country; e.g. Australia (ICSM, 2002), Germany, The Netherlands. But this is not sufficient, as the models should also be harmonised internationally as in the case of INSPIRE. One could raise the question: 'What is the best order for harmonising: first within a specific domain (at an international level as for example is the case with the CCDM) and then harmonise these different domains, or first within a specific country (including all relevant domains) and then harmonise these different country models?'. Anyhow, it will be an iterative process as our insight and knowledge will keep on refining (and both approaches will probably be applied). An extremely important aspect of the future Geo-Information Infrastructure (GII), in which (related) objects can be obtained from another side (instead of copied), is that of 'information assurance'. Though the related objects, e.g. persons in case of a cadastral system, are not the primary purpose of the registration, the whole cadastral 'production process' (both update and delivery of cadastral information) does depend on the availability and quality of the data at the remote server. Some kind of 'information assurance' is needed to make sure that the primary process of the cadastral organisation is not harmed by disturbances elsewhere. In addition, remote (or distribute) systems/users might not only be interested at the current state of the objects, but they may need an historic version of these object; 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').

Finally, a fundamental question is: 'How to maintain consistency between two related distributed systems in case of updates?' Assume that System A refers to object X in System B (via object id B.X_id), now the data in System B is updated and object 'X_id' is removed. As long as System A is not updated the reference to object X should probably be interpreted as the last version of this object available. Note that the temporal aspect is getting again a role in and between the systems! The true solution is of course also updating system A and removing the reference to object X (at least at the 'current' time). How this should be operationalized will mainly depend on the actual situation and involved systems. It might help to send 'warning/update messages' between systems, based on a subscription model of the distributed users/systems.

3. Core cadastral domain model

The core of the CCDM as depicted in Fig. 1 is the central part of the model and is very close to what 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. The relationship between RegisterObjects (e.g. parcels) and Persons (sometimes called 'subjects') via rights is the foundation of every land administration. Besides rights, there can also be restrictions or responsibilities between the real estate objects and the persons. Originally, Right (RRR) was an association class between the classes Person and RegisterObject. Note that this was an *n*-to-*m* relationship, with the conditions that every Person should at least be associated with one RegisterObject and vice versa every RegisterObject should be associated with at least one Person. The association class RRR is in the current model replaced by a normal class RRR. The reason for this is that now it is possible for a unique combination of a specific Person-RegisterObject multiple RRR instances can be associated, which was not the case in the construction with the association class RRR (only one instance could be associated with every unique pair). A person can be involved in any number of RRRs (indicated in the UML diagram with the multiplicity of '$*$' at the RRR-ends of the association) and an RRR can involves exactly one person (indicated in the UML diagram by omitting the multiplicity, which means '1'). In the current model there is no direct relationship between Person and RegisterObject, but only via RRR.

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

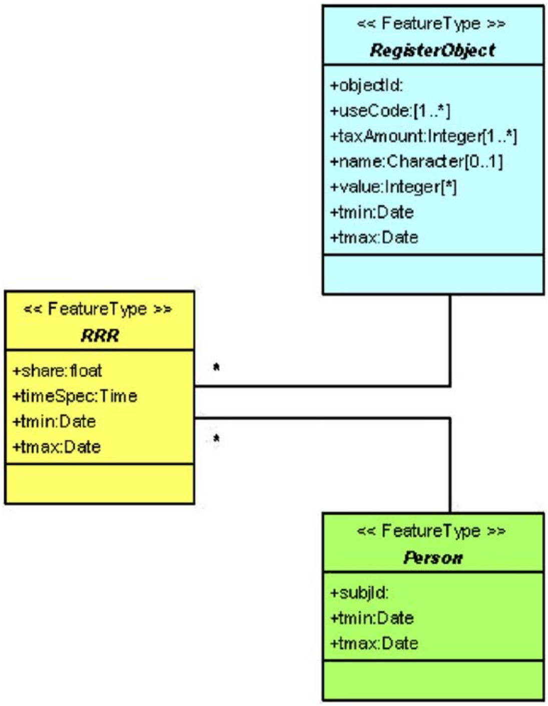

Fig. 1. Core of the CCDM: Person, RRR (Right, Restriction, Responsibility) and RegisterObject.

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, & Quinn, 1999).

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 et al., 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

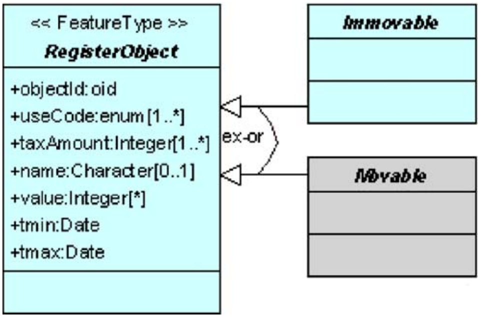

Fig. 2. The top level specifications of the RegisterObject: Movable, Immovable.

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[2] are representing UML 'packages' or coherent parts of the model: yellow: legal/administrative aspects, green: person aspects, blue: immovable object specializations, pink: surveying aspects and purple: geometric/topological aspects. The advantages of distinguishing several packages were already mentioned before (being able to present the CCDM in comprehensive parts, maintain and develop packages independently, possibility to use a package to implement one type of functionality). Furthermore basic packages could be implemented by software suppliers, e.g. GIS suppliers like ESRI, Bentley, Intergraph are providing models for several domains as was mentioned in Section 2.3.

Finally, it should be noted that though this is the core cadastral domain model, it has not the intention to be complete for one specific country. It is very likely that additional attributes, operators, associations and perhaps even complete new classes are needed for a specific country. These should be added to the model, based on the principles of object-orientation. However, it is only allows to extend packages and not to remove or rename parts (attributes, operations, associations and classes) of a package in order to be complaint with the CCDM. So, one should select the relevant packages and extend these for the local situation.

A RegisterObject is an abstract class, that is, there are no object instances of this object class. In a UML class diagram an abstract class is indicated by the italics used for the class name. RegisterObject has a number of specialization classes, in this case two: Immovable and Movable (see Fig. 2). In a UML class diagram the specialization classes point to the

[2] Note that in the journal version of this paper, the colours are translated into greyscales, but the on-line web version (accessible via http://www.elsevier.com/wps/find/journaldescription.cws_home/304/description#description and http://www.sciencedirect.com/science/journal/01989715) does contain the colour figures.

more generic class with an open headed arrow. The specializations are mutual exclusive as indicated by the 'ex-or' label between the arrows. The Movable objects, such as airplane, ship, train, car are outside the scope of the model (as indicated in Section 2.3).

3.1. Specializations of immovable

The Immovable objects are further refined into two main categories: land, or in 3D space, objects (the 'parcel' family in 2D and 3D in 'light blue') and the other objects (in 'blue'). The specializations of the Immovable class are represented in the 'light blue' and 'blue' package; see Figs. 3 and 4. The different types of land (space) objects include ('light blue', see Fig. 3): RegisterParcel, SpaghettiParcel, PointParcel, TextParcel, ParcelComplex, PartOfParcel. These classes can all have actual instances and these instances somehow describe a piece of land (in the case of 2D) or space (in the case of 3D). The other immovable register objects (blue) include: Building, Unit, NonGeoRealEstate and OtherRegister-Object. All these specializations of Immovable have associations with one or more Persons

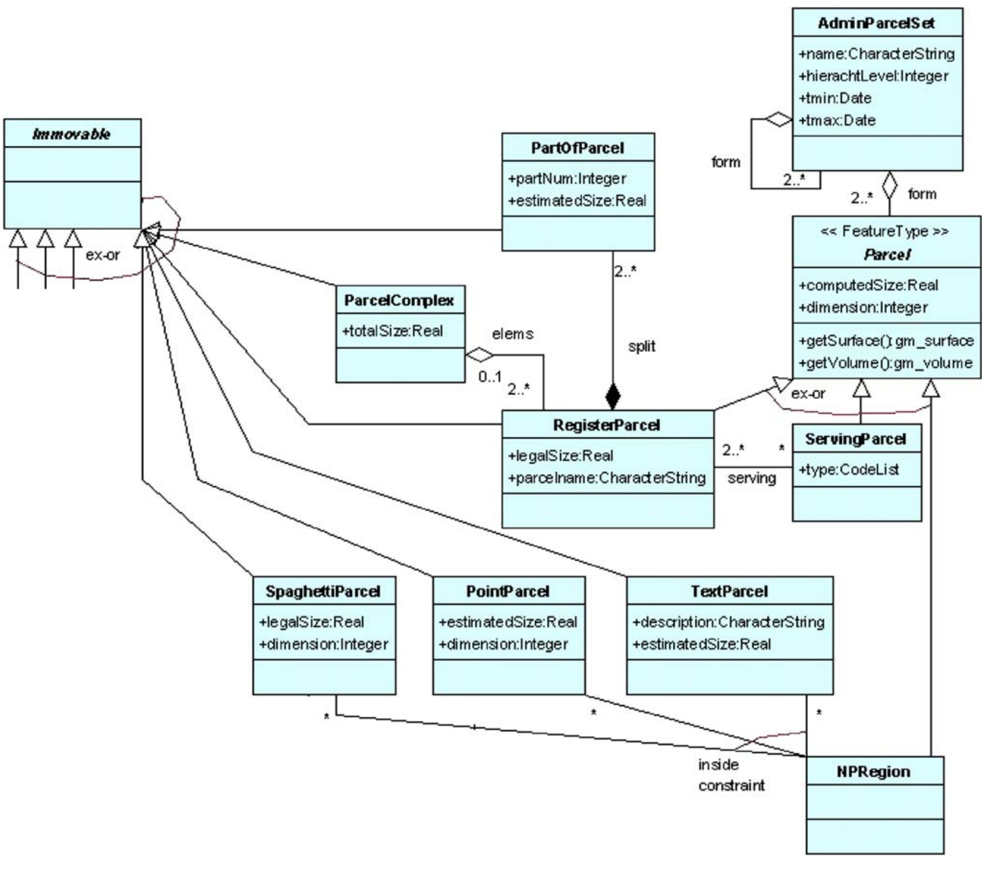

Fig. 3. The land (2D) or space (3D) 'Parcel family' package refined ('light blue' part); note that the other specializations of Immovable are depicted in Fig. 4 ('blue' part). For interpretation of the references in colour in all figures (except Fig. 10), the reader is referred to the web version of this article.

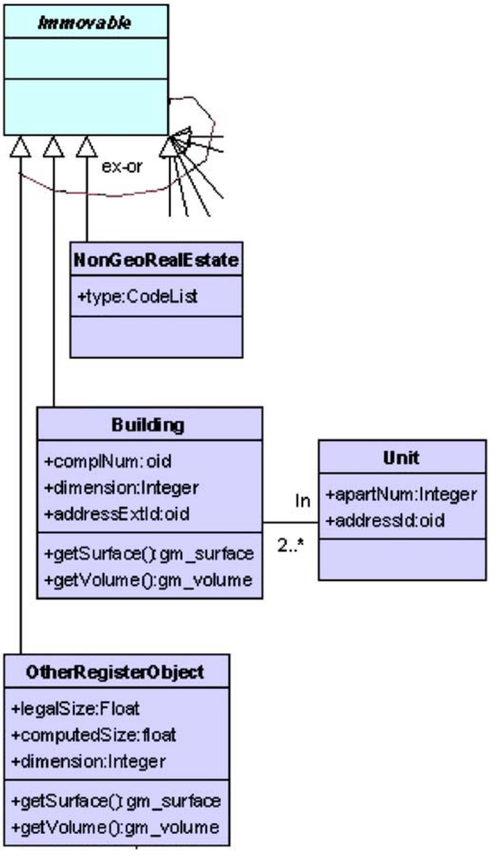

Fig. 4. The non-land (space) package refined: Building, Unit, NonGeoRealEstate and OtherRegisterObject ('blue' part); note that the other specializations of Immovable are depicted in Fig. 3 ('light blue' part).

via the RRR class. There are parts, called ServingParcels in the model, which only have direct associations with two or more RegisterParcels. Characteristic of a ServingParcel is that it serves a number of other RegisterParcels, and that it is held in joint ownership by the owners of those RegisterParcels. However in most cases this kind of joint ownership (in French: *mitoyenneté*) applies only to constructions, like a party wall, or a joint sewerage, in some countries this kind of joint facilities such as a path, parking or playground are known (e.g. the Netherlands: *mandeligheid*). A straight line between RegisterParcel and Serving-Parcel in the UML class diagram depicts this association. It can be considered as a (special) kind of joint ownership via the RegisterParcels.

The 'ServingParcel' principle could also be applicable to the common parts of apartment or condominium rights, if these common parts have been registered in the cadastral system as separate parcels, see page 27 of the UNECE Guidelines on real Property Units and Identifiers (UNECE, 2004): "A condominium may involve share ownership with an original volume of space being divided into a series of parcels, *one relating to the common parts of the building* and the remaining parts being in the private ownership of the individual residents. The common parts may belong to an individual who is the absolute owner of the whole block but who leases out separate parcels to tenants. Alternatively, *the common areas may be owned in shares held by the tenant of the separate apartments*, each owner having certain voting rights and financial obligations depending on the size of the shareholding." For the time being the 'ServingParcel' principle has not been applied to apartments (Building, Unit). To the contrary, perhaps even the ServingParcel itself could be removed from the model. In such a case a kind of fake NonNaturalPerson (related to the RegisterObjects/RegisterParcels being served) should be used and have some kind of 'serving right' via RRR.

In the UML class diagram RegisterParcel, ServingParcel and NPRegion are specializations of the topologically structured Parcel, which all-together form the partition (subdivision without gaps and overlaps) of the domain. The Parcel class, just as the RegisterObject class, is an abstract class as there will never be instances of this class. Note that RegisterParcel is based on multiple inheritance (from Immovable and Parcel, both abstract classes). The Parcel-family of classes is shown in Fig. 3. A ParcelComplex is an aggregation of RegisterParcels. The fact that the multiplicity at the side ParcelComplex is 0–1 (in the association with RegisterParcel) means that this is optional. A ParcelComplex situation might occur in a system where a set of RegisterParcels – 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 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. 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 (RegisterParcel), this is indicated with the closed diamond. 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 RegisterParcel. Further note that PartOfParcel is a specialization of RegisterObject (Immovable), making the unseparated piece of land (or space) a first class RegisterObject to which at least one Person is associated via RRR; e.g. in the form of ownership. Note that a ParcelComplex is a 'final' state (an aggregate of parcels, may be even disjoint, which together form one Immovable object), unlike a PartOfParcel, which is a kind of temporary object. So, ParcelComplex is not intended as a set of parcels to be merged into one new future RegisterParcel.

The model also offers the possibility to represent parcels not only based on a topological structure (faces of a planar partition in 2D or volumes of the spatial partition 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, a single point or a spaghetti polygon, which is not adjusted with it neighbors in a topology structure. The whole domain is subdivided into two types of regions: 1. regions based on a partition (P) and 2. regions not based on a partition (NP). Together the P and the NP regions cover the whole domain. The object class Parcel is therefore also specialized into NPRegion, besides the specializations RegisterParcel and ServingParcel. Note that an NPRegion 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 (specialization of RegisterObject) include the following specializations: TextParcel, PointParcel and SpaghettiParcel. These three 'alternative' non-topology representations of a land object can only exist in

NPRegion areas (and does not influence involve the clean topology RegisterParcel and ServingParcel areas). This can be represented via an additional (geometric) constrained in the model. A parcel may change its presentation over time from TextParcel, to PointParcel to SpaghettiParcel to RegisterParcel (but not back). However, this does not need to be the case in 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).

As mentioned above, the other immovable register objects, the non-land (or space in 3D) subdivision objects, include: Building, Unit, NonGeoRealEstate and OtherRegisterObject (see Fig. 4). The Building and Unit classes replace, as more general versions, the earlier ApartmentComplex and ApartmentUnit classes. In the CCDM there is no explicit association between Building and a parcel as this can be derived from the geometry and topology structures. In case this would not be possible, for example because a TextParcel (without geometry) is involved, an explicit association could be added in that specific country. Following the 'Cadastre 2014' principle of independent layers, it was decided not to include this association within the CCDM. There are two or more Units in a Building. Note that 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. Also the model does not intend to exclude Units where the construction is very small, or in fact absent, like in cases of parking spots, etc.

In most cadastral systems a restriction is associated to a complete RegisterObject (RegisterParcel) and this is also reflected in the presented model: a Person can have a Restriction (specialization of RRR) on a RegisterObject. However, this may be inconvenient in some cases: one 'thing' may cause the restriction on many RegisterObjects 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 RegisterObject, 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 Parcels) with own geometry (comparable with the layer concept of 'Cadastre 2014', Kaufmann & Steudler, 1998; Kaul & Kaufmann, 2003). These can be considered as a kind of RegisterObjects 'overlapping' other RegisterObjects, 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 3.4). This can be obtained via inspecting all rights associated with the RegisterObject and the overlapping OtherRegisterObjects. Note that OtherRegisterObjects are modeled as closed polygons in 2D or polyhedrons in 3D (and obtain their coordinates from SurveyPoints, see Section 3.2) and there is no explicit topology between OtherRegisterObjects, that is, they are allowed to overlap (and it is expected that they will not often share common boundaries as Parcels do). Typical examples of OtherRegisterObjects are: geometry of an easement (such as 'right of way'), protected region, legal space around a utility object.

The class NonGeoRealEstate can be useful in case where a geometric description of the RegisterObject does not (yet) exist. E.g. 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.

3.2. Surveying classes

Object classes related to surveying are presented in pink colour; see Fig. 5. 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. The individual SurveyPoints are associated with SurveyDocument. From the multiplicity it can be recognised that 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 the 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, …) 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 tmin/tmax). The associated classes do not have to be updated, only the SurveyPoint itself: new time stamp, better, better coordinate and association to new SurveyDocument. Pervious 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 the could also be other reasons for changing coordinates, for example map improvement or switching to a different coordinate

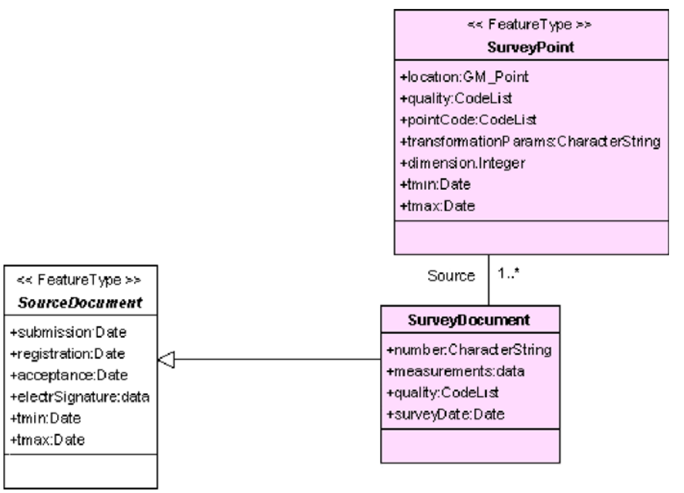

Fig. 5. The Survey Package, 'pink'.

reference system (or new calculation of same reference system). Also in this case the second option, new version of SurveyPoint (keep id) is to be preferred.

3.3. Geometry and topology: imported OGC/ISO TC211 classes

Object classes describing the geometry and topology are presented in purple; see Fig. 6. The CCDM is based on already accepted and available standards *on geometry and topology*

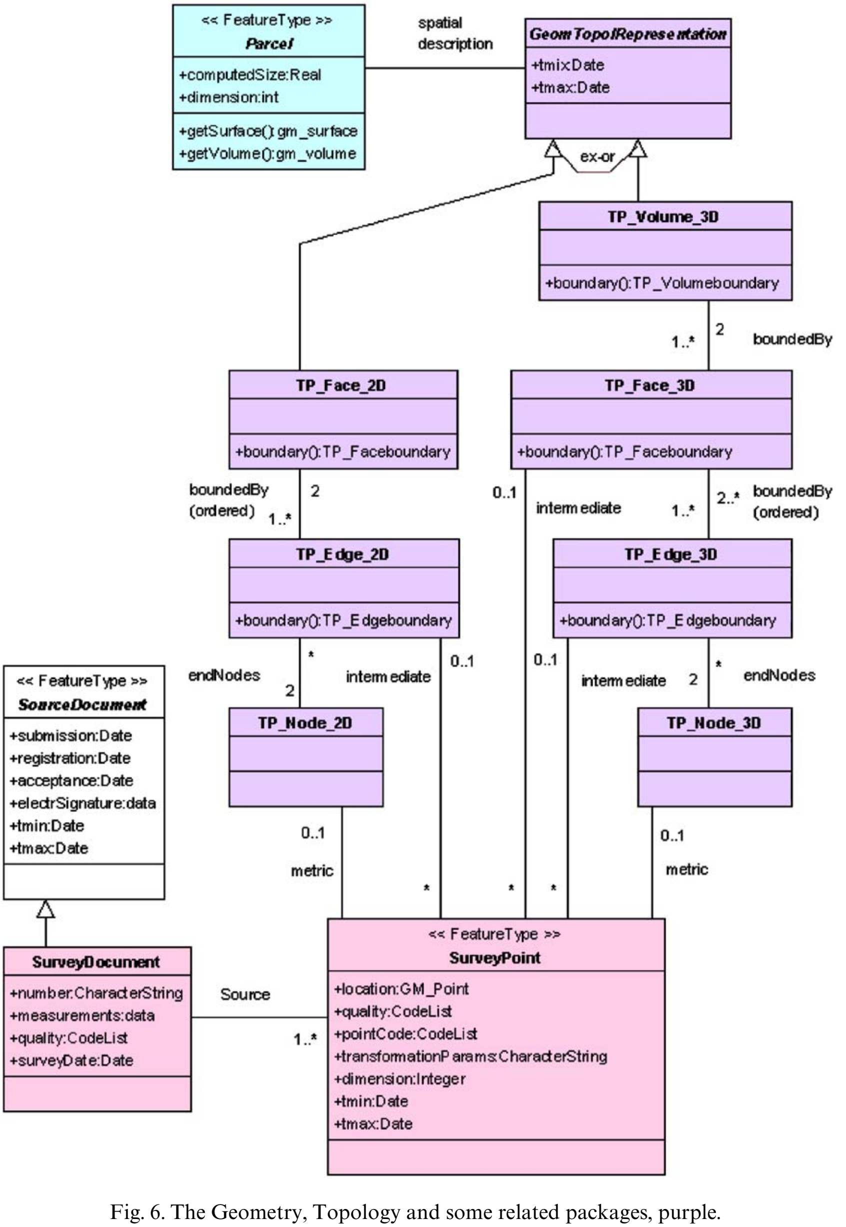

Fig. 6. The Geometry, Topology and some related packages, purple.

published by ISO and OGC (ISO, 1999a, 1999b; OpenGIS Consortium Inc., 1998, 2000a, 2000b, 2000c, 2000d). *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 (topology node), tp_edge (topology edge) and tp_face (topology face, only in 3D case) to describe intermediate 'shapes' points between nodes, metrically based on SurveyPoints.

Parcels have a 2D or 3D geometric description. A Parcel corresponds one-to-one to the tp_face (or tp_volume in 3D) in a topological structure (as defined by ISO TC 211 and OpenGIS Consortium). A volume is bounded by faces. A face is bounded by its edges. 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 'boundary' which can be used to obtain a full metric representation. An edge (or face in 3D) may further be extended with additional (non-geometric) attributes describing properties only belonging to the edge (face) and not to the whole Parcel or individual SurveyPoints.

There are other geometry layers, which are not based on explicit topology structure, these can be found in respectively the classes PointParcel, SpaghettiParcel, Building and OtherRegisterObject (again 2D or 3D). As in the topology/geometry layer of PartionParcel, all coordinates are obtained from the SurveyPoints. There are methods available within the OtherRegisterObject class to return the complete and explicit geometry respectively gm_surface and gm_volume. In 2D a geometry area is defined by at least three SurveyPoints, which all have to locate in the same horizontal plane (of the earth surface). In 3D a geometry area is defined by at least four non-planar SurveyPoints; this would result in a tetrahedron, the simplest 3D volume object.

A coherent region with Parcels is either 2D or 3D, but not mixed. This is not yet explicitly modeled in the current version of the CCDM. One could imagine a kind of 2D/3D administration class that indicates, which regions are 2D and which are 3D (compare to the NPRegion class for administration which regions are based on topology and which regions are not based on topology). So, it is possible to mix 2D and 3D parcels according to the model, but not within the same region. It is noted that if the registration is based on 2D Parcels, this does also imply the 3D columns (but these are not explicitly represented). In case a region has an explicit 3D representation, the tp_volume_3D may be open at the bottom and/or top side (corresponding to infinite columns). The z-coordinate (height/elevation) can be specified relative to the earth surface or in an absolute reference system (similar to x and y). It is advised to use absolute height values, because it is dangerous to associate rights based on relative heights (as the earth surface may change). In case of 3D objects based on absolute heights, also the earth surface plays an important role, in order to decide if certain objects are above or below the surface (or both). Currently, the earth surface elevation is outside the CCDM, but it should be accessible via the Geo-Information Infrastructure (GII). Further, it is possible to model the parcels in 2D, while modeling in the same region OtherRegisterObjects in 3D (e.g. underground utilities). Time is not (yet) integrated in the data types of the topology/geometry. It is currently treated as a separate attribute (tmin/tmax everywhere and timeSpec in RRR; also see Sections 3.5 and 3.6). One could image really full spatio-temporal RegisterObject representations for the definition of moving object with RRRs attached; e.g. to define grazing rights moving over time (2D and time) or a Marine cadastre with moving fishing rights in the ocean (3D and time).

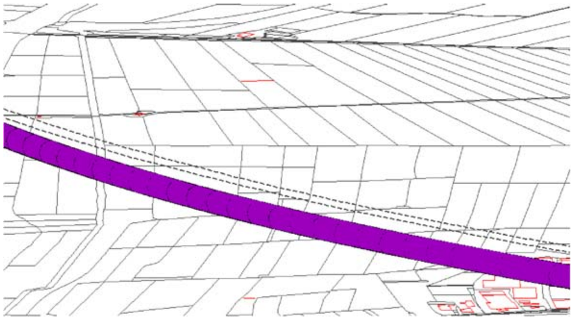

Fig. 7. Registration of the legal space of the railway tunnel. The dashed line is the projection of the tunnel on the surface. Note that the parcels are not divided into smaller parcels.

The 2D or 3D (ISO/OGC) topology structures are valid at every moment in time. There are never gaps or overlaps in the partition. However, to 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.

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, 2004; Stoter & Ploeger, 2002, 2003). In the previous version (van Oosterom et al., 2004) of the model the VolumentricProperty was introduced, but this class did have a bit of an exceptional position: 2D is the normal situation and 3D is considered an exception (and not treated based on topology). In the newest model 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 CCDM only covers the legal space. That 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). The registration of the 3D objects themselves (or even 2D or textual presentations) is outside the CCDM, but could be maintained in another registration (building, utility) to which the cadastral registration is linked via the GII.

The 3D legal spaces can represent the geometry associated with for example the right of superficies (*droit de superficie*, *Baurecht*), but also be related to full ownership. The solution of registering the legal space of 3D objects compensates many limitations of current cadastral registrations. For example, the surface parcels need not to be divided into smaller parcels. The spatial relationships between surface parcels and the (legal space of the) 3D physical object can be implicitly maintained with spatial overlay functions in the DBMS (see Fig. 7).

3.4. Person

The abstract class ‘Person’ (that is again a class without object instances) has as specialization classes NaturalPerson or NonNaturalPerson like organisations, companies,

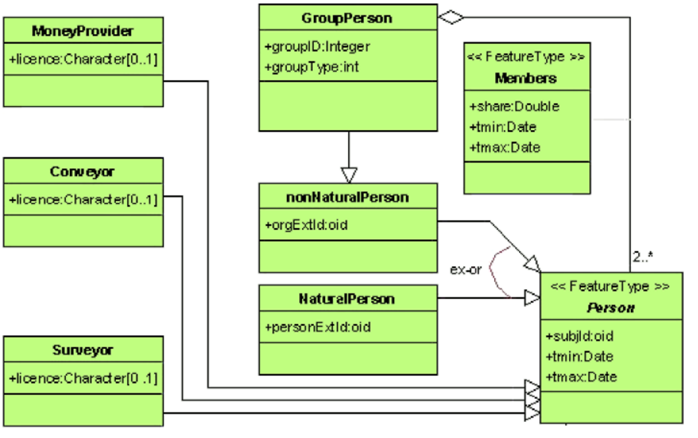

Fig. 8. The Person classes (‘green’ package).

co-operations and other entities representing social structures (see Fig. 8). If a Person is a NaturalPerson it cannot be a NonNaturalPerson and the other way around. That is, NaturalPerson and NonNaturalPerson are mutual exclusive. Besides the specializations NaturalPerson and NonNaturalPerson, a third specialization is added: 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, cooperations 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.

3.5. Legal/administrative classes

Object classes presented in yellow cover the refinements in the legal/administrative side; see Fig. 9. The main class in this package is the abstract class RRR with specializations Rights, Restrictions and Responsibilities. All RRRs are based on a LegalDocument 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 RRR and Mortgage. 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 RRR or Mortgage is always associated with exactly one LegalDocument as its source.

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 or freehold.
(b) Secondly we have derived rights from the previous category (limited real rights, or *ius in re aliena*) where the holder of this derived right is allowed to use the land in its totality (often with in the limits of a certain land use, e.g. housing or animal farming, and/or limited in time).
(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 (e.g. the land owner) who restricts his right by the newly created right. The rights and restrictions usually 'run with the land', with means that they remain valid even when the land is transferred 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 this. E.g., the right of 'ownership' might be 'Norwegian Ownership', 'Swedish Ownership', etc. 'Customary Right' related to a region or 'Informal Right' can be included; from modeling 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 a fake Person (either "the government" or "society-at-large") 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. 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 non-ownership Right by a third party (be it government or a private Person) causes a Restriction. These Restrictions have their own place in the CCDM: they are modeled as views. That is, not intended to be stored, but to be derived on demand when needed. Public restrictions with their own areas can be recorded via the OtherRegisterObject class. Obviously the documents on which they are based need to be included (in the case of public restrictions this would be laws, regulations, decisions). Other restrictions should be indirectly 'recorded' as rights in the name of the (positive side) holder. In certain countries some types do not explicitly state the holder (or the holder is a neighbouring RegisterObject, regardless of who holds that RegisterObject). In such cases the (positive-side) Right is recorded with a formal person indication the situation (e.g. neighbour Parcel; also see discussion in Section 3.1 related to ServingParcels). 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 with a fake Person' recorded, informing others someone already has a security right on this RegisterObject (often only a defined, and often recorded, amount of money is secured, and a second or third Mortgage could be created). For every RRR 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.

Right (a specialization of the abstract superclass RRR) is compulsory association between RegisterObject and Person, where this is not compulsory in case of 'Restriction' and Responsibility (the other specializations of RRR). The class RRR allows for the introduction of 'shares of rights' in case where more than one Person holds a undivided part of a 'complete' Right (or Restriction or Responsibility). Object classes presented in yellow cover the refinements in the legal/administrative side; see Fig. 9. Compared to the earlier versions of the model extensive rethinking was undertaken here. Several papers presented in Bamberg contributed to this. For the legal side especially Paasch (2004) and Zevenbergen (2004), and for the person side (van Oosterom et al., 2004). Of course the discussion before, during and after the workshop also contributed to these refinements.

The first refinement is the extension of the class RRR (which used to be called RightOrRestrction) 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, used to be presented as an association between Person and RegisterObject. In the current version of the model, this has been replaced by a normal class RRR with associations to both Person (exactly one) and RegisterObject (exactly one) as sug-

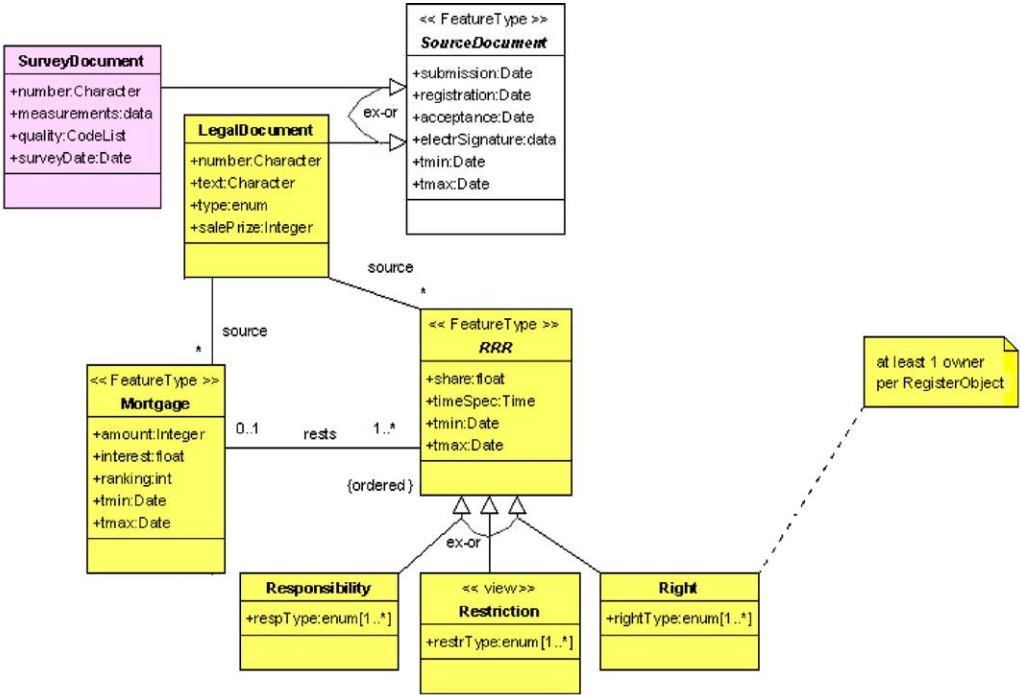

Fig. 9. The legal/administrative classes (yellow).

gested (Paasch, 2004; Zevenbergen, 2004). It is still possible that one RegisterObject is related to several Persons (via RRR associations) and reversely, 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 ownership, freehold or leasehold. Connected to this strongest right certain interests can be added, or subtracted from this strongest right. 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 his property, where it is a Restriction (encumbrance, negative-side) to your property. In the present model both sides are represented, but it is the intention to only store the positive-side and derive (compute) the negative side when needed (compare Zevenbergen, 2004). Therefore, Restriction is modeled as a view. Although some definitions of encumbrance seem to include the obligation to do something (as described under responsibilities before), we added it here as a separate specialization Responsibilities (or obligations) to avoid any confusion on allowing the registration of responsibilities (if and when the legal system is tailored for that).

A mortgage is always vested on a RRR, and should never be seen as a separate relation between Person and RegisterObject. On the other hand a Mortgage is usually vested as collateral for loan. Therefore the one providing the money, the mortgagee, is connected to the Mortgage as MoneyProvider; one of the specializations of the abstract class Person (see

Fig. 8, but also Fig. 11 in Apendix). 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 now a specialization of the abstract class SourceDocument (as is SurveyDocument). The one responsible for drafting the document (for instance a notary, lawyer or conveyancer) is connected to this as Conveyer; again a specialization of the abstract class Person.

The legal/administrative package as just described is based on the notion of one strongest (primary) right, with other limited rights derived from it. This notion can be found in most continental European countries, but it also fits to the different approach found in the Anglo-American law. That starts from the concept of property rights as 'estates' held in the land. Ownership in this approach is often seen as a 'bundle of sticks'. Separate 'sticks' of the bundle can be acquired in different ways, can be held by different people, for different periods. When a person owns all the rights, he is said to own the fee simple title. When he owns only some of the rights, he has a partial interest. This approach is also used in (Paasch, 2004). Further research is needed to ascertain that the CCDM can support land tenure systems based on other legal concepts as well; e.g. as in Arab and/or Islam countries.

Land administration systems that have to underpin customary land tenure systems, 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 formalized and more fuzzy and informal) are to be found in the same area, and should therefore be able to co-exist in the cadastral system, and thus in the core cadastral domain model.

3.6. History and dynamic aspects

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

- In event-based modeling, transactions are modeled 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 to keep the start state (and go back in time via the 'reversal' of events).
- In state-based modeling, only the states (that is the results) are modeled 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 consecutive states it is possible to reconstruct what happened as a 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 modeling 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 (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.

As not all temporal aspects are well covered with a simple time interval tmin–tmax, the temporal aspect is generalized to a TimeSpec attribute. This attribute is capable of handling also other temporal representation such as reoccurring pattern (every week-end, every summer, etc.) Note that nearly every object inherits the TimeSpec attribute via either RegisterObject, RRR or Person. It would have been possible to introduce a new object (TemporalObject with a TimeSpec attribute) from which in turn these three mentioned classes would inherit their temporal attribute (mainly because of legitability this was not done). In addition to the event and state modeling, it is also possible that the 'parent/child' associations between the Immovables (RegisterObject) are modeled (lineage); e.g. when a cadastral parcel is subdivided. 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. In case of Person and RRR it does not seam useful or meaningful to maintain lineage at all.

Besides the data modeling aspect of the dynamic processes within the CCDM, one could question how are the functions and processes related to each other? Focus within the CCDM 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. Fig. 10 shows a

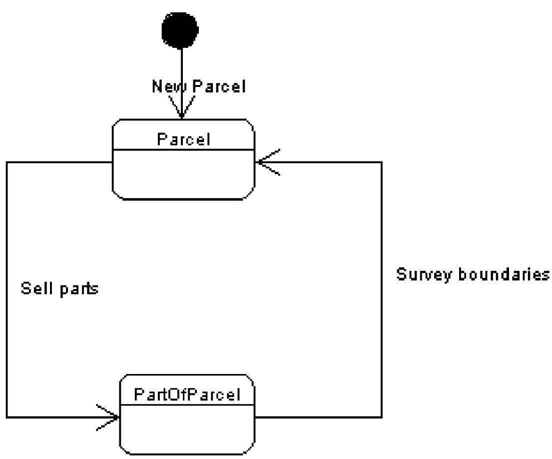

Fig. 10. State diagram of splitting a PartionParcel. If a part of a parcel is sold, the parcel is split into several PartOfParcels, which become regular parcels again only when their boundary is surveyed.

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 the (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.

The dynamic nature of land tenure is a major challenge for cadastral modeling. Above 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 a variety of forms of tenure (Toulmin & Quan, 2000), (Zoomers & van Der Haar, 2000) and it is possible to switch between these forms, and 'upgrade' 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 if they are recognised explicitly by statutory law. Without such recognition however one could assume that 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 rights to 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, van der Molen, & Groot, 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.) 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.

4. Embedding the model in ISO/TC211

In the context of GIS and Spatial data there is currently a lot of effort to standardize the modeling and exchange of this type of data. Most of the standardization effort is concentrated in the OGC Consortium and in ISO/TC211 and a combined effort has resulted in a harmonised model. This model is described in the ISO19100 standard series. Since most cadastral data is spatial the core cadastral model should be based on these standards. This will allow us to build on the rich model of geo-objects as defined in these standards and ensures that the model fits well in GIS software. In order to adhere to the ISO standard a model has to adhere to certain modeling rules (ISO19109, 2005) and the spatial types as defined in (ISO19107, 2003) have to be used. Other relevant parts of the standard are about: temporal modeling and geodetic coding. In the model the influence of the standard can be seen in various ways:

- All base classes that relate to ISO features get the ≪FeatureType≫ stereotype (in our model this applies to all classes either directly or indirectly via inheritance);
- The geometry (GM_datatypes such as GM_Point, GM_Curve, GM_Polygon, DM_Surface, GM_Volume) and topology (TP_Node, TP_Edge and TP_Face) model is based on the ISO19107 (2003) topology model;
- In the future when the 'timeSpec' is further modeled (instead of a CharacterString) the ISO temporal model should be used.
- Class names start with capitals (PointParcel) and attribute names start with non-capitals (surveyDate);
- The model fits in the metamodel as defined in ISO19109 (2005);
- Basic types have got another name (it was 'int' now 'Integer' and it was 'char[]' and it is now 'CharacterString').

One of the advantages of modeling in UML is that it gives the possibility to generate an exchange format for the data in a standardized way. The GML3 standard (ISO 19136) describes how to translate an UML model to an GML Applications Schema. This Application Schema uniquely defines an exchange format for data in the UML model. For the correct generation of such a schema the UML Model has to adhere to the encoding rules that are given in the GML Standard. Below an example of how a parcel with one obligation can be encoded. The xlink:href is used to encode a reference to the obligation. This reference can be stored in the same document (internal link) or somewhere else (external link).

```
<Parcel>
  <objectID>DEL00A 07564</objectID>
  <useCode>residential</useCode>
  <taxAmount currency="euro">1000.00</taxAmount>
  <name>Casa Grande<name>
  <tmin>1968-04-05T02:08:00+02:00</tmin>
  <tmax></tmax>
```

```
    <legalArea uom="squareMeter">42</legalArea>
    <parcelName>Casa</parcelNameame>
    <computedArea>41.4341572</computedArea>
    <geometry>
      <gml:Face xlink:href="#DEL00A07564"></gml:Face>
    </geometry>
    <Obligation xlink:href="#rrr?1686-44-058"/>
</Parcel>
```

Various tools exist that automatically convert an UML Model to an GML Application Schema. The ShapeChange tool (Portele, 2004) reads an UML Schema in the XMI exchange format and writes an XML Schema. The UML/INTERLIS Editor (Eisenhut, 2004) has an export button to generate a GML Application Schema.

5. Conclusion

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

1. Enable effective and efficient implementation of flexible (and generic) cadastral information systems based on a model driven architecture, and
2. 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 standardization. The CCDM ontology is very important for creating standardized information services in an international context (e.g. EULIS), where land administration domain semantics have to be shared between countries (in order to enable needed translations). It is not realistic to expect that involved countries will immediately change their registrations and adjust to the CCDM. However, the CCDM ontology can be used in translations from countries own registration terminology and concepts to the shared terminology and concepts (Heß & Schlieder, 2004; Heß & de Vries, 2004; Tiainen, 2004). This enables creating meaningful standardized information services.

How to implement or use the CCDM within a country (or between countries), depends on the organizations involved and the preferred manner of working (and available or planned communication infrastructure). The model itself does not say that something should be centralized or decentralized. In fact, it supports both. In case of a centralized implementation, the model provides the relevant classes. In case of a decentralized implementation, the model provides the required semantics (needed for meaningful communication) and also provides the interface definitions between the different decentral systems (XML/GML encoding; see Section 4). Many different implementation scenarios can be imagined. Two realistic, both decentralized, cases could be: (1) for every package of the model a different national organization is responsible for the maintenance of the information in classes within the package (Person, Legal, Parcel, Building, immovable/OtherRegisterObject, Survey) and consistent references between the packages, and (2) a local organization is responsible for the information in all packages within its territory, and has to take care of consistent references to and from data maintained in other territories. Many different implementation (or deployment) approaches are possible.

In this paper an improved version, the sixth, of the CCDM has been presented. Though the scope of the model did remain the same, several new classes and attributes have been added. This corresponds to further making implicit knowledge and structure explicit and thereby adding more semantics. The drawback is that it makes the model look more complex. However, this is not really the case as one could also look at the generalized classes, RegisterObject, RRR, and Person, and the model will look simple again. It has been tried to remain within the original scope of the model and not extend it with related domain models of topography, geology, geo-technical and soil information, pipelines and cables, addresses, buildings, polluted areas, mining rights, fishing/hunting/grazing rights, cultural history, (religious) monuments. (non-)natural persons, ship- and airplane (and car) registrations, etc.

The foundation of the new CCDM is a 2D and/or 3D parcel with temporal attributes (actually four dimensions) with possible fuzzy boundaries. This does not mean that every cadastral system should have four-dimensional fuzzy parcel, but the model gives the overall framework. The actual systems are in a certain sense 'special cases' of this general model; a number of examples of systems fitting in the CCDM:

- a traditional 2D parcel-based system (with exact boundaries)
- the system extended with 3D VolumeProperties
- a 2D system but with temporal rights, actually the RegisterObjects do have fixed geometry, but the right, restrictions or responsibilities do change over time (could be in according to some kind of repeating pattern)
- a 2D system with well defined parcels, but extended (in certain areas) with more fuzzy types of parcels (SpaghettiParcels, PointParcels, TextParcels)

The new version of the model is intended to be an interoperable implementation specification version of Cadastre 2014 (which is at a more abstract level). Being at an implementation level, it will guarantee that different systems adhering to this specification of the CCDM will be interoperable. The actual communication could take place via XML/GML encoding of the CCDM. An XML schema can be derived of the UML class diagram of the CCDM (as has been shown in Section 5). The current version of the CCDM is also 100% compliant with the ISO 19100 series of geo-information standards, including 'Rules for application schema' (ISO19109, 2005), 'Spatial schema' (ISO19107, 2003) and 'Geography Markup Language' (ISO19136, 2004).

The CCDM is one of the first examples of the new wave of geo-information standards: domain specific semantic models (based on the generic, domain independent ISO and OGC standards). It was shown in this paper that quite serious harmonisation was needed to achieve this, as the differences in the various cadastral registrations across the world are quite significant. In order to achieve true meaningful interoperability, more international, harmonised domain models will be needed (transportation, soil, topography, environment, defence, utilities, etc.). These domain models then represent the formal representation of our geographic knowledge needed for automated processing within the context of the semantic web. It can be argued that the cadastral domain, is a kind of worst case example (as it is related to local legislation and culture quite a lot) and that other themes should be a bit easier to harmonise across countries (as these are by nature more well defined, less dependent on culture). Besides international harmonisation within a domain between countries, another challenge will be the harmonisation between these different domains (as they may not be 100% independent and there are relationships). This is the task that lies ahead for the INSPIRE initiative in Europe: 31 themes have to be harmonised across 25 countries (with 21 different languages).

Finally, the list of future work includes:

- refine the current ontology/semantics by adding OCL to UML class diagram
- dynamic aspects of the involved processes
- true 3D/4D spatio-temporal parcels (if needed)
- highlight the layer structure in CCDM (by giving a number of examples)
- modeling of the field survey with more structure/attributes
- indicate which classes are part of the real obligatory core (also for attributes and relations)
- generation of a full XML/GML schema (not just an example fragment)
- test with real data (in EULIS context) and test data exchange
- harmonise with other domain models (topography, water, cables/pipes, etc.)

The CCDM has been reviewed by many experts in the field of cadastre and land registry. Co-operation with OGC and ISO in the further development of the model will be required. In addition to the cooperation with these organizations, a review and/or validation by a platform as EULIS, Eurogeographics or the Working Party on land administration should be performed. Finally, it is very important that also UN Habitat is involved in such a review and validation process.

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Appendix. UML diagrams

After having presented the main packages of the model it is good to put them all together and form the whole CCDM. Because of presentation reason this will be done with

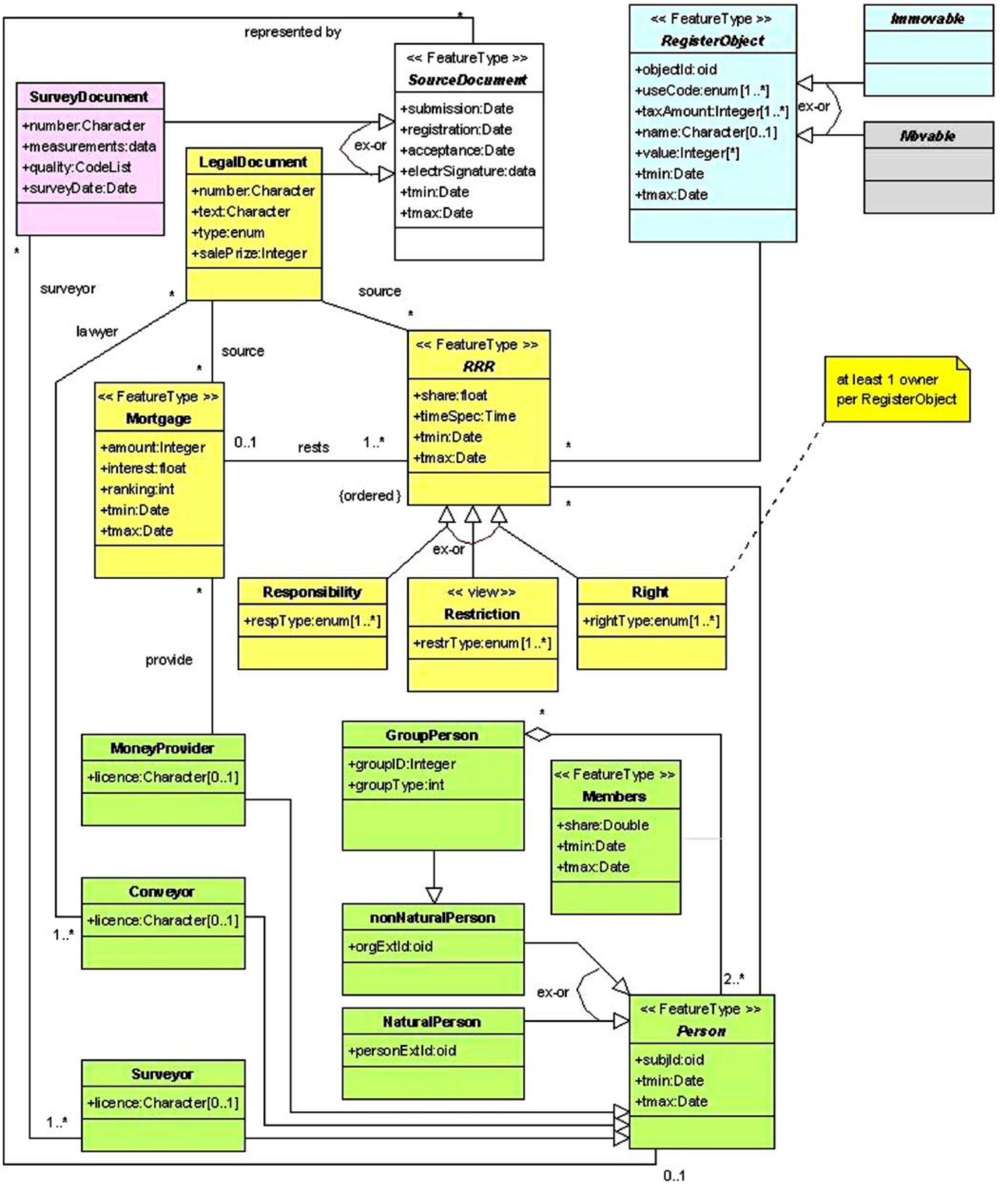

Fig. 11. The legal/administrative and person classes together.

the help of two additional figures: one combining the legal and person part of the model (Fig. 11) and one combining the Immovable RegisterObjects of the model (Fig. 12). Together with Fig. 6 (Geometry and Topology classes from ISO TC211) this forms the complete CCDM.

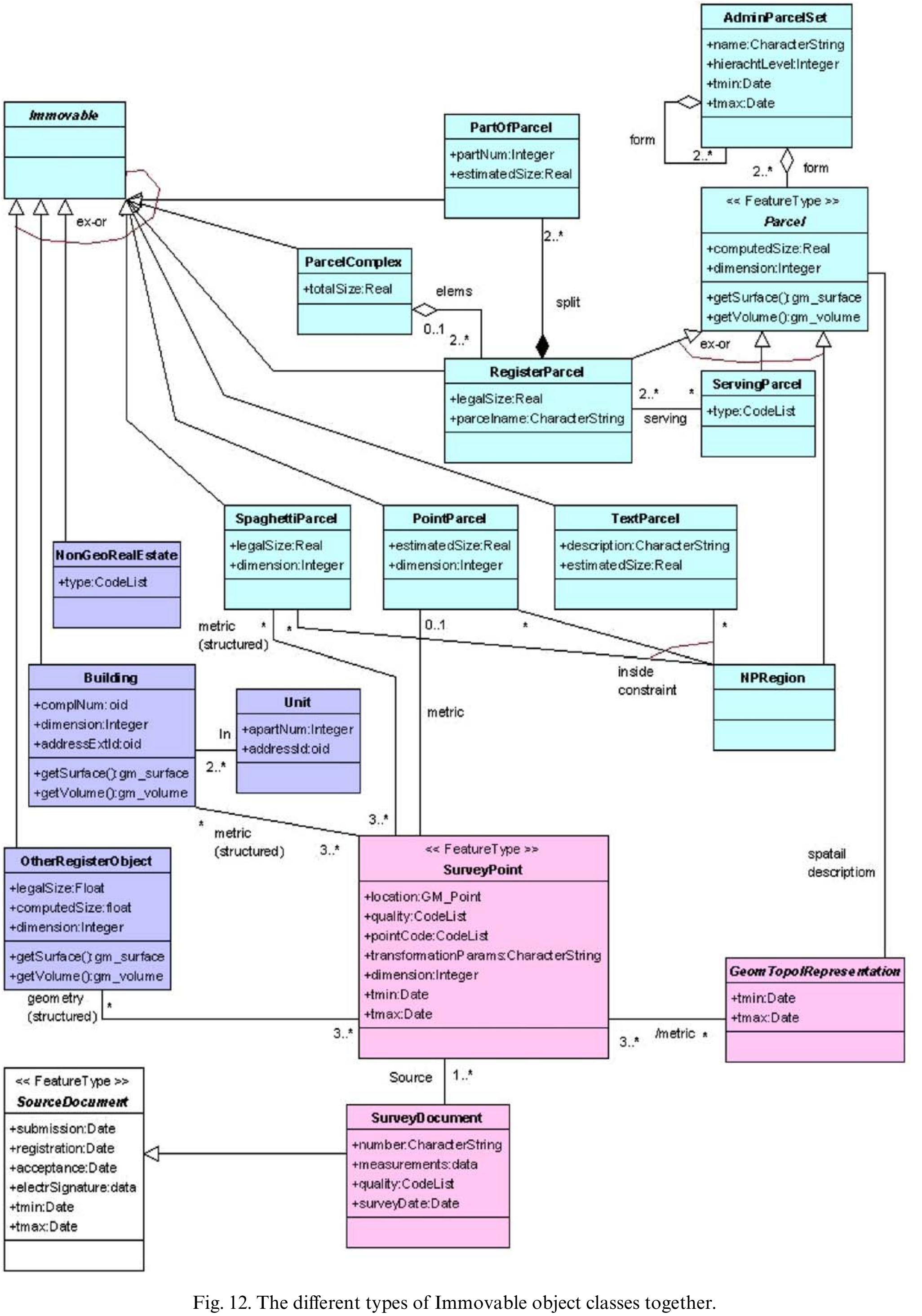

Fig. 12. The different types of Immovable object classes together.

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