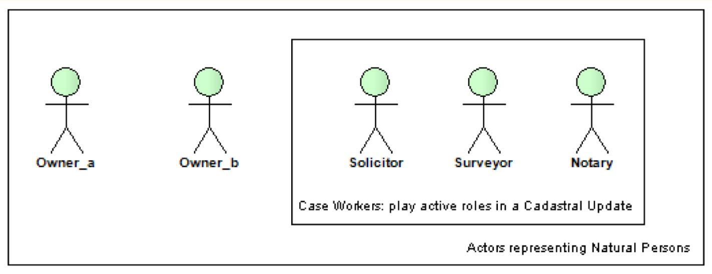
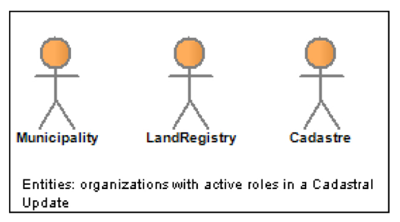
Development Methodology for an Integrated Legal Cadastre

João Paulo Hespanha





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Deriving Portugal Country Model from the Land Administration Domain Model

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I must begin to acknowledge the fundamental contributions of two remarkable persons, which were the main reason for my academic research area drift from my Geological Engineering backgrounds to the present field of Cadastre and Land Administration: Prof. Severo Gonçalves, who first call my attention to the (then) emerging field of Geomatics, and provided for the fellowship for my MSc at ITC - Enschede; and Eng. Elvino Duarte, the root cause for my work with the first digital cadastre made in Portugal, and who has always struggled for the development of a modern cadastral system in Portugal. They were both students at ITC (when it was Delft based), and together with my ESTGA colleague Luísa Gonçalves, gave me the initial suggestion to resume my academic career in the Netherlands. Which peace of advice I eventually followed, also due to the fact that there were no PhD studies on this research area in Portugal.

This strong Netherlands connection was the reason for me knocking at OTB door in the distant year of 2003, and having a first meeting with my current supervisors, Prof. Peter van Oosterom and Prof. Jaap Zevenbergen. They gave me an invaluable guidance at all levels of knowledge, from the technical to the legal and the methodological, so that my initial research proposal, too much applied and with a narrow focus on particular aspects of the Portuguese Cadastre, could evolve into an acceptable PhD research proposal. At the time, the idea for a Land Administration Domain Model was giving its first steps and gathering international engagement, and following Peter's suggestion, I have adopted it has the main basis for my research, with a first paper concerning its application to the Portuguese Cadastre, for which I have to thank to my supervisors and to my ESTGA colleague Gonçalo Paiva Dias, from the ICT field, for the collaboration in validating the proposed model.

Apart from the continuing online contacts with the supervisors, there were no significant study leaves during the initial years of my research. With the notable exception of the PhD course on cadastral development at Aalborg University, following Jaap's recommendation, and where I had the opportunity to exchange ideas on my research plan with other PhD researchers in the same area, and with the organizer, Prof. Erik Stubkjaer, who has called my attention to the contributions from the social sciences to the research of cadastral systems. During this event, I had the opportunity to meet Dr. Maria Augusta Silva, who eventually became the first PhD graduate in this field in Portugal. Many thanks for an inspiring preparation for a defence and for explaining the causes for the Portuguese "arrested development" on the cadastre, as reported in her thesis. At this time, I also meet with Jesper Paasch and had the opportunity to exchange some initial thoughts on the way to extend and apply his conceptual legal model to the generic Domain Model and the Portuguese Cadastre.

From this first personal contact, the collaboration continued through a research presented in a paper, with the co-authorship of Jaap and also Dr. Mónica Jardim from the Coimbra University Law Faculty. Without the intense discussion that followed and eventually lead the way to achieve the modelling of the legal component, both generic and for the country model, that important contribution to this thesis would not be possible. A special word to the patience Mónica has shown in dealing with the

UML modelling of legal concepts, which were absent from her academic backgrounds.

On the home front, and concerning the ESTGA cadastral project with the Municipality of Mira, I would like to leave a word of thanks to my former colleague Luis Galiza, who enabled the implementation of such project during a number of years, and to Ângelo Lopes from Mira's GIS Department, for the continuing support and guidance on the most relevant tasks concerning cadastral update. And of course, not forgetting all the students from the ESTGA BSc on Geographical Engineering that took part in the cadastral projects between the years 2007 to 2009, too many to mention here but whose contribution was fundamental in providing real data and allowing to identify a number of situations occurring in the field.

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During the winter semesters of 2007 and 2008, I was granted with special study leaves from the University of Aveiro, and this way I enjoyed the hospitality and highly inspirational research atmosphere of OTB in particular, and several TU Delft campus facilities. Needless to say that those were the times at which the research work progressed the most, due to the contributions of my supervisors and a good number of staff and research fellows.

I would like to leave a special word of thanks to: Elfriede Fendel, for the reception and taking care of the logistics of my TU Delft membership as a guest researcher. This way it was much easer to turn Delft into my home base during those months; Prof. Korthals Altes, for the initial discussions on my research path during the first leave; Marian de Vries, which followed my research from its beginnings and gave me new insights into the interesting field of semantic translation using models, not mentioning other equally interesting discussions when we shared the office; Martijn Meiers, with whom I also shared office, for all the discussions on modelling subjects and the help in the use and configuration of TU Delft campus and research software; Theo Thijssens, for the continuous words of support and all the help in setting up and providing licenses for several software, not forgetting his help in the set up of SVN repositories for the LADM models and my thesis research; Also to Wilko Quak, Sisi Zlatanova and Hendrik Ploeger for many, sometimes lengthy discussions, exchanging views and research experiences at their offices or around the coffee corner; And to Friso Penninga, the opportunity to use his LaTeX sources to set up and finally write my thesis, together with the first instructions on how to use this text compiler.

On the very technically demanding field of writing and implementing spatial OCL expressions and performing actual MDA transformations, a special word of acknowledgement is due to Jan van Bennekom-Minnema, which by evaluating his results so far let me think that the vision of a integrated CASE tool for assisting in the implementation of a country model is feasible in the medium term.

Concerning now contributors outside Portugal and TU Delft, I would like to leave my thanks to all the support through research papers and the work on the LADM, which were assured by Christiaan Lemmen (from ITC) and Harry Uitermark (from the Netherlands Kadaster).

Other key contributions arrived from various points scattered around the Globe, in the form of another country model, and which supplied an important feedback for the development methodology: Rod Thompson, also a TU Delft PhD, for his innovative concept as basis for the geometric component of LADM, and the Queensland (Australia) proposal for a country model; Paul Egesborg, for the documentation concerning the Canada Lands ILR and the description of reconciliation procedures; and Trigvy Ingvarsson (holding a TU Delft MSc), for his MSc thesis describing the methodology to achieve a country model for the Icelandic Cadastral Model.

Finally, last but not the least, an heart-full word of gratitude to my family for all the support and comfort relentlessly assured throughout this rather lengthy research period.

A todos, um grande Bem-Haja!

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Chapter 1

Introduction

The topographic-cadastral map depicted in reduced form in figure 1.1 exemplifies the way as to a property Cadastral map was done at the time of survey, the year 1858. At that time, there were no methods of formalizing a standard set of modelling elements describing the cadastral or topographic features depicted in the map. Likewise, other property Cadastre maps could follow different conventions, due to the lack of standards.

At this time, features were captured on paper which, although being a good media of preserving the information (given proper storage), implied a good deal of effort if a change of scale or an update has to be made to the map. The cadastral survey was done sporadically and usually covered just large properties owned by the crown (as in this case) or the nobility. The preferred method of survey was then traversing, complemented with the plane table, and the map shows an early adoption of the metre system. From the standpoint of rights and restrictions on land, there was no organized Land Registry at the time, not even a first Civil Code, and the overall situation could be classified as far more simpler than today, with much less administrative servitudes or public restrictions to consider.

This thesis will briefly outline the backgrounds of the present day organizations responsible for the Cadastre in Portugal, and the modern institutions and administrative procedures, in order to achieve a country model for the Cadastre, integrating the modelling of cadastral features based on existing or proposed international standards.

This chapter will cover the description of the research context in terms of current techniques and methods integrated into the development methodology, in 1.1, and the modern issues faced by Land administration (and Cadastres) worldwide (1.2.1) with a key tone on sustainability. Then, the current Portuguese Reform on Cadastre and Land administration is briefly outlined in 1.2.2.

Research prerequisites and the fundamental and detailed research questions follow

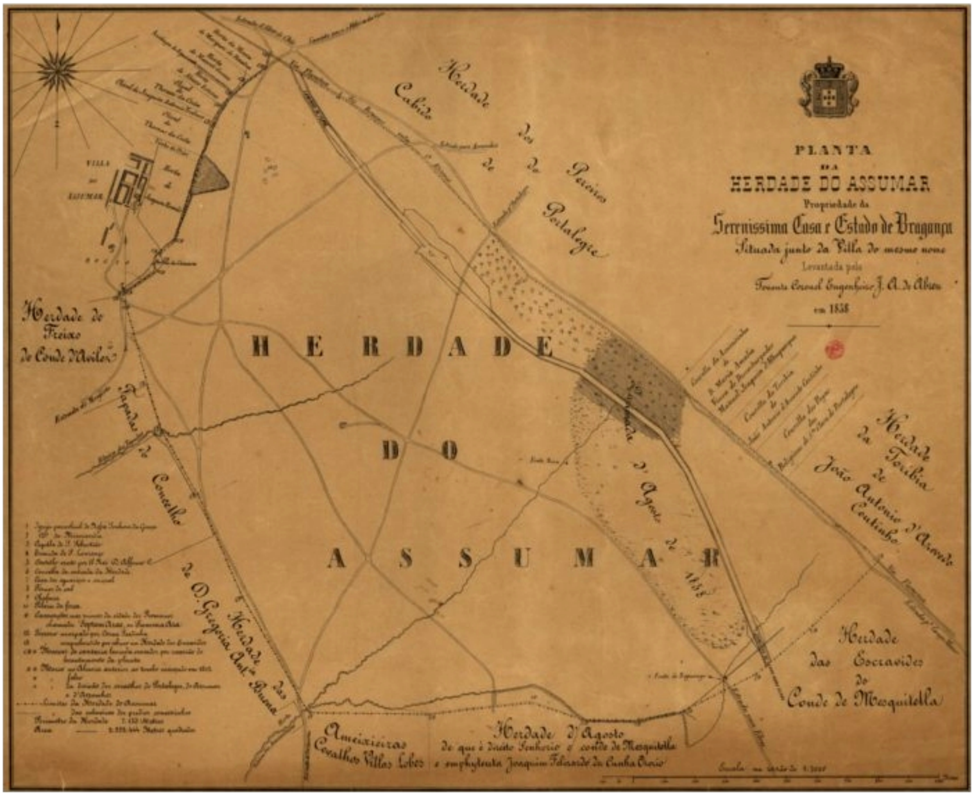


Figure 1.1: *Property map of the farm of Assumar, Portugal, by J.A. Abreu, 1858. Source: BND, "Biblioteca Nacional Digital", http://purl.pt/3365*

in section 1.3, these last ones framed by an aspect oriented view of the Land administration system. Section 1.4, after a brief discussion, lists the topics considered inside and outside the research scope. Next section lists a number of expected outcomes from research, both concerning the studied country (Portugal) and a more global perspective (1.5). The section 1.6 reports on the different methodologies contributing to the research, and a description of the research process supported by Unified Modelling Language (UML) Activity Diagrams.

A concluding section provides a description of the structure for this Thesis (1.7).

1.1 Context

The main subject of this Thesis concerns though the elaboration of a development methodology of a Cadastre, examined from the perspective of modern systems theory.

Concerning methodology, a distinction should be made between the development methodology as the main subject of the Thesis, its main results being reported in 4.3, and the research methodology and process, which has evidently many overlapping concepts, but is reported separately in section 1.6 of this chapter.

The development methodology reported herein is supported on a number of international standards developed generically for the area of geographic information, defining a commonly accepted set of concepts formalizing how geographic features should be described, stored, transferred or transformed (see 2.1.3). The core concepts pertaining to the domain of the Cadastre are captured through a proposed International Standards Organization (ISO) standard (2.6.2 and ISO/TC211 Geographic Information / Geomatics (2010)), ISO19152 - Land Administration Domain Model (LADM), forming the basis from where successively more detailed concepts can be captured.

The standardization procedure for LADM started with its submission by FIG to the International Standards Organization (ISO), constituting then a New Work Item Proposal (by February 2008). An ISO19152 Project Team was set, which prepared three successive Working Draft versions, discussed in meetings in Copenhagen (Denmark), Delft (The Netherlands) and Tsukuba (Japan), during 2008. This consensus-building phase ended with a Committee Draft, presented in June 2009 (Lemmen et al., 2009, p.2-3). A parallel development and voting process was also adopted by the "Comité Européen de Normalisation" (CEN) / Technical Commission (TC) 287, since February 2009 (Lemmen et al., 2009, p.4). Other important modelling activities have also received contributions from LADM, namely the UN-HABITAT Social Tenure Domain Model (STDM). This was a software development initiative to support pro-poor Land Administration. Another important example is INSPIRE theme 4 from Annex I: Cadastral Parcels (Lemmen et al., 2009, p.13). The current Final Draft International Standard (FDIS) publishes, as informative annex F, a total of eight country profiles, which demonstrate its feasibility and importance as a future International Standard (ISO/TC211 Geographic Information / Geomatics, 2011). Amongst its "earlier adopters" are countries in Europe (The Netherlands, Hungary), Asia (Japan, Korea and Indonesia) and Oceania (Australia's Queensland State). If everything goes as planned, LADM will reach an International Standard (IS) stage by 2012 (Lemmen et al., 2011, p.1).

The research follows thus a strong *model driven development* paradigm, implementing separation of concern and abstraction (see 2.1.1) through consideration of an initial abstract model of the system, from where the final outputs, in the form of (geographical enabled) information systems, have its core structure defined through successive model transformations (5.3). Using state-of-the-art *model driven architecture* (Sparx Systems (2007)) it is possible to keep the final implemented system and the specialized models updated and synchronized. In this research, the core concepts included in the abstract model constitute a *domain model*, and the more detailed models are called *specialized country models*.

The inclusion of country specific aspects and requirements in the areas of cadastral surveying, geographic representation, the legal domain of rights, restrictions and responsibilities pertaining to real property and other aspects of Land Administration, are all tackled through well defined phases within the development methodology. The next section shows the importance of this approach, as resulting from previous academic research conclusions.

The current trend, facilitated by developments in Information and Communications Technology, of considering a Land Administration system as a fundamental component of a Spatial information infrastructure (SII), namely through the definition and use of "authentic registers" (or "key registers"), as referred in (van Oosterom et al., 2009, p.2) is also considered as an important part of context to the research. The concept of the authentic registers, as the "sole officially recognized register of the relevant data to be used by all government agencies" (van Oosterom et al., 2009, p.15) which has been in existence in the Netherlands since 2002, has been recently passed in Portuguese law (Portuguese Law (2009)) also considering cadastral data as being covered by the key registers concept, although presently official cadastral data available electronically just respects the old rural cadastre and it is not up to date. Furthermore, the development project implemented by the Portuguese Geographic Institute which is called SINERGIC (see 3.3.1 and IGP (2006)) has as its goal to implement a system which will integrate data from different organizations in the field of the cadastre, and will be thus a fundamental part of the existing Portuguese Spatial Information Infrastructure, the SNIG[1].

Furthermore, being it caused by societal concerns related to the sustainable development agenda or other social or political movements, a reform to the Land Administration system does not occur in a vacuum, there are always a number of pre-existent frameworks (legislative, administrative, professional, etc.) to consider. The development methodology here reported, given its modelling flexibility and capability of incorporating new requirements on the diverse aspects considered (legal, administrative or technical), has the potential to be applicable in different contexts and countries. To achieve the specialised country model here reported, there were some important assumptions which have to be made explicit:

- Institutions governing the body of immovable property rights, or rights *in rem*, namely its contents, means of acquisition and cessation of such rights, should be already in place. These institutions constitute core elements of the modelling domain and the modelling exercise will be easier if its body is codified. Basing the case study on the Portuguese Land Administration system, the reported model will be adapted more easily to countries following the Continental European legal tradition, since the specialised legal component of the model conforms more closely to Civil Code legal concepts.

- Also derived from its case study context, modelling results concerning the land policy field are based (indirectly) on a number of land use planning directives issued by the European Union, as adapted to the Portuguese situation. Other public law based regulations affecting land use and private property are older and more country specific. This research makes the assumption that land use planning and administration tools be summarized in a small number of policy guidelines, acts or laws.

[1]SNIG: Sistema Nacional de Informa"c –c""˜–a"o Geogr"'–a"fica, can be accessed at http://snig.igeo.pt/Portal/; site is in Portuguese.

- Finally, the research also assumes a previous cadastral surveying and mapping component was already in place, defining a number of relevant mapping and surveying profession standards. In a process of Land Administration reform (as occurring in Portugal during this research), this can include specifications not yet implemented in current practice.

Studying existing institutions, laws and standards on the above referred fields concerning Land Administration, should be the first step in a development effort following the herein reported approach. Although some changes, namely concerning update procedures which have both legal and spatial components, are expected from the alignment between legal, administrative and technical components imposed by the modelling framework, the development methodology does not necessarily imply a radical and throughout re-engineering process. This means that the implementation of a country model under the presented methodology does not imply a throughout revision of existing laws, administrative procedures or technical regulations in the concerned cadastral components. On the other hand, both the underlying domain model and specific land issues reported in a given country can show that certain (mostly institutional) components were not yet sufficiently formalised as described above, thus demanding further initial studies.

A clear definition of terms is fundamental to achieve good research outcomes, and this is specially important in the field of Land Administration, for where a Cadastre constitutes a basic tool. In this view, a first clarification is due to the *Integrated Legal Cadastre* in the title. For Latin countries as Portugal, Spain or South American countries, a Cadastre is any type of systematic collection and organised record of items. Many times the items identify individuals, as in a Penal Cadastre, where civil crimes are recorded. Within this cultural context, the main sort of items has to be explicitly defined, so the right wording would be a *Real Property Cadastre*. But, as this thesis is bounded by the scope of Land Administration (as defined in the subtitle), from now on I will use just Cadastre to refer to a Real property Cadastre. Other countries in Continental Europe usually employ this narrower meaning for a Cadastre, and for countries on the Anglo-Saxon tradition, the term is seldom used at all, being replaced most of the times by the (much broader in scope) term of Land Administration.

There are not many countries in the world with complete cadastral coverage, and the ones that have are mostly being concentrated in Continental Western Europe. The majority of these cadastral systems have the fundamental goal of securing legal transactions, resulting in evidence that they have a legal basis. Although the taxation and valuation goal is also frequent and its current status within the Portuguese Cadastre is described in 3.2.3 and 3.3.3, this component was not further modelled or tested. In some of these countries, there is just one organisation which performs the functions of both a Cadastre and a Land Registry. This is indicated by the term *Integrated Legal Cadastre*. However, research assumes to have greater application to countries where the referred goal is broken down into specific goals which are performed by different organisations, guided by different institutions, and resulting into a rather fragmented and inefficient system.

The subtitle is also not self-evident and is briefly explained next.

The Land Administration Domain Model is a highly conceptual, formally defined model (through UML and textual descriptions), and is being discussed for adoption as an ISO standard. The development methodology reported hereafter (4.3) uses this existing model as starting point to derive a country model which is a specialised model from the former, taking into account results from the research on the Land Administration in Portugal.

1.2 Land Administration and Cadastre Issues

In this dawn of the third millennium of the Christian era, the United Nations defined eight so-called "Millennium Development Goals" which together aim at assuring better living conditions for all humankind. The seventh goal, titled "Ensuring environmental sustainability" acknowledges that it is not conceivable to maintain good living conditions for this and next generations without at the same time preserving environmental resources Sachs (2005). In other words, achieving and maintaining better living conditions for the humankind implies achieving and maintaining a healthy biosphere and related supporting elements like the land (and soils), water and air.
In a workshop from 1999 titled "Land Tenure and Cadastral Infrastructures for Sustainable Development", held in Bathurst, Australia, a few years before the UN Millennium Project has started, one of the conclusions stated in the resulting declaration is that

> Sustainable development is not attainable without sound Land Administration (Williamson, 1999, p.2)

Research developed at the University of Melbourne, also contributing to the above referred workshop, further detailed the key factors to consider in order to achieve the goal of sustainable development, through the reform of Land Administration Systems worldwide. The PhD Thesis "Principles for an Integrated Land Administration System to support Sustainable Development" (Ting, 2002, p.vi) shows that the focus for an effective integration of the legal, institutional and technical aspects of Land Administration supporting this goal can be achieved through the development of

> coherent tools of thought that allow people and governments to interact to envision and implement how rights and responsibilities over land should be defined and utilised.

Similar research can be reported at Delft University of Technology, namely through the PhD Thesis "Integrated Land Delivery: towards improving Land Administration in Zambia" (Mulolwa, 2002, p.1) where the author notes, after referring to a number of recommendations (including Bathurst Declaration), that

> It is now widely acknowledged though that success with a practice in one country does not translate to success in another country because of the differing institutions and cultures. To allow for modification or innovations

according to local conditions, a generic framework is required. A logical model provides such a framework.

Above citation is central to this research, given that the development methodology assumes that the Land Administration Domain Model is supplying the generic framework, and the specific procedure based on current information technology methodologies allow and further support for modification or innovations according local conditions, as shown by the Portuguese country model as a fundamental result of the research.

Above paragraphs allow to situate the fundamental importance of Land Administration Systems in today's world, and also point to some directions its reform should assume regarding the new Millennium goal, as results from academic research. Traditionally, Land Administration should manage three key attributes[2] related to land (Dale and McLaughlin, 1999, p.9): land tenure, value and use (see figure 1.2). Institutions regulating these attributes vary from Nation to Nation (or even within Nations, if more than one Jurisdiction is in action) as are also varying the organizations responsible to administer each key attribute. The most usual arrangement is to find the Ministry for Justice responsible for land ownership (representing tenure), the Ministry for Finance responsible for setting land values (usually for tax purposes) and the Ministry for Planning, Development and Environment, together with the Ministry for Agriculture and Forestry responsible for land use.

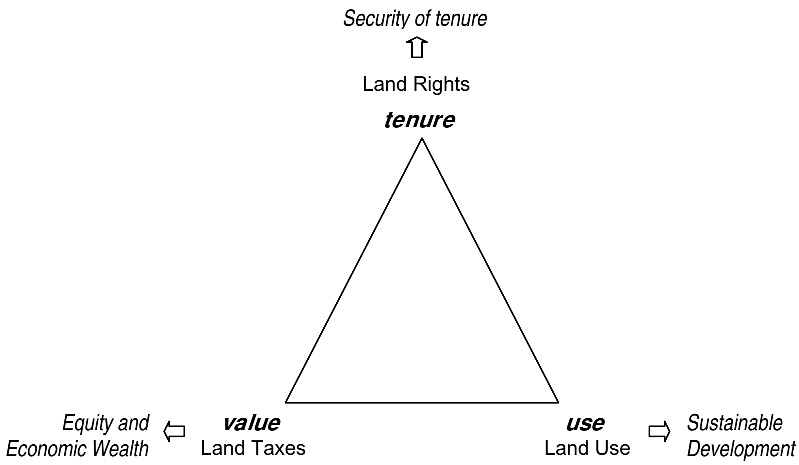


Figure 1.2: *The Land Administration Triangle, adapted from Dale&McLaughlin, 1999*

[2]The term *attributes* was used by the authors in (Dale and McLaughlin, 1999) and does not correspond to the concept of an attribute in modern modelling or software development sciences.

Each of the key attributes has its own set of goals, which can be formalized in a single Land Policy document, defining also the common goals. The Ministry of Justice, through the institution of Land Registration, should provide *Security of Tenure*. The Ministry of Finance, through institution of Land Tax and Bank Credits, should promote *Equity and Economic Wealth*. The Ministries of Planning, Development and Environment and of Agriculture and Forestry, through institution of a set of Planning Tools defining Zones where Public Regulations are enforced, should promote a proper Land Use.

The now worldwide assumed Millennium goal of Sustainable Development should not be circumscribed to any of the referred key attributes of Land Administration, instead it should be faced as a common goal of the overall system. Above referred research stresses the fact that, given the world variety of institutions, organizational arrangements, laws and regulations affecting rights and responsibilities over land and also the diversity of existing technical solutions, achieving such common goals require the availability of "tools of thought" or a generic framework in the form of a logical model.

A first contribution to the specification of such a tool can be found in the PhD Thesis "Systems of Land Registration - Aspects and Effects" (Zevenbergen, 2002), supported on previous research by Henssen (1995), where that component of Land Administration is examined following the systems approach and the stated aspects (technical, legal and organizational) are together considered in two views of the system of land registration: static and dynamic (see figure 1.3).

In this work, the static model of land registration has three main objects: owner, right and parcel. Further, it is discussed how different systems of land registration provide for the identification of each one of the main objects. The dynamic model, by its turn, depicts the three main functions related to cadastral processes: adjudication of land rights, land transfer and mutation.

In line with this research and again with contributions from Delft University of Technology, the Dutch Kadaster and the Faculty of Geoinformation Sciences and Earth Observation from Twente University, a first standardization proposal for a so-called "Core Cadastral Domain Model" concerning an Unified Modelling Language (UML) Class Diagram description of Cadastre and Land Registration was proposed at a FIG congress held in Washington (US) in April 2002 (van Oosterom et al., 2006). Main concepts associated with UML will be discussed in detail in Chapter 2, on Development Methodologies, now it will suffice to establish that it can indeed provide for the "tools of thought" mentioned in Ting's work (Ting, 2002), and at the same time being a logical model adapted to the state-of-the-art object-oriented paradigm respecting software and systems development.

The Core Cadastral Domain Model (CCDM) was further disseminated and discussed at the academic and professional communities worldwide, receiving a number of contributions, which in turn resulted into perfected versions of the model, however centred on a static systems view, that is, defining a set of main object classes to consider in the Cadastral Domain (including Land Registration as well as Cadastral Surveying and Mapping). In a comparison made with Cadastre 2014 by their authors, one of the conclusions is:

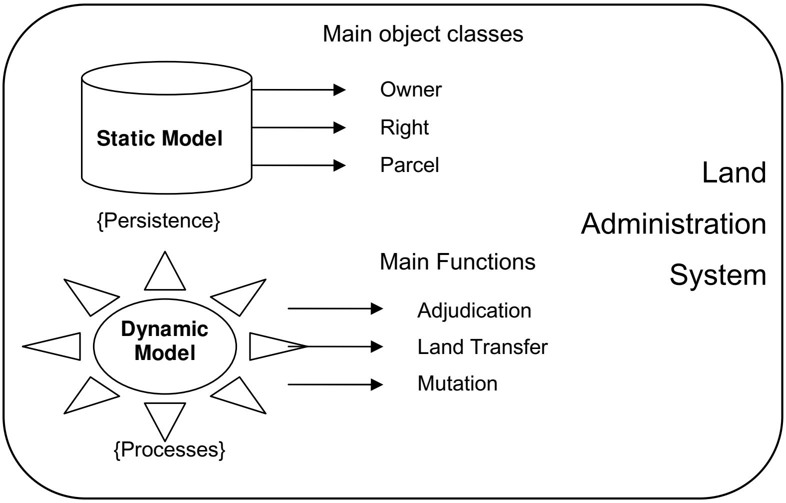


Figure 1.3: *Main goals of the Static and Dynamic models of Land Administration, according Zevenbergen, 2002*

> The core cadastral domain model initiative, trying to model existing occurrences of Cadastres, is confronted in every step with new questions. The development of the core cadastral domain model shows that with every step more elements of Cadastre 2014 are included. A trend in direction of Cadastre 2014 can be identified (Kaufmann and Kaul, 2006, p.172).

The above referred Cadastre 2014 resulted as a final report from a FIG Commission presided by Jurg Kaufmann and Daniel Steudler, which presented as conclusion "a vision of the cadastral systems in some twenty years" Kaufmann and Steudler (1998). This vision was summarized on six statements on Cadastre, from which statement 3 is specially relevant for this Thesis:

> "Cadastral mapping" will be dead! Long live modelling! Comment: Maps have always been models, but the available technology did not allow the use of these models in a flexible way. Thus mapping flexibility had to be brought in by different scales. Different scales had to be represented by different data models. Modern technology allows the creation of maps of different scales and registers in different forms out of the same data model (Kaufmann and Steudler, 1998, p.4).

It must be stressed however that, while Cadastre 2014 constitutes a set of guidelines for the reform of cadastral systems worldwide, above referred CCDM is a Model which can be developed to full implementation using available tools, as reported in this research.

The focus on Information and Communication Technologies (ICT) in above quotations recognizes that current modelling efforts rely heavily on the tools provided by this ever-evolving technological field; the same applies for the research documented in this thesis.

The Development Methodology here reported benefits from all the above contributions, and also from a number of ICT tools which will be further described in section 2.1. Before formulating this thesis fundamental and detailed research questions, the main global challenges that a modernized system of Land Administration should face in the new millennium will be further detailed in 1.2.1 and the main settings affecting the study of the Portuguese Land Administration and proposed implementation of a specialized, country version of the CCDM successor will be presented in 1.2.2.

1.2.1 Global Challenges

Land Administration systems around the world are facing enormous pressure, due to a number of very significant changes induced by current models of socio-economic development and major impacts resulting from the accelerated growth in human population, particularly in the past century. Large numbers of individuals have migrated from their rural places of birth to give origin to the ever growing slums and squatter settlements around the main urban areas. Another problem arising from such growth in population is the availability of fresh water. According the executive summary of Bathurst Declaration:

> At present consumption levels, two-thirds of the worlds population will live in water-stressed conditions by the year 2025 (Williamson, 1999, p.1).

Problems are not focused solely on the urban areas, once the migration to such areas can be partly attributed to a number of occurrences on the rural areas, namely overgrazing, soil erosion or deforestation, not to mention impact in ecosystems due to climate changes. The agricultural issues, from the Land Administration point of view, are well summarized in the following paragraph from Larsson:

> Appropriate land uses can also be mismanaged because of unsuitable agrarian patterns and outdated tenure systems with inadequate protection of tenure rights (Larsson, 1991, p.1).

Although it is debatable, from a social and political perspective, that customary tenure systems existing in many third world countries should be considered as outdated tenure systems, they are certainly not providing security of tenure, since they do not guarantee formal property rights. For example, in Zambia about 62% of the people live in rural areas under customary tenure (Mulolwa, 2002, p.2). This ultimately means that large tracts of the population of developing countries are denied the opportunity to participate in the formal economy of such countries due to lack of support by the corresponding Land Administration and its legal framework. These issues are gradually entering the agenda of land reform, particularly since the last two decades, namely sustainable development priorities, consideration of common property institutions, and informal systems regarding indigenous cultures and tenures (Williamson, October 2001). The absence of an efficient formal process of recognizing existent property rights in developing and eastern European countries, thus preventing corresponding assets to be traded, credited or otherwise transacted in a wider land market, is pointed by Hernando De Soto as the fundamental obstacle to generate capital and thus to promote wealth in such countries (de Soto, 2002).

Above paragraph deserves further explanations. By an efficient process one should consider an all-inclusive process not discriminating property owners based on the tenure system (usually implying ethnic and / or social class factors) or other social differences (like gender or religion). Access to formally recognized property rights and security of tenure should be no longer reserved to the economic elite but should be assured as a fundamental human right. The social and economic implications of a reform to the existing Land Administration systems complying with the design of such all-inclusive process is not the focus of this thesis, as will be further elaborated on section 1.3.

However, it will be argued how the development methodology here presented could contribute to the discussion and, finally, the design of such a process, albeit just at a high conceptual level. Important contributions are the flexibility offered by the initial domain model in supporting different sets of requirements, which are ultimately translated to implementation through the modelling process (refer to section 2.6.2 and following).

Apart from segregating certain land tenure systems, with all its social and economic implications, Land Administration systems worldwide suffer from *process fragmentation*. Processes are fragmented into vertical functions, mandated to different organisations, thus constricting data flow and leading to inefficiencies (Mulolwa, 2002, p.2). According to the results of the Portuguese Land Administration study reported in chapter 3, such a problem is particularly relevant concerning the large set of public imposed restrictions and regulations which can affect any individual land parcel, turning the complete description of both private and public rights, responsibilities and restrictions[3] extremely cumbersome.

1.2.2 Portuguese Reform on Cadastre and Land Administration

Previous sections gave mainly a generic and international perspective of the global issues and challenges faced by Land Administration systems. This section will be focused on the new developments concerning Land Administration in Portugal. Being the author's birthplace, and also the focus of previous teaching activities (also including field work practicals), the recent developments on the Cadastre and Land Administration in Portugal were one of the stronger motivations for this research. The main examples and the implementation reported as result of the application of

[3]Refer to subsection 2.6.2 for an explanation of this terms.

the proposed Development Methodology are all derived from this study, concerning the current Land Administration practice in Portugal.

The last two decades, particularly since adhesion to European Union, have seen a large reform on the different key attributes of Land Administration in Portugal [4].

On the land tenure side, by its turn, legislation regarding the Land Registry Code (CRP) was changed in rapid succession on the years 1983 and 1984, ending with the operationalisation imposed by Decree-Law 224/84, which introduced a number of changes aiming at a more effective transition to digital operations regarding the existing land records. The use of a file system to register information on each registered parcel, instead of the old book based record system persisting from the XIX century, and the official adoption of electronic communication to exchange of information between offices and for the general public were some of the innovations introduced at that time (Mendes, 2003a, p.9). Eventually, this led to the more recent adoption of a new computerized system, with a centrally managed database and a number of terminals in some of the existing offices, the Land Registry Information System (SIRP).

The land value side has seen major changes lately, namely through the new legislation on the Immovables Municipal Tax (IMI, Decree-Law 283/2003). This led to a recent and massive update on the fiscal records (called "Parcel Matrices") based on a new computerised procedure to assist on land valuation which uses census data contributed by the National Institute for Statistics (INE). Furthermore, some web services were implemented, allowing consultation of valuation zones and of individual parcel matrices (upon registration by the respective owner with the fiscal services).

Finally, there were also important and very recent legislation changes concerning the Cadastre[5], defining the general and conceptual principles of SINERGIC project (Decree-Law 224/2007, MAOTDR (2007)). This decree-law defines a temporary legal regime which results (concerning a number of pilot projects) will be evaluated after a term yet to be defined and should originate a more definite legal framework, potentially impacting other, above referred, legislation. The abbreviation can be translated to "Integrated System for Cadastral Data Browsing and Management".

The resulting system should provide a data core whose management is shared between main governmental organizations in this field, like the Portuguese Geographic Institute (IGP[6]), the General Directorate for Registries and Notaries (DGRN) and the General Directorate for Taxes (DGI). It should have geographically decentralized components, with well defined update responsibilities. Furthermore, a validation and harmonization effort should be promoted by IGP in order to assure information coherence.

The most relevant developments of SINERGIC project for this research, however, are the new set of technical specifications for the Cadastral Survey procedure, pub-

[4] A brief account of reforms concerning land policy and land management can be read in section 3.1

[5] Traditionally referring to the spatial or geometric component in Portugal, but moving towards an integrated view, as assumed in this Thesis.

[6] Note: all the abbreviations provided in this section correspond to the Portuguese initials of respective organisations and institutions.

lished in May 2009 (IGP, 2009). They contain a specification for a new Cadastral Data Model, following modern design guidelines and international standards in agreement with the Land Administration Domain Model. This Cadastral Data Model will be implemented in real practice in the near future, but for research purposes, forms the starting point of the implementation exercise documenting the technical component of the Development Methodology.

1.3 Research Aims

As reported in the previous sections, this research has both worldwide and country specific aims in the broad field of Land Administration. While the most relevant single contribution for achieving the research aims, the Land Administration Domain Model, should be indeed applicable in a variety of organizational, legal and technical frameworks around the world, the research here reported assumes a rather more limited and focused context, described in section 1.4.

1.3.1 Main aim and fundamental research question

Having all the prerequisites described in section 1.1 in mind, it is time to formulate the fundamental research question of this thesis:

How can a system development methodology support in a efficient and flexible manner the creation of an integrated legal Cadastre, while addressing the interrelations between the technical, legal and organisational aspects?

The main aim is thus to create an effective and efficient cadastral system, focused on both private and public law governing land tenure in a given jurisdiction, hence the adoption of the term "integrated legal cadastre". This system should form the core of a broader Land Administration system, able to support other recognized functions as valuation and administrative support for local government (mainly respecting issue of building permits). The component structure of the underlying model (LADM) and related modelling processes, aim to address for the interrelations between the different aspects of the system.

The relation of the main aim with the already stated Millennium Goal and the provision of "tools for thought" is further described in section 1.5.

1.3.2 Detailed research questions on the technical, legal and administrative domains

In order to achieve practical results from the main aim and research question, a number of related, aspect oriented research questions were also taken into consideration:

1. *How to develop a flexible system, where it will be relatively easy to include new requirements or changes?*

2. *Which methodological steps should be taken to cope with new and existing land related rights and regulations?*

3. *How to implement an enriched semantic model (through spatial and aspatial constraints and spatial profiles, enabling consistency checks) based on current Spatial Database Management Systems?*

4. *Furthermore, how can this enriched model support integrated update procedures in an interactive editor environment?*

The second question has a more legal and administrative nature, although impacting on requirements and the system development approach, while the remaining three are mostly technical oriented, but its specific answers (regarding modelling results) can also have non-technical implications.

To clearly define the scope of these detailed research questions, a short explanation of the key terms used above is given in the next paragraphs, including forward references.

Semantic model: In the research context, it is a model expressed in UML which uses the structural description of the domain (given by the Land Administration Domain Model) as a basis and includes a set of domain specific elements (namely UML profiles, *model constraints* and *implementation specific constraints*) which together are capable to specify the meaning of each entity and its relations in a given implementation (on a spatial database), for a given country. When applying Model Driven Architecture techniques, this is achieved in transformation steps (see subsection 2.1.1) and the final product will be the country model LADM_PT (see subsection 4.3).

Spatial profiles: They use the generic UML extension mechanism of UML profiles, through which the language can be extended to comply with domain specific structure and meaning. In the thesis context, this relates to the inclusion of spatial data types and their geometry and topology relations, for which constraints should be specified and applied (see 2.6.2 and 4.3).

Update procedures: As the specific country model implementation (of LADM_PT) includes Spatial Data Types as well as regular database types, an update procedure involves (usually) the change of geometry and possibly topology of a set of spatial elements, implying the use of a graphical editor working on top of a spatial database. Additionally, it can also change non spatial attribute values belonging to the spatial data type or to an associated aspatial data type. The update procedure has to verify the implemented type constraints and associations in order to maintain database integrity, which together define a complex update procedure (see section 5 and examples in 5.5).

1.4 Research scope

The range of topics to be covered in order to contribute a systems development methodology to an Integrated Legal Cadastre, considering its technical, legal and organisational aspects, is necessarily large and includes diverse scientific areas. In order to achieve potentially useful results, this research had to define a limited number of topics as being of fundamental importance, together defining the research scope. These are defined in the following paragraphs. The last paragraphs of this section summarizes topics inside and outside the research scope.

Concerning the technical aspects of systems development, the first topic to be considered within scope is the Land Administration Domain Model. This has a potentially wide scope, which has to be specified through the country specialisation procedure. In this research, the specialisation resulted in a focus on the spatial component (traditionally assumed by the geometric cadastre) and the legal component pertaining to the Land Registry. This traditional core was then enlarged with other topics considered for the legal and administrative component. A number of topics from the scientific field of Information and Communication Technologies gives important contributions to the methodology, and was thus considered to be within the research scope (see list bellow).

On the legal and administrative aspects, the traditional scope of the Cadastre was enlarged in order to consider other forms of property previously not considered in the Portuguese Cadastre (before SINERGIC), like informal urban settlements[7] and the “Baldio”[8]. The form of property hereafter called Public Domain, although still out of the scope of the new Portuguese Cadastre Data Model (in IGP (2009)), is included in the country model. From the Land Management component, only the topics considered for the Municipal Master Plans were taken into account in the country model, since they are the ones which larger implications on private property.

The Case Study on the Land Administration in Portugal considered all the key attributes of tenure, value and use, listing related institutions and organisations in charge of these aspects. It also included a view on institutional change regarding cadastral legal and fiscal components. The results contributed to the requirements model, although value and use aspects were not carried on to the following modelling phases.

Perhaps the most relevant absence in the reported methodology, taking into account that it should be applied in a reform of the Land Administration system, is an overall economic feasibility study. Application of the reported methodology will

[7]Known by the Portuguese initials AUGI, standing for Urban Areas of Illegal Genesis.

[8]A Portuguese form of property consisting of communal land used and managed as such since time immemorial, further described in 2.2.2

undoubtedly have major economic implications, since it implies institutional, organizational and technological changes. However, as recognized by Dale and McLaughlin:

> Several attempts have been made to evaluate costs and benefits in hard economic terms but they have had limited success and there have been very few post-implementation studies to confirm whether the predictions became realities. (Dale and McLaughlin, 1999, p.101)

It is the author's belief that research on a parallel methodology to evaluate social and economic impacts resulting from such a reform process as the one here reported would be of crucial importance to the decision-making process, contributing to a go / no go decision concerning the reform plans.

Although the reported research has a strong focus on modelling the conceptual/logical domain of Land Administration, it mainly covers the static components, that is, those that have been traditionally persisted through some form of recording system (be it paper based or digital). Consequently, some functions ascribed to the dynamics of Land Administration will not be covered here. Most notably, the process of Land Consolidation, which has been recognized as an important tool regarding nature and environment conservation (van Dijk, 2003, p.51), and thus related with the Millennium Goals, is not included.

List of topics inside and outside the research scope:

Inside Scope

- Modelling techniques (UML and OCL, Unified Process[9], Model Driven Architecture). Consideration of OCL includes definition of spatial constraints;
- The Land Administration Domain Model;
- Requirements: key attributes of Land Administration in Portugal, including related institutional change;
- Modelling traditional forms of property (Public Domain; "Baldios") and spatial and legal components of the Portuguese Cadastre;
- Public regulations imposed by Municipal Master Plans;
- Land Administration dynamics: simple update procedure (mutation) and the urban re-allotment process[10].

Outside Scope

- Not considered in subsequent modelling phases: value and use key attributes and Land Management tools (except above referred Municipal Master Plans);

[9] See the description in 2.1.1.

[10] These components are not inside the scope of ISO 19152 LADM and result from work developed in this research.

- Economic feasibility study and social impacts concerning eventual implementation;

- Complex Land Administration dynamics, for example Land Consolidation procedures;

- Development of a 3D Cadastre;

- Groundwater rights and other natural resources rights, namely mining or carbon credit registration rights.

1.5 Expected outcomes from research (global and local)

Global outcomes

- Use of the innovations brought by LADM and the related development methodology, namely through integration of the different aspects (technical, legal and organisational), in the process of deriving other countries specialised models.

- Understanding the importance of specifying modelling constraints in order to improve semantics, and the need to support constraints from modelling to implementation; and as consequence:

- Need for better modelling tools in the fields of constraint support and improved model transformations, namely covering the geometry and topology specifics of cadastral spatial data.

Local outcomes - Integrated Legal Cadastre for Portugal

- For experts in the Land Administration and Geographic Information community, increased perception of the interplay between the specialised classes concerning (former) geometric cadastre, land registry and administrative components;

- Perception, by national Cadastre and Land Administration professionals and academics, of the fundamental role modelling can play in the complete systems life cycle (not confined any more to the analysis and design phases);

- Developments which overcome the shortcomings related to lack of institutions (laws and regulations) providing for an Integrated Legal Cadastre, covering both public and private rights, restrictions and responsibilities;

- Consideration and further implementation, according to research results, of cadastral update procedures involving all the strategic partners already identified in the current SINERGIC project and decree-law.

1.6 Methodology and Research process

The methodology for developing an Integrated Legal Cadastre, being the fundamental research question of this thesis, has received contributions from a number of existing methodologies referred in the literature and further detailed in sections 2.1.1, 2.2.2 and 2.5 of Chapter 2. The main contributions are briefly presented in the following list of items, the order of presentation reflecting the research process as described ahead in this section:

- Use of a systems approach to Land Registries, which concludes that different *aspects* should be considered in order to evaluate the effectiveness of the system as a whole. This is included in the Ph.D. thesis from J. Zevenbergen, see (Zevenbergen, 2002, p.5)[11]. The different aspects, which are technical, legal, administrative and institutional, are interrelated and all of them should be considered for an effective Land Registration;

- Combined use of the software development life cycle methodology know as the Unified process (Arlow and Neustadt, 2005), further described in 2.1.1, considering its different phases and iterative development concept, and the Model Driven Architecture (Pastor and Molina, 2007), (Gaevic et al., 2006), applied to the field of Land Administration. This approach contributes to keep a persistence link between the model and the implemented system, assuring both are updated and the system is flexible to accommodate changes;

- Although, at the present date, can be considered more as conceptual frameworks than a reported methodology, there are two more contributions to the development methodology which are fundamental: The Land Administration Domain Model (ISO/TC211 Geographic Information / Geomatics (2010)), further referred in 2.6.2, which defines the main structure from which the country model is derived, and the Legal Model as defined by J. Paasch in (Paasch, 2005), described in 2.2.2. The Legal Model supplied the basic classification which enabled to expand the legal component of the Domain Model and include specialized legal classes at country level.

The following figures use the graphical notation of UML Activity Diagrams to depict the flow of main activities carried out in this research, as well as the main outcomes in term of products. The following paragraphs explain each of the elements and fill the purpose of presenting a summary of the research process, adding also a time line.

The initial research proposal, motivated by the situation of the Cadastre in Portugal, had from its inception the purpose to develop a new Cadastre based on the use of existent geographic information systems software. From this narrower and more

[11] The systems approach here mentioned shall be understood as applying specifically to the field of Land Registration, as expressed by (Zevenbergen, 2002), which cites previous work by (Williamson, 1991)

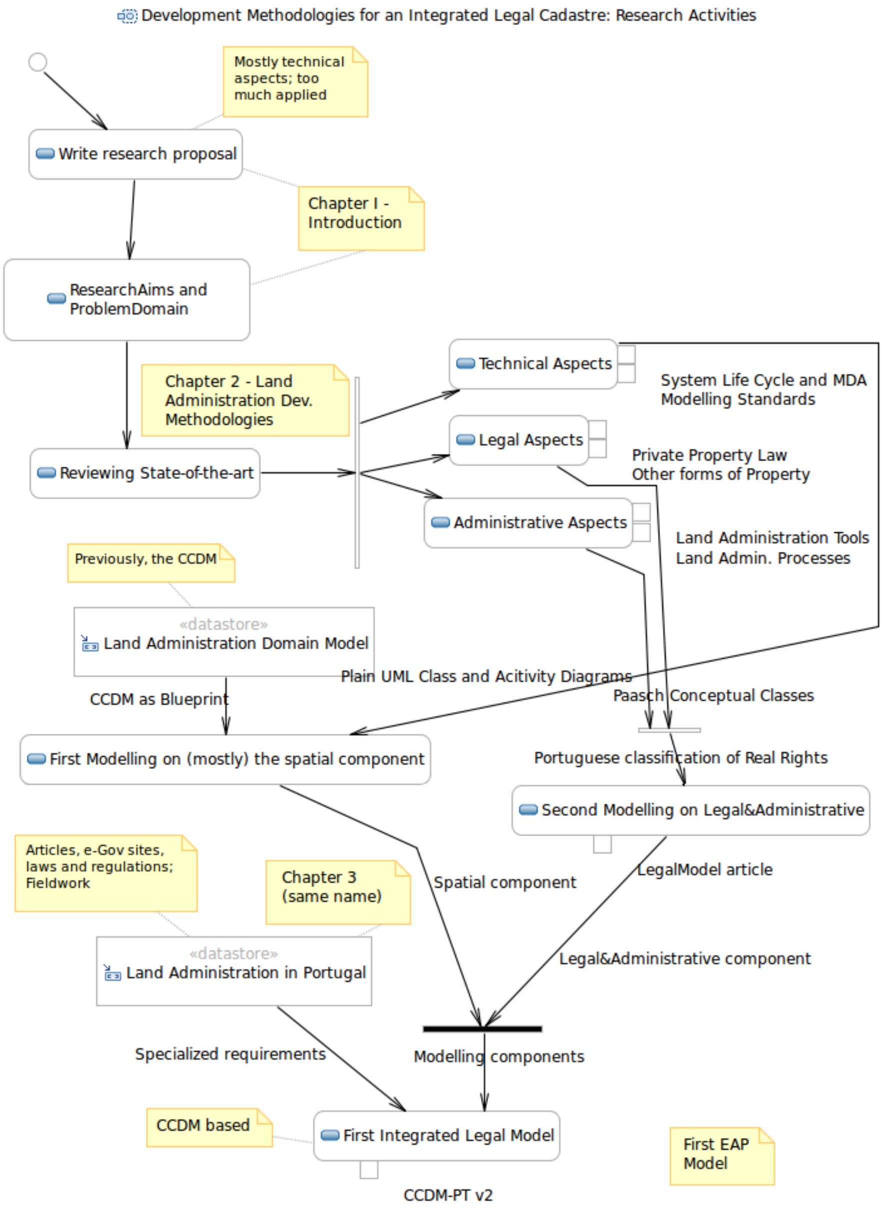


Figure 1.4: *The process of research as an UML Activity Diagram, part 1*

applied focus, and now with the support of my supervisors at Delft University of Technology (TUDelft), the emphasis moved to a broader scope, which can be applicable

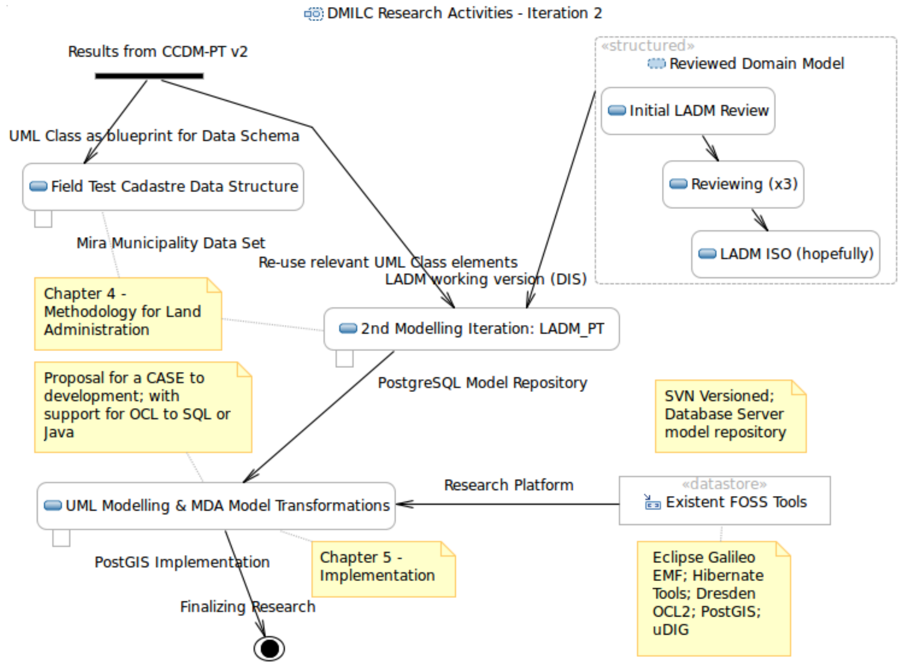


Figure 1.5: *The process of research as an UML Activity Diagram, part 2*

worldwide. This has been achieved through the consideration of the multiple aspects identified in the characterization of Land Registries across the World, according the work of J. Zevenbergen (as referred in the contributing methodologies) and in the precursor of the modern LADM, at the time named the Core Cadastral Domain Model (CCDM), as reported in the article from P. van Oosterom et al in (van Oosterom et al., 2006). The consideration of technical, legal, administrative and institutional aspects has guided the state-of-the-art review (as shown in the top part of figure 1.4) through literature research which is reported in sections 2.1, 2.2, 2.3 and 2.4, together with the existing domain model (CCDM), the development of some proofs-of-concept that where later reported in the form of two separate articles:

- CCDM-PT article: The proposal of a new Portuguese country model for the Cadastre, called CCDM-PT (Hespanha et al. (2006)). This proposal focused fundamentally on technical aspects regarding information systems modelling methodologies and the domain concepts introduced through CCDM, and covered the spatial component of the proposed specialized model in greater detail. From the discussions and feedback received from this first article, the decision was taken to have a more detailed model of the legal and administrative aspects of the Cadastre and Land Administration.

- Legal Model article: Supported in the additional conceptual modelling of the legal component by J. Paasch (in Paasch (2005)), a second article was presented (Hespanha et al. (2009)) which had a stronger focus on the modelling of Portuguese Real Rights and also a number of state wide imposed public restrictions and administrative servitudes.

Following this first, more analytical approach, which detailed the modelling in specific components of the proposed country specialization of CCDM, an integrated model relating the spatial, legal and administrative components in the overall framework of CCDM was created. The first version of the integrated legal model (as shown in the bottom part of figure 1.4 and referred by the name CCDM-PT v2) demanded the previous conclusion of a study on the fundamentals and daily practice of Portuguese Land Administration. This step of the research included literature study, review and conclusions draw from the participation in research and academic projects in Portugal (as reported, respectively, in 3.4, 3.5 and 4.6).

This version of the model was further formalised and documented through the use of the Model Driven Architecture software “Entreprise Architect” from Sparx Systems. This is referred in figure 1.4 as “First EAP Model”. Given that it is now outdated, this version is not presented in the thesis. The integrated model was also implemented in part (not the legal and administrative components) through a field test which used real cadastral data from Mira Municipality, achieved in the framework of ESTGA high school project led education, as shown in the upper left of figure 1.5.

In parallel to this development, CCDM gathered attention of world institutions like FIG and the United Nations and begun its transformation into the present draft international standard and changed its name to the Land Administration Domain Model. The author has participated in such international development efforts, namely through the initial design of a number of instance level (or object) diagrams with the aim to demonstrate the wide application of the domain model to different concrete situations listed in the model documentation and also proposed by country representatives. The author, together with the supervisor and staff from OTB Research Institute, also developed an implementation of the LADM model repositories in a PostgreSQL data base, and enabled centralized version control to the model through the implementation of a Subversion (SVN) server. In figure 1.5, this is referred as the “2nd Modelling Iteration: LADM_PT”.

The last step is also the one with the greater technical complexity and consists of the application of the Model Driven Architecture concepts in order to achieve (at least) partial model transformations. Such model transformations should assist a future developer of a concrete cadastral system to successively process the domain model in order to implemented the initial conceptual design of LADM into a specific software platform.

In this research, this is demonstrated through the use of a development framework which included a number of Free Open Source Software (FOSS), supported in the Eclipse Modelling Framework IDE. This is shown in the bottom part of 1.5. This is described in detail in section 5.3.

With the recent publication of the first UML and ISO standards based, official Portuguese cadastral model, sharing many similarities with the previously developed CCDM_PT, it was necessary to update the integrated legal model, such that the newer official standards could be integrated into the research effort and benefited from the MDA demonstration. The updated model and the methodology to derive it from the Domain Model, are described in 4.3 and 5. The previous research software platform was also updated and the implementation test ultimately runs on top of the Ubuntu operative system, a debian variant of Linux.

This way, the final LADM_PT country specialized model, which can be considered as a third iteration of the Model, is (partly) implemented into a PostgreSQL data base, spatially enabled through the PostGIS extension, and the model and data base components are linked through the Hibernate Java Persistence, which means the model and the data representations can be synchronized and applications can be run on top of this foundation, defining an additional business logic to the system.

1.7 Thesis Structure

This chapter presents the main aims and research questions concerning the elaboration of the Development Methodology and the main goals motivating the research. It also states a number of prerequisites under which the methodology can be applied, and the context supplied by the study of the Portuguese Land Administration system. A list of the topics to be considered in and out of the research scope was included. Expected outcomes from the remaining covered aspects are listed.

The conceptual (Class) model here presented (4.3 and 4.5) will further elaborate on the CCDM successor, the Land Administration Domain Model (LADM), through the consideration of a more involved conceptualization of the legal domain, encompassing both private and public law. This will be documented in sections 2.2 and 2.4 of Chapter 2. Such an extended model, intended to be applicable worldwide, is however far from a concrete implementation, once it consists on a high-level conceptual view (my version of Ting's "tools of thought" (in Ting, 2002)). To surpass this hurdle, the Model-Driven Architecture approach (MDA) is applied in order to derive a so called *country model*, here called LADM_PT (where PT stands for Portugal). Such technical aspects are covered in sections 2.1 (on the state-of-the-art) and new developments are covered in Chapter 4.

In order to accomplish the LADM_PT (country model) task, the existing Land Administration framework in Portugal was studied and is reported in Chapter 3. Intermediate implementation results were evaluated by means of a school project data set which used real cadastral data from a Portuguese Municipality, documented in section 4.6.

The Chapter 5 reports on the software procedures, research platform and results obtained with the implementation test covering the latest specifications (parts of the new Portuguese cadastral data model and the LADM integration into LADM_PT country model).

Finally, a concluding chapter presents the answers to the initial research questions, and a number of new questions resulting from the research itself, leading to possible future research paths.

Chapter 2

Current Land Administration Development Methodologies

This chapter describes the state-of-the-art concerning the four major disciplinary areas included in this research, which correspond to different aspects of Land Administration. The first area to be described is the Technical one, specifically concerning the field of system modelling and analysis and software development, in Section 2.1. Section 2.2 describes the conceptual approach that was used to detail the situation regarding Rights, Restrictions and Responsibilities (RRRs), that is, the Legal aspects. Section 2.3 reports on the contributions from institutional theory and institutional change in the area of property rights, and how it relates to the concepts in the LADM domain model. Section 2.4 reviews the Administrative aspects related to Land, in particular the framework defining Public domain lands and administrative servitudes, which in many countries are not integrated into a common information system. Section 2.5 introduces the basic categories of requirements and how current development methodologies tackle the issue of changing requirements during the system modelling and also during the lifetime of the system. Section 2.6 identifies common issues found in the definition of domain models, and how they were or could be solved specifically for LADM. This section concludes with the description of LADM core classes and the spatial unit package.

2.1 Generic system modelling

This section covers the current scientific and technical backgrounds supplying the infrastructure for the technical core of the Development Methodology and supporting the practical results achieved with the "UML OCL Class diagram to Spatial DB Schema" CASE tool[12] implementation exercise and Mira Municipal Cadastre pro-

[12]Described in detail in 5.4. This Computer Aided Software Engineering (CASE) example application performs a semi-automated implementation, starting from a UML class diagram with Object Constraint Language (OCL) constraints and transforming it into a Spatial data base schema. It supports the handling of spatial data types geometry and topology.

ject[13]. The Case Study in this Thesis concerns the description of the Land Administration in Portugal, and is reported in Chapter 3. Next paragraphs briefly describe the contents of the following subsections.

The Development Methodology for an Integrated Legal Cadastre elaborates on a modern version of the systems approach from the 1950 - 1970 decades, (Zevenbergen, 2002, p. 84) the Model - Driven Architecture (MDA). This approach uses current information systems and software development concepts such as the Unified Modelling Language (UML) and the object-oriented software development paradigm. These aspects will be covered in subsection 2.1.1.

A number of current digital standards, aiming at exchange of information through the web or digital networks and also to establish data base connections for transactions and queries, are currently being used by MDA tools and will be described in subsection 2.1.2.

Given the specifics of dealing with spatial data, mainly in the Cadastral components of the proposed conceptual model, the usual standards applied currently by MDA tools are not enough. This way, a number of Geographic Information standards were also used in this research; those will be described on subsection 2.1.3.

The CASE Tool and some results obtained from the Pilot Project were not possible without significant contributions from the Free Open Source Software (FOSS) community, which supplied the basic development platform for the research. All the software applications and development libraries used in the research are reported and briefly described in subsection 2.1.4.

To conclude this section, the usefulness of MDA (using UML as basic modelling language) to describe the ontology of the Land Administration domain will be examined, as well as the use of existent alternative languages which explicitly describe ontology (see subsection 2.1.5).

2.1.1 Information systems development life cycle with MDA

Although the overall Development Methodology to be applied to the reform of a Nation - Wide Land Administration System includes a number of contributions from other disciplines (namely, Management), this sub-section elaborates on the technical aspects and the related Information and Communications Technologies (ICT) infrastructure.

Contributions considering the Land Administration System as an interrelated set of processes which should attend to customer specified requirements, under a business management approach, are developed on section 2.3.

A first concept of Land Registration[14] under the Systems Approach is given by (Zevenbergen, 2002, p. 87):

> a set of *elements* together with *relationships* between the elements and between their *attributes* related to each other and to their *environment* so as to form a whole that aims to reach a certain *goal*.

[13] This research Pilot Project.

[14] A fundamental component of Land Administration as conceived in this work, together with the (Geometric) Cadastre and the Valuation or Land Taxes Office.

Above definition is not bound to the existence of any supporting ICT infrastructure, however (as will be seen within the present section and also Chapter 4) many of the emphasized words translate to concepts further developed at specific stages of the Model driven architecture.

As with other software development methodologies, the MDA approach should be included in a wider view of the so-called *software development life cycle*. Such a concept is part of the software engineering field and assumes that a lengthy and continuing process should exist in order a particular piece of software to fulfil its goals during a period of time. The process assures continuing operation through maintenance phases involving corrections and enhancements to an original production version, with all the versions subject to tests. The software development phases should not be interpreted as a linear list, where phases are executed under a rigid pre-defined sequence. From an original specification, one can move from any phase to any other phase (Carrano and Prichard, 2006, p.67).

This flexible view of phase sequencing is further re-enforced on a software development process specifically aimed at building object-oriented systems: the *Unified process* (UP). The UP life cycle approach builds on the concept of *iterative development*. Under iterative development (also adopted by a number of other software development methodologies), the overall system development is organized into a number of small scale iterations contributing to an incremental system growth where each iteration delivers a software component which was tested and is integrated into a package or a systems framework (Larman, 2005, p. 18-19).

The UP software development process is the fundamental reference for the technical core of the proposed Development Methodology and as such will be further described in the following paragraphs. Main MDA concepts will be also briefly described, and to conclude the sub-section, a proposal as how to integrate the MDA tool set into the UP development process will be briefly outlined[15].

A UP development life cycle consists of a number of iterations distributed across four major phases (Larman, 2005):

1. Inception: A short phase aiming to establish the basic scope and a common vision for the project. Only critical non-functional requirements and use cases (supplying functional requirements) should be examined, in order to evaluate project feasibility and provide a crude estimate of costs.

2. Elaboration: Includes a number of iterations where the core software architecture of the system shall be implemented and the majority of requirements are discovered and should reach a stable form. Problematic, high-risk software components should be tackled during this phase.

3. Construction: Using the core architecture from elaboration, implementation of remaining, lower-risk software components and other elements is done through a number of iterations. All the software system components should be completed and tested by the end of this phase (Boggs and Boggs, 2002, p. 25).

[15] Full description of such integration can be seen in Chapter 4.

4. Transition: Final packaging of the complete software system, including acceptance tests, user documentation and preparation for user training. A final update of development artefacts (namely any models describing the system) should provide important tools for future maintenance tasks (Boggs and Boggs, 2002, p. 26).

Some specific components of the Land Administration Domain Model (Portuguese country profile) pertaining to the Pilot Project were actually implemented, following part of the UP life cycle, namely the phases of inception and elaboration. Those two phases together cover the majority of (evolving) requirements[16] and critical decisions regarding the implementation of a complex software system, and will be described in more detail in the following paragraphs.

UP inception phase During inception, a common vision for the project should be attained by the stakeholders, in order to determine if it is feasible and as such, be subject to more involved investigation during elaboration. A number of artefacts are usually produced during inception (or early elaboration), which are subsequently refined during the following project iterations.

The following list, adapted from (Larman, 2005, p. 50), describes the main type of documents and artefacts typically resulting from the inception phase.

- Vision: Short document describing overall project goals and constraints, providing an executive summary to be considered by the main project stakeholders;

- Business Case: Initial analysis of the business around the proposed system. Documentation about high-level features of the system and general business outline (major actors and use cases) (Boggs and Boggs, 2002, p. 24);

- Use Case Model: This has the goal of describing the functional requirements of the system. During inception, just the more critical Use Cases should be described in detail (perhaps only 10% of the total number of named Use Cases);

- Supplementary Specification: Document describing key non-functional requirements;

- Glossary: Key domain terminology and data dictionary;

- Risk List & Management Plan: Describes the risks at different categories (business, technical, resources, schedule) and ideas for their mitigation;

- "Proof of Concept" Prototypes: Could be developed (usually in the form of User Interfaces demonstrators) in order to clarify requirements or to execute programming experiments for key technical issues;

[16]The country model assumed the main set of requirements contained in the Portuguese Technical Specifications for Cadastral Survey IGP (2009).

- Iteration Plan: A document describing what to do in the following iterations, which should be regularly updated at the end of each iteration. This applies to all the UP phases;

- Development Plan: Should describe the resources required in order to complete the elaboration phase. A Development Case should also be defined, where customized UP steps and artefacts are considered, regarding specifics of the project.

As can be deducted from the need of a specific Development Case, the UP is not a rigid methodology, rather it is flexible enough to adapt to the project's nature and complexities. This way, documents and artefacts in the above list could be omitted or very briefly outlined during inception.

A first mention is done to a specific artefact from the Unified Modelling Language (UML), the Use Case Model diagrams, further explained in the following sub-section (2.1.2). Usually, this is the only participation of UML during the inception phase.

UP elaboration phase Moving to elaboration, the main focus should be now setting the architectural foundation of the project. This should imply that development efforts should result in an *executable* architectural baseline (Larman, 2005, p. 128), supporting remaining packages and system components to be developed during following phases. The following list summarizes artefacts that might be started during elaboration. Usually, such artefacts require more than one project iteration in order to be refined.

- Domain Model: A visualization of domain concepts; similar to a static information model of the domain entities. Represented by the Land Administration Domain Model in this work. The purpose is to identify a rich set of *conceptual classes* and their most relevant attributes, in order to support a good system design. Such conceptual classes abstract real world entities and not software objects;

- Design Model: The set of diagrams describing the logical design of the system. A number of UML diagrams are usually produced during this phase, namely class, object interaction or component diagrams. These last ones should depict the large-scale logical architecture of the system, as coarse-grained packages or subsystems. The country profile modelling and implementation (see Chapters 4 and 4.6) covers the main layers of an information system, from the foundation layer to the User Interface. The class and interaction diagrams, in its turn, are used on the static and dynamic modelling, respectively;

- Software Architecture Document: Contains a summary of key architectural issues and their resolution in the design. Should focus on the motivation leading to the particular solutions adopted, essential components and main control flows, considered under a given perspective or *architectural view*, like the Use Case, Logical or Data views;

- Data Model: This includes the data base schemas and the object-relational mapping strategies addressing non-object representations. Currently, also the data model can be represented through UML, using available *UML Profiles* which include stereotypes for common data base design elements. This corresponds to the Data Base Management Systems design steps from the Conceptual Model to the Physical Structure of the Data Base, as referred in (Riordan, 2005, Part III);

- UI Prototypes: A description of the user interface, paths of navigation, usability models and so forth.

Items above cover the most important products of object-oriented analysis and design and those involving models (Domain, Design and Data Models) can be described by a set of UML diagrams. This is also the UP phase where the MDA approach can play a major role, namely in the transition from the Domain Model to the Design and Data Models.

The main goal of the Model Driven Architecture is to increase software development productivity and re-use through separation of concern and abstraction (Sparx Systems, 2007, p. 4). This is achieved through the consideration of an abstract model of the system, which originates a Platform Independent Model (PIM), from where, through the definition of one or more Model transformations, several Platform Specific Model (PSM) can be generated. In this view, concern is introduced via Model Transformation algorithms, translating the UML constructs usually found on a PIM to a range of languages specific to a given platform, namely a Data Definition Language of a particular Data Base system, an Object Oriented Language like Java to implement an User Interface or XML code for a variety of web based applications. The complete chain of transformations is not confined to a PIM to PSM transform, although certain steps are usually hidden from the modeller, or can be omitted for the modelling of simpler systems.

The Model Driven Architecture defines a four layered approach, on which the PIM and PSM form the two last modelling layers. The first layer (Layer 0) is comprised by a Metamodel, the Meta-Object Facility (MOF), having the goal of defining what can be asserted in a valid UML Model (Gaevic et al., 2006, p. 110). This layer is at the kernel of MDA software, offering functionality to validate the UML constructs belonging to the subsequent two layers: the Computational-independent Model (CIM) and the PIM.

The CIM forms Layer 1, corresponding to a Domain Model in the above list of elaboration phase artefacts. Being computational-independent means that it is not executable on any computer platform. The PIM, theoretically, should already allow execution on a technologically independent virtual machine (Gaevic et al., 2006, p. 111), although this is presently not available for UML based models.

From the paragraphs above, an outline integrating MDA concepts into the Unified Process is given, assuming however a limited (specific) implementation path. At the end of the elaboration phase, the following artefacts should be available:

- A Computational-independent Model, based on the concepts introduced by the

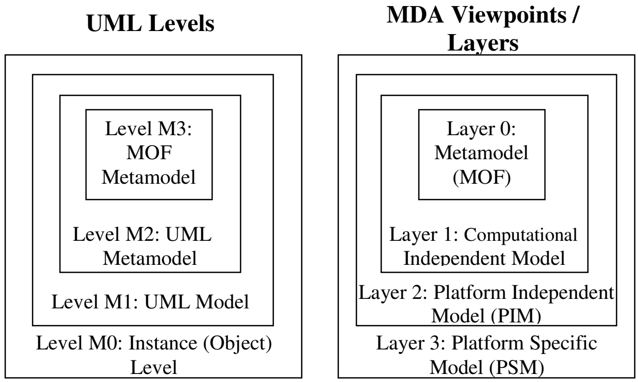


Figure 2.1: *The Level and Layer structure of UML and MDA*

Cadastre 2014 statements.

- Platform Independent Models, corresponding to the Land Administration Domain Model and to a UP Design Model. This last one will be package-centric and conform to a given country model. In this work, this corresponds to LADM_PT.

- A Platform Specific Model, assuming a specific implementation on a Spatial Data Base system; corresponding to a UP Data Model.

- Model Transformations, specifying the conversion chain from the Platform Independent Model into the Platform Specific Model, using a set of additional information attached to the Platform Independent Model (Truyen, 2006, p.4).

A detailed description of such models will be given in sections 4.1 to 5.3, respectively.

2.1.2 Modelling infrastructure standards

A number of technical standards from the ICT field were used in order to produce the main results from this research. The fundamental standard is without any doubt the Unified Modelling Language, whose constructs were used to specify various artefacts during the inception and elaboration phases.

It is not the purpose of the following paragraphs to explain in detail all the elements of the aforementioned standards used in this research, there are already plenty of excellent textbook references, not to mention the standards itself. The idea is just to explain the purpose and usefulness of introducing each of the standards elements in the overall development methodology outlined in the previous sub-section.

From its beginnings in 1997, UML was intended to model systems in a broad way, not limiting itself to software development, although applying much concepts from object-oriented programming. Other useful characteristics are its scalability, allowing modelling of complex, mission-critical systems, and the capacity of being understood by both humans and machines. It was intended to be the dominant, common modelling language used by industry (Eriksson and Penker, 1998, p. 5).

The Object Management Group adopted UML as a formal standard, which has known a number of versions and several added elements since then. Specially relevant for this work, that organization defined a related standard called Object Constraint Language, in order to formally express modelling constraints that otherwise could not be imposed using solely UML constructs. From version 2.1.1, UML explicitly supports the MDA approach, which is also an Object Management Group initiative (OMG, 2007a, p. 201).

Besides the above mentioned considerations, there was also the fundamental precedence of LADM being already expressed using a specific type of UML Diagram, the Class Diagram. All the different kinds of models pertaining to the MDA approach (CIM, PIM and PSM) are mainly defined through the use of Class Diagrams at its basis.

However, like referred for the UP Inception phase, the Use Case Model should be one of the first artefacts to be produced in the modelling process, this being addressed by the UML Use-Case View and related Diagrams. The following paragraph describes this concept (Eriksson and Penker, 1998, p. 15):

> The Use-Case View describes the functionality the system should deliver, as perceived by external actors. An actor interacts with the system; it can be a user or another system. The use-case view is for customers, designers, developers and testers; it is described in use-case diagrams and occasionally in activity diagrams.

To model complex systems such as Land Administration, an hierarchy of related Use case diagrams is needed, beginning with a *Context Diagram* which defines the system boundary and the main external actors. The main elements in a Use Case Diagram are actors, use cases and the subject (the system being modelled) (OMG, 2007b, p. 581).

Although not defined in the UML standard, a specific text format should be used to document a Use Case, and a careful text description of the system Use Cases is a fundamental component of a well designed Use Case Model.

Use Case Models were developed for the Portuguese Mira Municipal Cadastre implementation in the context of cadastral update procedures and are presented in section 4.6.2 and Annex E.

As referred above, the Use Case View can also include Activity diagrams. That type of UML Diagrams portray the sequential flow of activities pertaining to system operations. It is possible to define parallel sequences of activities and conditional flows and so some UML constructs are required in order to synchronize such flows. The fundamental element in an Activity Diagram is the Action; a higher-level Activity usually includes a number of structured Actions. The results from an Action can be an operation call or sending a signal, and they can alter the state of the system (OMG, 2007b, p. 219). As happens with Use Case Diagrams, there is an hierarchy of increasingly complex and detailed Activity Diagrams, starting with the display of *Fundamental Activities*, where each Activity is simply a node representing a group of Actions (OMG, 2007b, p. 295).

In this work, Activity Diagrams centred on the Cadastral Update procedures were developed for the Mira Municipal Cadastre, being related with the Use Case diagrams presented in section 4.6.2.

Both Use Case and Activity Diagrams belong to the behaviour or dynamic modelling component of UML, and diagrams depicting the system's Context and Fundamental Activities should be considered immediately from the Inception UP phase.

The structural modelling component of UML includes the Class Diagram at its core, but also Component and Deployment Diagrams. This last type is relevant during the Construction UP phase, which is not presented in great detail in this work.

The Class diagram is used to define both the Domain and the Design Models. The fundamental element is the Class, which can represent a software entity (typical of the Design Model) or an abstraction from a real world entity (typical of the Domain Model). Different kinds of relationships between Classes can be defined in a Class Diagram, namely simple or directed associations, composition or aggregations classes or generalization hierarchies. Classes and their relationships can be further grouped into packages. Also, specific instances from Classes can be used to depict particular system states, on related Object Diagrams. In a detailed Class Diagram, the internal Class structure is usually specified through a number of attributes and operations, following closely the object-oriented concept of encapsulation, and also constraints formally expressed in OCL.

In this work, sections 4.2 and 5.3 show how the Portuguese country profile was derived from the LADM, using UML constructs belonging to Class Diagrams together with a number of *UML extension mechanisms*. In version 2.1.1 of the UML standard, the main extension mechanism is the UML profile, now including formerly defined mechanisms (OMG, 2007b, p. 647):

> The Profile mechanism has been specifically defined for providing a lightweight extension mechanism to the UML standard. ...the notion of a Profile was defined in order to provide more structure and precision to the definition of Stereotypes and Tagged values.

As the core of the LADM includes a number of Cadastral Classes representing spatial entities, which possess their own set of constraints (most notably topology constraints) and define a topology structure, the main profile applied in the derivation process was Simple Features (An OGC profile derived from ISO 19136 GML, described in the following sub-section.

Besides all the above mentioned UML Diagrams and the UML Profile used during derivation of the Portuguese country profile, also version 2 of the Object Constraint Language (OCL) was used in order to impose a number of modelling constraints to specific Classes or relationships among Classes. The OCL is (OMG, 2006, p. 5):

> ...a formal language used to describe expressions on UML models. These expressions typically specify invariant conditions that must hold for the

system being modeled or queries over objects described in a model.

In this research, a number of OCL expressions were applied on the country profile PIM Class Models, and further interpreted by Model transformations in order to derive a special type of implementation on the final spatial data base, by means of a dedicated CASE Tool. This is reported through sections 4.2 to 5, being considered an important technical outcome of the research.

Another UML related standard used in this research was the XML Metadata Interchange (XMI), also issued by the Object Management Group. The version 2.1 of this standard defines both XML Schema Definition (XSD) and XMI Documents, the first type being optional. The purpose is to use a standard mechanism, capable of validation and following well formed rules, which can transfer UML Models between different tools without loss of information. As expressed on the standard for the XMI Documents (OMG, 2005, p. 57):

> XMIs XML document production process is defined as a set of production rules. When these rules are applied to a model or model fragment, the result is an XML document. The inverse of these rules can be applied to an XML document to reconstruct the model or model fragment.

As defined above, the possibility of applying reverse engineering is another useful characteristic of the standard, once it supports one of the requirements from the MDA approach: to synchronize the PIM and PSM models after updates being made to one of the models.

In this research, XML Parsers were used to import UML Model fragments written as XMI Documents (mainly concerning Class Diagrams) from external modelling tools to the CASE Tool, in order to be further processed.

The country model PSM considered implementation into a specific spatial data base, and although this PSM Model can be expressed equally in UML (through the aid of specific stereotypes or a UML Profile), it is currently not yet possible to generate a data base schema from an XMI Document in a completely automated way, due to technical limitations. Instead, another set of standards was used, ISO SQL3 for Relational data base Management Systems, and the more recent ISO/IEC 13249 SQL/MM or Structured Query Language for Multi-media standard. This last standard has several parts, Part 3 being dedicated to spatial data handling. As defined in (Stolze, 2003, p. 1), SQL/MM:

> ... is the international standard that defines how to store, retrieve and process spatial data using SQL. It defines how spatial data is to be represented as values, and which functions are available to convert, compare, and process this data in various ways.

The SQL/MM standard, however, does not define a topology structure, only geometry primitives and operations. Today, a number of major spatial data base management systems already adopted SQL/MM, which means it is possible to generate data base schemas for different vendors from the same PIM, combining UML derivation rules with the generation of SQL/MM compliant scripts, through successive Model Transformations.

The fact that SQL/MM is built upon the general purpose SQL3 standard means that specific data base implementations of the standard (also known as SQL dialects) must be taken into consideration when generating a SQL script document capable of producing or updating a data base schema. In this research, the primary SQL dialect was pgSQL, from PostgreSQL data base.

2.1.3 Geographic modelling standards

The Land Administration Domain Model and derived Portuguese country profile here presented, closely follow the ISO 19000 series of standards, also known as the *Geographic Information* series of standards. At its most fundamental level, a set of spatial data types which includes a topology structure is defined in ISO 19107: Geographic information - Spatial schema. This standard provides the foundation for a series of other standards, through the definition of geometric and topologic primitives describing the spatial component of geographic features. The standard provides a clear definition of a geographic feature (ISO/TC211 Geographic Information / Geomatics, 2003a, p. ix):

> A feature is an abstraction of a real world phenomenon; it is a geographic feature if it is associated with a location relative to the Earth.

The standard provides for the use of vector and (in a minor degree) raster data, thus accommodating all the major spatial data types used in today's Geographic Information System (GIS) software. Its main concern lies in the standardization of *Spatial Operators* defining the way each spatial data type should be manipulated (created, used, queried, modified or deleted). It also defines an hierarchy of spatial data types, starting from a root object, spatial primitive objects and aggregate or complex / composite objects defined from the primitive objects.

A geographic feature, however, has more than just a spatial data component. In order to define the complete structure of features and how they relate to each other in an application domain, ISO 19109 (Geographic information - Rules for application schema) defines a *General Feature Model* (GFM). The main characteristics of the General Feature Model are (ISO/TC211 Geographic Information / Geomatics, 2003b, p. 10):

> The things we want to classify we call features; the relations between feature types are feature association types and inheritance. Feature types have properties that are feature attributes, feature operations and feature association roles. All these concepts are expressed as UML metaclasses in the GFM.

Above sentence shows that this ISO standard uses the UML standard in order to express and convey its concepts, which is true also for the other standards in the ISO

19100 series. The GFM definition above, however, does not explicitly mention the possibility to add OCL constraints over the properties of features.

Other standards in the geographic information series also played minor (still important) roles in the design of the LADM country profile. One example is the ISO 19111 Geographic information - Spatial referencing by coordinates. This standard provides a way to describe and exchange information about Geodetic or Engineering Coordinate reference systems, including Datum and Ellipsoid parameters. It is related with the spatial schema's spatial data types through the geometry root object's *Direct Position* primitive data type.

Above referred ISO geographic information series of standards were not taken into account individually in the derivation of the country profile. Instead, they were considered altogether when importing the Spatial UML Profile based on the Open GIS Consortium (OGC) Simple Features Access standard. The OGC Simple Feature Access - Part2: SQL option, in particular, was adopted in this research once it provides a standard extending SQL in order to handle spatial data types, defining an SQL Schema where all the types defined in the Simple Features profile can be stored, queried and manipulated. Additionally, a number of SQL functions implement the spatial operators defined in ISO 19107, for the concerned data types (OGC and Herring , Editor, p. viii).

The definition of the SQL functions is based on the SQL/MM standard mentioned in the previous sub-section. By its turn, the Simple Features profile provides for an XML Schema (following the Geography Markup Language or GML), defining a subset of simpler geometric primitives subject to a number of constraints that allow for an easier implementation of software supporting GML. According to its definitions (OGC and Vretanos , Editor, p. xii):

> The SF specifications are more restrictive than GML, however, in that geometry is limited to points, lines, and polygons (and collections of these), with linear interpolation between vertices of lines, and planar (flat) surfaces within polygons.

The Simple Feature Access for SQL is built upon a number of previously defined standards (ISO 19000 series, GML Simple Features and SQL/MM), and in this research, supplied standard constructs for the definition of a Spatial UML Profile and also for the generation of SQL scripts as result of Model Transformations, producing thus the final implementation on a spatial data base.

2.1.4 FOSS solutions for Land Administration

Most of the software development tools used for creating the CASE Tool and also producing the implemented data base Schema (for the Pilot Project) were based on FOSS. This form of free licensing and free redistribution of software has been growing considerably during the present decade. Some of the advantages in adopting FOSS are lower software and hardware costs, simplified license management, ample support and the availability of quality software (Jason Williams and Dulaney, 2005, p. 1).

This results from a vast network of developers having access to code and contributing to beta testing and peer review of newly produced code.

For its reputation as a modern Integrated Development Environment sharing a vast number of software development projects through the Eclipse Foundation, the Eclipse Platform was a natural Open Source choice for this research. It offers a multi-platform, multi-programming language and multi-role (programming, modelling, testing, etc.) platform architecture which can potentially improve software development work (Carlson, 2005, p. 4).

Furthermore, it offers a good number of projects directly related with the information technology approach here followed, namely on the fields of modelling and support for model transformations. The main project components installed to the Eclipse platform during this research were:

- Eclipse Modelling Framework. It provides the basic foundation to set and manipulate models within Eclipse, namely those based on the UML standards;
- Graphical Editing and Modelling Frameworks. As their names implies, they supply the tools in order to graphically represent and change UML (and other types) of models, also including some degree of OCL support;
- UML2 Modelling plug in. It allows to create a UML version 2 model in Eclipse, requiring installation of the above referred frameworks.
- Hibernate and Hibernate Spatial persistence mechanisms. Supply the functionality to generate spatial data base schemas from a UML model.

Besides those Eclipse components and plug-ins, other components integrated into the programming language of choice, Java, were also used to perform specific tasks, namely JAXP. This application programming interface (API) is responsible for parsing and validating XML documents in general, and in this research it was used to parse XMI files including the serialization of UML models and OCL statements.

The generated LADM_PT platform specific model was implemented on a PostgreSQL open source relational data base, due to its widely acceptance in the open source development community and the existing support for spatial data types through the PostGIS extension. The PostgreSQL - PostGIS combination assures access to a multi-platform and multi-language robust data base using standards such as SQL-MM.

The implementation code was generated with the support of one of the so-called *Java persistence* API, Hibernate. Persistence is a fundamental concept in application development, assuring that all necessary data and objects are persisted after an information system is powered off. While programming in Java, this usually means storing data in a relational data base using SQL, having a JDBC (Java Data Base Connectivity) driver as the middleware (Bauer and King, 2007, p. 5). The Hibernate API specifically addresses the issues arising from persisting a schema developed through UML, and thus using object-oriented paradigms, into a relational data base using the relational paradigm. These are together called the *paradigm mismatch* and Hibernate proposed solution is to use Object-relational mapping (ORM) (Bauer and King, 2007, p. 24). However, plain Hibernate does not address the generation of SQL scripts supporting spatial data types, as required for implementing the LADM_PT schema into PostGIS. A full support for ORM including spatial data types in the OGC Simple Features Access for SQL standard is provided by the extension to the Hibernate core called Hibernate Spatial. This last piece of software supports also other relational spatial databases like Oracle or MySQL.

A detailed description of the ORM mappings required in order to implement the LADM-PT schema and further results obtained through the provision of the Hibernate component to the technical solution applied to the implementation test will be reported in sections 5.3 and 5.

2.1.5 The ontology of Land Administration as expressed by LADM and the use of ontology languages

This subsection examines the usefulness of considering formal ontology languages, in order to achieve greater interoperability between different country models derived from LADM, in the form of "semantic translation" of model elements. Particular applications to the cadastral systems and the legal domain are presented, together with existing software editor environments.

The Land Administration Domain Model, being described through UML, can be considered as explicitly encoding an Ontology. It captures a set of fundamental concepts about the domain through high levels of abstraction, translated into classes and their relationships. A more involved discussion on the issues relating to the development of a Domain Model in general and specifically LADM is included in section 4.2.

The word *Ontology* has a Greek origin, being formed by the parts *Ontos* from being, to be and *Logia* from science, study or theory. The philosophic concept developed in classical Greece, and can be defined as the study of the nature of being or existence in general, as well as the basic categories of being and their relations. In the era of information science, this definition evolved into a formal representation of a set of concepts within a domain and the relationships between these concepts[17].

The formal, explicit representations of an ontology were required for their application in computing, so that they could be *machine-readable* and further processed by a computer application. One of the first application domains was that of Artificial Intelligence and related fields of knowledge engineering and knowledge representation. According this application domain (Gaevic et al., 2006, p. 47):

> An ontology represents the fundamental knowledge about a topic of interest; it is possible for much of the other knowledge about the same topic to grow around the ontology, referring to it, but representing a whole in itself.

Today, there is a growing interest in the use of formal ontologies in areas like interoperation research, education and modelling. A formal ontology supplies the required constructs which can, to a certain degree of automation, detect the *semantic*

[17]Source for previous definitions: Wikipedia

differences between related representations of data in a computer system. If, for example, the same formal ontology description language is used to convey the concepts being used in two different, but thematically related spatial databases, then it would be possible to identify were the relations or individual attributes have a match or a partial match, or if there is a complete mismatch between the concepts (Hunter, 2002, p. 86).

The formal ontology and object-oriented modelling languages evolved independently during the last decade, although they share a significant number of concepts. This has been recognized recently by the Object Management Group (the developers of the UML standard), and subsequent work gave birth to the Ontology Definition Metamodel (ODM) standard. According ODM (OMG, 2009, p.31), an Ontology:

> ...defines the common terms and concepts (meaning) used to describe and represent an area of knowledge. An ontology can range in expressibility from a Taxonomy (knowledge with minimal hierarchy or a parent/child structure), to a Thesaurus (words and synonyms), to a Conceptual Model (with more complex knowledge), to a Logical Theory (with very rich, complex, consistent and meaningful knowledge).

Above referred ontology components (Taxonomy, Thesaurus, etc.) are described ahead in this section.

Further elaborating on the identification of semantic differences (through comparing explicit Ontologies), it is possible to create so-called query translators which can look for matches or even partial matches between two ontologies to translate a query issued in a departing ontology, to the corresponding query in a destination ontology. A prototype query translator was developed for a previous version of LADM and its core domain ontology was used to translate queries between two different proposed country implementations (for Greece and the Netherlands). Recommendations from this research stressed the importance of defining system boundaries and using an equivalent level of abstraction (Hess and de Vries, 2006).

Achieving interoperability between different implementations of the LADM is one of its stated goals, and currently, as the above experience shows, this can be done through the use of explicit ontologies.

Before presenting the main elements contributing to an explicit ontology, it is worth mention that, likewise what is being achieved through the standardisation procedure regarding LADM, an ontology conveys a shared understanding of a domain that is agreed between a number of individuals or agents (Gaevic et al., 2006, p. 48).

The main components of a formal Ontology are (Gaevic et al., 2006, p. 51-53):

- **Vocabulary**: Preferentially, a *controlled vocabulary*, where each term is defined unambiguously through a number of logical statements and rules and uniquely identified terms. A combination of a glossary (with terms described in natural language) and a thesaurus (giving a list of synonyms for each glossary entry) gives an alternative which is human-readable, but it is not completely objective.

- **Taxonomy**: A hierarchical categorization or classification of entities within a domain, including the specification of generalisation/specialisation (or part - whole) relations.

- **Ontology representation languages**: Classes resulting from categorisation are represented through their properties, property values and restrictions, so that knowledge is represented in a very structured way. This enables running consistency checks at instance level, when individual instances should obey to a particular ontology.

There were a number of ontology representation languages developed for the AI field, but the most used nowadays have an XML representation, like the Resource Description Framework - Schema (RDF-S), developed by the World Wide Web Consortium (W3C), or the Ontology Web Language (OWL), also developed by W3C. This last one is currently the most popular ontology language in use and includes the schema constructs supplied by RDF-S, as well as a number of elements which allow to specify a controlled vocabulary with description logic elements and constraints. It has three different sub-languages, with increasing expressiveness: OWL Lite, OWL DL (from *Description Logics*) and OWL Full (W3C, 2004).

Use in Cadastral Systems Modelling Such ontology representation languages have been applied in research related to cadastral systems, through the study of reference processes, that is, formal description of standard workflows (Hess and Schlieder, 2007, p.203). The examined workflows respected Property Transactions like sale processes or property subdivisions. The goal is to define reference processes through *inductive development*, starting from a set of formalized processes reflecting current practice in different national cadastral systems. The ontology modelling framework used in this research applied OWL within the Protégé editor (see bellow). The examples used in the paper refer to the sales process, with two countries activities being compared: Denmark and England & Wales. The reasoner supplied by the ontology editor identified three possible outcomes from the comparison (Hess and Schlieder, 2007, p.216), a complete correspondence for all activities, a partial correspondence or a complete mismatch between each country activities.

Use in the Legal Domain Pre-dating for more than one decade the research on cadastral systems using formal ontologies, there is the branch of Artificial Intelligence (AI) and Law. This field of research addresses the development of formal or computational models of legal knowledge, reasoning and decision making. An important precursor for modern legal domain ontologies concerns the research on Deontic Logic and its contribution to a comprehensive representation of legal knowledge, as reported in (Jones and Sergot, 1992, p.1). According these authors, Deontic Logic concerns *normative expressions*, that is, expressions pertaining to permissions, obligations and right of agents. Claiming that this area did not received (until then) sufficient attention in the AI and Law field, a methodology was proposed for the use of Deontic Logic in the analysis and representation of law. This research path has evolved and now it has been included into different legal ontologies, using the formalizations specified by the already mentioned RDF-S and OWL. Taking into consideration its potential use and benefits for the implementation of specific country (or thematic) models from LADM, specially in their legal and administrative component packages, two recent developments along the AI and Law research path were chosen:

- *MetaLex*, an XML (RDF-S based) standard for the markup of legal sources. The last version of this standard, along with more information on its component and products, can be read at (CEN Metalex, 2012);

- *LKIF-Core*, standing for the Legal Knowledge Interchange Format, an ontology of law for the semantic web and a knowledge representation language suitable for legal reasoning. It is a result of the European Commission funded Estrella project, and a complete specification can be read at (ESTRELLA Project, 2007).

Considering that both LKIF and MetaLex use the RDF standard and can thus access their respective data (and metadata), means an interface can be created which reads MetaLex metadata and further processes it using LKIF. The synergy arises from the fact that MetaLex describes a syntactical view of legal source texts, while LKIF models the semantics of the text; both referring to the representations of legal knowledge contained within the source text (Boer et al., 2007, p.13).

Recent developments in these projects include the availability of application programming interfaces for manipulation of LKIF knowledge bases and the consideration of time and versioning in XML files created and validated with MetaLex (Boer et al., 2007, p.19).

A particular branch from the MetaLex project is specially relevant to consider for (possible) integration into LADM: The Legal Atlas application framework. It presents a combined architecture of MetaLex (for regular legal sources) with geospatial regulatory information. It thus enables that spatial planning information, in GML standard format, be combined with a MetaLex XML file, through a interface which parses both types of data into a common ontology expressed in OWL format (Winkels et al., 2007, p.27).

Specifics on the relevance in the use of MetaLex and (specially) LKIF-Core concepts in the Legal and Administrative, and also the Spatial Unit components of LADM, will be further developed in Sub-section 2.2.2 ahead.

Ontology software and APIs An ontology developer will typically not write directly an XML encoded document describing an ontology, but will use instead an *ontology editor environment*. Much in the same way that Model Driven Architecture software or more simpler UML diagrams editors provide tools for specifying a UML Class model (and other UML constructs) and perform some model validation, there are a number of ontology editors which provide for reconciling syntactic, logical, and semantic inconsistencies among the elements of an ontology (Gaevic et al., 2006, p. 61).

The current leading ontology editor is Protégé, developed at the University of Stanford. It supports a variety of ontology representation languages, including OWL and

RDF-S, and allows to specify Domain Models using ontologies, with which knowledge-based applications can be developed through a Java language Application Programming Interface (API). During the years, a strong user community has contributed to this free, open source software, with a number of freely available ontologies, which most notably include a number of ontologies developed upon existing Geographic Information standards from ISO and the Open GIS Consortium.

The similarities which exist between the OWL Full and the UML Class metamodels allowed the definition of mappings between their constructs for specific purposes. For example, Protégé has a plug-in which can translate a knowledge base into an UML model (stored as an XMI file). Conversely, there are plug ins which read a UML Class Model and convert it into a Protégé - OWL knowledge base.

The recent ODM specification formalized the existing similarities through the adoption of the metadata language standard (Meta-Object Facility, MOF) as the common definition language specifying a number of above referred ontology languages as RDF or OWL. Furthermore, it has an informative chapter defining bi-directional mappings between UML and OWL expressed through the Query, Views, Transformation (QVT) (OMG, 2008) specification so that UML can be a basis for ontology development using a specific knowledge representation language, such as RDF or OWL (OMG, 2009, p.187-215). At the time of writing this thesis, however, there are still no software implementations of such mappings, and a number of problems do persist.

Like what was referred for the development of a CASE tool based on a UML model, also here a number of compatibility problems are reported concerning different versions of the base metamodels being used.

Giving the hypothesis that a useful mapping could be defined for the translation of the existing LADM (an UML Domain Model) into a corresponding domain knowledge base, then the benefits of both modelling tools could be enjoyed, namely enhancing the interoperability, educational purposes and support for implementation and application development for any specialised models to be developed based on LADM.

Considering the creation of an LADM explicit ontology, whichever the methodology to be followed, one must take care of the specifics of spatial data representation. Such an ontology must capture not just properties characterizing a given concept, having numeric, categorical or enumerations domains, but also the description of the geometrical / topological and locational elements of those concepts. Furthermore, spatio-temporal relationships possibly constricting different categories of concepts should also be considered (namely topological constraints). In such a way, an ontology specified domain model will require additional semantics to be included in the application schema, much in the same way UML extension mechanisms are needed to depict a domain model including geographic information. In discussing conceptual data models for geographic information (Fonseca et al., 2003, p. 361), says:

> Furthermore, in conventional models it is impossible to distinguish between object classes that have a geographic reference and purely alphanumeric classes. It is also difficult to represent the geometric nature of objects and the spatial relations between them.

Given current difficulties in developing meaningful ontologies for domains which include geographical information, there is research which argues that a simpler way would be to include ontologic data into the existing metadata standards, by extending them (Schuurman and Leszczynski, 2006, p. 710):

> Ontology-based metadata consists of eight categories for the capture of the culture and logics of data collection and formalization. These categories can easily be incorporated as fields for textual description into the structure of existing geographic metadata standards. Such an extended metadata framework will provide users with the information necessary to make evaluations of data appropriateness.

2.2 Legal modelling aspects

This section reports on the existing legal frameworks defining the Rights, Restrictions and Responsibilities component at the core of the Land Administration Domain Model. The methodology applied on this research began with a Case Study on the current situation of private property legislation (on immovable goods) in Portuguese law, using in the most parts accepted doctrinaire definitions of Rights *in rem*, based on a Continental Europe, Roman Law legal framework. This is reported on subsection 2.2.1.

The resulting set of definitions on Rights *in rem*, formerly classified according to doctrinaire views currently applied on law schools, was then reclassified under a new conceptual legal framework adapted to an information systems development using UML object-oriented concepts, and thus fitting the overall development methodology followed in the LADM and on the present Thesis. This new conceptual framework was reported on a more elaborated form in (Paasch, 2005), and the resulting classification[18], is reported in subsection 2.2.2.

In line with the broader context of Land Administration on which LADM is defined, and also with demands to include other types of Rights on Land besides traditional (private) ownership rights, the research examined also other forms of property. This study had a focus on Portuguese legislation and consequently enlarged the supporting conceptual framework in order to accommodate such definitions on a broader classification schema. The overall objective was to answer the first statement in Cadastre 2014:

> Statement 1: Cadastre 2014 will show the complete legal situation of land! Private and public rights and restrictions on land will be systematically documented!

This last research component on the legal domain modelling is reported on subsection 2.2.3.

[18] Which is applied to the Portuguese legal framework, becoming an integral component of LADM-PT country profile

2.2.1 Private property law under the Roman Law based legal framework

In most of the countries in Continental Europe, and also in other parts of the World which adopted a codified version of Civil Law, derived from the original French Civil Code, the Rights *in rem* were mainly grouped under the Right of Things title, which forms a branch of Private Law. According to the legal tradition in Portugal, the Rights *in rem*, also termed Real rights as a derivation from the Latin word for Things (*res*), are studied on a casuistic base (Hespanha et al., 2009, p. 11). This means that an analysis is made of specific Real Rights, given concrete situations.

A more systematic classification of Real Rights approach, however, was needed for this research, and an intermediary step used an extension of a classification schema proposed by Jaap Zevenbergen (Zevenbergen, 2005), since it closely follows legal concepts originating from shared Roman Law traditions (in Portugal and The Netherlands).

A definition of Real Rights originating from the Portuguese law school is a good starting point for the remaining discussion (Mesquita, 2000):

> Juridical relationship through which a thing[19] becomes under the domain or sovereignty of a person[20] according a certain statute which confers powers but also restrictions and obligations.

Above definition, not surprisingly, reflects the LADM Core which defines Real Rights as a relationship between a corporeal thing (e.g. a Real Estate) and a person (e.g. an individual). It seems more focused on the corporeal thing component (inherent); this being a consequence of the necessity to differentiate Real Rights from Personal Rights.

Also according to Portuguese legal doctrine, there are a set of common characteristics which belong to Real Rights and are useful to distinguish these from other types of Rights:

- Real Rights are **inherent** to the object of the Right (the corporeal thing);
- **Sequel**: Power granted to the Titular of a Real Right to execute is Right wherever the thing is or against a third party illegally possessing the thing;
- A Titular of a Security Right has a **preference** to receive his credit over any third parties not possessing a previous Security Right;
- Current juridical situation of the corporeal thing should obey to a **numerus clausus**[21];
- Current juridical situation of the corporeal thing must be **publicized** to interested third parties.

[19] A corporeal thing is in this sense any movable or immovable good which can be registered
[20] A person can be any individual (natural) or collective (non-natural) person
[21] Limited number of legally pre-defined Real Rights.

The set of Real Rights identified in Portuguese legislation was then grouped into the following legal classes, as proposed by Zevenbergen (Zevenbergen, 2005, p.141):

1. **Maximum Real Right**: the strongest right available in a jurisdiction, called e.g. ownership, freehold or property. In Portugal the best match is perfect property, definition is included in table 2.1;

2. **Derived Rights**: from the previous class, where the holder of this derived right is allowed to use the land in its whole (often within limits of a certain land use type);

3. **Minor Rights**: allow the right's holder to some minor use of part of someone else's land, e.g. walking over it to a 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;

4. **Security Rights**: rights whereby certain of the previously mentioned rights can be used as collateral, mainly through bank loans in the form e.g. of mortgage or lien;

5. **Acquisition Rights**: rights having as its object immovable property, to distinguish them from personal acquisition rights, and legally effective as a mean of acquisition of other real rights, namely ownership. This includes e.g. preemption rights.

The tables 2.1 and 2.2 summarize classification results and contain also short definitions to the Portuguese Real Rights, translated to terms in English.

The original article where these results were presented (Hespanha et al., 2009) included also the closest definition found in Black's Law Dictionary (Garner, 2004). Giving that this source reflects the concepts existing in Anglo-American Common Law, which seldom have a perfect match with the terms used in Civil Code tradition, these translations were omitted in this thesis. However, the conceptual approach presented in the next Sub-section, now integrated into LADM, intends to be generic and jurisdiction independent, although the results presented herein do conform to a Civil Code and Roman Law based country model.

A few notes on tables 2.1 and 2.2. First of all, the term "ownership" was avoided in the definition of individual Maximum Real Rights. The Black's Law Dictionary definition is (Garner, 2004, p. 1138):

> The bundle of rights allowing one to use, manage and enjoy property, including the right to convey it to others.

In this view, ownership refers to the complete set of Real Rights which applies to a given property, and not to any single right as defined in above referred tables. Secondly, for the Minor Rights just the Praedial Servitude is defined, but this Right can assume many different forms in Portuguese legislation. For the majority of different servitude types, it was possible to identify a similar type of Right on Blacks

Law Dictionary, suggesting that it is possible to converge on a commonly agreed set of definitions. This would be an important result contributing to modelling the legal domain in LADM.

Present *Final Draft International Standard* (FDIS) document for ISO 19152 LADM includes legal profiles for Rights, Restrictions and Responsibilities as an informative annex (Annex F, ISO/TC211 Geographic Information / Geomatics (2011)). These legal profiles are an important outcome of this thesis.

2.2.2 Conceptual approach into modelling the legal domain

The definitions and classification of Real Rights presented so far have followed a more legal doctrinal base, rooted in Roman Law traditions. In order to consider inclusion of the described Real Rights in an object-oriented conceptual framework, a more functional classification was used as a second step, following the proposal by Jesper Paasch (Paasch, 2005).

According to such a classification, and considering just the positive side[22] of Real Rights (which agrees with definitions presented so far), it is first defined the Appurtenance diagram as a UML Class Diagram. A specialization hierarchy is defined which classifies Appurtenance as the super-class from where five specialized classes are further defined.

All the super-classes defined in Paasch classification schema, comprising Rights and Restrictions both from Private and Public Law, have an association with the fundamental Ownership class. In this concept, Ownership corresponds to the bundle of rights affecting real property, no longer restricted to private rights, representing thus a broader concept than that of traditional common law.

The following items give brief definitions of classes in the Appurtenance diagram ((Paasch, 2005, p. 125-126); adapted):

- **Common Right**: A real right executed in common by a group of subjects, which is attached to a land parcel. The right belongs to the real property; when the property is sold, the common right follows the property, as it belongs to it and not to any individual owner.

- **Real Property Right**: It is a real property that is related to another real property through this right, as occurs in an easement or right-of-way. Seen as an appurtnance, it can affect another's property in whole or in part, or can be left unspecified.

- **Personal Right**: Right given to a person to expand or limit ownership through e.g. a rent or lease. It can be granted for a person lifetime, within a time limit or forever (undefined time limit).

- **Latent Right**: Right imposed on ownership but not yet executed, e.g. a preemption right over the acquisition of a neighbouring property.

[22] Those which are beneficial or appurtenant to the owner or to the holder of derived rights.

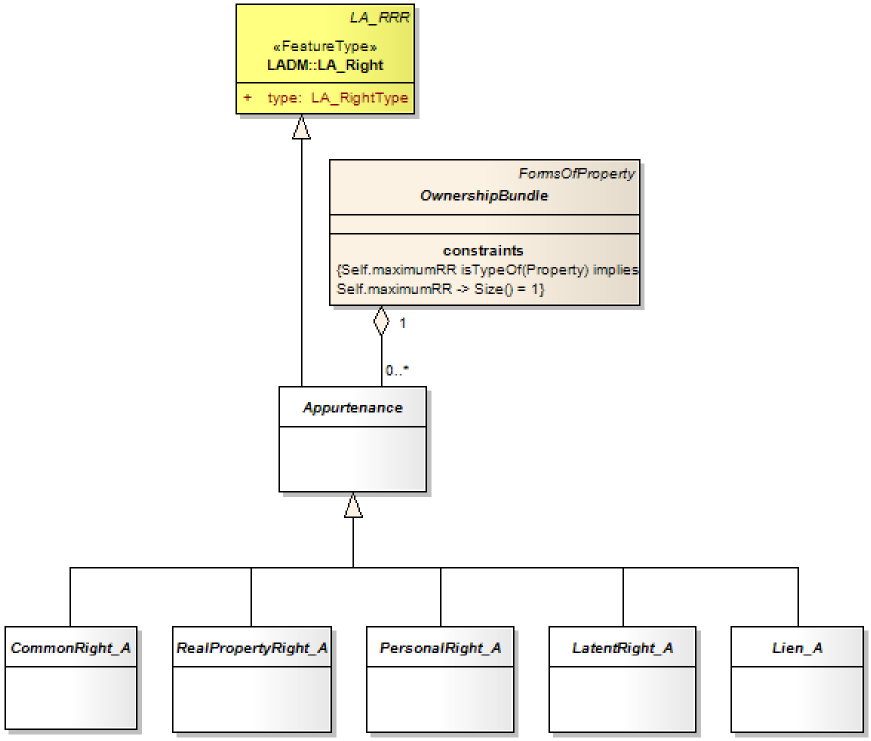


Figure 2.2: *Hierarchy of the Appurtenance abstract class in LADM* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2010).

- **Lien**: A security of payment right. It is an economical/financial right, which can be executed on real property, thereby regulating ownership, e.g. a mortgage.

As a final modelling step in the legal domain, the complete list of Portuguese Real Rights as described on tables 2.1 and 2.2 was ascribed to above appurtenance super-classes as specialized classes. The resulting class diagram and specific problems arising from this last conceptualization step are further detailed on section 4.5 (Comprehensive model for the legal and administrative domain).

Paasch's classification, as told, is not restricted to private rights, but includes also government imposed regulations which can constitute a benefit or a restriction to ownership. Accordingly, two abstract super-classes are defined (Paasch, 2005, p. 128):

- **Public Advantage**: An asset to ownership right resulting from positive results of legally (government) imposed burdens. For example, the property can be granted a dispensation, benefiting ownership as compared to neighbour parcels were the burden still exists.

- **Public Restriction**: Restrictions (government imposed) that regulate the ownership right. For example, a municipality urban plan regulation which imposes a certain colour when painting buildings in a specific city block.

Contrary to the Appurtenance diagram specializations, on the realm of public law there are no abstract specialized classes in the original Paasch classification. The administrative component of the country profile, however, identified a number of instantiable classes pertaining to concrete public regulations. These are reported and further detailed on several diagrams on section 4.2.3.

Legal Modelling with ontologies Besides the UML expressed, object-oriented approach presented above, a number of recent research initiatives has led to the development of ontologies for the legal domain, which were referred back in Subsection 2.1.5.

Beginning with the MetaLex standard (CEN Metalex, 2012), in its OWL ontology page are defined the conceptual classes and their properties, which mainly respect items related with the analysis of legal text sources. A total of five different hierarchic levels can be identified in its class structure, respecting fundamental concepts around a legal text, as "BibliographicItem", "Expression", "Work" or "Manifestation". Examples of more specific classes and sub-classes considered in this ontology are the "Bibliographic Reference" and "Bibliographic Citation" or the "Bibliographic Modification" and "Copy". Some of the properties in this ontology can be translated to UML class associations or its roles, and even to UML composition constructs, like the "partOf" restriction property, implying that a "Bibliographic Object" is composed of one or more "Fragment" object (instances). The MetaLex examples above clearly show the aim of this standard in syntactical analysis of a legal source text. This means that MetaLex alone is not capable of playing a role similar to Paasch's classification, expressed through UML class diagrams.

However, this (apparent) short come can be surpassed if the result of the MetaLex text parsing is further processed through the LKIF ontology. Similarly to what happens in UML modelling, there are different abstraction levels in LKIF, ranging from an upper ontology (with no equivalent level in LADM), to the legal core (equivalent to the LADM Domain Model), to a country or jurisdiction specific ontology (equivalent to Portuguese Country Model from LADM).

As in LADM, also LKIF claims that its core concepts are *legal domain independent* and thus can be used to access similarities and differences between concepts in equivalent legal domains of different jurisdictions (ESTRELLA Project, 2007).

At the time of writing this thesis, no specific application of LKIF to the legal domain of Real Rights was examined, although examples were reported for the Criminal Law in the Netherlands.

The LKIF-Core ontology, however, has a number of modules or core concepts, like "Place", "Time" or "Mereology", which supplies a part-to-whole, system oriented view of concepts, which are also used by LADM. It gives a larger focus on the modelling of dynamic aspects, such as the "Process" module (which uses the concepts defined in the Place and Time modules). Concerning its core classes or most important concepts, there are a number of them which are relevant to LADM as well, like: "right", "prohibition", "responsibility", "legal person" or "source of law". These are modelled in different packages of LADM, namely the Legal and Administrative, Party or Source (a special class).

In LKIF-Core, there is a rigorous Deontic Logic definition concerning each of the modules (ESTRELLA Project, 2007, Annex 2) and then the specific OWL definition of classes and properties (ESTRELLA Project, 2007, Annex 3) which enable the processing of LKIF validated files in knowledge based systems, namely for legal argumentation purposes. Which is presently out of scope of the LADM proposed standard.

The LegalAtlas application The most interesting use of MetaLex, as far as LADM is concerned (but not considering LKIF ontology) is the LegalAtlas application. It aims at make available the legal sources of spatial regulations in an integrated environment. The implementation used the Java programming language and RDF / OWL components in order to present linked map and regulation browsers. Queries can be started from the geometric or the legal source components. It presents several advantages as compared with existing GIS applications which have hardcoded hyperlinks between geospatial objects and a corresponding legal source text (Winkels et al., 2007, p.28). In the LegalAtlas, the linking between text and maps is established recurring to the MetaLex and GML standards, which are both transformed to RDF files. The problems arising from the integration between these components are further reduced through the consideration of a (RDF) schema which mediates between the legal source text and the geospatial objects. In the case of the current implementation, this concerns the Dutch IMRO2006 standard (Winkels et al., 2007, p.29). It stands for "Information Model Spatial Planning", and describes spatial plans at different administrative levels (municipal, regional and national). For processing both legal sources and the geometric component contained in IMRO2006 files, in order to automatically derive their linkages, ontologies were defined for concepts introduced by LegalAtlas, as well as for IMRO2006 spatial planning classes. In the LegalAtlas application, each IMRO file is processed into a spatial planning and a GML, both as OWL format files. The spatial planning component is linked to the MetaLex processed legal source, while the GML data is joined with GML data from the LegalAtlas ontology file, to supply data for the map browser component (Winkels et al., 2007, p.32).

As claimed by the authors of the LegalAtlas application, the solution can link any regulation (or other legal source) to a map, or vice-versa. The idea is to evolve to a webservice allowing users to investigate the rights, obligations and permissions of a particular area or parcel on a map. Thus sharing many commonalities with the goals of LADM.

In Section 6.3, the potential of the research concerning MetaLex, LKIF and the LegalAtlas application to the development of new tools integrating LADM is further examined.

2.2.3 Legislation on alternative forms of property

In the preceding sub-section, the most well-known forms of property belonging to the private and public domains were classified and described according a new conceptual approach. Information on land parcels where such rights and restrictions apply constitute the core of Land Registries and Land Information System (LIS). However, in many countries (namely in Europe) there exists another form of property ownership, usually referred as "Commons" (following British tradition). This form of property has deep roots in History, even preceding institution of the Roman Law and related private property forms.

It is not surprising then (with such deep roots in History) that the institution of the "Commons" eventually follow different paths among European countries and even in the New World. The following definitions belong to Black's Law Dictionary and are the ones most resembling a Common Right (see 2.2.2):

> Common appurtenant (Historical): landowners right to graze animals on another's land as a result of a written grant relating to ownership or occupancy of land (Garner, 2004, p. 291).

Interestingly enough, above definition has the label "Historical". A recent form of a Common right is the following:

> Common area or common elements: An area owned and used in common by the residents of a condominium, subdivision or planned unit development (Garner, 2004, p. 291).

On the original article by Paasch, a Common Right example is taken from Swedish law; the author claiming that such definition equals the concept of the British "Commons":

> ...a common property unit (samfllighet[23]), where several real properties own a share in the common property unit. The common right is in this case land or water solely owned by other properties, which can e.g. use it for grazing domestic animals or extracting natural resources, like timber or fish. If one of the shareholder properties is sold, the share in the common ownership right in the common real property unit automatically follows with the sale. (Paasch, 2005, p. 128-129)

Above definitions, covering similar rights existing in different jurisdictions (USA, UK and Sweden) all fit the Common Right concept under the overall Appurtenance super-class of the Legal Domain, thus classifying as private property rights, which could be (or should be) registered.

The Portuguese institution of the "Commons" followed a slightly different path, being known by the term "Baldios". The Constitution of the Portuguese Republic, Art. 89, on the property of means of production, states that the public sector is

[23]In Dutch: *mandeligheid*.

formed by goods and production units belonging to public entities or to communities, under three different management modes: State, cooperatives or local communities (Dinis et al., 1987, p. 271). This last mode is the one covering the legal mandate of a “Baldios” Commission, whose main mission is to administer goods in possession of a local community “Baldio” or a number of jointly administered “Baldios”.

The governing law for the “Baldios” is the Law 68/93 (Portuguese Law, 1993), with recent amendments given by Law 89/97. Following paragraphs briefly describe the mains legal characteristics of this form of property, justifying its different classification under this sub-section.

The subject is the local community, usually involving the inhabitants of a single settlement. The subject is defined as the universe of local community shareholders. Customary law (rooted in traditions since time immemorial) defines who is entitled to be a shareholder.

The object, here limited to the land parcels which classify as “Baldios”, is communal land used and managed as such since time immemorial, even if temporarily being left unused by the local community. Apart from this historical core and since 1976 and subsequently passed legislation, also land parcels (formerly “Baldios”) submitted to a forestry regime or left as unused reserve during dictatorship. Former “Baldios” taken over by private owners can revert to its original state, under the dispositions of by-law 40/76. Additionally, the local community can acquire private property and convert it to the “Baldios” legal regime. The “Baldios” are not limited to land parcels, as above described, but can equally include certain types of constructions like seed stores, windmills, watermills or bakery ovens, considered as communal use equipment.

The most frequently found Land Use in a “Baldio”, apart above referred communal equipment classifying as urban immovables, refer to rural uses. Usually there are multiple and often combined uses in a single “Baldio”, like forestry, pasture or agricultural uses, including plantations. The concrete use of a “Baldio” by its shareholders obeys to customary law or to a *Use Plan*.

The Use Plan was created by modern legislation and should result from cooperation between the local community and public authorities, specially those involved in Land Administration and Environmental Protection. This step ensures conformity with local, regional and national Land Planning and Policy.

The management of a “Baldio” is done by a shareholders assembly self-organized by the local community. This assembly should then nominate a board of directors and a inspection commission. Responsibilities held by these different organs is detailed with great care in the legislation (Art.s 15, 21 and 25 of Law 68/93).

The extinction of a “Baldio”, namely by converting it to private property through sale, requires a qualified majority of 2/3 of shareholders attending an assembly session. However, there are just two main legally recognized events which justify such sale:

1. The “Baldio” shares a common border with the settlement limits and the urban area must be expanded.

2. The future use is industrial, infrastructure or other types of equipments presenting a recognized collective interest for the local community.

A "Baldio" can also be expropriated by the state, after a declaration of public utility has been issued by national authorities. There is usually an indemnification to the local community resulting from the expropriation. Another reason for state expropriation is unjustified abandonment of "Baldio" use.

An encumbrance can be defined on a "Baldio", in the form of servitudes according to general law, thus including both praedial[24] servitudes from private law and administrative servitudes from public law.

A last legal figure for a "Baldio" is the **Cessation of Exploration**. The shareholders assembly can decide to cease the use of part or the whole of a "Baldio", for a period of 20 years (renewable), for Forestry exploration uses. Whenever possible, communal land use should be substantially maintained.

2.3 Institutional Built-up

This section shows the importance of institutional theory and institutional change (as a key to understand historical change) as contributions from social sciences to be included in the development of Land Administration systems. The selected examples all concern the institution of Property, as key to the definition of scope for a system based on Cadastre and Land Registration. Other institutions, not belonging to the legal or administrative realms, are also relevant to the development methodology, and were indeed considered for the case study of Land Administration in Portugal. Results are reported in section 3.5.

There is a common overlap, in everyday language, concerning the terms Institution and Organisation. In this research I adopted the definitions given by Douglass North, which also introduces the notion of Institutional change, as follows (North, 1990, p.3, 5):

> **Institutions** are the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social or economic. Institutional change shapes the way societies evolve through time and hence is the key to understanding historical change.

And concerning Organisations:

> **Organizations** include political bodies (political parties, the Senate, a city council, a regulatory agency), economic bodies (firms, trade unions, family farms, cooperatives), social bodies (churches, clubs, athletic associations) and educational bodies (schools, universities, vocational training centres). They are groups of individuals bound by some common purpose to achieve objectives.

[24] A Latin term from Roman Law; meaning Land or an Estate ((Garner, 2004, p.1211)).

Also according this author, while Institutions supply the rules of the game, Organizations provide the players.

At the heart of Land Administration systems worldwide and consequently of their diverse aspects described in the previous and following sections (Technical, Legal and Administrative), lie a significant number of *Institutions*.

These institutions are the result of a slowly and steady (sometimes abrupt) evolution of social facts, ultimately contributing to the *Construction of Social Reality*, according the Searle's formulation (Searle, 1995, p. 41):

> ... the decisive movement... in the creation of social reality is the collective intentional imposition of function on entities that cannot perform these functions without that imposition.

That is clearly the case of *Property*, one of the recurrent examples cited in the studies of institutional theory. Modern Land Administration systems, although still having the institution of Property at its core, have incorporated publicly agreed impositions on its basic core, which contribute to the society in general, like public infrastructures, or the protection of the environment and natural resources.

Not accounted on the initial Searle's explanations regarding the evolution and creation of social facts, a new dimension on the institutional reality should be considered, the dimension of *Representations*. A representation is not supported on any physical reality (or brute fact, according to Searle) and merely functions like a representation of a social fact. In the work of De Soto (2002), property records and titles together contribute to the "invisible infrastructure of asset management". Those representations are central to any modern Land Registry (if we enlarge the number of representations to include deeds as well), which by its turn is a fundamental element of any Land Administration.

Property related institutions, namely Property Law, can be formal (e.g., written laws and regulations) or informal (many customary law traditions). The branch of property law existing in British-originated Common Law and in (Continental Europe) Civil Code are examples of a formally defined institution. Each of these legal traditions has been adopted, freely or imposed through colonial regimes, by a significant number of countries throughout the world. Some countries even have a "mixed heritage" of both the Common Law and the Civil Code institutions, such as South Africa or Canada. This "institutional globalisation" movement happened mostly during the transition from the 19th to the 20th centuries.

However, in many countries in South America, Africa and Asia, there has not been an effective reform towards an uniform formal representation system regarding property, once the Western inspired property systems actually formed a "layer" of formally recognised property systems which in many cases is overlapping with more traditional customary law indigenous regimes, pre-dating the western inspired regimes for centuries (if not millennia). Implications for the Land Administration Domain Model are evident, once it is evolving to an International Standard of worldwide application.

The Development Methodology, reported in Chapter 4, does not offer any particular solution to those cases because it assumes that the developed legal and administrative model profiles are to be applied to Portugal, a country with deep Roman Law and Civil Code traditions and a Law School tradition since the Middle Ages.

However, LADM is sufficiently flexible to define legal profiless, and in fact that is the case of the Social Tenure Domain Model (STDM) specialisation, which has been adopted by UN-Habitat and already developed to a prototype that has been tested in the short term in Ethiopia (Lemmen, 2009).

In Western countries, the resulting property institutions we observe today are the result of a centuries-old evolution, which has been ultimately formalised and codified in the Civil Code (for countries in Continental Europe). The recent evolution for Portugal is referred to in section 3.2.

A deeper historical account referring a Civil Code country respects Denmark Stubkjaer (2008). In this document, a comprehensive account of the evolution of the institution of property rights in Denmark is described, covering a period from initial formalization of rights (during middle ages) to modern times.

The main concepts contained in the Property Law institution, and their relationships, can be examined in the form of an *Institutional Ontology*, like the UML modelling results presented in subsection 4.5 or results from law research (Meidinger, 2008). These last results are briefly summarized next, once they reflect a different approach, not related to systems modelling under the object-oriented paradigm, the main approach followed in this thesis.

According to Meidinger (Meidinger, 2008, p. 207), property law refers to relations among people with respect to a thing[25]. The first term to be examined is the "Thing", or *Objects of Property.* These can have two basic distinctions, land and other things, which receive different names under Common Law countries (real property and personal property) and Civil Code countries (immovables and moveables). Although this distinction seams simple, a number of specific cases are presented for Common Law, showing that real property can include certain types of moveables[26], and vice-versa. Many of the objects of property existing in developed societies, like intellectual property or financial assets, do not have any kind of physical existence, so they will fall in the category of representations.

The second term to be examined under Meidinger ontology is that of *Relations of Property.* This category has been divided into four sub-categories, briefly described next. It is a textual description; not formalized through e.g. UML or OWL

- *Powers*: Property rights include powers to take a number of different actions in relation to objects of property, like use it, exclude others from it, transfer it or divide it;

- *Duties*: Property owners are under duties such as to let others access the property under certain circumstances, to restrain vermin, to pay taxes and so forth. There are also rights of other persons in the owner's property, like the use of easements. Property rights over a object of property can thus involve multiple people, connecting them in different ways;

[25] Citing by its turn a definition from the American Law Institute
[26] Such as door keys, uncollected loose minerals or building "fixtures"

- *People*: The holders and subjects of property rights can range from those who directly use, control or transfer property to a broader set benefiting or being precluded from property (including society at large);

- *Time*: The role of time in property rights and problems of change and choice regarding division (fragmentation) or bundling of Property rights through successive mutations, are examined in the background of a specific case *Tulk v. Moxhay* (1848), which ultimately created the figure of equitable servitude.

From this very brief account on the institutional ontology regarding property law (Meidinger, 2008, p. 207-212), and comparing with the classification given in subsection 2.2.2 and also the core of the Land Administration Domain Model (see 2.6.2), it can be concluded that, in spite of the different approaches and scientific backgrounds, there are indeed quite a number of shared concepts and also some differences. These are summarized in the table 2.3.

Eidinger ontology	**Core LADM**
Definition: Property as the control (1) over a thing (2) by a person (3); Property involves rights to things Not defined Things are more general (moveables + immovables)	Shared: (LADM core classes) (1) LA_RRR (2) LA_SpatialUnit (3) LA_Party Difference: LA_BAUnit Difference: LA_SpatialUnit covers immovables
Powers	LA_Right
Duties	LA_Restriction and LA_Responsibility
People	LA_Party; the party type being a natural person
Time: a) time as dimension b) role in property rights	Shared: VersionedObject Difference: (dynamics of LA_RRR and LA_SpatialUnit) not modelled

Table 2.3: Similarities and differences between property law concepts

2.4 Administrative aspects

In this section, one will depart from the traditional context of Cadastre and Land Registration, to encompass the broader field of Land Administration, namely by considering parcels defined through Public Domain or Regulations. If we consider the three key attributes of Land Administration (tenure, value and land use) (Dale and McLaughlin, 1999, p. 8), then the focus will shift from tenure or Land Ownership to Land Use. Also according to (Dale and McLaughlin, 1999, p. 9):

> Rarely have the institutional arrangements been put in place to integrate the ways in which land is managed. Rather, the management of land and property as a national resource has tended to be fragmented.

To achieve an integrated management of land through implementation of LADM, previously described cadastral and legal domain components must be extended in order to capture concepts introduced by public laws and regulations at the different levels of government existing in a modern state.

This section begins to describe the main forms of Public domain land parcels, mainly supported on a study of Portuguese legislation. Taking into account that many of such laws and also regulations affecting land use, namely for the purpose of environmental protection, were translated from E.U. Directives, it is assumed that this grossly reflects the situation in Continental Europe.

Following sub-section stresses the importance of defining a generic Land policy document, describing a framework of planning and land use regulations which articulates between different levels of government. This should define the main tools of Land Administration, which are available state-wide to enforce land related strategies and policies.

Next sub-section deals with the main tools land administration authorities have in order to promote extensive land use changes. As this field of study has a rather broader scope, this thesis has focused just on the Urban Re-allotment process conducted by the local authorities.

The final sub-section on the Administrative Aspects acknowledges that world-wide tendencies recognized, for instances, in the Millennium Development Goals, are producing increasing social demands for better living conditions, in turn affecting existing land policy laws and regulations. In such a way, it will be examined how the previously described conceptual framework and state-of-the-art development methodologies can respond to an environment of ever-changing societal requirements.

2.4.1 Laws regulating the Public Domain

One of the main characteristics of things under the Public domain is that they are not susceptible of juridical business and consequently can not be acquired by an individual nor be converted into private property. This is stated in the Portuguese Civil Code, Art. 202 (Portuguese Law, 1998, p. 60-61). This applies to movables as well, although all the references hereafter refer to immovable property. That is not to say that any parcel of land (or water) which falls under the Public Domain remains forever in that regime. If a number of pre-requisites are met (as defined in the law (Portuguese Law, 2007)), property in the Public Domain can be declared to no longer satisfy its public utility, and then be alienated from the Public Domain and integrated into the ordinary private property regime. This is usually a lengthy administrative process, requiring the approval of ministries and central or local government assemblies (depending on the type of Public Domain).

Usually, the State has the responsibility to manage all land parcels under the Public Domain. Such management is defined (in most of the cases) by law, and can be delegated to central government agencies, to regional agencies or to the local government (municipalities or metropolitan areas). Government organizations can hand over administration of such areas to private persons, in the form of long leases or concession.

A number of different types of Public Domain exist; a few examples based on current Portuguese legislation are presented next.

- **Public Water Domain**: It is regulated through decree-law 468/71 (Portuguese Law, 1971). Includes maritime and inland waters, covering riverbed or seabed, the water covered surface and margins. Margins include a buffer 10 m wide for non navigable streams and 50 m wide for sea waters or navigable streams. In rivers and streams, margins are defined according a situation of mean flood waters, usually at the top of the natural slope at the river bank. Private property is only permitted within these areas if it has been registered prior to 1892 (for historical reasons; Civil Code, Art. 1386 (Portuguese Law, 1998, p. 339)). In those cases, administrative servitudes are imposed.

- **Public Municipal Domain**: It is (partly) regulated in the decree-law 555/99, the Juridical Regime for Building and Urbanization (Delgado and Ribeiro, 2004, p. 165). Includes a number of specific land uses which are administered by the municipality, namely green areas, collective use areas and equipment and the road infrastructure. Parameters defining dimension of parcels under municipal domain are contained in the Municipal Master Plan, which in turn should obey to National and Regional level directives. In an Urban Re-allotment operation, the administration of such areas can be granted to groups of neighbouring residents (units owners) through a long lease.

2.4.2 Enforcing Land Policies: Tools of Land Administration

In Portugal, regional level development plans (called "PDR"[27]) have been in force mainly since adhesion to the European Community, being partly funded through the E.U. budget. Such plans supply general guidelines which orient the production of OID - Integrated Development Operations. The majority of funds have been directed to infrastructure development, most notably the national roads and highways, but also to the implementation of drinking water and sewage networks (Marin et al., 2006, p. 218-232). Public and collective use facilities such as sports and recreation centres were also funded through such plans, although the general guidelines they defined had to be implemented by local level authorities, through elaboration of detailed urban plans. The "PDR" have a much broader scope which does not fit within the realm of Land Administration, such as promoting employment or vocational training; those actions will not be further referred here. A concrete application example, addressing the Land policy issue of unbalanced development between the inner countryside and the littoral, were the actions with impact in the rural world, like the Historical Villages Program

[27]PDR: "Plano de Desenvolvimento Regional" or Regional Development Plan, supplies land policy and management guidelines for the highest level of planning areas (five in the Continent plus Azores and Madeira archipelagos

(in force during the 1994-1999 and 2000-2006 terms), and the Rural Centres Program, seeking to revitalize rural settlements. A total of 45 settlements were supported during the referred terms. In the beginning, such actions addressed mostly material goals, like accessibilities or urban re-qualification. Later on, they integrated immaterial goals as well, like promoting cultural heritage and rural tourism (Marin et al., 2006, p. 221).

Another example deserving a special mention during this period, is the large Multiple Purposes Enterprise of Alqueva (EFMA). This plan, now partly implemented, predicted the creation of a large irrigated surface in dry out (and economically depressed) Alentejo province, through the building of Alqueva Dam and a network of irrigation channels, among other infra-structures. An especially relevant topic in this plan is the provision to create a support GIS having as basis digital cartography and cadastre, now in place (Carreira et al., 2006, p. 689-706).

At the local level of government, the most paradigmatic example is that of the Municipal Master Plan (MMP). In Portugal, the first two generations of MMP suffered from lack of support and technical planning guidelines from higher levels of administration. The implementation of such plans also suffered many management issues. Those problems were greatly solved with a new, post-adhesion, legislation (decree-law 69/90). This legislation defined three types of Municipal Plans:

- **Municipal Master Plan**: covers the whole area of Municipalities, defining general level zoning and regulations;

- **Urbanization Plans**: cover just certain urban areas or areas subject to urbanization, as defined in the MMP. Include the layout of specific urban zones and generic building and infrastructure regulations;

- **Detailed Plans**: cover small areas of Municipal Lands (namely on Public Municipal Domain), usually on urban areas. Include detailed regulations and specifications for the buildings and facilities in the plan.

This 3rd generation of MMP received technical support from Regional Coordination Commissions (CCR's), and this factor, together with certain penalties for not having an approved MMP, led to the near-completion of such plans by all Portuguese municipalities. Currently, a new legislation (decree-law 380/99) replaced the old one, and a 4th generation of MMP is being produced. There are some interesting new features, like definitions for rural and urban soil (with some categories within each) and the demand to characterize rural property structure in MMP and Detailed Plans. The Detailed Plans now request also definition of a "per-equação compensatória", a formula to designate compensation under Land Consolidation operations (Marin et al., 2006, p. 319-327).

Above mentioned regional level PDR's and local level MMP's are land administration tools of a generic nature, including a number of diverse Land Policy goals in an integrated and coherent framework. Several thematic or sectoral policies contribute to such plans, as the ones referred in the following examples:

- **National Agricultural Reserve**: The Portuguese acronym is RAN. It is regulated by decree-law 196/89. It aims at defending and protecting areas with good aptitude to agriculture, guaranteeing its due use such that a valid contribution will be given to full development of Portuguese agriculture and to an effective land management. Is defined at regional level by services of the Ministry of Agriculture and should be adapted locally to each municipality's MMP. It confers owners of parcels under RAN certain real rights, e.g. pre-emption rights to acquire neighbouring parcels also under RAN, and gives such owners special financial incentives. Also, cultivation unit doubles under RAN, with implications to eventual parcelling out on these areas (Delgado and Ribeiro, 2004, p. 781);

- **National Ecological Reserve**: The Portuguese acronym is REN. It is regulated by decree-law 93/90. It is aimed to ecosystems protection and to the preservation and development of biological processes fundamental to achieve equilibrium with human activities. The following land cover and geomorphology types shall be considered for inclusion on REN zones (this list is not exhaustive): Beaches, coastal dune systems, sea cliffs, estuaries, lagoons and marshes, maximum rainwater infiltration areas on a catchment basin, areas subject to river floods or escarpments and areas with high risk of erosion (Delgado and Ribeiro, 2004, p. 811).

These rights are already in place, but no significant results are reported. The SNIT portal has RAN and REN geometries in digital format, but there is no plan to integrate into SINERGIC.

2.4.3 Land Administration Processes

Land use planning and administratively imposed zoning regulations like the ones referred in 2.4.2 are a (required) first step in order to implement Land Policy measures. To actually produce Land Use changes which comply with existing plans and regulations, the government has a number of legally defined administrative procedures. They vary in numerous ways, from spatial extent to the organizations involved. This research elected just one type of such procedures for a detailed analysis, to offer an example on how to design and implement Land Administration Dynamics in the context of a LADM implementation.

The chosen administrative procedure was the Urban Re-allotment, whose overall responsibility lies with local government (the Municipalities in Portugal). This is a fairly complex procedure, involving core organizations in the field of Land Administration, and a number of different actors. The initiative to launch an Urban Re-allotment procedure can belong to the Municipality itself, but can also be a private initiative (from an individual owner or a private company). The main legislation governing the Urban Re-allotment procedure is decree-law 555/99, as referred in (Delgado and Ribeiro, 2004, p. 165). Following items describe the main steps and information flows under such procedure, and the actors (or organizations) involved.

- **Municipal License Request**: The first step includes an analysis of the requisition documents presented by the initiator, which is done against local level MMP zoning regulations. If required by the spatial extent of the operation (e.g. , affecting special zones like reserves) also central government agencies have to be consulted. After preliminary acceptance, the operation must be made public. Eventually, the Urban Re-allotment operation receives approval from internal and external entities, and a license is emitted. However, if the Urban Lot affects the local settlement in a significant way, there will be a period of Public Discussion, after which the request has to pass in the Municipal Assembly.

- **Urbanization Lot Registration**: After the first phase of "Land Policy Approval", the land division of the original parcel or group of parcels into lots has to be registered at the land register. The municipal license is the main prerequisite for registration. A number of different registry procedures may apply, depending on the type of urbanization involved. In the most complex scenario, each Lot will receive a separate Condominium, and related registries have to be prepared for each apartment unit. In this second phase, such Lots are first acquired by Building Firms, constituting a provisional register, and only then are sold to individual apartment unit owners.

- **Urbanization Lot Valuation**: After having received a municipal license and being registered into the Land Registry, the Building Lots have to enter the Tax Records and receive a valuation inspection which will set the tax rate they incur. A first valuation is done upon the building Project elements and is related to the provisional (legal) registries. A number of final tax inspections is conducted as soon as individual apartment units are sold.

- **Urbanization Lot Cadastral Survey**: Although being the last item in this list, the geometric component of the Cadastre should be updated as soon as possible, before provisional registration is concluded. This task should use final Urban Re-allotment Project documents (which already passed land policy approval), and optimally should have been revised by a cadastral expert or a chartered surveyor. At the end of the procedure, an "as built" survey should also be conducted, in order to update final figures related to building and units areas and common parts detached from the building, among other required cadastral objects.

This brief account of the re-allotment procedure, does not reflect entirely current practice in Portugal, since there are no legally defined statutes for chartered surveyors, and (in Urban areas) there is no legally recognized geometric component of the Cadastre. The procedure outlined above is thus a proposal drawn upon existing law, which will be further detailed in section 4.6 and related Annex E.

2.5 Responding to changing requirements

As reported in the subsection 2.1.1 on the description of the Unified Process development life cycle phases, the majority of requirements should be found, discussed and prioritized during the Inception and Elaboration phases.

Both UML and UP literature make this basic classification of requirements into (Arlow and Neustadt, 2005, p.52):

- Functional: statements about what the system will do;
- Non-functional: statements about constraints imposed on the system, like its performance, reliability or security aspects. That is, which are not specific for the application domain.

Further is is said that, during Inception, the focus of requirements analysis should be identifying critical Use Cases (defining functional requirements) and non-functional requirements. It has been also recognized that the specification of UML Use Case diagrams is only useful in capturing the functional requirements of a system. The specification of the main functions of a system shall begin with a context diagram which identifies the system boundary (or domain) and also identifies the major external Actors that interact with the system (see figure in 4.1). This broad, top-level view is then detailed into more specific Use Cases, up to the level where they can be further specified through a linkage to UML Activity diagrams or other UML diagrams describing system's behaviour, like Sequence diagrams.

According to UML terminology, both Use Case and Activity diagrams are considered to depict the *behaviour* of a system, which agrees to its use in the specification of functional requirements. However, and also according to a more classic system analysis view (Shelly et al., 2008, p.101) one should consider the main data types to be used, created or otherwise transformed (processed) by the system, in order to fulfil its basic functionality. This would correspond to identifying the *data requirements* of the system.

2.5.1 Handling requirements through the Unified Process

In the UP, this is done mainly during the Elaboration phase, upon consideration of a Domain Model (as identified during Inception), which then is further specified into successively more detailed Design Models. Those models use UML Class, Objects and ultimately, Component diagrams, which together specify the *structure* of the system. The UP, being based on the object-oriented software development paradigm, departs from the classic system analysis once it considers a much tighter integration of functional and data requirements through Classes. This can be specified, at a detailed level during Elaboration, through Interaction or State Machine diagrams.

Besides the classification into functional, non-functional and data requirements, other classifications can be useful, namely the specification of *user requirements* and *system requirements*. This users requirements can distinguish groups of users, namely *external* and *internal* users of the system. The system requirements usually overlap with the identification of non-functional system requirements, although they can cover more specific aspects of the hardware and software platform chosen for implementing the system.

In the UP, the specification of user requirements is done concurrently with the analysis of functional requirements, beginning with the identification of the main external users (through the above referred context diagram) and moving then to specific internal users, when the Use Cases are sufficiently detailed.

The depth and complexity of requirements analysis is dependent on the complexity of the system being modelled and also on the number of different internal and external users (also referred as "Stake Holders"). They could define a large and often conflicting number of requirements, demanding then elicitation and prioritizing tasks to be performed.

Large system analysis and design projects, like the one documented here, demand Requirements Engineering[28] and dedicated staff, the Requirements Analyst.

The failure to identify critical requirements from an initial phase (in UP, Inception) of the system analysis process is the *most common cause* for project failure. This could be defined as the system not being able to deliver even the basic tasks it was designed for (Arlow and Neustadt, 2005; Outsource2India, 2008).

In spite of above consideration, the depth and extent of the requirement analysis task is one of the major points of disagreement between the classic structured systems analysis methodology (also known as the Waterfall method) and more recent methodologies as the UP, XP ("Extreme Programming") or Agile Software Development ((Larman, 2005, sections 2.1 and 2.6)).

The classical view is that most of the system requirements should be gathered in the beginning of the process, and they should be detailed to the point of enabling the analysis and design of the whole system, from the earlier stages.

The critique to this approach of system design is that it could lead to a rather lengthy and slow development process. Furthermore, case studies (Larman, 2005, section 5.2) have shown that a significant number of early identified detailed requirements were never implemented in the system, some corresponding only to marginal Use Case scenarios which were not considered so useful after all. To complicate matters even further, as the classic methodology tends to deliver the actual, implemented system at the last stages of the process, only during the final system tests the users have an interaction with the implemented system applications. But a frequent result of such interaction is the definition of a number of new requirements, now made perceivable through handling of data and functions within the new software application context. Due to the way the classic Waterfall method was designed, this could mean serious trouble regarding previously stated project goals.

The UP makes the assumption that requirements *do change*, specially from a user point-of-view, during the software development life cycle. This being the main reason to focus just on those requirements considered critical for the system, in the early phase of Inception. This consideration is complemented with the definition of *Iterations*, through which critical core components of the system are implemented and

[28] Definition of a method for the systematic handling of requirements, (Outsource2India, 2008)

tested early in the UP Elaboration phase, so that new requirements can be identified early in the system development, and previously identified requirements can be further detailed.

2.5.2 Generic LADM requirements

This section continues with the specification of a set of requirements which can be considered as critical to the implementation of the Land Administration Domain Model in a particular country. These are a generic and conceptual level set of requirements that relate to the high level conceptual classes considered in LADM.

The more specific and concrete set of requirements considered for the implementation of LADM_PT specialized country model are described in subsection 4.2.1.

Previous consideration of changing requirements concerned those changes that are inherent to the process of developing the software itself. But there are changes in requirements which are imposed externally to the system being designed, or even when the system has already been delivered and has reached an operational status. This last type of change is what is referred to in classic structured system analysis as an “adaptive maintenance” operation, when the system is enhanced with new functionality and / or data handling capabilities, for example (Shelly et al., 2008, p. 511).

A short example drawn from the case study of Land Administration in Portugal, concerning the Portuguese cadastre (see subsection 3.3.1) shows how to proceed regarding the proposed methodology.

Assuming an implementation has already been put to practice concerning the requirements identified for the “Cadastro Predial”, back in 1995, then a *cadastral parcel* could belong to one of two types: a regular cadastral parcel or one considered as *deferred cadastre*. The last one consisted in those cases where one or more boundaries could not be precisely surveyed, the owner or representative is not known or there is a litigation about boundaries. This simpler classification, however, considered acquisition of data relating to the legal and fiscal registers a secondary goal, which could be handled later, after main field data acquisition. This proved to be a serious obstacle on the use of cadastral data as a basis for Land Registry and Land Tax services. The new legislation passed in 2007, concerning SINERGIC project, defined new requirements to overcome the mentioned problems. These were later taken into consideration in the design of the new data model for the cadastre IGP (2009). Specifically concerning the cadastral parcel, a new type should be defined, the *Transitory Cadastre*[29], covering those cases where data collection (which has been also revised) could not identify to which legal and fiscal records the parcel belongs. The previous regular type is now considered to be the *Harmonised cadastre* type, and concerns those parcels having all the data linkages (and thus being able to identify the legal owner), besides being precisely surveyed according specifications. The new data model implemented the previously mentioned types (Harmonised, Deferred and Transitory), keeping the same number of object classes but incrementing the literals

[29] Usually includes a collection of Parcels which could not be distinguished during survey.

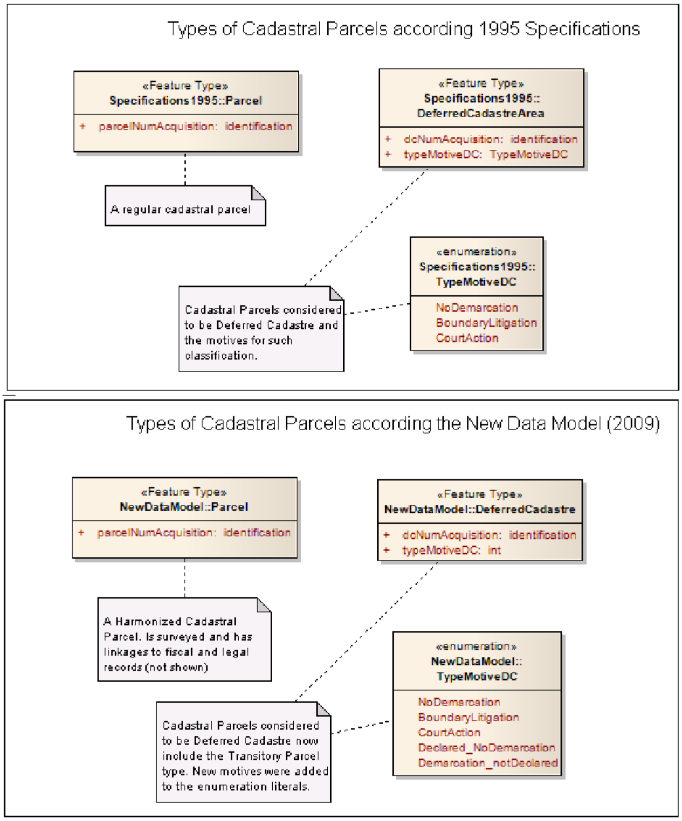


Figure 2.3: *Requirements change example; based on the Portuguese Cadastral Data Model.*

in the Deferred cadastre enumeration class or code list (which is extensible by definition), so that it encompasses parcels which classify into Transitory Cadastre. To clarify the described changes, the figure 2.3 shows the hypothetical class diagram for the 1995 situation, and a translated extract of the new data model, containing the involved classes. It must be clarified at this point that if a code list would be adopted instead, the change would be a simple update procedure, not requiring a new data model version.

So, how the described methodology can perform such an adaptive maintenance upon changing requirements, at a later stage of the software development life cycle?

Taking into account that the implementation is achieved through MDA technology and that the concerned class of objects is persistent, that is, should be defined and handled in a data base, one could start the maintenance procedure by redefining the deferred cadastre enumeration "TypeMotiveDC" in the data base. On modern Object-Relational data bases such as PostgreSQL, this is accomplished by inserting additional values in an *enum* type that is being used in a column of the deferred cadastre spatial table. This is an obvious choice when the system is already in operation. Further, a conversion method could be defined, so that the deferred cadastre records in the data base can be updated with the new enumeration types.

Now, it is probable that a number of object-oriented applications have been implemented on top of the object-oriented abstraction layer, corresponding with the data base records (through mappings). In order those applications will not fail (after the schema changes), the maintenance team should verify the reverse engineering templates and then apply a reverse engineering transformation. This has the effect of synchronizing schema changes in the data base with both the object-oriented layer and the UML class model representing the country PSM (Platform Specific Model).

Conversely, changes in the application layer which affect the persistent classes should be reflected in the data base schema, through definition of the object-relational mapping templates. The purpose of MDA and persistence technologies is then to keep the Model object-oriented and data base schema representations always synchronized. In this way, the UML specified model is not any longer used solely in the analysis and design of a new system and as a guideline for implementation. It should reflect changes motivated by new requirements at all times during the operational life of the system. The MDA presents then a better support for handling requirements changes than previous development approaches, given that all the system components, from the Model to the Data Base to the application layer, are changed in an integrated way (as enforced by the method itself), and not any more in an independent way, which could led to inconsistencies.

2.6 LADM modelling issues

In this section, a number of issues raised by the process of developing a Domain Model as LADM are presented, along with some of the solutions which have been applied (in 2.6.1). Then, the core classes of LADM are defined, with an emphasis on the definition of the Spatial Unit package, and the specializations from Rights, Restrictions and Responsibilities superclass (in 2.6.2).

2.6.1 Issues with domain modelling

In the development of a Domain Model intended to be globally applicable (considering its adoption as an International Standard), in this case for the field of Land Administration, a high degree of abstraction is needed to keep out the vast number of differences when considering the specifics of existing systems at the country level. The aim of this abstraction procedure is to reach an internationally agreed set of standard terms (expressing concepts), contributing to future cooperation and interoperability between country systems. Accepting thus that a high degree of abstraction is a required condition to achieve such an international vocabulary for Land Administration, poses a number of issues which should be taken care of during the development of the International Standard.

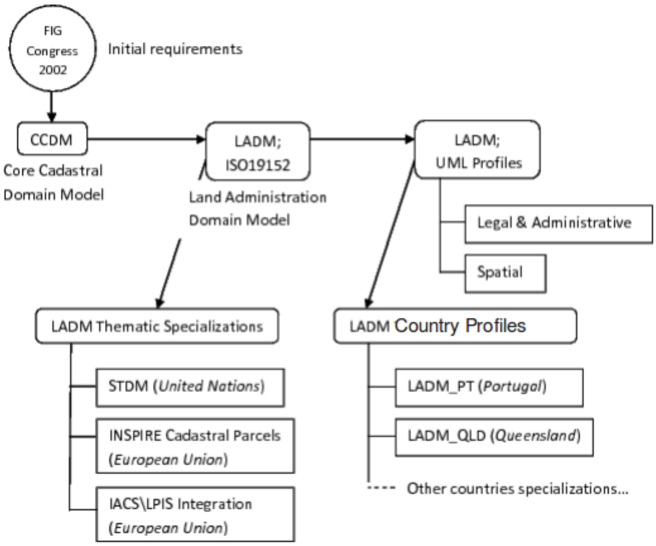


Figure 2.4: *LADM development path; situation as from the end of 2009.*

A fundamental issue is the definition of a set of standard terms to name the entities and other elements that will be present in the model. Even considering that the model itself is expressed using a standard formally defined language as UML, the actual meaning of each entity is supported by natural languages (English is being used for the ISO working drafts). The structure of the description itself uses formal standards such as ISO 19115 Metadata or a Feature Catalogue (named *Feature Concept Dictionary* in INSPIRE, (INSPIRE, 2009)).

The standardization process is a proper stage where to get a commonly agreed set of terms. The simple use of existing terms within the domain, even for a natural language as worldwide spread as English, can be misleading, given the fact that it does not necessarily translates to the level of abstraction required for LADM (Paasch, 2008).

The LADM addresses this issue through the definition of a set of natural language meaningful terms, borne from a consensus between experts from different countries participating in the standardization process (see figure 2.4).

A related issue will be largely dependent on the degree of adoption of the standard, and relates to the adhesion and understanding of the model concepts and terms by the professional community working on the Land Administration domain. If considering a wider audience, all major user and stakeholders involved in a development process based on LADM should be addressed by a proper education and training effort, including the understanding of a set of standards for the geographic information series, ISO 19xxx.

The domain model can play thus a major role in academia and other teaching and training environments, for pedagogical goals. This thesis gives a small contribution toward this goal, through a structured procedure which goes from LADM abstract concepts to concrete implementations having locally understood meaning.

Besides the needs for common terms and corresponding pedagogical efforts, the high degree of abstraction contained in LADM is also (potentially) detrimental to a precise definition of scope, or the boundaries of the domain. On one hand, there is a purpose to support a multitude of systems with different specific scopes which exist globally. On the other hand, LADM addresses this issue by considering a number of formally defined *UML Profiles* which constrain, in a way, the degrees of freedom existing in the basic domain model.

Furthermore, and due to its abstract nature, it can be hard to realize, even for a Land Administration expert acquainted with UML, how to implement a set of relevant LADM classes, e.g. concerning the spatial component. This question is addressed in the reported methodology, through consideration of a number of UML specialization mechanisms in the context of the MDA approach. Specific UML Profiles and MDA *Model transformations* performed in order to derive the specialized country model .

Concerning the analysis and reporting of requirements, and having in mind the concepts introduced in subsections 2.1.1 and 2.5, it should be noted that, by its nature, a domain model does not need a detailed level of requirements. The set of requirements considered for the specialized country model (LADM_PT) do consider concrete and detailed requirements . A main, context use case was taken as the departure point on reporting functional requirements for the country model. In LADM, requirements are implicit through the class diagram, thus translating into the high level of abstraction existing in the domain model. They can be classified into a set of general functional requirements, needed to define the domain of Land Administration from a static point of view. These implicit, general level functional requirements reflect the experts knowledge about the main functions of Land Administration, with a focus on the object classes which should be made persistent in a data-centric and static systems modelling view. The research did not address non-functional requirements such as those related with implemented system performance or availability and accessibility concerns. The purpose of such a static nature of the domain model is to capture the most fundamental data elements in the domain. Those can be regarded (taking the system as whole) as the elements with a more permanent status and are typically less subject to changing requirements, different administrative procedures and non-functional requirements to consider in, e.g. specific implementations.

Considering the Unified Process and as shown on this chapter, it will be possible to use specific domain classes to design procedures adapted to different local organizational and deployment contexts.

Due to its highly variable procedural arrangements, and as shown in other studies (Stubkjaer et al., 2007, p.18-20), it is correspondingly more difficult to abstract the dynamics (or behavioural, in UML) components in Land Administration, in a way as to include it in LADM such as to be useful worldwide.

An example from different uses and implementations of a LADM component can clarify the issues presented in the above paragraphs.

Consider two countries (A and B) implementing the spatial component of LADM.

The first LADM class to be addressed shall be the domain class representing a Spatial Unit. The object to be represented is the basic property unit geometry, but country A decides to use a Location by Text Spatial Profile[30], while country B will use the Full Partition Spatial Profile[31]. This first step toward implementation is supported by LADM modelling elements, and others referred to in chapter 4. Further, country A decides to process single units of property through a web application which builds a graphic representation from text. In Country B, on its turn, the newly created or updated objects are stored through a central spatial database. Country wide graphic data can be accessed by means of a WMS[32] server. The last steps are implementation and country specific and are outside the scope of LADM (being a domain model) but should be considered for the specialized country models.

The example shows that domain classes having a high degree of abstraction offer good flexibility in the modelling and implementation process, supporting very different solutions. But, in spite of the apparent differences a final user can confirm by comparing each implementation, both systems use the same core domain class structure to persist their data.

2.6.2 LADM core classes

Having discussed fundamental issues with domain modelling in general, and LADM in particular, this subsection describes the main classes in LADM, starting with its core. The design process leading to the specialised country model LADM_PT, by consideration of the existent official country model (included in IGP (2009)), assuring its compatibility and compliance with LADM, will be reported in subsection 4.3.1.

The core of LADM shows the fundamental relationship between persons and land via rights (see figure 2.5). This fundamental relationship has been acknowledge in previous works ((Henssen, 1995, p.6) and Zevenbergen (2002)) and at a high conceptual level, holds true for most (if not all) forms of human societies. In LADM, the person part of the relationship is called *LA_Party*, this being a more abstract term which can represent a natural (single individual) and non-natural (companies, associations and other collective entities) persons. It can also represent, through a specialized class, a group membership in an ownership relation, with the possibility to express shares in the group ownership. This allows the modelling of family, couples or even larger groups (as a local community) ownership in land[33]. In formal legal systems (like, e.g. in Continental Europe) the Party class is referred to as the subject of a Real Right, the land being the object of the Right. As shown through the definition of the Social Tenure Domain Model (Lemmen et al., 2007, p.9-10) as a specialisation of LADM,

[30] An historical example can be provided by the United States “Metes and Bound” text descriptions, from where modern GIS applications can derive spatial objects, for example, the Land Mapping and Deed Plotting software by (Sandy Knoll Software, LLC, 2009).

[31] Refer to subsections 2.6.2 and 4.3 for a complete explanation of classes and spatial profiles within LADM.

[32] WMS: Web Map Service.

[33] In fact, LADM supports a variety of so called Spatial Units, as defined in 2.6.2, and not just the classical definition of a land parcel.

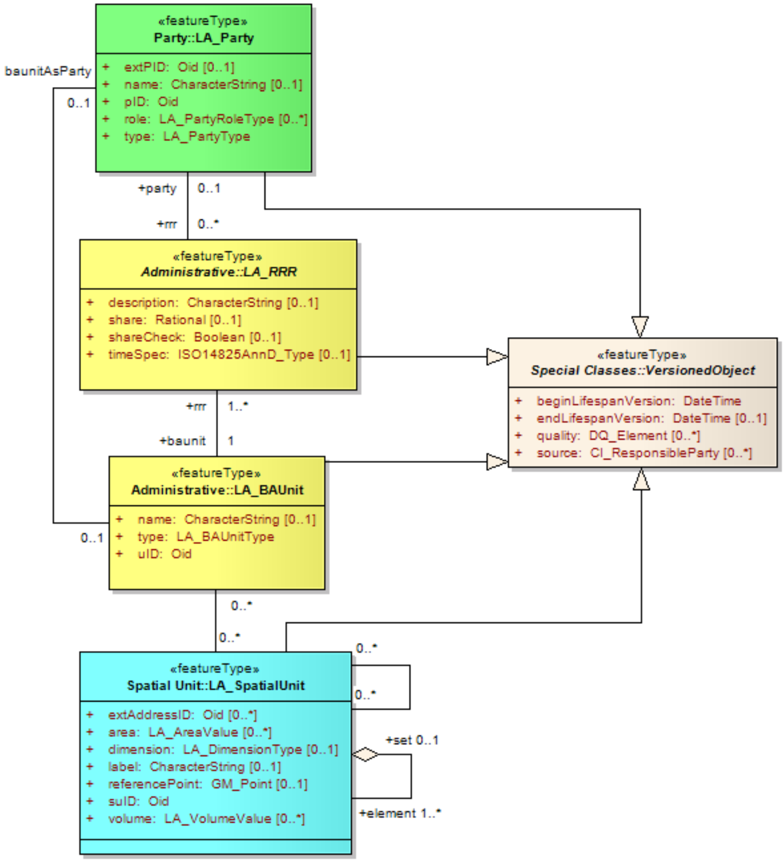


Figure 2.5: The LADM core, inheriting characteristics from the VersionedObject

the relationship via rights do not require that a formal legal system be in place. Also informal or customary forms of land tenure can be also represented.

Core representation of Rights, Restrictions and Responsibilities

The class representing the relationship between persons and land has its name abbreviated to *LA_RRR*, meaning *LA_Right*, *LA_Restriction* and *LA_Responsibility*. Each one has its specialised class, from where specific RRR can be defined, forming thus a hierarchy of rights, some of them being purely abstract (in UML: an abstract class). The following short definitions start from the point of view of a Party holding RRR, either formally or informally, over a piece of land.

- Right: grants powers to a Party, entitling it to do something related to the parcel (or parcels) of land covered by such right. It can cover the use, enjoyment the fruits (products) of the land, transfer the rights to another Party or a financial or security right. These powers are conferred in potential form, most notably could even include latent rights.

- Restriction: refrains a Party holding a right to exert the granted powers in full. Restrictions can be imposed by public authorities (representing the whole of society in a given jurisdiction) or through local neighbourhood relations. Restrictions also have a latent nature, which is triggered when an infringement occurs.

- Responsibility: usually results directly from the grant of a right, but this time demanding that the right holder actively do something in relation to the land it owns. The action can be done regularly based on an agreed time period, or can be triggered by e.g. a natural event.

The set of RRR related to a given Spatial unit or a number of Spatial Units where they apply, are stored in a Basic Administrative Unit (*LA_BAUnit*). This implies that some form of recording system be in place (not necessarily a Land Registry), in order to store the details regarding the basic administrative unit. This includes both land, volumes and water parcels (via any geometrical defined Spatial Unit) which can be the object of RRR held by a given Party. In a jurisdiction, several registers can co-exist; there could be a register of privately held land (and water), and a public register of country wide zoning regulations. In western countries, a multitude of registers do exist which cover specific RRR to BAUnit relationships, typically:

- Land Register: covers all privately owned land (possibly water)

- Spatial/Planning Government Portal: covers national to local level public regulations

- Exploration Rights: covers mining and spring water exploration rights

- Water Titles: covers rights to extract groundwater and use surface waters

- Cultural Heritage: covers protected monuments and archaeological sites

Spatial unit package

The BAUnit class has an association to a *LA_SpatialUnit* class (alias is LA_Parcel) which is the main spatial feature in LADM and the basis for the spatial representation of the BAUnit (see figure 2.6). Considered alone, the BAUnit does not hold any kind of spatial data type. It serves the purpose of defining the bundle of RRR specialisations that apply to a given SpatialUnit or a group of spatial units. In this way, it serves different definitions of a basic administrative unit. In some countries, each continuous parcel under unique ownership by a Party or even a GroupParty, and where a homogeneous property right cover the whole spatial unit (parcel), shall be recorded as a unique recorded object. In other countries, if the same Party or GroupParty holds an homogeneous property right over non-contiguous parcels or a

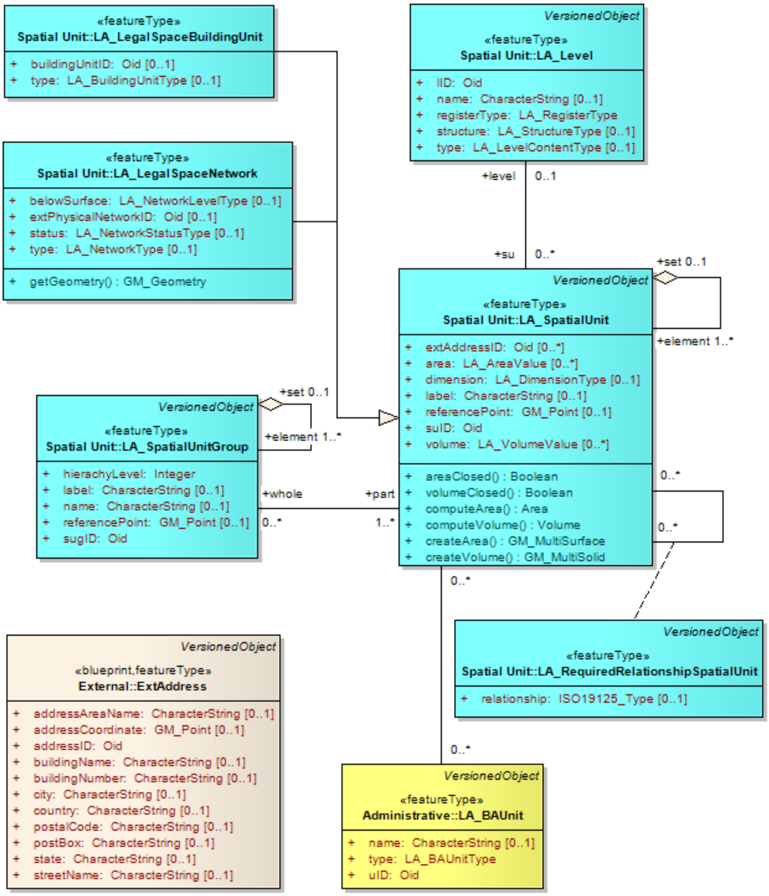


Figure 2.6: *The LADM Spatial Unit component and its specialisations*

single parcel, the aggregation of parcels still forms a single recorded object. This last form of recording is specially useful when considering farms which need a range of products and diverse natural conditions in order to work effectively. This situation has been described as a degree of beneficial fragmentation in (van Dijk, 2003, p.18).

A LA_SpatialUnit class can have (optionally) an association with a LA_SpatialUnitGroup, which represents a number of spatial units constituting an hierarchical relationship with any number of user defined levels, through recursion. This class serves the main purpose of providing the means to represent an hierarchy of administrative units into which the Land Administration data is organized within each country.

There are also two specialised classes from LA_SpatialUnit which were considered of such widespread use globally as to be inserted in the model. These are the *LA_LegalSpaceBuildingUnit*, representing the legal space of a whole building, which by its turn can be composed of several units (through recursion), typically representing apartments, offices, or shops having homogeneous property rights attached (e.g. in a Condominium). A second specialised class is called *LA_LegalSpaceNetwork* and represents the legal space of an utility network (e.g. distribution of water, gas, electricity; telecommunications, etc.), which in some countries has to be registered.

All these specialisations have in common the fact that they are well represented spatially especially if they are defined in 3D, which is one of the options available, given they typically depart from the ground surface, upwards or downwards (or both, e.g. a building with a basement).

Now, the SpatialUnit class has only one spatial type attribute (not mandatory), using the standard GM_Point (ISO/TC211 Geographic Information / Geomatics, 2003a, p.38). This meaning that by itself, it can only represent spatial units as points, which can be useful in certain implementations but it is rather limited.

To address the issue of spatial representation more effectively, LADM spatial component introduces two other spatial features, *LA_BoundaryFaceString* and *LA_BoundaryFace* (see figures 2.7 and 2.8). These have an association to at least one LA_SpatialUnit class. As seen above, the LA_SpatialUnit class can be exempt of considering the LA_BoundaryFaceString and LA_BoundaryFace classes, when it is represented by a point.

Again, the definition of such classes is the result of a high level of abstraction. The main assumption is that property rights exerted on a parcel (as alias for the LA_SpatialUnit), through the association with a basic administrative unit, are unbounded upwards and have as limit the center of the Earth downwards, which is indeed a definition of the legal space of a parcel in certain jurisdictions. In this way, the LA_BoundaryFaceString class should be interpreted as a collection of (semi-)unbounded vertical faces formed on the boundary of the parcel. The standard spatial type to be used is a simplification of this concept, assuming a bi-dimensional projection of the vertical faces into an horizontal plane of reference (typically, mean sea level). So, the LA_BoundaryFaceString objects use the generic GM_Curve (ISO/TC211 Geographic Information / Geomatics, 2003a, p.43) definition. This fact limits implementation using this class to a 2D coordinate space, in what is often called "linework" spatial data. If the implementation for a particular country requires a 3D coordinate space and 3D spatial objects, then the LA_BoundaryFace class has to be used instead.

The LA_BoundaryFaceString objects conceptually define a string of adjacent faces which are unbounded vertically, with positive (up) and negative (down) sides defined by the position of the GM_Curve itself.

The definition of the LA_BoundaryFaceString class only implements boundary objects, and not areal objects like polygons (although it could define closed boundaries). Values for the area and perimeter of a given spatial unit represented by a number of LA_BoundaryFaceString objects which form a closed boundary, can be derived through methods implemented on the LA_SpatialUnit class.

A given LA_SpatialUnit can have any number of LA_BoundaryFaceString and LA_BoundaryFace objects (for depicting arbitrary oriented faces), which allows modelling of complex 3D spatial features (when using 3D coordinate space). A

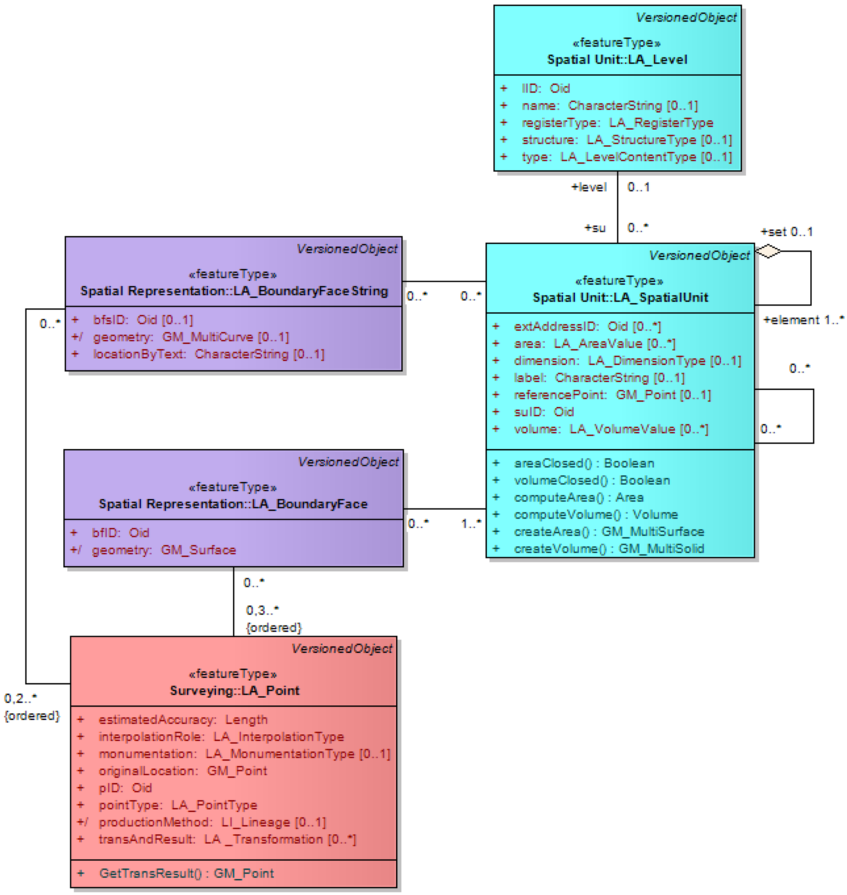


Figure 2.7: *The LADM Spatial Unit geometry components*

LA_BoundaryFace outer boundary can correspond to the boundaries defined by a number of LA_BoundaryFaceString. Validation and geometric computations using such a combination of LA_BoundaryFace and LA_BoundaryFaceString objects should be defined by implementing the methods included in the LA_SpatialUnit class.

A LA_BoundaryFace object, being a normal 2D surface in 3D space, is not unbounded, and it is instantiated through a GM_Surface type, and can even have one outer and one or more inner boundaries, that is, it defines a constrained plane with holes. However, conceptually it can be merged with the vertical face formed by a LA_BoundaryFaceString, when belonging to the LA_BoundaryFaceString vertical plane. Such a conceptual spatial structure must be made concrete through implementation of these classes, namely considering correctly derived spatial features from

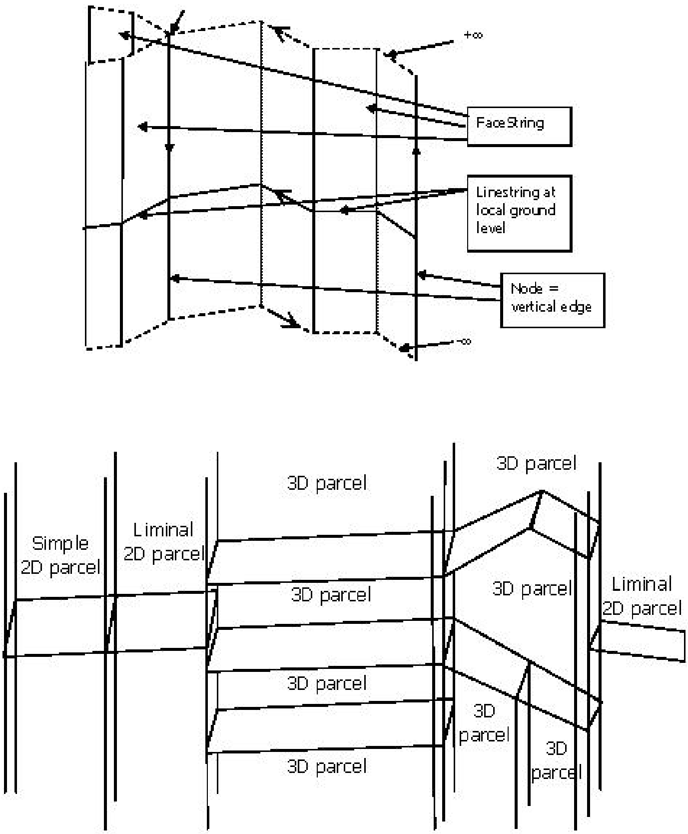


Figure 2.8: *A FaceString, adjoined by two other FaceStrings, and a combination of FaceString and Face objects.* Source: Rod Thompson, in (Lemmen et al., 2010)

the given ISO GM types[34], addressing both topological and geometric validation and analysis operations to be performed on the LA_SpatialUnit.

The final aim of the spatial representation sub-package is to allow correct geometry and topology operations to be performed on vector spatial types GM_Point, GM_Curve and GM_Surface (and related specialisations), such as to be able to represent complex 2D or 3D spatial units, or a mix of 2D and 3D spatial units. The figure 2.8 depicts the concept of a LA_BoundaryFaceString and different types of 2D and 3D representations using a mix of LA_BoundaryFaceString and LA_BoundaryFace objects.

The LADM also contains other packages, besides the core and the spatial component. These will be referred in subsections 4.2.1 and 4.3, already in the context

[34] ISO GM (19107) does not allow the representation of open or unbounded objects

of the LADM_PT specialised country model, where they work as defining (parent) classes.

Zevenbergen Classification	**Real Right** (with a brief definition)
Maximum Real Right	Property: Granting the titular of such Right to fully enjoy the usefulness of the thing, satisfying his legitimate needs within legal limits and observing legally imposed restrictions.
Id.	Co-Property: a Property Right having as object an immovable thing as a whole but shared by several subjects. Parties can ask for a division of the Thing
Id.	Joint-Property: indivisible Property Right which is shared by the Joint-owners. Parties can not ask for division of the Thing.
Id.	Horizontal Property: set of powers which has as object an autonomous fraction of an urban building and some common parts of the building. A number of common parts are defined by law, others by Title
Derived Rights	Usufruct: the right to fully enjoy another's thing or right, limited in time.
Id.	Use: Right to use a thing on another's property and have its fruits, as needed by titular and family.
Id.	Habitation: same as above, but the object is a residential building.
Id.	Superficies: Power to build or maintain a construction or plantation on another's parcel (the *implante*)

Table 2.1: Classification of Portuguese Real Rights: Part 1

Zevenbergen Classification	**Real Right** (with a brief definition)
Derived Rights (continued)	Time-sharing: right to use, for one fixed time period an habitation unit in a tourist enterprise, paying an annual fee.
Minor Rights	Praedial Servitude: An owner of a parcel has the right to use certain facilities of another's parcel, contributing to full use and benefit of his parcel.
Security Rights	Mortgage: Creditor's right to execute his credit plus interests by the immovable and certain movables value.
Id.	Retention: Debtor's right to maintain a thing on his possession against a creditor, provided he has a credit against the creditor.
Id.	Pledge of Receivables: Income from a parcel exploitation is used to fulfil an obligation. It has a maximum period. Also known as *Anticrese*
Id.	Privileges: Credit created in favour of public entities (state or municipalities)
Acquisition Rights	Pre-emption: Right to acquire ownership of an immovable for a contracted price, over third parties, within a time limit.
Id.	Preliminary Contract: Registration turns this a Real Right of ownership.

Table 2.2: Classification of Portuguese Real Rights: Part 2

Class	**Type**	**Short Description**	**Observations**
	Basic Scope	LADM addresses Land Tenure key attribute of Land Adminis tration; it should provide the Tenure status of each basic property unit	Useful to define the system boundary
Functional	External Registries	Remaining two key attributes of Land Administration, Land Value and Land Use, should be provided through linkages to external registers (systems)	Important, although it should provide this basic function
	Main Functions 1-Holder (Who?)	LADM must be able to identify holders of tenure types, for any juridical person or informal type of membership, individual or group	All these main functions should be considered as mandatory requirements
	2-Tenure type (How?)	LADM must be able to identify both formal and informal tenure types, as well as any encumbrances on a property unit; these can originate from different legal regimes and different forms of property	Idem

Table 2.4: General, Conceptual Level Requirements for LADM

Chapter 3

Land Administration in Portugal

This Chapter reports on background of the the main case study supporting the generation of a country model from the Land Administration Domain Model. The main organisational and institutional components of Land Administration in Portugal are examined and described along five sections. The first describes the basic Land Policy as well as the main Land Management tools currently in place. Section 3.2 gives an historical perspective on the roots and evolution of the Land Administration system in the country. Section 3.3 describes the current situation according the most recent legislation and regulations. Section 3.4 describes in detail a number of technical procedures which served the purpose of supplying requirements for the subsequent phases of modelling and implementation. The final section, 3.5, reviews the shortcomings of the current framework in providing an effective system, by pointing out needed innovations in the institutional, legal and technical aspects of Land Administration.

3.1 Land policy and management

The following paragraphs give a quick overview of the large number of reforms which occurred recently in Portugal, concerning basic law on Land Policy and a number of Land Management related legislation.

Beginning with the land use, a new general framework was defined through the basic land policy law on land use and urbanisation (Delgado and Ribeiro, 2004, p. 15), Law 48/98. This can be considered as the first, comprehensive, base law defining Land Policy and Land Administration. It defines a system of Land Management with different levels of application: National, Regional and Municipal. Furthermore, it defines the general guidelines for the creation and collaboration between these different types of Land Administration tools.

According to Law 48/98, there is a first level National Plan of Land Management (PNPOT), several Regional Level Plans (PROT) corresponding to the different coordination regions defined in the continent and the autonomous regions on the atlantic archipelagos and a set of Municipal Level Plans. The finer detail level is the Municipal one, where there can be defined one general master plan (PDM) and several detailed plans (PP) or urbanisation plans (PU)[35]. There are also a set of special purpose plans, like Dams and Public Waters (POAAP), Shore Land Plans (POOC) or Protected Areas Plans (POAP). These plans are produced and maintained by a large number of Central and Regional Administration agencies, and also by the Municipalities.

Other legislation related with the land planning function was also recently passed, both on the fields of Public and Private Law. In the first case, one can cite the new law on Expropriations (Law 168/99) (Delgado and Ribeiro, 2004, p. 379) and in the second case, the new law on urban areas of illegal origin (AUGI, Law 91/95), directly affecting other key functions of Land Administration, as the Land Registration (Delgado and Ribeiro, 2004, p. 471).

The relation of this laws and policies to Land Administration constitutes a problem, because the procedures are dispersed in numerous laws, and there are a lack of regulations. Also because cadastral update is almost non-existent.

3.2 Backgrounds of the real property system

Although the chapter title refers to the broader field of Land Administration in Portugal, following sub-sections will have a stronger focus on its cadastral core[36]. Traditionally, three different but interrelated components have developed in Portugal and eventually were included in the organizational schema of central government: the (Geometric) Cadastre, the Land Registry and the Tax Office (branch of Tax on Immovable Property). These organizations roles and description and its related institutional framework will be reported on 3.3.

Recognizing that the evolution and the historical roots of the real property system can give important insights to the current situation of the cadastre in a particular country, this section and following subsections will briefly report on the past and present situation of the Portuguese Cadastre.

The relevance of such studies can be ascertained through the following citation, supported on previous work by Hernando de Soto (2002):

> He also refers to the fact that most of the assets in Western nations have been integrated into one legal system, which is further formalised so that we have one formal representation system. This integration and formalisation went slow and rather unreflected during some hundred years. The question on, how it came into being has become urgent after the end of the cold war, where capitalism appears as the only serious option for development (Stubkjaer, 2008).

[35] Definitions for these plans where given back in subsection 2.4.2

[36] Comprising the geometric (or surveying and mapping) and the land registry components for a legal based cadastre.

The last part of above citation is rather debatable, this kind of (political) discussion is out of the scope of this research. On the contrary, the process leading to a formal representation system of a (mostly legally defined) number of assets is central to the research and is at the core of the following description.

3.2.1 History of the Geometric Cadastre

The first cadastral component to be addressed is the (Geometric) Cadastre. It must be stressed at this point that currently, Portugal has large portions of its territory which never received any cadastral survey. Also, many areas previously surveyed are now completely outdated and need revision.

Large scale maps depicting some form of cadastral information are known to exist since the 18th century. Those were merely sporadic surveys, with no systematic character or supporting institutional and legal framework. A royal decree from 1801 is the first legal reference to cadastral survey works to be developed in a systematic fashion. Work has begun, supported by the constitution of a national geodetic framework (since 1788). A period of political instability ensued (French invasions and Civil War), halting all such works during 30 years.

The vision of a "General Cadastre of the Kingdom" was proposed on 1847 by a report from Counsellor António José d'Ávila, supported on his experiences acquired from studying the Cadastre of Sardinia. This report presents some notable findings, from the study of XIX century European cadastres. Namely that the cadastre should not be limited to its Fiscal role, which should be considered just one of the many roles a cadastre should support. It was decided, however, (due to difficult economic conditions) that the focus of surveying should be diverted to the first national map series (1:100,000 scale). This task was concluded by the end of the XIX century, supporting many infrastructure developments like the railroad network. In the absence of a cadastral map, valuation procedures at the Tax Offices begun to be systematically recorded with a textual description of Parcels (by the end of the XIX century).

The first two decades of the XX century were another period of inactivity, also caused by political instability (Republican revolution and the First World War). In 1921 the first services for the "Geometric Rural Cadastre" were created, but with scarce resources. This was a solely Fiscal cadastre, with sporadic surveys and no connection to any base map reference.

The situation evolved in 1926, when the Geographic and Cadastral Institute was created, integrating Topographic, Geodetic and Cadastral services and related resources. A decree-law from the same year defined the legal basis for the Geometric Cadastre of Rural Property, which endured (with some revisions) until 1994 and now covers about half of the territory. The main aims of this first systematic cadastre were the following:

- Identification of immovable (rural) property;
- Land Tax collection (limited to Agricultural revenues);
- Promoting Land Reform, through modification of the property regimen;

- Creation of a national large scale base map of topo-cadastral content, including altimetry.

In the period from 1927 to 1945, the main method for cadastral survey was the surveying table, supported on a densified "cadastral triangulation" network. Field conditions were favourable to such method, once cadastral surveys begun in the region of Alentejo, a region of (almost) flat terrain and rather large properties. From 1945 onwards, the main surveying method on the field is Tacheometry, which, from 1950 onwards, is a field complement to photogrammetric survey.

In the last period of existence, from 1980 to 1994, the main survey method comes to be the field survey supported on orthophotos, and photogrammetry and tacheometry become subsidiary methods[37]. During all this period, valuation of rural property was in place and had a parallel evolution in methodology, from direct assessment on the field to statistical sampling supported on photo-interpretation.

It must be stressed that, although from its inception the Geometric Cadastre of Rural Porperty had mostly a Fiscal purpose, only from 1942 legislation was published which allowed the use of the cadastre at the Tax Offices as the main source for setting the values for the Agricultural Land Tax. And only in 1956 legislation was published which turns mandatory relating cadastral and fiscal elements with the Land Registry, for the Municipalities were the cadastre has been concluded.

During the years 1982 and 1983, a number of new laws were passed, substituting the old legislation from 1926 with the recent administrative and technical procedures found in current cadastral practice. However, a new plan to accomplish full cadastral coverage for the country, including the creation of the "cadastral expert" professional role was rejected by central government authorities.

Above paragraphs, documenting the history of the cadastre (geometric component) in Portugal, were mainly based on an article from a former President of the Portuguese Geographical Institute, Rui Henriques Galiano Barata Pinto (1985).

The last two decades assisted to the gradual decay in cadastral execution of the old Geometric Cadastre of Rural Property, and the complete halt of such operations in 1994. A new form of cadastre was then envisaged, which was formalised through decree-law 172/95 on the "Cadastre of Real Property" (MPAT, 1995). This new cadastre has some significant differences to the previous one, namely:

- Geometric description of all immovable property (rural and urban);
- Unique parcel number to be adopted by all administrative services;
- Support for the valuation procedures developed by the Tax Offices;
- Maintain cadastral data up-to-date, through sporadic ("Conservação") and systematic ("Renovação") operations;
- Certify cadastral attributes of each parcel, such as the title owner details and correspondence to tax or land registry records.

[37]The orthophotos provided the base where parcel cornerstones and boundaries are marked, while certain features were extracted using photogrammetry methods, like buildings, streamlines or roads.

With the transfer of the Portuguese Geographic Institute from the Ministry of Finance to the Ministry of Planning and Land Administration, this new cadastre moved his focus from the Fiscal to the Legal role. From its inception, digital technologies were adopted with the ultimate goal of implementing a Cadastre of Real Property National Information System (Veigas, 2002). This new cadastre open, for the first time, cadastral execution to private enterprises, through adjudication by public tenders.

However, cadastral surveys made within this new framework never reached full legal status, failing implementation of most of the above referred items. The main reason for such failure lies with the so-called "Harmonization" of Cadastre and Land Registry records. A number of concrete situations tampering such harmonization are referred in (Veigas, 2002, p. 7). The first two are perhaps the most significant: Registration is not mandatory, not even in areas subject to cadastral survey; Records in the Land Registry are outdated and / or are not accurate as to the *de facto* field situation.

The current situation regarding the geometric component of the Cadastre is referred in sub-section 3.3.1. A new set of administrative and technical (cadastral survey) procedures is being field tested in order to tackle with the Harmonization problems, while at the same time supporting valuation procedures. This ultimately led to the specification of a new cadastral data model (IGP, 2009) that is described in more detail in 3.3.1 and 4.3 (concerning its adoption as a LADM compliant country model).

Figures 3.1 and 3.2 show the map layout and a detail from a cadastral map sheet based on the specification following decree-law 172/95. In the extract, several different objects from the object catalogue can be seen:

- Green circles (cells): Property beacons;
- Magenta linework: Parcel boundaries;
- Blue linework: Margins of streamlines;
- Sepia linework: "Parcel Social Area" corresponding to e.g., Praedial Servitudes;
- Yellow linework: building outlines;
- There are other objects as well, e.g., labels (parcel and building numbers) and annotation for toponymy (local names and settlements).

3.2.2 History of the Land Registry

The following paragraphs describing the historical backgrounds of the Portuguese Land Registry were adapted from (Mendes, 2003b, p.9-34). The Portuguese Land Registry ("Registro Predial") assumes as main goal the publicity of the juridical status of private land parcels, in order to assure the security of legal transactions. This form of publicity has its roots in the Modern Age, when the concept of a National State as provider of security, justice and well-being for all its citizens has emerged. The

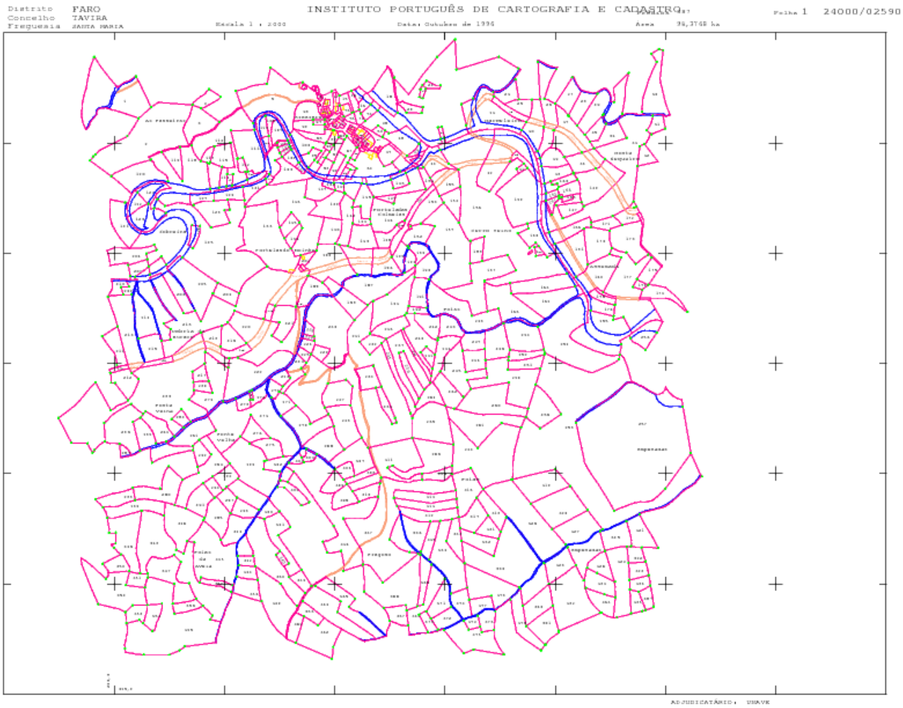


Figure 3.1: *A cadastral map sheet from the Real Property Cadastre (1996)* Source: IGP, Public Tender technical specifications.

pioneering institutions on the publicity of land records were those of the German Gründbuch (which has even older traditions) and the Prussian cadastre from the XVII century.

Institutional evolution of publicity of land records was eventually consolidated into relevant principles contained in the German Civil Code, which were later translated into the Spanish Law on Mortgages, and from there to the Portuguese Land Registry code.

In Portugal, there are no traces of a system of publicity of land records similar to the Germanic, previous to the XIX century. As a first effort into the constitution of a land registry, there was a royal decree from 1801 which imposed the task of organizing the cadastre and a “Properties General Book” including mandatory registration for all immovable property owners. The King Cosmographers were mandated with such task, but did not produce any results worth of mention.

Although the main principles of the current Portuguese Land Registry legislation have its roots on the Germanic system, there are also a number of dispositions that were introduced by the Civil Code from 1867, having French influence. The main result was that records on the Land Registry were no longer indispensable for pro-

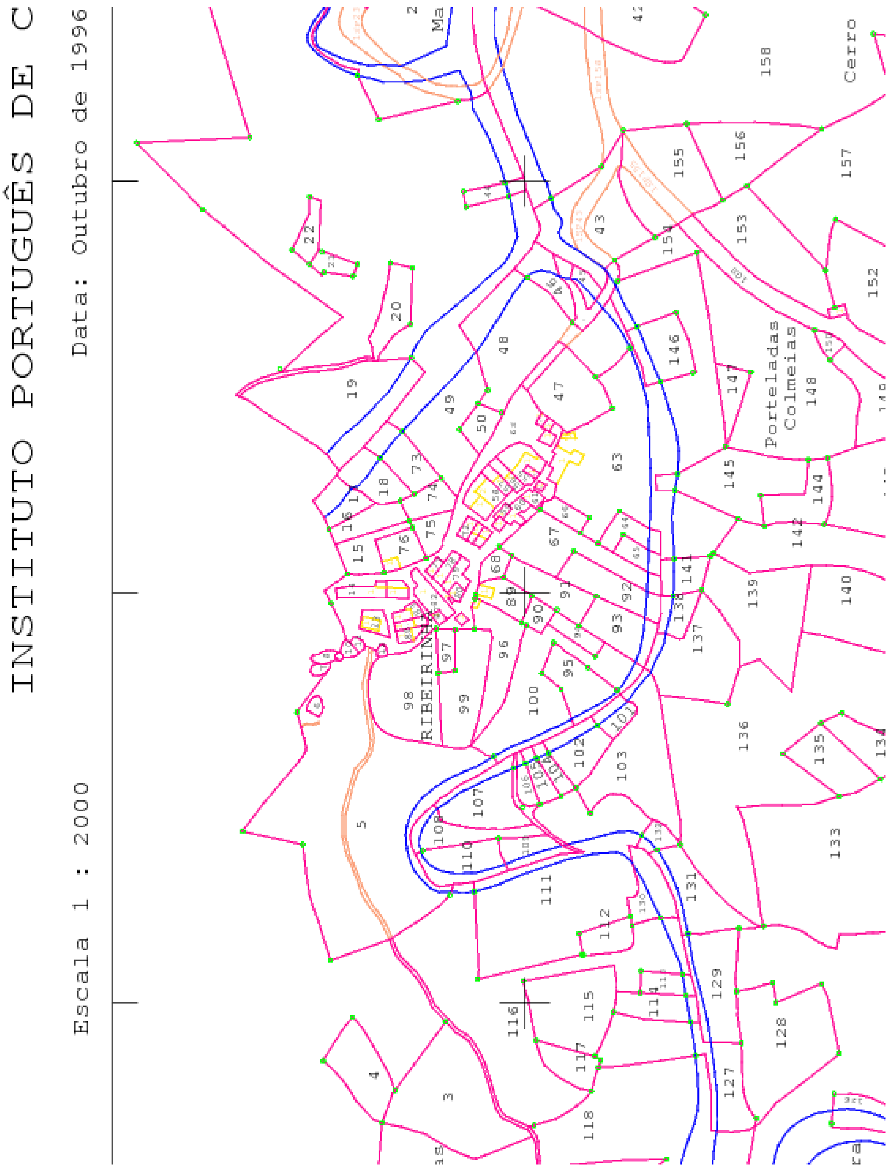


Figure 3.2: *An extract from the cadastral map showing its main objects.* Source: modified from figure 3.1.

duction of legal effects (namely in court actions), and so they could be used merely as opposition to third parties.

This had the practical effect of turning parcel registration as not mandatory. This situation was changed by the Civil Code from 1959, which turned registration mandatory in the case a mortgage has been contracted on an immovable. Since approval of Law 2049 from 1951, registration became mandatory for all parcels where the Geometric Cadastre of Rural Property has been completed.

Until very recently, the regime in force was that of an "indirect obligation" to register, imposed by law-decree 224/84. According to this regime, all transactions of real property involving transmission of rights or the constitution of incumbencies shall be registered on the Land Registry. This means that every real property for which there are no events changing its legal status, and were not previously registered, remain unregistered (except if the owners voluntarily want to register). Also, a number of events which can change, for instances, the geometry of the property (and thus its legal area), do not have to be registered. On the contrary, in the events of a sale where ownership is transferred or if a mortgage is contracted for the real property, there is the obligation to register.

Above paragraphs describing the historical backgrounds of the Portuguese Land Registry were adapted from (Mendes, 2003b, p.9-34).

In legal terms, a dual regime has been long in place in the country, with an "indirect obligation" to register within all the territory, and a mandatory registration covering municipalities where the old cadastre of rural property has been concluded. But in fact, updates to the legal description of parcels, sent by the registry to the cadastre (then belonging to the Ministry of Finance) were not reflected on the cadastral situation due to lack of resources for cadastral data updates.

The new Land Registry code (from 1984) reinforced the procedures for updates between the legal and fiscal records, but with no real reciprocity from the Tax Offices and no cadastral updates, those measures were not effective (Coelho, 1991).

According (Gomes, 1989), the Portuguese Land Registry system has evolved more on the last two decades of the XX century than on the previous 150 years. The new code approved on 1984, launched the basis for the digital information infrastructure now in place. Nevertheless, the need for an efficient connection and integrated maintenance with the fiscal records (including, at that time, also the cadastral records on rural property) is reinforced by this author. Questions arising from the measured legal area of parcels, many times involving obsolete and inaccurate methods, and the correct description of the *de facto* parcel situation (including location and spatial neighbourhood) are also referred to as persistent problems (Coelho, 1991; Veigas, 2002). It is clear from the above they stem from the lack of a geometric cadastre, which can not be solved only through new legal dispositions. An important revision to the existent legal framework concerning the Land registry has been passed recently (Portuguese Law, 2008) and it is discussed in more detail in subsection 3.3.2.

3.2.3 History of Land Taxes

Since approval of the first code for the immovable property tax (then called "Contribuição Predial"), from 1913, a valuation procedure has been set up for both urban and rural property. The general outlines of that procedure persisted unchanged for more than 70 years, until the fiscal reform of 1989. A significant change occurred, however, from the moment the first municipalities entered cadastral regime, when a different procedure for valuation of rural property, also including the computation of the agricultural industry tax ("Imposto sobre a Indústria Agrícola") was adopted. This had the result of imposing a dual regime also on the fiscal domain. This means that a different procedure is followed for the valuation of parcels (and also for the obligation to register, in the legal domain), depending on the location of the parcel in or out of cadastral regime areas. The fact this process has completely stopped, and just a part of the country is under cadastral regime, has led to the persistence of strong inequalities in tax values.

A special division of the cadastral services[38] received such task, the technical staff being formed by (among other professionals) Agrotechnology Engineers. Most of the cadastral updates, both systematic and sporadic, done by the cadastral services, had as its main goal to update the elements required to compute above referred land taxes. Geometric updates (e.g. as consequence of a boundary change) implied a lengthy procedure and were even less attended by the cadastre.

In a status report from 1989 (Mendes, 1991, p. 779), it is referred that most municipalities that have entered so far cadastral regime were left 20 to 30 years without any major revision of its valuation elements. The cause for this situation lies with the use of standards and methods that were totally outdated at the time. This cause, together with high inflation rates, is referred by (Mendes, 1991, p. 781) as the main factors leading to a steady decrease on land taxes revenues for the whole country, which from a 14.7 % of total fiscal revenue in 1940, had dropped to just 2.1 % in 1984. Off course other economical reasons played certainly a role, given that the Portuguese economy has evolved along the same general trends as other OCDE countries, as shown in the same article[39].

Valuation procedure under the old rural property geometric cadastre

The valuation of rural property based on the old geometric cadastre is briefly described next. The first step consisted in allocation of surveyed agricultural parcels to a number of predefined cultivated types. This should be done having the basic registered parcel as unit (under homogeneous ownership). This step implied great efforts in the office, due to an excess of agricultural parcels and types of cultivation. Several detailed measurements contributed to this allocation, like the tree tops coverage, plantations under a superficies right (counting individual trees if needed) or taking into account secondary products on the vegetation sub-cover.

From field data compiled for each Municipality, classification and tariff tables were derived for each classified cultivated type. Those tables provided further parameters to compute a final valuation number for each agricultural parcel, which were summed up for each registered parcel. Agricultural productivity and rotation of cultivated

[38] Direcção de Serviços Agronómicos do Cadastro
[39] Comparative Analysis of OCDE Countries on Land Taxes, Paris, 1983

species was taken into account, requiring a number of other ancillary data, e.g. soil type, market costs for agricultural production factors, and other factors.

The complete technical procedure was considered too complicated, being referred that, even recurring to computers (large mainframes at the time), the computation for just one Municipality could take a full month. The required field work to feed such computations, was several times longer. This situation was aggravated by a lengthy administrative procedure, involving several ministry departments and local cadastral commissions.

For instances, the parcel owners and tenants of agricultural parcels (together, the tax payers), had two different reclamation events, where they could ask for a re-evaluation or other minor corrections (Mendes, 1991, p.788-790). Above considerations respect just the valuation procedure and not cadastral updates caused by modification of the parcel geometry.

Nevertheless, the combined existence of a dual valuation regime on rural property with outdated cadastral based valuation data, could produce differences of 20 to 30 times on the land tax revenues (for the same land use and farm product), between neighbour municipalities. Different valuation procedures and even organizations responsible for the task of valuation of urban and rural property, led to a number of dubious situations on the suburban areas. Those are the areas where more requests exist to change the parcels classification from rural to urban, the prevailing situation favouring thus fraud and land speculation.

Reform of the valuation procedure

The recent fiscal reforms on land taxes had a special focus on the valuation of urban property, so the above mentioned problems have persisted for the valuation of rural property. It is envisaged by (Mendes, 1991) that a more effective and updated land tax, namely supported on cadastral data covering all kinds of immovable property, could reduce the number of absentee owners by imposing a tax that promotes sensible economic use of land, not encouraging any more inertia or speculation. This would have also the effect to promote fair and balanced transaction prices and to decrease the large numbers of buildings left unoccupied, mainly in the old town centres.

The current Land Taxes situation in Portugal will be described on 3.3.3. However, a word is due to the major Fiscal Reform of 1989, which had profound impacts on the way Land Taxes were computed. The former situation, above described, computed a tax value based on actual or potential income from an immovable. The actual income respect rented immovables, while a potential income was computed for the immovables which were not rented.

From 1989 onwards, all taxes on actual income were compiled into a single tax for individuals, and other for collective persons, respectively the IRS and IRC (“Imposto sobre o Rendimento Singular” and “Imposto sobre o Rendimento Colectivo”). This would leave the immovables which were not rented in a free tax situation, which was not an acceptable solution in terms of fairness and overall tax income. The solution was then to create a new legacy (or Patrimonial) tax on immovables, which reverted to the Municipalities and was called Municipal Contribution (“Contribuição Predial”).

The valuation changed then from computing a potential income to computing the economic capacity generated through ownership of immovable property. This new tax form covered all immovable property, thus raising the issue of double tax on rented immovables. During existence of the Municipal Contribution tax, from 1989 to 2003, the double taxation on rented immovables issue was solved turning the amount paid to Municipal Contribution tax-deductible on the IRS tax (Morais, 2005a).

In preparation to the Fiscal Reform of 1989 and also on a few occasions since then, the need for a comprehensive valuation code was stressed by the experts, and there was even a proposal for such code, but it was never approved. The final solution that came into law was to derive the tax amount from the previous methodology to compute potential income, into a legacy value supplying the basis for taxation. That solution was considered not satisfactory by the experts, and it was changed for the valuation of urban immovables in 2003, but the old methods still prevail (with some wrap ups) for the rural immovables (Morais, 2005a, p. 317-319).

3.3 Institutional and organizational framework

This section will describe the current set of legislation and technical specifications together defining the framework for Land Administration in Portugal. The focus is still the management of private real property by the three core organizations described in the previous section (Cadastre, Land Registry and Land Taxes). Institutions dealing with Public Property were briefly mentioned in 2.4.1, but the emphasis here is on Private Property.

Additionally, the role of local government as a main user and potential producer of cadastral information will be described in sub-section 3.3.4. Some of the legislation framework defining a number of local government administrative procedures will be described, with a special focus on the current urbanization juridical regime.

A Geographic Information Infrastructure (GII) approach has not been explicitly followed, although providing a method to cooperate between (at least parts of) different organisations in the field. It requires, however, the implementation of an open and interoperability approach, which is standards based.

3.3.1 Geometric component: the Cadastre

The current framework for the geometric cadastre is one of transition to a new set of procedures, caused by the failure of the Cadastre of Real Property in attaining its goals (as defined in decree-law 172/95). A new project was set up by the official responsible organization, the Portuguese Geographic Institute (IGP), which eventually was endorsed by the government through the Council of Ministries resolution 45/2006 from May 4$^{\text{th}}$.

This has been called SINERGIC, which stands for "Cadastral Information Exploration and Management National System". The newly proposed system seeks to overcome the main obstacles still prevailing which impede execution, management and exploration of cadastral information, in a sustainable, effective and coordinated way. Its main goals are the following:

- Integration of cadastral contents from several sources (old and new) internal or external to IGP;
- Optimizing cadastral management processes;
- Should be interoperable and multifunctional;
- Provides sustainability to Land Registry and Tax Office (through Unique Parcel Identification, IPU);
- Increase efficiency of provided services;
- Increase data privacy and security;
- Fulfil legal requirements of legislation in the cadastral domain;
- Provides a “citizen oriented” technological platform;
- Allows equal access to property information by property owners.

In the documentation, legislation or specifications concerning SINERGIC, there is no explicit consideration for any update procedures. The focus is on the first systematic cadastral survey and subsequent dissemination of data.

The (proposed) system architecture will consist of a data core whose management is shared between main governmental organizations in this field (IGP, the Land Registry and Land Tax Offices). It should have geographically decentralized components, with well defined update responsibilities.

A validation and harmonization effort should be promoted by IGP in order to assure information coherence. Implemented procedures should be governed by the “subsidiarity” principle, that is, information should be collected and maintained by the agents closer to the field, or at least, in close cooperation with such agents. Concerning data acquisition, it should be solely restricted to those identified as a result of system goals requirements.

As already defined in previous legislation, each cadastral unit characterizing element should be given a unique identifier. In the case it is a Parcel, it should be the Parcel Identification Number (NIP). The main strategic project partners will be the governmental organizations referred above, plus the Municipalities (IGP, 2006).

The SINERGIC project mentors, IGP, contracted a economic feasibility study to a consultants team composed of Augusto Mateus and Associates and Price, Waterhouse and Coopers. The main conclusions from this study were published in (Mateus, 2009, p.34-36). The main considerations and conclusions are presented in the following items list:

- A cost-benefit analysis was conducted considering economical, financial, environmental and social aspects over a 15 year term. Main stakeholders were interviewed in order to identify all expected benefits;

- The financial analysis was complemented by the assessment of economical benefits like cost savings, improved efficiency and effectiveness and positive externalities. Direct financial benefits amount to just 6% of total, while the expected economic acceleration (28%) and the reduction in the loss of assets (25%) forms the majority of quantified benefits;

- Costs will have greater impact on the initial investment years, while benefits will grow steadily during investment years and still have positive values during normal project operation. Overall financial cash-flow is negative 180 Million Euro, but the net cash-flow (considering both financial and economical benefits) amounts to a positive value of 3867 Million Euro;

- Economical benefits totally justify SINERGIC project implementation, this being supported in the experience of EU countries having effective cadastral systems, assuring thus public sector efficiency and increased competitiveness;

- A number of critical success factors were identified: management of the public tenders adjudication process; quality control and compliance with specifications; required changes in the legal framework to allow centralized management of SINERGIC data; promotion of synergies between the ICT and the Cadastral Survey fields.

In relation to SINERGIC and the Portuguese National Spatial Data Infrastructure (called SNIG), the European Directive INSPIRE - Infrastructure for Spatial Information in Europe, has been translated into Portuguese legislation through Decree-Law 180/2009 from 7th of August (Portuguese Law, 2009). The INSPIRE Directive includes specifications for data cataloguing and dissemination on “Cadastral Parcels”, in the Directive Annex I. General information about the implementation in Portugal is provided in the SNIG site (SNIG, 2011).

Resulting from SINERGIC, a pilot-project on new procedures for cadastral data acquisition was launched, covering the area of a small inland parish in the central area of the country, “Albergaria dos Doze” (see figure 3.4). The main goal was to test new procedures ensuring Harmonization with the legal and fiscal registries, as well as new field data acquisition methods capable of delivering more accurate positional data. The parish covers an area with patches of dense forest cover, alternating with burnt areas from recent wild fires, and a small urban nucleus surrounded by some agriculture plots. Derelict land is becoming an ever increasing problem due to an ageing population having scarce resources.

A detailed description of current technical procedures for field acquisition and cadastral map production will be given in subsection 3.4.1.

In order to comply with the Harmonization goals, initial arrangements were done with local (Municipal) offices of the Land Registry, the Fiscal services and the Municipality itself, regarding the exchange of records and other relevant information for the Cadastre. After a public announcement of the project on local news media, a new procedure was tested, consisting in obtaining a Title Declaration from property owners were they should fill in information regarding the parcels they owned on the parish, as well as their respective legal and fiscal registry numbers (if existing). In the meanwhile, property owners were also instructed on how to properly do demarcation of their parcels.

For community support, an office was open in the parish by IGP, where people could search for advice on demarcation and filling in the Title Declaration forms (see figure 3.3). After a first period of collecting declarations, field work begins. This aims to accurately describe parcels geometry including location of the property beacons left by demarcation.

Having reached a sufficient number of surveyed parcels and title declarations, a first Harmonization attempt is conducted, trying to relate each declared parcel to its geometric description. Different methods to establish such relationship were tested, with varying degrees of success. Although only a small percentage (0,6%) of Declarations did not supply at least the fiscal record (which is mandatory), just about one quarter of declared parcels had its geometry validated and from those, only 53% were completely validated.

Due to the small amount of surveyed parcels, a second period of data acquisition was conducted in 2007, including reception of new Title Declarations, and the pilot-project ended in May 2008 after confirming reclamations presented by the owners during public exposition of cadastral data. A complete online description of this project, including geometric data on parcels and beacons, can be consulted on (IGP, 2008).

The official definition of an experimental, transitional period for cadastral development on the grounds of SINERGIC project came with decree-law 224/2007 from May 31st (MAOTDR, 2007).

This decree-law foresees a major revision should apply to a number of existing by-laws, like the ones respecting adjudication of cadastral production public tenders to private enterprises or the definition of sporadic surveys. New by-laws will be required for the implementation of SINERGIC project.

IGP is appointed as manager of the proposed system, the other main stakeholders being the strategic partners already identified. Municipalities will be represented through the General Directorate of Local Government, DGAL[40].

The main modifications introduced by this decree-law which are relevant for the characterization of the cadastral domain are the following:

1. Regarding Forms of Property (Art. 4), besides recording the situation of private immovable property (the main focus of old legislation), also common lands known as "Baldios" and informal settlements complying with definitions on the AUGI[41] decree-law, should be also surveyed and recorded on the system;

2. Older areas commonly referred as *Sheet Social Area*, representing in older cadastral sheets common areas or serving parcels, and also other parcels under the public domain (national or municipal), are no longer explicitly mentioned in this decree. The current emphasis is thus on a simple survey of private property

[40] Direcção Geral das Autarquias Locais

[41] AUGI stands for Urban Areas of Illegal Genesis ("Áreas Urbanas de Génese Ilegal")

Figure 3.3: *The field office at Albergaria-dos-Doze; SINERGIC Pilot Project.* Source: IGP (IGP, 2008)

and harmonization with legal and tax records. This can introduce, however, geometry and topology inconsistencies because a full partition of space is no longer possible;

3. A new status type of cadastral parcels is introduced: the Transitory Cadastre (Art. 6). This corresponds to those parcels which were surveyed in the field but where there are no information regarding related tax and legal registers. The older concept of *Deferred Cadastre* still holds, completing thus three possible states for a cadastral parcel: Transitory, Deferred or Harmonized.

   The latest technical specifications aggregate the two states of transitory and deferred parcels, distinguishing them through type enumeration, while the harmonized parcels do constitute a separate class of features. All the records will be kept in SINERGIC, but just harmonized parcels have the links to legal and fiscal records. See also the related example in 2.5.2;

4. A newly composed *Technical Support Team* entity is defined. According the pilot project, this team typically includes one representative for each of the main strategic partners of SINERGIC, and should be formed at the local municipal level;

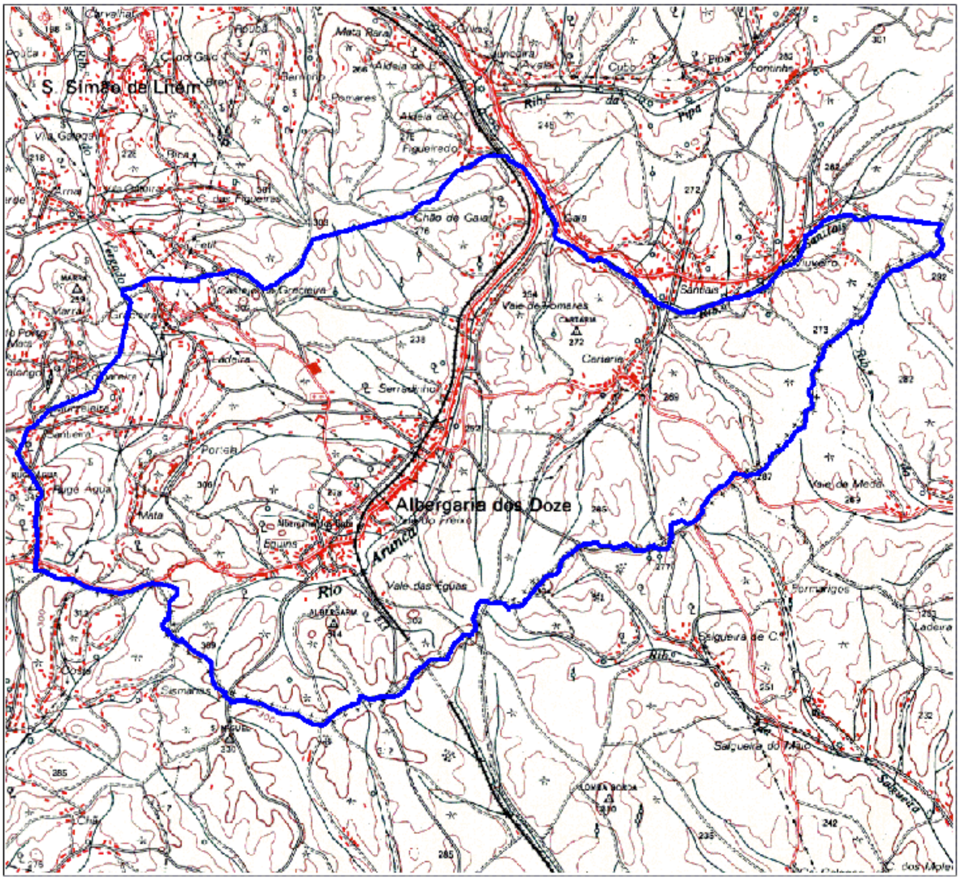


Figure 3.4: *The work area of the SINERGIC Pilot Project. The underlying map belongs to the 1:50,000 topographic map series (not to scale).* Source: IGP (2008)

5. The old parcel identification number is replaced by a new simplified format, and a provisional number is introduced. The new number no longer composes (distinguishes) between ground parcel and condominium parcels (called "Horizontal Property" or "Fractions" in Portugal). It simply sequentially increments through all this property types in a given section;

   No geometry is included in these records; just for the ground level. The Fractions have just alphanumeric records.

6. A new definition of *Cadastral Titular* is done, which includes both natural and non-natural persons and allows for proper register of joint or co-ownership situations; Titular's of derived rights on a given parcel and for "Compartes" in the commons. This replaces the previous situation, when just one owner or representative was registered, which complied more with old Fiscal traditions;

7. The major change regarding the cadastral survey procedures is the introduction of the *Title Declaration* (Art. 11), already explained above, and the subsequent harmonization procedure of relating those declarations with the surveyed parcels.

From the existing law, it is not very clear yet which are the competencies of entities participating in the processes of cadastral quality control ("Fiscalização" in Portuguese) and sporadic cadastral updates ("Conservação"). Although it is clear that the basic responsibility lies with IGP as the system manager.

The areas under the old Rural Property Geometric Cadastre are not considered to be surveyed according the new established regime (Art. 21), thus implying the need for its update according the new rules and data model. However, considering their value in terms of information content, the corresponding cadastral sections and all its contents concerning the geometry of rural parcels are being digitized and will become part of SINERGIC[42].

In the above mentioned law, the only mention to a Data Model (Art. 30) just enumerates property beacons and boundaries as cadastral entities. Other (required) classes are just referred as "any other elements considered relevant for parcels identification and description". A new technical specification for the Portuguese Cadastral Data Model has been published in May 2009 by IGP, supplying the required class definitions according modern modelling techniques (IGP, 2009).

Overall, this new decree settles a new institutional environment of greater cooperation and data exchange among the strategic partners, which has been already tested for the pilot project. And the new Data Model shares a significant number of modelling concepts and development methodology with the Land Administration Domain Model and the here reported research.

3.3.2 Legal component: Land Registry

As in the case of the geometric component, also the Land Registry Code defined by decree-law 224/84 has seen major modifications. In this subsection, and due to the very recent nature of modifications, an account of the generic procedures for registration is still based on the previous framework. The final paragraphs will describe the main changes introduced by decree-law 116/2008 from July 4$^{\text{th}}$.

The Land Registry ("Registro Predial" in Portuguese) is the source of all the information regarding rights or restrictions on a given cadastral element, combining this data with information on mortgages or other types of onus encumbering the property. Some of the data presently stored by the Register respects parcel's text descriptions; this being the type of information usually supplied by the cadastre in other countries. The geographic references are limited to natural features, local place names or street addresses (for urban parcels). Many times, such information is imprecise or outdated (or both).

[42]This digitizing effort recognizes the importance of the rural-urban boundary, but must be maintained as developments will happen.

The source of information for the register is a legal source document ("Requisição de Registo") containing three different types of specialized documents, typically supplied by an Owner who wants to register a Title, or any interested party in some form of Transfer of Rights. These three types of documents are paper based documents and respect a requisition, a main declaration and (optionally) a complementary declaration. The complementary declaration is needed in some cases, e.g. a first inscription or when a parcel is under a joint ownership.

Additional certificates can be required, depending on the modification being requested.

After the introduction of the digital information system for the Land Registry (SIRP[43]), a summary extract of the documents is recorded as a "presentation" element in a central database. The SIRP has been installed already in 200 offices[44] and country coverage is expected to complete in the year 2009.

Each record at the Land Registry should have at least one registered right (typically, ownership), although it can store several other types of derived rights or restrictions for a single parcel. In the case of a condominium (with "Fractions"), each record has a number of subordinate records, one for each of the Horizontal Property owners. It equally stores the history of each parcel, as every new entry is dated. This implies that, from first inscription in the Registry, all subsequent events implying transfer of rights should be recorded without time gaps. Furthermore, changes to the shape and area of the parcel, e.g. through a detachment, could not have impact on the recorded rights, but should also be registered once they alter the parcel's legal area.

Several tenths of different types of rights or restrictions are mentioned in the legal code. At a given time, there can also exist one or several mortgages upon the Parcel or a part of the Parcel. In the Portuguese Land Registry, the Parcel (as Basic Administrative Unit) is called the "Predio" and corresponds to a single record with an homogeneous ownership right. Several derived or minor rights and restrictions can be registered for the "Predio", most covering the whole of its area. However, certain rights or restrictions can have a specific location, defining thus one or more part of the Parcel ("Parcela" in Portuguese). In the Portuguese Civil Code, one can constitute a mortgage over rights of ownership, a long lease (provided it respects public domain parcels) or superficies rights (Hespanha et al., 2006).

A number of Real Rights defined in Portuguese Law were already listed in tables 2.1 and 2.2 from sub-section 2.2.1 on private property law. Not all the listed rights are subject to registration, though. Those rights which are fundamental to characterize the juridical situation of a given parcel, namely all different forms of the Maximum Real Right (Property) and all the listed Derived Rights should be registered.

Other type of situations which do not constitute Real Rights are subject to registration, e.g. seizure of property resulting from a bankruptcy process or execution of credits resulting from a mortgage. There are also a vast amount of administratively imposed servitudes, defined through decree-laws or by-laws, which should be also sub-

[43]SIRP: Sistema de Informação do Registo Predial
[44]As from October 2008

ject to registration. Usually, those servitudes are registered as an alternative for an expropriation process.

The following paragraph briefly summarizes the administrative procedure related with a single registration of a Parcel, in a Land Registration office. It corresponds to a first inscription in the Registry, that is, for a Parcel (allegedly) not registered.

The owner of the concerned parcel or a legal representative (e.g., a lawyer or a solicitor) are entitled to initiate a registration procedure (see figure 3.5). A predefined requisition form should be filled in and signed. It must be complemented by a main declaration and (in this case) a complementary declaration, where the identification and civil state of the previous owner be given. A (textual) description of the parcel and its area, including local toponymy and identification of neighbours, will supply the information to the parcel description, related to the main right of Property, to be recorded in the legal part of the register. That constitutes the main known problem with a descriptive Land Registry: No Survey!

Every right, restriction or other fact to be recorded in the legal part should be backed up through a legal document. This could be a problem for a first inscription, where such documents might not exist in the first place. One solution is to apply for the registration of the Real Right of *Usucapio*[45], which recognizes formal possession. The listing of documents presented and a summary of its claims receive a time stamp and are stored as a so called *annotation*. The request is then validated by the staff of the Land Registry office. It can be refused, e.g., when the parcel is not situated on the territorial jurisdiction of the office[46].

If all the required formalities are fulfilled, then a new register is made, but it will be provisional due to its nature of a first inscription. Other situations should be satisfied in order to turn the provisional register into definitive, e.g., all Land Taxes should be paid on the given parcel. The owner (or representative) could be requested to present additional declarations if the original documents are insufficient to clear all doubts.

In any case, a provisional register has a six month term to be turned definitive, otherwise it will be cancelled. If the first inscription had to be made through registration of Usucapio, only after this right has been considered definitive the owner can request the recognition of the formal right of Property. This second procedure is usually faster than the preceding one. Provided this new annotation is valid, the register of the Property right will be definitive in a 15 day term. In its final form, a register constitutes a presumption that rights exist and belong to the identified titular (Mendes, 2003a).

Note: in figure 3.5, the grey rounded rectangles represent digital objects to be stored in the Land Registry system during the first inscription procedure.

[45]Definition according (Garner, 2004, p.1579): The acquisition of ownership by long possession begun in good faith; especially the acquisition of ownership by prescription.

[46]a situation that has changed through the new decree-law 116/2008.

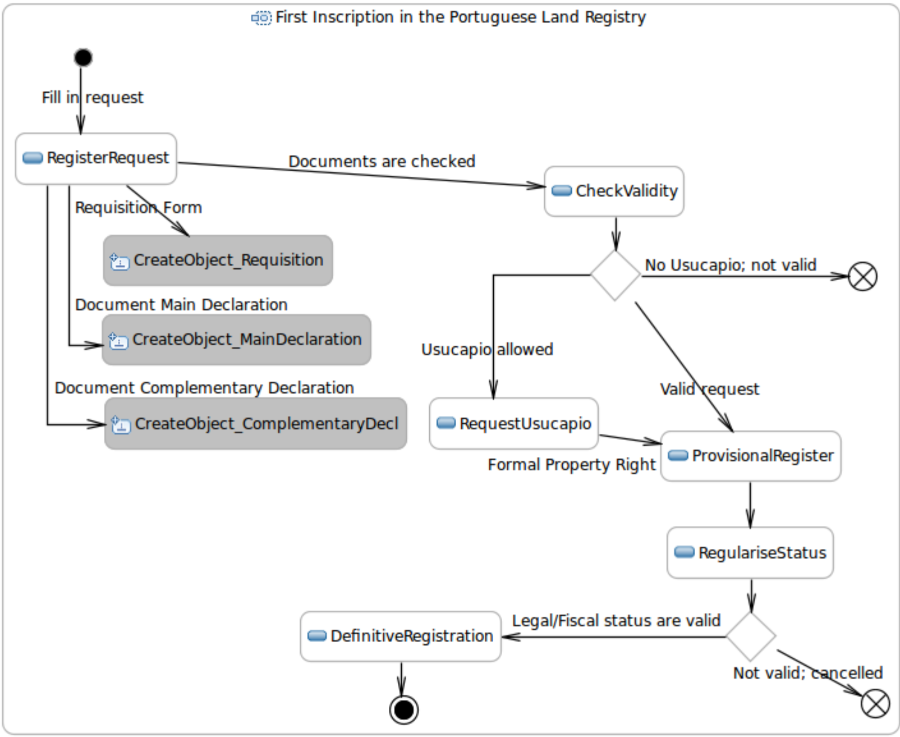


Figure 3.5: *UML Activity diagram depicting a first inscription in the Land Registry.*

A more complex registration procedure included in an overall administrative *Urban Lot* procedure will be described in subsection 3.4.2.

New decree-law 116/2008 has changed significantly the previous Land Registry Code. The most significant changes are listed next (Instituto dos Registos e Notariado, 2008).

- Registration is now mandatory for all cases of acquisition, transfer or extinction of rights and restrictions listed in the law. A major change that is also a fundamental step in establishing SINERGIC vision;

- Free registration (no fees) for all facts occurring previous to the 4th of July 2008. This measure is connected to the previous and promotes a general update of the registry;

- End of the Territory Competence of Land Registry offices. Requesting certificates or new / updated registries can be done in every office, independently from the location of the parcel. This results from the central database of the SIRP, covering all the national territory from the 1st January 2009;

- The Land Registry offices will have online network access to other public registries, namely the Identification Archives and the Collective Persons Registries, and will be capable to supply a significant number of documents previously supplied by the citizens. This network forms a Information Infrastructure (although has no geographic component), which is managed by ITIJ - Institute of Information Technologies from the Ministry of Justice;
- Credit institutions and Financial Societies are obliged to promote registration of private property in a short term legally defined, as well as the Law Courts (for legal actions including modification of rights or restrictions which should be registered);
- In Inheritance procedures, it is no longer required to register the intermediate state of a given register in favour of the inheritance author, provided the requisition is made by the heir itself.

This new legal framework is thus globally positive, as compared to the previous one, in the perspective of a modern information system towards the vision presented by LADM. There is also a negative aspect, considering the whole legal framework, where there is a lack of integration between the (Geometric) Cadastre and the Land Registry. Most important, it supports complete coverage and update of the legal status of real property, and the association of such information with external registries identifying natural and non-natural persons, that is, the LA_BAUnit to LA_RRR and from here to LA_Party core relationship in LADM.

The end of territory competence of Land Registry offices is also a natural consequence of the implementation according to modern information and communication technologies (ICT). Although LADM is a platform independent model and does not impose any particular hardware and software architecture, the implemented solution is one of the possible solutions using the most recent system development methodologies.

In spite of such positive aspects, this new decree-law does not include any considerations to support for the establishment of the other fundamental or core relationship in LADM: the association from the registry records (the LA_BAUnit class) to LA_SpatialUnit (or LA_Parcel, its class name alias). The main reason for that being the fact that SINERGIC legal framework and related technical specifications were declared as experimental, which ultimately leads to the conclusion that both legal frameworks will require further revision to implement in full LADM core concepts.

3.3.3 Fiscal component: Land taxes

The recent Land Taxes reform instituted through decree-law 287/2003 from the 12th November, substitutes old municipal taxes of "Sisa" and municipal contribution by the Municipal Tax on Transactions (IMT[47]) and Municipal Tax on Immovable (IMI[48]), respectively.

[47] Abbreviation from the Portuguese, "Imposto Municipal sobre Transacções"
[48] Abbreviation from the Portuguese, "Imposto Municipal sobre Imóveis"

Concerning the IMI, the main element of reform has been the general valuation procedure for urban immovables. This has the goal of correcting significant tax disparities occurring under the previous valuation regime. Those were mainly due to completely outdated valuation results for the majority of old buildings, while the major tax revenue for the municipalities come from a small number of new buildings.

The new valuation is based on a declared value by the tax payer and results from a direct valuation procedure. A set of objective rules defined in the law, guide interested parties in defining the tax value of their immovable, which should always be based on current market values for such property.

The tax value for urban immovables used for habitation, commerce, industry or services, results from a formula with the following factors:

1. Base value for buildings. Computed from a mean construction cost added in 25% to account for the cost of the base land parcel;

2. Gross construction area, added with a threshold area, usually to be held in common by the property owners;

3. Use coefficient, depending on the actual use that is given to the building;

4. Location coefficient, which relies on an weighted average of current market values within a defined zone;

5. Quality and comfort coefficient, which accounts for the quality of materials and construction methods, as well as the existence of certain luxury items;

6. Ageing coefficient, which measures building degradation by time.

These different parameters are recorded with the valuation record for each Parcel and building within it, although there are no regular systematic updates but irregularly spaced in time. For most of these factors, concrete valuation procedures and minimum / maximum permissible values were later defined through by-laws. A new organisation was established, the National Commission for Valuation of Urban Immovables (CNAPU[49]). This commission has, among other responsibilities, to update the indexes (on a yearly basis) used for the computation of above referred valuation coefficients (Morais, 2005b). There were no equivalent changes concerning the valuation of rural property, where the procedures still refer to the old cadastre and are thus outdated, constituting a complete anachronism with the recent developments in the cadastre.

The major impact for the tax payers come from the recent massive update of valuation figures in the fiscal records, according the transitional period established in law (Art. 13). The procedure is now more open and transparent to the general public, namely through creation of an Internet portal where the zoning related to the location coefficient can be consulted, as well as the contents of fiscal records itself. Data privacy is secured through log on mechanisms (citizens must provide

[49] Abbreviation from the Portuguese for "Comissão Nacional de Avaliação de Prédios Urbanos"

their fiscal number and request for a password). The general valuation procedure, as implemented by the mentioned decree-law, is referred next.

A first valuation is ordered by the chief of staff of a given local tax office. The elements for this valuation come from the existing fiscal records, which were declared by their respective tax payers. A direct valuation is then executed by a local expert[50], following the referred valuation formula and setting an updated tax value for each urban immovable. If a tax payer disagrees with the new tax value, a second valuation could be arranged. The new direct valuation is then executed by a commission of two regional experts, within a term of 30 days from communication to the tax payer. The result of this second valuation can only be contested in court (Portuguese Law, 2003).

3.3.4 The role of local government

By "Local Government" I refer mainly to Municipalities, once they are the main form for this level of government in Portugal. But to describe the role local government plays in Land Administration, also other organisational forms should be accounted for, like the Municipalities Associations or the Metropolitan Regions.

A number of land planning and administration tools were already referred back in subsections 2.4.2 and 2.4.3, namely the Municipal Master Plan (MMP) or related sectoral plans, e.g. the National Agricultural Reserve. The process of urbanization was also referred, where the Municipalities play a central role through the grant of Urbanization and Use Permits for new developments within areas classified as urban zones in the MMP.

The MMP imposes a significant number of restrictions on the use of private property, which are spatially defined through a zoning map. These form the decisive element to answer licensing requests from citizens (or enterprises), and eventually grant them a permit or reject the request. The Municipalities are then the first instance of administration that is consulted by citizens willing to modify the status of the Cadastre regarding parcel geometry or land use.

Furthermore, current administrative practice forces a number of contacts between the citizens and the Municipalities, in order to complete more complex procedures like that of urbanization (the Urban Re-allotment). In this view, Municipalities should play an important (even fundamental) role in Cadastral Updates.

Another usual source of modifications to the Cadastre are municipal led projects, referring to infrastructures of public use like drinking or waste water networks. On this kind of projects, and due to their complexity, cost and dimension, it is usual to have an Association of Municipalities leading the process, from the initial drafting of the public tender and technical specifications, to the operationalisation of the infrastructure. From the Cadastre point of view, the previous (private) parcel structure can be modified through the tools of Public Regulation, namely *Expropriation* or imposition of *Administrative Servitudes* (Hespanha et al., 2009, p. 20). The later

[50] Those are, preferentially, professionals with an academic degree on Civil Engineering or Architecture, or an equivalent technical degree

tools are a last resort, given that the usual procedure is to buy the land under private property.

Proceeding with the given example of a drinking water network, the Association of Municipalities can define a *Public Utility* clause in order to expropriate parcels or part of parcels where certain type of fixed and permanent facilities will be build. Those areas will revert to the public domain, and can subsequently be subject of a concession to a private water distribution firm.

Such areas which are traversed by the water network in a way that does not interfere with a (although restricted) land use by the private owner, are subject to an administrative servitude. This has the aim to assure regular network operation, allowing also for maintenance intervention to occur, by defining a legal space where the property owner is restricted from some types of modification, e.g. building on top of it. Most of the network facilities, however, will use existing public domain areas, in order to minimize impacts on private property. The larger utility companies and some Municipalities maintain technical, georeferenced information on these networks, which can have a 3D representation. However, there are no provisions in the cadastral specifications to integrate such information in the cadastre.

Other regular source of expropriation and creation of public municipal domain is precisely the municipal road network. On this particular type of municipal led projects, most of the modifications are done through expropriation and administrative servitudes have a smaller role. Besides the negative impact they could have on private property (e.g. splitting a parcel so that it looses its agricultural value), there is also the potential for a *Public Advantage* (Hespanha et al., 2009, p. 32). An example for this last case could be a parcel that had a limited access through a right-of-way and now has a front to a public road.

Yet another example of Municipal responsibilities which implies some forms of restrictions to private property originate from the demand of forest fire prevention. The problem of forest fires has been specially acute in Portugal in the first years of the XXIst century, and the government reacted with a series of measures defined in decree-law 124/2006 from the 28th of June.

Through this decree, the Municipalities should elaborate a plan for the defence of forest against fires, the PMDFCI[51]. For private owners having parcels used for forest production, this means that they are obliged to maintain the sub-cover clean from dry woods and other natural materials with the potential to ignite and fuel a forest fire[52]. Furthermore, if the property is adjacent to an existent urban or industrial area, an administrative servitude is imposed by means of a corridor on the related boundary(ies), where the plantation of large trees is forbidden. Other types of administrative servitudes or even expropriation can be imposed on forest cover areas, in order to assure an adequate infrastructure for the fire brigades to combat forest fires (DGRF, 2006).

The sum of both private and municipal initiative projects on which a Municipality has responsibilities given by law, together with the fundamental responsibility of

[51] Plano Municipal para a Defesa da Floresta contra Incêndios

[52] A responsibility which is dependent on the actual land use, and as such does not have to be registered.

defining and enforcing local level Land Planning, amply justifies their inclusion as strategic partner of SINERGIC project (refer to subsection 3.3.1). This is the situation described in law. But the execution has not progressed enough to judge how it will work in practice.

3.4 Technical procedures

A selected number of technical procedures, which were considered relevant for supplying detailed specifications for the Pilot Project, are detailed next. They include the latest techniques which are being used for cadastral surveying and mapping, according last results from the SINERGIC project (3.4.1). This corresponds to the procedure to follow in those administrative areas (usually Municipalities are considered) where no previous geometric cadastre has existed, thus covering mainly the Central and Northern regions of the country.

Concerning the demands for municipal applications requiring the set up of communication channels with a national cadastral system, the Urban Re-allotment procedure was selected and already reported in general on subsection 2.4.3. The following subsection 3.4.2 details just on the registration procedures related with an Urban Lot. Continuing in the same narrowly focused analysis trend, an account will be given on the municipal administrative procedures related with the issue of building / habitation permits for the simple case of a single family house (3.4.3).

3.4.1 Cadastral survey and mapping

New areas subject to a cadastral survey are said to be under *Cadastral Execution*[53], meaning no previous cadastral survey ocurred there in the past, not even the old geometric cadastre of rural property. To specify the different parameters of such a complex operation, this description is structured into the following series of sub-subsections:

- Preparation;
- Georeference basis;
- Photogrammetric support;
- Field survey;
- Spatial data base production;
- Harmonization and
- Public exposition and reclamation.

[53]Execução Cadastral

Preparation

A new Cadastral Execution usually covers the administrative area of one municipality, but can be limited to just one parish (e.g. in the SINERGIC Pilot Project). If such area has not undergone a previous procedure of official administrative boundaries survey, then this process can be launched in parallel with Cadastral Execution.

Other tasks for the preparation of the Cadastral Execution operation include a public announcement of the extent, period and aims of the operation, and public sessions to instruct property owners on how to proceed with demarcation and filling in Declarations. It is expected that those tasks will stay within responsibility of IGP.

Even before such tasks occur, IGP has to gather a number of georeference support materials, namely an orthophoto coverage of the area and topographic, land cover and land use data on which a decision is made on the level of resolution to apply to the cadastral survey[54]. Resulting specifications are then included in a Public Tender document. Following adjudication, subsequent tasks are handed over to one or more private enterprises which will complete Cadastral Execution.

Georeference basis

All georeferenced data acquisition should comply with a specific national datum. Formerly, a country specific datum named D73 - Melriça was applied to the "Cadastro Predial", but now IGP has moved into the European defined ETRS89[55]. The Portuguese realization of this datum is termed PT ETRS89 / TM06, the origin of such datum corresponds to geodetic coordinates of 39°40' 05",73 North and 08°07' 59",19 West; the reference ellipsoid is GRS80. The SINERGIC Pilot data, the new cadastre and all official mapping published by government authorities must apply the new coordinate system.

From the existing National Geodetic Network, which is now being expressed in the new datum ETRS89, a further densified network able to support cadastral survey operations should be implemented, called the *Cadastral Triangulation*. The name has more an historic reason, once modern Cadastral Triangulation is done through GPS static survey. This task is usually the first field operation conducted by the private firm (after winning the public tender) and could be complemented with a general reconnaissance of cadastral structure and status of demarcation and also with the acquisition of photogrammetric Ground Control Points (GCP).

A basic reference grid derived from datum projected coordinates, with a regular spacing of 1000m x 1000m defines the format for the orthophotos and related Cadastral Sheets, which however have an irregular shape in such a way to accommodate cadastral parcels without splitting their map representation. This grid can be tightened to just 500m x 500m in urban areas, allowing for more resolution in the map representation. The kilometric grid gives the basic reference to 1/2000 map scale cadastral sheets, and the half-kilometre grid, to the 1/1000 map scale cadastral

[54]The orthophoto has the highest resolution (supporting 1:2000 mapping) and is current. The topographic maps can have 1:10000 scale at best but can be more than 10 years old. The land cover data has resolution equivalent to 1:50000 scale and is updated every 10 years.

[55]Defined by EUREF - European Reference Frame

sheets. These cadastral sheets assumed a conventional view of use and dissemination of cadastral information through the sale of printed maps. Coordinate resolution should be limited to 1dm and the positional error for cadastral elements should be less than 1.2m for a statistical confidence interval of 90%. This last figure has been reduced to 0.4m in SINERGIC Pilot Project, due to intensive use of GPS field methods. Both positional error figures are expressed as absolute errors (related to the reference system).

Photogrammetric support

The same aerial photographs which were used to produce the orthophotos, or (if the orthophotos are somehow outdated) a new photo coverage, should be georeferenced using classic block aerial triangulation or modern GPS aided aerial triangulation. Photogrammetric GCP should thus be acquired through GPS field survey, such that a global positional error for each block is less than 8cm.

Such tasks should support high precision stereo restitution of a number of features which are relevant for Cadastral Execution. If the parcel structure is delimited through physical entities like ditches, canals, hedges or walls, then their stereo restitution will supply a significant amount of data for the final cadastral map. Indirect support for cadastral survey is also important, once this high precision data can be used as basis for field measurements with the aim of coordinate cadastral features.

Traditionally, such support was used in the field through plastic transparencies laid out on top of the orthophotos. In the office, data from stereo restitution could be used as a basic digital reference layer from where cadastral features can be derived, in a CAD or a GIS system environment. Using new technology, stereo restitution data can give an even greater support to field survey, provided a number of procedures for the use of such data be created and implemented on field devices like PDA or combined GPS + PDA. This later techniques have the potential to eliminate analogue to digital conversions at the office, which are time consuming and error prone.

All above referred tasks precede main cadastral field survey, in such a way as to supply field staff with accurate data used to reference cadastral data elements. At the moment field staff begin to move to their working areas, they should be able to:

- Position a GPS reference station at a Cadastral Triangulation point, allowing for real-time GPS survey to be conducted in the vicinity;

- Feed their PDA with basic imagery data (the orthophotos) and one or more layers of stereo restitution data, allowing for direct or indirect positioning of cadastral elements;

- Above mentioned data layers are also a useful reference to position local toponymy[56], a required data layer for the cadastral sheets.

[56] also referred as micro-toponymy, that is, local place names collected at a large scale resolution.

Field Survey

Field data collection comprises two components which must be acquired by so called reconnaissance teams: geometric data on parcels and features belonging to the cadastral map, and alphanumeric data identifying the owner of each parcel and / or the respective declaration number. Due to the harmonization goals introduced through SINERGIC, there is also the necessity to process all written Titularity Declarations, to allow for a complete parcel description, with references to the legal and fiscal records. The last task is done through a field office, properly equipped with computers and software, including a Declarations data base and OCR scanning software and hardware.

The traditional process consisted in marking directly on the orthphoto the position of the property beacons and parcel boundaries, through a rather expedite photointerpretation process. Field staff used pins, markers and even magnifying glasses to position cadastral features. This cumbersome procedure[57] can now be executed using Tablet PC or PDA, which allow for quick pan and zoom to the relevant area, with data being directly obtained in digital format and already georeferenced.

Using the stereo restitution layers in addition to the base image, increases the positional accuracy obtained through this field methods. The photointerpretation can be complemented through expedite topographic methods, namely using stereo restitution or other visible detail in the vicinity of a cadastral feature, and making a few tape measurements. In such cases, a field sketch is also produced, although this procedure could be also inserted into the PDA or other field devices, through proper software applications.

The more accurate method, though, is to use Real-Time GPS Survey to measure the position of property beacons and other cadastral features, assuring an accuracy far in excess of the specified one. These devices can be coupled to PDA and Tablet PC, so that field data is immediately entered as digital, georeferenced features. The obvious drawback of this last method is the extra cost of required equipment, apart from a carefully designed Cadastral Triangulation to support base GPS stations.

If a Real-Time GPS Survey is not considered, or just in part, there will be still a few areas where the previous mentioned methods would not assure sufficient accuracy. This could be due to, e.g. problems in the base imagery and a featureless area, or on dense forest areas. In all such cases, an additional topographic survey task is required[58]. This additional task uses topographic survey equipment such as Total Stations or GPS in order to provide accurate measurements in those problematic areas.

Every time the reconnaissance teams have sufficient geometric data in order to identify a parcel, they should form the related feature representation and give it a provisional identification number. The alphanumeric data component should be then filled in with data required to associate the geometry with the Titular's Declarations. Alternatives to this form of identification are direct contact with the owners in the

[57] A difficult task to execute in an accurate manner in the field; not mentioning orthophotos could become rapidly deteriorated

[58] called "Completamento" in Portugal

field, or taking note of owners initials left on the property beacons. Contrary to the normal procedure in other countries, the presence of both owners for the survey of a cadastral boundary is only required for individual updates (called “Conservacao Cadastral”). But these procedures were only done for the old rural cadastre. According to the cadastral data model (IGP, 2009, p.99-104), the field office has to input data contained in the Title Declarations into a number of objects belonging to the data schema. These include identification of persons and their roles (as titular or representatives), addresses, register numbers corresponding to legal and fiscal registries, the corresponding cadastral object and (optionally) a number of objects identifying legal documents as deeds, legal diplomas or court decisions.

The current data model does not have a specific class of objects to account for parcels in the Public Domain, while private property and communal land (the “Baldios”) should be surveyed in order to form valid polygonal (2D) representations. Also, the consideration of AUGI presents the (potential) problem of having those parcels superimposing on a former private parcels framework. This would contribute to, respectively, the existence of gaps and overlaps in the parcel fabric, which rule out the strict consideration of a full topological spatial data structure[59] (see subsection 4.3 for details on how different spatial profiles could be implemented with LADM).

Spatial Data Base Production

When the new digital “Cadastro Predial” was conceived, the alphanumeric data component was kept apart from the geometric data component. The first one was stored on a file based data base, having a very simple *flat table* data structure, while the geometric data was stored into IGDS[60] format files, two per cadastral sheet. The geometric data was line-based, codified (with regard to a feature catalogue) and having no explicit topology, while it was validated for connectivity and intersections, in order to comply with a node-link structure. The purpose was to provide correct measures of Parcel areas.

Eventually, the situation has evolved in order to be in tune with recent spatial data base technology. Both geometric and alphanumeric data are now acquired in digital format through field survey, with cadastral features being stored as feature classes or associated object classes (representing alphanumeric data). All data collected by the field teams must be checked in to the central database covering all the area under cadastral execution.

Data is validated during this operations, and also in a final stage, in order to assure its topology and logical consistency. The final result should be a topological validated, schema consistent, seamless data base, covering all the administrative area under adjudication. The new cadastral specifications, however, introduce a difficulty in the topological validation procedure, by not considering the survey of parcels in the public domain, so there will be gaps in the cadastral fabric. Map products as

[59]The main motivation to consider full topological structure is to enable efficient quality checks on the spatial data, in this case the parcel fabric.

[60]IGDS: Interactive Graphics Design System is MicroSation and Intergraph standard file format for storing 2D and 3D CAD elements.

the traditional cadastral sheet[61] could then be derived from the data base, through the use of symbology libraries and label / annotation placement, together with some amounts of manual cartographic generalisation.

Harmonization

In this context, this is the process of relating the parcel geometry with a given Titular Declaration. This is done by the field teams through fill in of appropriate key fields of alphanumeric data while surveying. The relationship can be established also in the field office, through indications left by the owners to the field teams, e.g., identifying the approximate location of their property on the orthophotos.

After checking in the field data into the spatial data base, and after importing the Declarations data base into alphanumeric tables of the spatial data base, an association can be established between these components through relevant keys columns, allowing to set the status of surveyed parcels as complete, transitional (no relation to fiscal or legal records) or deferred (no known owner; litigation or; insufficient demarcation). Regarding the new cadastral data model, a completely surveyed parcel, that is, one considered as harmonized, is one where the cadastral object superclass has associations with a declaration and fiscal or legal objects and the geometry / topology component is completely specified. Further, the parcel specialized class must have an association with at least one titular. The association to the Titular, together with the alphanumeric data collected for each parcel, represent the information for the Basic Administration Unit, which does not explicitly exists in this model.

Public Exposition and Reclamation

After the field operations are complete and the spatial data base has gone through final validation, information gathered so far can be consulted by property owners through public exposition of the (then considered) provisional cadastral data. In a term regulated by law, the owners can request for corrections being made on the cadastral data, through reclamation. Such reclamations can be rejected; the ones being deferred can be corrected at once at the field office (if not respecting geometric data), or further surveys can be required to solve such claims.

After all reclamations are resolved, the cadastral data base reaches a definitive status, through the issue of the Parcel Identification Number to all parcels except those within deferred cadastre areas. The operation of Cadastral Execution is considered concluded.

It is not explicit in the law how cadastral data should be maintained afterwards, namely which steps should be taken by the strategic partners in order to eventually eliminate all parcel under transitional or deferred status.

The above technical description was based on technical specifications belonging to the “Cadastro Predial” tenders (IGP, 1996) and also on the report from the SINERGIC pilot project (IGP, 2008).

[61] The new cadastral specifications contain fewer features to be represented. Basically, the parcel boundaries and cornerstones, parcel numbers and local and administrative toponymy.

3.4.2 Registration procedure: The Urban Re-allotment

On subsection 2.4.3 on Land Administration Processes, the Urban Re-allotment[62] procedure has been described in general, identifying the different organizations from local and central government which are involved. This subsection gives a more detailed account of the procedures which involve the Land Registry. Just the component treated by the Land Registry is described. A fragmented view, but the one (still) in place.

In terms of the Land Registry, the Urban Lot process only begins when the promoter (a Municipality or a private entity) receives the Municipal Permit to split a parcel or a group of adjoining parcels into Lots. The Urban Lot plan, at this time, has already received approval from central and local authorities, so its layout is according to national Land Policy.

On subsection 2.4.3, the role of the Land Registry was summarized into one activity, the *Urban Lot Registration*, although it was also referred different phases could exist depending on the arrangements between the original parcel layout and that of the resulting Lots. Lets so assume a not so simple layout of a group of adjoining parcels with different owners that forms a block delimited by existent municipal roads (which are public municipal domain). All parcels within the block will be subject to the Urban Lot operation. The promoter is a large (private) real estate agent, which will own all the Lots for construction. The Municipality itself, however, has reserved a part of the total area to be integrated into municipal public domain, namely an inner road network, parking areas and some green areas also.

Having in mind the above described scenario and the issue of the Municipal Permit, the tasks of the Land Registry are described at two moments in time:

1. Registration of Urban Lots according plan in the Municipal Permit;

2. Registration of Horizontal Property (Condominium) rights upon buildings construction, at some moment in the future.

Registration of Urban Lots

Every new Lot[63] for construction shall be described in an independent record at the registry. The listing of adjoining lots and municipal roads and the area of the Lot are given according the Municipal Permit (through the related re-allotment plan). The acquisition is registered in favour of the promoter, the new owner of the Lots for construction.

However, to maintain the chain of title, the Municipal Permit is first registered in every original record (of the original parcel layout), as well as the reference to the new Lot (or Lots) that will be created according the plan. The areas that are not covered by Lots for construction will be municipal domain, and accordingly, their detachment from the original parcels should be registered.

[62] Essentially a re-allotment procedure under an urbanization plan

[63] Depending on the type of building, can correspond to a single house or to multiple units in a multi-storey building.

The purpose of such complex procedure is to be able to know the situation before an existent Urban Lot is in place. If the departure parcel layout has a significant fragmentation, then the number of legal inscriptions on the original records will be substantial, not mentioning the new Lot descriptions and related legal inscriptions. The workload for the Legal Offices can be daunting, specially having in mind the recent surge in construction along littoral settlements. For this reason, it was suggested (Mendes, 2003a, p. 291) that the original parcel layout was first transferred to a single parcel under co-ownership, with shares proportional to the original distribution.

Registration of Horizontal Property

According the Municipal Permit and general law, the promoter has a term to develop the Urban Lots, following the related urbanization plan. In the above described scenario, the Real Estate agent will then contract one or more civil construction firms. Eventually, will receive the completed buildings from those firms and it will request an Habitation (or other use) Permit to the Municipality. This last type of Permit was not referred on subsection 2.4.3 but it will be described next (3.4.3). Because it implies inspection, the request is done near or at building completion.

Having received the Habitation Permit, the Real Estate agent will then begin to sell individual condominiums, which in Portugal are registered under the *Horizontal Property* real right. For each Lot in the Urban Lot plan, the general description of the building and its common parts is added to the Lot description in the registry, and then every new apartment unit is registered has a *subordinate record* from the main Lot record. The ownership details are then inscribed has an Horizontal Property on this sub-records, along with the unit description (address, gross area and other details).

Starting from May 2004, all the new buildings and their related apartment units should have an "Habitation Technical File" according decree-law 68/2004[64] (Portuguese Law, 2004). Such a file should be kept by the promoter and the owner of each unit, and according the recent law amending the Land Registry Code (decree-law 116/2008), a copy of it should be attached to each Urban Lot record. This file keeps a record of the responsible for each specialization field like architecture, water, gas, electricity, etc. The manufacturers and the type of materials used in the building are also listed. Safety instructions for the correct maintenance of installed systems shall also be provided, e.g. smoke and gas extractors (LNEC, 2004).

3.4.3 Municipal services: some procedures

A Building Permit should be requested to the Municipality wherever the underlying parcel is located outside Urban Re-allotment procedures or *Urbanization Plans*. Not all types of construction need a permit from the municipality, e.g. if it is just a small shack to store farm materials. In this subsection, however, it is assumed a single family house will be built on a vacant parcel.

[64] In Portuguese: Ficha Ténica de Habitação

Usually, the owner has acquired the parcel knowing that it is included in an urban zone according the Municipal Master Plan. Anyhow, the procedure can start by an *Information Request* to the Municipality, in order to know exactly what are the building regulations in force for that specific planning zone. If the parcel is not encumbered with administrative servitudes or public restrictions whose responsibility does not belong to the municipality, the information is given in a term of 20 days from initial request. If external entities have to be consulted, the process can be much longer.

The second step is then the request for a *Building Permit*, which should also include the architectural plan for the new building. If any results were obtained from external entities in the information request, then the information stays valid for a one year term. If, during appreciation, there are doubts that regulations and other constraints are not being taken care in the architectural plan, a new consultation could follow, or the request can be rejected. In the last case, there is the possibility to re-submit the request, correcting all the causes for rejection. The municipal services have then a term of 45 days to re-appreciate the request, and finally deliver the Building Permit.

The Building Permit contains a series of dispositions that shall be observed during construction, e.g. fences or obstructions to be put in an adjoining public road. It also defines the estimated date for conclusion of the building. There is a duty of publicity, that is, the owner should put a note near the construction containing the permit number and the author of the architectural plan, as well as the technician responsible for the construction.

When the building is concluded, a final *Habitation Permit* should be issued by the municipality, against the request of the responsible technician. If the construction has followed technical regulations and constraints in the Building Permit and related construction regulations, the issue of the Habitation Permit will follow on a short term. This implies, however, that the construction site received an inspection visit from municipal technicians in the meanwhile.

If the building was never inspected before, then an inspection should be made in a one month term from request. The inspection is performed by technicians with the proper academic degrees and professional expertise, who will determine if the building has followed existing regulations in terms of quality, safety and public health, according its use for habitation.

The source text for this subsection is (parts of) the decree-law 555/99 on the Legal Regime for Urbanization and Construction (Delgado and Ribeiro, 2004, p. 180-205).

3.5 Shortcomings of current framework and procedures

Currently, there are no mensurable results from the set of new legislation and technical specifications published since the announcement of SINERGIC project (the term from 2006 to 2009). The future execution of the announced cadastral survey public tenders, together with the implementation of the SINERGIC system core and the results of modernization of Land Registry services will express the effectiveness of those measures in a (predictable) short term. There are certainly advances in institutional and technical aspects, but considering the geometric, legal and fiscal components in isolation. There is still lack of an integrated approach and a real concern for cadastral update.

Considering now all the core organizations recognized as strategic partners of SINERGIC, legislation in the field of immovables valuation and public and private construction works licensed by municipalities must be added to the framework. Having in mind the complete framework set up by the Cadastre, Land Registry, Fiscal Offices and Municipalities, referred back in this chapter, the following shortcomings can be listed:

- Although a new technical specification for cadastral survey, including a data structure based on the latest standards and modelling methodologies is now in place, IGP did not detail yet any cadastral update procedures;

- Furthermore, IGP does not define (in spite previous attempts) any certification procedure for cadastral experts, nor the future role and competences of such a professional;

- A new set of technical specifications (from IGP) will be needed in order to convert old cadastral data (Geometric Cadastre of Rural Property and Real Property Cadastre[65]) to the new specifications. Otherwise, this old cadastre, covering more than half of the country, will not benefit of most of the services that will be eventually available through SINERGIC;

- Regarding the fiscal role, a comprehensive valuation code is needed such that current disparities in valuation are solved. This code should encompass the valuation of rural as well as urban properties, and should take into account data and services existing or to be proposed to the SINERGIC system;

- Regarding the role of local government, there have been a few attempts by individual municipalities to integrate cadastral data into their spatial data infrastructure, although not taking into account the latest developments in cadastral data structure. New specifications, following the same basic approach of the cadastral data model, should define how cadastral data can be used and integrated in current municipal management and how municipalities can contribute to update procedures to SINERGIC. This would constitute a truly Geographic Information Infrastructure based on standards and using cadastral data as a key register, as described in (van Oosterom et al., 2009);

- Finally, considering a possible extended role of SINERGIC in the broader scope of Land Administration, there should be a common interface able to register and maintaining as well the set of spatial units defined by the central government (through a number of ministries), like Public Domain, Restrictions and Administrative Servitudes affecting private property.

[65] Produced in the term from 1995 to 1999.

A rather complex and distributed (which means fragmented in most cases) infrastructure has been in existence in Portugal concerning the field of Land Administration and cadastre in particular. In recent years, as described in this chapter, it is in a process of reform and modernization affecting all the aspects of Land Administration (Technical, Legal and Administrative, Institutional and Organizational). This new infrastructure has already the basic components which could enable, in a medium term, the implementation of a Land Administration system as proposed by LADM and more specifically, the country model, implementing thus many of the visions of Cadastre 2014 manifest.

Considering the newest technical specifications for cadastral survey, and the new laws on the Land Registry, the proposed cadastral system in Portugal can be classified in the following terms, considering definitions in (Zevenbergen, 2002, Chapter 3, p.3-82):

- Fixed vs. general boundaries: in areas with no cadastre and text based records in the Land Registry, the concept of a boundary can be considered to fit into a general boundary, but just as an euphemism for an undefined boundary. In areas that will be surveyed according to the new specification and laws, the new demand for registration, together with the greater survey accuracy, could be considered as supporting a commonly agreed fixed boundary. However, as these concepts are absent from Portuguese legislation, one can consider that even with the new cadastre, the cadastral data base will just indicate the general boundaries, given that there will be no precisely surveyed line considered fixed by the registry; There are no defined procedures agreed between the cadastre and registry to survey a fixed boundary.

- Systematic vs. sporadic registration: given the previous legal regime of indirect obligation to register, many real property parcels are still left unregistered, specially in rural areas. Although in many places the desirable type of adjudication would be a land consolidation, what will be implemented in fact can be thought as a registration of rights which is deferred in time. This means that, after a systematic survey covering the area of a municipality, a number of deferred cadastre parcels will remain, for which there are no titular declarations and thus, its legal situation will remain unknown or is informal. The goal of the cadastral survey is mainly to record accurate geometric descriptions of real property where links can be established to the Land Registry and Tax records, while support for a subsequent, sporadic and now obligatory adjudication is left out of both SINERGIC and Land Registration laws and procedures.

This requires a whole new set of institutional, organizational and technical aspects. The thesis describes some, but not in detail. Except for the Mira Municipal Cadastre, which to my knowledge was the only case of Cadastral Update in Portugal for the XXI century, although based on the old specifications, and not endorsed by IGP.

Chapter 4

A methodology for Land Administration system development

This is the chapter where the methodology to be applied to the development of Land Administration Systems is reported in detail. Beginning with an overview of the state-of-the-art and the prerequisites for the research, in section 4.1, the application of the Land Administration Domain Model is described in the next section (4.2), considering different modelling issues like domain modelling or tackling changing requirements.

The section 4.2 continues with an account of the procedure of deriving a specialised country model from LADM, the LADM_PT (for Portugal). This has been divided into subsections covering the issues of the requirement analysis procedure for the LADM_PT country model (4.2.1, 4.2.2 and 4.2.3). Next section considers the detailed steps which were taken in order to derive the country model (4.3). The detailed description of the Spatial Unit package as considered for Portugal follows in section 4.4. The detailed description of the Legal and Administrative package which was modelled for this country model is presented in section 4.5 and finally, the Pilot Project on the Mira Municipal Cadastre is described in section 4.6.

4.1 Restating the problem domain

The development methodology described in this chapter concerns mostly static aspects of Land Administration centred on the *tenure key attributes* (as referred in section 1.2).

The context for the development methodology was summarized in a number of prerequisites (see section 1.1) which together assume that an existing Land Administration framework is in place, and its requirements concerning technical, legal and administrative aspects can be searched and reported.

The methodology described hereafter is supported by a number of state-of-the-art technologies, as reported on section 2.1. It is largely based on international standards, with the purpose to deliver a solution that has platform independence and can thus be implemented on a variety of hardware and software platforms of choice.

Although reported technical solutions are readily available worldwide, namely due to the open source and freeware character of most of the tools used in the research, the same does not apply to the availability of bibliographic references on the modelling and implementation of Legal and Administrative aspects (reported in sections 2.2 and 2.4, respectively).

Those aspects concern mostly the current Portuguese regulatory framework on the Land Administration domain. Comparisons with the legal domain of other countries were provided on subsection 2.2.2, which proposes a generic conceptual approach that can prove useful to model other country specialised models.

On the Administrative aspects, there is no comparable generic conceptual approach as in the technical and, to a certain extent, legal aspects. The only internationalisation which can be claimed here concerns the fact that most of the current planning regulations were translated from EU Directives. This implies that a related administrative conceptual approach could be eventually incorporated into the model, providing further support for specific country models within the EU.

The specialized country model proposed for the Portuguese Land Administration is supported by a number of requirements drawn from the study of Land Administration in Portugal in this research (see Chapter 3). Besides the most generic global challenges presented in subsection 1.2.1, the main focus of this research lies on addressing the shortcomings identified for the Portuguese situation in section 3.5.

The specialised country model LADM_PT will address the detailed research questions referred in subsection 1.3.2, together with the following ones, identified through the Case Study of Land Administration in Portugal:

- How can the LADM_PT provide for integration[66] procedures between the geometric, fiscal and legal components, namely accounting for the valuation of rural properties, in order to leverage it with existent urban valuation?
- How should other forms of property in Portuguese legislation be modelled into LADM_PT, namely property belonging to the Public Domain[67]?
- How should the Cadastral Update operations lead by the local government be integrated into LADM_PT?

4.2 Blueprint for reform: the LADM

The single, most important ingredient of the development methodology reported herein is the Land Administration Domain Model. As referred to already in the Introduction, the current version of LADM is the product of a development process started at a FIG Congress in April 2002. At the moment, it is under development at ISO / TC211, for possible adoption as an International Standard. The draft international standard (DIS) of the proposed LADM is the baseline reference version

[66] Although *integration* is the term used in information technologies literature, in the legal realm the term *harmonization* is used instead.

[67] The current technical specifications ((IGP, 2009, p.9-10,20-21)) include communal and informal forms of property, named in Portugal as "Baldios" and AUGI, respectively.

that will be used and reported on this Thesis (ISO/TC211 Geographic Information / Geomatics, 2010), although the most current version is the final draft international standard (FDIS) (ISO/TC211 Geographic Information / Geomatics, 2011).

Being a Domain Model, and considering object-oriented software development as reported in subsection 2.1.1, its main purpose is to convey a rich set of conceptual classes, abstracting real world entities (and not software objects). According to its stated domain (Land Administration) and intended worldwide application, the set of conceptual classes included in LADM covers common aspects of Land Administration, with a focus on property ownership related to land (and water) legal spaces and the required spatial components.

Given the diversity of existing Land Administration systems in the world, each reflecting its own development path[68], the consideration of a Domain Model handling such diversity required a high degree of abstraction. This is the starting point of defining a commonly agreed domain ontology, including entities descriptions within the scope, and their relationships. The ultimate goal, as claimed in (ISO/TC211 Geographic Information / Geomatics, 2008, p.7), is to enable parties involved in the development of a new or upgraded Land Information System to communicate based on the shared vocabulary implied by the model. And through this full communication of meaning, enabling the share of information within and between countries.

4.2.1 Requirements analysis under LADM

The subsection 2.6.2 addressed LADM itself. The current subsection is the first to address the steps needed to derive a specialised country model out of LADM. It covers the most critical requirements to be considered for the implementation of LADM_PT specialised country model. According to UP's Inception phase, only critical functional should be considered in this first development phase. The functional requirements should form a Use Case model, which will grow in the subsequent phase of Elaboration.

Other examples of documents resulting from the Inception phase were created for LADM_PT and are reported in Annex E of this Thesis.

The following Use Case diagram is a *context diagram* 4.1, that is, one that depicts the system boundaries and the main external actors, considering the critical functionality of *cadastral update* based on a simple case of parcel split. The Use Case Model uses a top-down hierarchy, in which the diagram elements proceed from generic ones (in a context diagram) to more detailed descriptions.

The reason to choose the cadastral update as a critical functionality, has a special meaning in the Portuguese context, where the old geometric cadastre of rural property experienced a lot of difficulties in keeping records up-to-date; in a similar way, the new "Cadastro Predial", official cadastral update never occurred in practice.

Use Case: cadastral update context

The context diagram "Cadastral Update Procedure" considers four major phases in a cadastral update caused by a property transaction (a sale with a part of parcel split).

[68] Each being a product of their respective national history; see section 3.2 for detail.

These phases could be detailed through particular Use Cases, in a first level of detail. They were identified as common phases of such a procedure in a number of European Countries, in the COST G9 Action "Modelling Real Property Transactions" (Ferlan et al., 2007, p. 32).

The notes attached to each of the four phases of Preparation, Land Policy Control, Formalization and Decision&Registration, explain the contents from the point-of-view of the Portuguese Land Administration. They consider the existent regulatory and legal framework, and present new procedures and activities to be considered under the new system.

The whole software component of the system is represented by a single package called "Integrated Cadastre", which structural components are described by LADM-PT diagrams. The Actors supplying information flows to this package, called "Land Registry" and "Cadastre", are the only ones to be considered internal to the system; all the others are external Actors. The Actors characterize the roles of individuals or collective entities like organisations, within the context of the Use Case. The basic assumption is to develop a legal based cadastre (Registry + Geometry), according the vision in the latest legislation.

At this level of analysis, just broad roles are defined. If moving to increased levels of detail, the organisational actors can assume more specific roles, e.g. job profiles within a department.

The internal Actors "Land Registry" and "Cadastre" play roles on the Decision&Registration phase, which are labelled by the association names "updatedLegalDesc" and "updateGeometricDescription". The final results from performing such roles are then send to the "Integrated Cadastre" package. By its turn, this package should supply a picture of the "Former Cadastral Situation" to the first phase of Preparation.

The above mentioned Actors, phases and associations together define the system boundary for LADM-PT.

The Actors assuming individual roles regarding the Preparation phase become then the main external Actors to consider for this critical system fuctionality: the parcel owner selling the parcel (Owner_a), the future owner (the buyer; Owner_b), the Solicitor and the Surveyor (only needed in case of selling a part of parcel or parcel split). The Solicitor has a supporting role in preparing documentation to present to a Notary or the Registry, and also a mediating role between buyer and seller. They all use information supplied by the "Integrated Cadastre", although the specific requirements can be different for each Actor's role.

The other Actors depicted in the diagram also play their roles on the Cadastral Update procedure, but they just relate indirectly to the system.

A number of high-level user (the Actors in the diagram), system and data requirements can be then inferred through the diagram and supporting notes. The Use Case description and their related requirements can be best expressed (though not formally) by the use of a text template like the one included in Annex E.

The main innovation compared to the current practice in Portugal, is the consideration of an Integrated Cadastre system which combines information flows from the Land Registry and Cadastre[69]. The context diagram also considers the role of Municipalities (as organisational Actor) and of the Surveyor. The current status is that the cadastral survey is almost non-existent (and no new cadastral operations are being conducted) and the role of municipalities was just recently recognised in the law. Innovative aspects should be considered with care when performing requirements analysis, once they are not supported on previous, standard practice.

Use Case: cadastral update decision and registration

Electing the "Decision&Registration" phase as the one critical to system's operation, a specific Use Case describe detailed activities in what will be called level of detail 1. The Use Case diagram "Cadastral Update: Decision&Registration", graphically depicts the boundary of the system, and further splits the internal activities into the components specific to each internal Actor (see figure 4.2).

In the "Decision&Registration" Use Case, the initiator of depicted activities is the Notary, which sends certified documents (resulting from the context level Formalisation phase) as input to the integrated cadastre system. Although a duplication in data input is depicted in the diagram, an alternative scenario could centralize all certified documents input through the legal component (the Land Registry), which then would send relevant update requests to the geometric component (the Cadastre). This level 1 Use Case still uses the same organisational Actors as the context diagram, although the diverse activities here depicted could be ascribed to different roles within the respective organisations, that is, to different internal Actors.

It is expected that a number of specific tasks regarding validation, both on the legal component activity "Validation Legal situation" and on the geometric component "Validation Technical Document", could be done automatically by the new system. Fundamental activities of "Registration new legal descriptions" or the "Cadastral Map Update" will require some degree of human intervention, as depicted through the associations to the internal Actors.

The activity of "Generate new Parcel Reports" should be the last to be performed, and is dependent on results form the "Cadastral Map Update" and a information flow from the "Registration" activity performed by the Land Registry, which was called "newLegalRegisterIDs". This means that such activity must integrate relevant data from both components and is critical to systems integration. The goal is to supply the Solicitor with a clear picture of the updated situation of the Parcel, regarding the new holder of the Rights; as long as the listing of any Rights, Responsibilities and Restrictions existing on the Parcel and which *follow with the land* (as usual, regarding Real Rights). The new geometric situation of the Parcel should be also supplied, concerning relevant location and shape attributes resulting from the survey.

In the Inception phase, is is not required to specify in detail what will be the actual contents of the Certified Documents used in the update request, or the textual and graphical (map) data to be inserted in the final Parcel Reports. The focus is

[69]Under the SINERGIC framework and also supported by LADM *External Registries*, the integration can be extended also to the Tax Office, although this situation was not considered in the Context Diagram.

the identification of the external and internal actor roles and their associations with activities to be performed by the system or at the system boundary.

The Use Case text template for the “Cadastral Update: Decision and Registration” diagram was inserted into Annex E.

The reported Use Case of Cadastral Update, however, can be considered as a simple form as compared to a re-allotment procedure (as described in 2.4.3). Even this simple form can have a main (or most frequent) scenario, plus other alternative scenarios. For example, the reported Use Case diagrams could be simplified for scenarios where there is just a transfer of Rights and no change in geometry, or the reverse. Other forms of Cadastral Update were also considered, namely the already referred urban re-allotment procedure as one of the Land Administration Processes.

In such a complex system as an Integrated Cadastre, further levels of detail can be specified beyond level 1. This is usually left for the phase of Elaboration which, following an Iteration Plan, begins by the implementation of core components of the new system’s architecture.

Keeping a focus on Cadastral Update, the decision was to proceed with prototype implementations concerning two core activities belonging to the level 1 Use Case diagrams: “Registration of new legal descriptions”and “Cadastral Map Update”. To detail such activities, the UML Activity diagrams were used, as described back on subsection 2.1.2. These can be used as an intermediate step between the Use Case specifications and the modelling of the behaviour upon the static, structured data model, represented by the UML Class diagrams of LADM-PT. This last one will be described in the following subsections, while Activity diagrams, considered to belong to the Use Case Model, are described next.

4.2.2 Iteration 1: Legal and Administrative

Beginning with “Registration of new legal descriptions” activity diagram, there is an initial state which considers documents making up the update request were validated (through a previous activity). The first step should then be a check out of the current status of parcels to be updated. This is still a structured activity, in which one can assume a number of individual actions will have to be performed in order to actually get data from the current records. Specific data contents and implementation details should be considered at later stages of the design process. If this diagram is assumed to be at the level of detail 2 in a scale of complexity for the Use Case Model starting with 0 for the Context Diagram, then at least level 3 will be required before actual implementation.

The set of checked out data and update request documents is then submitted to two activities, which can occur in parallel: “Update Legal Descriptions” (which are based on source documents) and “Update Rights”. The first one should trace the sources of documents, providing some administrative data to the system users, and should be also useful for reporting, once implies sections of text in human-readable form. The second should prepare actual update instructions to the system. A synchronizing activity, called “Consistency check Legal Description / Rights” should make sure that the description’s changes relate to the Rights being updated.

A fully updated description, however, is dependent on the results of the updated cadastral map data. New spatial objects with new (parcel) identifiers, ultimately supplying the graphical representation of the Parcel, could be created or updated. Its legal description will only be useful when providing correct links to this updated objects. That is the purpose of the sequence starting with "Notify Cadastral component" activity and having send and receive events which communicate with the geometric component.

The $\ll$ *datastore* $\gg$ stereotype implies that some storing mechanism should be implemented, enabling that a time delay or a long transaction occurs before the activity "Establish definite Links with Cadastre" completes. The finalization implies two activities, one of update of the History Layer" and the other performing a final check in of the updated legal situation into the Land Registry.

Consideration of a specific "History Layer" can be implicit on certain implementations already supporting such functionality. However, the maintenance of a Chain of Title is considered a critical requirement for the Land Registry, so special attention should be paid to this requirement, at implementation time.

4.2.3 Iteration 2: Cadastral update

The Activity diagram on "Cadastral Map Update" begins with a validated technical document (see figure 4.4). This document has been validated through the preceding activity, as shown in the Use Case (level 1) diagram. This document is prepared by the Surveyor and shall contain references to the previous situation, the type of update being performed and identification of parties involved (the Surveyor itself; the Owners, etc.). Most importantly, this document shall contain all the details of the survey operation, which contribute to the update of the parcel(s) geometry and topology.

The first step is checking out of the current cadastral plan parcels. Those should be the ones identified in the technical document. An update is then performed on the specific spatial data objects which were modified. A choice is then made, if the document contains new Field Survey References, to update the Cadastral Triangulation[70]. A second choice respects the issue of new spatial objects identifiers, like the Parcel Identification Number or NIP[71].

Not every cadastral update requires the issuing of new ID's or new Cadastral Triangulation, that is the reason for inclusion of the two successive choices in the diagram.

As in the preceding Activity diagram, the procedure ends with a updated data to be checked in into the system, while the history layer regarding the cadastral plan shall be updated as described in the diagram note. The same considerations apply here, regarding possible implementation solutions.

It must be stressed that, contrary to what is found in current practice in Portugal concerning the Land Registry, the Cadastre has no recent specifications concerning a technical (survey) document involving a cadastral update. There is not even any

[70]Consisting of monumented points integrated on a lower order of the National Geodetic Network

[71]NIP: Portuguese for "Número de Identificação de Prédio"

institution regulating the issue of certificates which enable a Surveyor external to IGP to perform cadastral survey operations.

The process of institutional built-up, referred back in section 2.3, is not covered by this methodology or in the pilot project “Mira Municipal Cadastre”, however it will be very important for the consolidation of SINERGIC goals (see subsection 3.3.1). Regarding the technical document, a study of similar documents existing in other countries led to a proposal inserted in Annex D, on the pilot project results.

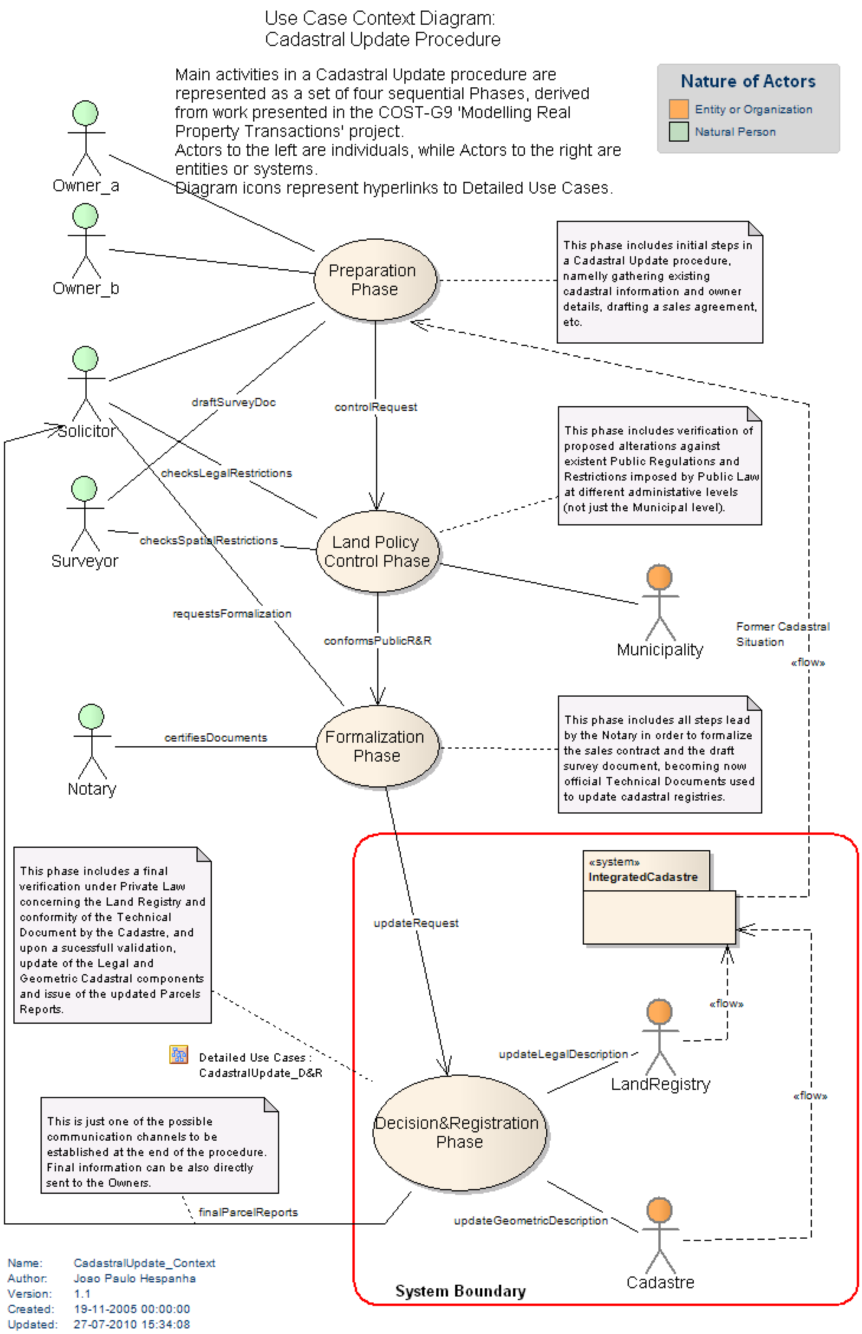


Figure 4.1: *Use Case Context Diagram: Cadastral Update*

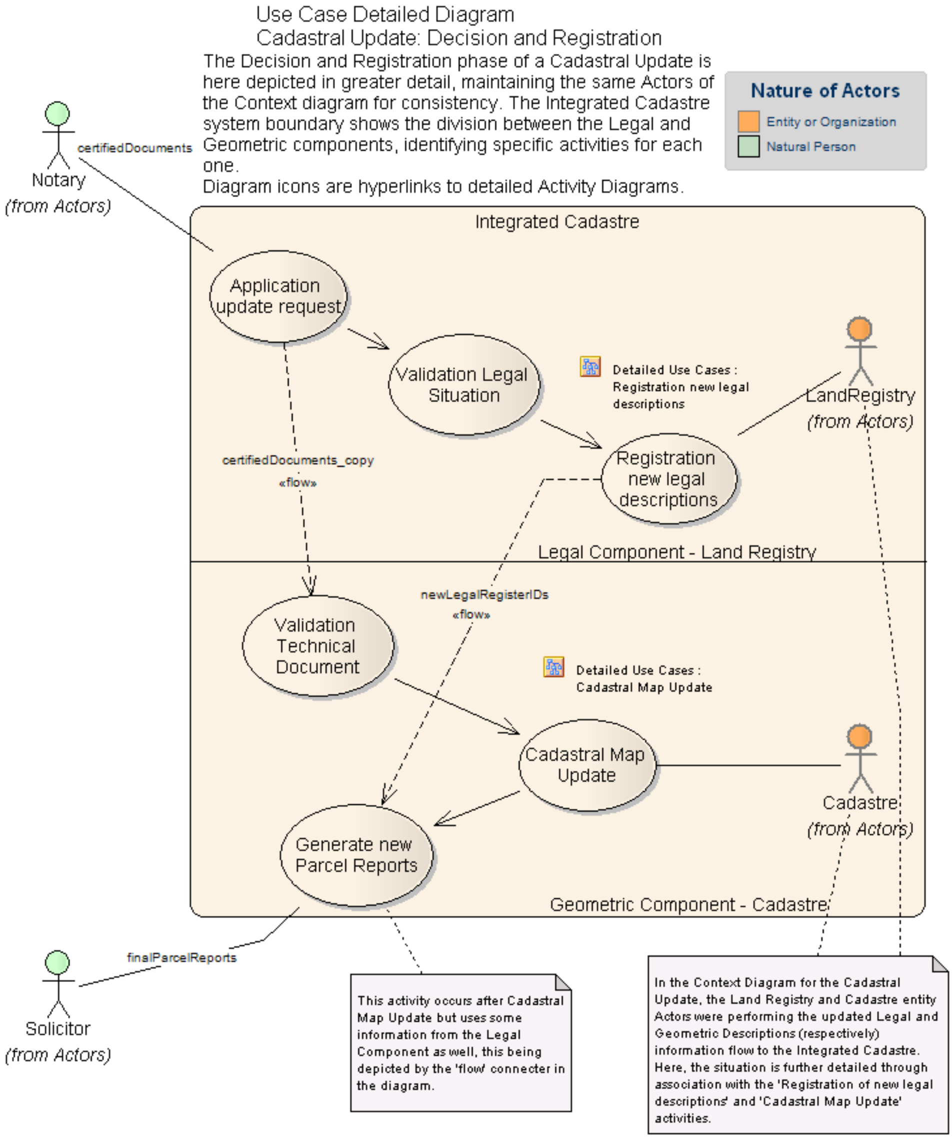


Figure 4.2: *Use Case Level 1 Diagram: Cadastral Update - Decision and Registration*

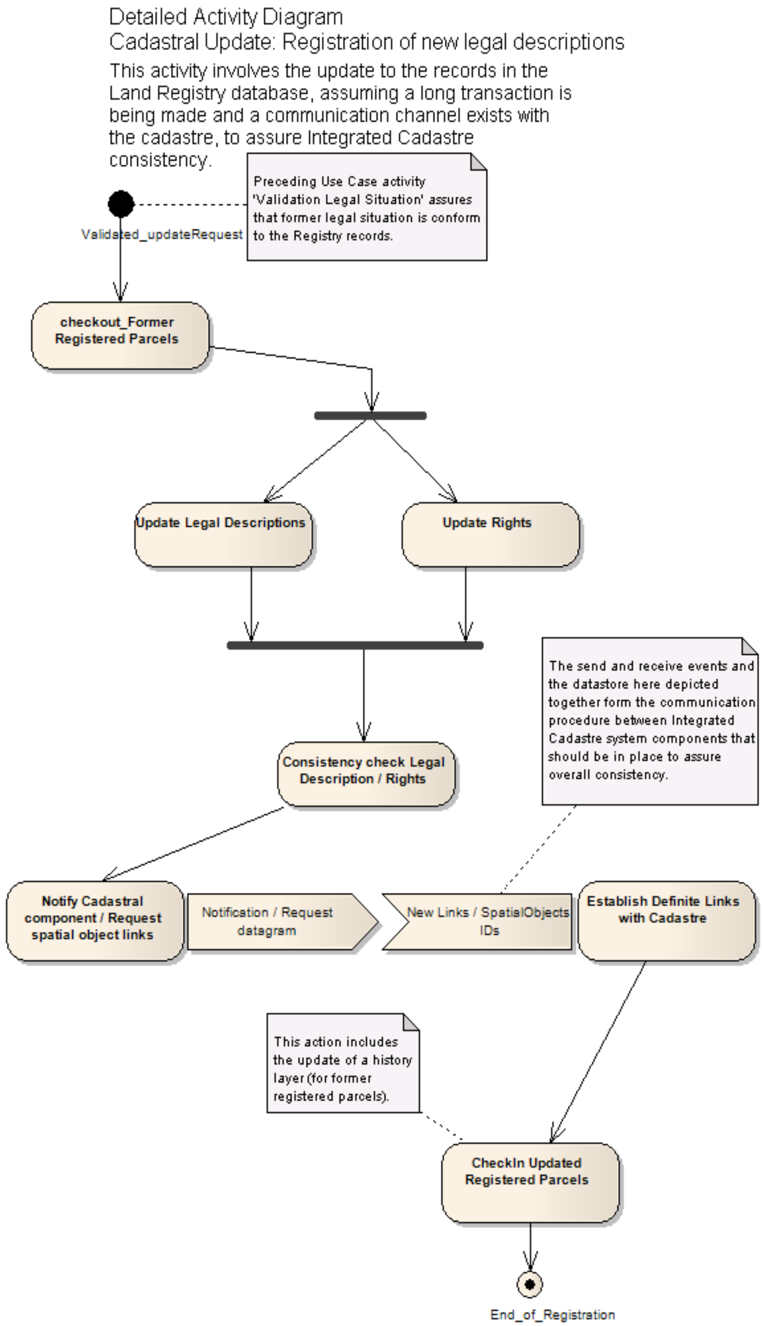


Figure 4.3: *Activity Diagram: Cadastral Update - Registration of new legal descriptions*

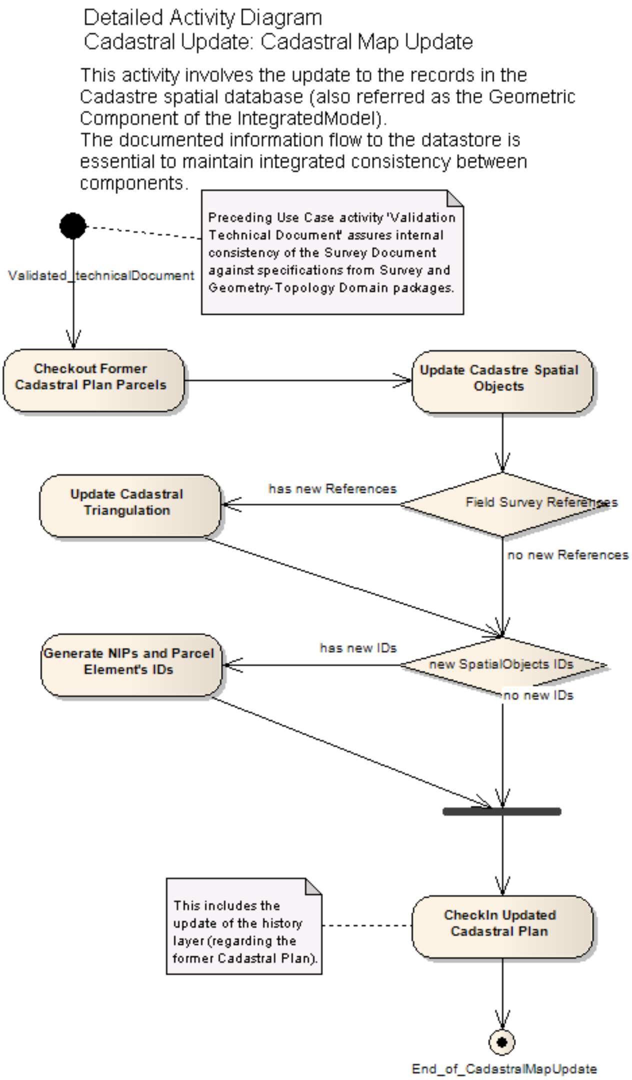


Figure 4.4: *Activity Diagram: Cadastral Update - Cadastral Map Update*

4.3 Deriving a country model

Before a detailed and systematic account is given on the procedure of developing the specialized country model for Portugal (LADM_PT) based on LADM, a table is presented which summarizes the main aspects and differences between the approaches taken by each of the other reported country models, respecting Iceland, Queensland State in Australia and the Canadian First Nations Indian Land Registry. A summary text was prepared for each country and included in subsections (F.1, F.2 and F.3) of Annex F.

As can be seen from the reported country models examples, each one has a particular key drive leading the respective research efforts and resulting documentation. These are:

- Iceland: Implementation of a model driven cadastre (geometric component);
- Queensland: Integration of 3D Parcels; Implementation of Spatial Profiles;
- Canada: Reconciliation of legal and geometric records; Integrated Cadastre.

The methodology comparison table (4.1) lists, in its first column, a generic description for a methodology phase which could be abstracted from the study of the country models development, and which are (all of them) present in the development methodology (see tables 4.2, 4.3 and 4.4). The difference is that the development methodology based on the Portuguese country model is described at a more detailed level and reports on specifics introduced by the Unified Process and Model Driven Architecture.

Each one of the following columns in table 4.1 briefly explains which were the main activities taken in the respective country models development (respectively for Iceland, Queensland and Canada), related to the generic description. The differences reflect, not only different key drives as above referred, but also different departure points, e.g. the Icelandic model is an early prototype still based in CCDM, while the other are already based in LADM.

The diversity of contexts and reported experiences from such country models supply complimentary aspects and can even enrich the LADM with useful (possibly) generic profiles and modelling patterns.

4.3.1 The Portuguese country model, LADM_PT

In this subsection, the development methodology which has been used in order to derive the Portuguese country model, identified by the acronym LADM_PT, is presented under two different views. First, a set of tables (4.2, 4.3, 4.4) will supply an overview of all the phases and activities considered to be within the research scope, with some additional recommendation of phases to be completed in the future. Then, a text template (p.133) will present detailed descriptions of each phase, together with a few critical questions to be answered by the researcher or a *country model design and implementation team*. It must be explained at this time that the study and

Generic Description	Icelandic Cadastre Model	Queensland DCDB	Canada CLSR/ILR
Legal framework requirements	Land Registry RRR & forms of property	RRR stored in DCDB	23 property regimes to be integrated
Land Administrat. structure and dynamics	Described with Use Cases; Transaction and subdivision	No further studies; implicit in DCDB	Land Management system is briefly described
Use of existing models	Reverse engineering (legal component)	Mapping tables to classes	Indian Land Regst. and Canada Lands Survey Records
Check current data availability	Spatial units' data sources	No need (data exists)	Data exists (but needs integration)
Decide which spatial profiles to use	Methods representing spatial location (no profiles then)	Unstructured & profile for volumetric parcels	Use is not explicit
Structure of Spatial Units / Levels	Planar and non-planar partitions	Planar (topo-base) & non-planar partition	Base layer and overlapping "Limited Right Areas"
Inclusion of Survey data	Planar partition associated to survey classes	Not included in the implementation	Uses LADM based classes, incl. spatial source doc.
Association to Legal/Adm.Classes	Associated to existent Land Registry classes	Specializations from LADM and new enumerations	Reconciliation procedures, e.g. "cardex holdings"
Implementation Test	Open source based prototype	Java abstraction layer from DCDB data	Unknown details
Country specific topics	No previous spatial component	Implementation of volumetric parcel	Reconciliation of registries

Table 4.1: Deriving Country Models: Methodology Comparison Table

report of the goals and methods applied in order to achieve the country models for Iceland, Queensland DCDB and Canada ILR, gave an important contribution to the development methodology here presented, and mainly a validation in the order and contents of some phases, specially in the case of Iceland, where the goals were closer to the ones in Portugal: to improve the geometric component of the cadastre, while supporting the integration with the Land Registry.

The development methodology received contributions from the Land Administration Domain Model and its consideration for the use of so-called profiles[72], the Unified Process and the Model Driven Architecture as software development methodologies, the consideration for the different aspects of a Land Registry system (by Zevenbergen,

[72]Strictly speaking, and according to OGC, these should be considered UML Modelling Patterns instead.

(2002)) and the initial conceptual model for the legal domain (by Paasch, (2005)). Details on these contributions, namely key terminology which is used in the following table and text descriptions, were already introduced in chapters 1 and 2.

Level of Detail	**Phase.-Activity**	**Deliverables**	**Short Description**
Highly Conceptual	1.0	Inception: Unique iteration; Domain Model	Consideration of LADM core classes as a conceptual description of the domain of Land Administration
Generic	2.0	Context Use Cases; Append to model	Capture critical requirements for an Integrated Legal Cadastre, considering three main aspects:
Generic	2.1	(part of) Use Case	Technical: main organization and system actors (software or paper-based)
Generic	2.2	(part of) Use Case	Legal: organizations responsible for the basic legal framework and related forms of property
Generic	2.3	(part of) Use Case	Administrative: actors responsible for critical activities as first inscription and cadastral update
Generic	3.0	Inception: business plan	Documenting generic functionality of the system main actors and activities
Generic	4.0	Inception: iteration and development plan	Decision on iterations to perform and required resources
Detailed	5.0	Elaboration: iteration 1	Focus on each of the identified cadastral components. The first should be the geometric component
Detailed	5.1	Use Cases and Activity Diagrams	Detail the Use Case concerning core activities pertaining to the geometric component
Detailed	5.2	Design Model: geometric component PIM	Examine legacy or non-LADM country models for the geometric component and produce a UML model to integrate
Detailed	5.3	LADM spatial profiles (adapted)	Decision about which spatial profiles are best suited for the geometric component of the country model
Detailed	5.4	Complete design model: geometric component	Decision on which levels to group spatial units and which interdependencies exist between them

Table 4.2: Development Methodology for an Integrated Legal Cadastre - Part 1

Level of Detail	**Phase.-Activity**	**Deliverables**	**Short Description**
Highly Detailed	5.5	M2M Transformations	Verify compatibility between the country model and LADM and keep the models in synch
Highly Detailed	5.6	M2T Transformations or ORM Mappings	Test the implementation of the geometric component into a specific Spatial Data Base
Highly Detailed	5.7	UI Prototype	Produce a prototype UI with basic functionality serving the component data core
Detailed	6.0	Elaboration: iteration 2	Focus on the development of the second component, that should be the Legal and Administrative
Detailed	6.1	Use Cases and Activity Diagrams	Detail actors and activities related to the legal status of spatial units, assuming basic procedures identified in 2.3
Detailed	6.2	Design Model: Legal&Adm. component	Examine legacy systems and further study the existing legal and administrative framework for the cadastre. Existent models have to be expressed in UML for integration
Detailed	6.3	Domain Model: Legal&Adm. profile	Consider the adoption of the LADM Legal&Adm. profile as a basis to define specialized country classes
Detailed	6.4	Complete Design Model (for the component)	Decision on which other forms of property to consider to extend the model in the future / during Construction
Highly Detailed	6.5	M2M Transformations	Verify compatibility for the Legal&Adm. component and keep the models (component) in synch
Highly Detailed	6.6	M2T Transformations or ORM Mappings	Test implementation of the Legal&Adm. component to the Data Base chosen in 5.6 (possibly other)
Highly Detailed	6.7	UI Prototype	Produce a UI prototype with basic functionality to serve the Legal&Adm. data core

Table 4.3: Development Methodology for an Integrated Legal Cadastre - Part 2

Level of Detail	**Phase.-Activity**	**Deliverables**	**Short Description**
Detailed	7.0	Elaboration: iteration 3	Integration of the design model: previous two components should become a single country model
Highly Detailed	7.1	Transformations Chain	Test the integrated model for the complete transformations chain (from LADM and legacy to implemented data schema)
Highly Detailed	7.2	Instance Level Diagrams	Document the integrated model with a number of instance level cases (depicting as much real life cases as possible)
Detailed	7.3	OCL File	Collect all component and integrated model OCL constraints into a file which can be processed
Detailed	7.4	OCL to code (generation)	Constraints can be implemented to the abstraction layer (e.g. Java code) or to a SQL script
Detailed	8.0	Construction: iteration and development plan	Prepare a plan for the following UP phase of Construction, identifying required resources
Varying	9.0	Design and Data Models, Transformations and UI's	Support Municipal land administration activities, e.g. issuing building and habitation permits
Varying	10.0	Idem	Implement web services (standard WMS or WFS)
Varying	11.0	Idem	Dedicated, map based edition layer for a specific GIS API
Varying	12.0	Idem	Cartographic data model, including feature portrayal defined according to ISO 19117

Table 4.4: Development Methodology for an Integrated Legal Cadastre - Part 3

The following paragraph presents the text template which is used in order to describe the different phases of the development methodology in detail.

The first line identifies each Phase and Activity within each Phase, using two integers separated by a point. Next to the numbering, a short title describes its main goal. Each activity is detailed then through a list of three items describing: Any deliverables (UML Diagrams or other documents) resulting from the activity and where they can be found in the Thesis; Pertinent questions to consider, which should guide the modelling of the specific country model being developed; A detailed description of the Activity contents concludes the template. Following paragraph shows a schematic description of the template.

Template for the Development Methodology description

Phase.Activity Short Title for the Phase
List of items describing each Phase.Activity:

- LADM_PT Deliverables and references to where they can be found;
- Pertinent (critical) questions to consider in the Phase.Activity;
- A detailed description, with references to relevant sections of the Thesis.

1.0 Use of the Domain Model

- LADM_PT Deliverables: LADM core and foundation classes imported into the model project;
- Pertinent questions: Do the stated research pre-requisites and the scope fit within those identified for the proposed system?;
- Detailed description: The Land Administration Domain Model is the main contribution and the starting point to consider in the derivation of a country model for the cadastre. The LADM is however sufficiently generic to allow for development paths which are not covered in this research. This way, in order for the development methodology be applicable to another country model, the pre-requisites listed in 1.1 should be verified, together with the country model scope. This scope, re-stated according the Unified Process principles, reads as follows: Elaboration of the core architecture of a cadastral system integrating the geometric (cadastral survey and mapping) and the legal components (land registry). The core architecture respects the specification of design and data models for the critical components of the system, and a demo implementation on the platform of choice. It is considered here that the critical components are those defined in the Domain Model, extended with the functions required to maintain (update) them.

2.0 Producing the Context Use Case

- LADM_PT Deliverables: Context Use Case diagram, see figure 4.1;
- Pertinent questions: Which are the main actors (organizations and systems) involved with the country's cadastral system?;

- Detailed description: The goal of this phase is to capture the critical requirements for the geometric and legal components, by identifying their main actors and those at the interface of the system, as explained in subsection 4.2.1. The context Use Case diagram is best achieved by considering the case of a cadastral update involving changes to both geometrical and legal components, and shall be examined under the Technical, Legal and Administrative aspects, as referred in the following activities.

2.1 Technical aspects of the Context Use Case

- LADM_PT Deliverables: Included in the Context Use Case diagram referred in 2.0;
- Pertinent questions: What are the components (systems, regulations) of the technical infrastructure of the country's cadastral system?;
- Detailed description: The main actors of the country's cadastral system should be examined for their existing technical infrastructure. Different software or paper-based sub-systems can exist for the components of the cadastral system, and they should be depicted in the Use Case diagram, together with the information flows between them. It is critical at this point to check for the existence of published data models for any of the identified sub-systems, given this can be a major contribution which can speed up the whole procedure. However, care should be taken at the up-to-datedness of that information, namely concerning current or new requirements.

2.2 Legal aspects of the Context Use Case

- LADM_PT Deliverables: Included in the Context Use Case diagram referred in 2.0;
- Pertinent questions: What are the main institutions and organizations responsible for the legal framework concerning immovable property?;
- Detailed description: The main actors of the country's cadastral system should be examined for their governing legal framework. In this aspect, it is important to check for the sources of legislation concerning the creation and modification of rights upon immovable property and regulations concerning the country's land registry. It is easer, from a modelling perspective, if any of this legislation has been *codified*, that is, organized in a systematic way.

2.3 Administrative aspects of the Context Use Case

- LADM_PT Deliverables: Included in the Context Use Case diagram referred in 2.0;
- Pertinent questions: What are the main actors and information flows involved in the critical activity of cadastral update?;
- Detailed description: Given the context Use Case main cenario of cadastral update, the main actors should be examined for any administrative procedures describing this activity. The examination of such documentation can eventually identify additional actors, possibly at the interface of the cadastral system, which were not captured in the preceding activities.

3.0 Cadastral system business plan

- LADM_PT Deliverables: Not developed so far;
- Pertinent questions: Which is the main functionality to implement in the renewed system and the main actors and information flows to consider within the scope of the system?;
- Detailed description: The business plan consists in a generic outline of the proposed renewed system, describing the main functions to implement and including the information gathered in the context diagram. This should be complemented by a textual description (usual a template is used) for the Use Case.

4.0 Iteration and development plan

- LADM_PT Deliverables: Check for phases (and their activities) 5 to 7;
- Pertinent questions: What are the resources (human, material, financial) and the time frame available to develop the core architecture of the cadastral system?;
- Detailed description: This phase consists in the tasks performed in order to conclude the UP's Inception phase and prepare for the next phase of *Elaboration*. Depending on the identification of the resources which will be available during Elaboration, and the description of the critical requirements summarized in the business plan, a decision should be made concerning the number and goals of iterations to perform. A project plan is useful at this phase, allocating resources to each iteration activity. There should be a single organization with the mandate to execute this (and subsequent) phases, where all the main actors participate. In Portugal, this corresponds to the SINERGIC project. Also, external resources and costs should be identified in the plan, given that the required expertise may be absent from the involved organizations.

5.0 Development of the core of the geometric component

- LADM_PT Deliverables: Spatial Unit, Representation and Surveying packages in LADM_PT model. These packages are described in 4.4 and the complete set of diagrams are in annex A;

- Pertinent questions: Consider the questions included in the corresponding activities (5.1 to 5.7);

- Detailed description: The core architecture of the geometric component should be implemented during this iteration, through the consideration of context and more detailed requirements which are country specific, and the corresponding packages of the domain model, LADM. The iteration activities consider not just the UP and MDA methodologies, but also details concerning the definition of the geometry (and topology) of features, imposed by the domain model. Depending on the existence of previous legacy systems or more modern models formalized in UML, activities of reverse engineering and models integration (or merge) should be considered.

5.1 Detailed use cases for the geometric component

- LADM_PT Deliverables: See Detailed Use Case diagram in 4.2 and Activity diagram in 4.4;

- Pertinent questions: Which are the specific actors and activities involved in the update of the geometric component for the critical case of cadastral update?;

- Detailed description: The specific requirements concerning the geometric component, in a cadastral update procedure, should be identified through a detailed Use Case description, complemented with Activity diagrams, further documenting the actions that shall be completed in order to obtain a full geometric description of new or modified parcels.

5.2 Integrate country models (geometric component)

- LADM_PT Deliverables: An Enterprise Architecture model file, with relevant information translated to English. This has been based in the published IGP data model in (IGP, 2009).;

- Pertinent questions: Are there any country level published data models concerning the elements in the geometric component? Which software architecture are they using? (that is, could an UML class diagram be directly obtained or obtained e.g. by applying reverse engineering a data base schema?);

- Detailed description: In order to include already processed country requirements, in the form of a set of modelling elements, the organizations responsible for the geometric component should be examined for the existence of published data models, even if they are not expressed using the same language and standards of the domain model. The current CASE / MDA tools are capable of converting from a number of legacy modelling languages and data models, through a reverse engineering procedure. Although requiring more expertise, it is possible to define a dedicated procedure for a more unusual country data model.

5.3 Use of LADM Spatial Profiles

- LADM_PT Deliverables: Spatial profiles included in the geometric component, namely the Simple Features for SQL Polygon profile and the unstructured or line based profile.;
- Pertinent questions: Considering the different spatial features (in the form of classes with geometry) identified previously in 5.1 and 5.2, which is (/ are) the most convenient LADM spatial profile to use? Note that different spatial features can use different spatial profiles;
- Detailed description: The domain model offers, for added flexibility, different forms of structuring the geometric component spatial features within a given country profile, through the use of one or more *Spatial Profiles*. Upon identification of the different spatial features to be acquired in the country model, and their spatial characteristics of coordinate and vectorial dimensions, together with their intra-class topology, a decision should be made concerning the best profiles to use. Although the existent profiles in LADM will cover the majority of cases, it is possible to define more profiles in future versions of LADM. The derivation of the country model can also impose specific constraints in elements of an existing profile, or add new elements, which can obviate for the need of a new spatial profile.

5.4 Geometric component Level Diagram

- LADM_PT Deliverables: LADM_PT Level and Inter-Level Diagrams, see figures 4.7 and 4.10;
- Pertinent questions: Which of the country's spatial features can use the elected spatial profiles, and what are the topology relations to enforce between these groupings?;
- Detailed description: It will be usual to have several spatial features using the same spatial profile to store and maintain their geometry. However, there could be the case where specific topology relationships are to be enforced between

these different features. In this case, LADM offers the concept of *Levels*, which should be used to formalize such groupings and define the specific constraints (topology or other) to impose between the elements in different levels.

5.5 Define Model to Model Transformations

- LADM_PT Deliverables: Yet to be developed;
- Pertinent questions: Which set of automatic modelling transformations between the input models and the output country model can be defined using the QVT standard language?;
- Detailed description: The Model to Model (or M2M) transformations are an integral part of the MDA methodology and can be used in this context having two goals in mind: 1. To test and validate the compatibility of the final country model with the domain model, by formalising the mappings between the two and 2. To enable for data conversions between the two models, considering one abstract level which can be further taken to instance level (referring to instance data). In the majority of cases, the LADM itself will not be the only input model, but must be merged or integrated with an existent country model (as in 5.2).

5.6 Geometric component implementation

- LADM_PT Deliverables: LADM_PT Hibernate Configuration and Data Base schema in PostGIS (see figures 5.12 and 5.14);
- Pertinent questions: Which specific software platform should be used that supports the data model specifics (namely standard data types and constraint checking)? Note: the actual decision can be restricted by the Object-Relational Mapping (ORM) software to be used;
- Detailed description: A Model to Text (M2T) transformation is the MDA solution to this specific methodology activity. There are currently so-called *Generators* which can transform model elements into specific code as Java, C++ or SQL, the last one being specially relevant in this case. The alternative in LADM_PT was to use a ORM solution which defines individual mappings between the model elements: a Java abstract layer where further applications can be linked, and a spatial data base (requiring the Hibernate-Spatial libraries). The obtained data schema is, in this case, the equivalent of the MDA Platform Specific Model. The UML class diagram and Java abstract layer which form this activity input Platform Independent Model could be published by the responsible organization, so that third parties could define their PSM (on a particular data base) from a verified source.

5.7 Geometric component prototype

- LADM_PT Deliverables: uDIG project connecting to the PostGIS spatial data base ;
- Pertinent questions: Which core functionality to implement on top of the geometric component data schema in order to test the resulting implementation?;
- Detailed description: The purpose of the first iterations in the methodology is to develop working prototypes which will be at the critical core of the system. The resulting deliverable should then be tested by an enlarged user team, and test results can be addressed in the following iterations. Obtaining working components of the system at early stages is one of the advantages of including the UP methodology.

6.0 Development of the core of the Legal and Administrative component

- LADM_PT Deliverables: Legal and Administrative package, as reported in 4.5;
- Pertinent questions: Consider the questions included in the activities 6.1 to 6.7;
- Detailed description: The core architecture of the system is not complete without addressing the legal and administrative component, as conceptually defined by the domain model and related profiles. It is expected that critical requirements concerning the legal framework and related administrative procedures, for a country, can be already present in an integrated country model. However, this is not the assumption followed in this research, where no data model depicting real rights and other land related administrative data was available. For this reason, the legislation and regulations concerning the Land Registry (and possibly, other organizations, e.g. administering land use) should be further studied, so that, together with LADM Legal and Administrative profile, the component can be detailed to a level where can be integrated with the geometric component prototype resulting from the previous phase.

6.1 Detailed Use Cases for the Legal&Adm. component

- LADM_PT Deliverables: See detailed Use Case diagram in 4.2 and the Activity diagram in 4.3;
- Pertinent questions: Which are the specific actors and activities responsible to maintain the legal status of immovable property, given the critical cases of cadastral update or first inscription?;

- Detailed description: The context level use case should be complemented with one or more levels of detail concerning the legal and administrative component activities, so that any additional actors or systems interfacing with this component (typically represented by a Land Registry) can be identified. Depending on the previously defined scope for the system (and development plan), additional registers could be also examined for future integration into the system (e.g. mining rights). Due to their complexity and specifics, it is recommended that they should be developed through a separate iteration.

6.2 Integrate legacy models for the Legal&Adm. component

- LADM_PT Deliverables: Report on backgrounds and current practice of the Land Registry and Administrative aspects of Land Administration in Portugal, in 3.2.2 and 3.3.2;

- Pertinent questions: Which real rights and administrative actions are to be registered and in relation to which geometric component spatial units? Are there existing country data models depicting these elements?;

- Detailed description: Depending on the level of previous integration between the geometric and legal and administrative components in the country, this activity can be achieved relatively fast, or it can take additional steps in order to reach the same level of concepts as in LADM and the geometric component. In the case of Portugal, at the time (year 2007) there was no such model, and this has lead to the proposal in the article (Hespanha et al., 2009). The focus of the study should be limited to the forms of property addressed by the land registry and the classification and enumeration of the specific rights, by examining the Land Registry Code. Simple and more complex administrative procedures should drive the study of existent documents and practice, e.g. first inscription, split and sale of a parcel (detachment) or a re-allotment, as defined in the previous activity.

6.3 Use of the LADM Legal&Adm. profile

- LADM_PT Deliverables: LADM_PT Legal&Adm. component used the corresponding profile from LADM in order to define its specialized classes;

- Pertinent questions: What is the legal foundation of the country's immovable property framework? What is the main form of property right considered to define the basic administrative unit? Note: if above answers are Continental European (civil code) foundations and private property, then the LADM Legal&Adm. profile shall be used;

- Detailed description: Given the proper requisites, as defined above, the LADM Legal&Adm. profile will provide a modelling framework which is integrated into LADM and is at a level of detail from where specific country classes respecting rights, restrictions and responsibilities, administrative source documents and other modelling elements can be defined.

6.4 Complete Legal&Adm. component design model

- LADM_PT Deliverables: Initial modelling for Public Domain classes, see the basic diagram in 4.11;
- Pertinent questions: Are there other forms of property in the country which are presently without of the scope of the system but could be integrated in the future?;
- Detailed description: Considering the classical scope (adopted in this research) of integrating the legal and administrative components related with the Land Registry and thus affecting just private property, and depending on the legal framework, significant parcels of the territory can be left uncovered. This meaning that more than one, possibly loosely integrated system, have to be queried to obtain the situation of a given spatial unit in a country. The LADM and its Legal&Adm. profile support the definition of other forms of property, like the Public Domain or communal lands, which, depending on their relevance, can be later integrated and implemented (e.g. during Construction).

6.5 Define component's Model to Model Transformations

- LADM_PT Deliverables: Not developed;
- Pertinent questions: Which set of automatic model transformations can be defined using QVT, for the Legal and Administrative modelling elements?;
- Detailed description: These set of transformations have the same generic goals as defined in 5.5 and can eventually consider the integration of LADM Legal&Adm. profile with a legacy country model for the Land Registry. The output should be (part of) the country model Legal&Adm. component, in the form of a PIM ready for implementation.

6.6 Legal&Adm. component implementation

- LADM_PT Deliverables: Not developed;

- Pertinent questions: Is the software platform used for the geometric component capable of handling the data model elements identified in this component? Will this component be implemented in an autonomous data base (from the geometric component)?;
- Detailed description: As referred in 5.6, a Model to Text transformation or a ORM mapping application can be used in this activity. In the last case, and if the Hibernate solution is used, then there will be no need to use Hibernate Spatial libraries, for there are no spatial data types in this component. The implemented result shall consist of a code abstraction layer and a data base schema.

6.7 Legal&Adm. component prototype

- LADM_PT Deliverables: Not developed;
- Pertinent questions: Which core functionality concerning the query, creation or modification of the legal description of each basic administrative unit, should be implemented in a demo prototype?;
- Detailed description: A working prototype for the Legal&Adm. component should be the final result of this iteration. This should be tested by an enlarged user team including staff from the Land Registry, and corrections shall be done at this phase, or considered for the next iteration (Phase 7), specially if respecting also the geometric component.

7.0 Integrated model core implementation

- LADM_PT Deliverables: Overview diagram for LADM_PT, in A.4;
- Pertinent questions: Consider the questions included in the activities 7.1 to 7.4;
- Detailed description: While there are advantages in the separate development and rapid prototyping of the geometric and the legal and administrative components, the final goal is to obtain an integrated model, which can be implemented into a specific software platform. The following activities describe additional steps to be taken to integrate the two components, specially considering the associations and constraints existing between them, mostly via the basic administrative unit class.

7.1 Define an integrated transformation chain

- LADM_PT Deliverables: Not developed;

- Pertinent questions: Can the component transformations be combined into a single, integrated transformation (with additional transformation mappings)? Can the two different types of transformations be chained, in order to trace elements from initial domain model to the final implementation?;
- Detailed description: There are two required steps for this activity. First, the model file should be integrated, considering the associations and constraints to be defined between the different packages. Second, the transformation scripts should be merged, and additional elements be defined, in order to test the transformation of the integrated model from LADM (and related profiles) and legacy models to the final integrated country model. Two deliverables should result from this activity: a PIM integrated country model and a PSM integrated data schema.

7.2 Document with instance level diagrams

- LADM_PT Deliverables: Refer to the diagrams in section A.3;
- Pertinent questions: How will the integrated model answer specific country cases related with the most common situations involving immovable property? Note: for a start, the instance level diagrams included in LADM can serve as a generic guide;
- Detailed description: In order to support discussions between the development teams and the user test teams, and also for documentation and dissemination into a wider audience, a relevant number of day-to-day situations (preferably supported in real data) shall be described by producing instance level diagrams based on the integrated model PIM. They can also be a further test to individual PSM, if more than one implementation is expected.

7.3 Generate an integrated OCL file

- LADM_PT Deliverables: Yet not developed (examples will exist for the geometric component);
- Pertinent questions: Which constraints were expressed during the modelling phases, for each individual component, and considering the integration between the components? Note: these constraints have to be expressed in the standard OCL language and can respect properties, methods or associations in the country model PIM;
- Detailed description: Modelling constraints can be passed by a legacy system or a previous country model. If not, they should be included in the country model PIM, preferably already expressed in OCL. They define constraints that

otherwise can not be modelled using UML alone, and as such are essential to further validate data input and results obtained from the system operation. All the types of OCL constraints should be collected for each package into a single file, to be tested in the following activity.

7.4 Validate and implement OCL constraints

- LADM_PT Deliverables: Yet not developed (see note in 7.3);
- Pertinent questions: Are the OCL constraints valid against the country model? Can they be implemented to the final PSM and corresponding software platform?;
- Detailed description: The collection of OCL constraints for the integrated model should be validated through the use of existing CASE tools, and corrections should be done in case of errors. They can then be implemented, theoretically using two different methods: 1. Generate Java classes which can then be associated with the abstraction layer or 2. Generate SQL scripts to be run against the final data schema. As it is expected that not all constraints can be implemented this way, it is recommended to attach the OCL file to the specific PSM's so that a future implementation team decide the best way to implement them into the chosen software platform.

8.0 Construction development and iteration plan

- LADM_PT Deliverables: See final recommended phases (9 to 12) in table 4.4;
- Pertinent questions: Apart the core architecture components already developed, which are the remaining components to be developed in order to achieve a full operational system? Which additional resources are needed for the system conclusion?;
- Detailed description: The implementation of the core architecture data schema and associated basic actions and check constraints, although already presenting basic functionality and prototype interfaces, it is not yet a fully functional system which can be used by all the actors identified in the early use cases. Considering, namely, a modern Spatial Information Infrastructure, it is expected that at least part of the data be served through standard web services. This development corresponds to the *Construction* UP phase, and a number of corresponding iterations should be designed and planed for the provision of adequate resources, similarly to what has been done in phase 4.

4.4 Modelling the geometric component of LADM_PT

The first package to be developed in the Portuguese country model LADM_PT, respects the geometric component of the cadastral system. In the domain model (LADM), this corresponds to the *Spatial Unit* package, which includes the *Spatial Representation* and the *Surveying* sub-packages, as described in 2.6.2.

In order to produce this package and besides the domain model packages and sub-packages, providing the parent classes and structure for the country's specialized classes, two other modelling sources were also considered: 1. The class model included in the new Portuguese Cadastral Data Model (called PT_CDM, described in (IGP, 2009, p.16-58)) and 2. The LADM spatial profiles included in Annex E of ISO 19152 DIS document (ISO/TC211 Geographic Information / Geomatics, 2010, p.73-77).

The specialized classes and other UML modelling elements here reported were obtained by manual derivation from the identified sources, and did not use any form of MDA model transformations or any type of CASE tools. Results obtained using existent CASE tools, for a subset of the spatial unit package of LADM_PT, will be reported in the subsection 5.3, with further results reported in section 5.3.

This section will report on the LADM_PT spatial unit package, beginning with a subsection that describes the two specific spatial profiles which were used and why they were chosen (4.4.1) and a subsection reporting on the individual spatial unit specialized classes created for the country model (4.4.2). This last subsection is divided into two paragraphs, the first reporting about the structure of instances of the LADM *LA_Level* class which were considered for the country model, and a second paragraph about the description of the specialized classes, including required constraints to be modelled and eventually, implemented.

4.4.1 LADM Spatial Profiles in the country model

In its DIS version, the domain model defines a total of six *Spatial Profiles*, which represent specific arrangements of LADM *Spatial Unit* and *Spatial Representation* classes. Each spatial profile defines what are the classes and attributes to consider for a specific type of spatial representation, including the case where the spatial units do not have any type of geometry attribute, but they use instead a textual description of location, stored as a character string (the *2D Text based* spatial profile).

The Portuguese country model LADM_PT, although currently and in the mid-term future there will be a substantial number of fiscal and legal records using textual descriptions of location, does not implement the 2D Text based spatial profile. The reason is that it inherently assumes that any data collected and uploaded to the system is acquired through a cadastral survey operation defined according the SINERGIC framework, and thus there will be always geometry data attached to the spatial units.

It is equally assumed that the first operational version of SINERGIC will not consider as well any tri-dimensional representation of spatial units, which rules out the *3D Topological based* spatial profile.

From the remaining four spatial profiles in LADM, and considering the purpose and contents of the Portuguese cadastral classes in PT_CDM, it was decided to use two different spatial profiles, on the following grounds:

- *2D Polygon based*: This profile admits a bi-dimensional coordinate space where each spatial unit forms a polygon using a closed boundary curve or any number of boundaries forming a closed figure. Does not require that a planar partition and corresponding topological relations are made explicit. This way, it admits that individual spatial units can overlap each other, or that the area covered by a cadastral survey can have gaps, that is, spaces which do not have any information. This is precisely what happens with some LADM_PT spatial units, so this spatial profile was preferred over the topological and the remaining profiles;
- *2D Unstructured (line) based*: This profile also uses boundary curves, but does not impose that these will necessarily form closed figures (polygons), and can also define a situation where a given boundary can be used (parts of) by different spatial units. These properties turn the line based spatial profile the most indicated for the *Deferred Cadastre* specialized type of spatial unit, where it is expected that incomplete survey information can be collected, but nevertheless should be stored in the system.

These spatial profiles and corresponding class diagrams are described in the following paragraphs.

The SFS Polygon Profile

The original Polygon Profile in LADM uses the more generic specification of a GM_MultiCurve to define the geometry type attribute of the LA_BoundaryFaceString class. This specification belongs to ISO 19107 Spatial Schema (ISO/TC211 Geographic Information / Geomatics (2003a)) and defines an aggregate of one or more GM_OrientableCurve types, which is limited, through the LADM spatial profile, to a 2D coordinate dimension. The ISO 19107 specification allows for a number of different geometric interpolations to define a curve from their primitives (a sequence of points).

Taking into consideration that the LADM_PT country model should be tested upon a spatial data base implementation, and that the majority of current data base management systems supporting spatial data use the *Simple Features for SQL* profile to implement their spatial types according to ISO 19125 (ISO/TC211 Geographic Information / Geomatics (2004)), the original LADM spatial profile was adapted in order to use the ST_MultiCurve type instead.

This means that the only allowed type of geometric interpolation is the linear interpolation between each pair of point primitives, and also that any type of constraints imposed on the geometry and topology of the LA_BoundaryFaceString class should use the methods and attributes of the ST_MultiCurve type as defined in ISO 19125.

The corresponding class diagram for the Polygon SFS profile, in 4.5 shows the three classes from LADM spatial unit package which are required to define specialized spatial unit classes, according this profile. The diagram shows all the attributes which

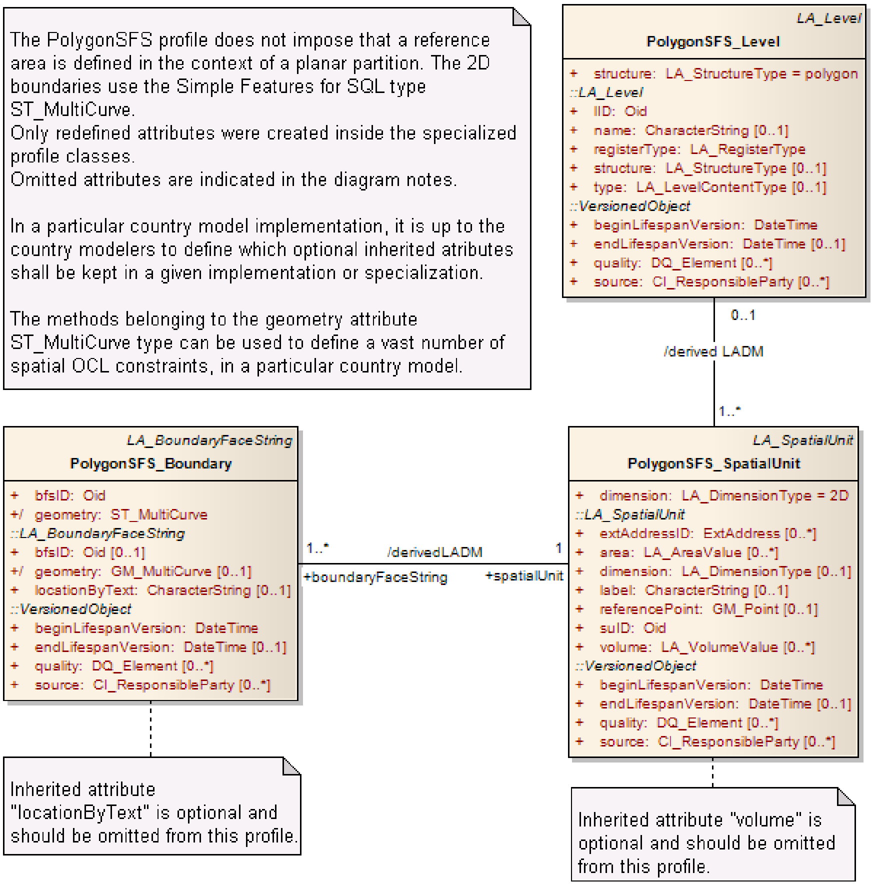


Figure 4.5: *Polygon Simple Features for SQL spatial profile* Source: ISO 19152 DIS, adapted.

are inherited by the classes, the attributes which are redefined within the profile, and as attached notes, the attributes which are of optional use in LADM and that should be omitted from any country model using this profile.

The following list of items describes the purpose and associations of each class, within the Polygon SFS profile[73] (see figure 4.5):

- PolygonSFS_Level: This class defines the geometry structure to be polygon, according LADM LA_StructureType code list, imposing that any spatial unit associated to this level uses the profile definitions. It also defines to which register type the spatial units should belong, and (optionally) the type of content in the level, according to the LA_LevelContentType code list. The joint

[73]As these classes belong to an informative annex in LADM, they do not have the "LA_" prefix.

use of the code lists means that each PolygonSFS_Level, although defining an homogeneous geometry structure, should group the spatial units based on the type of register and content, implying thus a legal and administrative based classification which can change from country to country;

- PolygonSFS_SpatialUnit: Any spatial unit in the profile is restricted to a 2D dimension type, and so the "*volume*" attribute should be omitted. As shown in the PolygonSFS_Level description, spatial units can be grouped according to register type and content, through an association to this class. Each instance of PolygonSFS_SpatialUnit has to be associated to at least one instance of PolygonSFS_Boundary, in order to get its spatial representation as a polygon;

- PolygonSFS_Boundary: The geometry attribute for this class is redefined as a ST_MultiCurve type and the optional attribute "*locationByText*" should be omitted from any country model, because does not belong to this profile. If a single instance of this class exists for a spatial unit, then it should form a closed boundary, so that an area can be computed. Considering that each instance is an aggregate in itself, it would be possible to consider a one-to-one relationship. However, other LADM or country specific attributes imply that a single spatial unit be represented by more than one multi-curve, e.g. if data source and quality is different along the polygon boundary.

The description of this spatial profile is still generic, given that assumes different implementations, based on the profile, can be made in different country models. That is the reason to keep a number of optional attributes in the diagram, so each country can derive their own specific combination, according to their requirements.

The specific use of this spatial profile for the Portuguese definition of spatial units will be described in the following subsection, and more concrete examples will be presented as instance level diagrams, further clarifying the concepts.

The Unstructured Profile

The Portuguese country model LADM_PT also uses the original Unstructured (line) based spatial profile from LADM. This profile has already been tested through an implementation in the Queensland Digital Cadastre Data Base, as described in (Lemmen et al., 2010, p.10-15) (see also figure F.1 and subsection F.2).

Given that its Unstructured_SpatialUnit imposes a 2D dimension, the "*volume*" attribute should be omitted from this profile. And as the geometry is defined through the Unstructured_Boundary class, having a GM_MultiCurve type, it also does not require the "*locationByText*" attribute. This modifications are thus similar to the ones performed in the Polygon SFS spatial profile. What is different is the consideration of a different structure type in the Unstructured_Level class and the possibility to associate one instance of the Unstructured_Boundary to more than one instance of Unstructured_SpatialUnit, avoiding the need to split a boundary line with common surveying or source attributes, per spatial unit (see figure 4.6).

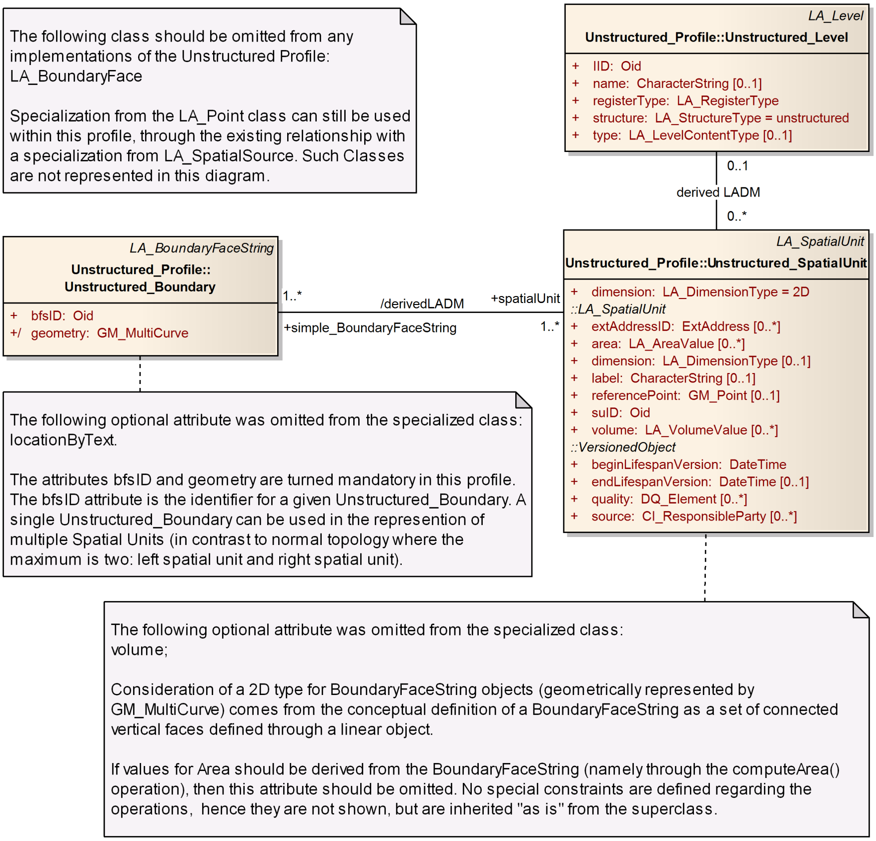


Figure 4.6: *Unstructured (line) based spatial profile* Source: ISO 19152 DIS.

As this profile does not impose any associations or constraints checking the resulting geometry and topology of the Unstructured_Boundary instances associated to any given Unstructured_SpatialUnit, it is equally possible to store incomplete or imprecise geometries for a given spatial unit, provided its definition does not impose that a closed figure is formed and / or topology constraints are observed. That would be the case, for instance, if a boundary of two adjoining spatial units do not close due to a missing cornerstone, in which case this incomplete boundary could be associated with two spatial units (of a special class and level), where an area could not be computed, but still an association could be established to administrative classes and, from there, to source documents.

This and other uses for the unstructured profile will be demonstrated in the following subsection, for a specialized class existing in the current Portuguese Cadastral Data Model, and as such modelled in the resulting country model: the *Deferred Cadastre*.

4.4.2 LADM_PT Spatial Unit specializations

In order to obtain the spatial unit package of the LADM_PT country model, the source Portuguese Cadastral Data Model was examined for all the classes containing geometry types and directly associated classes implying a specific type of register and content, similarly to the structure presented in LADM spatial profiles. This analysis proceeded in two phases:

1. Identifying, having as reference the LADM spatial profiles and related code lists, which will be the most appropriate *Level Structure* for the country model. The required Levels were identified and literals were given to the attributes of each instance to be created in the country model. The most adequate spatial profile (referred to in the "*structure*" attribute) was identified as reported next;

2. The Level structure was complemented through the application of the referred spatial profiles, resulting in the definition of four specializations of the LADM LA_SpatialUnit class for the country model. For the classes holding the geometry types (having as parent in LADM, the LA_BoundaryFaceString class), additional constraints were defined, as reported in the "Specialized classes from spatial unit" paragraph.

The Level structure

After examination of the current Portuguese Cadastral Data Model from IGP, four different Levels, and corresponding specialized spatial unit classes were identified. As this levels group the individual specialized spatial unit classes, they should be created as specific instances. That is the reason for the figure 4.7 be an object diagram.

Being objects, each individual Level in LADM_PT defines their contents in term of attribute values. The following attributes are code list types in LADM, this meaning that they can be modified for a given country model:

- registerType: the *RealProperty* type is created for LADM_PT, representing the union of the pre-existing *rural* and *urban* literals. The Portuguese country model makes no distinction affecting the spatial units, although the distinction exists for the administrative component;

- structure: no changes were introduced in the LADM code list;

- type: the new literal "*uncertain*" was added to the LADM code list, meaning that there is no sufficient data to make a definitive classification of the level contents, at the time of survey.

With these changes to code lists in mind, the four levels in figure 4.7 were created, and are further defined in the following list (numbers follow the Level ID or *lID* order):

1. RealProperty: The spatial units associated to this level represent real property (in the private domain) which has to be registered in the Land Registry and which represent a basic administrative unit, so the content *type* refers to

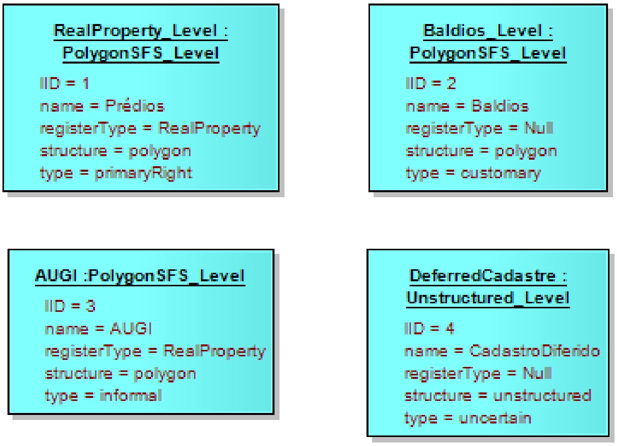


Figure 4.7: *The LADM_PT Level structure*

a primaryRight. In the Portuguese rights specialization (see 4.5.2), this corresponds to any specialization from a BasicOwnership conceptual class. The geometry structure should be formed by polygons;

2. Baldios: The spatial units associated to this level represent a form of communal property that is classified into the customary *type*, although it is not registered in the Portuguese Land Registry (it is not considered to be in the private domain). The geometry structure should be formed by polygons;

3. AUGI: The spatial units associated to this level represent a form of informal property referred as “Illegal Genesis Urban Areas” and that receive a special and temporary status in the Land Registry, before being eventually transformed into formal real property as defined above. The geometry structure should also be formed by polygons;

4. DeferredCadastre: The spatial units associated to this level represent temporary data which can be eventually classified into any other level, but at the time of survey there was no sufficient information (geometric, legal / administrative or both) in order to establish a definitive classification. These are the only type of spatial units which can hold incomplete or imprecise definition of geometry, so they use the “unstructured” as *structure* type.

There are a number of constraints to consider in the relationship between spatial units belonging to different levels, and these were modelled as specific constraint expressions within each specialized class, using the generic recurrent type of association existing in the LADM LA_SpatialUnit class. The constraints are explained, along the specialized spatial unit classes, in the following paragraph.

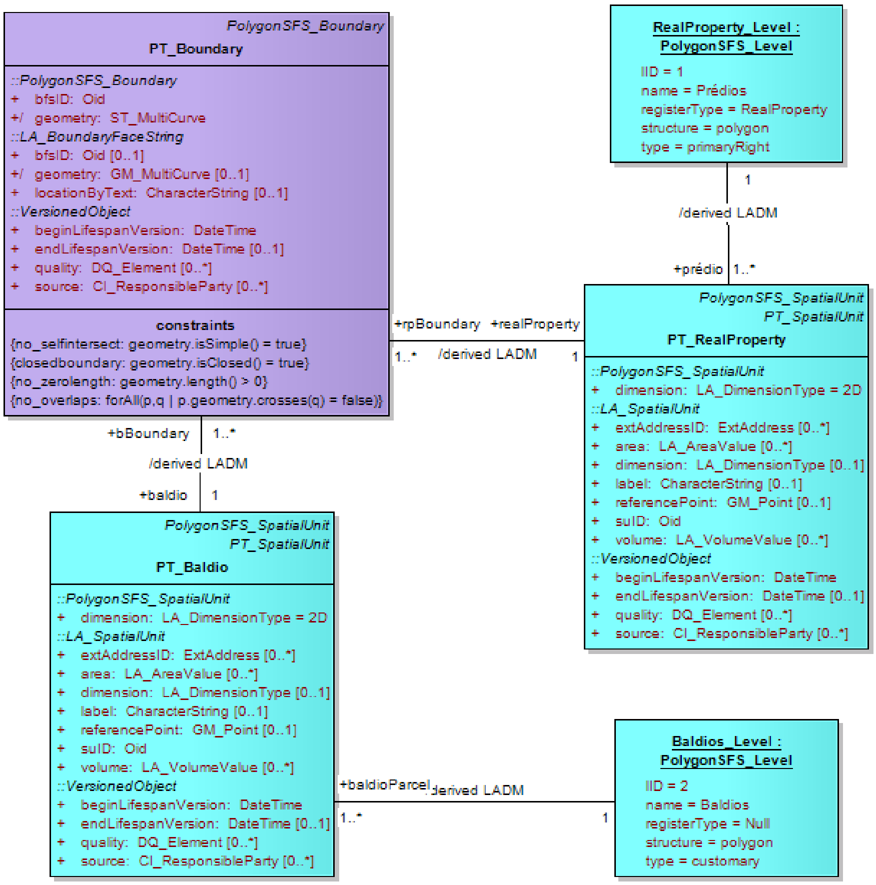


Figure 4.8: *LADM_PT spatial units: Real Property and Baldios*

Specialized classes from Spatial Unit

To each of the identified levels there corresponds a specialized spatial unit class in LADM_PT. The figure 4.8 depicts the PT_RealProperty and the PT_Baldio spatial units, which use the *PolygonSFS* spatial profile and define a single PT_Boundary class to store their geometry. The diagram shows the associations to the corresponding PolygonSFS_Level instances.

The following list describes particular behaviour, derivation and constraints belonging to each one of the five classes included in the 4.8 diagram:

- PT_Baldio: this specialized spatial unit can be associated to more than one PT_Boundary. In such cases, it can represent a detached parcel from the main Baldio (but belonging to the same community), or that an enclosed parcel (private or public) exists within the main Baldio spatial unit. The inherited "*referencePoint*" attribute is optional and shall be omitted from the specialized class. The "*extAddressID*" and "*suID*" attributes can be derived from the corresponding class in the PT_CDM data model;

- PT_Boundary: stores the geometry and sources for both the PT_Baldio and the PT_RealProperty classes. The "*beginLifeSpanVersion*" and "*quality*" attributes can be derived from information stored in PT_CDM classes. Further, there are a set of constraints, using methods belonging to the ST_MultiCurve type, which verify that each corresponding spatial unit has a correct geometry, forming closed figures with no self-intersections or overlaps.

- PT_RealProperty: as for a Baldio, this specialized spatial unit can be associated to more than one PT_Boundary, representing a detachment from the main parcel or a hole. Also, the inherited "*referencePoint*" attribute is optional and shall be omitted and the "*extAddressID*" and "*suID*" attributes can be derived from the corresponding class in the PT_CDM data model;

- RealProperty and Baldio_Level: these level instances were already explained in the level structure paragraph.

To the remaining two specialized spatial units, PT_DeferredCadastre and PT_AUGI, the unstructured and the PolygonSFS spatial profiles were applied, respectively. This originated the six classes represented in the figure 4.9. Due to the existence of different spatial profiles and inter-class geometry and topology relationships, specialized LA_BoundaryFaceString classes were created. The following list describes these classes.

- PT_DeferredCadastre: This specialized spatial unit defines a many-to-many association with the PT_DeferredBoundary class. In this way, it is possible to define a closed polygon with detachments (although it will not be enforced through constraints) or to associate a single, homogeneous surveyed boundary line, to more than one PT_DeferredCadastre spatial units. The inherited "*referencePoint*" attribute is optional and shall be omitted and the "*extAddressID*" and "*suID*" attributes can be derived from the corresponding class in the PT_CDM data model (called "Cadastro Diferido"). This class defines an additional attribute as an enumeration to be imported from PT_CDM, the "*DCMotiveType*". This enumeration has six different reasons for a given spatial unit be classified as a deferred cadastre, ranging from lack of administrative source documents, incomplete survey or litigations;

- PT_DeferredBoundary: Given that this specialized class belongs to the unstructured profile, the level of constraint checking is relaxed and no overlap or closed boundary checks will be performed, allowing for crossing or incomplete boundaries to exist for a spatial unit;

- PT_AUGI: This specialized spatial unit can be associated to more than one PT_InformalBoundary, representing detachments or holes in the informal prop-

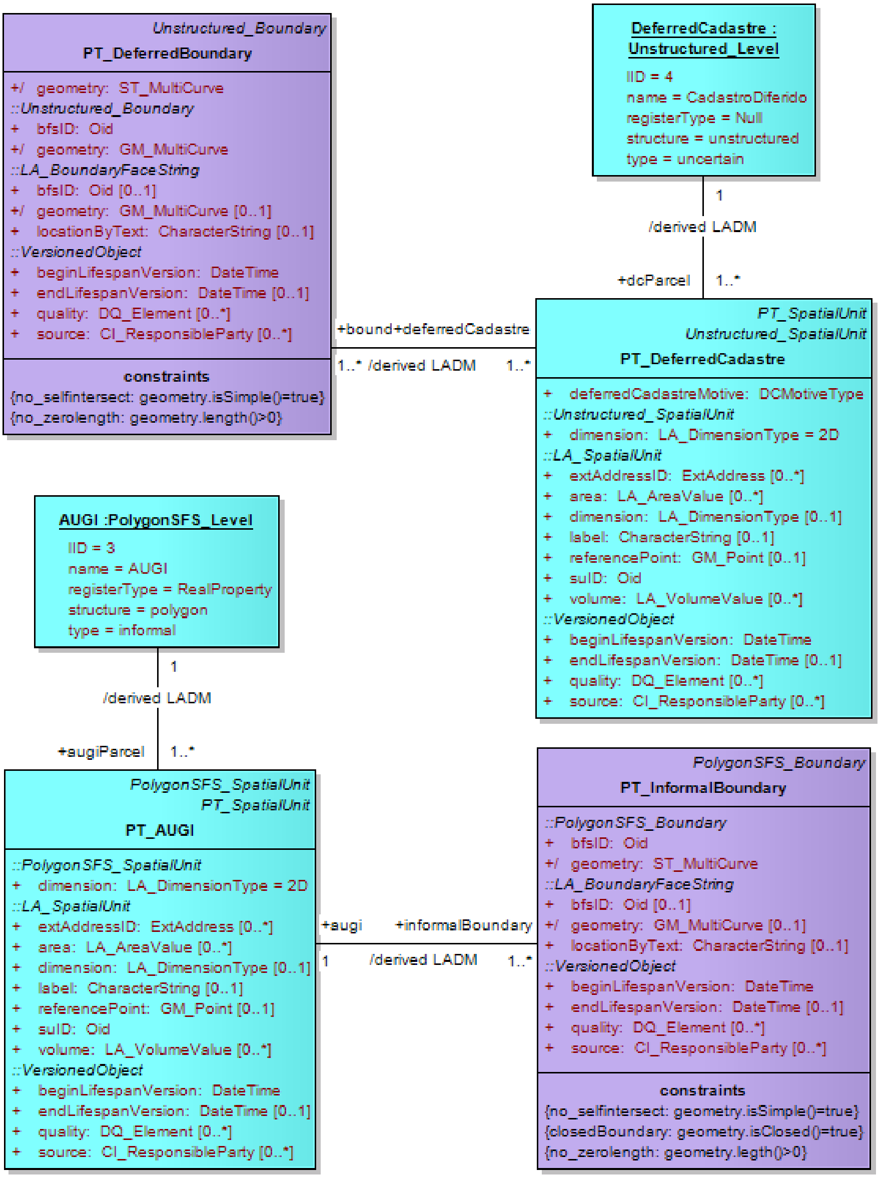


Figure 4.9: *LADM_PT spatial units: AUGI and Deferred Cadastre*

erty, which typically correspond to patches over one (or more) formal real property. The inherited "*referencePoint*" attribute is optional and shall be omitted and the "*extAddressID*" and "*suID*" attributes can be derived from the cor-

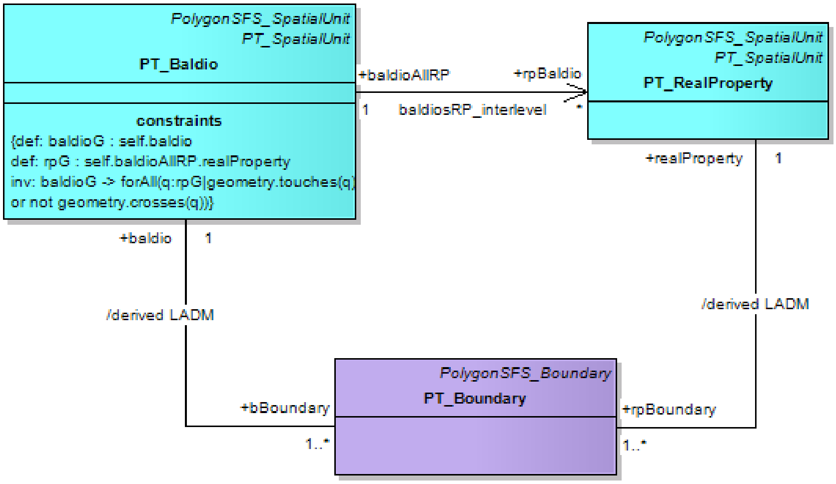


Figure 4.10: *Constraints between Real Property and Baldios*

responding class in the PT_CDM data model (having the same name). Each surveyed AUGI shall be related to a provisional register in the Land Registry, which eventually will become a (formal) Real Property. While temporary, it can be included or partially overlap a Real Property or even other AUGI, so the constraint for no overlaps is not enforced;

- PT_InformalBoundary: This specialized class enforces that closed boundaries be obtained, but does not check for overlaps and so a separate class from PT_Boundary was created, although they both use the PolygonSFS spatial profile and the ST_MultiCurve geometry type;

- DeferredCadastre and AUGI Levels: these instances were already explained in the level structure paragraph.

There are additional constraints to consider between the specialized classes, as exemplified in figure 4.10, complemented with table 4.5, describing all the in-class and inter-class constraints implemented on the boundary and spatial units.

The association between PT_Baldio and PT_RealProperty is the only case of a directed association in the country model. The reason being it is a topology constrained association based on the implementation reported in (Intesa GIS, 2004).

The constraint between the specialized classes PT_Baldio and PT_RealProperty checks for the topology relationships that must be obeyed between these classes, which otherwise would not be implemented, giving that they use the PolygonSFS profile (with no topology enforcement). The goal of this particular expression is to check that for all the PT_RealProperty and a given PT_Baldio, the boundaries of the

PT_RealProperty can touch boundaries of the PT_Baldio, but can not cross them, meaning that overlaps are not allowed, but the respective polygons can be adjacent or disjoint.

The check is done from the PT_Baldio side of the association, by collecting all PT_RealProperty for a given PT_Baldio instance, and then applying the OCL constraint. The constraint operates on the geometries of the spatial units, thus it has to "*navigate*" the depicted associations between the referred classes and the PT_Boundary class. Special care has to be taken so that every association role name is unique within the context of the expression. For example, the definition of "baldioG" in the expression uses the role name "baldio" to collect all the PT_Boundary instances associated to a given PT_Baldio, and then tests the geometry attribute using the methods belonging to its type (the ST_MultiCurve).

Two additional inter-class constraints were imposed from the PT_AUGI class to respectively the PT_Baldio and the PT_RealProperty, which use a similar structure as in figure 4.10[74]. The constraints verify that, for any given PT_AUGI boundary (collected from the associated PT_InformalBoundary class), there could not exist any PT_Baldio or PT_RealProperty which has the same geometry. This comes from the fact that both forms of property can not share the same exact space, although it is possible that they are adjacent to each other or partially overlapping each other.

Although the concept of the AUGI did not exist at the time of the previous cadastres were surveyed and digitized, and so currently there are no official cadastral data about them, concluded administrative procedures concerning AUGI (not involving the cadastre) show that the overlap exists mainly with real property and with public domain parcels. The later case, for LADM_PT, implies that PT_AUGI spatial units can be disjoint from the other classes, given that there are no public domain spatial units in the Portuguese cadastral model.

The table 4.5 lists all the constraints existing for the spatial unit package of LADM_PT, referring the class context for the expression or a class association (for inter-class constraints) in the first column, the body of the OCL expression (not including the context) in the second column, and short explanation in natural language in the third column. The context column is repeated for those classes having more than one constraint expression. The in-class constraints refer to the boundary classes, because they are the ones which store the geometry types. All the OCL constraints in the table are of the invariant type, although the *inv* keyword has been omitted from the ones which do not define local variables. So, for instances, the first expression would be written in full as:
$\{context\ PT\_Boundary\ inv\ no\_selfintersect:$
$geometry.isSimple() = true\}$

[74] The respective diagram is included in annex A.

Class Context	OCL Expression	Description
PT_Boundary	$\{no\_selfintersect : geometry.isSimple() = true\}$	Any given boundary line can not intersect itself
PT_Boundary	$\{closedboundary : geometry.isClosed() = true\}$	Each ST_MultiCurve must form a closed boundary. If more than one exists for a spatial unit, this would represent a detachment or a hole
PT_Boundary	$\{no\_zerolength : geometry.length() > 0\}$	There could not exist a geometry with zero length (initial vertex coincident with final vertex, and no additional vertices)
PT_Boundary	$\{no\_overlaps : forAll (p, q \| p.geometry.crosses(q) = false)\}$	There should be no crossing boundaries for the complete collection of PT_Boundary instances, meaning the derived Real Property and Baldios polygons should not overlap each other
PT_Informal-Boundary	$\{no\_selfintersect : geometry.isSimple() = true\}$	Same interpretation as for the PT_Boundary constraint
PT_Informal-Boundary	$\{closedboundary : geometry.isClosed() = true\}$	Same interpretation as for the PT_Boundary constraint
PT_Informal-Boundary	$\{no\_zerolength : geometry.length() > 0\}$	Same interpretation as for the PT_Boundary constraint
PT_Deferred-Boundary	$\{no\_selfintersect : geometry.isSimple() = true\}$	Same interpretation as for the PT_Boundary constraint
PT_Deferred-Boundary	$\{no\_zerolength : geometry.length() > 0\}$	Same interpretation as for the PT_Boundary constraint
PT_Baldio to PT_Real-Property	$\{def : baldioG : self.baldio$ $def : rpG : self.baldioAllRP.realProperty$ $inv : baldioG \Rightarrow forAll(q : rpG \| geometry.touches(q) or not geometry.crosses(q))\}$	In terms of (derived) Real Property and Baldios polygons, this means they could be adjacent to each other, but can not overlap
PT_AUGI to PT_Baldio	$\{def : augiG : self.augi$ $def : baldioG : self.augiAllBaldio.baldio$ $inv : augiG \Rightarrow forAll(q : baldioG \| geometry.equals(q) = false\}$	In terms of (derived) AUGI and Baldio polygons, they could not be coincident in space
PT_AUGI to PT_Real-Property	$\{def : augiG : self.augi$ $def : rpG : self.augiAllRP.realproperty$ $inv : augiG \Rightarrow forAll(q : rpG \| geometry.equals(q) = false\}$	In terms of (derived) AUGI and Real Property polygons, they could not be coincident in space

Table 4.5: In-class and inter-class constraints on the LADM_PT spatial unit package

4.5 Comprehensive model for the legal and administrative domains in Portugal

In the LADM_PT country model, the package concerning the legal and administrative aspects is focused on the specializations from the LA_RRR (Rights, Restrictions and Responsibilities) LADM core class. Definitions for LADM specialized classes from LA_Right, LA_Restriction and LA_Responsibility were given in subsection 2.6.2. The generic conceptual UML Class diagram for the modelling of Real Rights proposed in (Paasch, 2005) formed the basis for the legal and administrative profiles now inserted in ISO19152 LADM as (informative) Annex F, and which were developed by the Author. Each one of above referred specialized classes forms the top of the hierarchy of the corresponding profiles in ISO19152 Annex F: Rights, Restrictions and Responsibilities legal profiles.

The first two profiles were derived from Paasch's abstract superclasses Appurtenance and Encumbrance, respectively for the Rights and Restrictions profiles. Each one has five specialized classes, as described in sub-subsection 2.2.2. The Responsibility profile uses both Appurtenance and Encumbrance specializations and also proposes the association of the LA_Responsibility superclass with the LA_Right and the LA_Restriction superclasses, via UML compositions representing so-called "inherent responsibilities".

While the generic conceptual approach based on Appurtenance and Encumbrance abstract superclasses includes already the provision for inclusion of specific rights from the Private and Public legal regimes, the abstract class "FormsOfProperty" introduces the specialized class "CommonsOwnership" which allowed the inclusion of the alternative form of property known as "Baldios" in the LADM_PT (see definition in subsection 2.2.3).

The current subsection will be thus divided into two subsections, respectively describing the more generic legal and administrative profiles (as included in LADM) and the corresponding LADM_PT specializations. Each one of the sub-subsections is further split into three paragraphs respecting the hierarchy from LA_Right, LA_Restriction and LA_Responsibility.

4.5.1 LADM Legal and Administrative Profiles

The Rights Profile This legal profile includes the hierarchy for the FormsOfProperty abstract superclass, not existing as part of the core classes of LADM. This superclass represents the main forms of ownership existing in a given country, each defined by a specific legal regime. The generic profile included in LADM only recognizes three basic forms of ownership: OwnershipBundle (ownership regulated by Private Law), PublicDomainOwnership (ownership regulated by Public Law) and CommonOwnership (ownership regulated by a Commons specific regime).

While the last two FormsOfProperty are not further modelled in the profile, the OwnershipBundle is an abstract class representing the concept of ownership as a bundle of rights having a real property as its object (see figure 4.11). In the Rights legal profile, this bundle relates to two specializations from the core LA_Right class:

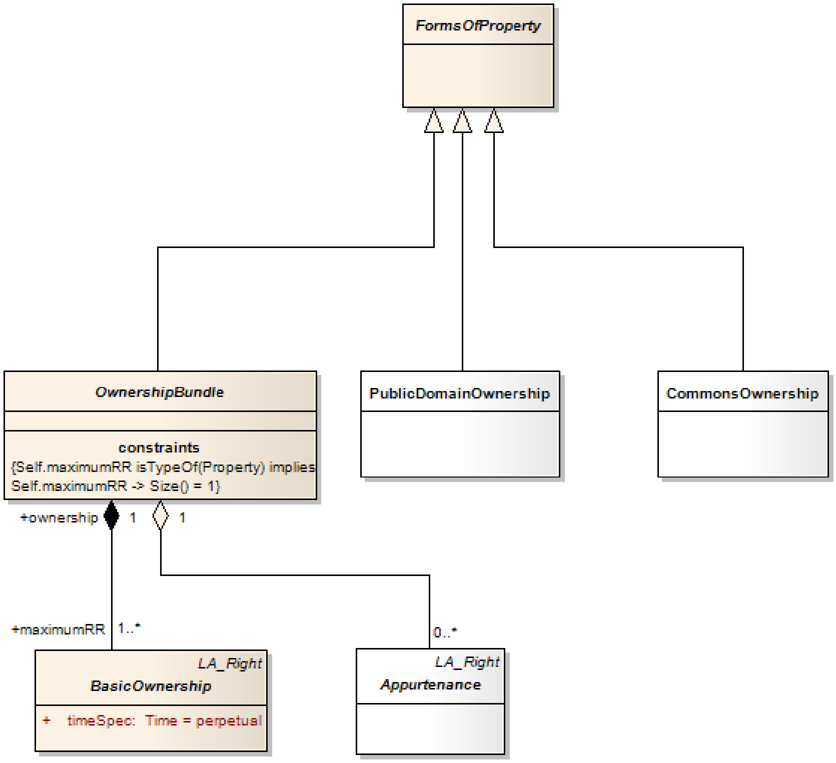


Figure 4.11: *FormsOfProperty hierarchy* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2010).

Appurtenance (already defined, see 2.2.2) and BasicOwnership. The OwnershipBundle class is a composition of at least one BasicOwnership to which one or more Appurtenance specializations can be aggregated.

The BasicOwnership is an abstract class representing different specialized classes having the Maximum Real Right on a given jurisdiction (as defined in subsection 2.2.1). The specialized classes considered in the Rights profile are common to both Anglo-American common law and to Continental Europe civil code based property law.

The Appurtenance abstract class hierarchy has already been presented (see Figure 2.2). The following figures depict the class diagrams for the FormsOfProperty hierarchy and the BasicOwnership hierarchy, both extracted from the Rights legal profile.

The definitions for the specialized classes depicted in figure 4.12 are given in the first four entries of table 2.1, on the classification of Portuguese Real Rights, concerning Property, Co-Property, Joint-Property and Condominium.

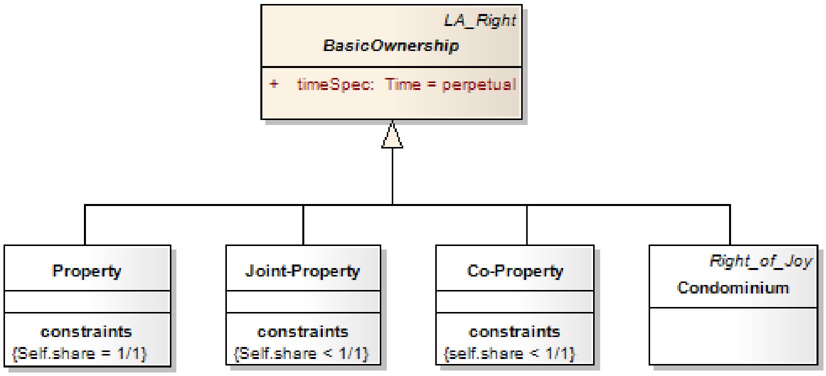


Figure 4.12: *BasicOwnership hierarchy* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2010).

The specialized classes from the Forms of Property abstract classes are the ones which are registered, and correspond to a complete flattening of the class hierarchy.

LADM Restrictions Profile The core LADM class for this profile is LA_Restriction. Both LA_Right and LA_Restriction classes have a type attribute which defines an enumeration including a number of most generic legal types, which can be adapted for the situation in a given country's jurisdiction (see Figure 4.13). The definition of rights and restrictions with the help of enumeration classes offers thus a simpler alternative to the use of the legal and administrative profiles. According to the concept used as basis for these profiles in LADM (Paasch, 2005) the abstract superclass Encumbrance is the root class for the negative side[75] of all Real Rights under the Private Law regime. It is specialized into a total of five classes, which have the same meaning as in the Appurtenance hierarchy, except this time they encumber ownership.

Further, they constitute also an additional aggregate class to the OwnershipBundle class, defined in the Rights profile. In this way, the OwnershipBundle shall aggregate both appurtenances and encumbrances from the BasicOwnership, and also aggregate restrictions imposed from the Public Law regime, which are represented in the profile by the PublicRegulation abstract class.

The Restrictions profile only defines a single specialized class from the PublicRegulation class called Administrative Servitude, which has a type attribute pointing to an enumeration class. This class represents a public right to use certain facilities of a private property, supported by a declaration of public utility. In the Restrictions profile, this class is encumbering a (private) ownership right and thus it is considered also a specialization of LA_Restriction, not included in the Encumbrance hierarchy.

It is expected that a generic classification could be sufficiently applicable world-

[75]From the usual perspective of the private property owner.

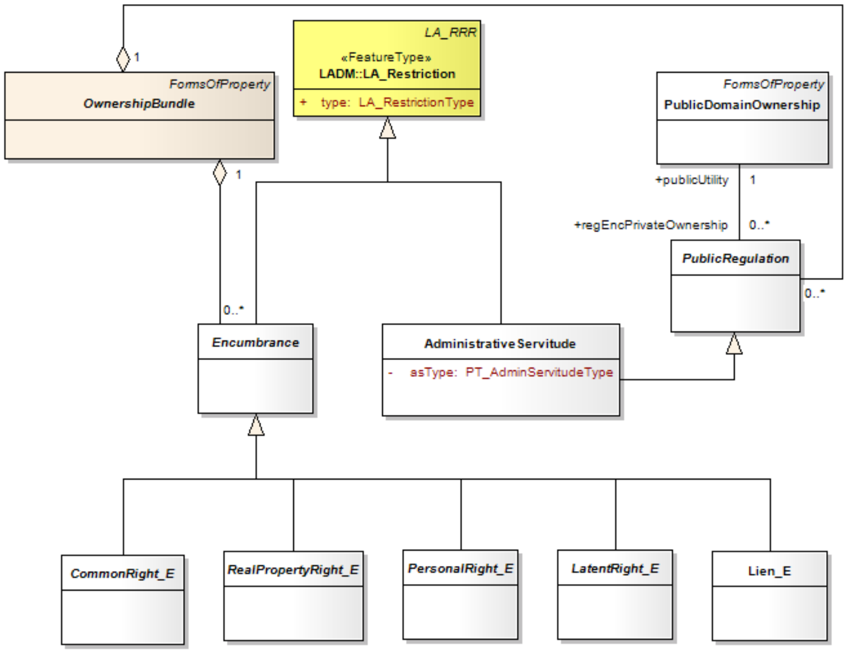


Figure 4.13: *Restrictions legal profile (extract)* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2010).

wide, with the consideration of country specific sub-types (as specialized classes and related properties) to be included in country models.

The Responsibility Profile This profile includes components derived both from the Rights profile and Restrictions profile of Real Rights. In the case of specific responsibilities imposed through restrictions, they can be originated by the Private or Public Law regimes.

Concrete classes included in this profile were primarily based upon examples found in Portuguese legislation, and further research is needed in order to check if they are sufficiently generic to be considered worldwide.

Beginning with the classes considered in the Private Law regime (see Figure 4.14), a proposal is included to consider two (optional) composition associations from the LA_Right and LA_Restriction core classes to the LA_Responsibility class. In such a view, a specific LA_Right (besides its own definition) can be optionally composed of several LA_Responsibility specific types, through an InherentResponsibility (Appurtenant) association. Equally, a specific LA_Restriction can be optionally composed of several LA_Responsibility specific types, through an InherentResponsibility (Encumbrance) association. This UML modelling reflects the fact that many responsibilities

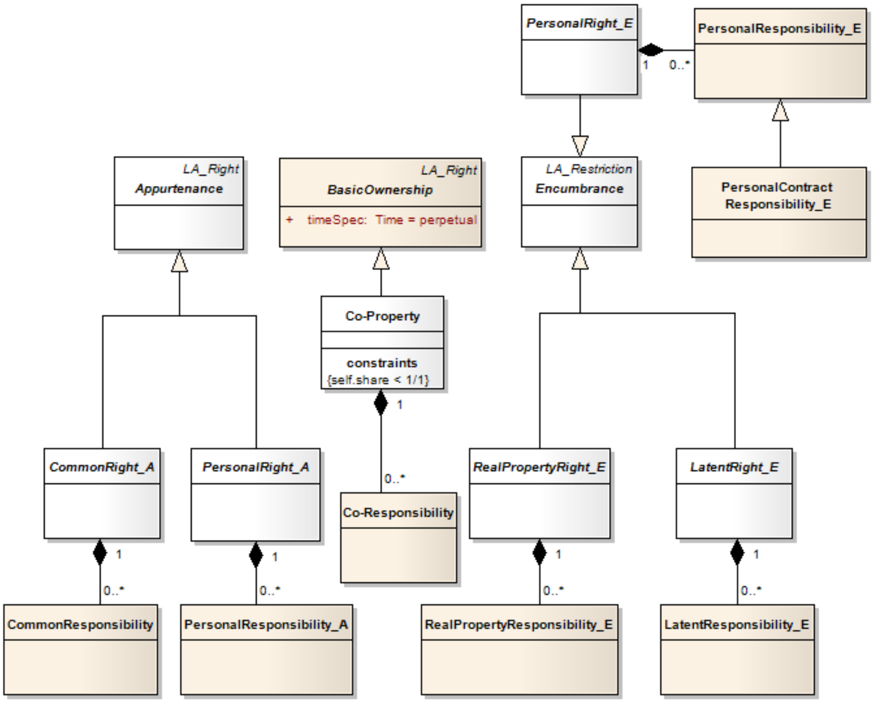


Figure 4.14: *Responsibilities: The Private Realm* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2010).

in Private Law are inherent to the Right which gives birth to them. If the Right is extinct, then all their dependent responsibilities will also disappear.

The dependent responsibilities can thus be associated with specialized classes from the Appurtenance and Encumbrance superclasses, but also with specializations from the BasicOwnership abstract superclass. One example of this last case is the Co-Responsibility class which is inherent to a Co-Property Right. This class represents the set of duties to be performed by the co-owners of a real property on a regular basis (maintenance tasks) or at certain events like a transfer with a share.

A third, generic, hierarchy level was considered for such restrictions imposed on ownership by Personal Rights (class PersonalRight_E). The concrete class which represents dependent responsibilities born from Personal Rights is the PersonalResponsibility_E and corresponds to maintenance duties to be performed by the real property owners. There is a special case for this PersonalResponsibility_E whenever the real property owners have to perform a duty benefiting a party which does not hold any Real Right on the property. For such a case, the Personal ContractResponsibility_E class is created.

In most cases, such dependent responsibilities are not subject to registry in a typical land registry, because they can be referred to in the existing legislation (namely in the Civil Code). However, their inclusion in a country model could fulfil an information duty to those citizens holding Real Rights over property, provided a procedure is implemented to keep such responsibilities updated with the current legislation.

Public responsibilities Considering now the realm of Public Law, a simple three level hierarchy is considered (see Figure 4.15), starting with the Public Regulation abstract class. Four generic classes were specialized from the abstract class PublicResponsibility, representing all kinds of responsibilities imposed by acts or regulations from the Public Law regime, upon owners of private property, or more generally, holders of Real Rights.

These generic classes represent:

- Urban Buildings Maintenance: imposed on owners of urban buildings, to keep property fit for use; ensure public health and safety;
- Adjacent Public Infrastructure: duty to maintain public infrastructure included or adjacent to private property;
- Exploration Duty: duty to maintain proper economic use for certain types of land use;
- Conservation Duty: assure proper environmental sustainability, usually defined through land policy and the environment acts.

The association here is defined at a higher level, with the Public Domain Ownership as a Form of Property.

4.5.2 LADM_PT Legal and Administrative Specializations

The Rights specialization The Portuguese country model LADM_PT defines specializations for all the previously described legal and administrative profiles of LADM. This first paragraph describes the specializations from the Rights profile, concerning just the realm of Private Law (that is, it covers just Real Rights).

As the Rights specializations were restricted to those which must be presently registered in the Portuguese Land Registry, only one specialization from the Appurtenance hierarchy was considered: the Common Right (Appurtenant). All the other specialized classes which are registered belong to the Encumbrance hierarchy and thus are included in the Restrictions specializations.

In the remaining description of specialized classes belonging to the Portuguese country model, the alias presents the Portuguese name for each class. Two concrete classes are defined as specializations from the CommonRight_A abstract class. These are:

- PT_CommonParts (alias: PartesComuns): it is a special type of joint ownership defined in a condominium building and includes a share over structural elements, common equipment, installation and circulation areas.

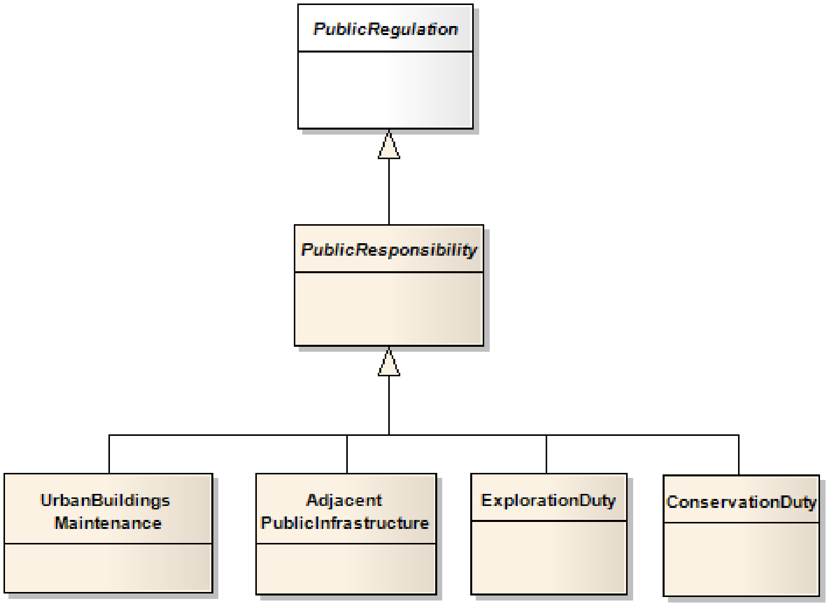


Figure 4.15: *Responsibilities: The Public Realm* Source: ISO19152 DIS, ISO/TC211 Geographic Information / Geomatics (2010).

- PT_ServingParcel (alias: AreaComum): the only known type of a Serving Parcel in Portugal respects a parcel used for rural irrigation which is owned by other real properties in the vicinity.

Apart from the Common Rights specialization, depicted in Figure 4.16, there are specializations from the BasicOwnership specialized classes Property, Joint-Property, Co-Property and Condominium, as follows:

- PT_Property (alias: Propriedade): represents full ownership (maximum real right) by a single Party to enjoy the usefulness of the immovable, but is nevertheless limited by legal restrictions and has inherent responsibilities;

- PT_JointProperty (alias: Comunhão): An indivisible Property Right which is shared by the joint-owners. Those would be represented by a LA_GroupParty object from the Party package. Single Parties can not dispose their shares or request a parcel split;

- PT_CoProperty (alias: Co-Propriedade): A Property Right shared by several Parties, which can dispose their shares or request for a parcel split;

- PT_HorizontalProperty (alias: Propriedade Horizontal): It is a Property Right

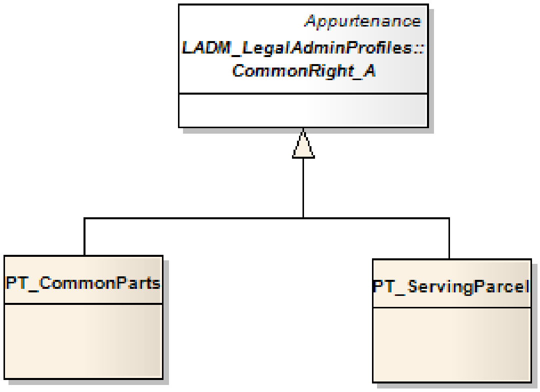


Figure 4.16: *LADM_PT specializations from the Appurtenance class.* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2010).

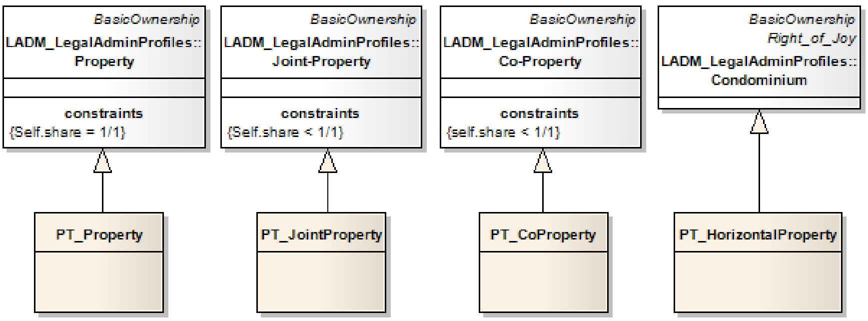


Figure 4.17: *LADM_PT specializations from the BasicOwnership class.*

to an autonomous unit or apartment of an urban building. Automatically creates the associated right PT_CommonParts.

It must be said that for each registered real property, represented in LADM by the LA_BAUnit class, and at a given instant, only one instance of the association with the above classes should exist. These specializations from BasicOwnership are depicted in Figure 4.17.

The Restrictions specializations Like what has been done in the Rights specializations, the modelling of Portuguese specializations of the Restrictions profile is limited currently to those imposed from Private Law and which are registered (in most of the cases). The Portuguese Land Register Code (Mendes (2003a)) considers that the majority of Real Rights to be registered in a given real property unit are taken from the Restrictions profile, and thus, in this modelling concept, are specializations from the Encumbrance abstract superclass.

The table 4.6 lists the identification of the profile parent class (first column), the name and the alias for the specialized class and a short description of its meaning.

Depending on the complexity of each Real Property unit, there should be registered one single type of right belonging to the BasicOwnership hierarchy and (optionally) one or more of the Restriction rights described in table 4.6, which are encumbering such basic ownership right.

The Responsibility specializations The Portuguese specialized classes from the Responsibilities profile include both private and public law derived responsibilities. Contrary to the previous specializations (Rights and Restrictions), most of the specializations considered herein are not registered, once they are inherent to specific Rights or Restrictions and thus are defined in law. The current situation results from law doctrine but do not consider ICT possibilities. This is a good point for a proposition.

The specializations currently described in LADM_PT are far from being exhaustive and many more could be identified through a comprehensive study of existent legislation concerning Real Rights, and even more are defined through Public Law.

According to Portuguese legal doctrine (Mesquita (2000)), responsibilities which are inherent to Real Rights are considered to be positive, imposing an active duty on the ownership of Real Property. Although there are no absolute independence between the concepts of Responsibility[76] and Real Rights, the root of the distinction can be traced back to Roman Law concepts of "agere licere"[77] for Real Rights and "agere debere"[78] for Responsibilities.

Moving now to the description of specific responsibilities, a first note is due to the class naming where, contrary to the Rights and Restrictions situation, there are no easily identified short terms to name a particular responsibility. The resulting longer names are an attempt to define a systematic nomenclature.

Beginning with the responsibilities inherent to Rights, three specialized classes are defined (Figure 4.18):

- PT_CommonPartsResponsibilities (alias: Obrigações dos Condóminos): a specialization of a Common Responsibility affecting the common parts of a Condominium, including the Civil Code dispositions of maintenance and fruition charges (art.1424), urgently needed repairs (art.1427) and a obligatory fire insurance (art.1429).

- PT_UseFees (alias: Encargos de Utilização): a specialization of a Personal Responsibility concerning maintenance and use fees that should be paid regularly

[76]In Portugal the terms "obligation" and "duty" are used instead.

[77]*Agere licere* or license to act means that the holder of the right has the power and the possibility to achieve and fulfil his interests.

[78]*Agere debere* or duty to act means that by holding a right, the holder has to take action, following a certain event or by court decision.

by holders of Personal Rights like Superficies.

- PT_CoOwnersResponsibility (alias: Obrigações dos Co-Proprietários): a specialization of a Co-Responsibility concerning duties to be performed by Co-Owners, namely (1) that Co-Owners should contribute to the Real Property maintenance proportionally to their shares and (2) a Co-Owner has the duty to inform others of the intention to sell its share to third parties.

Concerning the Responsibilities inherent to Restrictions, , four specialized classes are defined (Figure 4.19):

- PT_ServientResponsibilities (alias: Obrigações de Serventia): a specialization from a Real Property responsibility defining accessibility and maintenance duties to be performed on portions of the Real Property (in the role of servient parcels).

- PT_InformationDuty (alias: Dever de Informação sobre Preferência): a specialization of a LatentResponsibility where the holder of a Pre-Emption covering the acquisition of ownership has an information duty towards the previous owner.

- PT_BuildingMaintenance (alias: Dever de Manutenção): a specialization of a Personal Responsibility (encumbering) where a property owner where a building exists with one or more personal rights upon it (e.g., Habitation) has the duty to maintain the building in proper conditions. There are similar, possibly overlapping responsibilities which can be imposed from Public Law.

- PT_PublicTaxes (alias: Dever de Contribuição Pública): a specialization of a Personal (Contract) Responsibility. The property owners should pay annually the Municipal Tax on Immovables. This involves a responsibility towards a third party that has not any Real Right or restriction on the property, hence the consideration of a Personal Contract instead of a Personal Real Right.

Finally, three specialized classes are defined for the realm of Public Law concerning Public Responsibilities which are encumbering to private property (see also Figure 4.20):

- PT_CollatioViae[79] (alias: Manutenção de Vias Públicas): a specialization of the Adjacent Public Infrastructure type of responsibility defined according law 13/71 (on the National Road Network). Owners of real property adjacent to public roads should take measures to avoid damages to the road and traffic, e.g., by cutting tree branches which can cause harm to the traffic.

- PT_AgrarianExplorationDuty (alias: Dever de Exploração - Reforma Agrária): a specialization from the Exploration Duty responsibility, defined through law

[79] Collatio Viae: Maintenance of the roads was mainly the responsibility of the local community. This duty placed the burden of road maintenance on those who used them most often and dates back to a Roman practice.

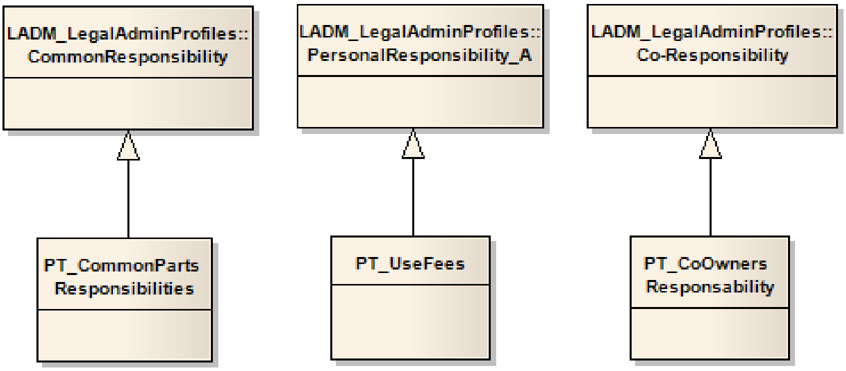


Figure 4.18: *LADM_PT Responsibilities Appurtenant.* Source: ISO19152 DIS, (ISO/TC211 Geographic Information / Geomatics, 2008).

on Agrarian Reform (77/77, amended by 109/88). Imposes an exploration duty to owners of rural property. Penalty for misused or derelict land could be expropriation or compulsory renting by state authorities[80].

- PT_EnvironmentConservation (alias: Dever de Protecção Ambiental): a specialization from the Conservation Duty responsibility. It is regulated by the Environmental law 11/87 and comprehends the generic obligation to perform technical, agricultural or forestry works to secure and benefit the land according dispositions contained in specific institutions (e.g. RAN, the National Agrarian Reserve).

An overview of the complete set of PT_RRR is inserted through the diagrams in Annex A.

4.6 Pilot Project

This section reports on the results obtained with the cadastre data set from Mira municipality (see location in 4.21), after applying it a database schema derived from the CCDM_PT country model as reported in (Hespanha et al., 2006) and referred in section 1.6. The basic technical requirements considered here were thus the ones belonging to the *"Cadastro Predial"* specifications (IGP (1996)), which were replaced by the new Cadastral Data Model in May 2009. However outdated in terms of specifications and data structure, the purpose of the section is to document a transformation from a PIM (corresponding to the CCDM_PT) to a PSM as described here, using real cadastral data and procedures. The Pilot Project is also referred in the text

[80] But there are not many known examples of such penalties being applied, specially in recent years.

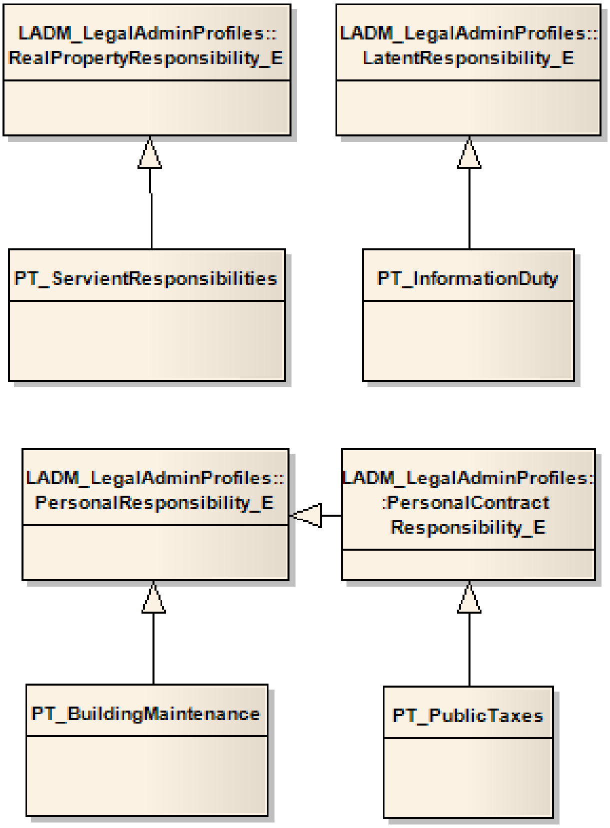


Figure 4.19: *LADM_PT Responsibilities Encumbering.*

as "Mira Municipal Cadastre". The procedure with the Mira Municipal Cadastre is described as follows: a first subsection reports on the context in which this Municipal Cadastre was set up, identifying the partners, the framework for funding and the goals of the start up project, called SICAVIM, and subsequent lecturing projects with the participation of the Author. The SICAVIM was a regional project involving three Municipalities and preceded the national level SINERGIC project, for which can contribute through its findings. In subsection 4.6.2, the issues found while (manually) creating the cadastral data base schema from the UML data model are reported. Such procedure was useful in later considering which steps can be done through MDA automation, and the level of interaction to consider. In subsection 4.6.3, some results are presented concerning the graphic user interface used at this time, and graphic and data base edition procedures to apply a systematic cadastral survey update. A concluding subsection (4.6.4) summarizes the issues found while working with real cadastral data, implementing the procedures as specified in the regulations, where existent, and the discussion of the new experimental procedures

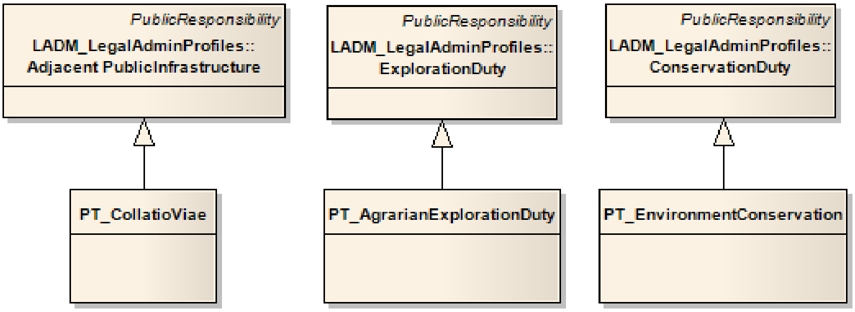


Figure 4.20: *LADM_PT Public Responsibilities.* Source: ISO19152 WD3, (ISO/TC211 Geographic Information / Geomatics, 2008).

Figure 4.21: *Location of Mira.* Source: GoogleMaps with TeleAtlas data from 2011; edited by the Author.

(not official) concerning cadastral update. In Annex D, some results of the creation of a mapping interface using the open source GIS application uDIG are shown for the Pilot Project.

4.6.1 Context: previous projects

The main set of cadastral data used to test the implementation of the development methodology and further results through a GIS application useful to local government administrative tasks, was achieved as result of the contributions from the EU funded project SICAVIM[81] (reported in Galiza (2006)) and through a series of protocols between University of Aveiro and Mira Municipality. The SICAVIM Project was partly funded by European Union FEDER-FSE budget, by the "Digital Cities" Government Project, and also by the involved Municipalities (Galiza, 2006).

The SICAVIM Project was inserted in the framework of the Portuguese initiative "Digital Cities", as part of a strategy to develop and implement geo-information systems in the local governments of Aveiro region (situated in the Centre-Northern Littoral of Portugal). Apart from other previous Projects forming on the acquisition of digital cartography, useful for the design of a new generation of Municipal Master Plans, the SICAVIM Project was centred on the development of a geo-information system for the Property Cadastre.

This situation benefited from previous large cadastral survey works, led by the Portuguese Geographic Institute (IGP), which covered three municipalities in the region: Vagos, Ílhavo and Mira. These systematic cadastral surveys produced the first geometric cadastre of both rural and urban parcels, in the referred Municipalities.

One of the aims of this project was to provide easy accessibility of cadastral information to the citizens and also to municipal departments requiring and modifying such information. However, the information concerned mostly the geometric data on parcels and basic administrative data; no integration with the Land Registry or Tax Office was offered to the user. This has been partly achieved, but required a major transformation of the data structure and technological platform (and architecture) formerly existent, as compared with the software platform used then by IGP.

Another aim was to integrate administrative processes involved in property transactions, and thus requiring the involvement of other state organizations as the Fiscal and Land Registry Offices, besides the IGP. This aim is far from being accomplished both within the project and in reality, and is where the research here reported can contribute most. This is equally one of the central aims of IGP's SINERGIC project, as described in decree-law 224/2007 (MAOTDR (2007)).

A summary of the work and research done during the SICAVIM project life time is given on the following pages.

Concerning the aim of providing easy accessibility of cadastral information to the citizens, the item where the project achieved greater success, this was implemented through a previous data migration from the original cadastral data structure (CAD like and vector line based with an external database) to a ArcSDE Geodatabase from ESRI. From this common data set, separate databases were extracted, for each one of the Municipalities. Using a web infrastructure supplied by a related "Digital Cities" project named SIGRIA, cadastral information was made available through

[81] SICAVIM: Sistema de Informação Cadastral de Vagos, Ílhavo e Mira (Cadastral Information System of the referred municipalities).

the web, using the ESRI software ArcIMS[82]. Each of the Municipalities configured differently the accessibility modes to cadastral information, once the web interface is customizable, although there is a common data structure.

This web infrastructure has been in place since project termination and can be accessed through the URL's in (Câmara Municipal de Ílhavo, 2009; Câmara Municipal de Vagos, 2009; Câmara Municipal de Mira, 2009). Regarding process integration covering legal, administrative and geographical data distributed in different organizations, targeting at a cadastral update procedure, the SICAVIM project did not go much further than identifying and reporting a set of requirements and giving some initial steps into design. These were reported through the use of literate UML and a number of Use Case and associated Activity Diagrams, focused on cadastral update procedures with the following details (Galiza, 2006, p.10-43):

- General cadastral update procedure, with detailed descriptions for (partial) updates to be made on the legal, fiscal and geometric (cadastral survey) components;

- Cadastral update in a urban re-allotment procedure, again considering partial updates made by municipal, legal and cadastral survey components.

The results from this study, as well as the actual data contained in the Mira Municipality Geodatabase were then used both in this research and in a number of ESTGA[83] lecturing projects. These last ones were made possible by the adoption of Project Based Learning and were integrated into the course curriculum of the BSc on Geographical Engineering. The projects made under protocols with Mira Municipality took place in the years from 2007 to 2009, with the following main aims:

1. 2007: Data migration from the existing SICAVIM data structure into a proposed data structure which was based on the previously mentioned CCDM_PT results (Hespanha et al., 2006);

2. 2008: Cadastral update upon the data structure obtained in the previous project, covering a motorway crossing over a rural area of Mira Municipality;

3. 2009: Cadastral update covering two tourist villages classified as urban parcels by legal services (although just one did include horizontal property).

The following figures show some results from the previously mentioned projects, covering the area of one of the tourist villages, called Miravillas. A comparison can be made between the cadastral data collected in the original survey by IGP, and the situation after the cadastral update procedure of the 2009 School Project. The screenshot on figure 4.22 shows the information available to the general public (no authentication required), which mainly covers cadastral map data and information on areas values for some selected features as parcels or social areas.

[82] ESRI's Internet Map Service

[83] High School for Technology and Management of Águeda.

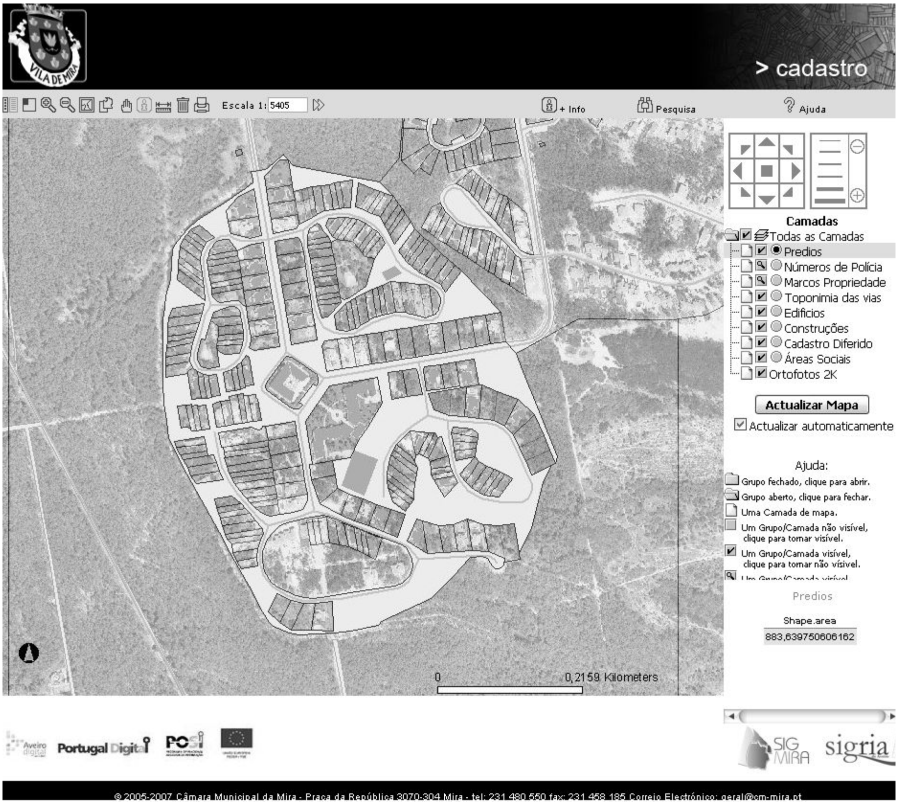


Figure 4.22: *Cadastral information in the Mira Municipality web site (Câmara Municipal de Mira, 2009)*

4.6.2 From the schema to the database

The first UML class diagram produced for the lecturing projects having a protocol with the Mira Municipality, dates back from 2007 and it is directly based on CCDM_PT. These projects did not considered the application of MDA principles, contrary to LADM_PT, but the role of each component can be still assigned to MDA concepts, as follows:

- Platform Independent Model: it is required by the class diagram called CCDM_PT, as reported in (Hespanha et al., 2006);
- Platform Specific Model: it is represented by a class diagram used as a basis for the implementation into an ESRI Personal Geodatabase (Zeiler, 2010, Chapter 1), here referred as "ESRI's CCDM_PT". This was divided into two components, the first including all the spatial features; the second being limited to alphanumeric features. This distinction is reflected also in the implementation software platform, ESRI ArcGIS;

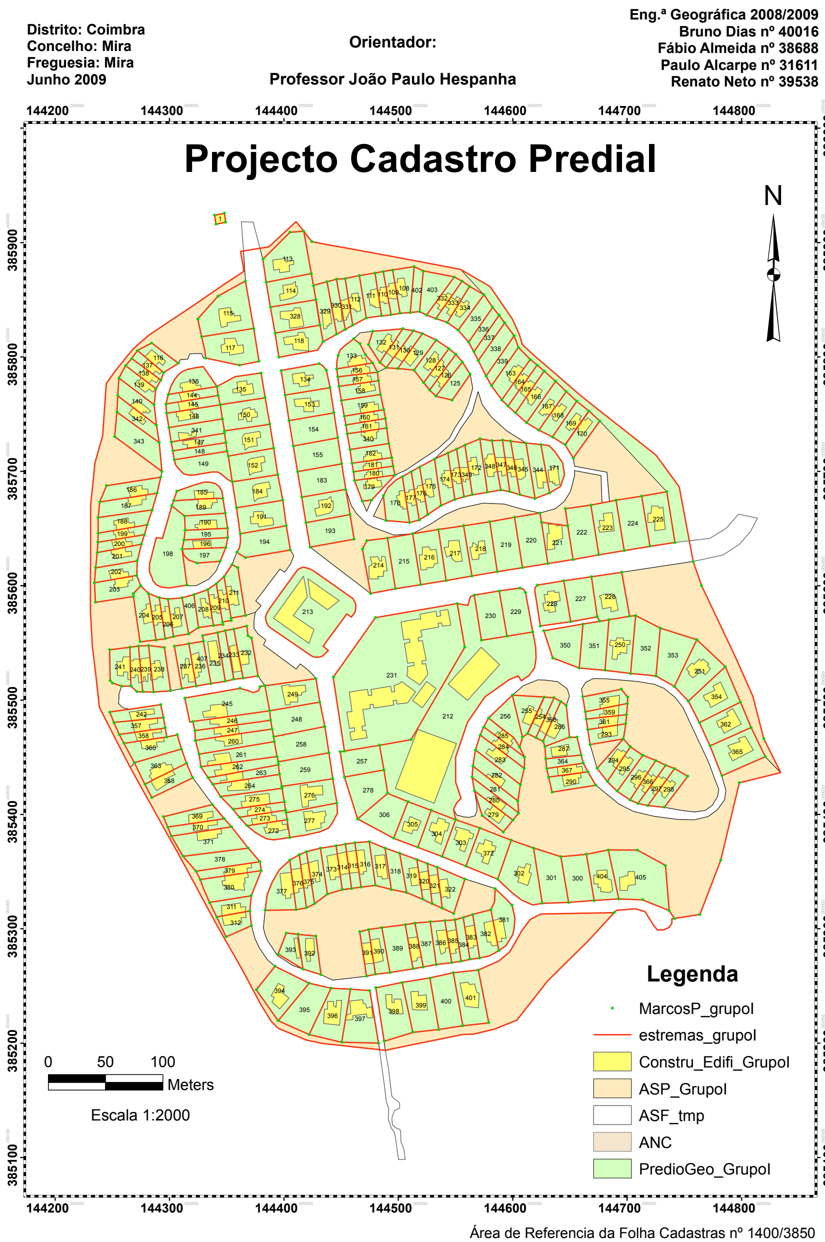


Figure 4.23: *Results from the 2009 Cadastral Update School Project (Dias et al., 2009)*

- Personal Geodatabase schema: the actual implementation obtained as result of the 2007 lecture project, which was further perfected in the following years.

In between the reported models and database schemas, there would be the corresponding model transformations, also according MDA. The first transformation would accept CCDM_PT as input model, producing the ESRI's CCDM_PT specific model (PSM), and can be classified as a Model to Model transformation. The second transformation would classify as a Model to Text or one which uses a Persistence mechanism, although the author does not know any type of such transformation applying to the Personal Geodatabase schema of ESRI.

Taking in mind the above parallels with the MDA approach, the remaining portion of this subsection details the specifics of the two different models and the final Personal Geodatabase, documenting a number of "transformation chains" concerning relevant classes.

The listing is grouped under the same components reported originally in CCDM_PT:

1. Domain Model Core;
2. Parcel component (in LADM: Spatial Unit package);
3. Geometry and Topology (in LADM: Spatial Representation sub-package);
4. Surveying classes;
5. Legal and Administrative component.

Before documenting individual classes and its corresponding "transformation chains", a word is due to the lecture projects scope, concerning specifics of the Portuguese Cadastre. In effect, the data that was migrated (from previous database schema) or surveyed during the 2007 - 2009 projects respects only the so-called geometric cadastre. In this way, the data belonging to the Portuguese Land Registry ("Registo Predial"), although briefly modelled in CCDM_PT and with greater detail in LADM_PT, it was never accounted for in the Personal Geodatabase schema.

It must be equally remembered that, while the departure point documented here is the CCDM_PT (a UML Class diagram), the original specifications are the ones of the Portuguese "Cadastro Predial", dating back from 1995, and which were based on a proprietary (Intergraph's IGDS) data format specification for the spatial features and a set of flat tables, file based and with ASCII encoding, for the alphanumeric component.

Domain Model Core In CCDM_PT, the fundamental relationship between persons (in LADM: Parties) and the Cadastral Object (in LADM: Spatial Unit) via Rights and Restrictions, is maintained without further adaptations from the original CCDM.

As the cadastral projects did not implement the Land Registry data, the core class representing Rights or Restrictions has no further specializations. Instead, the relationship between persons ("Titular" in both CCDM_PT and its PSM) and cadastral objects is maintained through geometric cadastre administrative data concerning the parcel and apartment units (in condominiums).

The persons class and the administrative classes (grossly playing the role of rights, but limited to Property Rights) were mapped to the alphanumeric component class diagram in the PSM.

The cadastral object class ("Objecto Cadastro Predial" in CCDM_PT) represents the parent class for a number of specializations in the spatial features component in the PSM. This last component has also a number of other classes, not in the CCDM core, but which nevertheless have CCDM equivalents, as described in the Parcel component.

The table 4.7 summarizes the transformations between CCDM_PT and the Personal Geodatabase, for core classes.

CCDM_PT (PIM)	**ESRI's CCDM_PT (PSM)**	**Personal Geodatabase**
Cadastral Object "Objecto Cadastro Predial"	Forms of Property (abstract) in the spatial feature compnt.	Specialized classes in MDDC feature data set; described in Parcel compnt.
Right or Restriction "DireitoOu Restrição"	Not directly represented; Parcel and Apartment Unit administrative data in alphanumeric compnt.	Non-feature tables and relationships in the Geodatabase root; described in the alphanumeric compnt.
Person "Titular"	Titular class	Titular table in the Geodatabase root; with relationship class to administrative data

Table 4.7: Core classes transformation chain in CCDM_PT

From the PIM to the PSM classes, other changes occur, namely the addition of a set of new attributes, given that the PSM is at a more detailed design level, and the consideration of ESRI's specific system attributes, like the ESRI Object ID or the Shape attribute for spatial features.

Parcel Component In CCDM_PT, the specializations of the Cadastral Object correspond to spatial features (that is, features which are georeferenced) that were already defined in the "Cadastro Predial" specifications, and were thus regularly surveyed.

These specializations are the Parcel ("Prédio") as the spatial feature representing the basic administrative unit in the country; the Apartment Unit ("Fracção") representing a condominium unit under the Horizontal Property real right; a specialization from a Restriction Area called "Área Social de Prédio", representing servitudes or common use areas affecting two or more Parcels; together with two classes which were proposed by CCDM_PT to support update procedures:

- Part of Parcel ("Subdivisão"): representing the split of a Parcel into two or more Parcels;
- Parcel Complex ("Loteamento"): representing an aggregation of two or more, often but necessarily adjoining Parcels, which will be considered for an administrative procedure where Lots are to be defined.

These classes have a temporary existence by nature and should be attached to administrative documents. Although the PSM did consider them for generation into the Personal Geodatabase, the actual implementation did not occur.

Apart the specializations from the Cadastral Object, other classes in the CCDM_PT Parcel component were also considered for implementation into the Personal Geodatabase.

These are:

- Serving Parcel ("Área Social de Folha"): Parcels representing common rights in both the private and public domains, and are associated with at least two Parcels;
- Building ("Construção"): represents any type of permanent building within a given Parcel, having thus an association to this class;
- Deferred Cadastre Area ("Área Cadastro Diferido"): represents a set of Parcels where their Titular or their boundaries could not be defined during survey. It was defined as a specialization of the CCDM's Partition Parcel (a class defining a 2D spatial partition).

Before detailing the Parcel's sub-components of Geometry and Topology and the Surveying classes, table 4.8 summarizes the transformation chains of the above referred classes, into the Personal Geodatabase.

All these were grouped into the (ESRI's CCDM_PT) spatial feature component of the PSM. This is depicted in figure 4.24[84].

[84]This class diagram is written in Portuguese, but translations were given concerning class names. Contrary to LADM_PT diagrams, CCDM_PT were produced by Poseidon - Community Edition modelling software

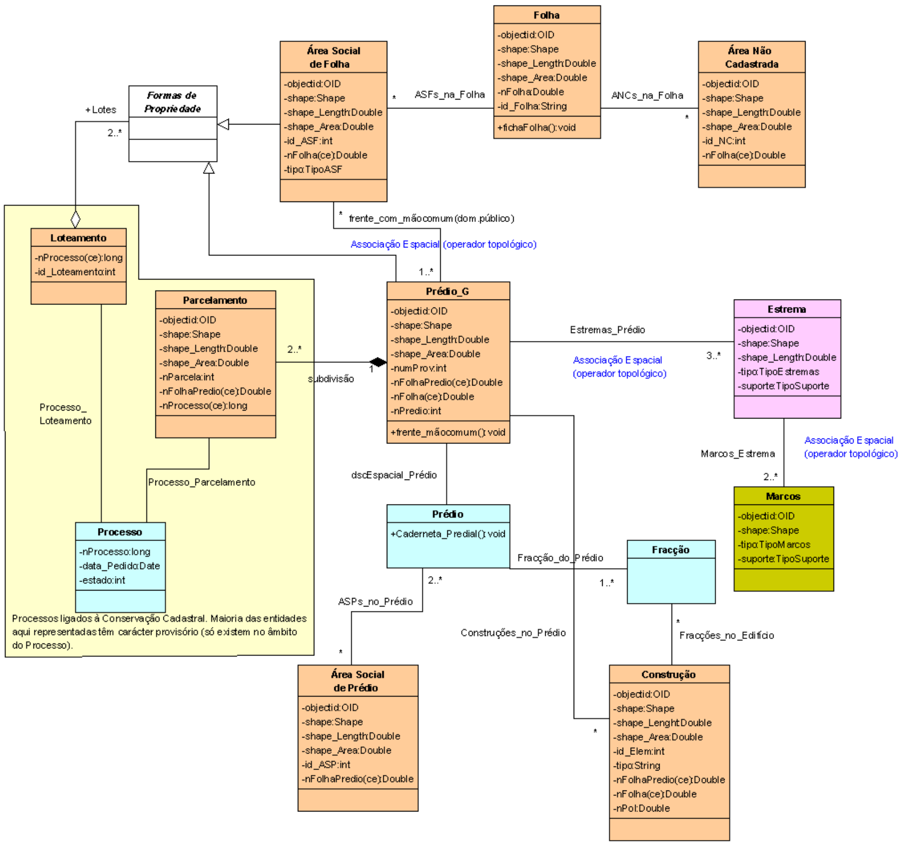


Figure 4.24: *Spatial Feature component of ESRI CCDM_PT*

Note: A word of explanation regarding the “with spatial feature attributes” in table 4.8. This refers to a group of three attributes (plus the required ESRI Object ID) which is used in all Polygon features, and can be considered as ESRI Personal Geodatabase system attributes: the Shape, which stores the feature’s geometry in the form of an ESRI Shape object; and the Shape’s length and area.

CCDM_PT (PIM)	**ESRI's CCDM_PT (PSM)**	**Personal Geodatabase**
Parcel "Prédio"	Predio_G, the spatial compnt. of the Prédio class, also with a alphanumeric compnt.	Predio_G Polygon feature in MDDC data set and corresponding relationship classes
Apartment Unit "Fracção"	"Fracção" class has no spatial representation and thus belongs to the alphanumeric compnt.	Referred to in the alphanumeric compnt.
Parcel Social Area "Área Social de Prédio"	"Área Social de Prédio" with spatial attributes	ASP Polygon feature in MDDC data set and relationship to Prédio
Part of Parcel "Subdivisão"	"Parcelamento", with spatial feature attributes	Not implemented
Parcel Complex "Loteamento"	Loteamento, as an aggregation of other spatial features	Not implemented
Serving Parcel "Área Social de Folha"	"Área Social de Folha", with spatial feature attributes	ASF Polygon feature in MDDC data set, with relationship to "Folha"
Building "Construção"	"Construção", with spatial feature attributes	"Construção" Polygon feature in MDDC data set, with relationship to Predio_G
Deferred Cadastre Area "Área Cadastro Diferido"	"Área Não Cadastrada", with spatial feature attributes	ANC Polygon feature in MDDC data set, with a relationship to "Folha"

Table 4.8: Spatial features component in CCDM_PT

Geometry and Topology The specialized country model (LADM_PT) uses the concept of spatial profiles in order to specify the arrangement of the spatial representation sub-package. Those profiles were absent from the CCDM_PT model. This considered a 2D topology, having as base class the Partition Parcel ("Planta Cadastral" in CCDM_PT). The "Planta Cadastral" is not implemented in the Personal Geodatabase, only its specialized classes: Parcel, Deferred Cadastre Area and the serving parcel, which are all Polygon features and together define the 2D spatial partition for the "Cadastro Predial". The "Planta Cadastral" is associated to a topology tp_face class. It is also associated to one or more Boundary ("Estrema"), which by its turn have an association to a tp_edge class. Finally, each "Estrema" has an association to a Survey Point ("Ponto Levantado"), which equally has an association to an explicit topology class, tp_node.

The specific implementation here reported did not create explicit topology classes in the geodatabase. Instead, it defined a number of topology rules obeying to the requirements contained in the original specifications, converted into a series of ESRI's geodatabase topology rules, implemented in a "Topologia" class belonging to the MDDC Feature Data Set.

Furthermore, the "Topologia" object class served the purpose of validating the relationship between the Parcel, its boundaries ("Estrema") and the defining property beacons, or "Marcos" in the PSM model.

The "Topologia" object stored also the topology rules required to validate the spatial partition defined by the "Planta Cadastral" specialized classes.

The table 4.9 summarizes the geometry and topology classes as implemented from CCDM_PT into the ESRI Personal Geodatabase.

CCDM_PT (PIM)	**ESRI's CCDM_PT (PSM)**	**Personal Geodatabase**
Partition Parcel "Planta Cadastral"	Specialized classes: Predio_G; "Área Social de Folha"; "Área Não Cadastrada"	Already referred Polygon features in MDDC data set
Boundary "Estrema"	"Estrema", with spatial feature attributes	"Estrema" Polyline feature in MDDC data set
Only the surveying classes exist	"Marco" (as a Property Beacon), with spatial feature attributes	"Marco" Point feature in MDDC data set
tp_face, tp_edge and tp_node topology classes	"Topologia" relationships are defined between Predio_G, Estrema and Marco	A topology object was created in the MDDC data set, with a set of rules enforcing topology relationships (also for Partition Parcel classes)

Table 4.9: Geometry and Topology in CCDM_PT

Surveying Classes Until the implementation of the Cadastral project Personal Geodatabase, the Portuguese Cadastral Data did not explicitly store any data from the surveys carried out in order to complete a cadastral sheet or a systematic or individual update.

The CCDM_PT presented a first proposal to include survey data along with cadastral data, having as data source a Survey Document ("Documento de Levantamento"). This document has administrative data, together with technical data defining one or more Survey Points. Contrary to the other classes in CCDM_PT, these were not modelled into the PSM, but were later implemented into the Personal Geodatabase, using two components:

- A cadastral network feature data set, called "Rede" and including two Point feature classes. These are the auxiliary points and the "Cadastral Triangulation" network or "Rede_TC";

- An ArcSurvey extension data base, included in the Personal Geodatabase and defining update links to the relevant MDDC data set classes.

The survey data base was further divided into a series of survey jobs, having all the data to update surveyed classes as "Marcos" or "Rede_TC". This thematic division was possible by filtering the original survey files according feature codes previously defined. In the case of Polygon features such as the Building or the ASP, the surveyed points in the respective survey job were used to define the vertex of the resulting Polygon object, using a joint geodatabase and survey geodatabase editing environment supported by ESRI ArcGIS software.

Legal and Administrative component As referred in the description of the CCDM_PT Core, the Person ("Titular") and the rights and restrictions (replaced by administrative data in the cadastral projects) were implemented in a separate component, called the alphanumeric component in the PSM.

Certain rights are indeed implicit through the associations between the Parcel and the "Titular" classes (through the "Fracção" class). An artefact was arbitrarily introduced into the PSM, to avoid the distinction between urban Parcels (with apartment units or "Fracção"). This was the introduction of a "zero Fracção" representing the whole surface area of the Parcel. This way, all the Parcel objects have at least one "Fracção", and the Titular can all be related to this class. The resulting implementation in the Geodatabase is as follows:

- A Parcel has only a "zero Fracção", which is associated to only one Titular. It is assumed that the Titular holds a Property Right;

- A Parcel has only a "zero Fracção", which is associated to two or more Titular. In this case, the Titular holds a Co-Property Right with a certain share, or a Joint-Property if the share is not defined;

- A Parcel has a "zero Fracção" and two or more regular "Fracção" objects, each having an association to a Titular. In this case, the Titular associated with the "zero Fracção" represents the Common Right of the condominium, and the other Titular have Horizontal Property rights.

The administrative data belonging to the parcel was stored in a "Prédio" alphanumeric class, having a one-to-one association to its geometric representation, the Predio_G class. Interestingly enough, the need for a separate class in the PSM reflects the necessity of the Basic Administrative Unit class, only introduced later in the LADM.

The table 4.10 summarizes the above referred transformations from CCDM_PT into the Personal Geodatabase.

CCDM_PT (PIM)	**ESRI's CCDM_PT (PSM)**	**Personal Geodatabase**
Parcel "Prédio"	Prédio, the alphanumeric compnt., with an association to the spatial compnt., Predio_G	Prédio table in the Geodatabase root, with relationship classes to Predio_G and Fracção
Apartment Unit "Fracção"	"Fracção", as an alphanueric class, with an association to "Construcção"	"Fracção" table in the geodatabase root, with relationship classes to Prédio, Construcção and the relationship class "Fracção_Titular"
Idem	"Fracção_Titular" as a relationship class in the association to Titular	"Fracção_Titular" table with attributes specific to the many-to-many relationship to Titular; in the geodatabase root
Person "Titular"	Already referred to in the	Domain Model Core table

Table 4.10: Alphanumeric component in CCDM_PT

4.6.3 Cadastral Update Editing tasks in ArcGIS software

The following items were taken into consideration when implementing the update tasks in the ArcGIS software:

- Administrative tables and records;
- Code lists or enumerations as drop-down lists (during data edition);
- Map interface (Levels as layers in the TOC).

From the resulting empty Personal Geodatabase schema, a proprietary XML schema file was produced and delivered in each year to the cadastral project groups. In each year, these groups received different working areas and had to achieve different goals.

A common procedure, followed in the years 2008 and 2009 as a result of the findings of the first projects, was to populate the working personal geodatabases with the data referring to each year group working area. The procedure loaded a portion of the original cadastral data, covering the complete municipality area (contained in a separate personal geodatabase) into the empty geodatabase, following two main criteria:

- Graphical: selection of spatial features based on the Polygon representing a specific cadastral sheet ("Folha");

- Alphanumeric: selection of non-spatial features based on an indexing attribute defined in the specifications, which included the sheet number. For some features, this implied a join or relate query.

The following steps were to prepare a cartographic representation of the cadastral data, under two different layouts: according to a "line-based", CAD-like cartographic representation conforming to original specifications; following a free design, which could give better support for the subsequent field survey operations.

These cartographic representations used the architecture of the ArcGIS software, which allows multiple specifications for cartographic representations to be stored in one or more MXD files, in this case regarding the data from the same personal geodatabase.

The cadastral update procedures, using the editing capabilities of the ArcMap component of ArcGIS and also the ArcSurvey extension, used as a working base the "free design" MXD file, where the disposition of layers in the "Table of Contents" followed an acquisition order enabling a correct editing sequence. This can be summarized as follows:

1. Survey jobs belonging to the ArcSurvey data base;
2. National Geodetic Network and Cadastral Triangulation reference points;
3. Property beacons ("Marcos");
4. Parcel boundaries ("Estrema");
5. Parcel (as polygon);
6. Sub-parcel elements such as buildings and ASP's;
7. Other cadastral data model elements such as ASF's or ACD's.

The figure 4.25 shows the arrangement of the ArcSurvey layers and the corresponding spatial features belonging to the first project group of 2009, as displayed through the standard ArcMap interface.

These lecturing projects were intended to follow the field survey and subsequent update procedures to the working personal geodatabase, simulating the systematic update of the cadastre known as "Renovação Cadastral" in Portugal.

So, the focus was on determining a proper update procedure which works for the geodatabase schema resulting from the CCDM_PT implementation. The results from the years 2008 and 2009 have some differences, due to the fact that the nature of the updates was different, and are summarized in the following lists.

Cadastral update of rural parcels by expropriation caused by a new public motorway

1. Creation of a new code list in the geodatabase, to capture the current status of the Property Beacons; The respective attribute was then updated according the field sketches;

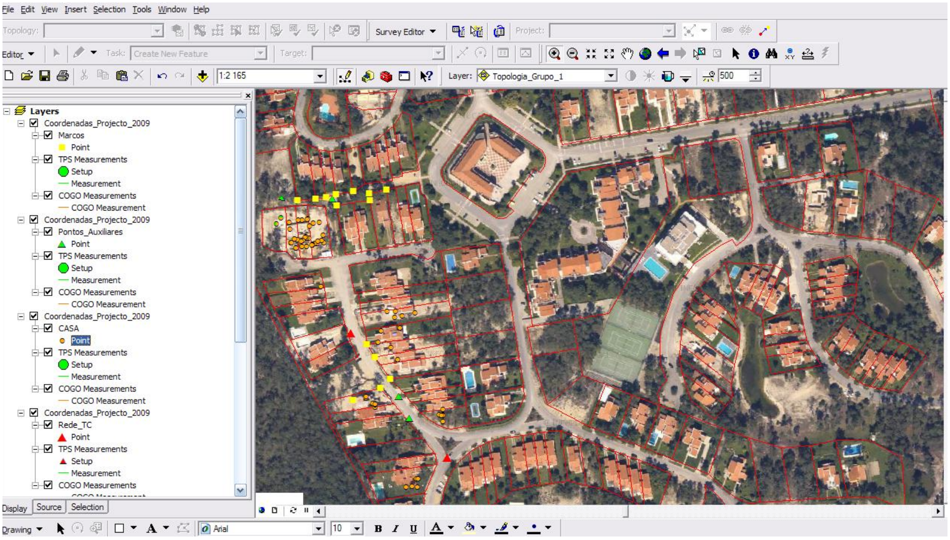


Figure 4.25: *Layer arrangement for the free design layout, project group 1, 2009*

2. New Property Beacons, reference marks and auxiliary points surveyed with GPS or Total Stations were input through the ArcSurvey editing interface;

3. The motorway "As Built" CAD drawings were added to ArcMap Table of Contents to serve as editing (and snapping) environment;

4. Parcel boundaries update, having as reference ArcSurvey or CAD drawings points. The shared editing in ArcMap makes possible the joint update of vertex, boundaries and polygons;

5. The original shape of modified Parcels is (previously) copied into an Historic layer, constituting a separate data set in the geodatabase;

6. Parcel removal, for those which are completely covered by the expropriation polygon; this can actually occur due to the small average size of the Parcels in the working area;

7. Parcels which are removed go equally to the Historic layer, but in this case, also the related alphanumeric description should be kept in an Historic layer;

8. New Parcels are created when the expropriation polygon leaves just one or more fragments of an original (larger) Parcel. In this case, new Parcel IDs should be given and the alphanumeric data has to be entered, possibly copying relevant attributes from the Historic layer;

9. A check should be performed to the alphanumeric data, so that data related to removed Parcels only exists in the Historic layers;

10. All the attributes which are derived from spatial (geometric) data, which were modified, must be recomputed;

11. In the end, the area which is left open by the update procedures should correspond to the expropriation and municipal servitudes in the CAD drawings, and a new ASF should be created there, so that the spatial partition is maintained.

Cadastral update of urban parcels following a tourist village urbanization plan In this case, the field collection of the alphanumeric component data assumes more relevance, namely due to the fact there exists more Co-Property and Horizontal Property. There were no removal of Parcels or new Parcels resulting from fragments, rather the creation of new Parcels and related Buildings within the ASPs areas belonging to the (larger) urbanization Parcel.

The following list reflects a so-called "alphanumeric editing" procedure applied by 2009 project Group 1.

1. Layout and printing of forms for the collection of alphanumeric data concerning Parcels, in the field;

2. Development of an MS Access application to collect the field data, including some internal verification procedures and automating some of the most redundant attribute fields, using configurable templates;

3. Field collection, which included the survey of local addresses and toponyms, and data supplied by the property owners. This data was later input into the MS Access application (at the office);

4. Import of the MS Access tables into the personal geodatabase and subsequent load of the imported data into the (existing) alphanumeric component tables;

5. Finally, the relationships in the geodatabase were updated, in order to reflect the new records input through both the alphanumeric editing and the spatial editing (not described here, but similar to the previous procedure).

4.6.4 Reflections on the Pilot Project

Through the process of modelling and implementing from the CCDM_PT into a Personal Geodatabase, using real cadastral data from the Mira Municipal Cadastre, a number of issues could be identified.

These were relevant for the subsequent modelling concerning the new Portuguese specifications and the LADM_PT specialized model. The following list presents these issues, with the order introduced in the preceding subsections.

- Domain Model (PIM) Core classes: The resulting implementation, and the preceding PSM reflect the scope of the existing requirements of a geometric cadastre, where the Cadastral Object class was further specialized and implemented, but the same does not succeeded with the Rights and Restrictions and the Person core classes.

- Core class specialization: The Core class which were specialized (the Cadastral Object) only remains as particular specializations; the Core class itself has disappeared in the PSM and in the Personal Geodatabase, corresponding to a *Flattening* procedure.

- The scope of a geometric cadastre has prevented the further modelling and implementation of specialized Rights and Restrictions classes.

- Country Requirements: The specific requirements, translated here to attributes to include in the PSM model, imposed by the "Cadastro Predial" regulations, were taken from existing data sets. However, this procedure did not implied the production of any UML class diagram from existing data.

- PSM concerns: As the PSM respects the implementation into an ESRI Personal Geodatabase, a number of so-called "system attributes", such as the Shape attribute in the Personal Geodatabase, should be introduced and configured, in order to achieve further automation.

- Procedural and Geodatabase concerns: The "Prédio" class in the PIM had to be split into geometric and alphanumeric components. This resulted from both procedural (surveying being separated from alphanumeric data collection) and the Geodatabase schema (Feature classes in a Feature Data Set; Alphanumeric classes being relegated to the Geodatabase root).

- Complex combination of constraints: Not considering a 3D spatial profile for implementation, and not willing to specialize the Parcel class into an urban and a rural specialization, led to the creation of the "zero Fracção" object, allowing to associate a Parcel to Titular, always through the "Fracção" class.

- The absence of any consideration for cadastral update procedures in the existing regulations, led to the lack of implementation of the "Subdivisão" and the "Loteamento" classes from the Personal Geodatabase.

- Implementation of Associations: The associations in the UML class diagram (the PSM Model) should be implemented as relationship classes in the Personal Geodatabase. This could be achieved through a proper transformation template.

- Implementation of Enumerations: These were not shown in the preceding subsections, but should be translated (also through a transformation template) into Personal Geodatabase data domains.

- Implementation of Topology: A mechanism (possibly a script transformation template) is totally absent, concerning the translation of PIM topology classes into a Topology object in the Personal Geodatabase.

- Support for Geometry Editing: There are other elements in the PIM which can not be validated only through a topology object. These could be handled through the consideration of OCL (absent from CCDM_PT).

- Support for Cadastral Update: Certain steps could be implemented, if considering stored procedures. However, such mechanism do not exist in the Personal Geodatabase. In this case, this has to be supplied through an ESRI's ArcObjects based application.

- Handling of derived attributes: this can be modelled through the insertion of method signatures in the corresponding classes. The methods could then be implemented through stored procedures or (for the Personal Geodatabase) through ArcObjects applications.

- Aggregation Interfaces: Data input forms (in a Cadastral Update) were absent from the PIM and the PSM, but could be introduced using a class (or a class aggregation) interface, which is a standard UML modelling element.

Concluding, the above list is (partly) handled by through a number of enhancements introduced by LADM and the reported development methodology, namely considering the introduction of the Spatial and Legal profiles; the consideration of OCL constraints; and the support for implementation introduced by both MDA and Persistence mechanisms.

Specifically concerning the Mira Municipal Cadastre implementation, more significant results would be obtained (if using MDA) if an ESRI Personal Geodatabase profile were developed for UML 2.x, and templates were developed to support for the transformation into a XML schema file.

4.7 Concluding remarks on the methodological approach

Re-capitulating all the previously presented list of phase.activity, one shall retain a number of key issues to consider if willing to apply the methodology to another country:

- The methodology is expected to have results as reported here, if a number of pre-requisites are fulfilled (property rights, a cadastre and a land registry, even if paper based, and a Civil Code or other form of codified law);

- It is assumed that optimal modelling results are to be achieved from the consideration of the actors and the activities contributing to the main cadastral update procedures;

- The methodology assumes the modular consideration of the different aspects of a land administration system (technical, legal and organizational);

- The methodology considers that the final composition of the system is to be obtained considering a number of iterations which include the geometric and the legal and administrative components, according LADM (as the basic framework). And also UP iterations and the use of LADM profiles;

- The UP Construction phase should be considered and further detailed in a number of activities, given that the current methodology fundamentally addresses the UP's inception and elaboration phases.

Legal Profile Parent Class	Name and (alias)	Description see also tables 2.1 and 2.2
RealProperty_E	PT_Praedial-Servitude (Servidão Predial)	Real Property owner's right (as praedium dominans) to use certain facilities of another Real Property (servient); it defines a related enumeration, PT_TypeOfPServitudes.
PersonalRight_E	PT_Superficies (Superfície)	Right to build or maintain a construction or plantation on another Real Property. This right can be temporary or perpetual.
PersonalRight_E	PT_Use&Habitation (Uso e Habitação)	Right to use a determined facility (it is an Habitation if the facility is a residential building) on another Real Property.
PersonalRight_E	PT_Usufruct (Usofruto)	Right to fully enjoy another's Real Property or right, limited to the holder lifetime or a shorter period.
PersonalRight_E	PT_TimeShare (Habitação Periódica)	A time share with the powers of a Real Right. Gives the right to use an habitation unit in a tourist condominium for a fixed time period.
LatentRight_E	PT_PreEmption (Preferência)	Right to acquire ownership over a Real Property for a contracted price over third parties in a sale; to be exerted within a time limit.
LatentRight_E	PT_Preliminary-Contract (Contrato Promessa)	A Real Right if it is registered. The contract vary depending on the nature of the immovable, usually a Condominium building. Defines a fixed term, after which ownership transfers
Lien_E	PT_Retention (Retenção)	Right of a debtor to maintain an immovable in his possession, provided he has also a credit against the creditor.
Lien_E	PT_PledgeOf-Receivables (Consignação)	Right to receive income generated from a Real Property economic exploit for a maximum term of 15 years.
Lien_E	PT_Mortgage (Hipoteca)	Creditor's right to execute his credit and interest by the value of a Real Property or certain movables.

Table 4.6: Restrictions specialization in LADM_PT

Chapter 5

Implementation Phase

This chapter reports on the methodology, research platform and results obtained with the implementation test covering the latest specifications (parts of PT_CDM and LADM integration into LADM_PT country model).

The Portuguese country model LADM_PT, obtained from the Domain Model (LADM) and the Portuguese Cadastral Data Model (PT_CDM), as described in the previous chapter, used a manual derivation procedure, supported with functionality from Enterprise Architect (EA) software (basic diagramming and UML validation functions). The same manual derivation procedure, although applied to older versions of the Domain Model and Portuguese cadastre specifications, and complemented with an implementation using real cadastral data for Mira Municipal Cadastre, is reported in section 4.6 as the Pilot Project.

In this chapter, a new procedure to derive LADM_PT is described, using the Model Driven Architecture (MDA) approach as it is currently supported through a number of Computer Aided Software Engineering (CASE) tools implemented in the open source Integrated Development Environment (IDE) called Eclipse.

This procedure starts with a number of UML packages being exported from EA (were all the original modelling was done) and parsed into Eclipse UML2 class models and diagrams, enabling then subsequent processing, which ultimately produced an implementation into a PostgreSQL/PostGIS spatial data base. More precisely, the final result corresponds to a Object-Relational Mapping with two components which are consistently synchronized: A Java abstract layer, accessible to other applications running under the Eclipse IDE; and the corresponding data base schema, which can be further populated with data through either one of the components.

The choice of the Eclipse IDE, complemented with the Modelling Framework, lies in the ability to perform a complete modelling cycle, from UML to a spatial database implementation. It is possible, due to the open source nature of all the required components, to adapt and modify the application code to the particular goal of generating a country model. Although it is possible to develop generation and transformation code in EA, other components are missing, like Object-Relational

Mapping.

The next two sections report on specifics of the Eclipse IDE as a development CASE tool, and requirements for the Model Transformations and Persistence; and the description of the subset of model elements which were used in the actual implementation test.

The remaining sections will give specific details of this MDA procedure, beginning with a description of the set of Model Transformations which are required in order to obtain a country model which can be implemented (5.3); and the settings required for the Persistence mechanism in order to derive the spatial data base schema (5.4). One additional section will report on validation tests and queries which can be applied to either component of the Object-Relational Mapping, and the processing of the OCL expressions (5.5).

5.1 Specifics of the Development Platform

In order to derive the final implementation (as a PostgreSQL/PostGIS spatial data base), a number of so-called plugins have to be installed on top of the Eclipse Modelling Tools package. This download package includes the Eclipse Modelling Framework (EMF) elements, together with other plugins supporting UML, OCL and several different types of Model Transformations. The most important plugins (external and internal to EMF) are:

- Hibernate Tools. For Java persistence through Object-relational mappings;
- Dresden OCL2 for Eclipse. For OCL expression validation and parsing;
- UML2 (in EMF). To specify an UML v2 model, and supporting the drawing of all sorts of UML diagrams;
- QVT Operational (in EMF). To write and perform Model to Model transformations.

The Galileo version of the Eclipse base package has been used (v. 3.5.2) with EMF version 2.5.0. The base package includes an XML Editor which is capable of editing and validating XML files, while offering the usual editing facilities in Eclipse, namely *syntax highlighting* and *content assist*, this last one having the ability to read schema definition files like DTD or XSD. The EMF extends this functionality with a XMI[85] Reader which is capable to handle Java, XSD based or (Eclipse) UML2 metamodels.

This functionality was fundamental to read the XMI files containing the UML packages exported from EA, without the need of a dedicated importer. However, in order for the export to succeed, a specific setup is required while exporting from EA, as follows:

1. UML and XMI reference versions should be 2.1 (both);

[85]XML Metadata Interchange standard, as explained in .2.1.2

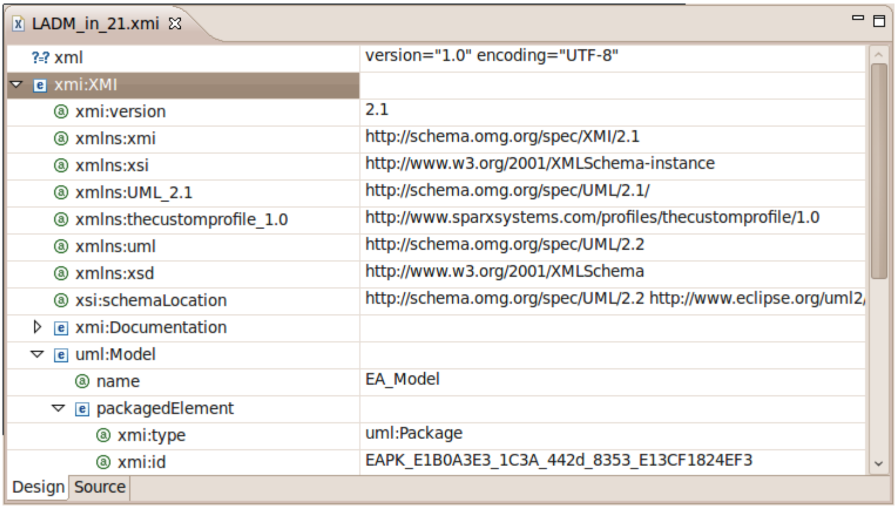


Figure 5.1: *The Eclipse XMI Editor design view of LADM*

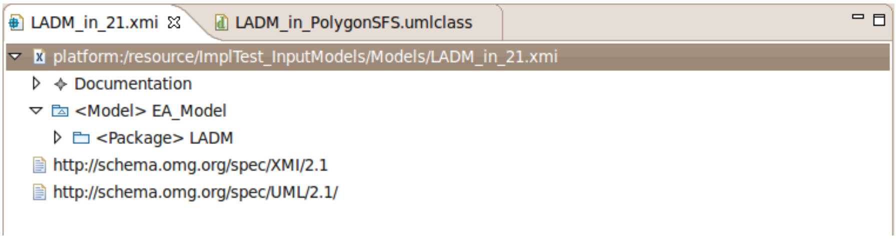


Figure 5.2: *The Eclipse UML Editor with the PolygonSFS_Profile from LADM*

2. There should be no roundtrip enabled;

3. There should be no EA Tags enabled.

This results in a XMI file with no proprietary EA packaged elements, which are not understood by the Eclipse XMI Reader and cause the parsing of XMI contents into Eclipse model elements to fail. The figure 5.1 shows the design view corresponding to the LADM package as exported from EA (just the file header portion with namespace URL's).

The figure 5.2 shows the resulting UML Editor view, as an Eclipse platform model resource, with specific modelling icons for Model and Package. This confirms that Eclipse was able to parse the XMI file into the UML2 elements. From this resource, diagram elements can be automatically initialized, like the ones belonging to the geometric component, referred as the "PolygonSFS_Profile", with a UML Class extension in the corresponding Eclipse project folder.

Apart from the basic UML modelling capabilities, two plugins were required in order to complete the implementation test:

- Dresden OCL2 for Eclipse (v. 2.2.0), to parse and validate OCL expressions in the country model;
- Hibernate Core (v. 3.3.2) and Tools (v. 3.2.4), to setup and maintain the ORM Persistence mechanism.

Taking into account that the model subset used for the implementation test contains classes belonging to LADM's spatial representation, which include geometry types, the basic Hibernate components are not sufficient, because they offer no support for geometry types. To include such support, a user library was created (out of existing libraries) in the Eclipse environment, gathering the following Java Archives (JAR's):

- Hibernate-spatial (v. 1.0-M2), with the associated PostGIS dialect support JAR;
- Java Topology Suite (JTS, v. 1.10), which provides a complete Java implementation for geometry types in the Simple Features for SQL specification;
- A basic PostgreSQL (v. 8.4) Java Data Base Connectivity (JDBC) drive, extended with a JDBC to support geometry types in PostGIS (v. 2.0.0).

Concerning the required Model Transformations in order to support the derivation of the domain model (LADM) into the country model (LADM_PT), the Eclipse implementation of the Query/View/Transformations Operational Mapping Language (as part of the specification in (OMG, 2008)) was selected from the available transformation languages. The definition of a transformation requires a dedicated project template in Eclipse, having one transformation file (with a "QVTO" extension) having its own editor environment, and requiring that metamodels of the intervening models in a transformation be registered in the Eclipse environment (Gronback, 2009, p. 238-240).

Every metamodel used as a "modeltype" reference in a transformation must be created or converted as an Ecore metamodel (file extension "ecore" in a Eclipse project). The Ecore model is based on the Meta Object Facility (MOF) standard metamodelling language and one of its fundamental design goals is to map cleanly to Java implementations (Steinberg et al., 2009, p. 103). An Ecore model can be derived from annotated Java, an UML2 model or a XSD file, but in the implementation test, an already registered metamodel was used as reference, the *Simpleuml* (a simplified subset definition of the UML standard, expressed as an Ecore metamodel).

There is another step within the adopted MDA procedure, where an Ecore model resource is required. It respects the automatic generation of Java source code, from the model resulting from the transformations (the Platform Specific Model version of LADM_PT). This is assured by the EMF Generator (which has configurable templates), through the creation of a plugin project, typically originating three sets of Java classes: interface, implementation and utility (Steinberg et al., 2009, p. 239).

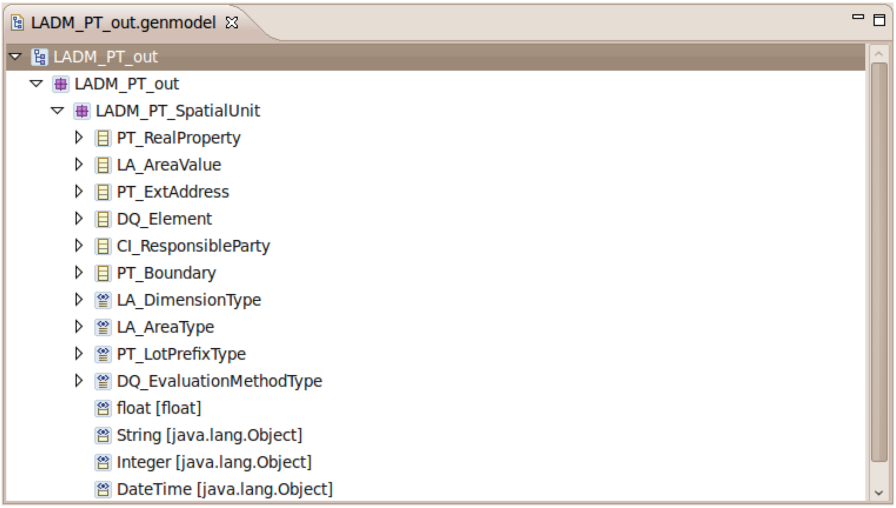


Figure 5.3: *The Eclipse Generator Model Editor with a subset of LADM_PT elements*

The figure 5.3 shows a preliminary result for the automatically derived generator code, from an Ecore model file representing a subset of the LADM_PT country model.

5.2 Subset of model elements used in the implementation test for LADM_PT

As reported in the Development Methodology table, part 2 (table 4.3), the complete LADM_PT country model demanded three Unified Process iterations during Elaboration, with the first iteration being focused on the geometric component. The intervention of MDA processes is referred in table 4.3 as Phase 5, Activities 2 to 6. The details regarding those processes are reported in this section, and the model elements belonging to the geometric component are thus the ones included in the implementation test subset.

The decision to focus the implementation test on the geometric component (Iteration 1) has taken into account the need to test a number of MDA related procedures (also Persistence procedures) with the inclusion of geometry types. In fact, the majority of handbook examples and tutorials concerning the different plugins and the Eclipse EMF platform do not consider geometry types. And, consequently, do not consider specifics concerning such types, namely the topology relationships or the need for metric operators to act upon these (often complex) types. Any of those geometry and topology aspects can imply the need for related validation procedures.

The LADM_PT geometric component resulting from the MDA process includes elements from the *PolygonSFS* and the *Unstructured* (line based) spatial profiles (Lemmen et al., 2010), with related LADM class specializations derived from LA_Level,

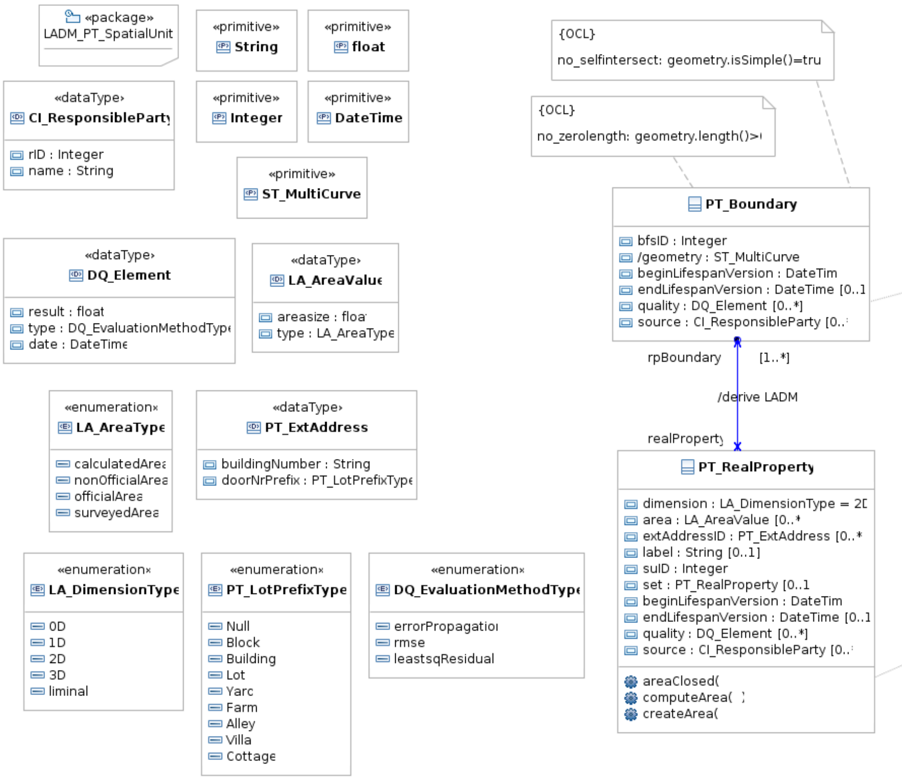


Figure 5.4: *The subset of LADM_PT geometric component elements in the implementation test*

LA_SpatialUnit and LA_BoundaryFaceString. Furthermore, it merges (through transformation mappings) model elements from the Portuguese Cadastral Data Model (PT_CDM): RealProperty, DeferredCadastre, CadastralObjectPolygon, CadastralBoundary and the SurveyedPoint.

The figure 5.4 depicts the (predicted) results from the MDA process, for the *PolygonSFS* profile of the geometric component, but omitting the Portuguese implementation of the PolygonSFS_Level class. This diagram shows that, in order for the EMF Generator and the Hibernate Persistence to work, every attribute type belonging to the modelled classes must be defined, be it a primitive type, a data type, an enumeration or a code list. This implied the late consideration, for data types not belonging to LADM or to PT_CDM elements input into the MDA process, namely DQ_Element (from ISO 19113) and CI_ResponsibleParty (from ISO 19115).

The *Unstructured* profile, also belonging to the LADM_PT geometric component, includes the classes supporting the modelling of the DeferredCadastre elements. These correspond to the: DeferredCadastre_Level, PT_DeferredCadastre and PT_DeferredBoundary and required OCL expressions. A simplified diagram (not

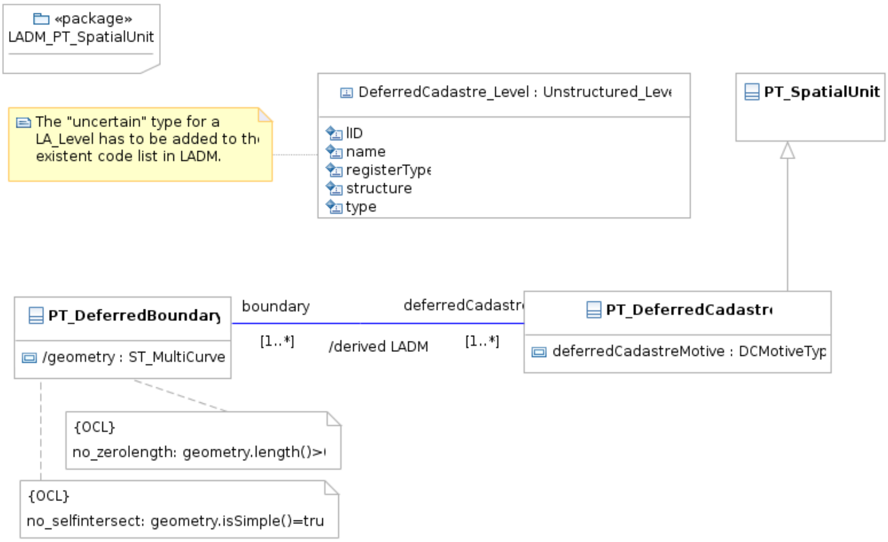


Figure 5.5: *The subset of LADM_PT geometric component for the unstructured profile*

including all the attributes and types required during implementation) is shown in figure 5.5.

5.3 LADM_PT in the MDA development cycle

This section reports on the required model transformations in order to achieve the resulting Platform Independent Model (PIM) country model, that is, LADM_PT. It has been divided into two subsections, the first showing the required transformations that will produce the geometric component and the legal and administrative component profiles, having as source the Domain Model (LADM).

The second type of transformations uses the result of the former transformations, that is, a "Profiled" LADM which conforms with the country specific requirements (regarding the use of existing profiles), and merges this model with the UML Model contained in the Portuguese Cadastral Survey Operations Specifications, called PT_CDM. The result of this model merge transformation is the country model LADM_PT.

For both types of transformations, which can be termed as "Profile Generation" and "Country Specialization by Merge", the Query/View/Transformations Operational Mappings language (QVTO), as implemented in the Eclipse EMF framework, is used for all the related examples and analysis. The following methodology was applied in order to identify the main transformation patterns required to go from the original source (LADM; the conceptual Domain Model) to the country model (LADM_PT):

- Identify the original and target classes which are needed in the context of the

Implementation Test (as defined in Section 5.2);

- Produce a set of tables (one per transformation) describing the detailed transformation operations for each pair of original and target classes;
- Abstract from the set of tables, the existing transformation patterns, previous to writing the actual QVTO examples.

All the elements in the methodology referred above (tables, transformation patterns and QVTO expressions), will be presented in the following subsections.

The model to model (M2M) transformations used in this methodology classify as *Endogenous*, according (Goldschmidt and Wachsmuth, 2008, p.2), given that the original and target reference metamodels are the same (the SimpleUML Metamodel as defined in Eclipse Ecore metamodelling language). The overall transformation pattern, as defined in the same article, is a *Refinement Transformation*, where large parts of the original model elements are preserved, while some refinements are introduced. Not considering this transformation as an *in place* transformation presents the advantage to maintain transformation traces which explicitly model, regarding LADM, the process of deriving various types of profiles (spatial or legal) from the Domain Model. The use of extensions or profiles means indeed more transformation work. But can be necessary, as in this case.

In a review of model transformation patterns, the article in (Iacob et al., 2008, p.5,10) also defines refinement transformations, and other pattern types, from which the *Flattening* transformation pattern is particularly relevant for the LADM to LADM_PT transformations. This transformation pattern has the goal of removing the hierarchical structure existing in the original model, to present a target model having just the more specialized elements. In the implementation test example, this situation applies to the Spatial Unit and the Rights hierarchies.

There is another potential benefit of specifying the Profile Generation as model transformations, as identified in the article (Dong et al., 2010, p.5), which is the possibility of maintaining an explicit and formal, documented procedure of evolution of the design patterns being used in LADM, as building blocks used to achieve a given country model. These authors identified a total of five categories of evolution of design patterns and propose related transformation rules, defined at the QVT *Relations* language[86].

The examples of model transformation patterns contained in the articles (Goldschmidt and Wachsmuth, 2008) and (Iacob et al., 2008) are also expressed in QVT Relations language.

5.3.1 Use of LADM spatial and legal profiles

Actually, the LADM spatial and legal profiles are design patterns which may be applied to the basic LADM model, being defined through the use of M2M transformations. In the implementation test subset of model elements, only two profiles have

[86]Contrary to the Operational Mappings language, which is an imperative language including procedural elements, the Core and Relations languages are declarative, with the Relations being the higher-level language in the QVT specification

to be generated from the Domain Model relevant classes, the Simple Features for SQL Polygon profile for the geometric component, and the Rights profile for the legal and administrative component. This can be accomplished through dedicated refinement transformation patterns, and a final set of merge mapping operations. This is described as:

$$M2M_a : refinement(in : LADM) \Rightarrow LADM\_SFSPolygon$$

$$M2M_b : refinement(in : LADM) \Rightarrow LADM\_Rights$$

$$M2M_c : merge(in : LADM\_PolygonSFS, in : LADM\_Rights) \Rightarrow LADM\_Profiled$$

The following table (5.1) shows all the original Domain Model classes which are required to generate the PolygonSFS profile, the respective target class names and a detailed description of each transformation. The detail mentions all the required primitive classes which have to be defined in the final LADM_PT so as to be able to generate code (and database elements).

To be able to exemplify a simple case of a property which is registered without other derived or minor rights (that is, hold in "fee simple" according to common law), the subset of elements documented in the implementation test are not sufficient. A few classes shall be considered from the legal and administrative component, and for this case, a minimum Legal Rights Profile is considered as a part of the Model Transformations. This profile has to include the pivot class for a system encompassing a Geometric Cadastre and a Land Registry, the LA_BAUnit Domain Model class. The table 5.2 is the answer to this requirement, and shows the transformations to be implemented in order to associate a property right to the Basic Administrative Unit.

Examining the set of transformations required for the generation of the PolygonSFS and the Legal Rights profiles, the following number of transformation patterns were identified:

1. Flattening of superclass attributes into children classes, with no further transforms;

2. Determining a default value for an attribute and validate through OCL from a given set of Enumeration literals;

3. Omitting an attribute from the target class, provided cardinality is [0..*] or [0..1];

4. Type replacement for a given attribute, with the replacement type being a subdomain of the source type.

5.3.2 Country Specialization by use of an UML Model

The model transformations applied so far are not yet able to generate a final Platform Specific Model (PSM) which includes specific country requirements not contained in the elements that constitute the so called spatial and legal & administrative profiles.

Original LADM (source)	Polygon SFS (target)	Transformation operations - detailed
Versioned-Object	Flattened to children classes	Attributes to be inherited by LA_Level, LA_SpatialUnit and LA_Boundary-FaceString: *beginLifeSpan* and *endLifeSpan* require a DateTime class; *quality* requires DQ_Element and *source* requires CI_ResponsibleParty primitive types.
LA_Level	PolygonSFS_-Level	Inherits the four attributes from the Versioned Object. The *structure* attribute should be set to "polygon"; requires Enumeration LA_StructureType; to enforce by OCL invariant. Remaining attributes to be kept.
LA_SpatialUnit	PolygonSFS_-SpatialUnit	Inherits the four attributes from the Versioned Object. The *dimension* attribute should be set to "2D"; requires Enumeration LA_DimensionType; to enforce by OCL invariant. The *volume* attribute is optional and shall be omitted; remaining attributes to be kept, using LA_AreaType Enumeration and ExtAddress type.
LA_Boundary-FaceString	PolygonSFS_-Boundary	Inherits the four attributes from the Versioned Object. The *geometry* type must be of type ST_MultiCurve (type replacement). The *bfsID* attribute is kept from source. The *locationByText* attribute is optional and shall be omitted. *Note: the geometry attribute can be derived from the related survey points in LA_Point*

Table 5.1: M2M Transformations - Refinement operations for the PolygonSFS profile

In other words, the previous set of model transformations are still sufficiently generic, so that they could be applied to different country models.

The model transformation here reported is one of the scenarios to consider for the generation of a country model, namely when the country requirements have been already processed into an UML class model which can be related to the given LADM profiled Domain Model.

This should be considered a second type of model transformation in the chain, contributing to a final (and complete) PIM, from where one or more PSM's can be generated, as follows:

$$M2M_d : merge(in : LADM\_profiled; in : PT\_CDM) \Rightarrow LADM\_PT$$

Original LADM (source)	Legal Rights (target)	Transformation operations - detailed
LA_BAUnit	Name is kept	Inherits the four attributes from the Versioned Object; Keeps own attributes
LA_Administrative-Source	Name is kept	No changes; structure should be copied during transformation.
LA_RRR	Flattened to children classes	Attributes to be inherited by Property and *timeSpec*.
LA_Right	Flattened to children classes	Attributes to be inherited by Property and *type* requires a RightType Enumeration
BasicOwnership	Flattened to children classes	The *timeSpec* attribute must be set to "Perpetual"; Attributes to be inherited by Property.
Property	Name is kept	Inherits the attributes (and default values) from LA_RRR, LA_Right and Basic-Ownership.

Table 5.2: M2M Transformations - Refinement operations for the Rights (Property) profile

Like in the previous subsection, the details of the required transformations are first listed in tabular format, by using separate tables for the spatial profile (table 5.3) and for the legal & administrative profile (table 5.4). The source model in the first column respects the result of the previous transformations (the "profiled" LADM), while the source model in the second column respect the country model (not complying with LADM). The target model obtained from these transformations is the LADM country model PIM.

In this set of model transformations, there are some LADM source code lists which were adapted to country specific enumerations. In the legal & administrative component, there are cases where no one to one mappings between the two sources (LADM_profiled and PT_CDM) could be defined. This meant, in this specific model transformation, that attributes in the target class (the country model) can be derived from the LADM_profiled alone, or by a one to many class mappings between the source models in specific merge operations. Another specific case regards the import of a few enumerations existing in the PT_CDM source, into the final country model. These last ones do not have any equivalence in the LADM_profiled source.

5.4 Producing a spatial data base schema

Up to this moment in the transformation chain from the original domain model (LADM), to the country model (LADM_PT), a number of model-to-model transformations were applied, resulting in a more specialized model (including country specific requirements) but that is still a Platform Independent Model. In order to

SFSPolygon profile (source)	**PT_CDM classes (source)**	**LADM_PT (target)**	**Transformation operations - detailed**
PolygonSFS_Level	No related merge classes	RealProperty_Level (singleton)	A single object should be instantiated. Set state of attributes to: lID = 1; name= "Predios"; registerType= RealProperty; type= PrimaryRight
PolygonSFS_SpatialUnit	RealProperty ("Predio")	PT_RealProperty (specialized class)	Omitted attributes: *referencePoint*; Derived attributes: *extAddressID*: obtain from *doorNumberPrefix* and *doorNrCadObject*; *suID*: copy from *acquisitionNumber*; *area*: computed from PT_Boundary; *label*: copy from NIP
PolygonSFS_Boundary	Boundary ("Estrema") associated to SurveyedPoint class	PT_Boundary	Derived attributes (from SurveyedPoint class): *beginLifeSpan*: earliest survey date; *quality*: methodology set from the *monumentation* attribute
LA_MonumentationType	Point Type (Enumeration)	LA_MonumentationType2	Replacing enumeration literals with: beacon; beaconZ; cornerstone; marker; notMarked
LA_Point	SurveyedPoint ("Ponto Coordenado")	PT_Point	Default attribute values to set: *interpolationRole*= isolated; *originalLocation*= ST_Point; Type replacement: *monumentation*= LA_MonumentationType2

Table 5.3: M2M Transformations - Country profile generation, spatial component

produce an implementation of this PIM in a given spatial data base, a simpler approach would be to define a new PIM to PSM model to model transformation, which in this case would have to be an *exogenous* transformation, given that the source and target metamodels are different (respectively UML and Entity-Relational). Following this transformation, a final model-to-text transformation would produce SQL source code from the PSM, in order to produce the spatial data base schema. Both transformations (model-to-model and model-to-text) have already examples recurring to OMG specification languages, respectively QVT Operational and Model to Text Language (MTL). An older example using this alternative is reported in (Kleppe et al., 2003, p.43, 46-47), where, after achieving a complete PIM, different PSM were derived, in particular a relational model, through a model-to-model transformation. This relational PSM is then transformed to SQL source code through model-to-text

Rights profile (source)	**PT_CDM classes (source)**	**LADM_PT (target)**	**Transformation operations - detailed**
LA_Administrative (source)	Deed ("Escritura") CourtDecision; LegalDiploma	PT_AdministrativeSource	Type replacement: main *type* is defined by new enumeration PT_AdminSourceType; sub-types exist in PT_CDM, but were not converted to LADM_PT
LA_Administrative-SourceType	Abstraction from above classes	≪enumeration≫PT_Admin-SourceType	Literals for the new enumeration: deed; court decision; legal diploma; other
Property	No equivalence	PT_Property	Type replacement: *type* is given by PT_RightType with value = 1. Default values: *share*= 1/1 with *shareCheck*= false
≪code list≫LA_Right-Type	No equivalence	≪enumeration≫PT_Right-Type	Literals for the new enumeration: Property; Joint-Property; Co-Property; Condominium; Common Parts; Serving Parcel
LA_BAUnit	Cadastral-Object and association to Land-Registry-Description	PT_BAUnit	Derived attributes: *cadastral-ObjectRegime*: import enumeration CadObjRegimeType; *landRegistryDescrNumber*: import from the LandRegistry-Description class; all other source attributes should be maintained

Table 5.4: M2M Transformations - Country profile generation, legal & administrative component

transformations. Other example could be the use of an XML schema (or XSD file) in order to perform an exchange of format.

One major drawback when considering spatial data bases, however, is that these existing transformations do not account for the specifics of spatial types, and how they should be included in a given spatial data base schema.

The implemented solution thus used a combination of the Hibernate core library, extended by Hibernate-Spatial to tackle the spatial types. This solution relies on a widely used and tested persistence and object-relational mapping (ORM) application, offering a good solution to the *paradigm mismatch* issues in ORM, specially considering richly typed Java domain models, as in the case of LADM. Furthermore, this solution maintains a business layer accessible to Java applications, with the code being executed in the Java VM (not in the data base), while still being able to load and store persistent objects in the data base (Bauer and King, 2007, p.35).

With the Hibernate-Spatial solution, one can establish equivalences to the simpler MDA approach, above referred:

1. The model-to-model transformation from the PIM to the PSM is replaced with a set of persistent classes mappings, specified through XML;

2. The final model-to-text transformation from the PSM UML elements to SQL source code is replaced for built-in, automatically generated SQL statements which are sensitive to different SQL dialects (depending on the specific data base to be used, (Bauer and King, 2007, p.350)).

In this way, it can be said that the Hibernate-Spatial solution tightly couples the two types of transformations, while offering tested solutions to ORM issues and being able to cope with different SQL dialects. The following expression summarizes this last step in the transformation chain.

Generating a data base schema from a UML Model The Persistence "transformation" corresponds to a succession of a model-to-model (M2M) and a model-to-text (M2T) transformations in MDA, and in this case is implemented through the use of Hibernate-Spatial libraries. This transformation can be described as:

$$M2T : Persistence(in : LADM\_PT) \Rightarrow output(AbstractJavaLayer; PostGISschema)$$

The implementation test subset of model elements has been translated to a PostgreSQL-PostGIS spatial data base schema, by using the related SQL dialect, available in the Hibernate-Spatial library. The following subsection shows the configuration steps required in order to set up a corresponding Eclipse project.

1. Hibernate-Spatial configuration setup: empty PostGIS schema; Connection; Properties for the Session; Eclipse Project folders;

2. Generator Java Classes as sources for Hibernate;

3. Hibernate Mappings regarding the implementation test classes;

4. Generate the data base with Schema Export.

5.4.1 Hibernate-Spatial configuration set up

Before configuring an Hibernate-Spatial Eclipse project, it is required to have an empty spatial data base in PostgreSQL, which uses the template schema "template_pgis". This template is created during the installation of the PostGIS extension, which spatially enables the PostgreSQL data base server.

In order to create an empty schema from the command line, a console is required, and the following commands must be run:

```
su postgres
psql -d postgres -U postgres
CREATE DATABASE [dbname] WITH OWNER = postgres TEMPLATE = template_pgis;
\q
```

Of course, above commands can only be issued after installing both PostgreSQL and PostGIS. The later can be installed using the *Stack Builder* application from PostgreSQL. The data base server has also to be previously configured, namely defining the username and password for the superuser ("su") and other parameters, like connection credentials for eventual clients. It is recommended to install the *PgAdmin III* client interface for PostgreSQL, which turns the definition and setup of new database schemas, users profiles and even data base queries, much easer to perform. The figure 5.6 shows an example of creating an empty PostGIS schema with the help of this application[87].

After creating an empty PostGIS data base where to implement the schema that will be defined by Hibernate, a new Eclipse Project has to be created, beginning as a standard Java project with separate source (src) and binaries (bin) folders, and a build path for the used Java Runtime Environment (JRE), as defined in the execution environment. In the implementation test, the Standard Edition version 1.6 was used.

However, because this will be an Hibernate-Spatial Eclipse project, additional libraries are required for the build path, namely those belonging to Hibernate core and to Hibernate-Spatial. One solution that can be used in Eclipse is to define custom libraries using all the JAR files contained in user defined folders. For this specific case, all the JAR contained in the Hibernate plug-in folder (org.hibernate.eclipse[version number]/lib/hibernate) were used to define the *HibernateLib*, while the JAR files contained in the custom folder HS_Libs were used to define the *HibernateSpatialLib*. Besides these (required) libraries, an additional library was used in order to tackle the sources obtained through the EMF Generator, which used a plug-in project, hence the inclusion of an automatically defined *Plug-in Dependencies*. This is not an absolute requirement for an Hibernate-Spatial project, provided the Java sources are defined by manually implementing the domain model, or using another procedure which does not imply a Plug-in project.

The figure 5.7 shows the set of libraries defined for the Hibernate-Spatial Eclipse project. The next step is to change to the Hibernate perspective (requiring that the Hibernate Tools Plug-in for Eclipse is installed), in order to complete the configuration set up.

This Perspective defines three new views in the Eclipse interface: The "Hibernate Configurations" in the upper left pane; the "Hibernate Dynamic SQL Preview" and "Hibernate Query Result" in the bottom pane. At this stage, the functionality offered by the "Hibernate Configurations" view will be used to add a new configuration file (with a specific XML format), having the default name of "hibernate.cfg.xml". The content of this file for the implementation test Eclipse project is shown in figure 5.8 and includes the data base connection details and the SQL dialect to be used by Hibernate,

[87] Installation language for this interface is Portuguese.

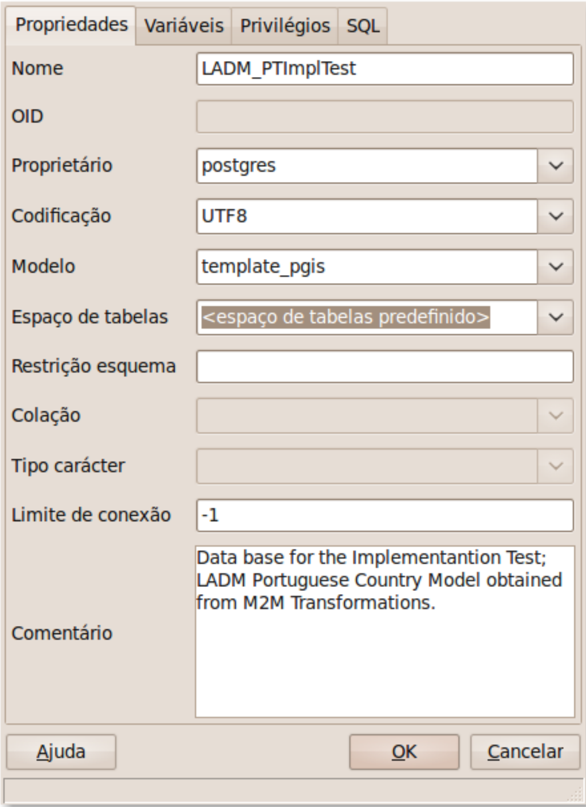


Figure 5.6: *Creation of an empty PostGIS schema with PgAdmin III*

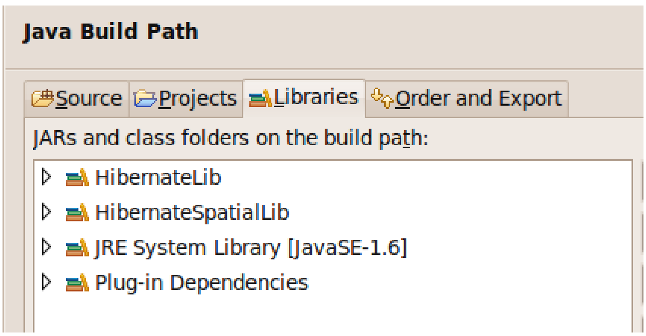
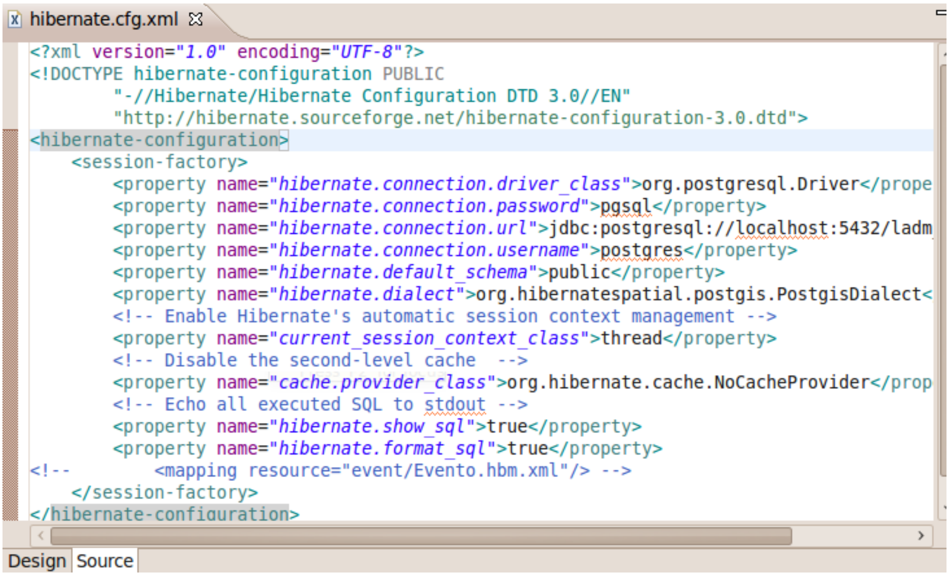


Figure 5.7: *Set of custom and standard libraries in the Eclipse Project Build Path*

which in this case is the PostGIS Dialect, extending the PostgreSQL Dialect existing in plain Hibernate. Other global configuration properties for Hibernate are also defined



hibernate.cfg.xml

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE hibernate-configuration PUBLIC
        "-//Hibernate/Hibernate Configuration DTD 3.0//EN"
        "http://hibernate.sourceforge.net/hibernate-configuration-3.0.dtd">
<hibernate-configuration>
    <session-factory>
        <property name="hibernate.connection.driver_class">org.postgresql.Driver</prope
        <property name="hibernate.connection.password">pgsql</property>
        <property name="hibernate.connection.url">jdbc:postgresql://localhost:5432/ladm
        <property name="hibernate.connection.username">postgres</property>
        <property name="hibernate.default_schema">public</property>
        <property name="hibernate.dialect">org.hibernatespatial.postgis.PostgisDialect<
        <!-- Enable Hibernate's automatic session context management -->
        <property name="current_session_context_class">thread</property>
        <!-- Disable the second-level cache  -->
        <property name="cache.provider_class">org.hibernate.cache.NoCacheProvider</prop
        <!-- Echo all executed SQL to stdout -->
        <property name="hibernate.show_sql">true</property>
        <property name="hibernate.format_sql">true</property>
<!--        <mapping resource="event/Evento.hbm.xml"/> -->
    </session-factory>
</hibernate-configuration>
```

Design Source

Figure 5.8: *Hibernate configuration source file*

in this file.

Besides the main configuration file, other configuration parameters can be defined through *properties* files, namely the “hibernate.properties” and the “log4j.properties” files. The first can be used to define additional properties, such as connection pooling. Dedicated connection pooling software, such as C3P0 (included in a Hibernate installation) provide for the management of connections between the application software and the data base, allowing to save system resources and to speed up the run time of Hibernate based applications. The parameters for setting up C3P0 include a minimum and a maximum number of connections, idle times and time outs ((Bauer and King, 2007, p. 53-56)), as shown in the code fragment below.

```
hibernate.c3p0.min_size = 5
hibernate.c3p0.max_size = 20
hibernate.c3p0.timeout = 300
hibernate.c3p0.max_statements = 50
hibernate.c3p0.idle_test_period = 3000
```

The second properties file sets up the log for Java (log4j) logging application. This configuration is specially useful for application developers and while designing an Eclipse Hibernate-Spatial project for the first time. The logging exposes a number of relevant events occurring during an Hibernate *Session*. The output goes to the console, by default, but can be redirected to an user defined log file. The logging environment should be disabled when the application reaches production stage, because it is a significant consumer of system resources.

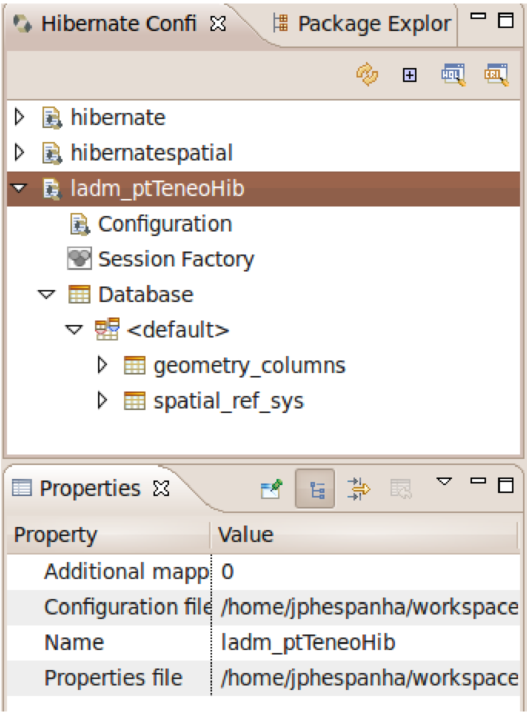


Figure 5.9: *Elements in an (empty) Hibernate Configuration*

After this initial configuration set up, the Hibernate-Spatial Eclipse project has the required global definitions to proceed, and the "Hibernate Configurations" view can indeed show the main elements for this type of applications: the *Configuration*; the *Session Factory* and the *Database*. These elements are not yet populated, though, because we did not define which Java classes have to be transformed into data base elements (through mappings); this is the subject of the following subsections. However, at this time, the data base connection is already working, and in this way the basic system tables of a PostGIS spatial data base can be seen in the <default> (that is, the *public*) schema. This is the situation depicted in figure 5.9.

5.4.2 Generator Java Classes as sources for Hibernate

The Hibernate-Spatial engine does not include any UML modelling or MDA capabilities, so as to define automatically or interactively which Java sources to use, and even to suggest ORM mappings. However, its availability in the Eclipse EMF environment partly overcomes these shortcomings, by the use of the in-built EMF Generator. In this case, the Generator was used to read the Ecore equivalent of the implementation test PIM (the subset of LADM_PT country model elements) and produce a set of corresponding Java classes. This last set obeyed to the pattern of an Eclipse plug-in

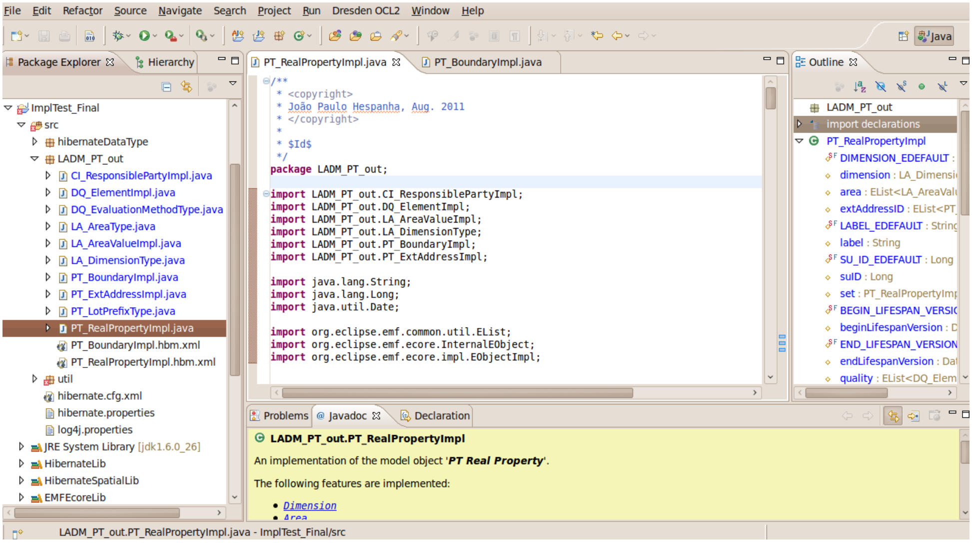


Figure 5.10: *The Java Perspective for the LADM_PT_out package*

development: a package with interface classes, the related implementation classes, and an additional utilities package.

From this Eclipse plug-in project and keeping the same libraries and configurations as defined in the previous subsection, a simplified project was defined. In this simplified project (not a plug-in), the implementation classes required for the geometric component classes PT_RealProperty and PT_Boundary constituted a single Java source package, which was called LADM_PT_out. The figure 5.10 shows the Java Perspective for this source package, centred on the PT_RealProperty class.

Using this final arrangement of classes, the corresponding hibernate mappings were defined, as reported in the following subsection. In the remaining part of this subsection, the main properties of the PT_RealProperty and PT_Boundary Java sources are reported. The Java code automatically created (for the most part) by the EMF Generator, from the Ecore model, has the following general structure[88]:

- A copyright notice section;
- Import statements, divided into three sections (used types and Enumerations, simple primitive types and Ecore classes);
- Class description as a Javadoc section, with links to individual methods descriptions;
- Attribute declarations and the corresponding Javadoc descriptions;

[88] The generator code corresponds to "stubs" with no final functionality. So it must be completed manually by the developer.

- One (or more) class constructor method;
- Getters and Setters methods for the defined attributes;
- Eventually, any other method declaration (as defined in the UML model).

The EMF Generator has some additional characteristics, which go beyond the regular "Plain Old Java Objects" (POJO) class structure. For instance, for every single valued attribute[89], a default value is declared through a "protected static final" instruction. The multi-valued attributes are defined through the use of a Ecore List (EList) collection type of the corresponding elements, and do not define default values. Another characteristic is that the EMF Generator does not define Getter and Setter methods for the EList types, although they are still required for Hibernate persistence.

This implies that the Java sources produced by the EMF Generator have to be manually edited in order to be useful for any Hibernate project. With the disadvantage that edits would have to be reconstructed every time there is an update to the sources structure.

> *Notice:* The complete source code and the XML mappings for both classes here reported were added to Annex C. The following paragraphs contain just a summarized description.

PT_RealProperty Java source

- Imports; used types: correspond to a total of five classes and one Enumeration (LA_DimensionType), all from the LADM_PT_out package;
- Imports; primitive types: String, Long and Date;
- Imports; Ecore EMF classes: EList, InternalEObject and EObjectImpl;
- Multi-valued attributes: implemented through EList collections for area, extAddressID, quality and source;
- Association: the one-to-many association to the PT_Boundary class is implemented as a EList of associated objects, and the attribute receives the name of the UML association end role, "rpBoundary";
- Recursive association: this association, inherited from LA_SpatialUnit, is implemented as the "set" attribute, defining a parent to children association within PT_RealProperty objects;
- Constructor: a public access empty constructor recurring to the superclass (EObjectImpl) was defined;
- Getters and Setters: standard getter and setter methods were defined for all the attributes. These are required by the Hibernate persistence mechanism;

[89] Attribute with a cardinality equal to one.

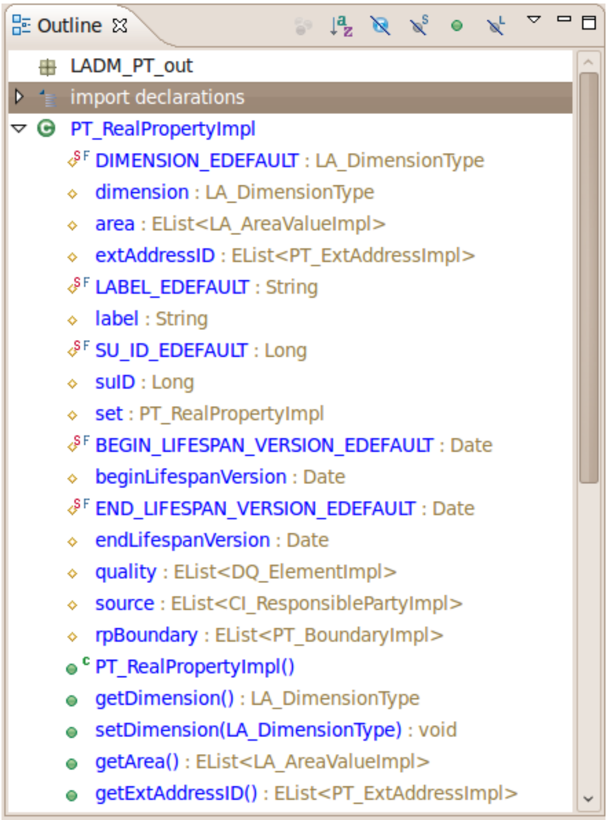


Figure 5.11: *Java Outline for the PT_RealProperty class (extract)*

- toString method override: overrides the method in EObjectImpl, which creates a text string with the name and values of the single-valued attributes of the corresponding object.

In figure 5.11, a part of the Java Outline view for the PT_RealProperty class is depicted, showing all the attribute declarations and the initial methods declarations.

PT_Boundary Java source

- Imports; used types: correspond to three classes defined in the LADM_PT_out package, together with the MultiLineString geometric type from the JTS library (com.vividsolutions.jts.geom);

- Imports; primitive types: Long and Date;

- Imports; Ecore EMF classes: EList and EObjectImpl;

- Multi-valued attributes: implemented through EList collections for quality and source;

- Association: this association end is implemented as an attribute receiving the "realProperty" UML role name, which stores a link to a single PT_RealProperty object;

- Constructor: a public access empty constructor of the same type of the PT_RealProperty class was defined;

- Getters and Setters and toString methods: defined in the same way as for the PT_RealProperty class.

In addition to the Java source classes defined through the EMF Generator, and as an alternative to the (simpler) solution of defining component mappings for Hibernate when using user types in classes, a few Hibernate User Data Types were defined. These were created in a separate package and used a Java source template defined in the example 6.2 of (Elliott et al., p.112-120), which is used to define persistent, immutable enumerations.

For this purpose, a total of eleven methods have to be defined in the new User Data Type. These in turn require a number of imports from the standard Java SDK library (in the java.sql package) and also from the Core Hibernate library (in the org.hibernate package).

The complete source code for the LA_DimensionType Enumeration User Data Type can be seen in Annex C.

5.4.3 Hibernate Mappings

This subsection has the purpose to identify the main issues to be considered when (manually) defining hibernate mapping files for a LADM specialization. It is anticipated that other issues will necessarily occur in a complete implementation (as for the complete LADM_PT). Anyway, the writing of the PT_RealProperty and the PT_Boundary do reflect the main topics to consider in a Java source class to Relational Data Base table (RDBMS) mapping.

The following items list presents the same order of appearance of the mentioned issues in a standard XML mapping file. The structure here reported conforms to the hibernate mappings DTD, version 3.0.

- Definition of the attribute to be mapped to the table primary key, and the corresponding generator;

- Definition of attributes that can work as a timestamp and can enable versioning at the RDBMS side;

- Definition of simple, primitive mappings to table fields;

- Definition of User Data Types as component mappings or new hibernate types;

- Mapping of Enumerations as persistent, immutable Hibernate User Data Types;
- Mapping geometry attributes to fields through the use of hibernate spatial data types;
- Mapping class to class associations, in this case, as a (bidirectional) one-to-many relationship.

The next two paragraphs use the above item list as a template, in order to describe specifics of the class mappings.

PT_RealProperty mapping

- Primary key attribute: It is the Object ID (OID) type attribute, in this case "suID" and uses the native hibernate generator to create an unique integer sequence;
- Timestamp (with versioning) attribute: Using a timestamp keyword enables versioning in hibernate. The "beginLifespanVersion" attribute was chosen for this role. There is also a primitive timestamp type in hibernate;
- Attributes with simple mappings: There are just two attributes in this situation, "label" as a string and "endLifespanVersion" as a (primitive) timestamp;
- Component mappings: a total of four attributes have a LADM user type that was mapped as an hibernate component. Each one (e.g., attribute "source" of type CI_ResponsibleParty) is defined as a series of simple mappings;
- Hibernate User Data Types: Used for the Enumeration related to the "dimension" attribute, defined by the LA_DimensionUserDataType class;
- Geometry attribute: No geometry attribute is defined in the Spatial Unit within this class profile;
- Association mapping: defined as a *bag*[90] of related PT_Boundary class type objects, with the "rpBoundary role name attribute and using the primary key as the association key.

The use of (Hibernate collection) bags in bidirectional associations is recommended in (Bauer and King, 2007, p.290), according to the fact that:

> Bags have the most efficient performance characteristics of all the collections you can use for a bidirectional one-to-many entity association...

In figure 5.12, the hibernate perspective of the Eclipse project is focused on the mapping of the PT_RealProperty class, showing the configuration, the XML editor, the outline and the properties views for the "rpBoundary" association attribute.

[90] A bag is an unordered collection that permits duplicate elements, constituting an Hibernate mapping. It can be implemented as a *java.util* Collection (Bauer and King, 2007, p.242, 244).

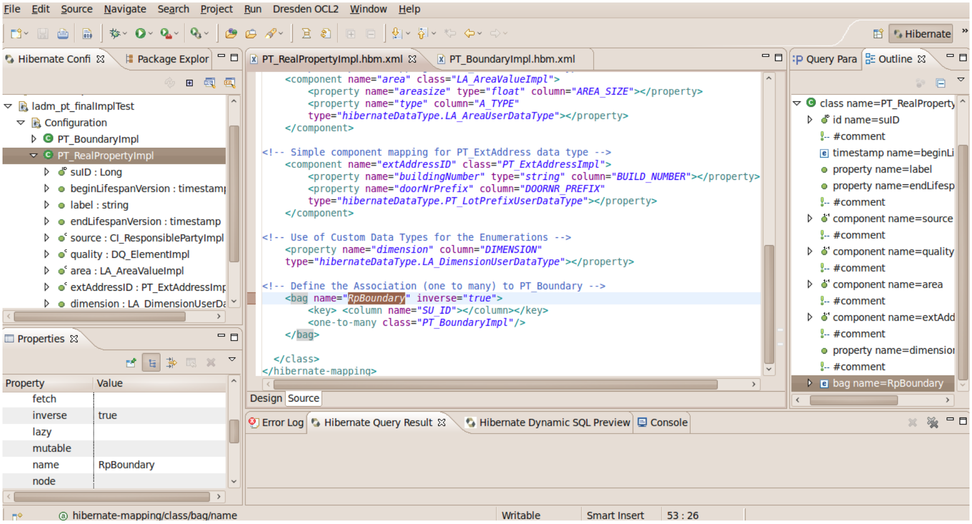


Figure 5.12: *The Hibernate Perspective for the PT_RealProperty class mapping*

PT_Boundary mapping

- Primary key attribute: implemented as a native hibernate generator sequence over the “bfsID” attribute;
- Timestamp (with versioning) attribute: defined for the “beginLifespanVersion” attribute;
- Attributes with simple mappings: “endLifespanVersion” as a primitive timestamp type;
- Component mappings: defined for the “quality” and “source” attributes, implementing mappings for DQ_Element and CI_ResponsibleParty types;
- Hibernate User Data Types: none defined for this class;
- Geometry attribute: Uses the GeometryUserType defined in the org.hibernate-spatial package, over the “geometry” attribute. This maps into the BFS_GEOM column of PostGIS geometry type, in the RDBMS end. The (Java) abstract layer definition is taken from the Java Topology Suite (JTS) definition for a MultiLineString. This maps into the Simple Features for SQL (SFS) PostGIS definition for the MultiLineString;
- Association mapping: defined as a many-to-one from this association end, which is mandatory (not null), over the “realProperty” attribute, which maps into a SU_ID foreign key.

5.4.4 Schema export: resulting database

Having done the required changes to the Java source class files and having written the hibernate mappings, as described in the previous subsections, it is now sufficient to apply a "Run SchemaExport" command from the hibernate perspective. To run this command, all that is required is to right-select the "ladm_pt" hibernate configuration and choose the respective command from the context menu.

If the hibernate tools Eclipse plug-in successfully validates the mappings and the configuration, including here the connection to the data base server (and the required login permissions), then the schema is automatically created in the destination data base.

The following paragraphs briefly describe the resulting "ladm_pt" data base, as created in a PostgreSQL data base server (version 8.3), with a PostGIS template.

Figure 5.13 shows how the data base schema is seen in the hibernate configurations view of the hibernate perspective. This view has expanded the details of the "pt_boundary" table. The fact that the geometry type of the "bfs_geom" column is referred as OTHER merely reflect the fact that hibernate tools do not integrate the hibernate spatial library. That is, hibernate spatial is not an Eclipse plugin and so does not reflect the type into the Hibernate Tools interface.

The resulting data base will be described according to the following items list:

- Sequences;
- PostGIS metadata tables;
- Table columns and data types;
- Table constraints.

The corresponding SQL code, as automatically created by the open source PgAdmin III application, is presented in Annex C. It includes the definition of the data base, the sequence and the pt_realproperty and pt_boundary tables.

ladm_pt data base schema description

- Sequences: an "hibernate-sequence" is created, with minimum value and increment of one. This is required by hibernate in order to manage unique primary keys;
- PostGIS metadata tables: the hibernate spatial engine does not insert any record in the geometry_columns table. This is (partly) explained by the fact that, although the geometry type is known from the Java source, there is no information about the coordinate dimensions or the spatial reference (SRID) to use;
- Table columns and data types: the pt_realproperty and the pt_boundary tables have all the columns defined by the simple types, plus all the columns defined by the respective component mappings. Regarding the data types, they are defined

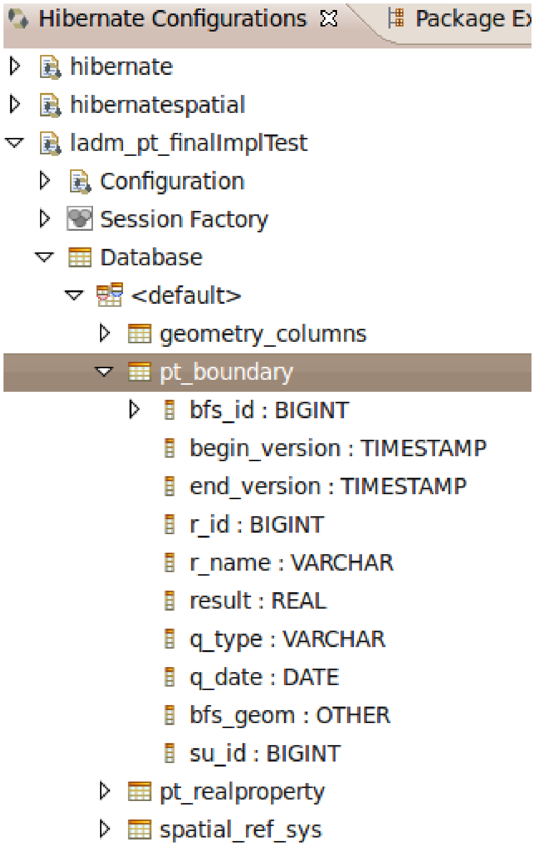


Figure 5.13: *The Hibernate Perspective for the pt_boundary table, after schema export*

by the hibernate engine, according the SQL dialect in the configuration. In this case, the following equivalences were applied: long to bigint; string to character varying (255); float to real; timestamp to timestamp without time zone;

- Table constraints: the primary key constraints are enforced in both tables and a foreign key constraint is defined for the pt_boundary table. This constraint does not define any cascading options. As referred above, additional geometry check constraints for the type, coordinate dimensions and the SRID were not created by hibernate spatial.

Figure 5.14 shows a view of the public schema of the "ladm_pt" data base, as presented by PgAdmin III. In the left pane, all the possible data base objects are listed. The view is expanded for the pt_boundary table. The upper right pane shows the table dependencies and the bottom right pane shows the SQL code required to create the table.

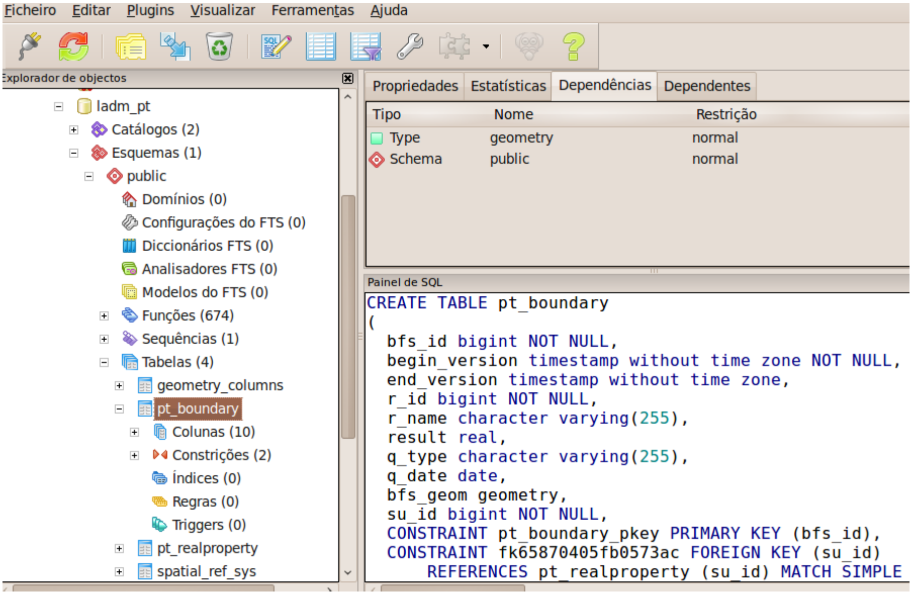


Figure 5.14: *The pt_boundary table details in PgAdmin III*

5.5 Final validation and tests

The following description concerns the identification of a methodology for testing and validation of the implementation solution and related ICT platform. It does not constitute a report of actual tests performed with the described techniques.

The main functional test categories reported in this section should comprehend all the classes within the LADM_PT country model. Due to the fact that it was decided to do an actual implementation just for a portion of the Spatial Unit component (and package) of LADM_PT, the scope is confined thus to the corresponding classes, although the so called "test matrix" (in table 5.5) could be extended to include the complete specialized country model.

The "test matrix" has two columns (indexed A and B) referring to the test environment, which is confined by the chosen implementation platform, using the Hibernate Tools (for Eclipse) Persistence mechanism. This fact creates the need to perform the test both at the data base server end (that is, the PostgresSQL + PostGIS combination), and the abstract layer residing in an Eclipse EMF project.

The rows of the "test matrix" consist in the test categories, and are indexed 1 to 3. They include the creation, update, querying and validation (through OCL constraints) of the data belonging to the LADM_PT implementation test schema. In this arrangement, each of the column and row combinations or cells is referred by their index (like in a spreadsheet), and will be further developed in the following paragraphs.

Environment: Abstract Layer	**Environment: Data Base Server**	**Test Categories (functions)**
A.1 - Class definitions to be added to Util package; Use of JTS functions	B.1 - (Data) Loading applications or action queries	Data loading and updating
A.2 - Use of HQL selects; Apply JTS functions and report results	B.2 - Use of regular SELECT queries; use of ST PostGIS functions	Querying for geometry, topology and thematic layers
A.3 - Creation of a model instance and application of Dresden OCL2	B.3 - Use of OCL22SQL; Implement and test stored procedures and triggers	Validation of OCL constraints

Table 5.5: The test matrix for LADM_PT implementation using Hibernate

A.1 - Class definition and update on the abstract layer This test category concerns the creation or insertion of new Spatial Units of the PT_RealProperty type, to which one or more PT_Boundary and the included geometry type has to be associated.

In the abstract layer, this can be accomplished through the definition of an *Util* package class. This class should define creation methods (or a main method) which can use a Well Known Text Reader (the class and methods exist already in the JTS library) and the correspondingly formatted input, or to the definition of a Geometry Factory object (equally using the JTS library), where a custom import format could be defined for the geometry. The remaining class attributes can be defined through standard Java constructs and types.

B.1 - Data loading and update on the Data Base Server If the initial creation or insertion of Spatial Units is done from the (spatial) data base end, then the classic SQL functions of INSERT and UPDATE could be used.

The most practical way shall be to define an SQL script file to do the job, and then to run it through the command line or through an application such as PgAdmin III. For the classes having geometry types, now mapped into tables with geometry columns, special PostGIS functions must be used, such as ST_GeomFromText. This functions demands that all the Spatial Unit coordinates be entered as Well Known Text formatted strings, and can be ineffective for bulk loads of data. One alternative is to use the *shp2pgsql* application (distributed with PostGIS), to be run from the command line. This command is capable of loading all the values in the different columns, provided the original shapefile format obeys to the table schema which resides in the data base. This command uses the more compact (and faster for insertions) Well Known Binary format, or in the case of a very large data set, there is the option to use the PostgreSQL *dump* format, which is the fastest option available.

Yet another alternative is to use an open source GIS application, such as uDIG, but as of version 1.2, it is not capable of loading data into a PostGIS data base from scratch (into an empty schema), while it can update or even make insertions in an existing PostGIS table. Such applications have the (big) advantage of offering a graphical interface and dedicated editing commands.

A.2 - Querying data on the abstract layer After the initial data loading, or any significant update transaction, it is naturally expected that the system users are willing to query data according to their specific interests and roles.

This way, it is important to anticipate a number of typically asked queries and to test them, in this case within the abstract layer environment. Another reason to run test queries is related to quality control choices. If an option to allow the loading of incomplete or partly inaccurate data (including the geometry component) is taken, then a number of topology and geometry queries should be run in order to quantify and identify any errors in the data, eventually producing data quality reports. To write and run queries in a Eclipse EMF project with Hibernate Tools, there is the option to use the fully object-oriented “Hibernate Query Language” (HQL). This language syntax is very similar to ordinary SQL, and within an hibernate perspective in Eclipse, it is possible to open an HQL Editor, giving then the advantage of syntax highlighting and content assist when writing queries. A special console pane, “Hibernate Query Results”, enables us to scroll through the results. It is equally possible to programatically run one or more queries through an helper class created within an *Util* or a *Test* package. If a certain function or SQL command can not be issued using HQL, there is also the possibility to run a direct SQL query in the data base, while retrieving the results in the abstract layer, by using the *createSQLQuery* method of the hibernate Session class.

Furthermore, using the hibernate spatial library, the standard HQL has been extended with most of the geometry and topology functions implemented in the SFS specification. So, it is possible to check the geometry of any given PT_Boundary object, or set related to a PT_RealProperty, through the use of the appropriate functions within an HQL query.

B.2 - Querying data on the Data Base Server To run test queries, as defined in the previous paragraph (A.2), but this time on the data base server end, it is sufficient to write ordinary SQL SELECT queries.

However, and given that the geometry and topology of tables having columns of the geometry type must be tested, a number of PostGIS “ST_” functions have to be used in such queries, many times in a recursive way. Given the fact that, in the PolygonSFS spatial profile, the actual polygon objects are not stored explicitly, but rather shall be derived from the set of related boundary face strings, is of utmost importance to define a number of test queries in order to verify that the related (Multilinestring) records do indeed form a single polygon, eventually with one or more holes.

Another set of tests should verify the relationships between the geometry of the spatial units and the original surveying package points (the PT_Point class for LADM_PT).

A third type of test queries should be of topological nature and must verify the inter-level relationships amongst different types of spatial units, like, e.g. PT_RealProperty and PT_Baldio. In this last case, only those spatial units which form correct polygons shall be submitted to this test.

In the writing of (mostly) topological queries, the spatial resolution of the coordinates must be accounted for. This is specially the case when default resolutions are used, and as a result, the coordinates of spatial units are expressed with an unrealistic precision. This will result in the failing of topological query tests, caused by such false precision, when in fact tests could be valid if survey specified resolutions were used instead. The following SQL topological query example shows how this problem can be tackled, with the use of a resolution parameter defining the creation of a buffer with a size coinciding with the survey specification resolution (in the example, one centimetre).

```
-- Topo query returning the boundaries crossing a property beacon of
-- the cornerstone type. At least two boundaries shall be returned.
-- Parameters: the cornerstone pid and the coordinate resolution.
select
b.bfsid,
b.source,
c.pid,
c.monumentation
from
pt_boundary as b,
pt_point as c
where
(c.pid = 1000 AND c.monumentation = 'cornerstone') AND
(ST_Intersects(ST_Buffer(ST_EndPoint(b.geometry), 0.01),
 ST_Buffer(c.originalLocation, 0.01)) OR
ST_Intersects(ST_Buffer(ST_StartPoint(b.geometry), 0.01),
 ST_Buffer(b.the_geom, 0.01)));
```

A.3 - OCL constraints on the abstract layer An implementation of the LADM_PT country model is not complete without the implementation of the OCL constraints which were defined for the model classes (and their associations).

As already discussed, there are no current tools granting full support for the combination of UML and OCL modelling constructs, and this is equally valid for the chosen platform, that is, Eclipse EMF. However, the *Dresden OCL2 for Eclipse* plug-in is capable of parsing and interpreting OCL constraints against a domain model based in a UML2 meta-model, thus covering the current LADM_PT model. It still requires that all the OCL expressions shall be collected from the UML model and input into a specially formatted text file with a OCL extension.

The parsing step (Wilke and Thiele, 2010, p.22-23) is done with the constraints file being validated in its syntax, against the model and its corresponding meta-model. The check for a correct parsing is done in the *Model Browser* tab, within each

"Constraint" object.

The interpretation step requires that a *Model Instance* be defined and imported by the Dresden OCL2 plug-in. A Model Instance can be defined through a *Provider Class*, to be written in Java source according to a template supplied by the existing examples. Alternatively, it could be defined through a specially formatted XML file, or as an Ecore Model Instance. In the current case, and given the fact that the abstract layer is expressed in Java, the logical choice is to write a Model Instance Provider Class in Java, this way defining one or more test cases to validate against the OCL constraints. After a Model Instance is correctly imported through the Dresden OCL2 plug-in, it is possible to interpret the chosen constraints and check the results in a *OCL2 Interpreter View*. This way, it is possible to identify which Model Instance values have passed the constraints, and which have failed (Wilke and Thiele, 2010, p.27-29).

The current version of the Dresden OCL2 plug-in is also capable to generate Java (actually, Aspect Java) source code from the OCL constraints, originating classes which can be submitted to JUnit testing.

It must be stressed, however, that the OCL specification "as is" raises implementation issues regarding spatial feature classes (as contained in LADM_PT), both at the parsing and interpretation steps, as follows:

- At the parsing step: to validate the syntax of expressions using geometry and / or topology methods, such methods must be explicitly described in the package to be parsed. This can be accomplished by attaching a composition class with the full description of the geometry type, plus describing any topology constraints via association classes;

- At the interpretation step: the Provider Class must use an SFS compliant implementation, such as the JTS library, including calls to the methods used in the OCL constraints.

The current limitations of OCL, regarding geometry types, imply that a full Model Instance validation can only be done by manual coding Java test classes (and their methods), or then to use experimental (and not standard) implementations of so-called "spatial OCL". One interesting example is presented in (Werder, 2009). This implementation extends OCL by defining a new data type (Geometry), and new operations on that data type. The new data type is not a simple OCL type like a String or Integer, but uses instead an OCL *Collection*. A number of operations are implemented, under three different categories: geometric, topological and statistic.

B.3 - OCL constraints on the data base server The version of Dresden OCL2 for Eclipse that has been tested did not implement the OCL22SQL tool, so for any SQL script to be generated, a previous version of the tool must be installed and run on the command line (and outside the Eclipse EMF environment).

This previous version implemented a procedure where the OCL constraints are transformed into SQL Views, so in that way, one would implement a quality assessment approach giving results on top of existing (and previously loaded) data.

The approach poses however a serious problem due to the current research environment, given the fact that is also generates a data base schema according to their own transformation (or mapping) rules, which are necessarily different from the schema generated through the hibernate mappings. Another, more strict approach, would be to implement the OCL constraints as SQL stored procedures, and then associate such procedures to INSERT and UPDATE triggers. This would contribute to a quality control approach, where data would be checked and validated previous to be actually committed to the data base, and thus only valid data would be allowed for storage.

Chapter 6

Conclusions and Recommendations

This chapter presents the conclusions, recommendations and suggestions for further research paths, resulting from this thesis. The Section 6.1 answers the detailed and main research questions, as enunciated in the Introduction chapter. In the following Section 6.2, and taking into account the results previously reported and the aspects that were not achieved as expected, the main contributions of the development methodology are listed as itemized lists. Finally, a number of paths open to future research are suggested (in 6.3), which will address the previously identified weaknesses and further contributions which are opened by the LADM adoption (expectedly) as an ISO and CEN standard.

6.1 Answers to research questions

To answer the main research question, which includes the different aspects of Land Administration under a systems approach (technical, legal and organisational), the order will be reversed regarding the presented in Introduction, so the detailed research questions will be answered first.

This approach finds a parallel with UML modelling, when a generalisation is abstracted from common and interrelated elements, which can reflect both static and dynamic properties, from a set of more specialized classes. So, the main research question is "generalized" from the set of detailed research questions.

In this way, the first (detailed) research question to be addressed is a more technically oriented one:

> *How to develop a flexible system, where it will be relatively easy to include new requirements or changes?*

A first consideration must be taken into account, concerning the research scope, which is centred on the modelling analysis and design, with minor consideration for the implementation phase. That means the inclusion of new requirements or changes as described in the thesis, concerns mostly the structural component of the system and addresses mainly the functional type of requirements, at the early stages of system development.

The integration of the Unified Process in the development methodology, as a mature and widely used methodology, has as one of its main assumptions that requirements *do change*, and that this change is induced by the development process itself. This way, the design of the development process, by considering its phases and iterations, with the delivery of system components along the way, which are tested, are the best guarantee that new or changed requirements are included while the system is being constructed.

This leads into a second consideration, which also defines the scope, and that is the assumption of a basic, non-functional requirement: the system development methodology is based on UP and further, the implementation should follow from the use of a Model Driven Architecture development platform. This has been an early choice, also considering newest modelling trends in the field.

The country model LADM_PT, here reported, is a clear example of (mostly) functional requirements changes, at both the basic level of the Domain Model, which evolved from CCDM to LADM through a series of versions, and the Portuguese specifications, which also got major changes from the 1995 "Cadastro Predial" to the current (2009) specifications from SINERGIC.

Two other, non-functional requirements adopted by the methodology also contribute to added system flexibility, on the implementation side: the consideration of a Java based CASE tool(s) allows work to be done on a variety of operative systems, namely for structure changes or even system applications; and the consideration of the Hibernate persistence mechanism, which follow MDA principles and can facilitate the change of the Data Base Management System with significant ease.

Finally, and considering now requirements changes that naturally can arise after the system is delivered and is completely operational, there is the "Adaptive maintenance" example from the Portuguese cadastral specifications. This concerns the different types of a cadastral parcel in "Cadastro Predial" and SINERGIC, and how they can be implemented through a change in an Enumeration class. The use of Persistence and MDA features of a reverse engineering transformation assure the DBMS, the abstract layer (Java classes) and the UML model stay consistent after the change is introduced.

The second detailed research question has a more legal aspect, while the answer considers also the technical aspect regarding the modelling and implementation platforms.

> *Which methodological steps should be taken to cope with new and existing land related rights and regulations?*

In any effort to reform an existing Land Administration system, or to create a new one according to modern technical and methodological capabilities as reported in this thesis, a key point to consider is the modelling of the legal framework concerning Real Rights. Or simply, land related Rights, where Roman Law concepts are absent. This follows naturally from the fact that, in the majority of Land Registration systems, the Basic Administrative Unit (in LADM, the LA_BAUnit class) represents the extent of ownership rights.

The first contribution for an answer comes from the LADM core, which considers the basic relationship between persons and land via rights as a universal assumption. The modelling of the Administrative package goes a step further, in considering three basic types of relationships: Rights, Restrictions and Responsibilities. In LADM, each one is a specialized class which is versioned, can be shared, and which can be exerted within a time frame. Further, each one has its own set of identified (but modifiable) types, through related code lists.

Although the LADM legal framework is widely applicable, the author felt that it should be further extended in order to include the specifics of the Civil Law based framework of private Real Rights in Portugal. With this aim in mind, it was recognized that the UML, object-oriented legal framework for Rights and Restrictions presented by Paasch (2005) could be a decisive contribution, specially if inserted into the LADM wider schema.

Starting now from this expanded legal framework, which currently is included in LADM as an informative annex (a contribution to the standard 19152 by the author of this thesis), a case study of the situation regarding Real Rights in Portugal was conducted, with contributions as stated in the paper (Hespanha et al. (2009)), first considering a more conservative approach (according to the legal doctrine), and then proposing a new classification which fitted into the new, UML defined, LADM Legal profile.

The integration of the case study results is reported as the "comprehensive model for the legal and administrative domain", concerning the respective component of the LADM_PT country model. The final modelling result, which is adapted to Portugal, can still be applicable to other countries, particularly those with the same legal tradition. There are specifically two modelling patterns in this respect: the consideration of different Forms of Property, defined in specific legal domains (private, public and commons) and having relationships between them which can constitute separate classes of Rights; and the consideration of Responsibilities as inherent to Rights or Restrictions, which consider the Appurtenance and Encumbrance hierarchy of the Legal profile.

These methodological steps were summarized and included in the development methodology. The remaining phases consider the integration of a basic UP development framework, and together form a specific iteration in the building of the system, implying that a complete cycle from concept to design to (finally) implementation, follows according to MDA principles.

The third detailed research question has a stringent technical aspect, which guided the choice of the development platform and also some modifications introduced to the domain model.

> *How to implement an enriched semantic model (through spatial and aspatial constraints and spatial profiles, enabling consistency checks) based on current Spatial Database Management Systems?*

In order to support the definition of an "enriched semantic model", the reported methodology includes an MDA process where the Domain Model supplies just the starting point in a transformation chain to a country level Platform Independent Model (PIM). To express modelling constraints over a diversity of possible spatial data structures, the UML extension mechanisms were used, through the specification of spatial profiles and patterns.

The inclusion of specific *spatial profiles*, also a contribution of this thesis author to the LADM standard, together with standard UML constructs, can be used then to supply the context where geometry and topology, or even aspatial constraints are formalized through the use of the Object Constraint Language.

In the LADM_PT country model, the structure and relationships of the different spatial units were developed from two LADM spatial profiles (in fact, patterns) which considered classes in the spatial representation sub-package of LADM.

An important step in reaching a country model PIM, in the spatial unit package, is the Level structure to be used, where additional inter-class constraints can be expressed. For implementation reasons, the widely used (in several DBMS) Simple Features implementation of Geography Markup Language (GML) was defined as a (true) UML Profile, for the Polygon (2D) Spatial Profile.

It should be stressed that, to reach the final Platform Specific Model, the current MDA transformation languages Query-View-Transformation (QVT) and Model Transformation Language (MTL) do not support specific transformations from Java based to Data Base types, in what concerns geometric types. This can be (partially) overcome through the use of Hibernate Spatial libraries.

Furthermore, the Hibernate mappings just considered standard Object-relational Mappings (class to table elements) and do not include any consideration for OCL expressions in the original UML model. In the specific case of the implementation test, the hibernate spatial did not take care of geometric type of constraints considered in a regular PostGIS schema.

Finally, acknowledging such shortcomings and implementing a short cut on the validation tests phase, which could read the PIM model and extract the OCL constraints to a file which could be then validated, still does not solve the issue of the implementation of constraints to the Data Base. Current capabilities of OCL tools (as OCL22SQL) implement a quality assessment perspective, through the production of SQL views which measure the number of features not complying to an OCL expression.

The fourth (and last) detailed research question reflect also a fundamentally technical aspect and concerns an achieved implementation. Thus being outside LADM scope, but inside scope of this thesis.

> *Furthermore, how can this enriched model support integrated update procedures in an Editor environment?*

A generic, integrated update procedure, comprising modification of both the geometric component and the legal and administrative component, is reported through UML Use Case and Activity diagrams. These documents were based on the current situation regarding land registration and cadastral survey operations in Portugal, and maintain the organizational structure of the Cadastre and Land Registry as separate organizations, although collaborating in an integrated flow of information. This is shown, in the corresponding activity diagrams, through synchronization events and communication procedures, which relate the system components in a tighter integration (as compared to the existing situation).

Additional activity diagrams, reported in Annex A, covered the specific update procedures regarding the annexation of (part of) a parcel, and the creation of an Urban Lot in a re-allotment procedure. All these types of cadastral updates include both the geometric and the legal and administrative components; the last one (the more complex) also including the (critical) role of the Municipalities.

Although these modelling activities, inserted into the inception and elaboration phases of the methodology, allow to identify the participating actors and their roles, the flow of activities and the organisations involved; they are not sufficient to specify the procedures at an implementation level (concerning the data structure and algorithms). Given that they do not fully relate the activities to individual classes in the PIM model.

Although there are no update procedures developed on the implementation test data for the LADM_PT country model, several cadastral update procedures were conducted using real data. These were carried out using older "Cadastro Predial" specifications and a CCDM based implementation over an ESRI Geodatabase. They were reported as the Pilot Project for the Mira Municipal Cadastre. Two specific cadastral update procedures were implemented, using the ArcSurvey extension and the ArcCatalog and ArcMap components of the ESRI ArcGIS software. The results of the Pilot Project have shown that a reasonable complex update procedure has to be followed in order to maintain the association between the geometric and administrative data, the topology of the geometric component, and the maintenance of an History layer (in LADM, a separate History layer is not required; such information is stored in the actual objects). It must be stressed that the data in the Pilot Project do not cover the description of the legal situation of the parcels, as required by the Land Registry.

Finalizing now this section, the answer to the main research question is presented, by summarizing the findings listed above.

How can a system development methodology support an efficient and flexible manner the creation of an integrated legal Cadastre, while addressing the interrelations between the technical, legal and organisational aspects?

The development methodology is based upon the Unified Process and includes MDA principles. The development of system components through iterations considering (partial) implementation is capable to support the expected requirement changes along the development process. Assuming at its base the use of LADM Core classes for the conceptual description of the Land Administration domain, the methodology proceeds with capturing context and aspect driven (technical, legal and administrative) Use Cases. The implementation of the UP Inception phase concludes with documentation activities. The methodology Elaboration phase has a total of three iterations, each involving detailed design elements, like Activity Diagrams, component based PIM's and Model to Model and Model to Text transformations. The iteration order (per component) is: Spatial; Legal and Administrative; and a final Integration. The implementation of the OCL constraints is the last stage before the Construction phase (outside scope), and shall be performed on the integrated model.

The consideration of a research platform, for the system's modelling and implementation tests, based on open source applications, offers an added flexibility to a development team. It can work over a variety of operative systems, DBMS's and GIS software.

The author provided a major contribution to the development of an expanded legal framework, through the creation of a basic Rights, Restrictions and Responsibilities profile to LADM and the subsequent study of the Portuguese legal framework in order to derive a legal and administrative component for LADM_PT.

This provided further support for the legal aspects in the systems development, including the consideration of legal domains other than private law based, and the relationships which can be established between them.

Although the modelling result reflects the situation in Portugal, its development, based on a generic legal profile and the LADM core, can contribute to the analysis of the legal framework in other countries with similar legal traditions.

The modelling to implementation cycle considered an MDA approach, which allows to establish relations between the Domain Model source (LADM as the original PIM) and the final result (LADM_PT). The development methodology considers the choice of spatial profiles (including UML profiles and patterns, also a contribution of the author) and the formalisation of geometry, topology and other modelling constraints, through OCL, providing thus an enriched semantics model.

The use of standard UP techniques to document Use Cases and related Activity diagrams and Use Case templates, should be considered in order to capture the systems dynamics, in particular the design of integrated update procedures, which are key to an operational system. Although the implementation test of LADM_PT has not reached an operational level in this thesis, the documentation regarding the Pilot Project gave important insights as to a number of items to consider in this respect.

6.2 Main contributions of the methodology

Considering the answers to the research questions given in the previous section, a final balance of the aspects to improve (through further research) and the main contributions of the development methodology are presented as an item list, for clarity.

The identified aspects to improve are considered as providing the basis for further research, which can eventually overcome them and achieve thus a perfected and complete CASE tool(s), to support the development methodology. This is referred to in the following section, together with other possible research branches.

Main contributions

- The integration of well known and proven development methodologies and techniques from the ICT domain, such as UP and MDA, supports a formalized, yet flexible, system development. The iterative development is also able to cope with expected requirement changes along the process of deriving a country model from LADM;

- Most of the basic elements considered during modelling and even implementation phases is based on international standards and specifications, such as the ISO 19000 series or UML and OCL. This adds in interoperability of the modelling elements and some components of the implementation, namely the data base;

- The introduction of the documentation of specific Land Administration cases, supported by LADM through Instance Level diagrams, was another major contribution from the author. This modelling element proved to be a useful tool during the development of LADM, as well as in related research.

- The consideration of Spatial and Legal Profiles (mostly in the form of UML Patterns) in LADM, for which the author gave an important contribution, allows the introduction of more flexibility and functionality to the process of deriving a country model from the domain model;

Aspects to improve

- The role of Time in the definition of RRR's according to Relations of Property from Institutional Ontology (a contribution from Social Sciences) is not fully modelled in LADM, and consequently in LADM_PT. This includes the modification or cessation of Rights in time, as prescribed in law or due to, for instance, inheritance. Although the basic elements are already modelled;

- Although the Legal component of LADM was further extended with the Legal Profiles, and there is so a modelling proposal for the country model LADM_PT, the implementations performed (including the Pilot Project) did not considered actual data concerning Rights, as needed to create or update the Land Registry;

- The emphasis of the Legal profiles lies on the regime of private law (and property), while the public and commons law regimes are not specified with equivalent level of detail;
- On the more technical side of the CASE Tools and the derivation of the country model from the domain model, the model transformations were just specified at a generic level (no actual QVTO code is implemented), and it was not possible to validate the OCL expressions in the final transformation to the data base schema;
- The dynamic modelling of the cadastral update procedures did not reach a sufficiently detailed level, so that a link from the activity to the class diagrams could be established, and from there to actual implementation.

6.3 Paths open to future research

In this section, future research paths that can address the previously identified aspects to improve are referred first. All of them are of a generic nature and can contribute to LADM, although quicker results are to be expected if the LADM_PT results are used.

To conclude the thesis, related research paths where the author has given already some initial contributions are referred.

As can be read from the listed weaknesses, there is a clear need to further develop the legal component, so that two items can be addressed:

- Specification of the dynamics of land related rights, restrictions and responsibilities against time, to a more detailed level where implementation guided by MDA transformations is possible;
- Enlarging the (legal) modelling to other regimes than the private (public and commons; possibly others), taking into consideration the relationships to the basic administrative units as the primitive class to extend the (basically private) land registry.

Such studies could be accomplished through a logical extension of LADM_PT in the context of SINERGIC project in Portugal, or (but implying a lengthier process) the derivation of a Legal Profile for any other country looking for a LADM based reform of its Land Administration system, and having a Civil Code law tradition concerning real property rights.

Such an extension of LADM_PT legal modelling should be done in conjunction (or integrating) the major findings on the use of ontologies and the semantic web. Specially using an extension of the results obtained with the LegalAtlas application (in 2.2.2). Taking into account the framework reported in this application, the role that the Dutch IMRO2006 standard for spatial planning would be played by a OWL version of the LADM_PT country model. To take advantage of the Logical constructs defining the Real Rights, Restrictions and Responsibilities, a jurisdiction specific ontology should be derived from the LKIF-Core. Thus implying that the analysis of legal and administrative source documents (by using the MetaLex standard) had to be complemented by "LKIF_RealRightsPT". This would add a number of advantages to the use of LADM, considered solely as a UML / OCL defined domain model:

- A proper formalization of the legal concepts in land administration, which can be used in reasoning;
- Present the legal (and even surveying) source documents in a standard way, where elements are syntactically and semantically described. Thus enabling also the translation of specific concepts in different jurisdictions;
- Link the LADM defined Spatial Units to its legal or administrative sources, in a more complex and flexible way than an hardcoded HTML link.

Regarding the enhancement of further development of open source CASE tools assisting the derivation process, the shortest path would be an extension to the reported implementation test, concerning the derivation of LADM to LADM_PT by merging the specifications contained in PT_CDM. As in the current state, there is an excessive focus on the geometric component, the set of implemented classes should also include (a part of) Legal and Administrative package classes. This would also contribute to the specification of new, detailed level of OCL expressions. This has happened (as a choice) in the implementation test; not in the modelling phase.

As a last recommendation to address the above referred weaknesses, a pilot project should be conducted using actual cadastral data, as obtained according the last specifications (that is, those represented by PT_CDM) and addressing a number of typical update procedures, promoted by single owners or by the concerned Municipality. The documentation and implementation of such procedures should follow the development methodology, but with a special focus in detailing the relationships between the dynamic and structural modelling aspects.

On the expected developments concerning LADM as ISO19152, it is suggested that:

- A documented procedure should be disseminated and implemented by the future contributors of versions to the basic LADM, as well as to document country models as they are added, namely concerning conformance and compatibility issues. Previous tests with concurrent versioning software can prove useful for the future;
- The already existing LADM Wiki at the TU Delft site (van Oosterom (2011)) should serve as the basic dissemination platform for any new developments concerning this standard, and be announced by all active collaborators in conferences, journals and workshops.

Concerning now LADM related research that is outside of this thesis scope, the author has participated, with another consultant of ISAC - Spatial Analytics Consultants, Tarun Ghawana, and the thesis supervisors Peter van Oosterom and Jaap

Zevenbergen, in the modelling of groundwater rights from a Land Administration and Management perspective. This research has the goal of

> bridging the gap between the technical and administrative aspects of groundwater management,

and illustrates the potential of considering LADM elements and related spatial and temporal dimensions in order to address a range of critical and current issues of worldwide impact. The research conducted so far is reported in papers (Ghawana et al. (2010) and Ghawana et al. (2011)).

Annexes

Chapter A

Annex A: LADM_PT, the integrated model for the Portuguese Cadastre

This Annex lists the complete set of UML Diagrams (of various types) describing the integrated country model for the Portuguese Cadastre, LADM_PT. The Annex comprises three sections, the first being dedicated to the diagrams of a dynamic nature, namely Use Case and Activity diagrams. The second section describes the static component of LADM_PT, through Package and Class diagrams. Finally, the third section is dedicated to the Instance Level or Object diagrams. Each section includes a small initial template identifying the relation to the Unified Process (UP) phases and the Development Methodology Phase.Activity number. The second section also identifies the grouping of diagrams into packages and profiles.

The sectional template is as follows:

- UP Phases: identification on which phases where the diagrams produced;
- Phase.Activity number: identification on which development methodologies phases where the diagrams produced;
- Reference of figures already inserted in the text (a number and a short description);
- Reference to figures inserted in the Annex (new figures);
- New figures, inserted in the order given above.

This template presents the diagrams making the LADM_PT in an orderly fashion, while avoiding repeating the insertion of diagrams previously inserted in the text. The new diagrams are inserted at the end of each section. For these new diagrams, a short description is included first, giving that they were not explained in the main text.

A.1 Dynamic Diagrams: Use Case and Activity

- UP Phases: Inception and Elaboration;
- Phase.Activity: 2.1 to 2.3; 5.1 and 6.1;

Reference to Figures in the text:

Figure 4.1: Use Case Context Diagram (for a Cadastral Update).

Figure 4.2: Use Case Level 1 Diagram (Decision & Registration).

Figure 4.3: Activity Diagram (Registration of new legal descriptions).

Figure 4.4: Activity Diagram (Cadastral Map Update).

New Figures:

Figure A.1: Cadastral Update Actors.

Figure A.2: Activity Diagram for the Annexation of part of a parcel.

Figure A.3: Activity Diagram for the Creation of an Urban Lot.

The Use Case diagram in figure A.1 is a special type of diagram, where just the Actors are depicted. In this case, they represent actor roles in a (generic) cadastral update procedure. The legend distinguishes Organizational and Natural Actors by colour. The following two Activity diagrams (in figures A.2 and A.3) were copied from Hespanha et al. (2006) and depict two specific cases of a Cadastral Update. The first concerns an annexation of part of a parcel which modifies an existent parcel, while the second respects the creation of an individual Urban Lot in a re-allotment procedure. The lanes in the diagrams identify specific responsibilities (of organizations or individuals) within the procedures. Although the diagrams are reported to the old CCDM_PT model, they are still valid for LADM_PT, provided the referred object instances be updated to equivalent LADM_PT objects.

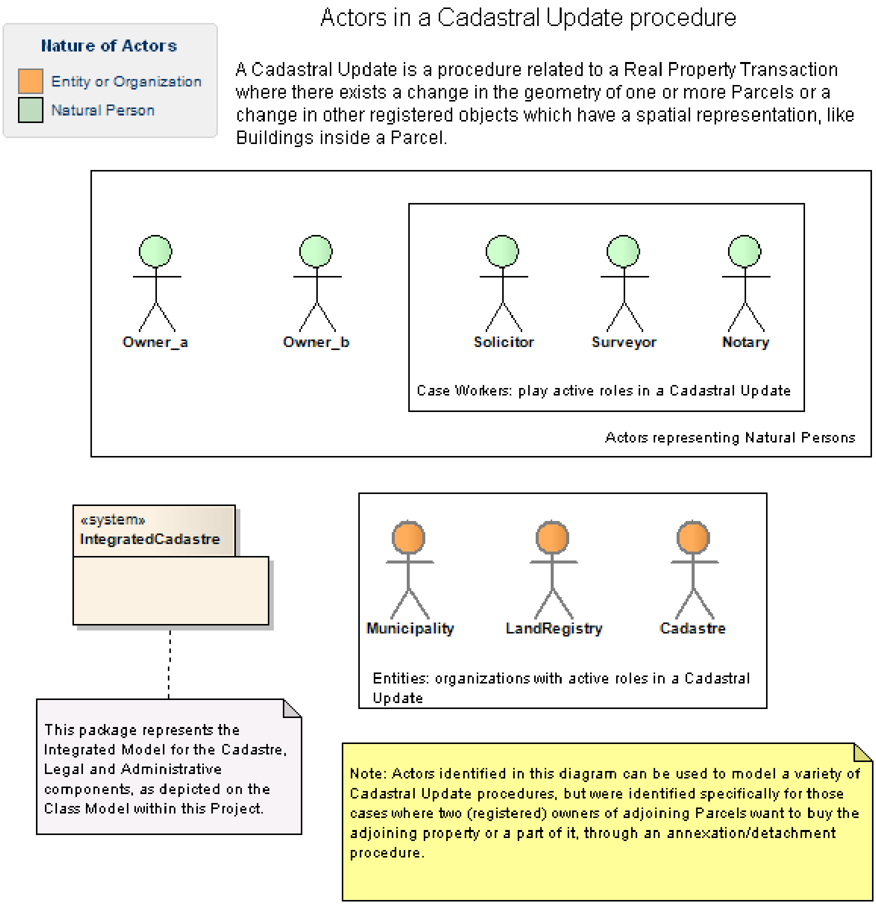


Figure A.1: *Use Case Diagram: Cadastral Update Actors*

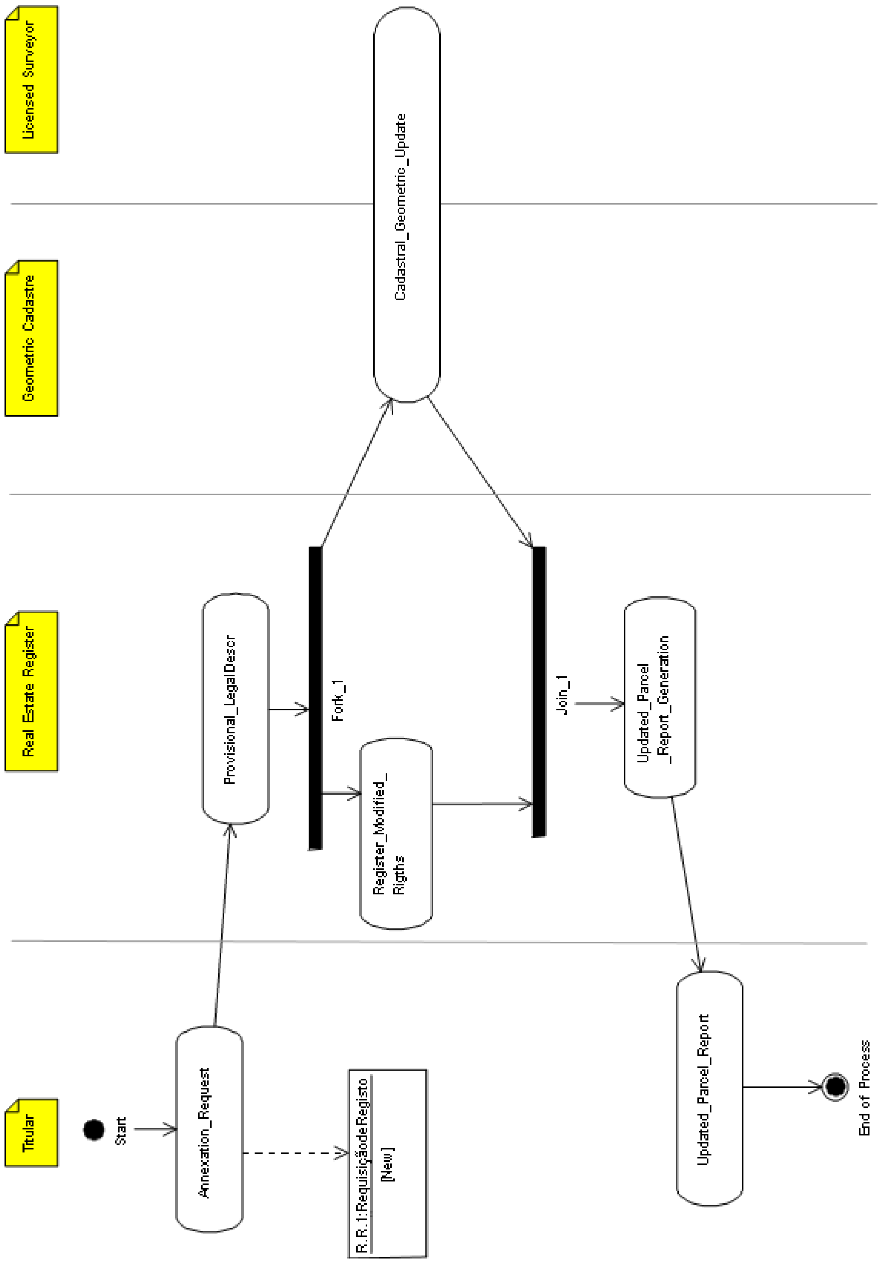


Figure A.2: *Activity Diagram: Annexation of part of a parcel*

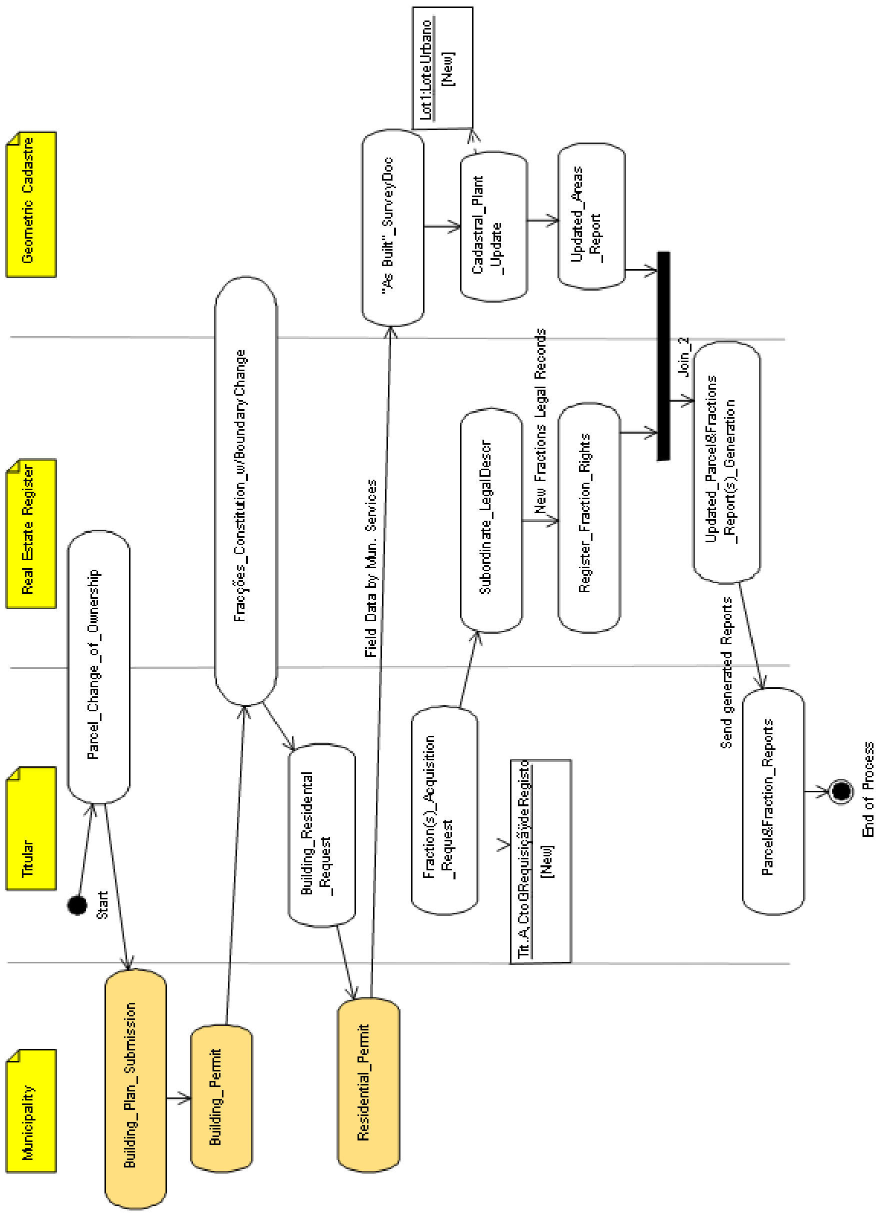


Figure A.3: *Activity Diagram: Creation of an Urban Lot*

A.2 Structural Diagrams: Package and Class

- UP Phases: Elaboration, Iterations 1 to 3;
- Phase.Activity: 5.2 to 5.4 and 6.2 to 6.4;

Reference to Figures in the text: Spatial Unit package

Figure 4.5: Polygon SFS spatial profile.

Figure 4.6: Unstructured spatial profile.

Figure 4.7: Level structure.

Figure 4.8: Real Property and "Baldios".

Figure 4.9: AUGI and Deferred Cadastre.

Figure 4.10: Constraints on Real Property and "Baldios".

Reference to Figures in the text: Legal and Administrative profile

Figure 4.11: Forms of Property.

Figure 4.12: Basic Ownership Rights.

Figure 4.13: Restrictions.

Figure 4.14: Responsibilities.

Figure 4.15: Responsibilities (from the Public Domain).

Reference to Figures in the text: Legal and Administrative package

Figure 4.16: Appurtenance specializations.

Figure 4.17: Basic Ownership specializations.

Figure 4.18: Responsibilities Appurtenant.

Figure 4.19: Responsibilities Encumbering.

Figure 4.20: Public Responsibilities.

New Figures:

Figure A.4: Overview of LADM_PT Integration.

Figure A.5: Surveying sub-package classes.

Figure A.6: Constraints on AUGI and other spatial units.

Figure A.7: Portuguese Basic Administrative Unit.

Figure A.8: Portuguese RRR Hierarchy.

Figure A.9: Portuguese Administrative Source classes.

The overview of LADM_PT in figure A.4 presents the complete set of Portuguese spatial unit classes, and the super-classes for the Legal and Administrative package. It allows a comprehensive overview of LADM_PT classes, although it was prepared for A3 paper size printing. The figure in A.5 depicts the Portuguese specialization for LA_Point class. The diagram notes explain the actions needed to integrate LADM and the PT_CDM models, in order to generate the PT_Point class. Figure A.6 shows the associations and constraints needed in order to check topology relationships between spatial units in different levels, in this case Real Property and Baldio against the AUGI class. The figure A.7 shows the classes associated to the PT_BAUnit class, with diagram notes explaining integration actions. The values for its attributes are derived from a number of PT_CDM classes, because there is no single equivalent class in the Portuguese specifications. The class diagram in figure A.8 shows the PT_RRR super-classes, and the respective enumeration literals correspond to the specialized classes which were modelled in the Legal and Administrative component. In figure A.9, three different administrative sources were specialized from LADM LA_AdministrativeSource class. The diagram notes show integration actions from specific classes in PT_CDM.

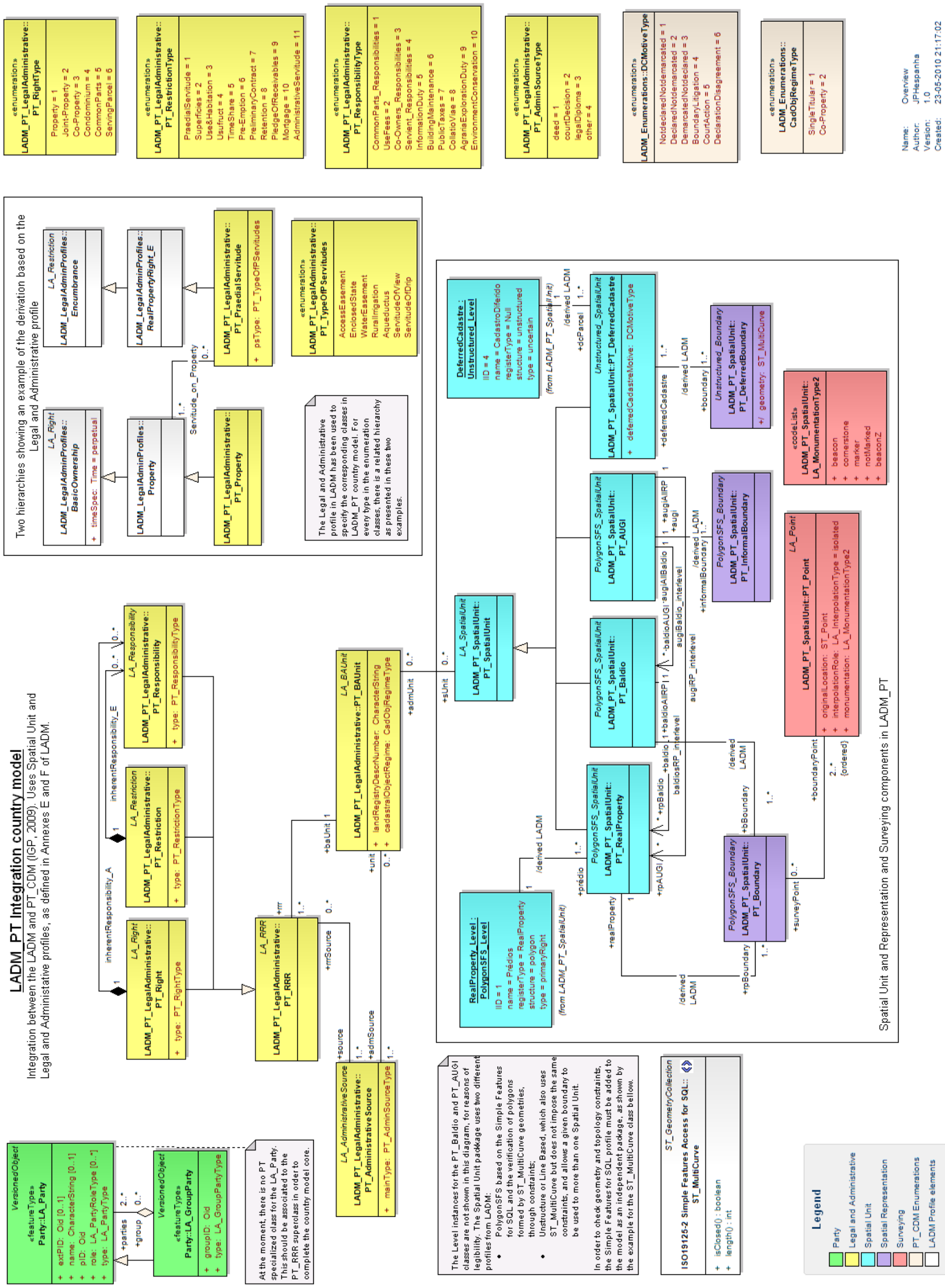


Figure A.4: *Class Diagram: Overview of LADM_PT Integration*

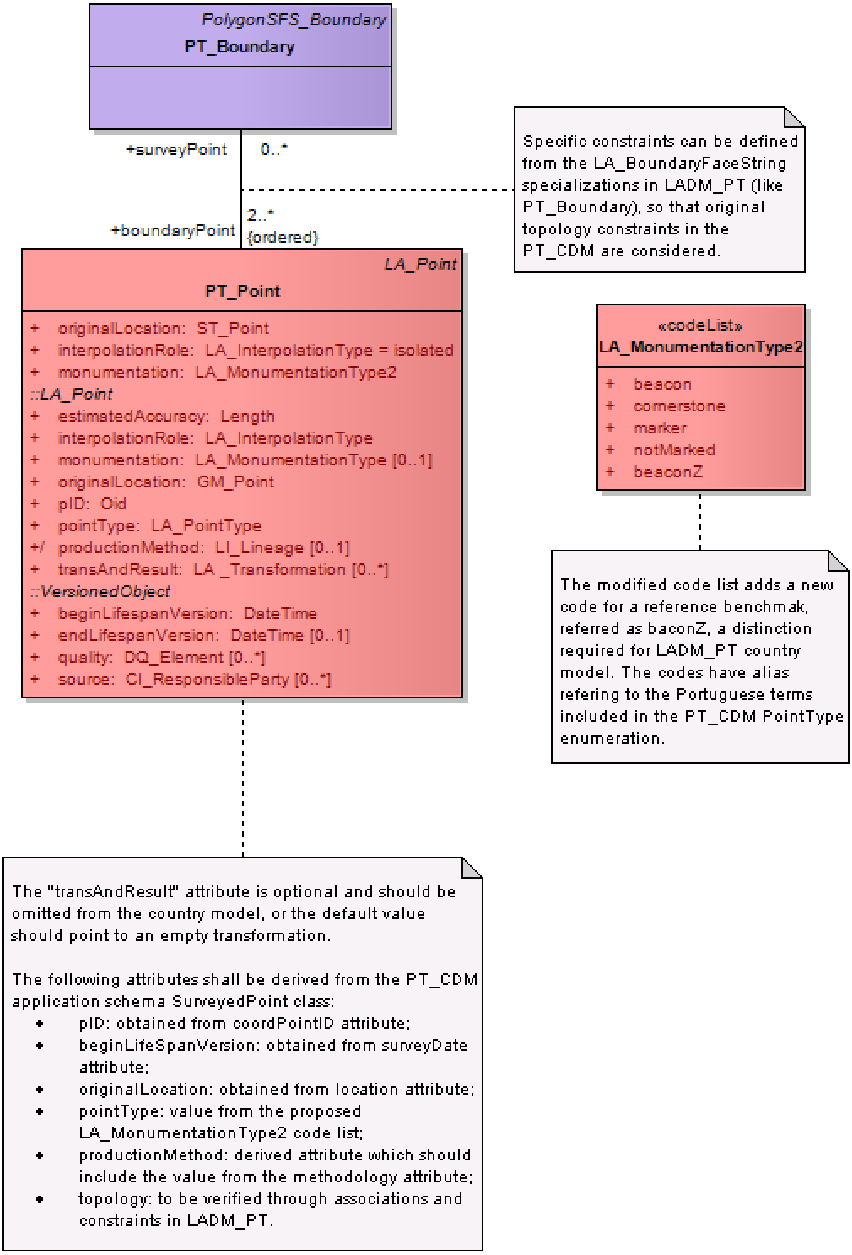


Figure A.5: *Class Diagram: Surveying sub-package*

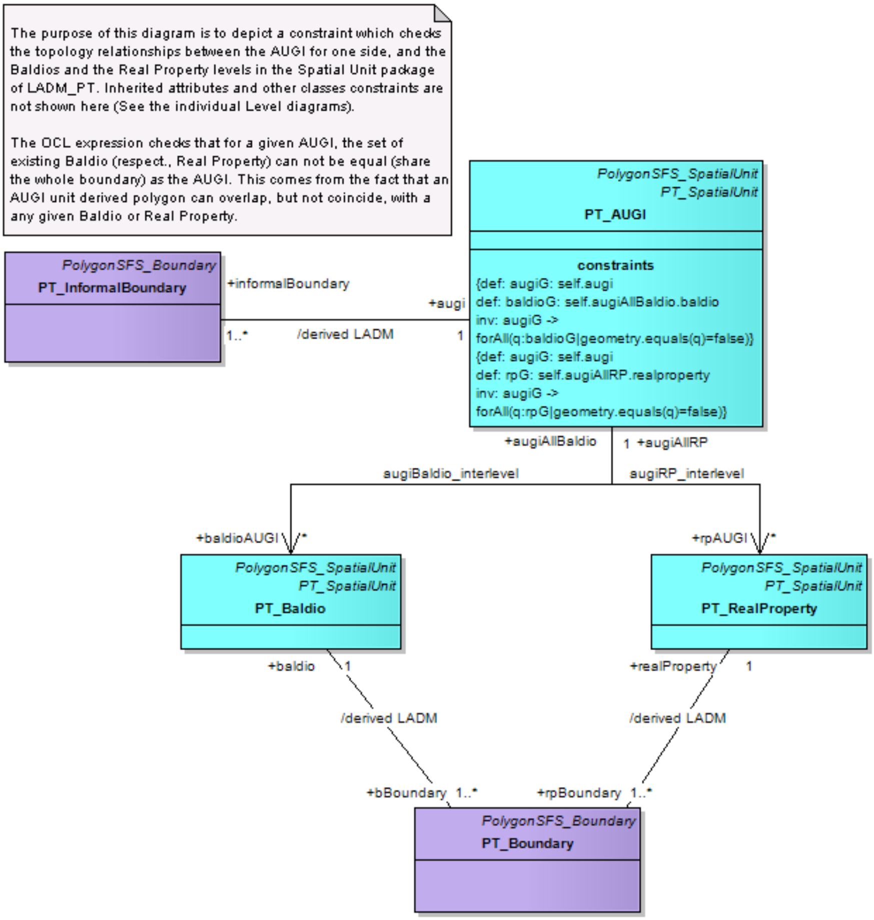


Figure A.6: *Class Diagram: Constraints on AUGI and other spatial units classes*

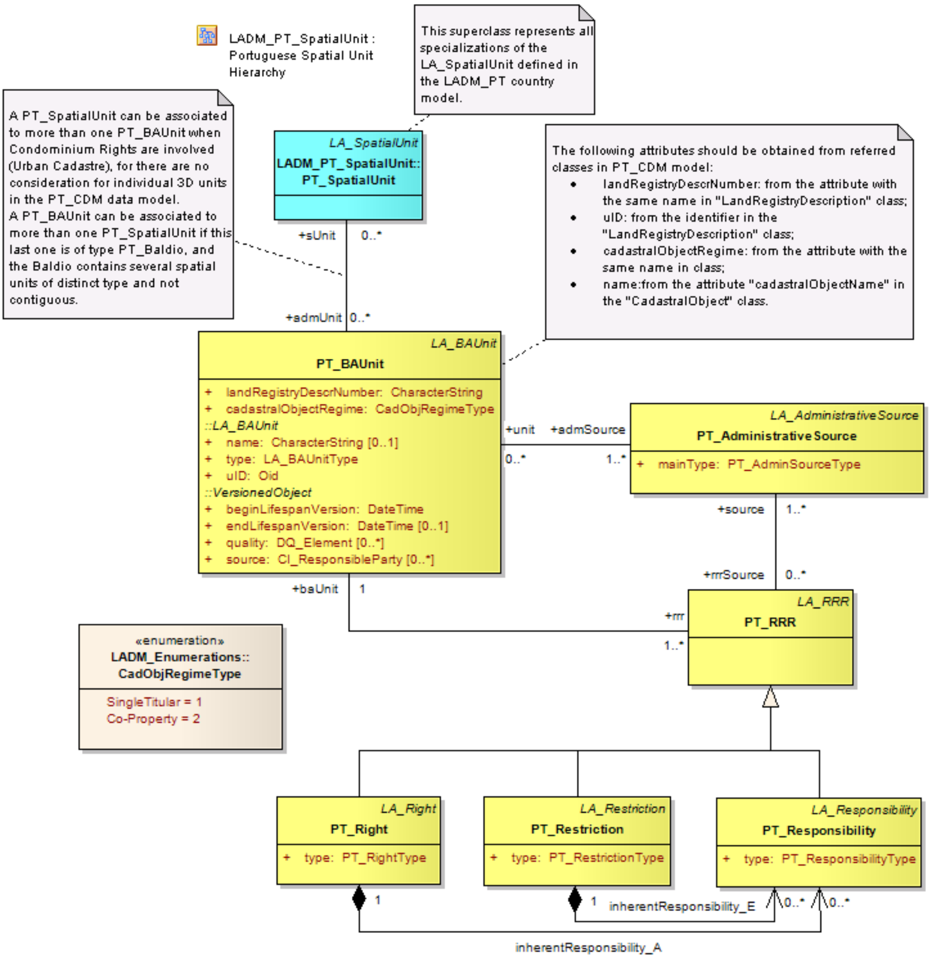


Figure A.7: *Class Diagram: Portuguese Basic Administrative Unit*

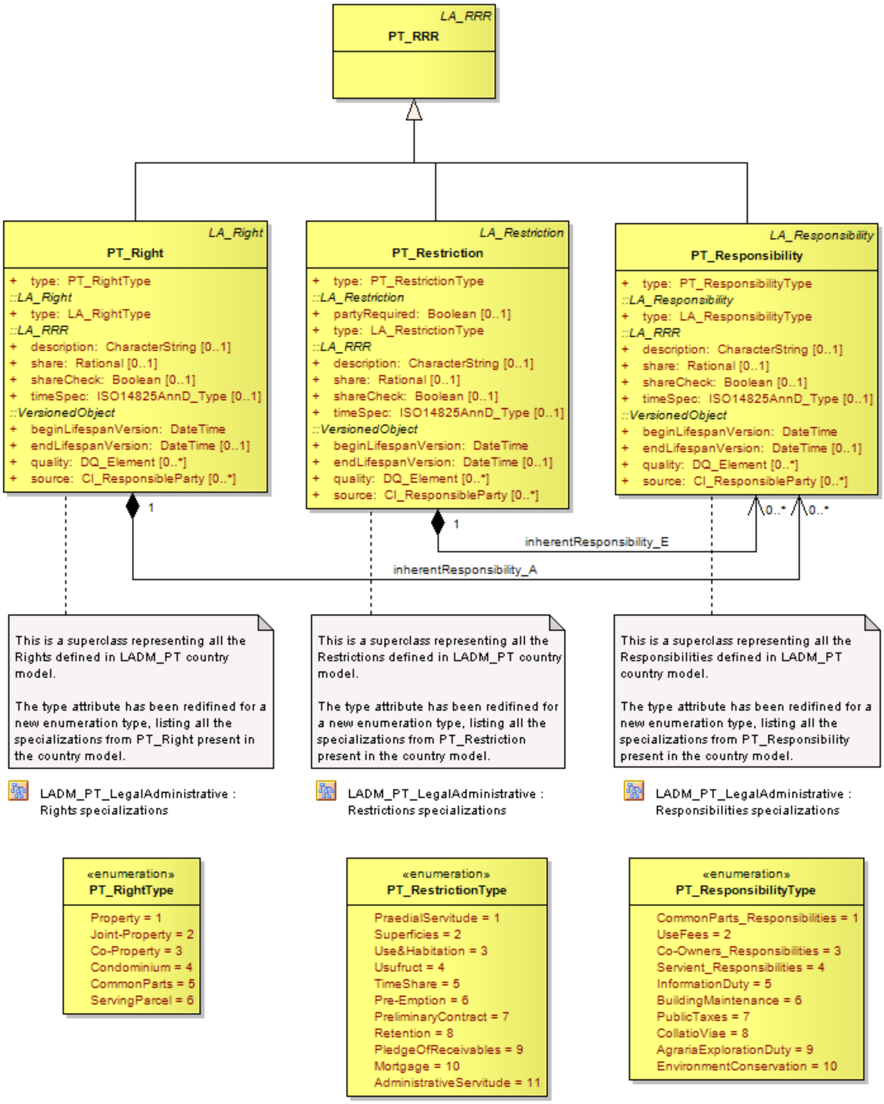


Figure A.8: *Class Diagram: Portuguese Rights, Restrictions and Responsibilities (RRR) Hierarchy*

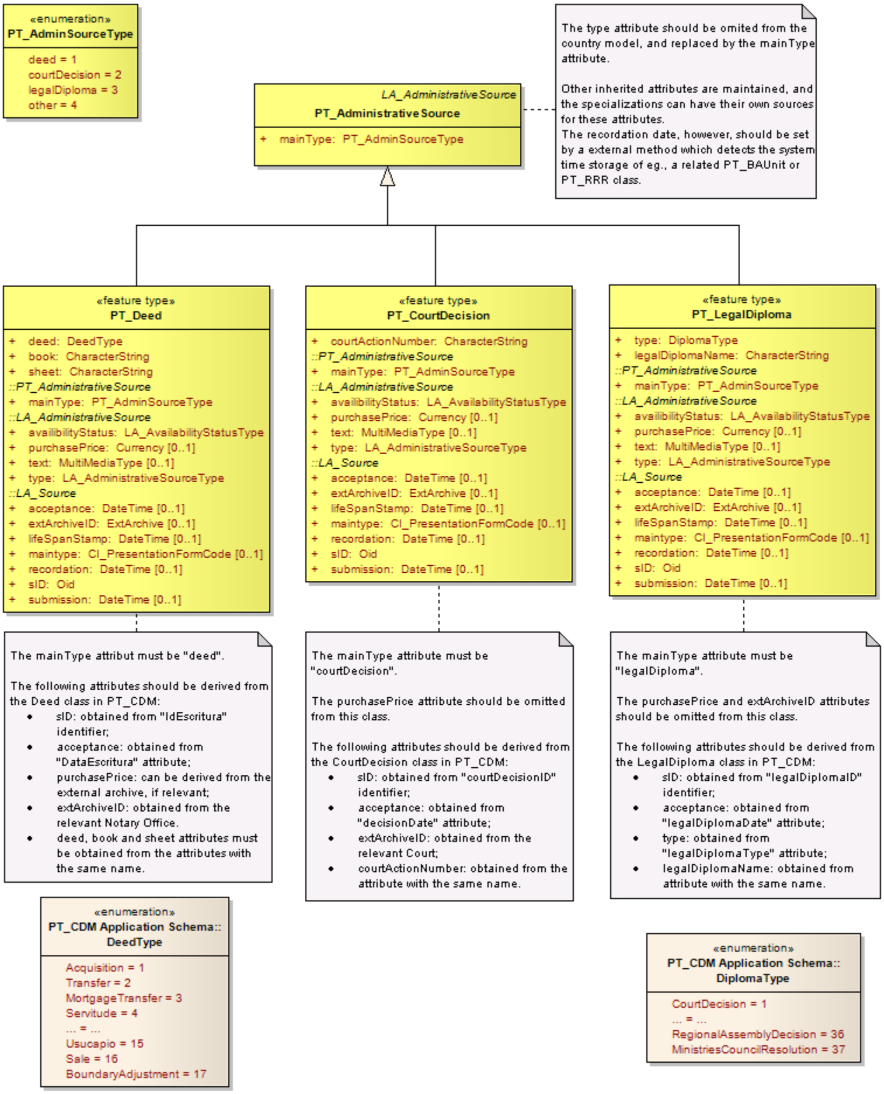


Figure A.9: *Class Diagram: Portuguese Administrative Sources*

A.3 Instance Level (Object) Diagrams

- UP Phases: Iteration 3;
- Phase.Activity: 7.2;

New Figures:

Figure A.10: Instance of a PT_Baldio class.

Figure A.11: Instance of a PT_Co-Property (real right) class.

Figure A.12: Instance of a PT_DeferredCadastre class.

Figure A.13: Instance of a PT_Taxation class.

The Instance Level diagrams show next depict how LADM_PT can model specific real world or simulated cases for various situations concerning Portuguese Cadastre and Land Administration. The diagram in figure A.10 shows a possible instance level originating from an actual Portuguese Baldio, as explained in the diagram notes. There are two non contiguous spatial units in the Basic Administrative Unit, which is unusual for private property, but it happens frequently in the case of "Baldios". The diagram in figure A.11 shows the simplest case of a Co-Property, a single (private) Basic Administrative Unit which is shared between to individuals. The spatial unit is represented by a single polygon. The figure A.12 depicts an instance of a Deferred Cadastre spatial unit in the case of a boundary litigation. There are two PT_Deferred-Boundary instances associated to the spatial unit. The exterior boundary defines the limits of the disputing parcels with external parcels for which there are no demarcation doubts, and the legal and fiscal situation is known. The internal boundaries represent one or more curves (the geometry type is a GML Multi Curve) which require further confirmation. The instance in figure A.13 shows how Tax records applying to immovable property (in Portugal, the IMI tax) can be modelled by a specialization of LADM External Classes, acting as a "blueprint" for model elements required to link to external records. The specific case in the diagram respects a IMI tax over a Condominium unit.

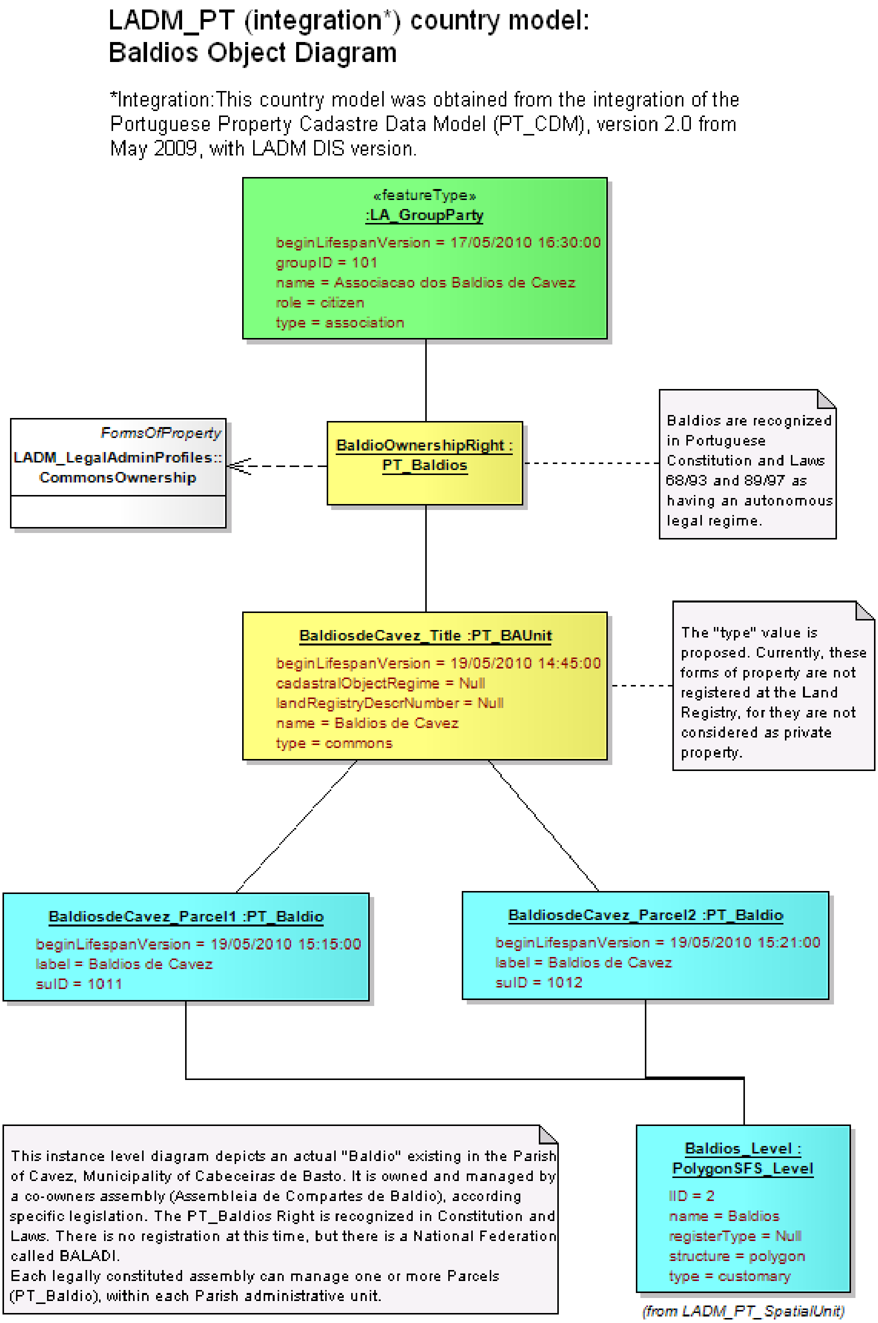


Figure A.10: *Object Diagram: PT_Baldios*

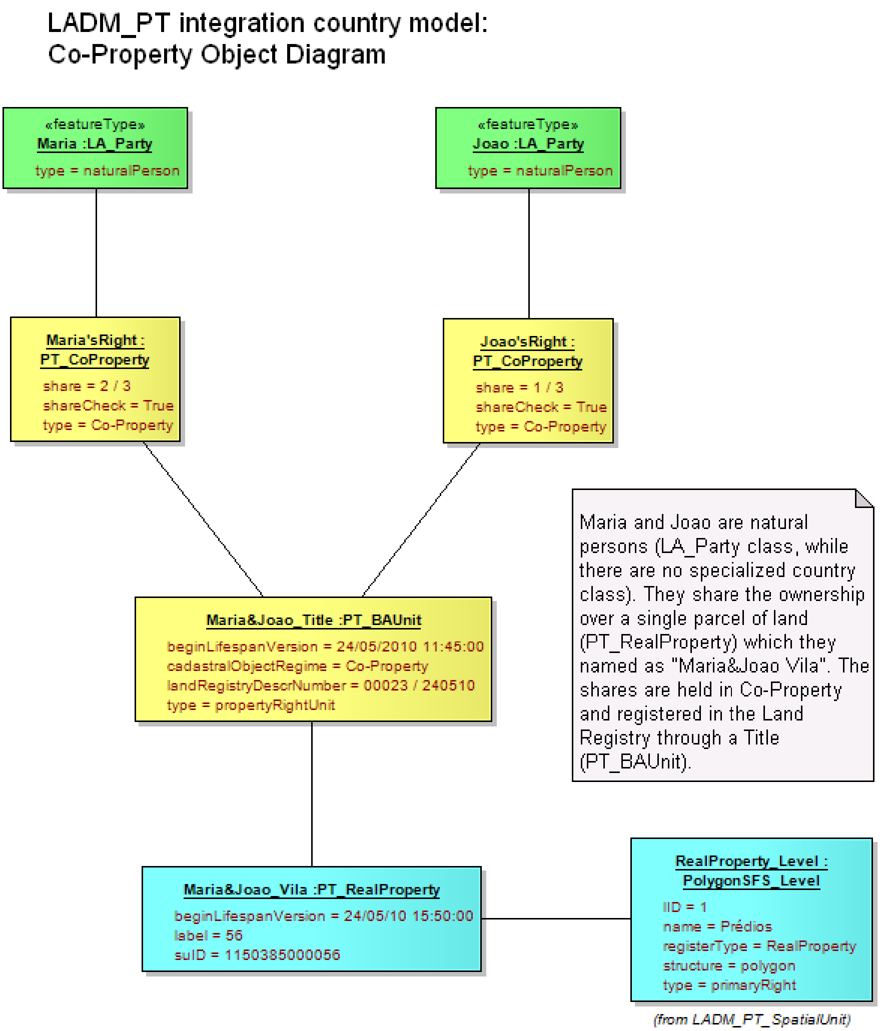


Figure A.11: *Object Diagram: PT_Co-Property*

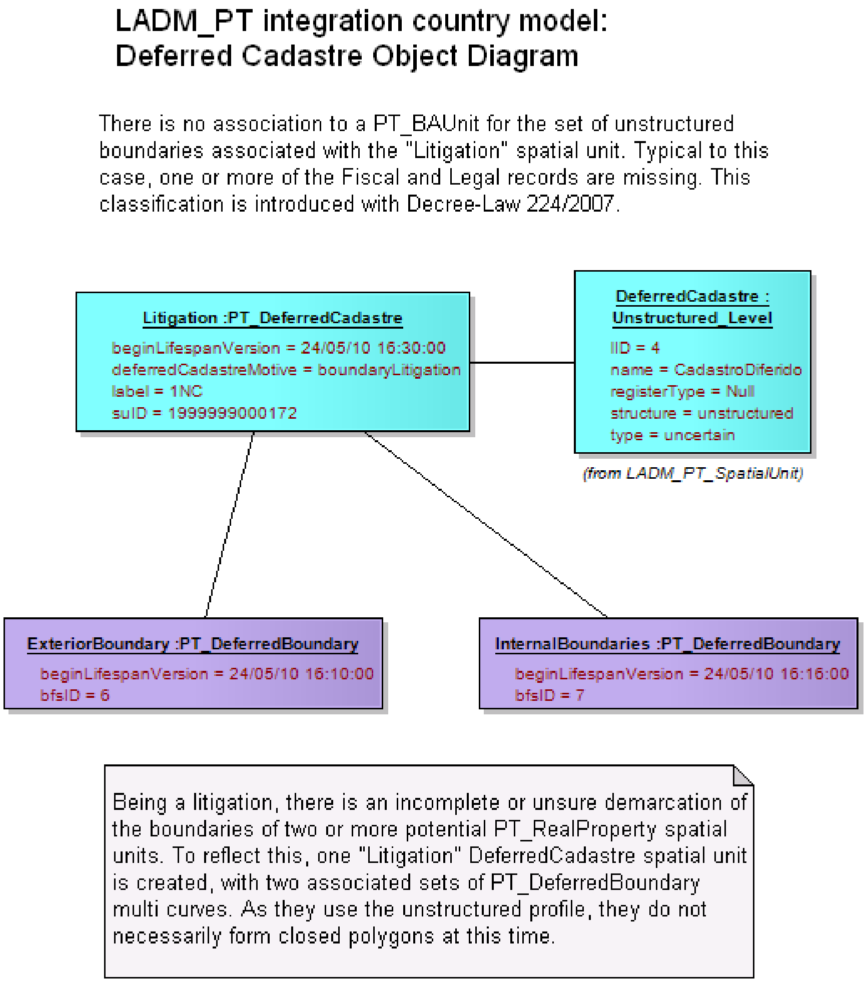


Figure A.12: *Object Diagram: PT_DeferredCadastre*

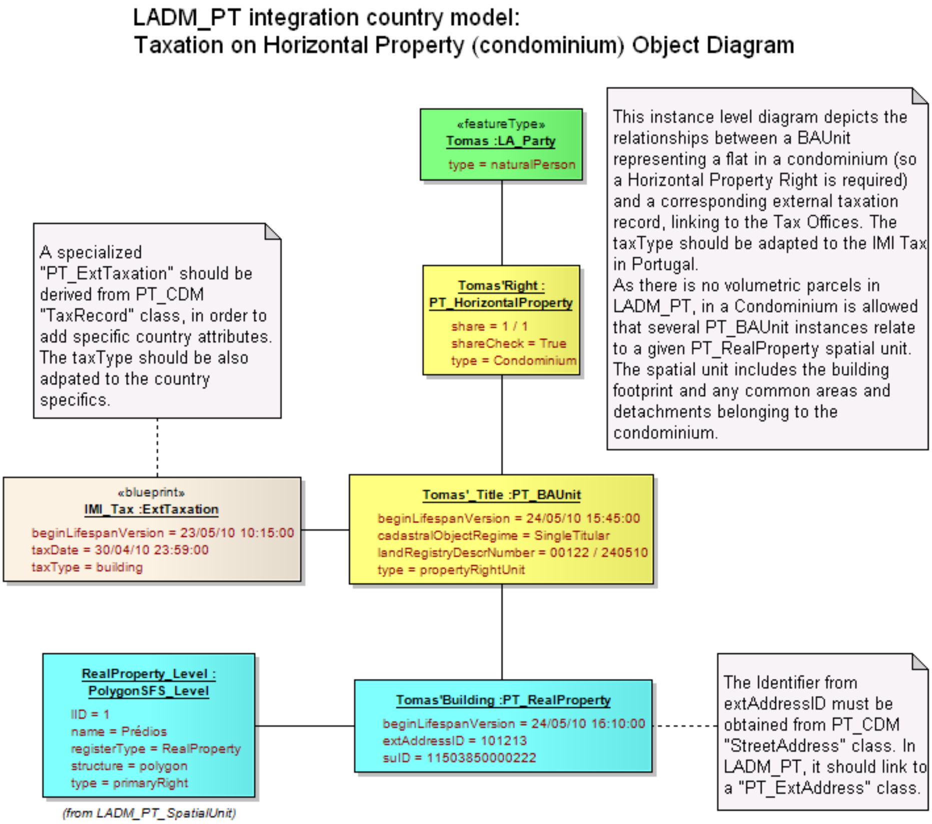


Figure A.13: *Object Diagram: PT_Taxation*

Chapter B

Annex B: Simple Features for SQL (SFS) Profile

The SFS Profile results from the Open GIS Consortium specification *Simple Features Access*, which was later adopted as ISO19125 standard. The SFS Profile is a true UML Profile and has been defined initially in Enterprise Architect MDA software. It is a foundation class profile that has been used in LADM Polygon Spatial "Profile" (actually, a design pattern). In the LADM_PT country model, it is used as part of the definition of the classes PT_RealProperty, PT_Baldio and PT_AUGI, which are specializations from LADM Spatial Unit. In the Development Methodology, it is used as part of Phase.Activity 5.3, to define the spatial profiles to be used in a country model.

The figure B.1 shows a Class (Profile) Diagram, with the classes exhibiting a specific UML stereotype identifying them as profile members. The diagram shows the hierarchy for the ST_MultiCurve, which is the geometry type used for all the spatial units in the Polygon Profile. This diagram is adapted after the MSc Thesis from Helen Ghirmai (Ghirmai (2008), ITC, 2008) which also included a number of OCL constraints allowing to validate the geometry and topology of instances of SFS classes. In figure B.1, only the methods defined or inherited by ST_MultiCurve are shown. These can be grouped under the following functional categories:

- Unary functions: These act upon a single instance of the class and perform type conformance checks, conversions or geometry operations. Examples: ST_GeometryType, ST_AsText, ST_Boundary;

- Binary functions: These act upon two instances of the same class, or different classes using an SFS geometry type, and correspond mostly to topological relationships. Examples: ST_Intersects, ST_Contains;

- Set functions: These act upon collections of geometries of the same or different classes and correspond to vector overlay operations. Examples: ST_Intersection, ST_Union.

The inclusion of the SFS Profile in the Spatial Unit package of a country model allow thus the definition of specific validation constraints in a formal way, namely expressed in OCL. In LADM_PT, this procedure is shown (namely) in figure 4.8, concerning the PT_RealProperty and PT_Baldios classes.

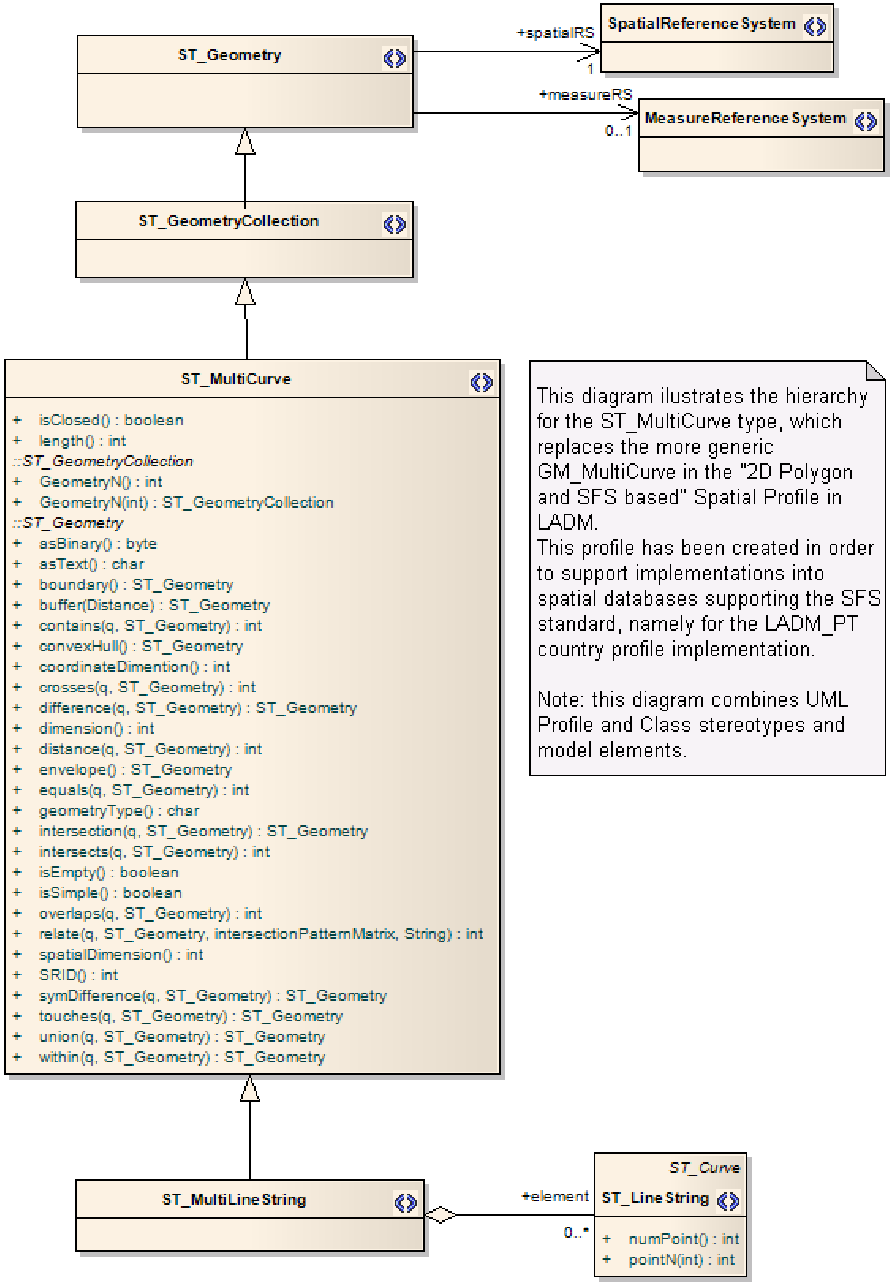


Figure B.1: *Class (Profile) Diagram: The hierarchy of the SFS MultiCurve class*

Chapter C

Annex C: CASE tools documentation

This Annex contains a few elements produced by the CASE tools which were used during the implementation test for the LADM_PT specialized country model. All the elements presented bellow were produced in the Eclipse Modelling Framework (EMF) environment with the Hibernate Tools plug-in, except the SQL code, that was produced by the PgAdmin III open source application for PostgreSQL.

A brief description about the specific contents is introduced after each one of the paragraph headings. The elements are inserted in the order they must be used in the generation of a data base schema, from the final modelling elements in UML, to the spatial data base (PostGIS, in this case).

Java source code for PT_RealProperty and PT_Boundary

This source code begun to be automatically produced from the Ecore model version of the final, specialized LADM_PT UML2 model.

In a second, manual editing stage, the Java source code is modified in order to comply with the Hibernate persistence environment. The source code here reported is the final one.

Notice: The code was formatted in order to fit the margins and to save space (extra empty lines were removed). Only an extract of the complete code is shown, focusing on the class header.

PT_RealProperty source code

```
/**
 * <copyright>
 * Joo Paulo Hespanha, Aug. 2011
 * </copyright>
 *
 * $Id$
```

```
 */
package LADM_PT_out;

import LADM_PT_out.CI_ResponsiblePartyImpl;
import LADM_PT_out.DQ_ElementImpl;
import LADM_PT_out.LA_AreaValueImpl;
import LADM_PT_out.LA_DimensionType;
import LADM_PT_out.PT_BoundaryImpl;
import LADM_PT_out.PT_ExtAddressImpl;
import java.lang.String;
import java.lang.Long;
import java.util.Date;
import org.eclipse.emf.common.util.EList;
import org.eclipse.emf.ecore.InternalEObject;
import org.eclipse.emf.ecore.impl.EObjectImpl;

/**
 * <!-- begin-user-doc -->
 * An implementation of the model object '<em><b>PT Real Property</b></em>'.
 * <!-- end-user-doc -->
 * <p>
 * The following features are implemented:
 * <ul>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getDimension <em>Dimension
 </em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getArea <em>Area</em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getExtAddressID <em>Ext
 Address ID</em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getLabel <em>Label</em>}
 </li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getSuID <em>Su ID</em>}
 </li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getSet <em>Set</em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getBeginLifespanVersion
 <em>Begin Lifespan Version</em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getEndLifespanVersion
 <em>End Lifespan Version</em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getQuality <em>Quality
 </em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getSource <em>Source
 </em>}</li>
 *   <li>{@link LADM_PT_out.PT_RealPropertyImpl#getRpBoundary <em>Rp
 Boundary</em>}</li>
 * </ul>
 * </p>
 *
 * @generated
 */
public class PT_RealPropertyImpl extends EObjectImpl {
```

```
/**
 * The default value of the '{@link #getDimension() <em>Dimension</em>}' attribute.
 * <!-- begin-user-doc -->
 * <!-- end-user-doc -->
 * @see #getDimension()
 * @generated
 * @ordered
 */
protected static final LA_DimensionType DIMENSION_EDEFAULT =
LA_DimensionType._0D;

/**
 * The cached value of the '{@link #getDimension() <em>Dimension</em>}'
 attribute.
 * <!-- begin-user-doc -->
 * <!-- end-user-doc -->
 * @see #getDimension()
 * @generated
 * @ordered
 */
protected LA_DimensionType dimension = DIMENSION_EDEFAULT;
.../...
Other getter and setters for the attributes have similar coding and are
not shown. Following the class constructor and the toString methods.
.../...
/**
 * <!-- begin-user-doc -->
 * Empty constructor turned into public access; recurring to the super
 constructor <br>
 * from EObjectImpl class (in Ecore).
 * <!-- end-user-doc -->
 * @generated
 */
public PT_RealPropertyImpl() {
super();
}

/**
 * <!-- begin-user-doc -->
 * <!-- end-user-doc -->
 * @generated
 */
@Override
public String toString() {
if (eIsProxy()) return super.toString();
StringBuffer result = new StringBuffer(super.toString());
result.append(" (dimension: ");
result.append(dimension);
result.append(", label: ");
```

```
result.append(label);
result.append(", suID: ");
result.append(suID);
result.append(", beginLifespanVersion: ");
result.append(beginLifespanVersion);
result.append(", endLifespanVersion: ");
result.append(endLifespanVersion);
result.append(')');
return result.toString();
}
} //PT_RealPropertyImpl
```

PT_Boundary source code

```
/**
 * <copyright>
 * Joo Paulo Hespanha, Aug. 2011
 * </copyright>
 *
 * $Id$
 */
package LADM_PT_out;

import LADM_PT_out.CI_ResponsiblePartyImpl;
import LADM_PT_out.DQ_ElementImpl;
import LADM_PT_out.PT_RealPropertyImpl;
import com.vividsolutions.jts.geom.MultiLineString;
import java.lang.Long;
import java.util.Date;
import org.eclipse.emf.common.util.EList;
import org.eclipse.emf.ecore.impl.EObjectImpl;

/**
 * <!-- begin-user-doc -->
 * An implementation of the model object '<em><b>PT Boundary</b></em>'.
 * <!-- end-user-doc -->
 * <p>
 * The following features are implemented:
 * <ul>
 *   <li>{@link LADM_PT_out.PT_BoundaryImpl#getBfsID <em>Bfs ID</em>}</li>
 *   <li>{@link LADM_PT_out.PT_BoundaryImpl#getGeometry <em>Geometry
 </em>}</li>
 *   <li>{@link LADM_PT_out.PT_BoundaryImpl#getBeginLifespanVersion <em>
 Begin Lifespan Version</em>}</li>
 *   <li>{@link LADM_PT_out.PT_BoundaryImpl#getEndLifespanVersion <em>End
 Lifespan Version</em>}</li>
 *   <li>{@link LADM_PT_out.PT_BoundaryImpl#getQuality <em>Quality</em>}
 </li>
 *   <li>{@link LADM_PT_out.PT_BoundaryImpl#getSource <em>Source</em>}</li>
```

```
 * </ul>
 * </p>
 *
 * @generated
 */
public class PT_BoundaryImpl extends EObjectImpl {
/**
 * The default value of the '{@link #getBfsID() <em>Bfs ID</em>}'
 attribute.
 * <!-- begin-user-doc -->
 * <!-- end-user-doc -->
 * @see #getBfsID()
 * @generated
 * @ordered
 */
protected static final Long BFS_ID_EDEFAULT = null;
.../...
Other attribute default values and getters and setters not shown,
except for the geometry attribute below.
.../...

/**
 * This field stores the geometry of PT_Boundary, implemented as a JTS
 <br>
 * MultiLineString object (complies with GML Simple Features spec).
 * @author Joo Paulo Hespanha
 * @generated not generated by the EMF generator!
 */
protected MultiLineString geometry = GEOMETRY_EDEFAULT;

/**
 * <!-- begin-user-doc -->
 * Changed to public constructor, with a EObjectImpl super-constructor.
 * <!-- end-user-doc -->
 * @generated
 */
public PT_BoundaryImpl() {
super();
}

/**
 * This getter retrieves the geometry type of the PT_Boundary class<br>
 *
 * @author Joo Paulo Hespanha
 * @generated not generated by the EMF generator!
 */
public MultiLineString getGeometry() {
return geometry;
}
```

```
/**
 * This sets the geometry field of PT_Boundary with a (previously
 constructed) <br>
 * MultiLineString object.
 *
 * @author Joo Paulo Hespanha
 * @generated not generated by the EMF generator!
 */
public void setGeometry(MultiLineString newGeometry) {
this.geometry = newGeometry;
}

} //PT_BoundaryImpl
```

XML hibernate mappings for the above referred classes

These XML files were manually created in an Hibernate perspective of an Eclipse EMF project, with the help of the in-built XML Editor.

A few hibernate tutorials and reference examples guided the code production, covering the mappings of ID's, simple types, component and user data types, geometric types and associations. Each file establishes the relationship between a Java source class and its used types (geometric or other) and Enumerations, and the corresponding data base table.

Mapping for PT_RealProperty

```
<?xml version="1.0"?>
<!DOCTYPE hibernate-mapping PUBLIC
"-//Hibernate/Hibernate Mapping DTD 3.0//EN"
"http://hibernate.sourceforge.net/hibernate-mapping-3.0.dtd">
<hibernate-mapping package="LADM_PT_out">
  <class name="PT_RealPropertyImpl" table="PT_REALPROPERTY">

<id name="suID" column="SU_ID">
   <generator class="native"></generator>
   </id>

<!-- A timestamp automatically enables versioning in Hibernate. This
 mapping element
 should follow the "id" generator element in a mapping file. -->
<timestamp name="beginLifespanVersion" access="field"
column="BEGIN_VERSION"></timestamp>

   <property name="label" type="string" column="LABEL"></property>
   <property name="endLifespanVersion" type="timestamp"
```

```
   column="END_VERSION"></property>

<!-- Simple component mapping for CI_ResponsibleParty data type -->
<component name="source" class="CI_ResponsiblePartyImpl">
<property name="respID" type="long" column="R_ID"
not-null="true"></property>
<property name="name" type="string" column="R_NAME"></property>
</component>

<!-- Simple component mapping for DQ_Element data type -->
<component name="quality" class="DQ_ElementImpl">
<property name="result" type="float" column="RESULT"></property>
<property name="type" column="Q_TYPE"
 type="hibernateDataType.DQ_EvaluationMethodUserDataType"></property>
<property name="date" type="date" column="Q_DATE"></property>
</component>

<!-- Simple component mapping for LA_AreaValue data type -->
<component name="area" class="LA_AreaValueImpl">
<property name="areasize" type="float"
column="AREA_SIZE"></property>
<property name="type" column="A_TYPE"
type="hibernateDataType.LA_AreaUserDataType"></property>
</component>

<!-- Simple component mapping for PT_ExtAddress data type -->
<component name="extAddressID" class="PT_ExtAddressImpl">
<property name="buildingNumber" type="string"
column="BUILD_NUMBER"></property>
<property name="doorNrPrefix" column="DOORNR_PREFIX"
type="hibernateDataType.PT_LotPrefixUserDataType"></property>
</component>

<!-- Use of Custom Data Types for the Enumerations -->
<property name="dimension" column="DIMENSION"
type="hibernateDataType.LA_DimensionUserDataType"></property>

<!-- Define the Association (one to many) to PT_Boundary -->
<bag name="RpBoundary" inverse="true">
<key> <column name="SU_ID"></column></key>
<one-to-many class="PT_BoundaryImpl"/>
</bag>
  </class>
</hibernate-mapping>
```

Mapping for PT_Boundary

```
<?xml version="1.0"?>
<!DOCTYPE hibernate-mapping PUBLIC
"-//Hibernate/Hibernate Mapping DTD 3.0//EN"
"http://hibernate.sourceforge.net/hibernate-mapping-3.0.dtd">
<hibernate-mapping package="LADM_PT_out">
  <class name="PT_BoundaryImpl" table="PT_BOUNDARY">

<id name="bfsID" column="BFS_ID">
<generator class="native"></generator>
</id>

<timestamp name="beginLifespanVersion" access="field"
column="BEGIN_VERSION"></timestamp>

   <property name="endLifespanVersion" type="timestamp"
   column="END_VERSION"></property>

<!-- Simple component mapping for CI_ResponsibleParty data type -->
<component name="source" class="CI_ResponsiblePartyImpl">
<property name="respID" type="long" column="R_ID"
not-null="true"></property>
<property name="name" type="string" column="R_NAME"></property>
</component>

<!-- Simple component mapping for DQ_Element data type -->
<component name="quality" class="DQ_ElementImpl">
<property name="result" type="float" column="RESULT"></property>
<property name="type" column="Q_TYPE"
 type="hibernateDataType.DQ_EvaluationMethodUserDataType"></property>
<property name="date" type="date" column="Q_DATE"></property>
</component>

<!-- Mapping the geometry field with Hibernate Spatial data types -->
<property name="geometry" column="BFS_GEOM"
type="org.hibernatespatial.GeometryUserType"></property>

<!-- Many to One Association to PT_RealProperty mapping -->
<many-to-one name="realProperty" column="SU_ID"
class="PT_RealPropertyImpl" not-null="true"></many-to-one>
  </class>
</hibernate-mapping>
```

Java source code for LA_DimensionUserDataType

This is the example code for the definition of a new Hibernate User Data Type, in this case representing a persistent, immutable Enumeration. This code used Example 6.2 in (Elliott et al., p.114) as a template to define this new hibernate type.

This code assumes the Enumeration source code is already available, in this case corresponds to the class LA_DimensionType in the LADM_PT_out package.

```
package hibernateDataType;

import java.io.Serializable;
import java.sql.PreparedStatement;
import java.sql.ResultSet;
import java.sql.SQLException;
import java.sql.Types;
import org.hibernate.Hibernate;
import org.hibernate.HibernateException;
import org.hibernate.usertype.UserType;
import LADM_PT_out.LA_DimensionType;

/**
 * This class defines the Hibernate User Type mapping for a persistence,
 immutable enumeration <br>
 * regarding the literals in LA_DimensionType. <br>
 * @author jphespanha
 *
 */
public class LA_DimensionUserDataType implements UserType {

/**
 * Reconstruct an object from the cacheable representation. At the very
 least this <br>
 * method should perform a deep copy if the type is mutable. (optional
 operation)
 *
 * @param cached the object to be cached
 * @param owner the owner of the cached object
 * @return a reconstructed object from the cachable representation
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public Object assemble(Serializable cached, Object owner)
throws HibernateException {
return cached;
}

/**
 * Return a deep copy of the persistent state, stopping at
 * entities and collections.
```

```
 *
 * @param value the object whose state is to be copied.
 * @return the same object, since enumeration instances are singletons.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public Object deepCopy(Object value) throws HibernateException {
return value;
}

/**
 * Transform the object into its cacheable representation. At the very
 least this
 * method should perform a deep copy if the type is mutable. That may
 not be enough
 * for some implementations, however; for example, associations must be
 * cached as identifier values. (optional operation)
 *
 * @param value the object to be cached
 * @return a cachable representation of the object
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public Serializable disassemble(Object value) throws HibernateException
{
return (Serializable)value;
}

/**
 * Compare two instances of the class mapped by this type for
 * persistence "equality".
 *
 * @param x first object to be compared.
 * @param y second object to be compared.
 * @return <code>true</code> iff both represent the same SourceMedia
 type.
 * @throws ClassCastException if x or y isn't a {@link SourceMedia}.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public boolean equals(Object x, Object y) throws HibernateException {
// We can compare instances, since SourceMedia are immutable
singletons
return (x==y);
}
```

```
/**
 * Get a hashcode for an instance, consistent with persistence
 "equality".
 * @param x the instance whose hashcode is desired.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public int hashCode(Object x) throws HibernateException {
return x.hashCode();
}

/**
 * Indicates whether objects managed by this type are mutable.
 *
 * @return <code>false</code>, since enumeration instances are
 *        immutable singletons.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public boolean isMutable() {
return false;
}

/**
 * Retrieve an instance of the mapped class from a JDBC {@link
 ResultSet}.
 *
 * @param rs the results from which the instance should be retrieved.
 * @param names the columns from which the instance should be
 retrieved.
 * @param owner the entity containing the value being retrieved.
 * @return the retrieved {@link SourceMedia} value, or <code>null
 </code>.
 * @throws SQLException if there is a problem accessing the database.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public Object nullSafeGet(ResultSet rs, String[] names, Object owner)
throws HibernateException, SQLException {
// Start by looking up the value name
String name = (String) Hibernate.STRING.nullSafeGet(rs, names[0]);
if (name == null) {
    return null;
}
// Then find the corresponding enumeration value
try {
```

```
    return LADM_PT_out.LA_DimensionType.valueOf(name);
}
catch (IllegalArgumentException e) {
        throw new HibernateException("Bad Dimension value: " +
        name, e);
}
}

/**
 * Write an instance of the mapped class to a {@link
 PreparedStatement},
 * handling null values.
 *
 * @param st a JDBC prepared statement.
 * @param value the SourceMedia value to write.
 * @param index the parameter index within the prepared statement at
 *       which this value is to be written.
 * @throws SQLException if there is a problem accessing the database.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public void nullSafeSet(PreparedStatement st, Object value, int index)
throws HibernateException, SQLException {
String name = null;
if (value != null)
    name = ((LADM_PT_out.LA_DimensionType)value).toString();
Hibernate.STRING.nullSafeSet(st, name, index);
}

/**
 * During merge, replace the existing (target) value in the entity we
 are merging to
 * with a new (original) value from the detached entity we are merging.
 For immutable
 * objects, or null values, it is safe to simply return the first
 parameter. For
 * mutable objects, it is safe to return a copy of the first parameter.
 For objects
 * with component values, it might make sense to recursively replace
 component values.
 *
 * @param original the value from the detached entity being merged
 * @param target the value in the managed entity
 * @return the value to be merged
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
```

```
public Object replace(Object original, Object target, Object owner)
throws HibernateException {
return original;
}

/**
 * Determine the class that is returned by {@link #nullSafeGet}.
 *
 * @return {@link SourceMedia}, the actual type returned
 * by {@link #nullSafeGet}.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public Class<LA_DimensionType> returnedClass() {
return LADM_PT_out.LA_DimensionType.class;
}

/**
 * Determine the SQL type(s) of the column(s) used by this type
 mapping.
 *
 * @return a single VARCHAR column.
 *
 * @author Example 6.2 in Harnessing Hibernate
 */
@Override
public int[] sqlTypes() {
// Allocate a new array each time to protect against callers
changing
// its contents.
int[] typeList = new int[1];
typeList[0] = Types.VARCHAR;
return typeList;
}
}
```

SQL script code for data base, sequence and tables

The following SQL scripts were automatically created and copied from the SQL panel of the PgAdmin III application, when connected to the “ladm_pt” data base resulting from the Eclipse Hibernate Tools Schema Export.

The sub-paragraph text identifies the purpose of each one of the scripts.

Data Base creation script

To be noted: this automatically created script does not include the reference to the PostGIS template.

```
-- Database: ladm_pt

-- DROP DATABASE ladm_pt;

CREATE DATABASE ladm_pt
  WITH OWNER = postgres
       ENCODING = 'UTF8'
       CONNECTION LIMIT = -1;
COMMENT ON DATABASE ladm_pt IS 'Teste com o Teneo e Hibernate';
```

Sequence creation script

```
-- Sequence: hibernate_sequence

-- DROP SEQUENCE hibernate_sequence;

CREATE SEQUENCE hibernate_sequence
  INCREMENT 1
  MINVALUE 1
  MAXVALUE 9223372036854775807
  START 1
  CACHE 1;
ALTER TABLE hibernate_sequence OWNER TO postgres;
```

pt_realproperty table creation script

The component types attributes were aggregated into the resulting table, but all of them are single-valued.

```
-- Table: pt_realproperty

-- DROP TABLE pt_realproperty;

CREATE TABLE pt_realproperty
(
  su_id bigint NOT NULL,
  begin_version timestamp without time zone NOT NULL,
  label character varying(255),
  end_version timestamp without time zone,
  r_id bigint NOT NULL,
  r_name character varying(255),
  result real,
  q_type character varying(255),
  q_date date,
  area_size real,
  a_type character varying(255),
```

```
  build_number character varying(255),
  doornr_prefix character varying(255),
  dimension character varying(255),
  CONSTRAINT pt_realproperty_pkey PRIMARY KEY (su_id)
)
WITH (
  OIDS=FALSE
);
ALTER TABLE pt_realproperty OWNER TO postgres;
```

pt_boundary table creation script

The script defines the geometry type for column “bfs_geom”, but does not define any check constraints for specifics of the geometry type.

```
-- Table: pt_boundary

-- DROP TABLE pt_boundary;

CREATE TABLE pt_boundary
(
  bfs_id bigint NOT NULL,
  begin_version timestamp without time zone NOT NULL,
  end_version timestamp without time zone,
  r_id bigint NOT NULL,
  r_name character varying(255),
  result real,
  q_type character varying(255),
  q_date date,
  bfs_geom geometry,
  su_id bigint NOT NULL,
  CONSTRAINT pt_boundary_pkey PRIMARY KEY (bfs_id),
  CONSTRAINT fk65870405fb0573ac FOREIGN KEY (su_id)
      REFERENCES pt_realproperty (su_id) MATCH SIMPLE
      ON UPDATE NO ACTION ON DELETE NO ACTION
)
WITH (
  OIDS=FALSE
);
ALTER TABLE pt_boundary OWNER TO postgres;
```

Chapter D

Annex D: Implementation test results

The following figures (screen captures) show the results obtained from the Pilot Project, as reported back in section 4.6, where the respective data was loaded into an open source spatial data base (PostGIS) and used a geographical information system interface.

In a first step, all the classes subject to cadastral update field operations, namely the parcel polygons as in figure D.1, were exported from the original ESRI shapefiles, into PostGIS spatial tables, using the tool "SPIT" available in Quantum GIS. This acronym stands for "Shapefile to PostGIS Import Tool". This tool allowed to specify an import using the Polygon geometry (as specified in SFS Simple Feature) and a custom defined Spatial Reference Information (the SRID column in the database), corresponding to the Portuguese Datum as defined prior to the adoption of the European Terrestrial Reference System (called ETRS89).

After importing the most relevant cadastral layers from the Mira Municipal Cadastre, as a result of the updates which have been made through School Projects at ESTGA, a new project has been set up within uDIG, comprising reference and property beacons, the boundaries and the property areas as (2D) polygons. All the country specific attributes, and the corresponding geometries (polygons, polylines and points) where imported into PostGIS tables and added to the uDIG view.

Attention should be called to the fact that, in earlier versions of PostGIS (prior to 1.5), the old Portuguese Spatial Reference Systems did not exist in the respective PostGIS system table, and so they have to be defined through a dedicated SQL script. This problem has been overcome through the adoption of the current European standard (ETRS89), together with the use of recent versions of PostGIS.

In figure D.2, the map panel is showing "Predios_Polylines" representing private property boundaries, and the respective administrative attributes in the lower panel. The attributes correspond to a query for the boundaries of parcel number 227. A total of 21 features (parcel boundaries) were obtained as result of the query.

The figure D.3 shows the working area for the school projects from 2008, for the update of two cadastral sheets in the Mira Municipality, where the social areas are

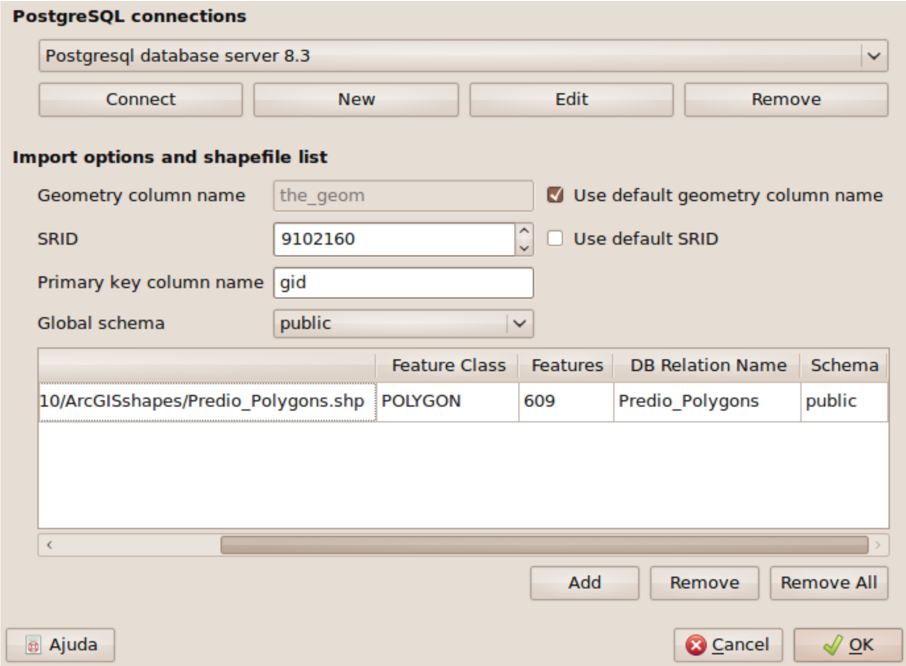


Figure D.1: *Shape to PostGIS export: Exporting an ESRI shapefile to PostGIS*

shown as blank areas against private property parcels. At this time, it was only possible to update the crossing of the new A17 motorway in the northern cadastral sheet. It must be noted that cadastral sheets in this portion of the country have a 1 square kilometre reference area, which can translate to a slighter higher or lower figure due to the specific parcels layout within this area. At that stage in the production of a uDIG compliant map project, some errors still persisted in the data, as a parcel with ID 156 with no data (in the remaining attributes). The number of errors was however extremely small, showing that the original data has a high quality standard, following the national (IGP) standards.

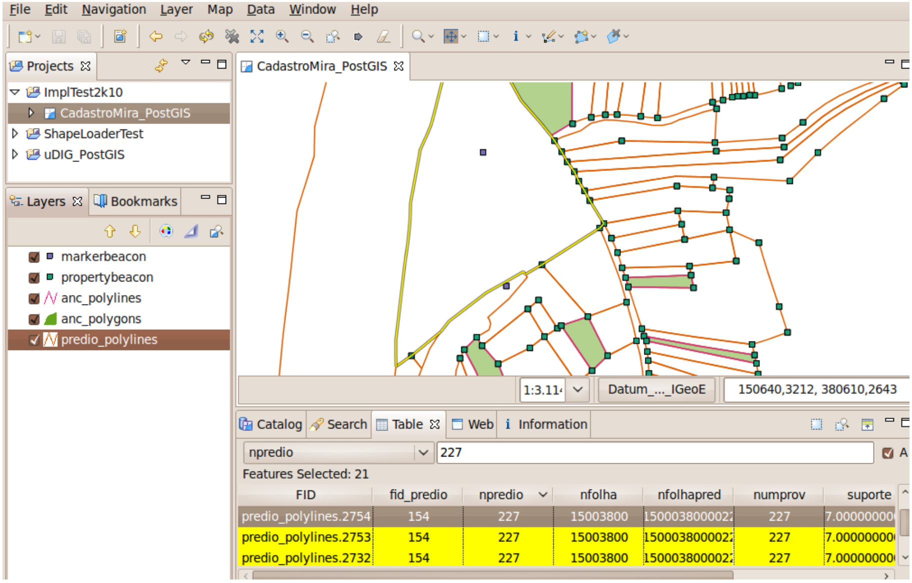


Figure D.2: *Parcels and deferred cadastre in uDIG*

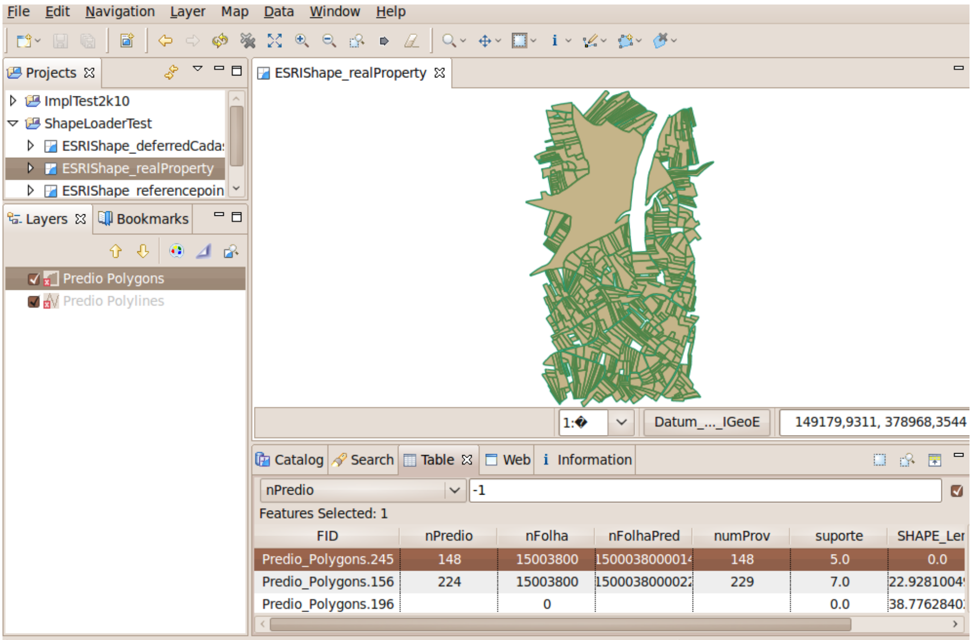


Figure D.3: *Work area for the school projects in 2008, covering two cadastral sheets*

Chapter E

Annex E: UP Inception phase example documents

As the Annex title suggests, the Inception phase, as the first phase in the Unified Process for software development, as introduced by Rational Software, defines a number of documents (also termed as "artifacts") which should be delivered during this phase. The following sections will include examples concerning the specialized country model for Land Administration in Portugal, LADM_PT, namelly covering the *Vision Document* (section E.1) and *Use Case requirements templates* (section E.2). In each of the sections, a description of the template elements is first introduced, and then the example document is described in detail.

E.1 Vision Document

As referred in (Kroll and Kruchten, 2003, Chapter 6, objective 1), a Vision document should be produced in medium to large size development projects, in order to reach a consensus amongst the involved stakeholders, around a number of key points, namely:

- The benefits and opportunities that will be provided by building the application;
- The problem(s) the application will solve;
- Who the target users are;
- At a very high level, what the product will do, expressed as high-level features or in terms of outlining a few key use cases;
- Some of the most essential non functional requirements, such as supported operating systems, database support, required reliability, scalability, and quality, as well as licensing and pricing, if that is relevant.

This document is to be presented at the end of the Inception phase, however, it is expected to change as result of subsequent UP phases, so it should be kept updated during the UP life cycle.

According the same reference (in (Kroll and Kruchten, 2003, Chapter 15, Develop a Vision)), a Vision document should be developed around the following topics:

- A list of project's stakeholders;
- Project constraints, including those introduced by non functional requirements;
- The Problem statement;
- A feature list (of services to be provided by the system).

Although including the topics listed above, the Vision document for LADM_PT is based on a more developed template produced by the Rational Software Corporation and available online through the Malmö University site (Rational Software Corporation, 2001, Requirements artefact set; Vision). It is structured in the following subsections and sub-subsections, from *Introduction* to *Documentation requirements*, although not all the topics of the original template were covered.

E.1.1 Introduction

The purpose of this document is to present a high-level description of the requirements and needs for an Integrated Legal Cadastre system for Portugal, supported in a specialized class model -LADM_PT- developed from the Land Administration Domain Model (ISO19152, DIS version). The document identifies the main stakeholders and target users of the resulting system and their respective needs, specially centred on the data update procedures. The specific user needs are captured and described in the following section of this annex, on Use Case requirements (presented as text templates).

Purpose

High-level description of the Portuguese Integrated Legal Cadastre and supporting specialized country model, LADM_PT.

Scope

This document results from a PhD research conducted at Delft University of Technology, with the aim to evaluate how state-of-the-art ICT technologies, namely UP and MDA, could be used in the derivation of a country specific Land Administration model, based on the LADM. The research has been focused on the modelling design and analysis corresponding to UP phases of Inception and Elaboration. This means that the scope is centred on the core capabilities of the system, namely:

- The legal and administrative component, covering the rights, restrictions and responsibilities related to spatial units; the definition of the basic administrative unit and required administrative documents; all being related to the management of real property;

- The geometric component, including the description of the spatial units required for the jurisdiction and their organization into levels; and consideration for specific geometry and topology constraints. This component also includes the specification of classes required for cadastral surveying activities.

Definitions and Acronyms

All the terms and acronyms required to properly interpret this vision document were inserted into the Thesis Glossary. The following list of terms and acronyms gives a quick check for the entries that can be found at the Glossary:

Domain Model

ICT - Information and Communication Technologies

Integrated Legal Cadastre

UP - Unified Process (the entry also reports on its phases)

MDA - Model Driven Architecture

ISO - International Standards Organization

LADM - Land Administration Domain Model

SINERGIC - National System for Browsing and Management of Cadastral Information

SNIT - National Land Information System

SIRP - Land Registry Information System

References

The full references can be consulted in the Thesis bibliography. The following are the documents which contributed the most to this vision document.

- Land Administration Domain Model, Draft International Standard (see ISO/TC211 Geographic Information / Geomatics (2010)).
- Portuguese Technical Specifications for the Cadastral Survey procedure (see IGP (2009)).
- Application of MDA to the Land Administration Domain Model (see Hespanha et al. (2008)).

Also, relevant sections of this Thesis were used as sources for this document, namely the section describing the Portuguese Land Administration Institutional and Organizational framework (3.3) and the sections describing the LADM_PT geometric (4.4) and legal / administrative (4.5) components.

Overview

The remaining sections of this document are organized as follows. First, a Positioning section addresses the opportunity of this research and proposed system and the problems to be addressed by the system. Next, a section identifies profiles for the users and stakeholders and their key needs. This is followed by a Product Overview, identifying system capabilities, configurations and interfaces. A Product Features section describes high-level capabilities of the system. The following sections describe external and design Constraints, the Precedence and Priority for different system features and other Requirements, namely applicable standards. A concluding section refers the Documentation Requirements as resulting from the (mainly research) scope.

E.1.2 Positioning

Business Opportunity

There are both local (Portuguese) and generic potential benefits from the research results. Starting by the local business opportunity, Portugal is in the middle of a Cadastral Reform, promoted by the responsible organization (the Portuguese Geographical Institute, IGP). The major legal framework concerning the geometric and the legal components has been recently reviewed. New technical specifications for the cadastral survey operations have been issued and Public Tenders covering eight municipalities have been adjudicated and are now in place (reporting to the end of 2010). Another related opportunity results from the adoption of the INSPIRE directive by Portugal (and the concept of key registers covering cadastral data whenever available in digital formats). In both situations, there is the need to implement UML defined class models, and it is expected that these implementations will include some spatial database. In this way, the reporting of the application of MDA techniques, supported with design patterns and profiles developed in LADM, in the framework of a development methodology, can be beneficial to all the related parties (private enterprises doing cadastral survey and the IGP).

In a medium to long term, research results could be of potential benefit to the interchange and joint analysis of cadastral data, to be made compatible with a future LADM as a ISO standard, given the fact that is describes transformations from a country based technical specification (expressed as an UML class model) and the LADM. This procedure, and the reported development methodology, can prove useful for other countries going through similar reforms to its legacy systems, particularly if they adhere to the LADM standard and thus pretend to develop their own country (specialized) model.

Problem Statement

There has been a persistent problem of “Process Fragmentation” concerning the different components of the cadastre in Portugal, that is, affecting the IGP and the Land Registry as the main stakeholders. And, by consequence, all the users of cadastral information. Historically, there has been some degree of integration concerning the geometric and fiscal components and the procedure of cadastral valuation on rural property. But a similar level of integration was never achieved in the modern real property cadastre and its (mainly) legal role.

Furthermore, there are now an ever increasing number of regulations affecting real property, due to a vastly improvement of infrastructures like water and waste water networks, telecommunication or gas networks, to name a few. All these contribute to the growth of the "process fragmentation", turning increasingly difficult to obtain a complete picture of the *"de facto"* situation of any given parcel of land.

The Integrated Cadastral Model, based on the current version of the LADM, offers a basic step towards a solution, by providing a conceptual domain model which includes a framework where to support both private and public law based rights, restrictions and responsibilities.

Although the first iterations reported in the research scope are centred just on the issues affecting IGP and the Land Registry, the model offers the potential to be extended in the future, so it can address the issues of other governmental or private users and stakeholders.

Product Position Statement

The results of this research, particularly in the development steps which consider the application of the MDA concept, and also the enhanced validation procedures by considering a combined UML and OCL design model, assume a special interest for software system developers. These potential customers are the IGP and Land Registry information system offices, but also the private enterprises involved in cadastral survey and updates (in an expectedly short term), or any consultancy firm third party, contracted specifically for the purpose of implementing such systems.

Unlike the current software IDE's which support some form of MDA development, the implementation example concerning LADM_PT includes the support of spatial data through the use of design patterns and international standards for geometry features, namely LADM spatial profiles and the use of Simple Feature for SQL (SFS) types.

Being based on the LADM, it further provides a modelling framework which answers to specific requirements of a cadastral system, thus supporting the development of LADM - compliant country models, and their continued update, being LADM_PT or more generally, other country model to be based on LADM.

E.1.3 Stakeholder and User Descriptions

The following summary of stakeholders and users respect the Integrated Legal Cadastre system resulting from the development of the LADM_PT country model, and not the users of the development methodology and tools, as reported in the position statement.

It does not describe specific stakeholder or users requirements, it provides instead a background and justification for the identified requirements (as reported through the templates in the following section).

Stakeholders Summary

- Portuguese Geographic Institute (IGP): the (central) government organization officially responsible for the geometric component of the cadastre. It is also the coordinator of the SINERGIC project, which implements the cadastral reform in Portugal. Other key responsibilities include the definition of technical specifications and regulations for cadastral survey operations, and the launch of Public Tenders for cadastral survey and updates.

- Land Registry ("Registro Predial"): The organization officially responsible for the legal and administrative component of the cadastre. Its key responsibility is to secure juridical business of real property through publicizing the legal status of each registered parcel.

- Tax Offices ("Repartições de Finanças"): The General Directorate for Tax from the Ministry of Finance is the responsible to collect the tax on immovables (IMI), which reverts to the municipalities. To this end, the local offices maintain a fiscal record concerning each parcel, in order to compute the tax amount through valuation procedures.

- Municipalities: the main bodies of the local government, they are responsible to define the Municipal Master Plans, and more specific urbanization plans, which impose a number of restrictions over private property. They are also responsible to issue building and habitation permits, which by its turn can change the state of cadastral parcels and therefore affect any other of above described component records.

User Summary

- Owner / Prospective Owner: Or seller and buyer in a Real Property Transaction. These are ultimately the end users of the system. They should supply information on their intentions concerning the update of rights and / or the update of the geometry of a parcel. They can also request for information or certificates to be produced by the system. They can be represented / assisted during a Real Property Transaction, by a Solicitor.

- Solicitor: Is a type of lawyer who can represent owners in the various phases of a Real Property Transaction. Assists in the preparation of sales agreement and other documents required for registration, namely any issues that could arise about the legal validity of the procedure.

- Surveyor: It is a certified professional[91] responsible to verify existing spatial restrictions which can affect a transaction or other types of cadastral update, and should present a survey document with the intended geometry of the parcels.

[91] Not yet defined in Portuguese Law.

- Notary: Could be a private or public individual. Is responsible to verify all documents to be presented to the registry and, upon confirmation, these certified documents shall be attached to an electronic update request to the registry.

A note on Special Interests User Groups. The description so far respects mainly a cadastral update affecting a small number of parcels in a single transaction. There are certain user types, however, which typically are involved in the update of large numbers of parcels, concerning primary or derived Rights and / or the parcels geometry. These users include private or public infrastructure firms contracted for public works or infrastructure maintenance, such as building highways or laying out new waste water networks. These users have special needs concerning the cadastral system, which should be addressed specifically by considering additional development iterations during Elaboration and (mainly) Construction phases, beginning by the inclusion of an additional level of complexity in the Use Case model.

Key Stakeholder/User Needs

- Owners: Accurate and up to date information concerning the property. Previous procedures of a mainly descriptive cadastre; registration not being mandatory and a high degree of informality, particularly in rural areas, has lead to inaccurate and outdated cadastral information. The problem affects the other users and stakeholders, and is being addressed in part by the new framework resulting from SINERGIC project.

- Surveyors: Definition of a professional profile and clear responsibilities for a cadastral expert; availability of large scale topographic information. There never has been a professional profile and legal framework enabling single individuals to perform cadastral surveys of any type. And for large tracts of the country, there is no sufficiently detailed topographic information where to support the survey documents.

- IGP and Land Registry: Integration of services and harmonization of records. The insufficiency of cadastral survey, which covers just half of the country (with often outdated data), together with descriptive registers and the absence of a greater services integration, results in the occurrence of many cases of incomplete, outdated and inaccurate registers.

- IGP / Land Registry and Tax Offices: There is an equal need for the integration of services and harmonization of records, for the same reasons presented above.

- Special Interests User Groups: Lower costs in the procedure of registering expropriation and servitudes (or even new parcels) in large public works. Due to the existing insufficiencies, mostly (but not limited) in the geometric component, these users have to incur repeatedly in expenses covering cadastral survey and collection of involved tax and legal registry records.

E.1.4 Product overview

This section provides an high level view of the capabilities of the Integrated Legal Cadastre, with a first subsection where it is put in Perspective of a broader system for Land Administration, stating to which external registries / systems has to interface. The following subsection will provide a summary of the major capabilities of the Integrated Legal Cadastre.

Perspective

As explained in the Scope, the research project is focused on the core capabilities of the system, supported on the definition of the LADM_PT country model. Any working implementation of this model has to define interfaces with the following (existing) systems:

LADM_PT (Pack.; Class)	**Interfaces to (external system)**
Legal&Admin.; Public Regulation	SNIT[92]
Legal&Admin.; Administrative Servitudes	SNIT; other SIUG owned systems
LA_Party; not further modelled	Natural and collective persons registers, ANI and RNPC
Blueprint class; ExtTaxation	DGI - Tax Offices ("Matriz Predial")

Table E.1: Integrated Legal Cadastre: interfaces to external systems

Furthermore, the core components, as defined in the Scope (geometric and legal & Administrative) should be implemented as a fully integrated system, while currently their capabilities are supported by two loosely coupled systems: The geometric cadastre (at IGP) and the Land Registry (SIRP).

Summary of Capabilities

The following table lists major benefits for the previously defined users, and the corresponding supporting features to be offered by the system.

User benefits	Supporting Features
Owner / Prospective owner quickly retrieve current status of parcel(s)	Query / report supported on the PT_BAUnit class and its associations to rights and spatial units. A digital equivalent to the "Caderneta Predial".
Solicitor and Notary can retrieve and validate standardized documents	Query to any type of PT_AdministrativeSource class (and referred documents), in association to individual PT_BAUnit class instance
Surveyor can retrieve cadastral geometric comp. and specific survey info and can upload survey docs.	Query to any type of PT_SpatialUnit, related or not to PT_BAUnit class. Sub-query to any surveying classes data related to retrieved PT_SpatialUnit; Upload procedure for a Survey Document source
Municipalities can retrieve areas of cadastral info in order to support plan review/ creation and evaluate issue building permits	Query returning spatial units and legal status of parcels, against the definition of an area of interest (subject to an authorized login)
IGP, Land Registry and Tax Offices benefit of integrated info for record updates	Establishment of update procedures including triggers /stored procedures issuing update warnings between system components and external system interfaces

Table E.2: Integrated Legal Cadastre: summary of capabilities

E.1.5 Product features

The implemented system shall offer all the supporting features as described in the second column of the table E.2. Other, more generic or related to other usual software components (namely the graphic interface, networking or security features) were not considered at this time.

E.1.6 Constraints

Being a research project relying in advanced and often experimental technical components, which were not necessarily designed to work together as in this research proposal, it is expected that a number of design constraints have to be accounted for. The constraints arise specially in the geometric component, concerning:

- Persistence for special patterns (spatial profiles in LADM) of spatial units, from the class model to data bases with a spatial extension;

- Expression of object constraints, using OCL, and their validation and implementation.

There are other constraints arising from the expected evolution of the external systems. At this level, the main constraints are:

- SNIT interface: a fully developed Land Information System should account for a centralized record of public law based regulations and administratively imposed servitudes. It is not mandatory that this information resides in SNIT, however (it could constitute a new system);
- Tax Offices interface: the proposed solution of the ExtTaxation class can prove insufficient. Another solution would be to develop a further Integrated model, similar to the existing Agricultural parcels / LPIS integration with LADM.

And, of ultimate importance, there are the political / financial constraints for a continued, high level political commitment to further developments of the SINERGIC project framework. This has been backed up, foreseeable up to the end of 2013, by resolutions of the Portuguese Council of Ministries.

E.1.7 Precedence and priority

Considering the previously listed system capabilities and also the present stage of development of the SINERGIC project, where cadastral survey operations play a major role, the following priorities are enumerated:

1. Implementation of the Spatial Unit package (core capabilities: the geometric component);
2. Support for online update procedure concerning the surveying classes within the Spatial Unit package;
3. Implementation and upload support for the PT_BAUnit class and any associated Administrative Source documents;
4. Implementation of the Legal component, in a first iteration to be restricted to the handling of Rights and Restrictions in the Private Domain, which are currently registered at the Land Registry;
5. Development of a more involved and detailed model for integration with the Tax Offices (Enhancing and expanding on the ExtTaxation LADM class);
6. Extend the Legal & Administrative package so as to handle the majority of Public Regulations and Administrative Servitudes, that is, an extension to the Public Domain;
7. Implement web services, including map interfaces, open to all end users, but considering special capabilities for Special Interests User Groups.

E.1.8 Other product requirements

This section comprises a listing of the standards to which the Integrated Cadastral Model should comply to (basically implicit by the use of LADM), and the consideration of system requirements needed for the implementation of the core capabilities.

Applicable Standards

Considering that the development and implementation use the MDA approach, the following standards are required:

- Generic modelling standards: Unified Modelling Language and related Object Constraint Language (OMG specifications). In order to exchange components between applications, also the XML and XMI specifications are required;
- To formalize and produce Model Transformations: Query/View/Transformation language (an OMG specification);
- Spatial features modelling standards: A number of ISO 19000 series for Geographic Information are required, namely ISO 19107 spatial schema, ISO 19109 general feature model and ISO 19125 simple features for SQL (which implicitly requires OMG's GML specifications);
- Domain Model: ISO 19152 Land Administration Domain Model (currently at FDIS phase).

System Requirements

Having in mind the application of MDA from modelling to implementation, the following software components have to be present:

- Operating System: taking into account that most of the software is available open source and it is Java based, there is no specific requirement here, although for the best results, a Linux system is recommended;
- UML modelling tool, preferably integrated in a framework supporting also OCL parsing and validation and model transformations (including code generation);
- A Java Persistence mechanism applying Object-Relational Mapping and with extended support for spatial features and finally;
- A Data Base with a spatial extension with support for the ISO Simple Features for SQL standard, and whose SQL dialect is supported by the Persistence mechanism.

E.1.9 Document requirements

This section describes what types and contents should be provided to users (internal and external) of the deployed Integrated Legal Cadastre system, and (made implicit through the research scope) also documentation available to developers of system extensions.

- (Generic) User Manual: It should be concise, without recurring to much detail, and be focused on the procedures to query cadastral data and the information the system can provide on the status of a given cadastral update procedure. It is of fundamental importance to include a glossary of terms, which can be built upon existing technical specifications;

- Surveyor Manual: As any licensed surveyor (the "cadastral expert") will have access to system components not allowed for regular users, it should have a separate manual. This will be focused on the elaboration of the Survey Document and updates to the geometric component. A tutorial covering the most typical situation can be also included;

- Special Interest User Groups manuals: depending on the level of support for specific capabilites supported by the system, it could be useful to develop manuals for specific user groups. These would describe procedures supporting users planning, building and reporting needs, including querying and download of large numbers of parcels (which will also include certain procedures for surveying procedures);

- IGP / Land Registry / Tax Offices Administrative Manual: this manual must provide the description of validation and reporting procedures, and also provide additional queries required for these internal users planning needs. Other non-functional requirements, such as security and backup procedures and performance tuning should be also included in this manual.

- Developer Manual: It should include the description of the main artefacts resulting from the Development Methodology. Namely, references to the Domain Model, this Vision document and Use Case requirements, the used Spatial and Legal & Administrative profiles and Model Transformations resulting in LADM_PT. Finally, the report of the Persistence mechanism. All these components are best reported at the end of the Construction phase, but should be available during Elaboration. Ideally, a dedicated IDE can be included and in such case, an installation and configuration guide should be provided as well.

E.2 Use Case requirements

The template that was used to describe the Use Cases included in the Thesis is freely available from TechnoSolutions, at the URL: http://www.technosolutions.com/-use_case_template.html In this simple and straightforward (but useful) template, a compounded Use Case Id was used, with the following generic format: [Use Case Level].[Sequential ID].[Alternative], where the first and last should be single digits, and the sequential ID has two digits. In the paragraphs below, each Use Case description is inserted as a subsection in the form of an itemized list.

A new topic was added to the original template, called "Diagram reference", which adds a reference to the respective Use Case or Activity UML Diagram, as inserted in the Thesis. Although the original template does not require the presence of UML Modelling, the supplement or even automatic generation of Use Case written templates is offered by some UML CASE Tools.

The list bellow shows all the descriptions included in this section, and their corresponding Use Case Ids.

- 0.01.0: Cadastral Update;
- 1.04.0: Decision and Registration;
- 2.04.0: Registration of New Legal Descriptions;
- 2.05.0: Cadastral Map Update;
- 2.06.0: Annexation (of Part of Parcel);
- 2.06.0: Urban Lot Creation.

It must be noted that the Level 2 descriptions were depicted as Activity Diagrams in 4.2.1 and A.1.

E.2.1 Cadastral Update

- Use Case: Generic Cadastral Update procedure
- Id: 0.01.0
- Description: A Real Property transaction covering a sale with a parcel split. The four major phases of Preparation, Land Policy Control, Formalization and Decision & Registration correspond to those identified in the study "Modelling Real Property Transactions" from the COST G9 Action. At the context level, all the actors fill generic or organisational roles. The system component of the Integrated Cadastre is represented as a package interacting with Actors "LandRegistry" and "Cadastre" and with the Preparation phase.
- Level: 0 (Context)
- Diagram reference: 4.1
- Primary and supporting Actors: The primary actors are the seller (Owner_a) and the buyer (Owner_b) of the new property resulting from the parcel split. These are supported by a Solicitor and a Surveyor during the initial phases of Preparation and Land Policy Control.

- Stakeholders and Interests: The internal (organisational) actors of "LandRegistry" and "Cadastre" are the main stakeholders concerning the context of a cadastral update to the Integrated Legal Cadastre. The Municipalities also have a stake at the Land Policy Control phase, and indirectly, they can involve various central government organisational actors (not depicted in the diagram).

- Pre-conditions: The primary actors should fulfil the basic legal prerequisites to perform a property transaction.

- Post-conditions: The integrated legal cadastre is updated (in its legal and geometric cadastre components), and the primary actors were notified of this changes.

- Trigger: The primary actors reach a sales agreement.

- Main success scenario: The buyer and seller (primary actors) address a Solicitor, in order to arrange and formalize a sales agreement describing the intended parcel split. The Surveyor must be involved in the Preparation phase, producing a draft survey document. A Land Policy control request follows, involving also the Municipality, where eventual Public Regulations and Restrictions are examined in order to check the validity of the request. Being in agreement with local Land Policy, the request is formalized with the support of a Notary. The resulting certified documents are presented to the Land Registry and Cadastre integrated system, in order to update the parcel information and to send the final parcel reports back to the primary actors (or indirectly through the Solicitor).

- Alternatives: There a number of alternative scenarios, particularly in the first two phases of Preparation and Land Policy Control. The following is thus far from being an exhaustive list. Id 0.01.1 - Former Cadastral Situation is outdated; Id 0.01.2 - Former Cadastral Situation is not registered; Id 0.01.3 - Parcel split is not allowed under Land Policy rules; Id 0.01.4 - Parcel split demands special confirmation from one or more central government agencies.

- Data input Variations: As this is a context level description, many potential input variations could be accounted for. The main assumption for the system should be that the information flows to and from the primary actors have to accommodate both paper based and digital documents, and different communication channels (desk, regular mail, email, internet).

- Frequency: Giving the absence of a fully functioning cadastre, and the changing legal and technical environment, any number will be a grossly estimate.

- Assumptions: The update procedure assumes the new legal framework for the Cadastre and the Land Registry, as described in the SINERGIC project. It is not a description of current practices.

- Special requirements: Information flows and cadastral data to be made available by the system should comply with personal data privacy laws.

- Issues: At this stage, there are no supporting system for the Preparation and Land Policy phases. The current cadastral situation is that of a substantial amount of incomplete, outdated and / or inaccurate cadastral records.

- Alternatives: should be described through Use Case diagrams; Finding also an estimate for their frequency.

E.2.2 Decision & Registration

- Use Case: Cadastral Update Decision and Registration

- Id: 1.04.0

- Description: The Decision and Registration phase of a Real Property sale (with a parcel split). The set of phases forming the (higher-level) Decision and Registration phase, delimits the system boundary of the Integrated Legal Cadastre and constitutes a critical phase of system operation. There is an internal boundary which distinguishes the phases belonging to the legal component (the Land Registry), and those which belong to the geometric component (the Cadastre). The normal flow of information between these phases is described in the main success scenario entry bellow.

- Level: 1 (Detail)

- Diagram reference: 4.2

- Primary and supporting Actors: In this phase, the Notary assumes a Primary Actor role, on behalf of the buyer and seller in the Real Property sale. The Solicitor continues to perform a supporting role, namely in receiving the final reports for the updated parcels.

- Stakeholders and Interests: The organizational actor "Land Registry" has the duty to publicize the updated legal situation of the parcels, while the organizational actor "Cadastre" has to update the Cadastral Map with the new geometric information of the parcels.

- Pre-conditions: The Notary has been able to certify the documents presented by the Solicitor (and the Surveyor).

- Post-conditions: Both the legal and the geometric cadastral components have been updated with the new data for the involved parcels.

- Trigger: The Notary sends an update request, attaching the certified documents, to the Land Registry.

- Main success scenario: The Notary applies for an update request together with the legal component of the Integrated Legal Cadastre. The certified documents received from the Solicitor and Surveyor are attached to this request. As this involves also a geometric update, a copy of relevant request documents is sent to the geometric component. From this point, there is a parallel validation procedure: “Validation Legal Situation” and “Validation Technical Document”, in the legal and geometric components, respectively. The legal component then proceeds with the “Registration new legal descriptions”, and sends the new linkages to the legal records to the geometric component. This component performs a “Cadastral Map Update”, and at the end of the procedure, it “Generate new Parcel Reports”. The finalized Parcel Reports are send to the Solicitor (or directly to the buyer and seller).

- Alternatives: The alternative scenarios are mainly triggered by the failure in the validation phases in either one of the components. So, there could be a 1.04.1 - Legal situation is not valid or a 1.04.2 - (Survey) Technical document is not valid. In the first case, the geometric component can still be registered as a deferred cadastre. In the second case, there could be a provisional registration. In any case, the temporary situation must be resolved, or the previous situation has to be restored.

- Data input Variations: Both the legal and the geometric component documents can contain data input variations. Legal inscriptions potentially have the greatest variation in textual descriptions; this should be reduced through formalization. The survey document data should have strictly defined variations, depending on the methodology.

- Frequency: No known estimate at the Integrated Cadastre level.

- Assumptions: The internal system boundary assumes that the integration does not require an actual merge between the existing organizations, although an integration should be implemented at system level.

- Special requirements: Cadastral records should be secured through a backup and security policy. Data should be readily available to stakeholders and end users.

- Issues: There are no previous experience concerning procedures for integrated sporadic updates in the Portuguese Cadastre, including technical and professional regulations.

E.2.3 Registration of new legal descriptions

- Use Case: Cadastral Update - Registration of new legal descriptions

- Id: 2.04.0

- Description: Upon validation of the update request documents, the current status of parcels to be updated is retrieved from the system, through a check out. The exact check out procedure and other implementation details require a level 3 - implementation detail description. Data retrieved through the check out is then updated according the request documents in a process described in the main success scenario below. The update of the legal component has to be complemented with the update of the geometric component, and thus this phase of the update procedure ends with a notification to the cadastre and a final check in, including references to the spatial units (parcels).

- Level: 2 (High Detail)
- Diagram reference: 4.3
- Primary and supporting Actors: The internal system actors belonging to the Land Registry are the primary actors at this level. Two roles can be assigned here, one for technical staff throughout the update procedure, and a chief of services to resolve any eventual issues with checking out / in procedures.
- Stakeholders and Interests: The same as in Use Case description 1.04.0
- Pre-conditions: The cadastral update request (and related documents) has been formalized and validated.
- Post-conditions: The legal component of the cadastral records is updated and a valid link has been established with the geometric component.
- Trigger: Acceptance of an update request.
- Main success scenario: After receiving the update request, there is a check out of the current status of parcels. The update then considers two parallel activities of “Update Legal Descriptions” and “Update Rights”. The first activity should provide human-readable sections of text, which can be later reported, while the second should prepare actual update instructions to the system. The result should be synchronized with a “Consistency check Legal Description / Rights” to confirm that updates are related. The next step is to “Notify Cadastral Component” so that the geometric component update results can be linked to the updated cadastral records. A final check in assures the updated information is written to a data store (typically, a Spatial Data Base), while the previous status of the parcel (or parcels) is stored in an Historical layer.
- Alternatives: There are some failure scenarios which can be accounted for at this level of detail. These depart from a successful check out of the current status of parcels. So, there can be a 2.04.1 - Legal Description is invalid; a 2.04.2 - Updated Rights (Restrictions or Responsibilities) are invalid; a 2.04.3 - Legal Description is inconsistent with updated Rights and a 2.04.4 - No links with the Cadastre (geometric component). To resolve those situations, some feedback to earlier phases of the update procedure have to be established. In the last alternative scenario, there could be a provisional record concerning the legal component, with the definitive record pending from the geometric component update procedure.
- Data input Variations:

- Frequency: No known estimate at the Integrated Cadastre Level, but the Land Registry at National level can handle up to ?? update request per day.

- Assumptions: Documents attached to the update request have been verified and formalized, and there is a successful check out concerning the current parcel legal status.

- Special requirements: The implementation must assure there is a secure connection with the geometric component services, and define procedures for the case where communications are off-line.

- Issues: No previous procedures to support semi-automatic or fully automatic generation of legal descriptions from request forms and update of rights (and restrictions) objects.

E.2.4 Cadastral Map Update

- Use Case: Cadastral Map Update

- Id: 2.05.0

- Description: Starting with a validated technical survey document, prepared by a licensed surveyor, which shall contain all data required to update the parcel(s) geometry and topology, an updated record is produced with new geometric data and object identifiers. The main success scenario describes these activities, considering a complete update which includes survey references for the Cadastral Triangulation.

- Level: 2 (High detail)

- Diagram reference: 4.4

- Primary and supporting Actors: The internal system actors belonging to the Cadastre (IGP in Portugal) are the primary actors at this level. Similarly to Use Case description 2.04.0, there could be two different roles, the technician doing the check out and update activities, and a chief of services to resolve any eventual issues with checking out / in procedures.

- Stakeholders and Interests: The same as in Use Case description 1.04.0

- Pre-conditions: There is a validated and formalized technical (survey) document with data required for the update.

- Post-conditions: The Cadastral records are updated, including geometry, topology and new ID's.

- Trigger: A copy of relevant documents is issued from the legal component (Land Registry), after an update request.

- Main success scenario: Upon acceptance of a validated technical survey document, the previous situation of concerned parcels is checked out. With the geometry and topology data contained in the survey document, the involved parcel(s) elements are updated. From here, there are two successive checks: for new Field Survey References, in which case the Cadastral Triangulation has to be updated; and for the existence of new parcel identifiers, in which case the legal component notification has to be replied. Finally, the updated data is check in to the system.
- Alternatives: There are two alternative scenarios already included in the main success scenario. Besides those, one can consider a 2.05.1 - Deferred Cadastre for incomplete legal data or a 2.05.2 - Deferred Cadastre for incomplete survey data.
- Data input Variations:
- Frequency: No known estimate at the Integrated Cadastre Level, and the old geometric cadastre of rural property, although having accumulated tenths of thousands of update requests during more than 30 years of operation, being fiscal based, is not directly applicable to this case.
- Assumptions: There exists a validated survey document and the previous geometric component status of parcels is known.
- Special requirements:
- Issues: There is no previous experience regarding a survey document which can be issued by a cadastral expert (external to IGP).

E.2.5 Annexation of Part of a Parcel

- Use Case: Cadastral Update - Annexation of Part of a Parcel
- Id: 2.06.0
- Description: This Use Case description can be considered as an alternative from the generic cadastral update for a sale with a parcel split, in 1.04.0 and following. The main difference lies in resulting updates to cadastral records. While the parcel split results in two new parcels (and respective parcels ID's), the annexation corresponds to the update of the legal and geometric components of an existing parcel, while maintaining the parcel ID. The geometric component update can be deferred in time, while a provisional legal description is checked in into the system. Like in the previous Use Cases, a final Parcel Report shall be issued after the geometric and legal components are synchronized. The main success scenario below describes the normal flow of activities.
- Level: 2 (High detail)
- Diagram reference: A.2

- Primary and supporting Actors: The Titular (registered property owner) is referred to in the diagram, although the organizational actors of the Land Registry and the Cadastre (IGP) shall be considered as primary for the level 2. The discrepancy is due to a different level of aggregation regarding 2.06.0 and 2.07.0.

- Stakeholders and Interests: The above referred organizational actors and (depending on the concrete type of annexation) the Municipality and private third parties representing utility companies.

- Pre-conditions: A validated annexation request and a complete record of the previous parcel status.

- Post-conditions: Both the legal and geometric component records have been successfully updated, and a Parcel Report has been generated.

- Trigger: The Titular (or a Notary in his/her behalf) presents an annexation request to the Land Register.

- Main success scenario: Upon receiving an annexation request including a set of administrative documents, the Land Registry issues an order for a provisional legal description, from where there are two parallel activities of modifying the legal component ("Register Modified Rights") and the geometric component ("Cadastral Geometric Update"). After both activities are concluded, the update is completed with the generation of a new Parcel Report, which can be send back to the Titular.

- Alternatives: If the ownership status does not change with the annexation, two main alternatives can be considered. The 2.06.1 - Deferred Cadastre for incomplete survey data (Annexation) and 2.06.2 - Invalid synchronization of legal and geometric components.

- Data input Variations:

- Frequency: In principle, a fraction of the major type of cadastral update, the parcel split. Although there are no known estimate at the Integrated Cadastre Level.

- Assumptions: There exists a previous (complete) record of the parcel. If there is a transfer of ownership that is related with the annexation, the required mutation shall be recorded previously, that is, in a different update procedure.

- Special requirements: The same as referred in 2.04.0.

- Issues: There is no defined measure, in cadastral regulations, to distinguish between an annexation and a parcel merge.

E.2.6 Urban Lot Creation

- Use Case: Cadastral Update - Urban Lot Creation
- Id: 2.07.0
- Description: A creation (new record) of a single Urban Lot in a re-allotment procedure. This type of update considers also the activities to be performed by a Municipality concerning the re-allotment procedure, and a few interim status of records. The change of status evolves from a single large parcel owned by the Municipality or a development firm, to a final Urban Lot including a number of condominium owners.
- Level: 2 (High detail)
- Diagram reference: A.3
- Primary and supporting Actors: The Titular of the parcel to be subject to re-allotment, which can be supported by a Real Estate agent or a Solicitor.
- Stakeholders and Interests: The organizational actors representing the Land Registry and the Cadastre (IGP), the Municipality, private third parties representing utility companies and building firms.
- Pre-conditions: The new Titular of the parcel(s) to be subject to re-allotment presents an update request to the Land Register and submits a Building Plan to the Municipality.
- Post-conditions: The condominium, with all the apartment units subordinate records, are registered, and reports are send to the condominium owners.
- Trigger: A development firm (or the Municipality itself) acquires ownership of a parcel where is allowed to execute a re-allotment plan.
- Main success scenario: For the case where the Municipality is the promoter of the re-allotment plan, a third party development and / or building firm purchases one of the Urban Lots predicted in the plan, registers its ownership and submits a Building plan to the Municipality. When it receives a Building Permit, construction begins, until finally there is a new Condominium building where individual units have to be registered in order to be sell to individual owners. These condominium units (in Portugal, "Fracções"), along with the Common Parts of the Condominium, are registered as subordinate records from the Basic Administrative Unit. The building firm then, have to request Residential Permits to the Municipality in order that condominium units can be inhabited. At this point in time, the "As Built" situation shall be surveyed, and an update be made to the Cadastre. Eventually, the condominium units are all sell to individual owners (acquiring "Horizontal Property" Rights), with each sell updating the Land Registry subordinate records. Each individual owner should receive a Parcel and "Fracção" Report at the end of the procedure.

- Alternatives: As this is a long and complex procedure, which can take some years to complete, there are (potentially) many possible alternatives. A few are referred next: 2.07.1 - Urban Lot creation with boundary change (also called "rectification" in Portugal); 2.07.2 - Urban Lot creation without a Condominium; 2.07.3 - Urban Lot creation with Building Permit refusal; 2.07.4 - Urban Lot creation with Residential Permit refusal; 2.07.5 - Urban Lot creation with invalid legal description(s); 2.07.6 - Urban Lot creation with irregular survey situation.

- Data input Variations: As in previous cases, different forms of communication should be predicted between the users (unit owners, building firms, the Municipality) and the system. However, there should be just a small amount of input variations regarding formal, standard documents such as the Legal Descriptions, Survey Documents or Parcel Reports.

- Frequency: no known estimate at the Integrated Cadastre Level.

- Assumptions: The main success scenario assumes only the participation of the Municipality, a building firm and the individual condominium units owners. More complex scenarios do occur, with involvement of more intermediate actors, namely real estate managers and mortgage banks. It also departs from a single owner for the whole re-allotment area.

- Special requirements: Establishment of communication channels (or a degree of process integration) between the future system and Municipalities.

- Issues: The system should also be capable to model the case where the area subject to re-allotment be owned by a number of individual owners.

Chapter F

Annex F: Other examples of the development of country models

The three sections in this annex will report on efforts taken by different researchers in different countries in order to derive their own specialized country models. Such brief accounts include a description of the research context within each country's cadastral system, the methodology which has been used and conclusions from such research at the present moment. In the main text, in section 4.3 a comparison is made between the methodologies applied in order to derive these country models, which ultimately contributed to the derivation of Portugal country model, LADM_PT.

F.1 The Land Registry of Iceland (LRI)

The specialized country model for Iceland resulted from academic research and it is reported in the MSc Thesis (Ingvarsson, 2005). The research departed from the cadastral situation in Iceland as its main case study and further studied the applicability of open source geo-information to cadastral registration. The Republic of Iceland run, at the time of research, a modern digital Land Registry Database supported on a long tradition of land registration that dates back from the first settlers (around 900 AD).

The digital database registers land ownership rights for each parcel, but has no geometric data on the spatial extent or location of the parcels[93]. The responsibility to keep a geometric register of the parcels, and their relation to the unique land identification provided by the Land Registry Database belonged to the Municipalities. This ultimately resulted in (Ingvarsson, 2005, p.ix):

> Making these diverse local cadastral repositories internally incomparable in terms of what is registered, attributes, quality and metadata, etcetera.

The government of Iceland, through the Land Registry of Iceland (LRI), initiated then an active search for ideas and solutions. The answer was found in the form of

[93] Although there are textual descriptions on the boundaries, some more than 200 years old.

the LADM precursor, the already mentioned Core Cadastral Domain Model (CCDM: Hespanha et al. (2006), van Oosterom et al. (2006)).

Apart the study and report of state-of-the-art on open source geo-applications, a study of the diverse rights to which immovable property is subject in Iceland, constituted the first phase towards the Icelandic Cadastral Model (ICM). The first phase of research also identified the main spatial units which are registered into the Land Registry Database and the respective legislative support. At this phase, the research identified three basic forms of property: private ownership, public ownership and collective ownership.

A classification of Real Rights according previous research ((Ingvarsson, 2005, p.69) citing Matthíasson (2003)) conforms in a significant way to the Rights, Restrictions and Responsibility package of LADM to be reported in 4.5, although a more detailed conclusion has to be supported with further studies. It should be remembered that at the time, there was no elaborate legal profile attached to CCDM. Anyway, the reported classification aligns significantly with the classification proposed by Zevenbergen (see 2.2.1), namely concerning the division between a maximum real right and other types as derived, acquisition and other real rights.

The second phase of research resulted in the description of the organisational structure of Land Administration in Iceland, by identifying the main actors responsible for implementing and maintaining cadastral information in the country. Three main administrative levels were identified (central, counties and municipalities), each one having a specific set of responsibilities within the Land Administration system.

Then, the research moved towards the study of basic Land Administration dynamics regarding transaction and registration procedures. The procedure of subdividing a land parcel is detailed using a text based template where 11 major steps are identified.

After these three first phases, characterizing in a broad and general level the legal, administrative and organisational aspects of Land Administration in Iceland, the research presents a more detailed description of the technical aspects concerning the Land Registry Database (LRD).

The LRD comprises four sections, where data on the basic administrative units (real property and other units) are stored in the base section, to which all the others refer by maintaining proper links. The implementation of a fifth section is then proposed as a research result, where the geometric data on parcels should be stored. At the time, there was no explicit formal data model, so the decision was made to reverse engineering the currently operational LRD data base schema in order to obtain an UML model for enabling a comparison with the existing CCDM.

The mapping of the data structure in LRD into classes and attributes of a single UML class diagram was obtained with the help of the examination of data samples extracted from the database, county office registers and relevant handbooks. The result, which is called the LRD diagram, was an important intermediate step in obtaining the country model, because many of the terminology of CCDM was already used at that stage.

Before extending the LRD diagram with spatial data comprising the proposed new cadastral section of the database, a country specific analysis was required in order to verify the availability of spatial data which could (eventually) populate a cadastral spatial data base.

The final phase in deriving the country model for Iceland (the ICM) examined the possibility of fitting the LRD diagram into CCDM, adding from the later the classes now called the spatial unit package.

The first step on the LRD extension considered the different methods to represent geographical location within CCDM, which are now called the spatial profiles (see 2.6.2). Due to the fact that the availability study has shown that a multitude of methods was being used in Iceland, all the then available geographical representations were considered:

- Parcel (topological based);
- PointParcel (point based);
- SpaghettiParcel (line based);
- TextParcel (textual descriptions of location and extent).

The decision was to include all these forms of representing spatial units (including shape, size and location) and extent into the model, with a final objective that (gradually) all other forms of representation should evolve to the topological based Parcel.

All the parcels and associated spatial classes such as the ServingParcel, which are topologically based, together form a planar partition, represented by the class PartitionParcel, which in turn can also be aggregated in order to represent administrative subdivisions. All the other representations belong to the non-planar partition region (NPPRegion) superclass.

The ServingParcel includes inland waterbodies surrounded by real property or urban playgrounds belonging to adjoining apartment units, where there is a common interest shared by the involved owners. It can be assumed to comply with the Common Right as a private real right in 2.2.2. The use of a versioning system, now (in LADM) implemented through the VersionedObject superclass, is also discussed within the ICM, giving the highly dynamic nature of Iceland's crust, which can affect surveyed boundaries quality, so they require updates.

The ICM model bases its topological based structure for a planar partition in a set of geometry and topology classes which comply closely with CCDM. The considered associations are listed in table F.1.

Geometric Primitive	**Spatial Unit / Survey**	**Topological Class**
Polygon	PartitionParcel	TP_Face
Line	ParcelBoundary	TP_Edge
Point	SurveyPoint	TP_Node

Table F.1: Geometry and Topology classes in ICM

The survey package classes are introduced into the model via the SurveyPoint, which has a SurveyDocument as its source class.

The main difference introduced into ICM, as compared to CCDM, was the split of the RealEstateObject superclass into two superclasses, the LandParcelObject, which should form the planar partition of the territory, and a RealEstateObject (from ICM), which in this case represents just those objects not belonging to the planar partition (namely buildings), and can have (optionally) no associated geometric representation. The associations of the RealEstateObject and the RealEstateComplex classes with the LandParcelObject make the actual linkages between the LRD and the CCDM-derived classes.

It must be stressed that, at the time, CCDM did not define an equivalent to the LA_BAUnit belonging to the administrative package, because this was only later added to LADM. The most logical superclass to occupy such role in ICM would be the Object for registration, assuring that a single registration ID could be given to a registered parcel, but (in CCDM) this could not be composed of planar and non-planar partition objects, given that it could associate to just one spatial unit.

After the different spatial units required for the Icelandic Cadastre have been identified and ascribed to planar and non-planar partition classes, and associations have been established with survey classes, geometry and topology classes (mostly coincident with CCDM) and LRD specific classes as the AppraisalTable, the modelling process moves to areas where some differences and totally new extensions to CCDM were considered.

The root for such differences lies within the legal domain, once ICM assumes that the Object superclass should have associations with only the positive side of real rights[94]. As a consequence, a new class PublicRestriction is created and associated with CCDM's RestrictionArea. As a future goal of the model, also movable objects (representing movable property which is registered, such as cars, ships or planes) were considered to be a specialized class from the Object superclass.

While this last class hierarchy is not considered in LADM (considered out of scope), the current legal profile, as explained in subsection 4.5 do considers both private and public domain restrictions.

The generated ICM was then critically evaluated, by taking a broader perspective of all the actors (organizations), institutions and legal framework, as identified during the initial research phases.

A first conclusion is that, while outside the scope of the existent LRD, there are a significant number of different organizations collecting (mainly) public restrictions data which do not have a central repository, neither a standardized data format. However, such information is needed for constituting a multi-purpose cadastre, namely by making the coverage more complete and enabling better consistency and the transfer between public and private property. Another eventual demand is to consider the registration of public roads, an issue that (Ingvarsson, 2005, p.80):

> ... will be hard to solve without changing current law and procedures...

Another, more generic conclusion, is that the obtained ICM model

[94]Rights which are appurtenant to private ownership.

... is a realistic foundation for the start of spatial cadastral registration in Iceland.

The CCDM domain model performed well in the sense that only minor things were changed or need to be added. The research towards ICM also acknowledges the problems raised by conceptually considering a 2D planar representation of cadastral objects in traditional law and registries, versus modern real rights such as the condominium rights.

To finalize this sub-subsection on the Icelandic Cadastre, it must be said that, in view of some of the issues presented with CCDM, there could have been benefits from the newest version of LADM. Furthermore, the methodologic approach shares many points with the one considered for LADM_PT. The table F.2 shows a summary of the phases followed in order to derive ICM.

Level of Detail	**Phase Nr.**	**Short Description**
More general	1.	Describe the legal framework for cadastral registration (real rights; forms of property)
Id.	2.	Organizational structure of Land Administration (actors and their roles)
Id.	3.	Describe basic Land Administration dynamics (transaction and subdivision)
More detailed	4.	Obtaining an UML class model out of the current LRD (through reverse engineering)
Id.	5.	Check availability of existing spatial data sources for the cadastre
Id.	6.	Obtain the final country model (extending LRD with spatial classes from CCDM)
Greater detail	6.1	Elect which methods to represent geographical location to use (in LADM: spatial profiles)
Id.	6.2	Identify specialized classes belonging to the planar and non-planar partition
Id.	6.3	Link relevant classes (planar-partition) to Geometry-Topology and Survey classes
Id.	6.4	Check associations with existent LRD registry classes
Id.	6.5	Extend the model regarding foreseeable future uses

Table F.2: Research Methodology in Iceland Cadastral Model

F.2 Digital Cadastre Database of the Queensland State, Australia

The specialized country model for the Digital Cadastre Database (DCDB) of the Queensland Sate in Australia is one of the examples included in Annex D of the latest version of LADM (ISO/TC211 Geographic Information / Geomatics, 2010). This model, referred hereafter as LADM_QLD, is the result of a research effort from the staff from the Department of Environment and Resource Management of the Queensland Government, the organization in charge for DCDB.

The Queensland DCDB results from a digitizing effort which took place between 1981 and 1992, replacing a conventional paper based recording system including thousands of maps, survey plans and other documents. The current DCDB includes data on Titles, State Land and Valuations (Tarbit and Thompson, 2006), along with notations (e.g. proposed road closures) and several layers of georeferenced data. These last ones include data belonging to the base layer of topographic features which include the definition of natural boundaries such as watercourses and other layers of data representing polygonal features such as (private) property, roads or easements (Thompson, 2009b), for reference purposes.

The requirements for cadastral data acquisition and maintenance in the state of Queensland are based on legislation and case law, with specifics from common law doctrine supplying additional requirements as to define the extent of interests (Rights, Restrictions and Responsibilities) in 3D. Apart from the basic law condensed in the Land Title Act (from 1994), the current DCDB is the key contribution to the State Digital Cadastral Dataset as defined through the Survey and Mapping Infrastructure Act from 2003.

According this last Act, DCDB is able to supply a digital graphic representation of each parcel of land, a unique description and the approximate coordinates of corners concerning each parcel. However, parcels which respect buildings and volumetric (3D) parcels are not required to be included at the Land Registry side and are currently maintained in separate data formats, such as specific survey plans.

The volumetric parcels are defined and have a legal status according to Queensland property law.

The existing geometric data structure of the DCDB stores 2D coordinates for the different parcel types and other spatial data as referred above, resulting from the projected straights of survey observations into a horizontal datum which defines a common geodetic reference system.

Recognition of key emerging trends within digital cadastres, including demands for a three dimensional cadastre with 3D topology and the related use of this cadastre to define 3D legal extents of interests, constituted the main reasons for research conducted in Delft University of Technology and the Department of Environment and Resource Management (Queensland). Some preliminary results from this research are reported in (Lemmen et al., 2010) and they have supplied working examples of the current spatial representation and spatial profiles within LADM-ISO19152 (ISO/TC211 Geographic Information / Geomatics, 2010).

Real cadastral data extracted from the existing DCDB has been used in order to generate a prototype, according the research work by Rod Thompson on the implementation of spatial profiles. This prototype implements one of the spatial profiles included in LADM, the unstructured or line-based profile.

The basic spatial objects within the profile are instances of the LA_FaceString LADM class and are used to define the boundaries of spatial units (namely parcels

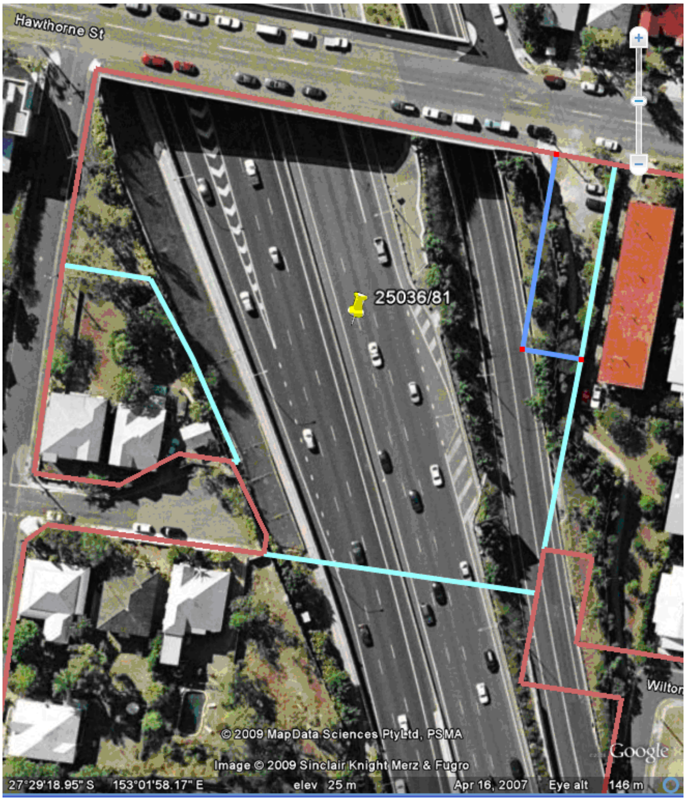


Figure F.1: *A single face string participating more than once in the definition of a parcel.* Source: Rod Thompson, 2009, (Thompson, 2009a, p.4).

in the DCDB). The reference point attribute of the spatial unit has been used as a centroid for each parcel, to which administrative and legal data can be associated.

This arrangement is specially useful, once specific quality and lineage information can be attached to each LA_FaceString instance. It is possible then, through the specification of appropriate validation and construction methods, to use existent data of different quality and even including topological errors, and put the result to immediate use.

This particular implementation has used Java classes for the spatial data and Informix DBMS to store the data extracted from DCDB. The unstructured spatial profile from LADM was further extended in order to handle the definition of a spatial unit using just a part or even multiple, not connected parts of a particular LA_FaceString. The results from such an arrangement can be seen in figure F.1.

As the existing spatial methods, namely those defined through the Simple Features Access for SQL standard, are not directly applicable to such a spatial data structure, a number of new methods were defined (Thompson, 2009a, p.5-7) through which various types of selections, graphic depiction and type conversions were made available.

Furthermore, the handling of volumetric (3D) lots has been tackled through an implementation using a mixture of LA_Face and LA_FaceString objects. This mixed 2D/3D representation is allowed by the LADM spatial representation package, although no spatial profile has been defined up to the moment.

The tested implementation used planar surfaces complying with the GML standard in order to define (mostly) vertical and horizontal faces which, together with the vertical, unbounded faces defined by the LA_FaceString objects, define the boundary of a solid. An additional method, "AsPolyhedron", was coded in order to provide the conversion of parcels defined in the mixed 2D/3D profile, such that they can be seen in a VRML viewer (Thompson, 2009a, p.8-13).

The implementation tests suggested that the unstructured (2D) and mixed 2D/3D profiles as derived from LADM constitute a workable structure for the storage of cadastral data, which can offer some performance advantages, namely concerning simple spatial location queries.

Apart from this particular research agenda, which defined a possible implementation for the spatial representation package of LADM_QLD, also the basic classes of LADM were considered, through the definition of specialized classes from LA_SpatialUnit, LA_BAUnit and LA_Restriction super-classes. Contrary to the situation in Iceland, the DCDB contained already the geometric data required to represent the spatial units, which is stored using extended spatial types in object-relational tables. In this case, no reverse engineering method was used in order to obtain an UML Class Model for the existing DCDB structure.

In a first phase, the methodology employed a first order approximation so as to establish equivalences between existing tables and proposed specialized classes (e.g. Lot table / QLD_LAUnit or Parcel table / QLD_SpatialUnit). The subclasses then included additional attributes, not present in LADM but required for the Queensland Cadastre.

There was also the consideration of new subtypes, which were condensed into an enumeration class by using a combination of existing attributes (e.g. ParcelTypeId, coverageId and parcelIndicatorId together define the QLD_ParcelSubType enumeration).

The existing LA_RightType code list (from LADM) was also enlarged with a number of rights representing different forms of tenure like "freehold", "landsLease" or "mineTenure" which, due to their generic content[95], were added to LADM, rather than defining a new subtype specific to the country model.

A second phase in the generation of the LADM_QLD model was to examine each individual table in DCDB so as to decide how data can be migrated or simply omitted when considering a conversion into the LADM_QLD structure. There are different reasons to omit a particular attribute from the mapping between the original DCDB tables and the corresponding LADM_QLD classes. Two examples come from the mappings defined in the Parcel table:

1. An attribute can be omitted if the corresponding value can be obtained through

[95] At least concerning countries which legal systems are based in the British Common Law.

a spatial query involving spatial units in different layers; e.g. the parishId can be obtained querying the underlying QLD_AdminArea class;

2. Equally, an attribute can be omitted if its value can be obtained through an association with other classes in the specialized country model; e.g. the accuracyId can be replaced and retrieved from associations of the QLD_SpatialUnit to the classes in their spatial representation (and eventually, from there to survey classes, including a LA_SpatialSourceDocument).

Although this matter is not fully developed as in the Icelandic Cadastre, the Queensland country model also makes the distinction between spatial units in a base layer (forming a planar partition) and those which may overlap like easements, volumetric lots or administrative areas[96] (Thompson, 2009b, p.4). Apart from the reported implementation tests using the unstructured and a proposed 2D/3D mixed spatial profiles, which used implementations from GML curve and surface classes, LADM_QLD also bases its geometric features upon an implementation of the LA_Point class from the Survey package of LADM. The source points corresponding to cornerstones and reference marks of real property parcels are constructed from the parcel object (geometry) currently stored in the DCDB Parcel table.

Finally, it is worth to mention that the existing DCDB has a history mechanism, implemented using a History_Header table and associations to creation and destruction keys in relevant tables (e.g. Parcel and Lot tables). Such account of past changes, fundamental to a Land Titles registry, can be maintained during a migration to the LADM_QLD, through the consideration of mappings to the beginLifeSpanVersion and endLifeSpanVersion attributes belonging to the VersionedObject superclass in LADM.

To conclude the migration proposal, some final issues were identified. Those include:

- DCDB currently does not store the volumetric lots as 3D geometric objects, rather has just a 2D (projected straights) representation of such objects;

- The QLD_LAUnit class (a specialization of the LADM BAUnit) can not have its register type attribute populated from the existing DCDB tables, once there are no correspondence with the code list entries.

As compared to the Icelandic Cadastre Model research, there was no comprehensive study of the legal framework and land administration in Queensland, but it must be pointed out that Queensland has a long tradition of cadastral mapping and that administrative procedures, legislation and technical regulations evolved and now support a working digital cadastre infrastructure, namely represented by the referred DCDB. In this light, it becomes clear that the issues faced by the adoption of the LADM are at a different level than those from Iceland.

[96] These last type of spatial units do not have associations to LA_RRR specialized classes.

However, and from the proposals contained in this Thesis, there could be made further improvements to the LADM_QLD by considering the explicit inclusion of survey package classes and also considering specialized rights and restrictions as specified in the legal and administrative profiles (Annex F of LADM).

Level of Detail	**Phase Nr.**	**Short Description**
More General	1	Study the existent data schema of DCDB, including storage of forms of property and spatial data layers.
More detailed	2	Identify requirements specifying the extent of interests (RRR) over 3D volumetric parcels
idem	3	Development of two LADM spatial profiles, to support: 1- existent data (unstructured profile) and 2- volumetric parcels (mixed 2D/3D profile)
idem	4	Derivation of a country model, LADM_QLD, considering spatial profiles and other classes, with three iterations:
idem	4.1	Establish equivalences between tables and classes including new sub-types and enumerations
idem	4.2	Decision on which tables should be migrated to LADM_QLD
idem	4.3	Distinction of a Level structure, having a base layer and other (overlapping) spatial units
Greater detail	5	Implementation test using real DCDB data, converted into an abstract layer of Java classes. Both profiles were implemented

Table F.3: Research Methodology in deriving the LADM_QLD

F.3 The Canadian Indian Land Registry

The specialized country model for the Indian Land Registry on Canada Lands (hereafter called LADM_ILR) is one of the projects for the modernization of Cadastral Systems in Canada. The governmental organization Natural Resources Canada, through its Surveyor General Branch, is responsible for the property cadastre geometric component (termed Canada Lands Survey Records), while a number of organizations are responsible for specific land registries (the legal component; there are a total of 23 property rights organizations (with their own jurisdiction area and scope) in Canada).

One of the main goals of the modernization effort is the integration of land registries into one Integrated Cadastral Management (SGB, 2009).

In the case of LADM_ILR, the organization responsible to keep a record of property rights over the area of Indian Reserves is the Indian and Northern Affairs Canada

(INAC) which, together with Natural Resources Canada (NRCan), form the infrastructure of a Land Management System. It must be clarified at this point that the territorial jurisdiction of the geometric component is limited to Canada Lands and not to all the country extent. The Canada Lands cover the Public Lands in the Northern Territories, the National Park System, a Maritime offshore area and a total of 2900 Indian Reserves (where LADM_ILR applies).

The implemented country model results from a modelling effort that dates back to the previous CCDM version of the domain model. The government of Canada has been an active member in the ISO19152 LADM standardization project, having nominated a number of experts from government agencies and academia, including the Surveyor General Branch.

As a result, regardless of the fact the LADM_ILR model has not been included into Annex F (Country Profiles) of the latest ISO19152 document, it is compatible with the newest version of LADM.

The LADM_ILR is briefly described in Egesborg (2009) and starts by establishing an equivalence between the basic classes (some being superclasses) of LADM and corresponding classes belonging to the geometric and legal components of the integrated cadastre, as shown in table F.4.

Cadastral Component	**CLSR/ILR Data Model**	**LADM**
Indian Land Registry	Person	LA_Party
	Right	LA_RRR
	INACParcel	LA_RecordedOject
Canada Lands Survey Record	NRCanParcel	LA_SpatialUnit
	Boundaries	LA_FaceString
	Points	LA_SourcePoint

Table F.4: Equivalence between Canada Lands ILR and LADM basic classes

From this higher conceptual level of basic LADM classes, the LADM_ILR presents an extended data model which relates specific country model classes to LADM parent classes through specialization chains. This has been done separately for the legal and geometric or spatial unit packages (see Figure F.2 below).

In the legal component, specialized classes Encumbrance and Designation are specialized from LA_Restriction, while Lease and Lawful_Possession are specialized from LA_Right. These are all associated (through the parent class) to the LA_Recorded-Object class, which is used without modifications in LADM_ILR. Concerning the geometric component, a specialized class Survey_Plan from LA_SpatialSourceDocument is associated to the Recorded Object and Spatial Unit classes, which were taken from LADM without modifications.

As in the case of other countries previously reported, also in LADM_ILR there is the consideration of different levels of spatial unit specializations (see table 4.1), which differentiate between a base layer represented by the Land_Parcel specialized class, and possibly overlapping spatial units represented by the Limited_Right_Areas

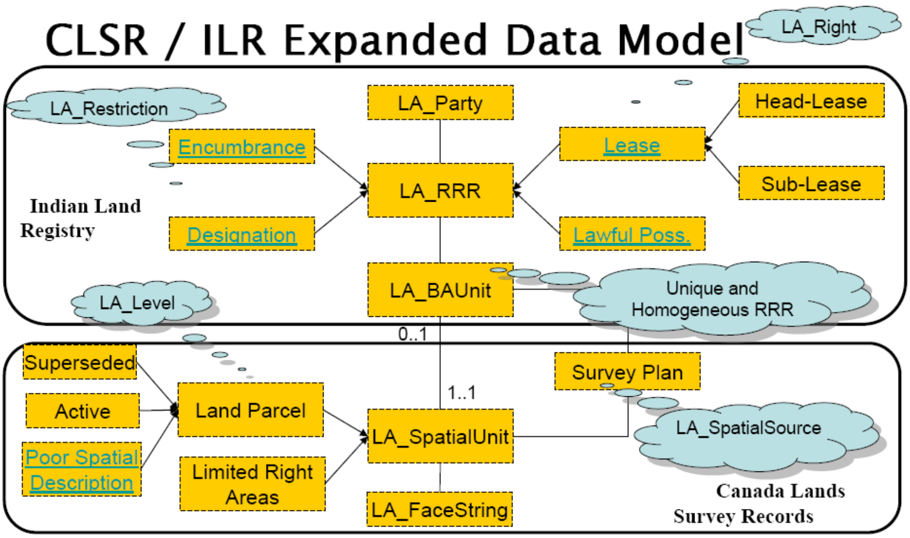


Figure F.2: *CLSR / ILR Expanded Data Model* Source: Paul Egesborg, 2009, (Egesborg, 2009, p.5).

specialized class. The Land_Parcel class, by its turn, has different specializations which can use different forms of spatial representation, that is, spatial profiles within LADM.

One example is that of the Poor_Spatial_Description specialization, also termed "Cardex Holdings" in Canada, which could use the LocationbyText spatial profile, including a textual description and an address together defining an approximate location and extent.

Being a reconciliation project where the existing Indian Land Registry records should be associated to the Canada Lands Survey Records, the LADM_ILR documents several specific reconciliation procedures (although not using UML Object or Activity Diagrams). The reported procedures start from the specialized classes in the legal component and depict how the association can be done between the two components, under a set of premisses which roughly configure a Use Case. There is an additional procedure concerning a reconciliation for the Cardex Holdings.

The implementation of this project (for which no documentation details exist) has already succeeded in the reconciliation of 45000 spatial units and should be complete by March 2010.

It is expected that the LADM_ILR model can be expanded in order to cover other property regimes in the Canada Lands, namely Oil and Gas rights, Mining rights and Condominiums. This way, ISO19152 LADM can be a key contribution to implement the vision of an Integrated Cadastral Management in Canada[97].

[97] Integration of Provincial records at conceptual level and via a shared Geographic Information Infrastructure (GII).

Although LADM_ILR has already a successful implementation history, in view of this Thesis research, its documentation could be further detailed through the use of legal and spatial profiles already existing in LADM. This situation is similar to the one reported for the LADM_QLD country model.

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Glossary

activity diagram A type of UML diagram, describing the flow of activities performed during system operation. Its fundamental element is the action or structured action in higher-level diagrams. Actions can send messages and change a system's state. 32

administrative servitude A type of servitude imposed by the State on private property, with the aim to support different types of infrastructure or facilities of public use. Is defined by Public Regulations and usually demands a Public Utility declaration. There are hundreds of different types, regulated by a number of Ministries, in a given country. 25

AUGI Áreas Urbanas de Génese Ilegal. 15

baldio Land owned by a local community and where this shared ownership is regulated by customary law or modern statutes. It can consist of communal land or individual facilities, such as a communal bakery. 15

basic administrative unit A core LADM class, identifying the basic record element in a given jurisdiction, by which it is possible to identify the bundle of Rights, Restrictions and Responsibilities applied to a Spatial Unit or group of Spatial Units, through model relationships. 70

cadastre Comprehensive register of real property within a country, including details about the location, figure, area and other geometric details of each property, and supplies a media to relate to other registries concerning real property, like ownership and valuation or tax value. 1

CASE Computer Aided Software Engineering. 25

CCDM Core Cadastral Domain Model. 8

class diagram A type of UML diagram, which fundamental element is the class, representing a software entity or an abstraction from a real world entity. The diagram also depicts different types of relationships (association, generalization, composition, etc.) existing between these classes. Following the object-oriented paradigm, a class encapsulates its attributes and operations. 33

commons Usually refers to portions of land including natural resources that are held in common by a local community. The term also applies to a type of private property right where a number of Real Properties share a common property (playing a role of the subject of the right). A modern counterpart of this last role are the common parts in a condominium right. 50

coordinate reference system A system comprising cartographic projections, a datum and an ellipsoid, aiming to precisely locate any geographical feature in relation to the Earth. It can be applied globally or it can have a more limited extent. The coordinates can be rectangular, geocentric or geographic (this last type dispensing cartographic projections. 36

deferred cadastre A term used in the Portuguese cadastre regulations, identifying those parcels which are incompletely surveyed, namely due to incomplete delimitation, a disagreement between the owner's declaration and legal or tax records, or the absence of such records (derived from lack of registration or outdated registration. 64

domain model A visualization, which can use a formal modelling language, of the concepts belonging to a particular domain of knowledge. Its core elements abstract real world or virtual entities. 3

EMF Eclipse Modelling Framework. 37

FOSS Free Open Source Software. 21

GIS Geographic Information System. 35

GML Geography Markup Language. 36

harmonised cadastre A term used in the Portuguese cadastre regulations, identifying those parcels which were completely surveyed, that is, where their location, extent, shape, legal and tax records are all known and agree with the owner's declarations. 63

IGP Instituto Geográfico Português. 12

IMI Imposto Municipal sobre os Imóveis. 12

immovable property rights An often limited number of relationships, governed by private law, between a subject (natural or non-natural person) and an object. This object is classified as immovable according the right of things, a branch from private law. 4

institutional change In this work, it was examined under the contribution to the development of Land Administration systems. Considering that institutions are the rules of the game in a society and their change shapes the way society evolves, attention should be given to the development of key institutions such as Property Law and related representations such as titles or deeds. 52

ISO International Standards Organization. 3

java persistence a collection of Java libraries or a API aiming at persisting all necessary data and objects in a running application, when the system is powered off. This can be achieved, namely, by storing relevant data in a relational data base (using object-oriented mappings. 37

JDBC Java Data Base Connectivity. 37

LADM Land Administration Domain Model. 3

land administration Set of government bodies responsible to administer the aspects related to the three key attributes of tenure, value and use of land in a country, along as the procedures by which these attributes can be changed for each particular parcel of land (or water). 1, 2

land policy A set of generic strategic goals for land planning and land use in a given country, which can be condensed into a single Law or Act. This document should define a framework with several government levels (national, regional and local), with a set of well defined public documents resulting from administrative procedures, contributing to the dissemination, monitoring and enforcement of such policies. 56, 57

land tenure Defines the different forms by which land can be used in a given country, including both formal and informal forms of tenancy and ownership. Public, private and local community laws can regulate different forms of land tenure within the same country. 7, 11

legal profiles A term used in the context of the Land Administration Domain Model, including any legal and administrative package component which is derived from the core structure of Rights, Restrictions and Responsibilities. In strict modelling terms, it is not a UML Profile mechanism, rather a more flexible modelling pattern. The existing legal profile is based on a formal , western based property law, and it was used to specify the Portuguese legal component in the specialized country model, LADM_PT. 54

LIS Land Information System. 50

metadata generally, is any type of data describing any given data set. In a geographic context, several standards for metadata were developed, namely ISO 19115. This reports on the definition, extent, quality, spatial and temporal schemas, spatial reference and other aspects of a geographical data set. 43, 66

metamodel It is a model which defines the elements comprising a lower level modelling language. Usually, has to be defined by a meta-modelling language which is closed (conforms to itself). The most prominent example is Meta-Object Facility, which defines (among others) the UML metamodel. 30, 39

MMP Municipal Master Plan. 58

model driven architecture A software development methodology aimed to increase productivity and re-use through separation of concern from abstraction. The software development is driven by the definition of an abstract model of the system, the Platform Independent Model (abstraction), which can originate one or more Platform Specific Models (concern), through Model Transformations. 3, 27

model transformation A procedure which is central to the Model Driven Architecture, by which a Platform Independent Model is transformed into a Platform Specific Model. Several proprietary transformation languages exist. The Object Management Group defined Query, View, Transformations (QVT) as the standard transformation language. In practice, more than one transformation step could be required in order to achieve implementable code. 30, 34, 37, 67

object-relational mapping It consists of a series of templates, available in a software library or user-defined, which are able to convert object-oriented elements into relational data base schemas, and back. They offer a solution to the "paradigm mismatch" between object-oriented and relational data base concepts. 30, 37

OCL Object Constraint Language. 25

OCL22SQL Object Constraint Language version 2 to Structured Query Language. 221

ODM Ontology Definition Metamodel. 39, 42

ontology In its original (Greek) semantics, is the study of the basic categories of being and their relations. Today, corresponds to a formal representation of a set of concepts within a domain, and the relationships between them. A domain ontology can be described by a language such as OWL. 26

OWL Ontology Web Language. 40

ownership According to common law tradition, it is defined as the bundle of rights allowing a person to use, manage and enjoy property, and convey it to others. It can represent a number of different real rights hold by a person, concerning a property. 45

PIM Platform Independent Model. 30

positive side In the context of Real Rights, it is any type of derived or minor right which is contributing or is benefiting to ownership, in the point of view of the holder of a maximum Real Right (eg. property). In Common Law countries, these are the rights appurtenant to ownership. 46

process fragmentation In the context of Land Administration, processes are fragmented when they are arbitrarily split into a number of vertical functions mandated to different organizations, namely Land Registry, Cadastral Survey and Mapping, Municipalities, Ministries, etc.. The effect is to constrict data flow, leading to inefficiencies. 11

PSM Platform Specific Model. 30

public domain When referring to immovable property, includes all portions of land and inland and offshore waters which are owned by the State and are regulated by Public Law and regulations, which are usually sectoral (Maritime, Natural Reserves, Public Infrastructures, etc.). 25, 56

real property A type of property right having as its object land, as defined in related law. This term is used in common law based countries, and is equivalent to immovable property in civil law based countries. 5

real rights Also termed rights *in rem* according Roman Law tradition, represent different types of relationships between immovable or moveable property which can be registered (the object) and a natural or non-natural person (the subject). They range from property rights to use or servitude rights. In Civil Code based countries, their number is fixed by a numerous clausus principle. 44

requirements analysis One of the first phases in any software development process, it should identify the needs and conditions a product (typically, a software application or a complete system) should meet. Different development methodologies identify different types of requirements; the most acknowledge being the distinction between functional and non-functional requirements. A complete analysis should also cope with the main problems in this phase: conflicting requirements defined by the stakeholders and changing (or new) requirements arising during the development process. 61, 62

reverse engineering in this book, it is used in the context of MDA, thus representing the process of deriving a object-oriented model from a specific software implementation or data base schema, or further moving to a higher-level UML model through an abstraction process. 34, 65

SINERGIC Sistema Nacional para a Exploração e Gestão de Informação Cadastral. 4

SIRP Sistema de Informação do Registo Predial. 12

SNIG Sistema Nacional de Informação Geográfica. 4

software development life cycle The different phases a software application or system crosses, from its inception to its substitution. The processes by which the software evolves through development phases (and the definition of the phases) are governed by methodologies such as the Unified Process. 27

Spatial Data Type In the context of object-oriented programming, corresponds often to complex types representing real or fictitious spatial features which are georeferenced in a Coordinate Reference System. 14

spatial information infrastructure Complex set of hardware, software, communication networks, institutions and organizations, usually managed by a national level agency, aiming to promote access and use of diverse types of information which has a direct or indirect georeference. Often, it includes at its core georeferenced information classified as Key Registers, namely Land Administration related. 4

spatial unit A core LADM class, defining any type of geographically referenced or text based element. If related to Rights, Restrictions and Responsibilities via a basic administrative unit, then it refers to cadastral parcel in the broadest sense permitted by LADM: it can represent a land or water parcel depicted in 2D, or a volumetric parcel in 3D. 70

SQL Structured Query Language. 34

STDM Social Tenure Domain Model. 54, 68

sustainable development Aims at a use of natural resources which can support human needs while preserving the environment and simultaneously assuring the sustained use of these resources for future generations. 6

system boundary In a software development process context, it defines which elements (or system components) form the system, and which are external but should be identified because they define the main inputs and outputs at the system boundary and which are the system's end users. In the Unified Process, this is defined in a context level UML Use Case diagram. 32, 61

UML Unified Modelling Language. 2

unified process A software life cycle development methodology aimed at building object-oriented systems under an iterative development approach. It recognizes four major phases: Inception, Elaboration, Construction and Transition. 18, 27

use case diagram A type of UML diagram, aiming to describe the functionality of a system, as perceived by external actors (users or other systems). The functionality is described through the association of actors to use cases, which can be further detailed in a use case model and through a UML use case view, including related activity diagrams. 32

waterfall method A nick name for the structured systems analysis methodology, inherited from the manufacturing industries and applied to software development since the 1970's (thus, in an age of procedural programming). Corresponds to a sequential design process, in which the whole system is tackled under a particular aspect, at each development phase. Does not use the concept of iterations. In response to the problems identified with this method, several modified versions were presented later. 62

WMS Web Map Service. 68

XMI XML Metadata Interchange. 34

zoning regulation Refers to an administratively imposed areal extent, usually at the local level of government, regulating allowed land uses and other details, such as building maximum heights and volumes (in the case of urban planning zones). It contributes to the implementation of Land Policies. 59, 70

Summary

This Thesis describes the research process followed in order to achieve a development methodology applicable to the reform of cadastral systems with a legal basis.

It was motivated by the author's participation in one of the first surveying and mapping operations for a digital cadastre in Portugal, and the problems faced by the cadastre, and more generally, the Land Administration System in Portugal.

After approaching Delft University of Technology (more specifically OTB Research Institute) with a research proposal mainly applied and restricted to the Portuguese cadastral situation, it was suggested to propose a new Cadastral Data Model, to be derived from the (then called) Core Cadastral Domain Model. This last model has evolved into the current Final Draft International Standard ISO 19152 - Land Administration Domain Model (LADM).

The use of LADM as a fundamental contribution to the research, along with the participation in its development, allowed to expand from an applied and focused research context, to a more generic and widely applicable one. Although the main Case Study is still describing Land Administration in Portugal, the resulting development methodology equally benefited from the study of country models developed elsewhere in the World (Iceland, Queensland (Australia) and Canada (federal land)).

The generic and worldwide nature of the LADM allowed thus to formulate the main aim and research question of this Thesis:

How can a system development methodology support in a efficient and flexible manner the creation of an integrated legal Cadastre, while addressing the interrelations between the technical, legal and organisational aspects?

The remaining paragraphs of the summary will report on how the resultant development methodology was obtained, as well as the actual products from the implementation test on the existent Portuguese Cadastral Model (hereafter referred as PT_CDM) leading to the single, most important outcome; the Portuguese country model, LADM_PT.

Starting from the more generic concepts applied to the development methodology, the systems approach as applied to Land Registries, which recognizes different aspects

under which the system can be examined and described (technical, legal, administrative and institutional), was the underlying concept for this Thesis, resulting from the contribution from (Zevenbergen, 2002).

The technical aspects of an integrated legal cadastre, or more generically, a Land Administration System, were the ones that received greater attention. The software development life cycle methodology called Unified Process (UP) and the Model Driven Architecture (MDA) supplied the more important concepts and procedures to derive a specific country model from the domain model.

Both sets of concepts (UP and MDA) were adapted and merged into the development methodology, taking into consideration the specifics of the different aspects of an integrated legal cadastre.

The design of the different components (translated to UML packages in the country model) has used a number of existing standards and specifications from international organizations as ISO, the Open GIS Consortium (OGC), the World Wide Web Consortium (W3C) and the Object Management Group (OMG). This way, it is heavily standards based.

On the legal aspects, the most important input to the research was the Legal Model as developed by (Paasch, 2005). This provided an object-oriented view reflecting generic legal concepts, as abstracted from a number of Western Europe legal frameworks, and which can be applied (at least) to both countries with Civil Code and with Common Law based legislations.

The administrative aspects were equally considered, namely by the integration of elements belonging to that component in LADM, with specific classes present in the Portuguese Cadastral Model. Additional UP products, which included UML defined elements such as the Use Case Model and related Activity Diagrams reflecting cadastral update procedures, were developed in complement to the country model.

The main institutions related to a legal based cadastre, namely those related with the fundamental institution of Property and the related Real Rights, and those related to the cadastral surveying and mapping component, were studied and reported for the Case Study. Contribution from Social Sciences in the fields of institutional theory were considered, concerning the institution of Property. In particular, the ontology description of Property is compared to the Domain Model description, identifying its similarities and differences.

The following list of items reports on the products developed by the application of the development methodology. It follows the steps to get from the non-compliant, existing Portuguese Cadastral Data Model (PT_CDM) to the LADM based country profile LADM_PT.

- Use Case Model, comprising a context and more aspect oriented Use Case Diagrams and the respective text templates. This is used to capture critical functional requirements, and constitutes a single inception iteration (according to UP).

- Vision document, identifying which problems the system will solve; who are the target users; what the system will offer in terms of features, and a listing of non-functional requirements. This is a result of the inception phase. The scope of the vision document is centred on two core capabilities, described next.

- Core Capability #1: Legal and Administrative component, covering the relation of Rights, Restrictions and Responsibilities (RRR) to the Spatial Units, through the Basic Administrative Unit. The terms name core classes belonging to the Domain Model.
- Core Capability #2: Geometric component, describing the organization of Spatial Units into different levels and considering geometry and topology constraints. This component specifies also cadastral surveying classes.
- Iteration plan for the UP Elaboration phase, which considered separate iterations for the core capabilities, followed by an integration iteration. Each iteration comprises: A detailed Use Case; a Design Model; use of one or more LADM profiles (UML patterns); a complete design model; MDA transformations and ORM Mappings enabling the implementation into a spatial data base.
- Transformation chain (MDA) for the integrated model, merging LADM with the legacy model and considering the LADM profiles.
- Instance Level Diagrams, which document the application of the integrated model for a number of real life, concrete cases.
- Model constraints collected into an OCL file (a formal constraint language), tested for syntax, and from which additional code can be derived.

The fundamental contribution and answer to the main research question is thus the development methodology itself, whose products are referred above for the LADM_PT country model. But the research path followed to obtain this methodology provided other contributions, which are summarized in the following list.

- Standards based modelling and development, namely considering geographic information (ISO 19000) series of international standards, OMG modelling standards for UML and OCL, or OGC standards in the spatial feature types.
- Development and later inclusion in LADM of spatial unit and legal profiles, specified as UML patterns which can be used in order to derive other country models besides LADM_PT.
- Documentation of a series of specific Land Administration cases through the production of Instance Level Diagrams, which are annexed to the (ISO/TC211 Geographic Information / Geomatics, 2011).

Finally, the results obtained so far, namely considering the data in the implementation test (a subset of model elements belonging to the derivation of LADM_PT from LADM), identified a number of paths open to future research.

The most relevant would be the specification of the dynamics of RRR's through time in a way that future results are integrated into the methodology. The legal model of other forms of property (legal regimes) besides those already considered for the realm of private property will also benefit a Land Administration System, extending its role from the traditional Land Registry and Cadastre.

In the Information Technology field, the research and development of an enhanced set of open source CASE tools assisting the derivation process, following MDA principles, is highly desirable. In particular, the support for the specification of OCL constraints in all phases of the derivation process should be further improved.

At last, and considering the expected approval of LADM as ISO 19152 in the short term, a documented procedure should be agreed by future contributors to the Domain Model itself, and mainly to the reporting of new country models, for which this Thesis can provide a first input.

Samenvatting

Dit proefschrift beschrijft het onderzoeksproces dat heeft geleid tot een systeemontwikkelmethodiek voor de hervorming van juridisch kadastrale systemen.

De motivatie komt voort uit deelname van de auteur aan een van de eerste meet- en karteringsoperaties voor een digitaal kadaster in Portugal, en de problemen waarmee het kadaster, en meer in het algemeen het land administratiesysteem, in Portugal worstelt.

Na het benaderen van de Technische Universiteit Delft (meer specifiek het Onderzoeksinstituut OTB) met een toepassingsgericht onderzoeksvoorstel gericht op de Portugese kadastrale situatie, werd voorgesteld om een nieuw kadastraal gegevensmodel te ontwikkelen, gebaseerd op het toenmalige CCDM ("Core Cadastral Domain Model"; kadastraal kern domein model). Dit laatste heeft zich inmiddels ontwikkeld tot het huidige FDIS ("Final Draft International Standard", definitieve concept internationale standaard) ISO 19152 - Land Administration Domain Model (LADM; land administratie domein model).

Het gedocumenteerde *gebruik* van LADM (een aanzienlijke onderzoeksbijdrage op zich), ging gepaard met deelname aan de LADM ontwikkeling. Dit maakte de uitbreiding mogelijk van een toegepast en Portugees gericht onderzoek naar een meer generiek en breed toepasbaar onderzoek. Hoewel de belangrijkste casestudie nog steeds de beschrijving van de land administratie in Portugal is, heeft de beschreven systeemontwikkelmethodiek even zozeer geprofiteerd van de bestudering van elders in de wereld ontwikkelde modellen (IJsland, Queensland (Australi) en Canada (federaal land)). Het generieke en wereldwijde karakter van de LADM maakte het mogelijk om de centrale onderzoeksvraag als volgt te formuleren:

Hoe kan een systeemontwikkelmethodiek ondersteuning bieden aan het efficint en flexibel realiseren van een geïntegreerd juridisch kadaster, met aandacht voor de onderlinge relaties tussen de technische, juridische en organisatorische aspecten?

De rest van deze samenvatting beschrijft de wijze waarop tot de resulterende systeemontwikkelmethodiek is gekomen, evenals de gerealiseerde producten van de implementatie test op het bestaande Portugese kadastrale model (hierna PT_CDM),

dat geleid heeft tot het belangrijkste resultaat: het Portugese land-specifieke model, LADM_PT.

Uitgaande van een generieke ontwikkelmethodiek, is de systeembenadering toegepast op kadasters, waarmee verschillende aspecten worden onderzocht en beschreven (technische, juridische, administratieve en institutionele), zijnde het onderliggende concept van dit proefschrift; conform (Zevenbergen, 2002).

De technische aspecten van een geïntegreerd juridisch kadaster, of meer algemeen, een land administratiesysteem, hebben de meeste aandacht gekregen. De software ontwikkelmethodiek genaamd "Unified Process" (UP) en de "Model Driven Architecture" (MDA; model gedreven architectuur) aanpak zorgen voor de belangrijkste concepten en procedures voor het uit de domein standaard afleiden van een land-specifiek model.

Beide verzamelingen concepten (UP en MDA) werden aangepast en samengevoegd tot de ontwikkelmethodiek, met inachtneming van de specifieke kenmerken van de verschillende aspecten van een geïntegreerd juridisch kadaster.

Het ontwerp van de verschillende model componenten (vertaald naar "UML-packages" in het land-specifieke model) heeft gebruik gemaakt van een aantal bestaande standaarden van internationale organisaties, waaronder de International Organization for Standardization (ISO), het Open Geospatial Consortium (OGC), het World Wide Web Consortium (W3C) en de Object Management Group (OMG). Op deze manier is het ontwerp sterk op standaarden gebaseerd.

Voor het juridische deel was de belangrijkste input voor het onderzoek het juridische model zoals ontwikkeld door (Paasch, 2005). Dit leverde een objectgeoriënteerd model op met generieke juridische begrippen, geabstraheerd vanuit een aantal West-Europese juridische stelsels, welke zowel in continentaal Europa (met op een burgerlijk wetboek gebaseerde wetgeving), als op de Britse eilanden (met op jurisprudentie gebaseerde wetgeving) kan worden toegepast.

De administratieve aspecten werden eveneens onderzocht, namelijk door de integratie van elementen van deze component in LADM met specifieke klassen aanwezig in het Portugese kadastrale model. Extra UP producten in de vorm van UML "Use Case Diagram" (gebruikssituaties) en UML "Activity Diagram" (activiteiten) voor kadastrale update procedures, werden ontwikkeld in aanvulling op het land-specifieke model (UML "Class Diagram" (klassen)).

De belangrijkste instanties met betrekking tot een juridisch kadaster, gerelateerd aan zowel eigendom en beperkt zakelijke rechten), als aan kadastrale meting en kartering, werden bestudeerd en beschreven voor de Portugese casestudie. Bijdragen van de Sociale Wetenschappen op het gebied van institutionele theorie werden beschouwd, met betrekking tot het begrip eigendom. In het bijzonder een ontologie gebaseerde beschrijving van het begrip eigendom is vergeleken met een domein modelgebaseerde beschrijving, waarbij verschillen en overeenkomsten zijn geïdentificeerd.

De volgende lijst geeft de tussenproducten van het toepassen van de voorgestelde systeemontwikkelmethodiek aan. Het volgt de stappen om van het niet-conforme Portugese kadastrale model (PT_CDM) tot het op LADM gebaseerde land-specifieke model LADM_PT te komen.

- Use Case Diagram, bestaande uit een algemene context en meerdere aspect gerichte gedetailleerde Use Case diagrammen met bijbehorende tekstsjablonen. Dit wordt gebruikt om essentiële functionaliteit vast te leggen, en vormt de beginfase ("inception iteration" (start iteratie) volgens UP).

- Visiedocument met identificatie van de problemen die het systeem gaat oplossen, wie de beoogde gebruikers zijn, wat het systeem zal bieden in termen van functionele aspecten en niet-functionele aspecten. Dit is een resultaat uit de beginfase. Het visiedocument is gericht op twee belangrijke onderdelen, hieronder beschreven.

- Kernonderdeel #1: de juridische en administratieve component, waarbij de relatie van rechten, beperkingen en verantwoordelijkheden (LA_RRR) naar de ruimtelijke eenheden (LA_SpatialUnit, d.w.z. percelen) wordt gelegd via de basis administratieve eenheden ("LA_BAUnit"). De namen voor deze kernklassen komen uit het LADM.

- Kernonderdeel #2: de geometrische component voor het beschrijven van de ruimtelijke eenheden (LA_SpatialUnit) in verschillende lagen en rekening houdend met de mogelijke geometrische en topologische constructies. Dit onderdeel omvat ook de klassen voor de kadastrale metingen (LA_SpatialSource).

- Iteratieslag voor de UP Uitwerkingsfase, die aparte iteraties onderscheidt voor de kernonderdelen, gevolgd door een integratie iteratie. Elke iteratie bestaat uit: een gedetailleerde use case beschrijving, een globaal ontwerp model, het gebruik van één of meer LADM profielen (UML patronen), een gedetailleerd ontwerp model, MDA transformaties en ORM (object relationele model) transformaties nodig voor de implementatie in een ruimtelijke database.

- Transformatie keten (MDA) voor het gentegreerde model (met zowel de juridische en administratieve component als de geometrische component), waarin het LADM model is gecombineerd met het bestaande model met verdere toepassing van de LADM profielen.

- Objectinstantie diagrammen (UML "instance level diagrammen") welke het gebruik van het gentegreerde model illustreren voor een aantal realistische concrete situaties.

- Model geldigheidscondities ("constraints") welke zijn vastgelegd in OCL (een formele taal voor geldigheidscondities) en gecheckt voor wat betreft de syntax en waaruit extra code gegeneerd kan worden voor het afdwingen van geldige data bij opslag.

De fundamentele bijdrage en het antwoord op de centrale onderzoeksvraag is de systeemontwikkelingmethodiek zelf, waarvan de producten hierboven zijn genoemd voor het LADM_PT land-specifieke model. Maar het onderzoek om tot deze methodiek te komen heeft ook nog andere resultaten opgeleverd, welke als volgt kunnen worden samengevat:

- Standaardengebaseerde modellering en ontwikkeling, met name op basis van de geografische informatie (ISO 19000) serie van internationale standaarden, OMG modelleringsstandaarden voor UML en OCL, en OGC standaarden voor ruimtelijke objecttypen.

- Ontwikkeling (en latere opneming in LADM) van model profielen voor de ruimtelijke eenheden en de juridische component, gespecificeerd als UML patronen die kunnen worden gebruikt om hieruit ook andere land-specifieke modellen dan LADM_PT te ontwikkelen.

- Documentatie van een reeks realistische concrete land administratie situaties door de het maken van aantal UML objectinstantie diagrammen, welke als bijlage aan de FDIS LADM zijn toegevoegd (ISO/TC211 Geographic Information / Geomatics, 2011).

De ervaringen en resultaten tot dusver verkregen bij de uitvoering van de testen (met gegevens binnen een subset van het LADM_PT model) geven aanleiding voor een aantal toekomstige onderzoeksvraagstukken.

Belangrijk toekomstig onderzoek dient zich te richten op hoe met de dynamiek van RRRs in de tijd moet worden omgegaan, zodanig dat toekomstige resultaten in de methodologie geïntegreerd zullen zijn. Daarnaast zou het juridische model verder moeten worden uitgebreid met andere vormen van RRRs (gebaseerd op wettelijke regelingen) naast de gemodelleerde vormen van privaatrechtelijke eigendom. Dit komt ook ten goede aan een uitbreiding van rol van een kadaster systeem richting een land administratiesysteem.

Op het gebied van de informatietechnologie, is meer onderzoek naar en de ontwikkeling van verbeterde open source CASE-tools voor het beter ondersteunen van het ontwikkelproces volgens MDA principes zeer gewenst. Met name de ondersteuning van geldigheidscondities (constraints) in alle fasen van de ontwikkelproces moet verder worden verbeterd.

Tenslotte, en rekening houdend met de verwachte goedkeuring van LADM als ISO 19152 standaard op de op korte termijn, is het van belang dat er een gedocumenteerde procedure voor het continue beheer van het LADM wordt overeengekomen. Daarnaast moeten er ook afspraken worden gemaakt voor de rapportage van nieuwe op LADM gebaseerde land-specifieke modellen, waarvoor dit proefschrift een eerste aanzet geeft.

Sumário em Português

Esta Tese descreve o processo de pesquisa seguido em ordem a alcançar uma metodologia de desenvolvimento aplicável á reforma de sistemas cadastrais com uma base legal.

Ela é motivada pela participação do autor numa das primeiras operações de levantamento (dita "Execução") cadastral em Portugal, em moldes digitais, e pelos problemas encarados pelo cadastro, ou de forma mais geral, o Sistema de Administração do Território em Portugal.

Após um primeiro contacto com a Universidade Técnica de Delft (mais especificamente, com o Instituto de Pesquisas OTB), apresentando uma proposta de pesquisa principalmente aplicada e restrita à situação cadastral Portuguesa, foi sugerido propor um novo Modelo de Dados Cadastrais, a ser derivado a partir do (então chamado) "Core Cadastral Domain Model". Este modelo evoluiu até ao actual "Final Draft International Standard ISO 19152 - Land Administration Domain Model[98]" (LADM).

O uso do LADM como uma contribuição fundamental para a pesquisa, assim como a participação no seu desenvolvimento, permitiu expandir a proposta desde um contexto aplicado e focado, para um genérico e amplamente aplicável. Embora o principal caso de estudo é ainda circunscrito à Administração do Território em Portugal, a metodologia de desenvolvimento resultante beneficiou igualmente do estudo de modelos nacionais desenvolvidos noutros países (Islândia, Queensland (na Austrália) e em Território Federal do Canadá).

A natureza genérica e global do LADM permitiu pois formular o principal objectivo e questão de pesquisa desta Tese:

Como pode uma metodologia de desenvolvimento de sistemas suportar de um modo eficiente e flexível, a criação de um Cadastro Legal Integrado, endereçando as interrelações entre os aspectos técnicos, legais e organizacionais?

Os restantes parágrafos deste sumário irão reportar como a metodologia de desenvolvimento resultante foi obtida, bem como os produtos obtidos do teste de implementação sobre o Modelo Cadastral Português existente (adiante referido como

[98]Que se pode traduzir por Modelo de Domínio da Administração do Território.

PT_CDM). Que conduziu ao resultado mais importante; o modelo nacional para Portugal, LADM_PT.

Começando pelos conceitos mais genéricos aplicados à metodologia de desenvolvimento, o conceito de Sistema como aplicado ao Registro Predial, que reconhece diferentes aspectos sob os quais o sistema pode ser examinado e descrito (técnicos, legais, administrativos e institucionais), foi o conceito base para esta Tese, resultando de uma contribuição de (Zevenbergen, 2002).

Os aspectos técnicos de um cadastro legal integrado, ou mais genericamente, de um Sistema de Administração do Território, foram aqueles que receberam maior atenção. A metodologia de ciclo de vida de desenvolvimento de software chamada Unified Process (UP) e a Model Driven Architecture (MDA)[99] forneceram os conceitos mais importantes e o procedimento para derivar um modelo nacional específico a partir do modelo de domínio.

Ambos os conjuntos de conceitos (UP e MDA) foram adaptados e juntos na metodologia de desenvolvimento, tendo em consideração os diferentes aspectos específicos a um cadastro legal integrado.

O desenho dos diferentes componentes (traduzido para pacotes UML no modelo nacional) usou um número de standards e especificações existente, a nível de organizações internacionais como a ISO, o Open GIS Consortium (OGC), a World Wide Web Consortium (W3C) e o Object Management Group (OMG). Deste modo, é fortemente baseado em standards.

Nos aspectos legais, o contributo mais importante para a pesquisa foi o Modelo Legal desenvolvido por (Paasch, 2005). Este forneceu uma visão orientada ao objecto reflectindo conceitos legais genéricos, abstraídos de um conjunto de quadros legais da Europa Ocidental, e que podem ser aplicados (pelo menos) a legislações de países, baseadas no Código Civil e na Common Law.

Os aspectos administrativos foram igualmente considerados, nomeadamente pela integração de elementos pertencentes a essa componente no LADM, com classes específicas apresentadas no Modelo Cadastral Português. Produtos adicionais da UP, que incluíram elementos definidos em UML como o Modelo de Casos de Uso e Diagramas de Actividade relacionados, reflectindo procedimentos de actualização cadastral, foram desenvolvidos como complemento ao modelo nacional.

As principais instituições relacionadas com um cadastro de base legal, nomeadamente aqueles relacionados com a instituição fundamental da Propriedade e os Direitos Reais com ela relacionados, e aqueles relacionados com a componente do levantamento (e mapa) cadastral, foram estudados e são reportados no Caso de Estudo. Foram consideradas contribuições das Ciências Sociais nos campos da teoria das instituições, no que toca à instituição da Propriedade. Em particular, a descrição ontológica da Propriedade é comparada com a descrição do Modelo de Domínio, identificando as suas semelhanças e diferenças.

A seguinte lista de itens reporta quais os produtos desenvolvidos pela aplicação da metodologia de desenvolvimento. Segue as fases requeridas para, desde o uso do Modelo Cadastral Português existente (PT_CDM), alcançar o perfil nacional LADM_PT

[99] Que se podem traduzir por UP - Processo Unificado e MDA - Arquitectura guiada pelo Modelo.

(baseado no LADM).

- Modelo de Casos de Uso, compreendendo um diagrama de contexto e outros diagramas de Casos de Uso mais orientados a aspectos específicos, e os respectivos modelos de texto. Este é usado para capturar requisitos funcionais críticos e constitui uma única iteração da fase de Inception (de acordo com o UP).
- Documento de Visão, identificando que problemas o sistema irá resolver; quem são os utilizadores finais; o que o sistema irá oferecer em termos de funções, e uma listagem dos requisitos não funcionais. Este é um resultado da fase de Inception. O âmbito do documento de visão é centrado em duas capacidades básicas, descritas de seguida.
- Capacidade Básica #1: Componente Legal e Administrativa, cobrindo a relação dos Direitos, Restrições e Responsabilidades (RRR) com as Unidades Espaciais, através da Unidade Administrativa Básica. Estes termos são os nomes dados às classes fundamentais pertencentes ao Modelo de Domínio.
- Capacidade Básica #2: Componente Geométrica, descrevendo a organização das Unidades Espaciais em diferentes níveis e considerando condicionantes geométricas e topológicas. Esta componente especifica também classes ligadas ao levantamento cadastral.
- Plano de Iterações para a fase de Elaboração (UP), que considerou iterações separadas para as capacidades básicas, seguidas de uma iteração de integração. Cada iteração compreendeu: Um Caso de Uso detalhado; um Modelo de Design; uso de um ou mais perfis LADM (UML patterns); um Modelo de Design completo; transformações MDA e mapas ORM que capacitam a implementação numa base de dados espacial.
- Cadeia de transformações (MDA) para o Modelo Integrado, juntando o LADM com o modelo herdado (PT_CDM) e considerando perfis LADM.
- Diagramas de Objectos (Instance Level), que documentam a aplicação do Modelo Integrado para um número de casos concretos, retirados de situações reais.
- Condicionantes do modelo, coligidas num ficheiro OCL (uma linguagem formal expressando condicionantes), testado quanto à sintaxe, e a partir do qual pode ser derivado código adicional.

A contribuição fundamental desta Tese e resposta à questão de pesquisa principal é assim a própria metodologia de desenvolvimento, cujos produtos são referidos acima para o modelo nacional LADM_PT. Mas o percurso seguido para obter esta metodologia providenciou outros contributos, que sáo sumariados na lista seguinte.

- Modelação e desenvolvimento baseado em standards, nomeadamente considerando os standards internacionais da série de informação geográfica (ISO 19000), standards de modelação para UML e OCL (OMG), ou standards OGC para tipos de objectos (“features”) espaciais.

- Desenvolvimento e posterior inclusão no LADM, de perfis para as unidades espaciais e legais, especificados como UML patterns que podem ser usados de forma a derivar outros modelos nacionais para além do LADM_PT.

- Documentação de uma série de casos específicos à Administração do Território, através da produção de diagramas de objectos, anexados ao documento FDIS do LADM (ISO/TC211 Geographic Information / Geomatics, 2011).

Finalmente, os resultados obtidos até ao momento, nomeadamente considerando os dados do teste de implementação (um subconjunto dos elementos do modelo pertencendo à derivação do LADM_PT a partir do LADM), identificou um número de percursos abertos a pesquisas futuras.

O mais relevante será a especificação da dinâmica dos RRR[100] ao longo do tempo, de um modo que os resultados esperados possam ser integrados na metodologia. O modelo legal referido a outras formas de propriedade (ou regimes legais), para além das já consideradas para a esfera da propriedade privada, irá beneficiar um Sistema de Administração do Território, estendendo o seu papel desde o tradicional Registro Predial e Cadastro.

No campo das Tecnologias da Informação, a pesquisa e desenvolvimento de um conjunto reforçado de ferramentas CASE em código aberto, assistindo o processo de derivação, seguindo princípios MDA, é altamente desejável. Em particular, o apoio à especificação de condicionantes OCL em todas as fases do processo de derivação deve ser ainda melhorado.

Por último, e considerando a aprovação esperada do LADM como ISO 19152 no curto prazo, um procedimento documentado deve ser acordado pelo futuros contribuintes ao Modelo de Domínio, principalmente no que toca ao reporte sobre novos modelos nacionais, para os quais esta Tese pode fornecer uma primeira contribuição.

[100] Direitos, Restrições e Responsabilidades, acrónimo em Inglês.

Curriculum Vitae

João Paulo Hespanha was born in 1964 in Lisbon (Portugal), where he grew up and concluded his secondary education. In 1982 he moved to Aveiro (Central Portugal) to conclude an BSc on Geographical Engineering, with the specialization of Geophysical Prospector obtained in 1988. He has worked as a junior researcher with University of Aveiro, Geology Department, collaborating in research projects and geological mapping in the field of photo-geology and geomorphology interpretation, also delivering vocational training in those areas. During the years 1990 to 1992 he moved to Enschede (The Netherlands), where he concluded an MSc in Integrated Geoinformation Production, given by the International Institute of Geo-Information Science and Earth Observation (ITC).

After returning to Portugal, he worked for UNAVE, the Vocational Training and Research Association of University of Aveiro, during the years from 1992 to 1997, where, besides giving long term and post-graduation training courses in the field of GIS, participated also in the first national topographic and cadastral mapping production opened to private enterprises.

From 1997 he is an adjunct professor at the Technology and Management Polytechnic School of Águeda, University of Aveiro, Portugal, where he gave lectures on several disciplines for the BSc on Geographical Engineering. He has been involved in lecturing and research projects on Cadastral Surveying and Mapping since adoption of project-led education in 2001. From 2004 to the present date he is doing research on modelling in the cadastral domain at Delft University of Technology (OTB Research Institute). The integration of the lecturing and research activities allowed the completion of a number of semester long projects involving the Municipality of Mira (Central Portugal), one of the few having a digital cadastral data base in Portugal.

More recently (since 2010) he is also a consultant for Integrated Spatial Analytic Consultants, a private firm based in India, where he cooperated conducting research in the field of modelling indigenous land rights, supported in the Land Administration Domain Modelling.

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