Masters Program in **Geospatial Technologies**

A PLUGIN FOR SPATIAL AND THEMATIC COMPARISON IN THE CADASTRAL DOMAIN

Paulo Gama Bianchi Candeias

Dissertation submitted in partial fulfilment of the requirements for the Degree of *Master of Science in Geospatial Technologies*

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Dissertation supervised by

PhD Professor Marco Painho
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa, Portugal

PhD Professor Angela Schwering
Institut für Geoinformatik
Westfälische Wilhelms-Universität Münster, Deutschland

PhD Professor Joaquín Huerta
Departamento de Lenguajes y Sistemas Informáticos
Universitat Jaume I, Castelló de la Plana, España

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“Without people you’re nothing.”**Joe Strummer**

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ABSTRACT

Over the years, the Municipalities have been dealing with a growing number of requests for cadastre use updating. In most cases, these requests originate from the owner's will to perform an urban intervention in a parcel. Urban intervention are defined as physical operations of urbanization, construction and use of land. To issue an urban intervention permit for a parcel, the authorising municipal entity has to conduct a Spatial and Thematic comparison between the existing municipal rustic cadastral cartography and the urban intervention project.

The aim of this research is to develop a database and ontological framework that incorporates Spatial and Thematic verification to support the describes cadastre update and facilitate the automation of the process within municipal entities.

The development of an object relational database management system is supported by an Entity-Relation model compliant with INSPIRE data specification on theme Cadastral Parcels and ISO/LADM models. The Methontology method is applied to model a decree-law ontology that enables the representation of legal relationships between the municipal master plan and the urban land use categories. The `Spatial comparison` operation uses a spatial predicates set based on the Calculus Based Method to test and classify relationships between the rustic and urban geometries. The `Thematic comparison` performs a set of operations to ascertain the relationship between rustic and urban categories, extract and assign its annotation to the urban project. Finally, a free and open-source Java Plugin integrates the ORDBMS and the ontology models and implements the proposed methods.

The Plugin provides an efficient platform for the executation of data visualisation and comparison, although it is limited to the information retrieved from the analysis of the Spatial and Thematic relationships. An assessment on distinct design principles demonstrate that the integration of the selected information technologies can ensure the adaptation of the Plugin to the various cadastre update processes existing in the Municipality.

The proposed cadastral database model can facilitate the integration of the municipal cadastre update process in the future SiNErGIC platform. The use of free and open-source GIS and Semantic Web technologies can efficiently support less sophisticated cadastral operations and assist the customisation and adaptation within the municipal entities. Overall, the Spatial and Thematic comparison operations implemented in the Plugin, can contribute to automation and celerity of the cadastre update process.

KEYWORDS

Application Ontology
Cadastre Update
Cadastral Database
FLOSS GIS
Ontology Engineering
Spatial Comparison
Thematic Comparison

ACRONYMS

API – Application Programming Language
CBM – Calculus-Based Method
CC – Cadastral Cartography
CCDM – Core Cadastral Domain Model
CS – Cadastral System
DBMS – Database Management Systems
DL – Description Logics
E-R – Entity Relation
EPSG – European Petrol Survey Group
FAO – Food and Agriculture Organization
FIG – International Federation of Surveyors
FLOSS – Free/Libre Open-Source Software
GIS – Geography Information Systems
GML – Geography Mark-up Language
GUI – Graphical Unit Interface
IDE – Integrated development Environment
IGP – Portuguese Geographic Institute
INSPIRE – Infrastructure for Spatial Information in Europe
IPCC – Portuguese Institute of Cartography and Cadastre
ISO – International Organization For Standardization
IT – Information Technologies
LA – Land Administration
LADM – Land Administration Domain Model
MRSC – Multipurpose Real State Cadastral
OGC – OpenGIS Consortium
ORDBMS – Object Relational Database Management Systems
OWL – Web Ontology Language
PDM – Municipal Master Plain

RDBMS – Relational Database Management Systems

RDF – Resource Description Framework

SDI – Spatial Data Infrastructure

SINERGIC – National System for the Operation and Management of Cadastral Information

SQL – Structured Query Language

STDM – Social Tenure Domain Model

SW – Semantic Web

UML – Unified Modelling Language

UN – United Nations

UN-Habitat – United Nations Human Settlements Programme

W3C – World Wide Web Consortium

WWW – World Wide Web

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

1. INTRODUCTION

This thesis proposes a free and open-source Java Plugin to perform `Spatial comparison` using a object relational database management system and `Thematic comparison` supported by a semantic web technology, within the cadastral domain.

1.1 Background

With the beginning of a 'new era' after the end of the Second World War, the United Nations (UN) started to be interested and play an active role on Land Administration (LA) and cadastral related issues. In the beginning of the 80's, following the exponential increase of population, land use and new geographic information technologies, the researches concerning reforms on land information systems became more intense and covering wider perspectives. This evolution tendency made international agencies sensitive to future Cadastral System (CS) models.

However, CS that until some years ago were only used as 'fiscal' records by the public sector and as 'legal' records by the private sector (cited in Larsson, 1991), started to be regarded as a vital legal instrument for economical, social and environmental management and development (Kaufmann and Steudler, 1998). In 1994, the International Federation of Surveyors (FIG) published a document called *FIG Statement on the Cadastre* (FIG, 1996). From this statement the UN assumed Cadastre as "...normally a parcel based, and up-to-date land information system containing a record of interests...geographically referenced to unique, well-defined units of land" (FIG, 1995).

By the end of 2006 at the FIG Congress *TS 12 Cadastre 2014 and Cadastral Modeling* in Munich, Germany, Lemmen and Oosterom (Lemmen and van Oosterom, 2006) presented the version 1.0 of the FIG Core Cadastral Domain Model (CCDM). The proposed model was divided in five aspects represented by Unified Modeling Language (UML) coloured coherent parts: Legal/Administrative (Yellow); Person (Green), Immovable Object Specializations (Blue); Surveying (Pink); and Geometric/Topological (Purple). The core of CCDM is represented by the relationship between Subject (persons) and Real Estate Object (land) via Rights (people land relation) (van Oosterom et al, 2006).

However, two years after the CCDM version 1.0 had been released, Hespanha et al.(Lemmen and van Oosterom, 2006) presented at the FIG Working Week 2008 in Stockholm, Sweden, the version 1.1 of the CCDM now dubbed Land Administration Domain Model (LADM). This change is due to fact that "the term 'land administration'better covers the full scope of the model" and "the term 'cadastral' was not perceived by everyone to cover both the legal/administrative side and the geometric side such a registration.". In this document the LADM-PT was also described: a LADM Country Profile developed to cover Portuguese cadastral reality. The described research proved to be very important because of the experiences and lessons learned concerning the derivation of a Country Profile from LADM.

Prior to 1995 the cadastre in Portugal was only geometric and its main purpose was to be a land use inventory. This type of cadastre is called rustic, and does not cover the legal ownership of land parcels. Since 1995 the Portuguese Institute of Cartography and Cadastre (IPCC) initiated the country's multipurpose real state cadastral (MRSC) project, by classifying and mapping the land properties as rustic or urban cadastre parcels. Before this change, the cadastre information was dispersed by distinct institutions and characterized in order to serve the needs of each institution, being complicated (and time consuming) to connect and share information of each land parcel (Veigas, 2002). To help on how to deal with such issues and others related, the Decree-Law nr. 172/95, dated July 18^{th}, was published to regulate MRSC for Portugal (DL, 172/1995). Due to economical and development issues, the MRSC project suffered economical and technological delays and was never initiated.

However, in 2006, the Resolution of the Council of Ministers nr. 45/2006 (RCM, 45/2006) proposed the creation of a National System for the Operation and Management of Cadastral Information (SiNErGIC), in order to enable the implementation of a national real estate cadastral information system. The SiNErGIC was mainly conceptualized and modelled based on Cadastre 2014 and CCDM. It is intended that, in future, the SiNErGIC ensures an interoperable and transversal CS, making possible the registration, execution and dissemination of cadastral information within the same technological infrastructure.

Such platform will allow to maintain updated the continuous changes associated with any rustic parcel. This update process is divided into six stages: Instruction; Reception and pre-analysis; Resolution; Process Information; Office analysis; and Conclusion. The nature of the requested update can be: parcel division; parcel division for urban purposes; area rectification; boundaries rectification; parcel elimination; parcel union; sub-parcel land use change; parcel designation change; and parcel elimination. It is expected that, in the future, these updating procedures will be automated and managed mainly by public authorities such as Local Offices, Land Registry Offices and Municipal Entities.

1.2 Motivation

The CC is an important tool in the municipal, infrastructure and environmental land management. However, in some situations, CC can be complicated to deploy due to the constant changes that it is exposed to. These occurrences come from Spatial and Thematic order, and in most cases are originated by changes in the use of parcels or in updates of the PDM. Over the years, the Municipality is dealing with a growing number of requests for cadastre use updating. In most cases the owner's will to perform an urban intervention in a parcel originate these requests.

To issue an urban intervention permit for a parcel, the authorising municipal entity requires the owner to deliver a preliminary project draft. One of its basic requirements is a map consisting of the geo-referenced boundary. In order to accept that draft, the municipal entity has to conduct a comparison between the existing municipal rustic CC and the urban intervention map delivered by the land owner. For comparison between both data sets some Spatial and Thematic analysis have to be applied. This research proposes to develop a free and open-source framework to support the automatic verification of Spatial and Thematic changes between cadastre parcels.

1.3 Aim and Scope

The aim of this research is to develop a database and ontological framework that incorporates Spatial and Thematic verification to support the cadastre update and facilitate the automation of the process within municipal entities.

1.4 Research Objectives

As a result of the identified problems, aims and scope of the research, the objectives are:

- Update of municipal database model to make it compliant with the INSPIRE cadastral parcel and ISO LADM models;
- Design and development of `Spatial comparison` method based on spatial predicates using Structured Query Language (SQL);
- Design and development of `Thematic comparison` method based on a semantic web language; and
- Implementation of a customised Plugin within a free and open-source Geographic Information Systems (GIS) software.

1.5 Research Questions

- How can the use of customised free and open-source GIS and Semantic Web Technologies improve the performance of cadastral operations executed by the municipal authorities?
- How can a spatial database and ontological framework benefit the automation `Spatial and Thematic comparison` within the cadastre update process?

1.6 Study Area and Data

This research will take place in Oeiras municipality (see appendix 1.), Portugal. Oeiras is a town and a municipality in western Lisbon metropolitan having approximately a population of 171,000 inhabitants. The WGS84 geographic coordinates of the council are on 38° 41'N and 9° 19'W, with an area coverage of about 45.8Km^2 and having a total number of 10 parishes (C.M.O, 2009).

The Oeiras CC is composed by 45 sections in vector and raster formats. The Oeiras rustic cadastral vector and raster cartography (1:2000 scale) are owned and kept up-to-date by the Oeiras Municipality. The Portuguese rustic and urban cadastral vector and raster cartography (1:2000 scale) are maintained by Portuguese Geographic Institute (IGP) (Decree-Law nr. 8/2002) and can be obtained through official channels (not free of charge); however, it is not always available within the desired time or formats.

This research proposes to use municipal rustic cadastral data and urban cadastral data that will be obtained from the municipality and from the data contained in the project draft delivered to the Municipality by the land owners, respectively.

1.7 Approach

This research consists of four phases: Literature review, Conceptualisation, Design and Evaluation.

The literature review phase comprises two parts: in the first part is provided a review of the past, present and future cadastral researches on an international and national level; and in the second part, a review of existent organizations, standards and available open-source GIS and Semantic web technologies relevant to this research.

The conceptualisation phase defines the structure of the framework. The database E-R model based on Infrastructure for Spatial Information in Europe (INSPIRE) cadastral standards (INSPIRE, 2009) will be depicted. Applying the Methontology (Fernandez, Goméz-Peréz, and Juristo, 1997) method a decree-law conceptual ontology model will be developed. Finally, the graphical unit interface of the Plugin will be represented using a mock object.

The design phase presents the designing and implementation of the conceptual framework. Based on the E-R schema developed during the conceptualisation phase, the database will be developed in two stages: the design and physical. Supported by the conceptual ontology, a decree-Law application ontology will be created. Finally, the Plugin will be design and implemented using a programming language with the intent to connect the database and the ontology.

The evaluation phase presents an assessment of the design and implementation of the conceptual framework. Based on the framework implementation results, the Plugin will be tested against the workflow of the municipal cadastre update process. Finally, the tests results will be evaluated considering the strengths and limitations.

1.8 Thesis Structure

This thesis is structured in seven chapters. The first chapter introduces the topic and its relevance to the cadastral scenario in the Oeiras Municipality. In order to clarify the choices, the hypothesis and objectives are pointed out and stated. Closing the chapter, the chosen approach is explained and discussed.

Chapter two gives an overview of International and Portuguese cadastral main events since 1994 until the present days, trying to underline the importance of new adopted models to support and update existent land management and cadastral systems. To enrich this topic some characteristics and findings are also described for both cases. Closing this chapter, the cadastre update process carried out by the technicians of the Oeiras Municipality is discussed.

Chapter three gives a literature review on organisations related with cadastral, existent cadastral, geo and web standards, relational object databases, semantic web technologies and free/libre open-source software (FLOSS). Based on this brief analysis and with the intent to support the objectives previously defined in the first chapter, the main guidelines and points covered on the conceptualization of the framework are presented and grounded.

Chapter four starts with a diagram of the conceptual framework of the research. Each module and package is enumerated and the `Spatial comparison`, `Consistency checking`, `Thematic comparison` and `Acceptance consistency` methods are explained. Also, technical and legal issues are enumerated and reviewed in order to bring the proposed model closer to the existent municipal reality. Based on these points, the conceptual approach of the database schema to be generated, the methodology adopted to support the development of the conceptual ontology and a sketch of the Plugin to be designed are described.

Chapter five depicts and explains the design and physical modelling of the database model in order to support `Spatial comparison` and `Consistency checking` between cadastre land parcels. The logical design of the conceptual ontology and how it supports the `Thematic comparison` and the `Acceptance checking` is also described. Closing the chapter, the framework implementation as a Plugin is presented and discussed.

Chapter six describes the evaluation of the framework implementation. Firstly, a workflow of operations is presented and, secondly, the test dataset is introduced and described. Based in these two sections, the characteristics, components and processes are tested and compared taking into account the municipal cadastre update process. This chapter ends with a discussion of the strengths and limitations of the framework.

Chapter seven holds a debate covering the research objectives and questions. To close this document future work is pointed out and commented.

1.9 Tools

In this research all the software that will be used is free or open-source. The Operation System that will support all the applications is the Linux Ubuntu 10.04 LTS. The written part will be processed in OpenOffice 3.3.0 suite and the final product generated in LaTeX through Kile 2.0.85. The diagrams will be draw in the diagram editor Dia 0.97.1 and in the CmapTools 5.04.01. The images will be edited in the image editor GIMP 2.6.8; The research documents will be organised in the Mendeley Desktop 0.9.8.2. The E-R model will be designed in the MySQL Workbench 5.2.31. The database will be developed and implemented in the Database management System PostgreSQL 8.4.1 with PostGIS 1.4.0 and accessed through the pgAdmin III 1.10.0. The ontology will be developed in the ontology editor Protégé 4.1 Beta. The plugin will be implemented in the integrated development environment (IDE) NetBeans IDE 6.8 and accessed through the GIS Desktop OpenJump 1.4.0.2s.

2. STATE-OF-THE-ART

2.1 International Cadastral Information Systems

2.1.1 Until 1994

With the beginning of a 'new era' after the end of the Second World War, the UN started to be interested and play an active role on land administration (LA) and cadastral related issues. Early in the 1950's, the Food and Agriculture Organization (FAO) contributed with a series of studies addressing land registration processes. Among them one discussing the rights in land was selected and used until the appearance of new cadastral reforms (model). In the beginning of the 80's, following the exponential increase of population, land use and new geographic information technologies, the researches concerning reforms on land information systems became more intense and covering wider perspectives. This evolution tendency made international agencies sensitive to future CS models.

2.1.2 The beginning of the end for old fashioned Cadastral Systems

CS that, until some years ago, were only used as 'fiscal' records by the public sector and as 'legal'records by the private sector (cited in Larsson, 1991), started to be regarded as a vital legal instrument for economical, social and environmental management and development (Kaufmann and Steudler, 1998). In 1994, the FIG published a document called *FIG Statement on the Cadastre* (FIG, 1996). From this statement the UN assumed Cadastre as "...normally a parcel based, and up-to-date land information system containing a record of interests...geographically referenced to unique, well-defined units of land" (FIG, 1995).

The traditional CS in its majority were developed on human based and conventional operations. There was clearly a lack between ownership rights and usage rights that were not helping to keep CS in harmony with the economic and social demands. In order to overtake those limitations, the UN-FIG presented in 1996 the *Bogor Declaration*, where relevant guidelines for a future cadastral and LA vision were formulated and discussed. To guarantee the success and harmonize planning and development of the ongoing reforms, more studies and works started to be developed (FIG, 1996) (Williamson and Ting, 2001).

2.1.3 Cadastre 2014

In 1998 after four years of work, the FIG brought to light the *Cadastre 2014 - A vision for a future cadastral system.* This document developed by the FIG Commission 7 presents a modern cadastral 20 year vision that perceives changes on "the role of governments in society,...relationship of humankind to land,...influence of technology on cadastral reform,...influence of technology on cadastral reform,...changing role of surveyors in society...and growing role of the private sector in the operation of the cadastre" (Kaufmann and Steudler, 1998). FIG defined Cadastre 2014 as "a methodically arranged public inventory of data concerning all legal land objects of a certain country or district, based on a survey of their boundaries" (Kaufmann and Steudler, 1998). This data inventory contains "...The outlines of the property, the identifier together with descriptive data, may show for each separate land object the nature, size, value and legal rights or restrictions associated...In addition...contains the official records of rights on the legal land objects." (Kaufmann and Steudler, 1998).

Cadastre 2014 vision discusses the re-engineering of existent LA and CS based in a conceptual LA system. This conceptual model reflects the idea of a standardized and complete multi-purpose CS, designed to be an active part of any national spatial data infrastructure (Williamson and Ting, 2001) (Kaufmann and Steudler, 1998). The core essence relays on six statements as guidelines to promote a complete documentation of public and private law and legal systems, to redefine the role of cadastral mapping for cadastral modelling, to encourage the use of digital spatial objects and models, to ensure a better cooperation between public and private domain, and to stimulate the investment ensuring a return. Out of these statements this document also discusses how Cadastre 2014 vision can be used to support sustainable development, to help in land use planning, to contribute for political stability, and to support economy. This approach was the turning point from the old to the new system, although still very focused on the CS and on the technological changes and less concerned on defining a structure for cadastral domain model (Larsson, 1991).

In 2000, following the works already initiated, Stubjkær and Stuckenschmidt (2000) use an ontological engineering approach with the intent of conceptualizing the cadastral domain. This vision contemplates how an ontology can contribute to the data modelling process by allowing scheme integration and semantic interoperability. At first, by helping the merge of different data models or their integration with existent information systems, and in second by preserving information meaning when exchanging data through distinct infrastructures beyond national level. In this document, apart from Cadastre 2014, there is a constant suggestion to use Geo-ICT languages such as OIL and XML, for engaging data exchange and integration.

2.1.4 A Cadastral Core Domain Model based on Cadastre 2014

Even with the works and studies conducted, such as ESRI ArcGIS Parcel Data Model (van Meyer, 2004), CS continued heterogeneous, and it became more and more imperative to find solutions to standardise the existing models. In the end of 2002, van Oosterom and Lemmen (2003) presented at a workshop in Delft, Netherlands, the progresses made to develop an international CCDM based on OpenGIS Consortium (OGC) (OGC, 2007) and on International Organization for Standardization (ISO) 19100 geographic standards. This work was developed with two major goals: to support "extensible basis for efficient and effective cadastral system development based on a model driven architecture" and to "enable involved parties, both within one country and between different countries, to communicate based on the shared ontology implied by the model" (Hespana et al, 2008). To ensure dissemination and implementation of the CCDM in different organizations, such as municipalities or governmental agencies, the use of available Geo-ICT standards is incentivated. The model was designed and documented based on UML standards making it possible to be applied in Geographical Data Base Management Systems (Geo-DBMS), implemented in Java making use of OGC standards or even translated to XML/Geography Mark-up Language (GML) (van Oosterom and Lemmen, 2003).

Two years later, in 2004, Kaufmann by invitation wrote an *Assessment of the Core Cadastral Domain Model from a Cadastre 2014 point of view* Kaufmann (2004) to be presented at FIG/COST Workshop on Standardisation in the Cadastral Domain in Bamberg, Germany. The document sort out five main ideas: the context between both approaches are not very different; the necessary standardization of the models on both cases; the ontology discussion should be continued; Cadastre 2014 does not clearly state the role of the cadastral surveyor; and that CCDM is being improved with elements from Cadastre 2014. During the same workshop, Hess and Schlieder (2004) brought to scene an *Ontology-based Verification of Core Model Conformity in Conceptual Modeling* study. From the work developed in this research some considerations were made: is difficult to preform a conformity verification on the CCDM current stage; CCDM should be improved with help of experts connected to the national CS; the CCDM and other cadastral models should be studied on a equal level of abstraction; conformity results shows that CCDM approach can be a valid contribution to standardisation; CCDM should contain the minimum common data of all domain models, thus enabling data sharing on a national or international level; and that development of software should be considered in a next phase. Another work presented was *Cadastre 2014 From vision to GIS* by Bjorsson (2004). This paper draws attention to the importance of Cadastre 2014 implementation as the first step of any cadastral information systems; to the number of available GIS technologies capable to implement a cadastral management system; to the CS that needs to follow standards and be interoperable; to the importance to have CCDM as foundation; and that GIS products for cadastral management should provide functions such as rule-based topology, multi-user access and interoperability between systems.

2.1.5 FIG CCDM v1.0

By the end of 2006 at the FIG Congress *TS 12 Cadastre 2014 and Cadastral Modeling* in Munich, Germany, Lemmen and van Oosterom (2006) presented the version 1.0 of the FIG CCDM. After four years of research, papers, meetings and case studies, a refined version capable to be implemented in organizations at different national levels and to provide communication through standardized processes emerged. The proposed model was divided in five aspects represented by UML coloured coherent parts: Legal/Administrative (Yellow); Person (Green), Immovable Object Specializations (Blue); Surveying (Pink); and Geometric/Topological (Purple). The described division by 'packages' was conceptualized to provide more flexibility of adaptation, development, implementation, and maintenance of each part of the model. Like already proposed in previous versions, the core of CCDM is represented by the relationship between Subject (persons) and Real Estate Object (land) via Rights (people land relation) (van Oosterom et al, 2006). This indirect communication is the main essence of land tenure and in CCDM it is represented by the relationship between Person (Green) and RegisterObject (Blue) through RRR (Right, Restriction, Responsibility) (Yellow).

Such approach guarantees that cadastral information systems not only covers the geographical side, but also the legal/administrative side of the relationship between subject and real state object. One of the most important aspects of the CCDM was the international cooperation between countries. This cooperation designed a version 1.0 of the CCDM more detailed and comprehensive by relating common aspects of land registration and cadastre (Lemmen and van Oosterom, 2006). For Europe the CCDM was proposed to be the basis for the INSPIRE cadastral data specification, in order to cover 31 themes within 25 countries (Hespana et al, 2008). The idea of international participation was becoming narrow and a specialization model started to be develop for developing countries by FIG and United Nations Human Settlements Programme (UN-HABITAT). To keep the CCDM updated, a continuous maintenance process and an aligned vision with emergent information technology is suggested (Lemmen and van Oosterom, 2006).

2.1.6 LADM release

Two years after the CCDM version 1.0 had been released, Hespana et al (2008) presented at the FIG Working Week 2008 in Stockholm, Sweden, the version 1.1 of the CCDM now dubbed LADM. This change is due to fact that "the term 'land administration' better covers the full scope of the model" and "the term 'cadastral' was not perceived by everyone to cover both the legal/administrative side and the geometric side such a registration.". Such conclusion gained relevance by comments of experts from UN-Habitat and ISO/TC 211 when the first attempt to transform LADM into an ISO standard (New Work Item Proposal, NWIP 1859, CCDM) was being developed. Besides the change in the name (and regarding the latest model version), two other differences are noteworthy: some subclasses with less meaning were excluded, and the model is now fully compliant with ISO 19107 Spatial Schema. In the same document that LADM v1.1 was introduced, the LADM-PT was also described: a LADM Country Profile developed to cover Portuguese cadastral reality. The describe research proved to be very important by the experiences and lessons learned concerning the derivation of a Country Profile from LADM.

2.1.7 From LADM to ISO19152

In the beginning of 2009, at the FIG Working Week 2009 in Eilat, Israel, Lemmen et al (2009) presented *Transforming the Land Administration Domain Model (LADM) into an ISO Standard (ISO19152)*, a summary of the ISO19152 Committee Draft (CD) deliver. This standardisation process started with the submission of NWIP 1859 and was followed by three Working Drafts (WD). Since 2003 the European Committee for Standardisation (CEN) agree to joint forces between the CEN/TC287 and the ISO/TC211 to make global harmonisation of standardisation process possible. In the same day that NWIP 1859 was presented to ISO/TC211 so it was to CEN/TC287. Since that day the LADM (future ISO19152) started to be followed and voted simultaneously by both technical committees. Once accepted the LADM would then be an International and European standard. Regarding International cooperation, it was also discussed the engagement of LADM/INSPIRE and of LADM/Social Tenure Domain Model (STDM). The first refers to INSPIRE Cadastral data specification as a future appendix of the ISO19152 and the second refers to "a multi-partner software development initiative to support pro-poor land administration...based on open source software development principles" as a future informative appendix of the ISO19152. Later, by the end of the same year, FIG published some news announcing that the LADM ISO19152 proposal had been approved as

Draft International Standard (DIS) (Lemmen, 2009). Again, just like in previous occasions, it was suggested that FIG, CEN, OGC, ISO, and other communities connected with the GIS industry, continue the contribute for LADM development and implementation into national and local Spatial Data Infrastructures (SDI) worldwide.

2.1.8 From to 2010 to 2025

In 2010, one year after the presentation of ISO19152 CD, Uitermark et al (2010) presented *From LADM/STDM to a spatially enabled society: a Vision for 2025* at the World Bank Annual Bank Conference on Land Policy and Administration in Washington D.C., USA. In this presentation, the recent demonstration of STDM and a vision for LA system towards the year of 2025 were discussed. Regarding the future of STDM, the use of this model regarding the revitalisation of developing countries land systems was appealed. The importance of stimulating open source communities and commercial software providers to develop new land information software based on the LADM specifications was also highlighted. The vision for 2025 was developed on the expectation of some advancements that would help build a 'spatially enabled society': Maturation of information infrastructures; Development of social and economic dynamic process models; Expansion of administration systems for 3D/4D Space+Time objects; Harmonization of land object registration system; Straightforward update procedures for land object registration; Improvement of standards for data exchange at global level; Formalisation of semantic web technology; Increase of mobile applications development; expansion of monitoring applications for Geographical information infrastructures; and availability augmentation of land information from public sector side. The previous expectations were pointed out as basic needs for public/private entities to perform future land analysis, predictions and decisions. In short the 2025 vision has LADM and STDM as a present and future basis to "register worldwide the information-related components of Land Administration (LA) in a standardized way" (Uitermark et al, 2010). A very important future mark for LA and CS will be the release of ISO19152 as an International Standard IS on June of 2011.

In the same month as the previous presentation, FAO in collaboration with the FIG working group 7.3, published *Floss in Cadastre and Land Registration: Opportunities and Risks* (Uitermark et al, 2010). This publication focuses on being a source book with guidelines for countries that want to implement or reinforce their own LA and CS by using FLOSS. Knowing how vital information technology (IT) is for a responsible land governance and for strengthening financial systems, the pros and cons of using such open resources to diffuse cadastral and land registration information are discussed. From the beginning, commercial off-the-shelf products are becoming the basis for developing information infrastructures, but due to economical constraints, it is necessary to develop and maintain efficient and cost effective tools for them to be used, improved and shared between cadastral and land experts. Open Geo-DBMS and GIS desktop applications are versatile and can be adapted concerning present issues or improved for future needs. Even when making use of the described features, the open source software's are far from getting into a comfortable position and to offer secure solutions, being of major interest to test and try to integrate them more and more with national and local land administration systems.

2.2 Cadastre in Portugal

2.2.1 The year of the Multipurpose Real State Cadastral

Prior to 1995 the cadastre in Portugal was only geometric and its main purpose was to be a land use inventory. This type of cadastre is called rustic, and does not cover the legal ownership of land parcels. Since 1995 the IPCC initiated the country's MRSC project, by classifying and mapping the land properties as rustic or urban cadastre parcels. Before this change, the cadastre information was dispersed by distinct institutions and characterized in order to serve the needs of each institution, being complicated (and time consuming) to connect and share information of each land parcel (Veigas, 2002). To help on how to deal with such issues and others related, the Decree-Law nr. 172/95, dated July 18th, was published to regulate MRSC for Portugal (Decree-Law nr. 172/1995).

This document reinforces the idea that a precise knowledge of real state cadastre is essential for a proper infra-structuring, use and management of the land and a vital support for economical activities that depend on it. The new cadastral model was conceptualized to help modernise the public administration, to represent the real state cadastral domain and to be an active part in the Portuguese development. To support this model some articles from previous Decrees-Law were preserved, others repealed and new ones introduced. From the discussed decree-law only the relevant articles for this research will be enumerated (Decree-Law nr. 172/1995).

The second point from the first article defines real state cadastre as a "data set that characterize and identify the existing parcels in the country". The forth article states that all rustic and urban title registers should be elaborated based on cadastral elements extracted from the national cadastral map. The first point from the sixth article reveals that the existent rustic cadastre will be valid until next renewal operation. The second article of the chapter one defines that a land parcel is characterised by its administrative and geographic location, geometric configuration and area. The administrative location is defined by the district, municipality and parish where the land parcel is located. The geographic location is defined by the position of their boundary in the adopted coordinate system. The geometric configuration is defined by the cartographic representation of a closed polygon and the area is the mathematical value of that boundary. The sixth article points out that each land parcel has an unequivocal numeric code (NIP) and that this code is mandatory to be present in all public documents as an identification of cadastre land parcels. This code is part of the parcel identification card. Each cadastral parcel is represented in a cadastral section that is part of the national cadastral coverage (Decree-Law nr. 172/1995).

The point one of the ninth article states that the IPCC competences related to Portuguese rustic and urban cadastral are: a) implementation, renewal and conservation of MRSC in any Portuguese administrative areas; b) construction and maintenance of networks to support the operations described in the preceding point and establishment and management of the corresponding databases; c) issue of parcel identification card; d) Certification of geographical location, geometric configuration and identification of land parcels; e) Establishment of standards and technical specifications for MRSC; and h) approval of cadastral works executed by other entities. The second point of the ninth article states that the IPCC may request the collaboration of public and private entities for the performance outlined in points a), b) and e) (Decree-Law nr. 172/1995).

The tenth article describes the duties and obligations of the land parcel holders or beneficiaries: to inform IPCC about a) the existence of parcels of which they are owners or beneficiaries, as well any errors in characterisation of registered land parcels and b) of changes in registered parcels that modified the positioning of any boundary, regardless of changes in area value. Point b) covers the cases of rectification of parcel boundaries by blending and fractionation, detachment, sharing or assembling. Until MRSC starts to be implemented, all rustic cadastral information will be converted to digital format in order to preserve historic records, maintain update information and improve access to data (Decree-Law nr. 172/1995).

2.2.2 The IGP foundation

In 2002, IGP was created by fusion of the IPCC and the National Centre of Geographic Information (CNIG) and made official by the Decree-Law nr. 8/2002, from January 1^{st}. This document assigns competences and responsibilities to: define references for rustic and cadastre land parcels; recognize referenced properties; issue real state identification cards; support assessment of real state properties; maintain and update cadastral data and information; and provide certification of existent cadastral elements (Decree-Law nr. 8/2002).

One of the IGP major challenges is to harmonise and coordinate the articulation between different institutions. From all those entities the IGP must ensure, with the General Directorate of registries and Notaries (DGRN), with the General Directorate of Taxes (DGCI) and with the Property Register Conservatories, the mutually exchange and update of real state data information. Even with such clear competences, the IGP deals with a difficult task regarding the harmonization of Portuguese Real State Cadastre. Until all institutions ensure interoperability standardised methods and processes among their information systems, the lack of cadastre information will be a strong barrier on progress and development of Portuguese cadastral panorama (Decree-Law nr. 8/2002).

2.2.3 The beginning of SiNErGIC project

In 2006, the Resolution of the Council of Ministers nr. 45/2006 proposed the creation of a National System for the Operation and Management of Cadastral Information (SiNErGIC), in order to enable the implementation of a national real estate cadastral information system. The SiNErGIC was mainly conceptualized and modelled based on the Cadastre 2014 and the CCDM. It is intended that, in future, the SiNErGIC ensures an interoperable and transversal cadastre system, making possible the registration, execution and dissemination of cadastral information within the same technological infrastructure (see appendix 2.) (Resolution of the Council of Ministers nr. 45/2006).

Such platform will allow to maintain updated the continuous changes associated with any rustic parcel. This update process is divided into six stages: Instruction; Reception and pre-analysis; Resolution; Process Information; Office analysis; and Conclusion. The nature of the requested update can be: parcel division; parcel division for urban purposes; area rectification; boundaries rectification; parcel elimination; parcel union; sub-parcel land use change; parcel designation change; and parcel elimination. It is expected that, in the future, these updating procedures will be automated and managed mainly by public authorities

(IGEO, 2009). The presented example (see figure 2.1) is composed by nine stage, being the seventh stage (Municipal Certification) one of the main motivations of this research.

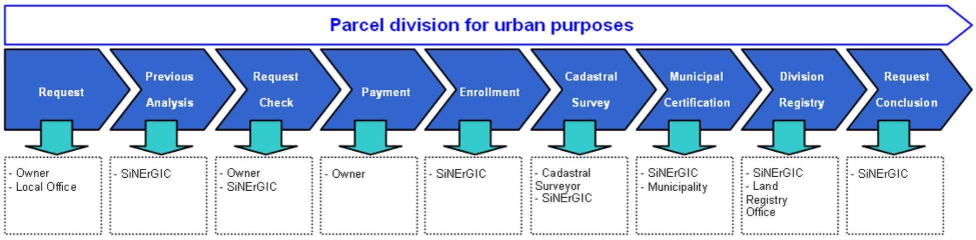

Figure 2.1: Update procedures for a parcel division (IGEO, 2009).

The update process starts with the land parcel owner requesting through SiNErGIC a parcel division for urban purposes (first stage). With the cadastral survey finished, the owner uploads the data in the SiNErGIC platform (sixth stage). The SiNErGIC mechanism validates and stores the survey. After that, the platform notifies the Municipality and asks for the division certification. In this stage (seventh), the Municipality's role is to certify "that the parcel division for urban purposes update fulfils all the legal requires and its jurisdiction". To issue the certification into the system the municipality has to first perform some analysis operations to be sure if the request is valid or not. If the analysis results are satisfactory, the municipality will certify the request through the platform, but if the results are unsatisfactory the request is denied. In the last stage (ninth) the SiNErGIC platform assigns the new NIP to each involved parcel and update online the cadastre information (IGEO, 2009).

It is expected that Municipalities start to use real state cadastre information as basis for development and implementation of PDM when SiNErGIC reach to its full operation stage. Until SiNErGIC reaches maturity, the IGP will continue to work on implementation of the Geometric Cadastre of Rustic Property Information System (SICGPR). This project consists on the conversion of rustic cadastral maps into raster and vector format in order to preserve historic records, maintain updated existent data and improve information access (IGEO, 2009).

2.3 The municipal cadastre update process

Over the years, the Municipality is dealing with a growing number of requests for cadastre use updating. In most cases, these requests originate from the owner's will to perform an urban intervention in a parcel. The Decree-Law nr. 26/2010 defines an urban intervention as a physical operations of urbanization, construction and use of land. These uses of land consider six categories and are defined by the Decree nr. 11/2009. This Decree also states that each land use should be compliant with the municipal PDM in order to be regulated and accepted. The PDM is the basic tool for planning and aims to define a coherent model of development based on a set of objectives and a strategy that promotes a balanced occupation of the soil (Resolution of the Council of Ministers nr. 15/1994).

To issue an urban intervention permit for a parcel, the authorising municipal entity requires the owner to deliver a preliminary project draft. One of its basic requirements is a map consisting of the georeferenced boundary. In order to accept that draft, the municipal entity has to conduct a comparison between the existing municipal rustic cadastral cartography and the urban intervention map delivered by the land owner.

The spatial verification is based on a geometry comparison and usually executed using computer-aided design (CAD) tools. The thematic verification is based on a comparison between the parcel land use designated in the PDM and the urban land use proposed for the urban intervention. This comparison is commonly based on a interpretation founded on the law and on the knowledge of the technician. The results of these comparisons are classified, described in a report and then remitted to the land owner. This update process based on a urban intervention project is fully depicted in figure 2.2.

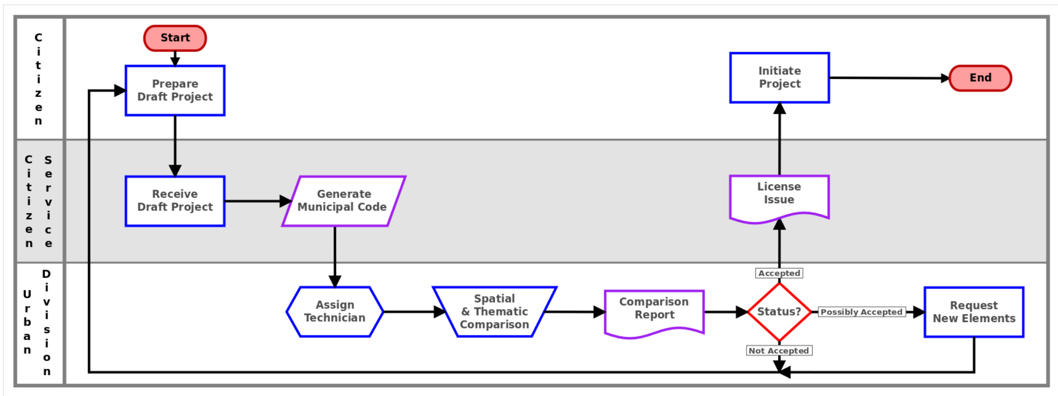

Figure 2.2: Muncipal cadastre update process.

3. THEORETICAL BACKGROUND

The previous chapter introduces an overview of cadastral systems evolution on an international and national level. From this progression, some of the enforcements made by different organizations to create international standards are pointed out, in order to create common rules and facilitate interoperability between heterogeneous systems. This chapter presents the theoretical background research made about the relevant topics for this project. Section 3.1 gives an overview of the institutions related with the development of the cadastral models described in the chapter 2. Section 3.2 focuses on spatial Relational Database Management Systems (RDBMS) and its components. Section 3.3 introduces the semantic web definition and describes some of the semantic web technologies that help to ensure interoperability among existent cadastral applications. Finally, section 3.4 highlight some of the concepts of FLOSS relevant for this research.

3.1 Institutions & standards overview

3.1.1 FIG

The Fédération Internationale des Géomètres (FIG) was founded in 1878 in Paris, France. It is an international organization that represents globally the survey community and more than 100 countries all over the world. The FIG has as members in its group: National associations connected to surveying disciplines (members associations); Surveying associations (affiliates); Organizations, institutions or agencies that provide surveying commercial services (corporate members); and Organizations, institutions or agencies that provide surveying education or research (academic members). The FIG technical work is distributed by ten commissions, being each commission managed by a delegate of one member association. All the technical work related with cadastre and land management is coordinated by Commission 7. Furthermore, this commission is divided in three working groups: 7.1 – Development of Pro Poor Land Management and Land Administration; 7.2 – Development Sustainable Land Administration to Support Sustainable Development; and 7.3 – Application of Innovative Technology in Land Administration (FIG, 2011).

3.1.2 OGC

The Open Geospatial Consortium (OGC) appeared in 1994 as a consortium of companies, government agencies and universities that work to develop free and open international standards. This interoperable and public standards are available with the purpose to bring geographic capabilities into geospatial and location based services. In 1997 OGC brought to public a first technical document named as OpenGis Simple Features Specification (SFS). This standard suggests procedures to store digital geographic data composed by spatial and non-spatial attributes. Since the release of SFS, standards such as the OpenGis Geographic Objects Interface Standard (GOS), the OpenGIS Geography Markup Language Encoding Standard (GML) and also the OpenGIS Simple Features Specification For SQL (SFSS) were developed and continuously updated. OGC vision is based on a spatial platform of products and services where developers and users can participate actively in the creation of new international 'geo-standards'(OGC, 2011).

3.1.3 W3C

The World Wide Web Consortium (W3C) was founded in 1994 by Tim Berners-Lee, the 'father' of the World Wide Web (WWW). The W3C is mainly focused on creating protocols, guidelines and materials to support the WWW development and its potentiality. This international consortium has the mission to produce high-quality standards grounded on the active participation of members, experts, Web community and public. In order to better organise this intensive participation and to proceed with its mission, the W3C is composed by: working groups that produce deliverables, interests groups that gather people to perform evaluation and coordination groups that promote communication inside and outside the organisation. All the work developed by these groups stand on the following principles: a 'Web for all' , a 'Web on everything' , a 'Web of data and services' and a 'Web of Trust'. The W3C present and future vision point towards a Web built based on participation, knowledge sharing and global trust (W3C, 2011).

3.1.4 FAO

The Food and Agriculture Organization (FAO) was founded in 1945, is part of the UN and its primary goal is the fight against hunger around the World. FAO assumes the paper of neutral mediator between countries with the objective of promoting agreements and discussions on agriculture, forestry, fisheries practices and global nutrition (FAO, 2011).

3.1.5 European Commission INSPIRE Directive

The Infrastructure for Spatial Information in Europe (INSPIRE) is a directive created by the European Union to regulate the creation of a European Spatial Data Infrastructure (SDI). Through the development and publishment of Data Specification documents, the

INSPIRE Thematic Working Groups provides guidelines to promote the interoperability and implementation of a large number of spatial data sets and services.

The INSPIRE *D2.8.I.6 Data Specification on Cadastral Parcels* is a document that provides guidelines for the harmonisation on the geometrical aspects of the existent cadastral systems in the European Union. This document describes a data model compatible with the upcoming international standard on LADM (INSPIRE, 2009).

3.2 Database Management Systems

3.2.1 Spatial databases

A spatial database system is an information management system that is capable of dealing with spatial data by making use of spatial data types, spatial indexing, spatial operators and spatial application routines. This spatially enabled system was primarily designed with the intent to pre-process and process data so that it could later be analysed and modelled by the GIS desktop applications. These applications were also providing means to access, updating and extraction of the spatial data contained inside the database systems. In the present days, with the evolution of the IT and standards, spatial databases are growing in capabilities and functions such as: different types of geometries; topological, projective and metric operators; semantic reasoning; and spatial SQL. In consequence of this exponential development, it is now possible to deal more and more with spatial data without making use of GIS desktop applications (Yeung and Hall, 2007).

3.2.2 E-R Model

In 1976, Chen (1976) introduced the entity-relationship model as a tool for database design. This model based on a unified view of data has the intent to represent “the important semantic information about the real world” through entities and relationships in a structured way. In this model, an entity is a 'thing' that can be 'distinctly identified' and the relationship as an 'association among entities' . In order to enrich the semantic information and the linkage between entities, attributes, value-types and cardinality information should be considered in the model (see figure 3.1). Currently the E-R model continues to be broadly used in the development of RDBMS.

3.2.3 SQL

The Structured Query Language (SQL) was designed with the intent of dealing with data from RDBMS. This declarative query language, originated in the relational algebra, started to be more applied when Codd developed a relational model to be applied in database management systems. In order to perform an extensive number of operations with the data stored in RDBMS, the SQL is composed by language elements such as 'Clauses', 'Expressions', 'Predicates', 'Queries'and 'Statements'(figure 3.2). These elements are invoked in SQL through the use of the Data Definition Language (DDL), Data Manipulation Language (DML), Data Definition Language and Data Control Language (DCL) (Culturalview, 2010).

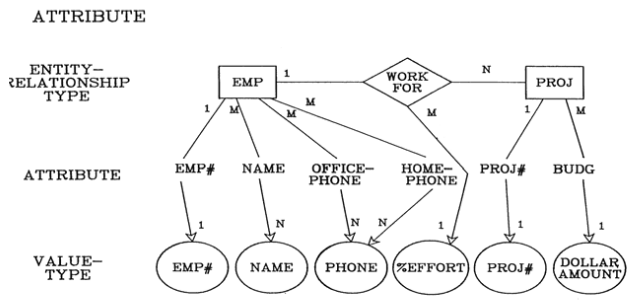

Figure 3.1: An Entity-Relationship (ER) Diagram (Chen, 2002).

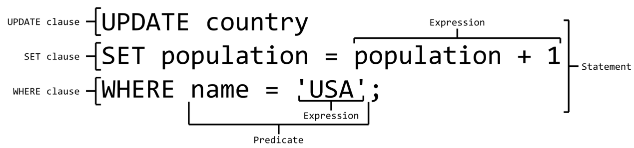

Figure 3.2: Some of the elements that can compose a SQL statement (Culturalview, 2010).

3.3 Semantic Web

The vision of a Semantic Web (SW) started to be sketched by Tim Berners-Lee in the beginning of the WWW; however only in 1998 did it become more solid and real. This vision has as main principle the need to populate web resources with enough context so software agents can better 'think' and, in consequence, improve their decision capabilities. The context provides description capabilities to web information, making it possible to find an object not only by its content but also by its 'metadata'. Being conscious of the possibility that WWW may succumb to commercial interests, the W3C decided to develop new open standards in order to ensure interoperability and homogeneity of the web universe (Matthews, 2005).

3.3.1 Knowledge Representation

3.3.1.1 Ontology

"An ontology is an explicit specification of a conceptualization." (Gruber, 1995), being conceptualisation an abstract representation of the domain knowledge to be described. Although the ontological research for knowledge management and sharing had its exploitation in Artificial Intelligence (AI), it quickly became essential to more areas of the computer science as well to other communities (Fonseca et al, 2000).

Understanding the generality level of an ontology is vital to an appropriate knowledge representation and extraction in the conceptualised domain. For this purpose Guarino (1997a) suggests four types of ontologies grouped into three levels of dependence: Top-level ontologies have the intention to illustrate broad concepts such as space, time, object, event, action, etc., independently of a specific domain; Domain ontologies and task ontologies have the intention to cover the vocabulary of a wide domain or a wide task or activity, by depicting the terms included in the top-level ontology; Application ontologies is a specialisation of the domain and task ontologies and it is defined to be used with a specific application (Guarino, 1997b). "In that sense, they tend to translate the user necessities regarding a particular application, as for example, some spatial analysis operations in the context of the GIS software."(Painho, 2007).

Defined the type of ontology that better represents a specific domain, the following design criteria should be taken in account: 'Clarity', 'Coherence', 'Extendibility', 'Minimal encoding bias', and 'Minimal ontological commitment' (Gruber, 1995). Finally, it is vital that the resultant ontology contains the following elements: 'Lexicon'; 'Concepts'; 'Semantics properties', 'Semantic relations', and 'Relations'; and 'Axioms' (Tomai and Kavouras, 2003).

3.3.1.2 Methontology

Fernandez, Goméz-Peréz, and Juristo (1997) pointed out that the ontological "art will became engineering when there exist a definition and standardization of a life cycle that goes from requirements definition to maintenance of the finished product, as well as methodologies and techniques that drive their development.". Based on this idea, Fernandez, Goméz-Peréz, and Juristo. proposed a structured method, based on natural language, to describe the entire life cycle of an ontology.

3.3.2 Semantic Web Technologies

In 1998, the W3C created the Web Metadata Working group with the intent to develop the Resource Description Framework (RDF) Model and the RDF Schema Specification. However, the work progression was limited and consequently in 1999 the United States of America (USA) Defense Advanced Research Projects Agency (DARPA) initiated the DARPA Agent Markup Language (DAML) programme. This project opened new trails to the SW development by bringing some innovative approaches to the existent problems. At the end of 2000 at the XML 2000 Washington DC conference in USA, Tim Berners-Lee depicted the hierarchy of the SW technologies (figure 3.3). Motivated by the SW evolution, in 2001 the W3C created two more working groups: The RDF Core Working Group and the Web Ontology Working Group (Matthews, 2005).
Later in the same year, the DAML+Ontology Inference Layer(OIL) was proposed as a W3C standard (Connolly et al, 2001).

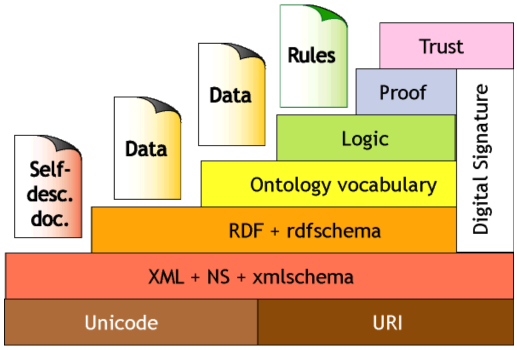

Figure 3.3: Tim Berners-Lee Semantic Web Layer Cake (Berners-Lee, 2000)

3.3.2.1 RDF

Being the third layer of the Berners-Lee SW 'cake', RDF is a data standard that brought new capabilities to conceptual description and information modelling. RDF uses a graph-based approach to represent information as statements. Such set of assertions are called 'Triples' and are composed of three elements: 'Subject', 'Predicate'and 'Object'. The subject is the thing described by the statement, the predicate represents the relationship between the two nodes using an Uniform Research Identifier (URI), and the object is a concrete value. (table 3.1) depicts an excerpt of a RDF ontology.From all the existent ways to serialise RDF statements, RDF/XML, Terse RDF Triple Language (Turtle), and N-Triples are the most commonly used (Klyne, Carroll, and McBride, 2004).

```
<Class rdf:about="http://ex.owl#PA">
    <equivalentClass>
        <Class>
            <intersectionOf rdf:parseType="Collection">
                <Restriction>
                    <onProperty rdf:resource="http://ex.owl#hasType"/>
                    <someValuesFrom rdf:resource="http://ex.owl#ULU"/>
                </Restriction>
                <Restriction>
                    <onProperty rdf:resource="http://ex.owl#hasType"/>
                    <someValuesFrom rdf:resource="http://ex.owl#PDMA"/>
                </Restriction>
            </intersectionOf>
        </Class>
    </equivalentClass>
    <rdfs:subClassOf rdf:resource="http://ex.owl#xxxxxx"/>
    <rdfs:comment xml:lang="en">etc...etc</rdfs:comment>
    <equivalentClass>
</Class>
```

Table 3.1: Excerpt of a RDF/XML document structure.

3.3.2.2 OWL

The Web Ontology Language (OWL) was developed by W3C and its first release was on February 2004. The OWL is a vocabulary extension of RDF and emerged from the DAML+OIL Web Ontology Language. The main purpose of this language is to define and instantiate Web Ontologies. The OWL provides classes, properties and instances. 'Classes' are groups of individuals that share common properties; 'Properties' have the function to connect individuals; and 'Individuals' are classes instances. Making use of formal semantics OWL allows the reasoning about classes and individuals and, therefore, derive facts that are not directly explicit in the ontologies but are evident through the semantic statements. Taking into account different needs of ontology developers and users, the OWL language is divide in three sub-languages: OWL Lite; OWL DL; and OWL Full.

The OWL Lite mainly supports "classification hierarchy and simple constraint features". The OWL DL gives "maximum expressiveness without losing computational completeness and decidability of reasoning systems". OWL DL supports Description Logics (DL) and therefore provides a more complete reasoning. The OWL Full gives "maximum expressiveness and the syntactic freedom of RDF" (Smith, Welty, and McGuinness, 2004).

In October 2009 W3C announced the release of OWL2. This revision of the OWL is composed by three distinct syntactic categories: 'Entities' are elements of the domain, such as classes, properties, and individuals; 'Expressions' are the representation of domains complex notion; and 'Axioms' are true statements about the domain. With OWL2 came the possibility to annotate entities, axioms, and ontologies, although they can not yet be used by reasoning systems in inference operations. In relation to the previous version, the OWL2 brought some new features and improvements, such as: property chains; richer datatypes, data ranges; qualified cardinality restrictions; asymmetric, reflexive, and disjoint properties; and enhanced annotation capabilities (Bao et al, 2009). Table 3.2 depicts the same excerpt presented in the RDF section, but in a OWL2 version.

```
<EquivalentClasses>
    <Class IRI="http://ex.owl#PA"/>
    <ObjectIntersectionOf>
        <ObjectSomeValuesFrom>
            <ObjectProperty IRI="http://ex.owl#hasType"/>
            <Class IRI="http://ex.owl#ULU"/>
        </ObjectSomeValuesFrom>
        <ObjectSomeValuesFrom>
            <ObjectProperty IRI="http://ex.owl#hasType"/>
            <Class IRI="http://ex.owl#PDMA"/>
        </ObjectSomeValuesFrom>
    </ObjectIntersectionOf>
</EquivalentClasses>
<AnnotationAssertion>
    <AnnotationProperty abbreviatedIRI="rdfs:comment"/>
    <IRI>http://ex.owl#PA</IRI>
    <Literal xml:lang="en" datatypeIRI="&rdf;PlainLiteral">etc...etc</Literal>
</AnnotationAssertion>
```

Table 3.2: Excerpt of an OWL2/XML document structure.

3.3.3 Description Logics

“Description logics (DL) are a family of knowledge representation languages that can be used to represent the knowledge of an application domain in a structured and formally well-understood way”. DL can be a very useful tool on the definition, integration and maintenance of ontologies. Each DL language uses atomic concepts and roles to define concept descriptions, which in turn will describe the domain notions (Baader, Horrocks, and Sattler, 2007).

A DL knowledge-base (KB) is composed by statements derived from concept descriptions. This KB is divided by a terminological part (TBox) and an assertional part (ABox). The TBox contains properties of concepts and roles, and also the relationships between both of them. The ABox defines the properties of each existent individual. Making the analogy with database settings, the TBox is the schema and the ABox is the data (Baader, Horrocks, and Sattler, 2007).

3.3.4 Reasoning

From the extensive variety of DL languages, the most commonly used in DL reasoning services is the Attributive concept Language with Complements ($\mathcal{ALC}$). In order to answer the needs of the emergent semantic web technologies, $\mathcal{ALC}$ had to be expanded with some new capabilities. For the three OWL 2 types is possibly to use the following DL language expressiveness: $\mathcal{SROIQ}(\mathcal{D})$ for OWL Full, $\mathcal{SHOIN}(\mathcal{D})$ for OWL DL, and $\mathcal{SHIQ}(\mathcal{D})$ for OWL Lite (Baader, Horrocks, and Sattler, 2007).

Using the mentioned DL languages the reasoning systems can automatically deduce knowledge that is indirectly expressed in the explicit knowledge. The use of DL reasoning during the design and deployment phases may help to enrich the ontology quality and structure respectively (Baader, Horrocks, and Sattler, 2007).

3.3.5 XML

The Extensible Markup Language is a self-descriptive text format extended from the ISO Standard Generalized Markup Language (SGML). This standard was developed with the main purpose to exchange and to make data interoperable through the World Wide Web (WWW). XML v1.0 was developed by the W3C XML Core Working Group in 1996 and the last document specification (fifth edition) update was released on November 2008. The version 1.1 was released on February 2004 and had its second edition on August 2006. This new version brought support to Extended Binary Coded Decimal Interchange Code (EBCDIC), although, it is no so commonly used. The XML was designed with the intent to easily be supported by an extensive number of software solutions, to be human-legible and comprehensible, to be quick to prepare and to be simple to create (Bray et al, 2008).

A XML document to be valid should contain reference to a schema and be composed by a logical and a physical structure. The first contemplates element-tags that serve as document boundaries and are identified by type and name. The second encompasses entities that play a role of contents storage and that can be parsed or unparsed. Due to the XML scalability and strong support for different languages through UNICODE, a large number of XML-based formats have been developed over the last years (Bray et al, 2008). This extensive list contains names as: OIL, OWL, RDF, RFML, RSS, SHOE, etc. (Cover, 2005).

3.4 FLOSS

3.4.1 Free software

"Free software is a matter of the users freedom to run, copy, distribute, study, change and improve the software.". Being free does not mean that is free-of-charge, but says that no permission is needed to do any of the things pointed out in the previous sentence. Also, free software does not discard the idea of being non-commercial, but says that independently of the price the user should be free to copy, modify or distribute the acquired software (GNU, 2010).

3.4.2 Open-source software

A software to be considered open-source should guarantee the following criteria: Free redistribution or in other words, who redistributes should not have any cost with it; the source code should be accessible to the user; the license of the software should allow changes or 'clone' distributions under the same terms; the integrity of the author's source code should be respected; the software license should not discriminate any person or group; the software license should not discriminate any field of endeavour; the rights of the software should be common to all the redistributed versions; the license of the software should not be specific to a product; the license of the software should not restrict other software's; and the license of the software should be technology-neutral (OpenSource, 2011).

3.4.3 FLOSS Applications

3.4.3.1 PostgrsSQL/PostGIS

In 2001 the Refractions Research company released an open-source spatial database technology, called PostGIS. This database extension acts as a 'spatial enabler' for PostgreSQL relational database, making it an object-relational database equipped with more than three hundred spatial functions. These functions are primarily based on the the *OpenGIS Simple Features Specification for SQL* (OGC, 2010) and the *OGC/ISO SQL/MM-Part 3: Spatial* (Ashworth, 2004), while most of the rest are native from PostGIS. Currently this database spatial extension provides capabilities to connect through GIS desktop software, basic topology support, data validation, coordinate transformation through the Cartographic Projections library Proj.4, write functions with different programming languages, spatial and statistical analysis, export data in several standards formats, etc. (Refractions, 2011a) (Refractions, 2011b).

3.4.3.2 Protégé

The Protégé was developed and is maintained by Stanford Center for Biomedical Informatics Research at the Stanford University School of Medicine. The Core Protégé is a free and open-source ontology platform developed to provide modelling tools to create domain models and knowledge-based applications. This software allows one to conceptualise, visualise, edit, and share different semantic web formats, such as Manchester Syntax, Turtle, RDF, OWL1 and OWL2. Using the OWL editor interface or through the OWL Java-based Application Programming Interface (API), it is possible to customize or create semantic tools and applications. Protégé 4.1 built on OWL API 3.0.0, the most recent version made available, is the first to meet the OWL 2.0 W3C standard (Stanford, 2010a) (Stanford, 2010b).

3.4.3.3 OpenJump

In 2002, founded by a joint project of four organizations, the Vivid Solutions Inc. designed and developed a commercial GIS software that was called Java Unified Mapping Platform (JUMP). Since there was not a constant development, in 2004 some users decided to initiate the JUMP Pilot Project (JPP) in order to create an active JUMP community of developers and users from all over the world. Because of the different JUMP 'clones' that were being produce by community users, the JPP formed a Development Committee to coordinate and support the creation a free and open-source version of JUMP. To this new GIS software based on OGC standards, the community renamed it as OpenJUMP. The roots that helped this open platform grow were (and continue to be) based on global ideas such as: support and expand the existent user community to an international level; share without discrimination the software source code; and give opportunity for users to design, costumise, and enrich the application (JumpProject, 2009).

3.4.4 Java

Java language was created by James Gosling and made public in 1995 as core component of the Sun Microsystems Java platform (Oracle, 2011a). This derivation of C and C++ syntax was developed based on five primary goals with the intention to be "simple, object oriented, and familiar", "robust and secure", "architecture neutral an portable", "interpreted, threaded, and dynamic", and executed with "high performance" (Sun, 1997). Through the years Java environment became very popular within the available programming languages, and is broadly used in Web services, Desktop and Server applications software, mobile devices, etc.. Even after being purchased by the Oracle Corporation in January of 2010, the Sun Microsystems slogan "Write Once, Run Anywhere™" continues to illustrate the present and future of Java Technology Platform (Oracle, 2010a) (Oracle, 2011b).

4. CONCEPTUALISATION

The state-of-the-art chapter exposes the evolution of the cadastral models from the 90's decade reform to a 2015 vision. It also explores the adopted multipurpose cadastral model in Portugal that, until the present moment, is a pilot project. This model will give opportunity to maintain updated and to share cadastre information between entities and citizens. On a different regional level it will be possible for the citizen to perform an extensive number of requests to distinct entities, that until now are not connected. Furthermore, it is depicted the flowchart of the operations executed inside the Oeiras municipality when the citizen requests a parcel update certification. Having investigated the process workflow and the functions performed by each actor, a different number of issues and needs were identified: cadastral model renovation, interoperability, changes in national articles of the Law, automation of spatial analysis and GIS software budget constraints.

This chapter is dedicated to investigate how different solutions can be merged into a single framework, and how the proposed framework can provide a suitable automated solution to be applied in a specific phase of the municipal cadastre update process. The methodology pointed out in this chapter outlines the way how the proposed work is going to be structured in order to address the research objectives (section 1.4) raised in the first chapter.

4.1 Methodology

To assist in the automation of parcel update from rustic cadastre to urban cadastre, the proposed framework is composed by:

- **(S1)** A spatial database populated with Inspire attributes (INSPIRE, 2009) for storing cadastre parcels and to ensure interoperability between several institutions;
- **(S2)** A set of spatial predicates to classify relationships between 2D geometries using the OpenGIS Simple Features Specification for SQL (OGC, 2010) that implements the Clementini et al. Calculus-Based Method (CBM) (Clementini, 1993);
- **(S3)** A set of geometry processing functions to perform spatial measurements on 2D geometries using the SQL-MM specification (Ashworth, 2004);
- **(T1)** An ontology to store legal information about rustic and urban cadastre categories;

- A set of DL constraints **(T2)** to enable semantic reasoning **(T3)** over the ontology concepts; and item **(C1)** A plugin to assemble the stated functions and run the `Consistency checking` and the `Acceptance checking` of results **(C2)** within a open-source GIS solution.

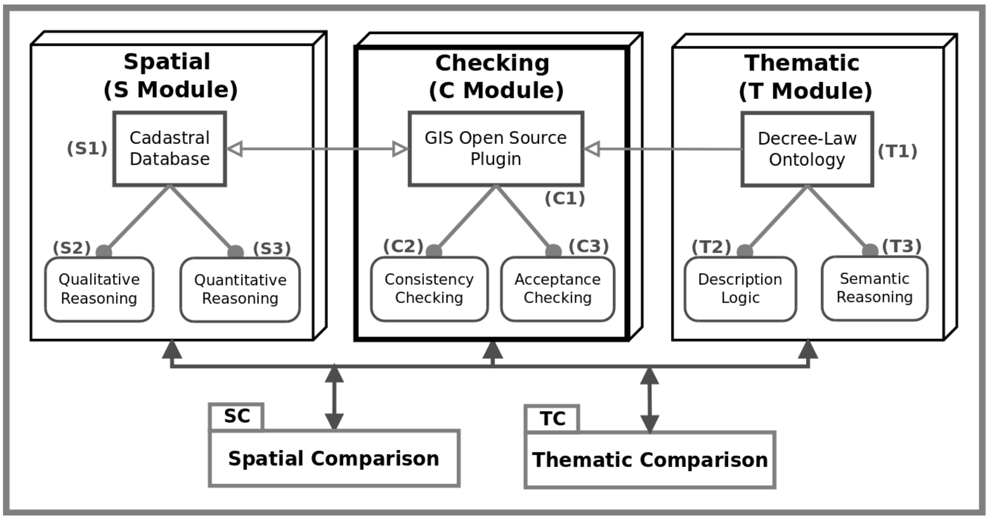

Figure 4.1: Conceptual Framework

As a result, the proposed framework (figure 4.1) should be capable to perform `Spatial comparison (SC)` and `Thematic comparison (TC)` between cadastre polygons, retrieve the results and store information in the cadastral database.

4.2 Conceptual Framework

4.2.1 S Module

In order to ensure the data interoperability between distinct European Community institutions, the remodelling of the existent municipal cadastral database based on the *Inspire Data Specification on Cadastral Parcels* is proposed. These European guidelines can give support on geometric data harmonisation according to the national vision, reality and governance (INSPIRE, 2009). With the idea to satisfy the research objectives and based on the municipal and national future requisites, the proposed database model should satisfy the following requirements:

- Accept existent cadastral Spatial and Thematic entities;
- To be compliant with *INSPIRE data specification on theme Cadastral Parcels* and LADM;
- Store new or updated rustic and urban cadastre data; and

- Ensure that Spatial and Thematic attributes are compliant with defined and planned constraints.

The first requirement proposed a survey of the existing database classes (table 4.1) that should prevail in the model. Since the existent database just contains geometric cadastre of rustic property and the SiNErGIC project is not yet implemented, only the entities depicted in table. are considered in the new model.

Entity	Description
Rustic Parcel	Rustic areas represented in the municipal and national cadastral cartography.
Parish	Administrative areas that contains rustic parcels.
Ownership	Land registers information.

Table 4.1: Entities collected from the municipal cadastral database.

With the necessary entities compiled and explained, the basis for the second requirement is defined. From the INSPIRE cadastral parcel model derived from LADM (INSPIRE, 2009) (see appendix 3.), all entities are considered except the cadastralBoundary as depicted in appendix 4.**a**. This is due to the fact that the existent database only contains 2D entities and this research does not require a model with such complexity. Furthermore, the entity cadastralZoning is simplified on the cadastral parish level.

Taking into account that the rustic data is going to be store in the entity CadastralParcel, to fulfil entirely the third requirement, it is necessary to define how the urban data will be stored. As previously explained in the 2.3, only urban intervention projects are relevant for this research. When submitted to appreciation, the urban boundary is compared with the rustic boundary and the differences associated with this operation need to be stored. To guarantee this condition three entities are suggested: UrbanIntervention, OuterArea and InnerArea (see appendix 4.**b**).

To answer the fourth and last requirement, the relationships between entities and the inherited cardinality are described in table 4.2 and 4.4 respectively.

Entity	Description
Cadastral Parcel	Rustic areas defined by cadastral registers or equivalent. a)
Basic Property Unit	Unique ownership and homogeneous real property rights. b)
Cadastral Zoning	Administrative areas used to divide the Municipality territory into cadastral parishes. a)
Reference System	Coordinate reference system represented by an EPSG code. c)
Urban Intervention	Interventions with urban purpose carried out in urban areas. c)
Outer Areas	Areas of an urban intervention that overlay the neighbouring urban parcel. c)
Inner Areas	The complement of an urban intervention area within the urban parcel. c)

a) Adapted from *INSPIRE data specification on theme Cadastral Parcels*.
b) Transcript from *INSPIRE data specification on theme Cadastral Parcels*.
c) Adapted from conventions adopted by municipality technicians.

Table 4.2: Entities considered in the proposed cadastral database model.

one Cadastral Parcel **is described by** *one and only one* Basic Property Unit
one Cadastral Parcel **relates** *one or more* Urban Ontervention
one Urban Ontervention **contains** *zero or more* Outer Areas
one Urban Ontervention **contains** *zero or more* Inner Areas
one Cadastral Zoning **contains** *one or more* Cadastral Parcel
one Reference System **grounds** *one or more* Cadastral Parcel
one Reference System **grounds** *one or more* Urban Ontervention
one Reference System **grounds** *one or more* Cadastral Zoning
Italic: Cardinality; Underline: Entity; **Bold:** Relationship

Table 4.3: Relationship description of the Entities of the proposed cadastral database model.

After assuring the four requirements, it is now possible to present the E-R model containing the entities and relationships (figure 4.2) discussed in the previous points.

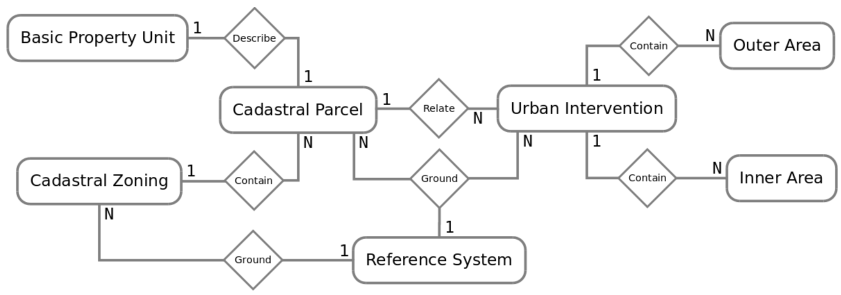

Figure 4.2: E-R model of the proposed cadastral database.

Apart from the entities already described in the E-R model, the entity reference system is also represented. Since the cadastral data to be shared under INSPIRE directive should be published in ETRS89 (INSPIRE, 2009), the entity reference system contemplates this one and also the other coordinate reference systems currently used in the Municipality.

4.2.2 T Module

Defined and conceptualised the `S module`, the thematic side of the proposed framework (see figure 4.1) is discussed in this section. This module should be composed by an expert system that enables the representation of legal relationships between cadastre thematic categories. These relationships and categories are defined by some Portuguese decree-laws (see section 2.2) with some modifications in order to fit the research purposes. To satisfy these purposes and based on the framework requisites, the proposed knowledge-based system should fulfil the following requirements:

- Be capable to deal with constant changes within the content level, ensure structure integrity and provide decision support;
- To be integrated and connected with other modules present in the framework; and
- To follow a unique development process in order to ensure a concrete and complete domain description at the application level.

To meet the first requirement, it is necessary to have the idea that the decree-laws are constantly renewed or new ones are issued, obligating municipalities to be aware and to apply such changes since the moment that these are officialised. In order to be aligned with this reality and ensure freedom of description when conceptualising the understanding of the technicians on legal matters, the development of an ontology is suggested (see section 3.3.1.1).

After defining the expert system to be used and in order to answer the second requirement, it is vital to understand what type of ontology should be integrated in the framework. Being aware that the ontology has only the purpose of storing legal information and it is going to be queried from a software component existing inside a desktop application, the selection rests on an application ontology.

The third requirement can be satisfied by electing a systematic methodology based on a concise and structured life cycle. Taking into consideration these requisites the choice falls on one of the most "comprehensive ontology engineering methodologies" (SemanticWeb, 2010), the METHONTOLOGY. This methodological approach used to build conceptual models of ontologies from scratch is divided in seven phases, as depicted in figure 4.3. Since this chapter is focused in the framework conceptualisation, only the first three phases are depicted and discussed.

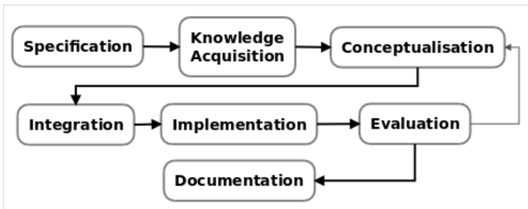

Figure 4.3: METHONTOLOGY life cycle (Pereira, 2005).

4.2.2.1 Specification

This phase is a first attempt of describing in natural language some of the main ideas and questions to be included in the ontology (Fernandez, Goméz-Peréz, and Juristo, 1997) . As discussed previously, this ontology only covers the land use categories used in land management by the municipal entities. Apart from these categories, in this phase, the two existent types of land parcels represented in the cadastral cartography and the three possible status of the `Thematic comparison` between parcels are also presented. Table 4.4 presents a survey of the requirements' specification in the domain of the decree-laws pointed out in section 2.3.

Domain:	Land Administration Laws
Date:	February, 2011
Conceptualized-by:	Paulo Bianchi Candeias
Implemented-by:	Paulo Bianchi Candeias
Purpose:	Ontology describing decree-laws to be used when information about municipality director master plan (PDM) and urban intervention categories is required in cadastre update. This ontology could be used to ascertain the acceptance relationships between rustic and urban land use categories.
	Scope
List of PDM categories (sub-concepts):	Economic Activities, Equipment, Green Spaces, Residential.
List of Urban Intervention categories (sub-concepts):	Environmental Balance, Hydric Domain, Industrial, Industrial Expansion, Maritime Public Domain, Multi-use, National Agricultural Public Domain, National Ecological Reserve, Natural Protected Areas, Public Domain, Semi-Rural, Tertiary, Urban and Urbanised.
List of Land Parcel types (sub-concepts):	Rustic and Urban.
List of Concepts and other sub-concepts:	Feature, PDM Categories, Urban Land Use Categories, Geo-Feature, Land Parcel, Status, Accepted, Not Accepted and Possibly Accepted.
List of Properties:	has category, has relation.
Sources of Knowledge:	Decree-Law nr. 26/2010; Decree nr. 11/2009; Resolution of the Council of Ministers nr. 15/94; Cadastral information system - a resource for the E.U. Policies.

Table 4.4: METHONTOLOGY Requirement Specification Document (Fernandez, Goméz-Peréz, and Juristo, 1997).

4.2.2.2 Knowledge Acquisition

This phase covers the sources of knowledge surveyed, studied and analysed during the specification phase (Fernandez, Goméz-Peréz, and Juristo, 1997) . Together with the knowledge of the technicians involved in the municipal certification (see section 2.3), the information contained in the decree-laws described in appendix 5. is conceptualised and modelled in order to fit the purposes of this research.

4.2.2.3 Conceptualisation

This phase is defined by five stages. Each of these stages are composed by specific activities performed in order to support the modelling of the conceptual ontology.

a) Glossary of terms

In this first stage a survey of relevant concepts, instances, verbs and properties is compiled in a concise document. During the entire conceptualisation phase, this document should be reviewed and improved whenever new terms are shown to be relevant for the ontology development (Fernandez, Goméz-Peréz, and Juristo, 1997). Appendix 6. points out the terms that populate the glossary used in this ontology.

b) Concept Classification Tree

Based on the glossary presented in the (see appendix 6.), the terms are disposed on an hierarchical order expressing the concepts, sub-concepts (Belhadef and Kholladi, 2009) and relations to be included in the final ontology (see figure 4.4). The METHONTOLOGY method does not contemplate the representation of relations in the classification tree, but since this conceptual ontology only requires two, the use of a dashed line to depict them is stipulated. From all the concepts represented in the classification tree, it is important to highlight the sub-concepts of the Accepted, Not Accepted and Possibly Accepted concept. These sub-concepts have inherited the same names of the sub-concepts of the PDM Category concept. This case is due to the fact that the Oeiras PDM is the basic tool for land planning and management used in the Municipality (Resolution of the Council of Ministers nr. 15/1994). These sub-concepts conceptualise the idea that the status in what relies each urban land use category, is the result of the acceptance of each urban land use category when compared with the PDM categories.

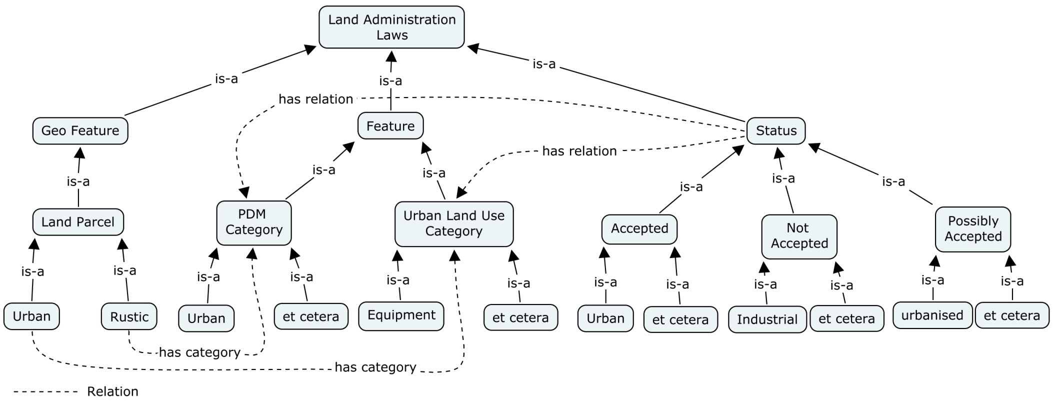

Figure 4.4: METHONTOLOGY Concept Classification Tree (Belhadef and Kholladi, 2009).

c) Concept dictionary table

In this third stage one or more synonyms are assigned to each concept (Belhadef and Kholladi, 2009), in order to enrich the semantic interoperability (see appendix 8.). Since the sub-concepts of the Accepted, Not Accepted and Possibly Accepted concept have the same name of the sub-concepts of the PDM category concept, their names are not presented.

d) Binary relations table

Based on the designation and synonyms of each concept, the relations and the cardinality constraints for the related instances of the source and target concepts are defined in this stage (see appendix 7.) (Belhadef and Kholladi, 2009). These relations, already depicted in figure 4.4, allow the connection between concepts from the viewpoint of the domain.

e) Logical Axioms Table

In this last stage of the conceptualisation phase each concept is characterized by an axiom which, in turn, is described by a first-order logic expression (FOL) (Belhadef and Kholladi, 2009). Since the FOL expression of each sub-concept of the Accepted, Not Accepted and Possibly Accepted concepts is very similar, the appendix 9. only presents one expression for each of these concepts. Finished the conceptualisation phase, this conceptual ontology is now ready to be modelled into a logical ontology. This operation is discussed and depicted in the next chapter.

4.2.3 C Module

After conceptualising the `S and T Modules` of the framework, it is essential to define how the `C Module` can be connected with both modules, and retrieve the results. This module is the core of the framework and should be operated from a GIS Desktop. It is expected that the triggered actions can be performed in an encapsulated way, presenting to the user just the results of the `Spatial and Thematic comparison`. To satisfy the research objectives (and based on the framework requisites), the proposed plugin should fulfil the following requirements:

- Be capable to read rustic and urban data from the spatial database and to present it to the user;
- Perform a `Spatial comparison` over the geometry of the selected cadastre data;
- Run the `Consistency checking` of the `Spatial comparison` based on the defined constraints;
- Associate results with urban parcel, retrieve it to the user and store it in the database;
- Perform a `Thematic comparison` between the categories of the selected cadastre data;
- Run the `Acceptance checking` of the thematic results based on the defined ontology structure; and
- Associate results with urban parcel, retrieve it to the user and store it in the database.

The first requisite demand is to provide a simple and intuitive interface for the user to insert the number, the parish and the section of the desired rustic parcel, and the Municipality reference of the urban parcel. Making use of the same interface, the user should be capable to search the database and visualise the retrieved data. The interface should provide a function to perform the second action, the `Spatial comparison`. From the enumerated requisites this is the only one that needs the user's interaction, since the other actions are encapsulated and only retrieve information. The (figure 4.5) depicts a case representing all the points discussed in this first requirement.

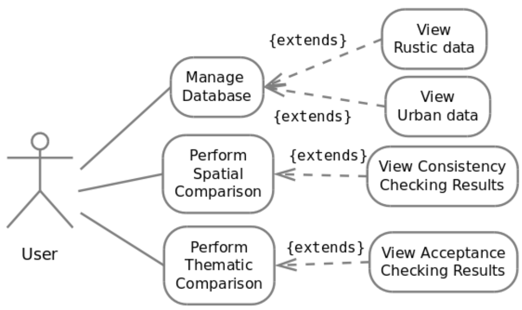

Figure 4.5: Use Case Diagram for C Module.

4.2.3.1 Spatial Comparison and Consistency Checking

The `Spatial comparison` operation uses a spatial predicates set to classify relationships between the rustic and urban geometries. This classification is based on the CBM. Although this function is part of the S Module (see figure 4.1 in section 4.2), it is chosen to be explained and depicted on the present section, in order to provide a more detailed understanding. In this research the OGC implementation of the CBM is used to represent a set of six topological relationships between area features (OGC, 2010) (Clementini, Di Felice, and van Oosterom, 1993). This method is used to distinguishes cases when the relationship between cadastre parcels is equal, touch, disjoint, contain, within or overlap (figure 4.6). Taking into account the binary result of the relationship and based on the defined rules, the `Consistency checking` process assigns six possible classifications. Since the request for a cadastre update depends on the presentation of an urban project, the assigned classification should be associated with the urban intervention entity in the database.

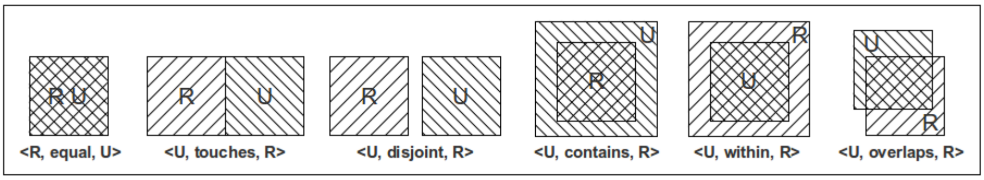

Figure 4.6: Six toplogical relationships based on CBM (Clementini, 1993).

- So when the spatial relationship is equal, the urban intervention is classified as Consistent. In this case there is no more spatial operations, and the next step is the `Thematic comparison` process;
- If the relationship is touch or disjoint, the urban intervention is classified as Inconsistent. In this case the task flow ends;
- If the relationship is contain, the urban intervention is classified as Possibly Consistent. In this case the urban parcel encloses the rustic parcel and overlaps one or more neighbour parcels. In the end, these overlapped areas are stored in the outer area entity and followed by the `Thematic comparison` process;
- If the relationship is within, the urban intervention is classified as Possibly Consistent. In this case the urban parcel is enclosed by the rustic parcel, and therefore the urban parcel needs to be subtracted from the rustic parcel in order to obtain the remaining areas. In the end, these areas are stored in the inner area entity and followed by the `Thematic comparison` process; and
- If the relationship is overlap, the urban intervention is classified as Possibly Consistent. In this case, the urban parcel partially covers the rustic parcel, and one or more neighbour parcels. The neighbours overlapped areas are stored in the outer area entity, the remaining areas from the rustic parcel are stored in the inner area entity, and the task flow is followed by the `Thematic comparison` process.

The figure 4.7 depicts a flowchart representing the points previously discussed.

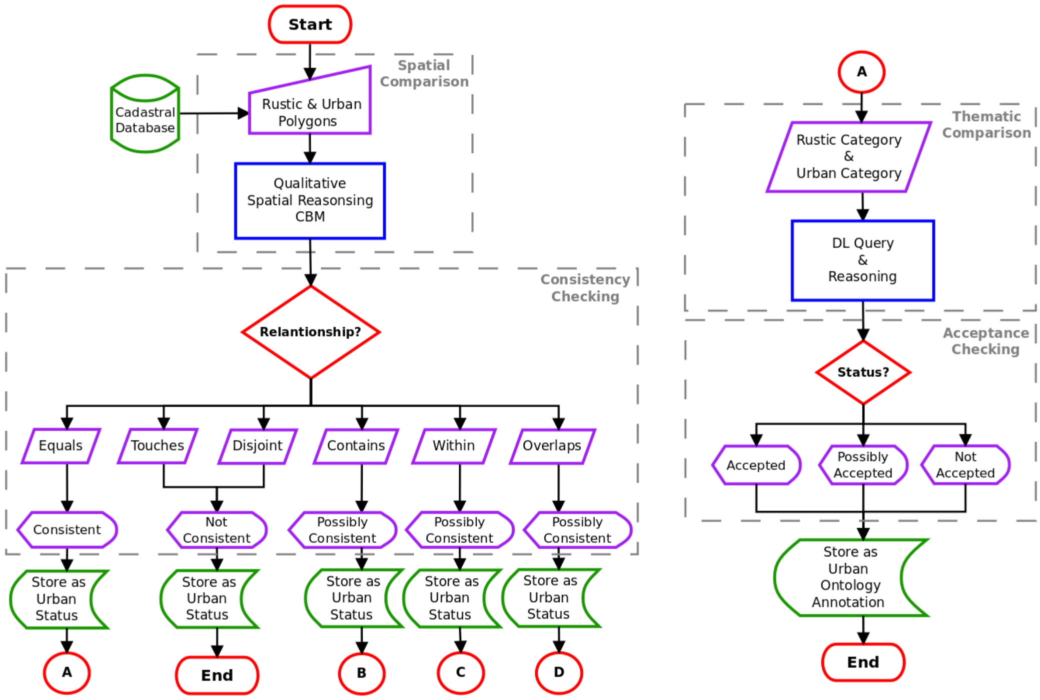

Figure 4.7: Spatial comparison and Consistency checking flowchart.

After reaching this point, the second, third and fourth requirements are fulfilled and the next step in the conceptualization of this module can be defined.

4.2.3.2 Thematic Comparison and Acceptance Checking

Although the `Thematic comparison` is part of the T Module (see figure 4.1), for a better understanding, this is explained and depicted in the present section. This comparison operation makes use of DL querying (Baader, Horrocks, and Sattler, 2007) and reasoning capabilities over the ontology to ascertain the concept that describes the relationship between rustic and urban categories. Based on the query findings, the `Acceptance checking` process extracts the annotation of the ascertained sub-concept, that can be contained in one of the following three predefined concepts: Accepted, if the rustic category comprises the urban category; Not Accepted, if the rustic category does not comprise the urban category; or Possibly Accepted, if the rustic category partial comprises the urban category. After the extraction process, the annotation should be assigned to the urban intervention feature and consequently presented to the user through the proposed interface. The figure 4.8 depicts a flowchart representing the points previously discussed.

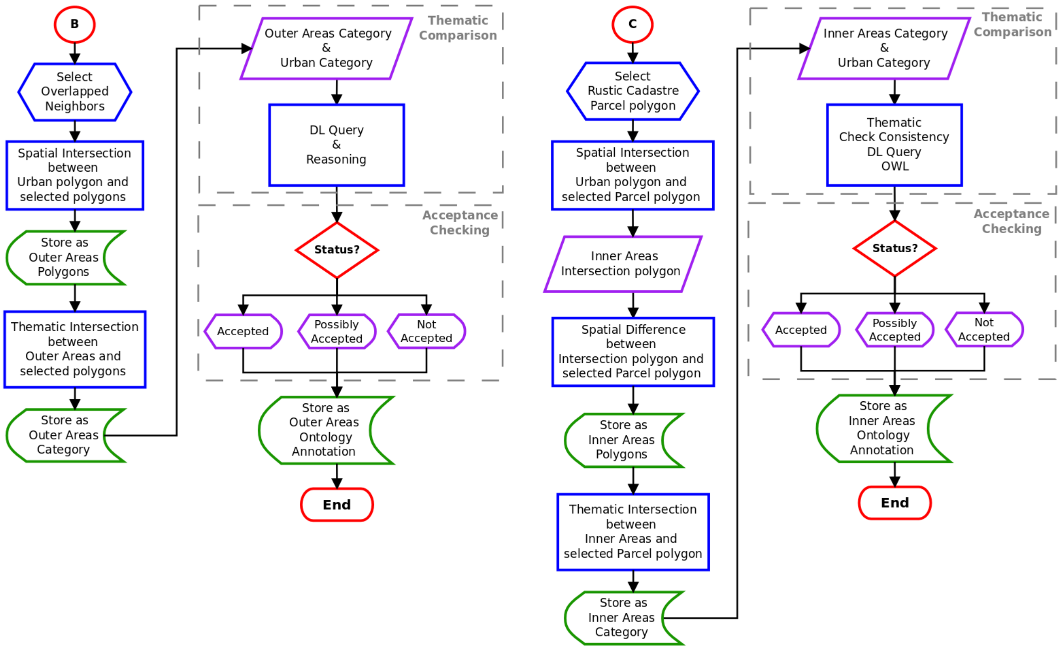

Figure 4.8: Consistency checking - Possibly Consistent Classification Flowchart.

Should this point be reached, the fifth, sixth and seventh requirements are fulfilled and, hence, the conceptualisation of this module is totally described.

4.2.3.3 Prototype

In order to meet some of the discussed requirements, an explicit representation of the desired Graphical Unit Interface (GUI) to be built in the design phase is suggested. This mock-up prototype ensures that the input, navigation, and information functions are represented accordingly to the framework specifications. Given that the user interaction with the system is minimal, this research points directly towards an high-fidelity prototype (Benyon, Turner, and Turner, 2005), or in other words, a prototype produced in a prototyping development software (figure 4.9).

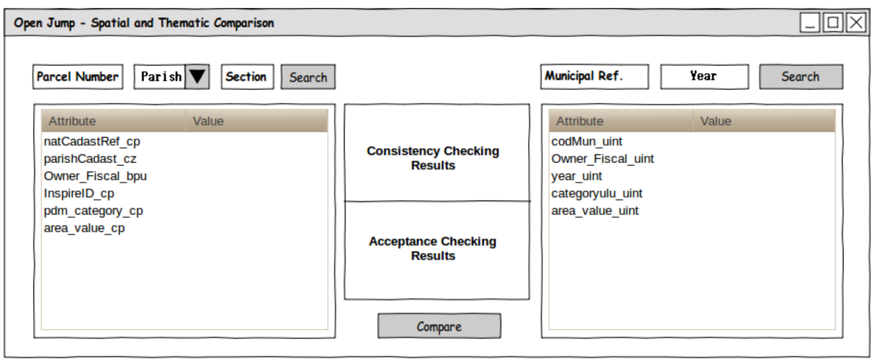

Figure 4.9: Plugin Interface Mock-Up Prototype.

5. DESIGN

The previous chapter discussed the conceptualisation of the three modules underlined by this research. For each module the approach and motivation chosen to support the framework development from the conceptual phase to the implementation phase is defined.

To address the identified issues and needs, the theoretical background chapter highlights how spatial databases, semantic web technologies, and free open-source GIS solutions can be efficient tools to incorporate a framework capable to support the municipality certification process. Object-relational databases fitted with spatial tools can easily integrate cadastral data, perform qualitative and quantitative analysis and guarantee interoperability between systems, by making use of existent standards. Semantic web technologies such as the OWL standard can give conceptual freedom for update and expansion, without jeopardizing the various data models already implemented. Free and open-source solutions give flexibility in implementation, migration and acquisition with a less cost impact, an idea that is part of the governmental vision disseminated through public entities and organizations since 2005 (Caro, 2007).

In this chapter the architecture modelling is described in detail, being defined for each module the software application used to generate the final product that is desired to be interconnected and implemented.

5.1 Database Design

This section covers the two last steps from the four-step database design process: the logical design and the physical design (Fahrner and Vossen, 1995). The logical one refers to the transformation of the conceptual schema into the logical schema based on a specific logical model. The physical design step discuss how a physical schema is created from the logical one, taking into consideration the Database Management System (DBMS) where is going to be implemented.

5.1.1 Logical Data Model

The database conceptual schema presented previously in figure 4.2 highlights the entities and relationships that need to be mapped in the logical schema. Since the database to be developed is relational, the logical schema should take into consideration the following requirements:

- Include entities and relationships specified in the E-R diagram;
- Define attributes for each entity described in the previous point;
- Define value-types for each attribute described in the previous point;
- Define the primary keys for each entity; and
- Define the foreign keys for each entity.

Based on the entities surveyed in the first and second requirement of the section 4.2.1 and taking into consideration the relationships defined in table 4.4 and in figure 4.2, the attributes and constraint keys necessary to develop the logical data model are proposed and discussed. Due to the page limitation, the attributes of each entity are presented in the final E-R model (see figure 5.1).

Appendix 10. presents the definition, the value-type, the multiplicity and the existence in the INSPIRE cadastral model for each attribute of the entity Cadastral Parcel. The definitions presented are adopted from the INSPIRE document and the database existent in the Municipality. The value-type is defined in this phase of the design process in order to identify what kind of data type needs to be assigned to each attribute. For the first time, the concept of spatiality is introduced in this database. The attribute boundary relates to the parcel geometry and is represented by a polygon. This attribute is of great value for the `Spatial comparison` operation. Regarding the `Thematic comparison`, the attribute pdmCateg is presented and assigned to the value-type characterString. The multiplicity constraint defines for each attribute if it exists in the real world or, in other words, if the attribute should have a value assigned when it is inserted in the database. This type of notation is not common in the E-R model but is adopted from the INSPIRE guidelines in order to fit the research purposes. In this table all the attributes have a multiplicity of 1, so all the attributes of the cadastral parcel entity needs to have one and only one value assigned when uploaded in the database. The column INSPIRE attribute defines what are the attributes that are adopted from the INSPIRE/LADM cadastral model. It is also important to mention that each attribute name finishes with the initials of the attribute from where it belongs. For example, the attribute id_cz refers to the id attribute from the entity cadastral zoning (INSPIRE, 2009).

In table 5.1 based on the relationships and cardinality depicted in the figure 4.2 the primary keys and foreign keys of each entity are presented. Since the primary key of each attribute needs to be unique, it is adopted the best practice to create a numeric univocal attribute for each entity. With the exception of the entities Spatial reference system, Inner area and Outer area, the remaining have an attribute named id as primary key. In the case of the entity Spatial reference system, the European Petrol Survey Group (EPSG) Coordinate System (CS) code is adopted as primary key. Since the EPSG CS code is unique (OGP, 2010), it is simple to adopt it as primary key. In the case of the entities' inner area and outer area, since they are weak entities or, in other words, their meaning of existence is dependent of the existence of another entity with which they have relationships, these two entities need to inherit the id from the entity urban intervention. Since each of these entities can contain zero or more areas with relation to one urban intervention area, it is necessary to define a concatenated primary key composed by the urban intervention id and the inner area or outer area boundary, for example id_uint, boundary_ia. This concatenated key ensures that inside the entity does not exist an outer area with the same id_uint and boundary_ia or, in other words, if two or more outer areas have the same geometry then they can not belong to the same urban intervention. Regarding the foreign keys, only the entities that have a cardinality n (many) in a relationship inherit the primary key of the entity that have a cardinality 1 (one) (Harrington, 2009).

Entities	**Primary Key**	**Foreign Key**
Basic Property Unit	id_bpu	
Cadastral Parcel	id_cp	codEpsg_srs, id_cz, id_bpu
Cadastral Zoning	id_cz	codEpsg_srs
Outer Area	id_uint, boundary_oa	
Inner Area	id_uint, boundary_ia	
Spatial Reference System	codEpsg_srs	codEpsg_srs, id_cp

Table 5.1: Primary and Foreign Keys for each entity of the Cadastral Database.

Once the requirements discussed in the beginning of the logical data model are assured, it is then possible to present a more detailed E-R model as depicted in figure 5.1. It is important to refer that in this model the relationships and the cardinalities are presented using a more complex notation that the ones used in the figure 4.2. For example, in the case of the relationship between the entity urban intervention and the entity inner area, the notation should read as follows: An urban intervention contains 0 or more inner area and an inner area is part of one and only one urban intervention (Harrington, 2009).

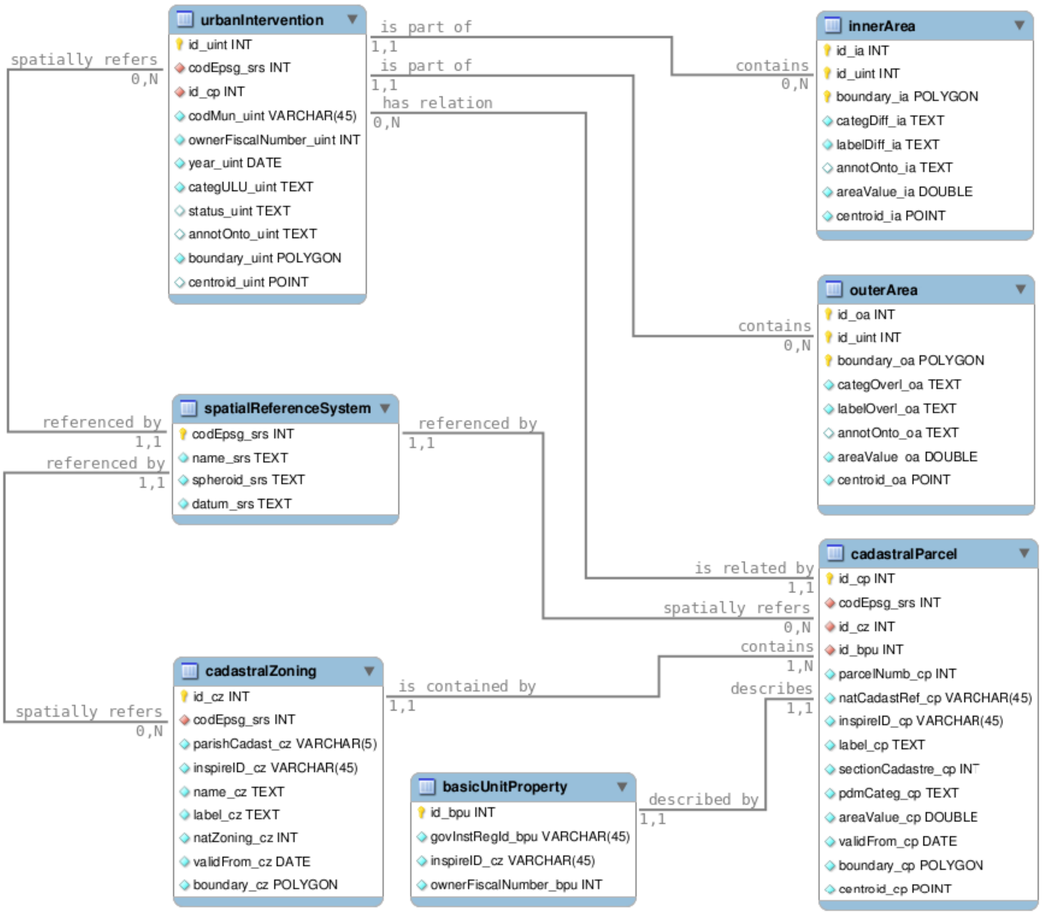

Figure 5.1: Final E-R model.

5.1.2 Physical Data Model

The logical schema presented in figure 5.1 describes in detail the requirements that need to be implemented in a DBMS. In this section, the choice of this system, how the E-R model elements are implemented physically, and what type of procedures can be invoked to access the cadastral data and to perform the desired spatial analysis are discussed. To meet these demands the following requirements should be fulfil:

- Select a DBMS that fits the research purpose;
- Define tables, attributes, data-types and integrity constraints based on the E-R model;
- Define primary and foreign keys based on the relationships described by the E-R model;
- Define spatial predicates and the geometry processing functions to be applied in the `Spatial comparison` process; and
- Define procedures for data store, queries and analysis.

Taking into consideration that the logical data model is based on an E-R schema and some entities contain attributes with value-type geometry, the elected DBMS should be an object relational database management system (ORDBMS). To fit this purpose the chosen DBMS is the `PostgreSQL v.8.4` with extension `PostGIS v.1.4` (see section 3.4.3.1). Since this DBMS is managed from a command-line mode, making it not user-friendly, to implement the logical data model and to upload and manage the cadastral data, the design and management interface `PgAdmin III v1.10` is elected (figure 5.2). This GUI is composed by a main window where the structure of the database and other details related with the objects in it are presented (figure 5.3). It also gives the possibility to invoke the query tool window where arbitary SQL commands can be executed and an edit grid tool window where the data stored can be visualised and edited (figure 5.2) (pgAdmin, 2011).

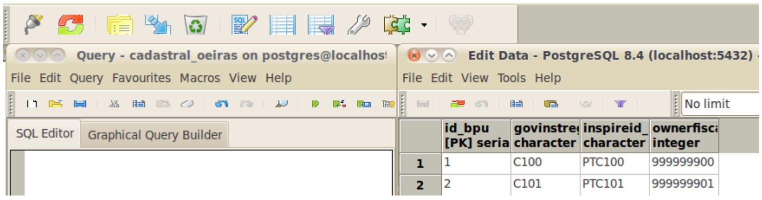

Figure 5.2: pgAdmin III GUI

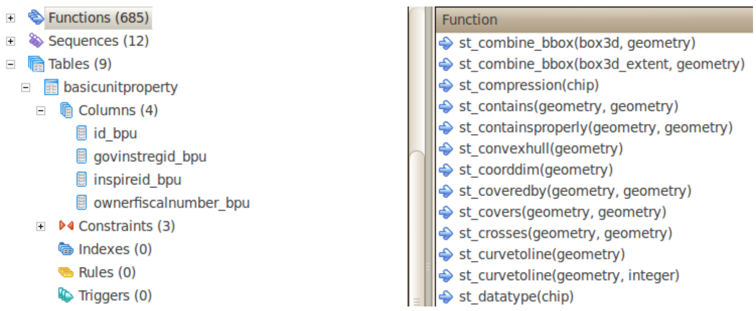

Figure 5.3: pgAdmin III Main Window

In order to implement the E-R model, the first step, after creating the database, is to physically create the entities. In the physical data model the entities are named after tables and are created by making use of SQL sentences (see section 3.2.3). The figure presented in appendix 11. is divided into two parts: the non-spatial and the spatial SQL commands, that are used to create the table cadastralParcel. The first part is based on DDL and presents the essential commands to create the non-spatial attributes. To each attribute the data-types (value-types in the E-R model) and the multiplicity are also defined. After setting the attributes, but still within the commands for the table creation, the primary key is defined and the unique constraints are applied to the attributes that can not have the same value more than one time. The second part presents the spatial SQL commands that allow the creation of the geometry attributes. The geometry attribute is created using the function addGeometryColumn, that needs to include the schema name, the table name, the attribute name, the spatial reference system (EPSG CS Code), the geometry type and the geometry dimension. At last, as depicted in appendix 12., the foreign key constraint is created (Refractions, 2011b).

Once the physical data model is implemented, the next step is to define the SQL commands that are used to perform the `Spatial comparison` and the `Consistency checking` operations (table 5.2). For the `Spatial comparison`, a query where one selects a cadastre parcel and the associated urban intervention by means of an inner join is performed. From the chosen objects the attribute boundary is selected and used inside a qualitative spatial predicate in order to classify the relationship between geometries. The elected spatial predicates to be used in the `Spatial comparison` are: ST_OrderingEquals, ST_Disjoint, ST_Contains, ST_Within and ST_Overlaps. It is important to mention that theST_equals predicate is deprecated in favour of the ST_OrderingEquals, because it only ensures that the relationship is spatially equal but does not verify if the ordering of points is the same. This function is specially effective because it detects if the polygons have the same geometry and the same direction from node to node. Finally, based on the binary result of these `Spatial comparison`, the `Consistency checking` operation updates the attribute status of the selected urban intervention. An example of this operation is depicted in the last two lines of table 5.2 (Refractions, 2011b).

```
...
SELECT c.natcadastref_cp, u.codmun_uint,
        ST_OrderingEquals(u.boundary_uint, c.boundary_cp) AS topology
FROM cadastralparcel AS c INNER JOIN urbanintervention AS u
        on c.id_cp = u.id_cp
WHERE c.natcadastref_cp = '1110BA21356' AND u.codmun_uint = '100_2003';

UPDATE urbanintervention SET status_uint= 'Consistent'
WHERE codmun_uint = '100_2003';
...
```

Table 5.2: Spatial Comparison and Consistency checking in SQL.

Taking into consideration the points discussed in section 4.2.3.1, if the result of the predicate ST_Contains, ST_Within or ST_Overlaps is true, then some operations should be performed. Table 5.3 depicts the qualitative and quantitative functions that are applied when the result of the predicate ST_Contains is true. The first SQL statement invokes the spatial predicate ST_Intersects to select the neighbouring parcels that are overlapped by the urban intervention. The second statement applies the geometry processing function ST_Intersection to store the geometries that represent the shared portions of the urban intervention polygon and the neighbouring rustic parcel polygons. Simultaneously, from each of them, the PDM category is extracted and assigned to the shared portions. In the third and last statement, all the polygons resulting from the ST_Intersection operations are stored in the outerareas table (Refractions, 2011b).

```
CREATE OR REPLACE VIEW p_overl AS
SELECT c.boundary_cp, c.id_cp, u.id_uint, c.pdmcateg_cp, c.natcadastref_cp
FROM cadastralparcel AS c INNER JOIN urbanintervention AS u ON
    ST_Intersects(u.boundary_uint, c.boundary_cp)
WHERE u.codMun_uint='103_2003';

CREATE OR REPLACE VIEW p_EOA AS
SELECT p.id_uint, p.pdmcateg_cp, p.id_cp, ST_Intersection(u.boundary_uint, p.boundary_cp)
    AS EOA_geom
FROM p_overl AS p, urbanintervention AS u
WHERE u.codMun_uint='103_2003'AND p.natcadastref_cp!='1110BA21356';

INSERT INTO outerareas(id_uint, categoverl_oa, areavalue_oa, boundary_oa, centroid_oa)
SELECT p.id_uint, p.pdmcateg_cp, ST_Area(p.EOA_geom), p.EOA_geom, ST_Centroid (p.EOA_geom)
FROM p_EOA AS p;
...
```

Table 5.3: Qualitative and Quantitative functions performed in case of a Contains relationship.

Assured the requirements discussed in beginning of the physical data model, the spatial database, the `Spatial comparison` and the `Consistency checking` are now prepared to be integrated within the `C Module`.

5.2 Logical Ontology Design

This section discuses the conversion of the conceptual ontology developed based on the METHONTOLOGY (see section 4.2.2) into a logical ontology encoded in OWL 2. This computational aspect should provide a correct representation of the conceptual aspect in order to ensure efficient interpretation and reasoning by machines (Hart, Dolbear, Goodwin, and Kovacs, 2007). To meet these demands the logical ontology should take into consideration the following requirements:

- Select an ontology editor that fits the research purpose;
- Define the mapping between the concepts and the classes;
- Define the mapping between the relationships and the object properties;
- Define annotations of classes and properties;
- Define class axioms, class expressions and cardinality constraints; and
- Define DL Queries.

Considering that the ontology should be developed in OWL 2 (see section 3.3.2.2) and, at the same time, be converted to RDF/XML (see section 3.3.2.1), the elected ontology editor should be compliant with the most recent semantic web technologies standards. To fit this purpose the chosen ontology editor is the Protégé 4.1 beta (see section 3.4.3.2) (Stanford, 2010b).

The Protégé is composed by pre-defined tabs which include different types of views. Nevertheless, each of them can be configured to support the ontology editing tasks, in order to fit the user needs (Stanford, 2011). Figure 5.4 depicts the commonly used views in this research: Class hierarchy, Class description, Class annotations, Object property hierarchy (Horridge et al, 2009).

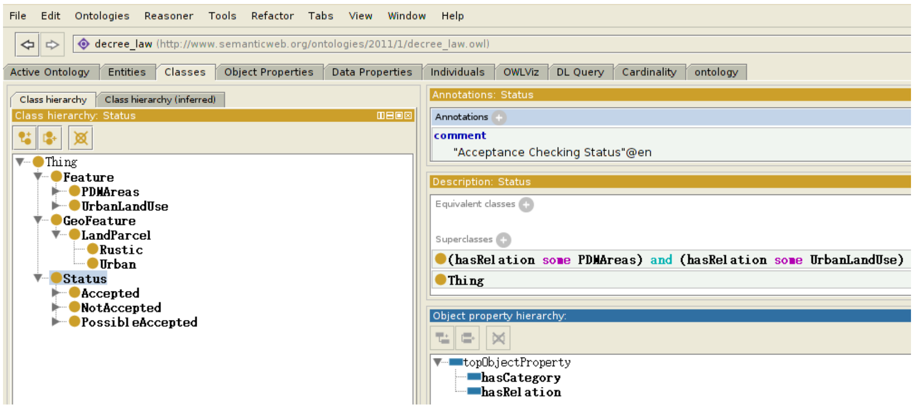

Figure 5.4: Protégé Main Window

Making use of the Class hierarchy view, the concepts names defined in the METHONTOLOGY (see section 4.2.2) are created, in the OWL, as sub-classes of Thing by the same hierarchy as previously depicted in figure 4.5. When defining the ontology taxonomy, in order to ensure that there is no class overlap, the classes that are disjoint from each others are also defined (Horridge et al, 2009). Completed the taxonomy, the ontology schema, depicted in appendix 13., is generated using the OWLViz plugin (Drummond, 2007).

As it should be more readable when discussed, the developed OWL file is presented on RDF format. Appendix 14. shows the class LandParcel, that is a sub-class of Geofeature and has the annotation Municipal land unit. It is important to mention that in the classes UrbanLandUse, PDMAreas, Accepted, NotAccepted and PossiblyAccepted, the name of the sub-classes finishes with the initials of the class from where it belongs. Making use of the Object property hierarchy view in Protégé (figure 5.4), the relations defined in the METHONTOLOGY (see section 4.2.2) are created in the OWL as object properties. Appendix 15. shows the Object Property 'hasRelation' that have the annotation 'Relationship between Status and Feature'.

Table 5.4 shows the class Maritime_Public_Domain_PA that is a sub-class of Possibly_Accepted and has the annotation Possibly_Accepted: if they are covered by planning and urban management. This class is represented by: the intersectionOf the object property hasRelation that has someValuesFrom the class Facilities_ULU and the object property hasRelation that has someValuesFrom the class Maritime_Public_Domain_PDMA. In Protégé this intersection between these two classes is defined as an equivalent class in the class description view. For a better comprehension, figure 5.5 generated by the ontoGraph plugin depicts the structure of the class Maritime_Public_Domain_PA (Falconer, 2010).

```
<!-- http://www.decree_law.org/decree_law.owl#Maritime_Public_Domain_PA -->
<Class rdf:about="http://.../decree_law.owl#Maritime_Public_Domain_PA">
  <equivalentClass>
      <Class>
        <intersectionOf rdf:parseType="Collection">
          <Restriction>
            <onProperty rdf:resource="http://.../decree_law.owl#hasRelation"/>
            <someValuesFrom rdf:resource="http://.../decree_law.owl#Facilities_ULU"/>
          </Restriction>
          <Restriction>
            <onProperty rdf:resource="http://.../decree_law.owl#hasRelation"/>
            <someValuesFrom rdf:resource=
                        "http://.../decree_law.owl#Maritime_Public_Domain_PDMA"/>
          </Restriction>
        </intersectionOf>
      </Class>
  </equivalentClass>
  <rdfs:subClassOf rdf:resource="http://.../decree_law.owl#PossiblyAccepted"/>
    <rdfs:comment xml:lang="en">Possibly Accepted: if they are covered
                              by planning and urban management.</rdfs:comment>
</Class>
```

Table 5.4: OWL Class in RDF format.

Defined all the equivalent classes of the status sub-classes, the `Thematic comparison` and `Acceptance consistency` operations can now be performed through the DL Query tab (see appendix 16.) (Stanford, 2009). Making use of the reasoning capabilities and by querying the ontology based on the expression (hasRelation some Facilities_ULU and hasRelation some Maritime_Public_Domain_PDMA), the equivalent class that results from the query is the Maritime_Public_Domain_PA. Appendix 17., appendix 18. and appendix 19. depicts the all the status sub-classes in DL formal language (Baader, Horrocks, and Sattler, 2007). As soon as the requirements pointed out in the logical ontology design are assured, the application ontology is then capable to be integrated with the `C module`.

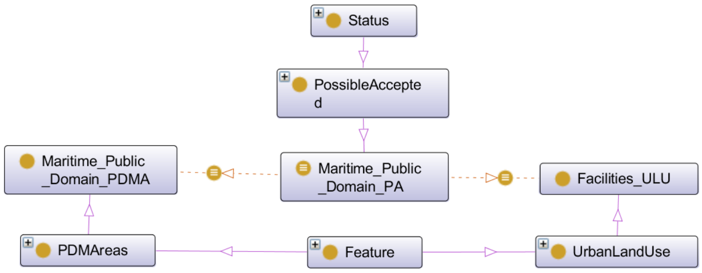

Figure 5.5: Structure and relationships of a Possibly Accepted Class.

5.3 Framework Implementation

This section discuses the implementation of the `C Module` (see section 4.2.3) as Plugin based on Java-language for a FLOSS GIS Desktop. This Plugin is simple and objective, having been built only for the sole purpose of answering to the demands of this academic research. To ensure a compatible connection with the `S Module` and the `T Module`, thus enabling the processes specified in the design phase, the following requirements should be taken into consideration:

- Select a software development environment capable to support the development of the Java Plugin;
- Select a GIS Desktop software capable to host the proposed Plugin;
- Define the essential API's to be used;
- Define the type of connection that should allow bilateral interaction with `S Module`;
- Define the type of XML parser that should allow one to read and extract information from `T Module`;
- Define the design and implementation of the GUI;
- Define the implementation of the `Spatial comparison` and the `Consistency checking` procedures;
- Define the implementation of the `Thematic comparison` and the `Acceptance checking` procedures; and
- Define the implementation of the store procedures.

Considering that the proposed plugin is based on Java programming language and the FLOSS GIS Desktop OpenJump is written in Java (see section 3.4.3.3), the elected Integrated development Environment (IDE) should provide tools for programming in Java language and for designing Swing GUI's. To fit this purpose the chosen IDE is the NetBeans IDE v.6.8 (see appendix 20.). In the development of the Plugin some methods of the Java SE 6 API (Oracle, 2010b), the OpenJump API (JumpProject, 2010) and the SAX XML API (SAX, 2004) are used.

In order to ensure a bilateral connection with the DBMS, the method ConnectionManager that belongs to the class ConnectionPanel from the Package com.vividsolutions.jump.workbench.ui.plugin.datastore is invoked (see appendix 21.) (JumpProject, 2010). This panel gives the possibility to choose, add, copy or delete a database connection. The type database connections available are dependent of the drivers stored in the lib folder of the OpenJump directory.

Due to implementation constraints it is not possible to implement the OWL API. To overcome this scenario, the SAX XML API is elected to perform the XML parsing (SAX, 2004). In order to search for information inside the OWL file, the parser first requires to know its structure. Since the structure of the OWL/XML (see section 3.3.2.2) file is difficult to be recognised by the parser, the ontology has to be converted to RDF/XML format (see section 3.3.2.1). Before the parser is initialised, the category associated to each of the selected polygons needs to be extracted from the database. The method getAnnotation (see appendix 22.) is invoked and it searches for similar strings inside of the OWL file. Once the object's properties that contains the desired categories are found, the saxParser reads the annotations and stores them in memory.

In order to be possible for the Plugin actions to be triggered by the user, the declared methods have to be assigned to each of the buttons located in the GUI of the Plugin. Appendix 23. demonstrates, partially, how the method jbCompareActionPerformed is assigned to the event performed by the button Compare (Arnold, Gosling, and Holmes, 2005).

Considering the SQL statements discussed in the section 5.1.2, the method jbCompareActionPerformed is created to perform the `Spatial comparison` (see table 5.5) and the `Consistency checking` (see appendix 24.) operations. Making use of two for-each loops, the SQL code is adapted and simplified. The first loop triggers the `Spatial comparison` and depending on the outcome, the second loop executes the `Consistency checking` to assign one possible status to the urban intervention (Arnold, Gosling, and Holmes, 2005).

Appendix 25. depicts the method that triggers the geometry processing function ST_Intersection and, simultaneously, extracts the PDM category and assigns it to the resulting polygons. Finally, making use of the SQL commands previously discussed in the end of the section 5.1.2, the polygons are stored in the table outerareas.

```
private void jbCompareActionPerformed(java.awt.event.ActionEvent evt) {
    String natCadastRef = cadParcel.getAttribute("natcadastref_cp").toString();
    String codMun = urbanInt.getAttribute("codmun_uint").toString();
    String [] functions = {"ST_OrderingEquals", "ST_Disjoint", "ST_Touches",
        "ST_Contains", "ST_Within", "ST_Overlaps"};
    String [] status_labels = {"Consistent", "Not_Consistent", "Not_Consistent",
        "Contains", "Within", "Overlaps"};
    for (int i = 0; i < functions.length; i++) {
        String query = "SELECT c.natcadastref_cp, u.codmun_uint,       "
            + functions[i]+"(u.boundary_uint, c.boundary_cp) AS topology"
            + " FROM cadastralparcel AS c INNER JOIN urbanintervention AS u "
            + "on c.id_cp = u.id_cp "
            + "where c.natcadastref_cp = '"+natCadastRef+"' AND u.codmun_uint = 
             '"+codMun+"'";
```

Table 5.5: Java implementation of Spatial comparison operation.

After completing the implementation of the `S Module`, the implementation of the `T Module` is presented. First the urban intervention is queried and after, depending on the status, its category and the related areas are extracted (table 5.6). The `Thematic comparison` operation occurs when these categories are used by the method getAnnotation (see appendix 26.), and after the `Acceptance checking` operation, as depicted in appendix 22., ensures that the XML parser retrieves the annotation that corresponds to the relation between both. Finally, this annotation is stored in the corresponding attribute of each area.In short, after assuring the requirements discussed in the previous points, the implementation phase is accomplished and the performance of the Plugin can be analysed and evaluated.

```
void outOwl(String codMun) {
    String status="";
    FeatureInputStream fis=null;
    try {
      fis = ConnectionManager.instance(wbContext).getOpenConnection(connection).execute(
          new AdhocQuery("SELECT u.status_uint
          FROM urbanintervention AS u WHERE codmun_uint = '"+codMun+"'")
          );
      Feature f = fis.next();
      status = f.getAttribute("status_uint").toString();
    }catch(Exception e){
        JOptionPane.showMessageDialog(this, "Failed to get intervention status.");
        return;}
...
    try {
        fis = ConnectionManager.instance(wbContext).getOpenConnection(connection).execute(
          new AdhocQuery("SELECT u.codmun_uint, u.categulu_uint, i.id_ia, i.categdiff_ia "
          + "FROM urbanintervention AS u INNER JOIN innerareas AS i "
          + "on u.id_uint = i.id_uint WHERE u.codmun_uint = '"+codMun+"';")
          );
        inner=fis.next();
```

Table 5.6: Java implementation of Thematic comparison operation.

6. EVALUATION

The previous chapter presented the logical design and physical design of the Spatial database, the logical ontology design, and the framework implementation. The end result of these stages is reflected on a Java Plugin to be operated in a GIS Desktop software, which allows the connection and operation between the `S Module` and `T Module` comprised in the framework.

In this chapter focuses on the workflow of the Plugin actions, the data used in the test, the procedures to be analysed and evaluated, and the strengths and limitations of the methodology adopted in this research.

6.1 Workflow

This section presents a step-by-step procedure pointing out the actions that the user should execute, in order to acquire the expected results when using Plugin (table 6.1).

Task Workflow

1^{st}	Starts OpenJump.
2^{nd}	Click the menu Cadastral and select the tool Compare.
3^{rd}	Insert Parcel number, select Parish and insert Section number.
4^{th}	Click Search button.
5^{th}	Insert the Urban Intervention number and the year.
6^{th}	Click Search button.
7^{th}	Click Compare button.
8^{th}	Close the tool.

Table 6.1: Plugin Task Workflow.

6.2 Test datasets

This section introduces the area and the number of parcels that are used in the testing scenario. The dataset depicted in figure 6.1 is located in the Barcarena Parish (C.M.O, 2009), Section 21, and contains eight rustic parcels and six urban interventions. Each urban intervention represents a possible relationship with the rustic parcel number 356 (parcel with the border line represented by the red colour). The spatial reference system is the ETRS89/PT-TM06 and has the EPSG CS code 3763 (OGP, 2010).

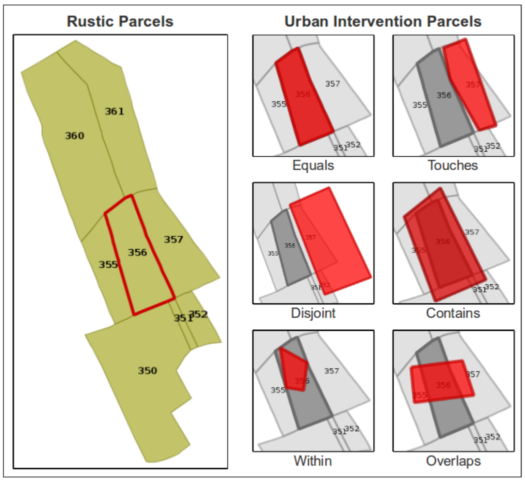

Figure 6.1: Test Datasets.

6.3 Testing

This section discusses the Efficiency and Effectivity of the Plugin. In order to elucidate the meaning of each expression, Efficiency is considered as the useful work performed by a machine (Oxford, 2010a) and Effectivity as the success in producing a desired or intended result (Oxford, 2010b) To test these two states the following processes are analysed and evaluated consequently:

- Rustic and Urban data querying;
- Query results;
- `Spatial comparison` and `Thematic comparison`; and
- Retrieving of comparison results.

In relation to the Plugin efficiency regarding to the data querying, it is possible to say that by introducing the parcel number, selecting the parish, introducing the section number and clicking the Search button, the user can visualise the rustic parcel data. In relation to the Plugin effectivity, it is possible to say that the query performed for the Rustic parcel only retrieves the attributes described on the table cadastralParcel (see figure 6.2). Regarding the efficiency and effectivity, the observations for the urban intervention are similar to the rustic parcel.

In relation to the Plugin efficiency regarding the `Spatial comparison` and `Thematic comparison`, it is possible to say that by clicking the Compare button, the user can execute all the tasks related with these two operations. In relation to the Plugin effectivity regarding the comparison results, it is possible to say that from the tasks performed, the user can only visualise the `Consistency checking` and the `Acceptance checking` status (see figure 6.3).

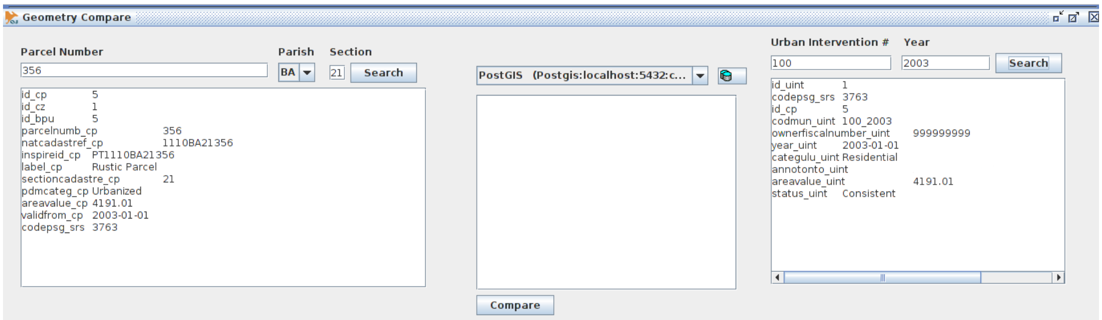

Figure 6.2: Plugin query results.

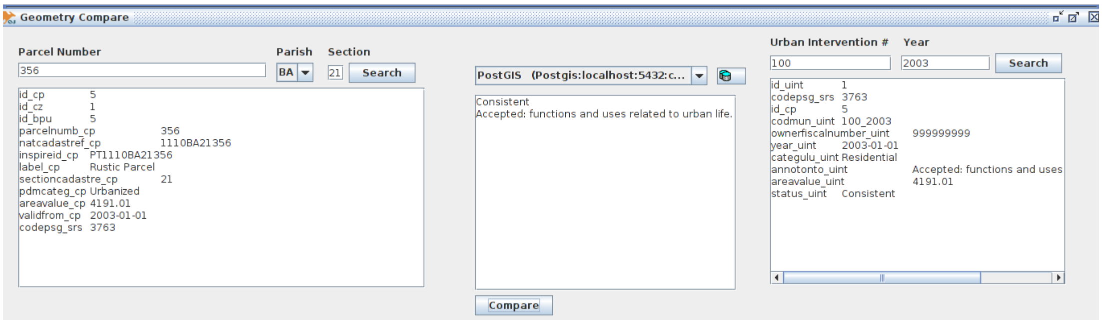

Figure 6.3: Plugin comparison results.

Soon after finishing the `Spatial comparison` and `Thematic comparison` tasks, the Plugin can then be closed and from the OpenJump main window, the user can add a Datastore Layer in order to visualise the results from the operations (see appendix 27.). In appendix 28. the three `Possibly Consistent` situations and respective resulting areas are depicted.

6.4 Strengths and Limitations

This section evaluates the computer languages and standards adopted in the design and implementation of the framework, with reference to the following design principles: maintainability; modularity; minimum redundancy; extensibility; implementability; simplicity; interoperability; stability; and robustness (Bos, 2003) (see appendix 29.). The approach to these principles is marked in accordance with the research goals, time constraints and availability of technology. In overall, the Plugin provides an efficient platform to data visualisation and comparison execution, although it is limited to the information retrieved from the analysis of the Spatial and Thematic relationships. An assessment on distinct design principles demonstrate that the integration of the selected information technologies can ensure the adaptation of the Plugin to the various cadastre update processes existent in the Municipality.

7. DISCUSSION AND CONCLUSION

In this chapter, the state-of-the-art, the conceptualisation, the design, the implementation and the evaluation are converged, in order to support the final considerations of the developed research. Firstly, with respect to the research objectives, the modules of the developed framework are analysed and discussed. Secondly, the research questions formulated in section 1.5 are assessed and discussed. Thirdly, an overall conclusion presents a resume of the research objectives and questions. Finally, directions for future research are presented and discussed.

7.1 Research Objectives

The primary idea of this study is to support the automation of the municipal cadastre update process based on urban intervention projects. In order to fit this requirement, the following research objectives were proposed to be accomplished:

- Update of municipal database model to make it compliant with the INSPIRE cadastral parcel and ISO LADM models;
- Design and development of `Spatial comparison` method based on spatial predicates using SQL ;
- Design and development of `Thematic comparison` method based on a semantic web language; and
- Implementation of a customised Plugin within a free and open-source GIS software.

The conceptualisation and modelling of the SiNErGIC platform is based on Cadastre 2014 and CCDM. This platform initiated in 2006 still remains as a pilot project and is not yet implemented at the National or Local level. Nevertheless, CCDM ended in 2008 and converted into LADM, which in turn is being revised to be approved as an ISO standard. Considering these changes, a cadastral database model compliant with the INSPIRE cadastral parcel model derived from ISO LADM is suggested, in order to facilitate the integration of the municipal cadastre update process in the future SiNErGIC platform. At the same time, it is important to stress that this research only needs to deal with polygons geometries, a reason which limits the implementation of the INSPIRE/ISO LADM in its fullness.

`The S Module` indicates the Spatial component of the framework and it is mainly represented by the cadastral database model. This logical data model is physically implemented in an ORDBMS that aggregates a set of spatial predicates based on the CBM. Making use of these predicates, the `Spatial comparison` verifies the relationship between rustic and urban geometries that are stored in the database. The `Consistency checking` operation classifies the relationships Equals as Consistent, Touches and Disjoint as Not Consistent and Contains, Within and Overlaps as Possibly Consistent. In the case of a Possibly Consistent classification, new geometries are processed by geometry functions and consequently categorised and assigned to the urban intervention.

The `T Module` indicates the Thematic component of the framework and it is mainly represented by the ontological model. The PDM and the urban intervention categories defined in the decree-laws are conceptualised in an application ontology. The `Thematic comparison` operation relates these two types of categories based on an interpretation of the legal information provided by the decree-laws. The `Acceptance checking` operation assigns a status of Accepted, Not Accepted or Possibly Accepted to the relationship of the categories. Each of these status is annotated with information transcribed from the legal information provided by the decree-laws. It is important to stress that in this Module, unlike what happens in the `S Module`, the `Thematic comparison` and the `Acceptance checking` operations are terms used to reflect stages of the ontology conceptualisation. However, none of these operations are implemented in the `C Module`, but rather used to point out tasks performed during its execution.

The `C Module` is the core of the framework and implements the `S Module` and `T Module` as a Plugin to be used inside a FLOSS GIS Desktop. Accessed through an interface, this Plugin provides means to query the rustic and the urban data stored inside the ORDBMS. Based on the selected data, the `Spatial comparison` is performed and the `Consistency checking` status presented. Using the information of the cadastre parcel categories, the `Thematic comparison` searches the ontology and the `Acceptance checking` retrieves the relationship between categories as an annotation. It is important to stress that all the presented results are assigned to the urban intervention and related areas.

7.2 Research Questions

Municipal cadastre update process based on an urban intervention project is defined in this research as 'approval of the change of use based on the acceptance of an urban intervention project that presents satisfactory Spatial and Thematic differences between its boundary and the boundary described in the official rustic cadastral cartography'. Based on this definition, the research questions with respect to customisation and automation are addressed:

Question 1: How can the use of customised free and open-source GIS and Semantic Web Technologies improve the performance of cadastral operations executed by the municipal authorities?

In the current days, the access and use of geographic systems and data is a common practice on the different levels of governance. The use of free and open-source technologies can help the containment of costs, customisation of common platforms, dissemination in distinct workplaces and flexibility of adaptation to modernisation.

The proposed Plugin is developed with the attempt to fit the needs of the municipal authorities involved in the cadastre update process. This free and open-source approach is presented with the intend to ensure an implementation and dissemination with less costs for the present and future. Being based on open standards and languages allows a high degree of customisation on the different levels of usage and functions. Since it is only dependent on a DBMS and on a Semantic Web technology, it is simpler to be integrated and available on the server and desktop level. Based on the evaluation, it is possible to say that free and open-source GIS and Semantic Web technologies can efficiently support the requests of less sophisticated cadastral operations. This is achievable due to the degree of customisation and adaptation to different needs and visions. It also gives possibilities to be implemented, maintained and continued with a low level of investment.

Question 2: How can a spatial database and ontological framework benefit the automation of the `Spatial and Thematic comparison` within the cadastre update process?

During the cadastre update process, usually, the `Spatial comparison` is executed using CAD tools and the `Thematic comparison` is based on an interpretation founded on the decree-laws and on the knowledge of the technicians.

The proposed `Spatial and Thematic comparison` framework is based entirely on automated operations. Using an ORDBMS with spatial analysis capabilities, it is possible to perform geometry comparison supported by spatial predicates. Without overloading the comparison operation with quantitative measurements, the relationships are tested and subsequently classified based on defined rules. As soon as the related tasks are finished, the resulting information is then stored in the database. Regarding the `Thematic comparison`, the legal information described in the decree-laws is conceptualised in an application ontology and subsequently classified and annotated. Due to the degree of interoperability provided by this knowledge representation, based on programmed methods, the information is queried, extracted and assigned to the spatial data stored in the ORDBMS. Analysing the proposed framework, it is possible to say that the use of ORDBMS to perform spatial analysis on geometries and ontology web languages, to conceptualise and classify legal information can be a considerable contribution in the automation of the `Spatial and Thematic comparison` operations within cadastre update process. The capabilities of an ORDBMS to analyse, store, query, update and export data, allied to the flexibility of an ontology to represent information that is constantly changing and subjected to different interpretations, can bring celerity to the cadastre update process.

7.3 Overall Conclusion

The proposed cadastral database model compliant with the INSPIRE cadastral parcel model derived from ISO LADM, can facilitate the integration of the municipal cadastre update process in the future SiNErGIC platform. The use of free and open-source GIS and Semantic Web technologies can efficiently support less sophisticated cadastral operations and assist the customisation and adaptation of different needs and visions with a low level of investment. The developed Plugin, implemented inside a FLOSS GIS Desktop, using an ORDBMS to perform spatial analysis on geometries and an OWL to conceptualise and classify legal information, can contribute to the automation of `Spatial and Thematic comparison` operations and bring celerity to the cadastre update process.

7.4 Directions for future research

In the end of this research, several issues regarding the `Spatial and Thematic comparison` and Plugin capabilities are raised. To address them, the following future research works are suggested:

- Implement OWL API to perform DL queries;
- Provide the possibility to merge rustic parcels on-the-fly;
- Enrich the capabilities of querying and data visualisation in the Plugin interface;
- Provide a detailed report in text format of the `Spatial and Thematic comparison`;
- Present the rustic, urban and resulting geometries in the OpenJump interface; and
- Provide a function for exporting rustic, urban and resulting geometries to standard spatial data formats.

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APPENDICES

1. Map of Oeiras

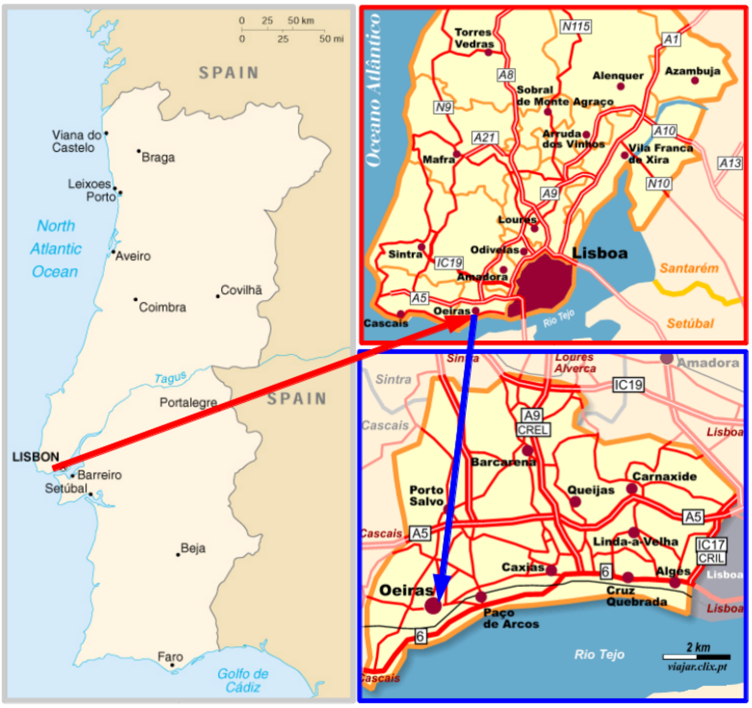

Figure I: Oeiras Map. (source: http://viajar.clix.pt)

2. SiNErGIC Technological Infrastructure

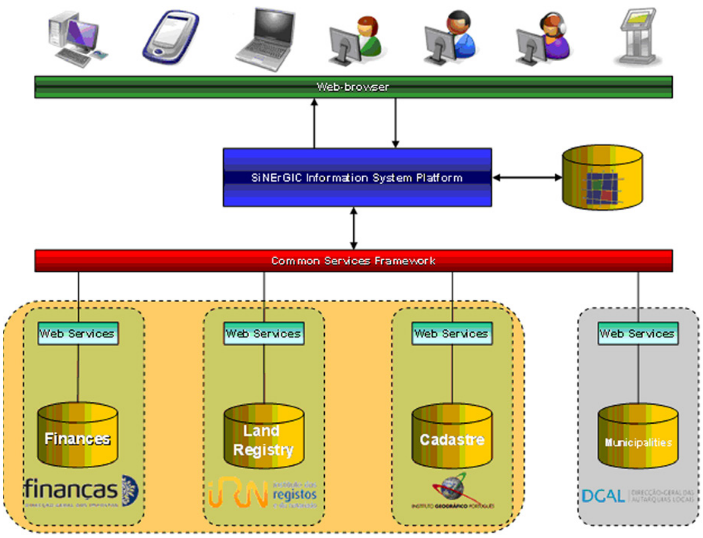

Figure II: SiNErGIC Technological Infrastructure (IGEO, 2009).

3. INSPIRE CPM derived from ISO LADM

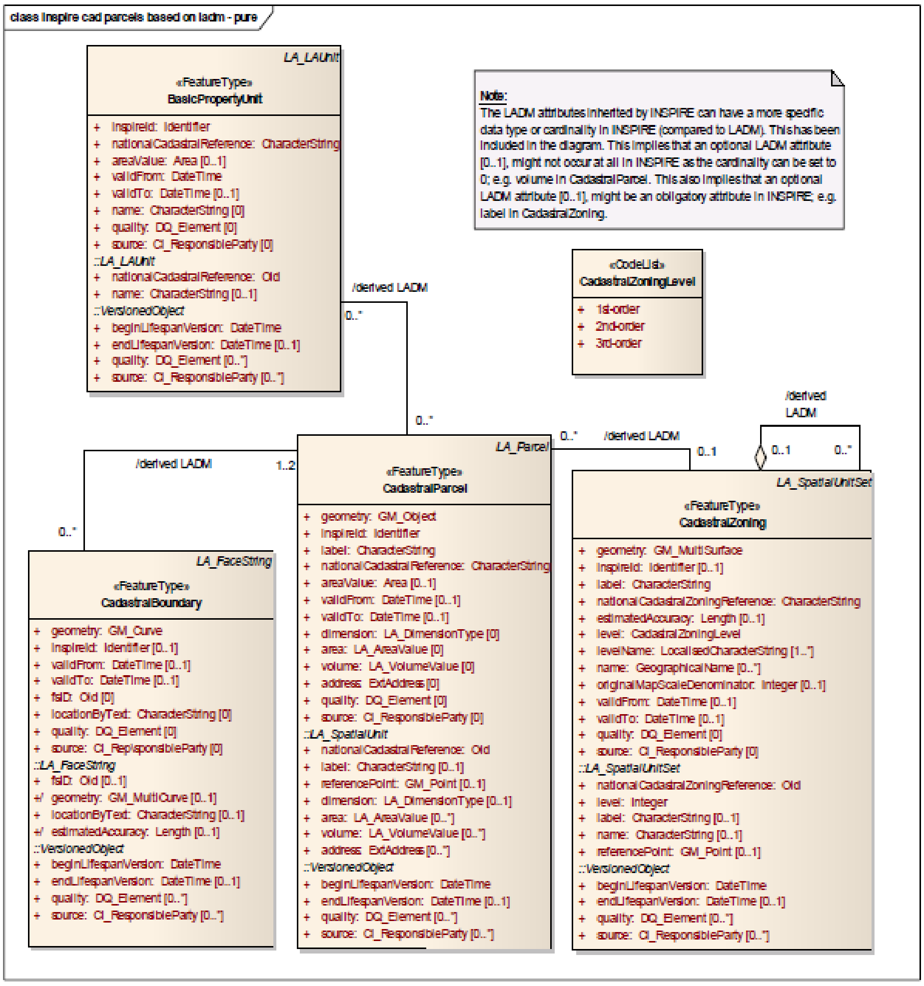

Figure III: The INSPIRE cadastral parcel model derived from ISO LADM(INSPIRE, 2009).

4. Entities selected for the Municipal Cadastral Database

Figure IV: a) Entities adopted from INSPIRE CPM — b) Urban Intervention entities.

5. Knowledge Acquisition

Sources of Knowledge	Description
Decree-Law nr. 26/2010	Describes an Urban Intervention based on the legal regime for urbanization and construction.
Decree nr. 11/2009	Classifies the urban land use areas based on the instruments for territorial management.
Resolution of the Council of Ministers nr. 15/94	Classifies the PDM land use areas based on the Regulation of the Oeiras Municipal Master Plan.
Cadastral information system - a resource for the E.U. Policies	Describes the Cadastral register in Portugal.

Table V: METHONTOLOGY Knowledge Acquisition Document (Fernandez, Goméz-Peréz, and Juristo, 1997).

6. Glossary of Terms

Concept Name	Description
Land Parcel	Cadastre property defined by the following spatial elements: parcel, its boundaries and the corresponding defining property marks. a)
Rustic	Rural Property Cadastre composed by additional elements regarding the rural property evaluation, such as land use. a)
Urban	Urban Intervention that address the physical operations of urbanization, construction, and use of land. b)

a) Transcripted from the Cadastral information system - a resource for the E.U. Policies.
b) Translated from the Decree-Law nr. 26/2010.

Table VI: METHONTOLOGY Glossary of Terms Document (Fernandez, Goméz-Peréz, and Juristo, 1997).

7. Binary Relations Table

Relation Name	Source Concept	Source Cardinality	Target Concept	Target Cardinality	Inverse Relation
has relation	Status	(1,n)	PDM Category	(1,n)	is relation of
has relation	Status	(1,n)	Urban Land Use Category	(1,n)	is relation of
has category	Rustic	(1,n)	PDM Category	(1,n)	is category of
has category	Urban	(1,n)	Urban Land Use Category	(1,n)	is category of

Table VII: METHONTOLOGY Binary Relations Document (Belhadef and Kholladi, 2009).

8. Concept Dictionary Table

Entity	Description
Feature	Thematic property
Feature	Thematic property
Urban Land Use Categories	Urban human use of land.
Economic Activities	Office areas, Commercial areas.
Equipment	Industrial areas.
Green Spaces	Gardens, Golf fields.
Residential	Urban area.
PDM Categories	Municipal master plan thematic class.
Environmental Balance	Rural and urban green areas
Hydric Public Domain	Inland water bodies.
Industrial	Equipment areas.
Industrial Expansion	Equipment areas.
Maritime Public Domain	Beach areas, Coast line.
Multi-Use	Urban and Industrial areas, Technological pole.
National Ecological Reserve	Protected ecosystem areas.
Natural Agriculture Public Domain	Vineyards.
Public Domain	Historic municipal areas.
Semi Rural	Areas with Rural and Urban characteristics.
Tertiary	Industry, Services.
Urban	Residential areas, Commercial areas.
Urbanized	Residential areas, Commercial areas.
Geographic Feature	Spatial Thing.
Land Parcel	Muncipal land unit.
Urban Intervention	Urban project.
Rustic	Rural land.
Status	Acceptance Checking Status
Accepted	Approved, Conceded, Granted.
Not Accepted	Reproved, Refused, Rejected.
Possibly Accepted	To Amendment, to Review, to Consideration.

Table VIII: METHONTOLOGY Concept Dictionary Document (Belhadef and Kholladi, 2009).

9. Logical Axioms Table

Concept Name	Axiom Description	Logical Expression
Rustic	is a land parcel that has a PDM category.	$\forall$ x, Rustic(x) $\Rightarrow$ $\exists$ y, PDM Category(y) $\wedge$ hasCategory(x,y)
Urban	is a land parcel that has a Urban Land Use category.	$\forall$ x, Urban(x) $\Rightarrow$ $\exists$ y, Urban Land Use Category(y) $\wedge$ hasCategory(x,y)
Environmental Balance Accepted	is a Accepted Status **and** it results directly from the relation of the Environmental Balance category and from the relation of the Green Spaces category **or** from the relation of the Environmental Balance category and from the relation of the Facilities category.	$\forall$ x, Environmental Balance Accepted(x) $\Rightarrow$ Accepted(x) **and** (($\forall$ y, Environmental Balance(y) $\wedge$ hasRelation(x,y)) $\wedge$ ($\forall$ y, Green Spaces(y) $\wedge$ hasRelation(x,y))) **or** (($\forall$ y, Environmental Balance(y) $\wedge$ hasRelation(x,y)) $\wedge$ ($\forall$ y, Facilities(y) $\wedge$ hasRelation(x,y)))
Industrial Not Accepted	is a Not Accepted Status **and** it results directly from the relation of the Industrial category and from the relation of the Facilities category **or** from the relation of the Industrial category and from the relation of the Residential category.	$\forall$ x, Industrial Not Accepted(x) $\Rightarrow$ Not Accepted(x) **and** (($\forall$ y, Industrial(y) $\wedge$ hasRelation(x,y)) $\wedge$ ($\forall$ y, Facilities(y) $\wedge$ hasRelation(x,y))) **or** (($\forall$ y, Industrial(y) $\wedge$ hasRelation(x,y)) $\wedge$ ($\forall$ y, Residential(y) $\wedge$ hasRelation(x,y)))
Urban Possibly Accepted	is a Possibly Accepted Status **and** it results directly from the relation of the Urban category and from the relation of the Green Spaces category **or** from the relation of the Urban category and from the relation of the Economic Activities category.	$\forall$ x, Urban Possibly Accepted(x) $\Rightarrow$ Accepted(x) **and** (($\forall$ y, Urban(y) $\wedge$ hasRelation(x,y)) $\wedge$ ($\forall$ y, Green Spaces(y) $\wedge$ hasRelation(x,y))) **or** (($\forall$ y, Urban(y) $\wedge$ hasRelation(x,y)) $\wedge$ ($\forall$ y, Economic Activities(y) $\wedge$ hasRelation(x,y)))

Table IX: METHONTOLOGY Logical Axioms Document (Belhadef and Kholladi, 2009).

10. Cadastral Parcel Attribute Table

Attributes	Definition	Value-Type	Multiplicity	INSPIRE Attribute
id_cp	univocal numeric code.	identifier	1	n
codEpsg_srs	univocal numeric code from entity Reference System.	identifier	1	n
id_cz	univocal numeric code from entity Cadastral Zoning.	identifier	1	n
id_bpu	univocal numeric code from entity Basic Property Unit.	identifier	1	n
parcelNumb_cp	National Cadastral parcel identification	identifier	1	n
natCadastRef_cp	Full national code of the cadastral parcel.	characterString	1	y
inspireID_cp	INSPIRE identifier of the cadastral parcel.	identifier	1	y
label_cp	Cadastral parcel identification.	characterString	1	y
sectionCadastre_cp	Number of the cadastral section where the parcel is located.	identifier	1	n
pdmCateg_cp	Category defined in the Oeiras municipal master plan.	characterString	1	n
areaValue_cp	Quantification of the area projected on the horizontal plane of the cadastral parcel.	area	1	y
validFrom_cp	Official date and time the cadastral parcel was/will be legally established.	dateTime	1	y
boundary_cp	The cadastral parcel geometry.	geometry Polygon	1	n
centroid_cp	The centroid of the cadastral parcel geometry.	geometryPoint	1	n

Table X: Cadastral Parcel Attribute Table.

11. Cadastral Parcel Database Table

```
CREATE SEQUENCE id_cp_seq;
CREATE TABLE cadastralparcel (
        id_cp SERIAL,
        id_cz integer,
        id_bpu integer,
        parcelNumb_cp integer NOT NULL,
        natCadastRef_cp varchar NOT NULL,
        inspireID_cp varchar NOT NULL,
        label_cp text NOT NULL,
        sectionCadastre_cp integer NOT NULL,
        pdmCateg_cp text NOT NULL,
        areaValue_cp double precision NOT NULL,
        validFrom_cp date NOT NULL,
        codEpsg_srs integer,
        CONSTRAINT cP_pk PRIMARY KEY (id_cp),
        CONSTRAINT inspireID_cp_ck UNIQUE (inspireID_cp),
        CONSTRAINT natCadastRef_cp_ck UNIQUE (natCadastRef_cp),
        CONSTRAINT parcelNumb_cp_cp_ck UNIQUE (parcelNumb_cp)
);
SELECT AddGeometryColumn ('', 'cadastralparcel', 'centroid_cp', '3763', 'POINT', 2);
SELECT AddGeometryColumn ('', 'cadastralparcel', 'boundary_cp', '3763', 'POLYGON', 2);
```

Table XI: CadastralParcel SQL Table.

12. Cadastral Parcel Foreign Key

```
ALTER TABLE cadastralparcel
        ADD CONSTRAINT cP_fk1
        FOREIGN KEY (id_cz)
        REFERENCES cadastralzoning (id_cz)
                ON UPDATE CASCADE ON DELETE RESTRICT;
 ...
```

Table XII: Example of one Cadastral Parcel Foreign Key.

13. Ontology Schema

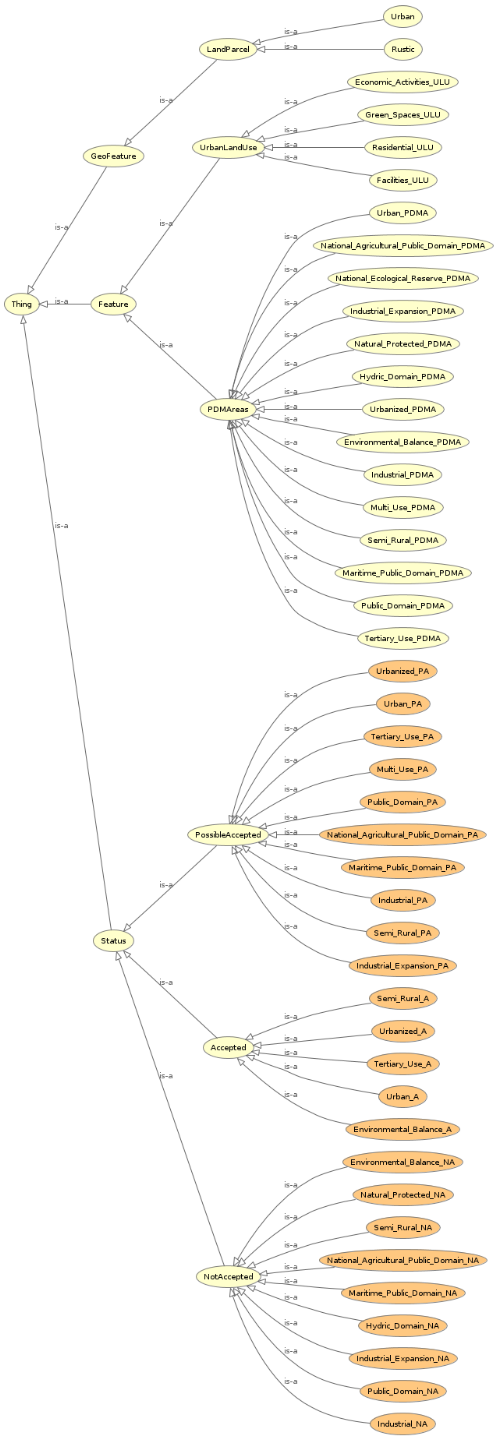

Figure XIII: Ontology Schema.

14. Ontology Class - LandParcel

```
...
<!-- http://www.decree_law.org/decree_law.owl#LandParcel -->

<Class rdf:about="http://www.decree_law.org/decree_law.owl#LandParcel">
    <rdfs:subClassOf rdf:resource="http://www.decree_law.org/decree_law.owl#GeoFeature"/>
    <rdfs:comment xml:lang="en">Muncipal land unit.</rdfs:comment>
</Class>
...
```

Table XIV: OWL LandParcel Class in RDF.

15. Ontology ObjectProperty - hasRelation

```
...
<!-- http://www.decree_law.org/decree_law.owl#hasRelation -->

<ObjectProperty rdf:about="http://www.decree_law.org/decree_law.owl#hasRelation">
    <rdfs:comment xml:lang="en">Relationhip between Status and Feature.</rdfs:comment>
</ObjectProperty>
...
```

Table XV: Ontology hasRelation ObjectProperty in RDF.

16. DL Query Tab

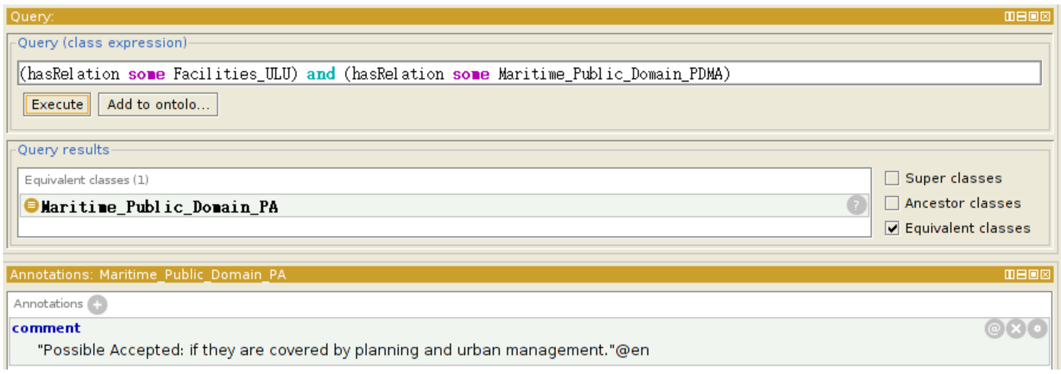

Figure XVI: DL Query tab.

17. Accepted Sub-concepts in DL

Environmental_Balance_A ⊑ Accepted
Environmental_Balance_A ≡ ∃ hasRelation Environmental_Balance_PDMA ⊓ ∃ hasRelation Facilities_ULU
Environmental_Balance_A ≡ ∃ hasRelation Environmental_Balance_PDMA ⊓ ∃ hasRelation Green_Spaces_ULU
Semi_Rural_A ⊑ Accepted
Semi_Rural_A ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Semi_Rural_PDMA
Tertiary_Use_A ⊑ Accepted
Tertiary_Use_A ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Tertiary_Use_PDMA
Tertiary_Use_A ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Tertiary_Use_PDMA
Urban_A ⊑ Accepted
Urban_A ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Urban_PDMA
Urban_A ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Urban_PDMA
Urbanized_A ⊑ Accepted
Urbanized_A ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Urbanized_PDMA
Urbanized_A ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Urbanized_PDMA
Urbanized_A ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Urbanized_PDMA

Table XVII: Accepted Sub-concepts in DL language.

18. Possibly Accepted Sub-concepts in DL

Industrial_PA ⊑ **PossiblyAccepted**
Industrial_PA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Industrial_PDMA
Industrial_PA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Industrial_PDMA
Industrial_Expansion_PA *sqsubseteq* **PossiblyAccepted**
Industrial_Expansion_PA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Industrial_Expansion_PDMA
Industrial_Expansion_PA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Industrial_Expansion_PDMA
Industrial_Expansion_PA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Industrial_Expansion_PDMA
Maritime_Public_Domain_PA *sqsubseteq* **PossiblyAccepted**
Maritime_Public_Domain_PA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Maritime_Public_Domain_PDMA
Multi_Use_PA *sqsubseteq* **PossiblyAccepted**
Multi_Use_PA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Multi_Use_PDMA
Multi_Use_PA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Multi_Use_PDMA
Multi_Use_PA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Multi_Use_PDMA
Multi_Use_PA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Multi_Use_PDMA
National_Agricultural_Public_Domain_PA *sqsubseteq* **PossiblyAccepted**
National_Agricultural_Public_Domain_PA ≡ ∃ hasRelation Facilities_ULU
⊓ ∃ hasRelation National_Agricultural_Public_Domain_PDMA
Public_Domain_PA *sqsubseteq* **PossiblyAccepted**
Public_Domain_PA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Public_Domain_PDMA
Public_Domain_PA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Public_Domain_PDMA
Semi_Rural_PA *sqsubseteq* **PossiblyAccepted**
Semi_Rural_PA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Semi_Rural_PDMA
Semi_Rural_PA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Semi_Rural_PDMA
Tertiary_Use_PA *sqsubseteq* **PossiblyAccepted**
Tertiary_Use_PA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Tertiary_Use_PDMA
Tertiary_Use_PA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Tertiary_Use_PDMA
Urban_PA *sqsubseteq* **PossiblyAccepted**
Urban_PA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Urban_PDMA
Urban_PA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Urban_PDMA
Urbanized_PA *sqsubseteq* **PossiblyAccepted**
Urbanized_PA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Urbanized_PDMA

Table XVIII: Possibly Accepted Sub-concepts in DL language.

19. Not Accepted Sub-concepts in DL

Environmental_Balance_NA *sqsubseteq* **NotAccepted**
Environmental_Balance_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Environmental_Balance_PDMA
Environmental_Balance_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Environmental_Balance_PDMA
Hydric_Domain_NA *sqsubseteq* **NotAccepted Hydric_Domain_NA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Hydric_Domain_PDMA**
Hydric_Domain_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Hydric_Domain_PDMA
Hydric_Domain_NA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Hydric_Domain_PDMA
Hydric_Domain_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Hydric_Domain_PDMA
Industrial_NA *sqsubseteq* **NotAccepted**
Industrial_NA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Industrial_PDMA
Industrial_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Industrial_PDMA
Industrial_Expansion_NA *sqsubseteq* **NotAccepted**
Industrial_Expansion_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Industrial_Expansion_PDMA
Maritime_Public_Domain_NA *sqsubseteq* **NotAccepted**
Maritime_Public_Domain_NA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Maritime_Public_Domain_PDMA
Maritime_Public_Domain_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Maritime_Public_Domain_PDMA
Maritime_Public_Domain_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Maritime_Public_Domain_PDMA
National_Agricultural_Public_Domain_NA *sqsubseteq* **NotAccepted**
National_Agricultural_Public_Domain_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation National_Agricultural_Public_Domain_PDMA
National_Agricultural_Public_Domain_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation National_Agricultural_Public_Domain_PDMA
National_Agricultural_Public_Domain_NA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation National_Agricultural_Public_Domain_PDMA
Natural_Protected_NA *sqsubseteq* **NotAccepted**
Natural_Protected_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Natural_Protected_PDMA
Natural_Protected_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Natural_Protected_PDMA
Natural_Protected_NA ≡ ∃ hasRelation Facilities_ULU ⊓ ∃ hasRelation Natural_Protected_PDMA
Natural_Protected_NA ≡ ∃ hasRelation Green_Spaces_ULU ⊓ ∃ hasRelation Natural_Protected_PDMA
Public_Domain_NA *sqsubseteq* **NotAccepted**
Public_Domain_NA ≡ ∃ hasRelation Residential_ULU ⊓ ∃ hasRelation Public_Domain_PDMA
Public_Domain_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Public_Domain_PDMA
Semi_Rural_NA *sqsubseteq* **NotAccepted**
Semi_Rural_NA ≡ ∃ hasRelation Economic_Activities_ULU ⊓ ∃ hasRelation Semi_Rural_PDMA

Table XIX: Not Accepted Sub-concepts in DL language.

20. NetBeans GUI

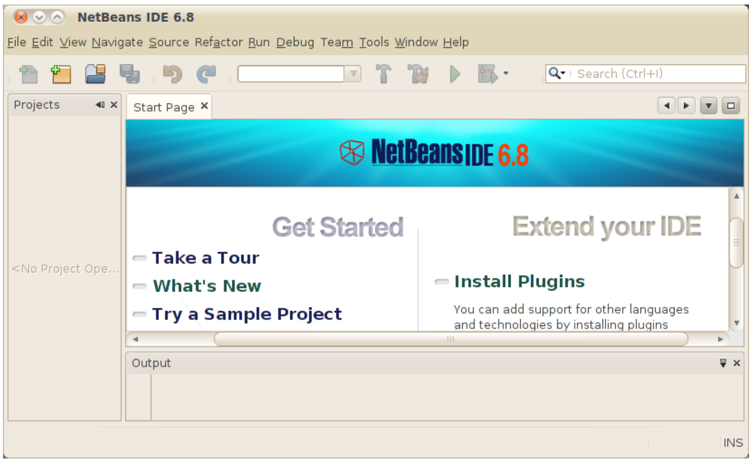

Figure XX: NetBeans GUI.

21. OpenJump Database Java Connection

```
void chooseConnection(){
 ConnectionManagerPanel panel = new ConnectionManagerPanel(
    ConnectionManager.instance( wbContext ),
    wbContext.getRegistry(), wbContext.getErrorHandler(), wbContext );
 OKCancelDialog dialog = new OKCancelDialog((Dialog) SwingUtilities.windowForComponent(panel),
       I18N.get("JUMP.WORKBENCH.UI.PLUGIN.DATASTORE.CONNECTIONPANEL.CONNECTION-MANAGER"),
       true, panel,
       new OKCancelDialog.Validator() {
           public String validateInput(Component component) {
               return null;
           }
       });
 dialog.setVisible(true);
```

Table XXI: Implementation of the Java OpenJump Database Connection.

22. SAXParser API Connection

```
public static String getAnnotation(String pdma, String ulu, String filename) throws Exception {
    SAXParserFactory factory = SAXParserFactory.newInstance();
    SAXParser saxParser = factory.newSAXParser();
    XMLHandler handler = new XMLHandler();
    handler.setRelationStrings(pdma, ulu);
    saxParser.parse(filename, handler);
    return handler.getComment();}
```

Table XXII: getAnnotation method.

23. Java Swing Panel

```
<Component class="javax.swing.JButton" name="jbCompare">
  <Properties>
    <Property name="text" type="java.lang.String" value="Compare"/>
  </Properties>
  <Events>
    <EventHandler event="actionPerformed" listener="java.awt.event.ActionListener"
     parameters="java.awt.event.ActionEvent" handler="jbCompareActionPerformed"/>
  </Events>
</Component>
```

Table XXIII: Java Swing Button jbCompare.

24. Consistency Checking Java Implementation

```
try {
 FeatureInputStream fis =
            ConnectionManager.instance(wbContext).getOpenConnection(connection).execute(
            new AdhocQuery(query)
            );
    Feature f= fis.next();
    if(f.getAttribute("topology").toString().equalsIgnoreCase("t")){
        query = "UPDATE urbanintervention SET status_uint= '" + status_labels[i] + "' "
              + "WHERE codmun_uint = '"+codMun+"'";
        executeQuery(query);
        if(!status_labels[i].contains("Consistent")){
            if(status_labels[i].equals("Consistent")){
                jTextArea3.setText("Consistent\n");
            }else{
                jTextArea3.setText("Possibly Consistent\n");
            }
```

Table XXIV: Java implementation of the Consistency checking operation.

25. Store Proceedings Implementation

```
void storePolygons(String inc) {
  String natCadastRef = cadParcel.getAttribute("natcadastref_cp").toString();
  String codMun = urbanInt.getAttribute("codmun_uint").toString();
  String[] containsQueries = {
   "CREATE OR REPLACE VIEW p_overl AS SELECT c.boundary_cp, c.id_cp,
     u.id_uint, c.pdmcateg_cp, c.natcadastref_cp FROM cadastralparcel
     AS c INNER JOIN urbanintervention AS u
     ON ST_Intersects(u.boundary_uint, c.boundary_cp)
   WHERE u.codMun_uint='"+codMun+"';",
     "CREATE OR REPLACE VIEW p_EOA AS SELECT p.id_uint, p.pdmcateg_cp,
     p.id_cp, ST_Intersection(u.boundary_uint, p.boundary_cp) AS EOA_geom
     FROM p_overl AS p, urbanintervention AS u
     WHERE u.codMun_uint='"+codMun+"'AND p.natcadastref_cp!='"+natCadastRef+"';",
   "INSERT INTO outerareas(id_uint, categoverl_oa, areavalue_oa, boundary_oa,
     centroid_oa) SELECT p.id_uint, p.pdmcateg_cp, ST_Area(p.EOA_geom),
     p.EOA_geom, ST_Centroid (p.EOA_geom) FROM p_EOA AS p;"
    };
```

Table XXV: Store Proceedings Implementation in Java.

26. Acceptance Checking Implementation

```
    String annotation = "";
    String pdmcat = cadParcel.getAttribute("pdmcateg_cp").toString()+" PDMA";
    String catulu = urbanInt.getAttribute("categulu_uint").toString()+" ULU";
    String owl="/tmp/cadastral.owl";
  if(status.equalsIgnoreCase("Consistent")){
  try{
     annotation = OWL.getAnnotation(pdmcat, catulu, owl);
     String id_uint = urbanInt.getAttribute("id_uint").toString();
     String q = "UPDATE urbanintervention SET annotonto_uint='" + annotation
              + "' where id_uint='" + id_uint + "'";
     executeQuery(q);
     jTextArea3.setText(jTextArea3.getText() + annotation);
```

Table XXVI: Java implementation of the Acceptance checking operation.

27. Comparison Results Visualisation in OpenJump

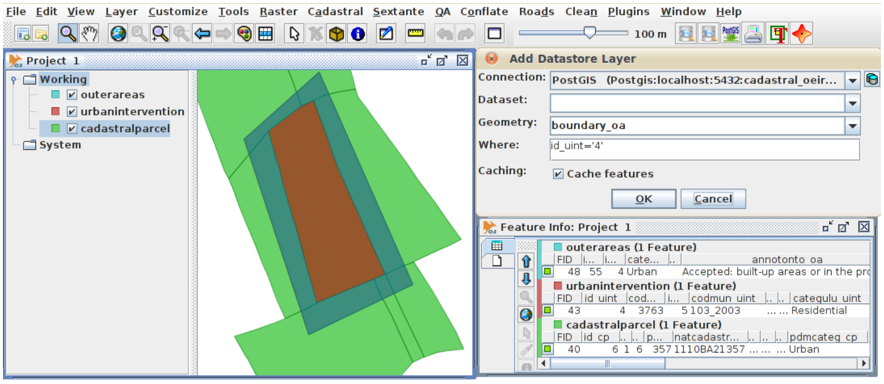

Figure XXVII: Comparison Results Visualisation in OpenJump.

28. Possibly Accepted Areas

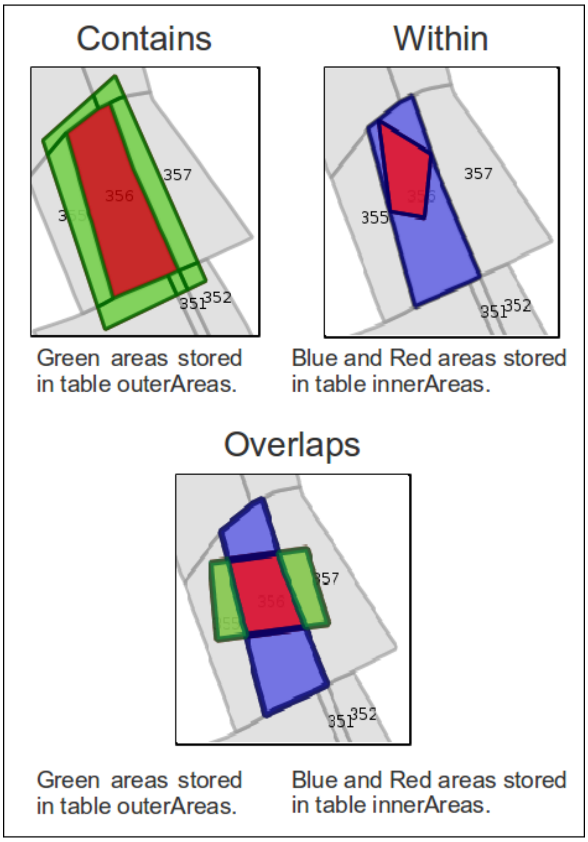

Figure XXVIII: Possibly Accepted Outer and Inner Areas.

29. Plugin Strengths and Limitations

Design Principles	Strenghts	Limitations
Maintainability	The SQL sentences follow predefined rules. The OWL code structure is defined by standards.	Structure and cleanness of the Java code dependent of the programmer.
Modularity	Contains two modules: Spatial, Thematic. Both are explicitly divided and the functions well distributed.	Each module is limited to the the tools that have inside.
Minimum redundancy	In the OWL and in the SQL select and quantitative and qualitative predicates statements, it is minimum.	In Java and in the SQL data store procedures and view creation the redundancy level is medium.
Extensibility	The OWL and SQL can easily be updated into a new version. Plugin is dependent of the OpenJump API and not from the version where is running.	The Java is more complicated to update and some functions may need to be rewritten.
Implementability	The Java is only dependent of the Java virtual machine installation OWL is an XML file. OpenJump is stand-alone.	The PostgreSQL/Postgis needs to be installed and needs to have a port assigned to him.
Simplicity	The SQL code and the OWL code are clear and sequential	The Java code is not always easy to maintain organised.
Interoperability	OWL is a standard and Java is not dependent of vendors.	SQL incompatible between vendors.
Stability	Java and SQL are being used since the last 15 years and the differences from one version to other are not very pronounced.	Ontology languages are presenting pronounced changes from one version to other.
Robustness	The OWL and SQL, due to the structures are more difficult to commit errors on the design and implementation.	In the Java programming language is more likely to commit errors during the design and implementation, when compared with the OWL and SQL.

Table XXIX: Plugin Strengths and Limitations.

Masters
Program
in **Geospatial**
Technologies

Supported by:
Education and Culture
ERASMUS MUNDUS