Computer Science and Information Systems 12(3):1033–1053 DOI: 10.2298/CSIS141031009S

The Use of Ontologies in Cadastral Systems

Dubravka Sladić, Aleksandra Radulović, Miro Govedarica,
Dušan Jovanović, Đorđe Pržulj

Faculty of Technical Sciences, Trg D. Obradovića 6,
21000 Novi Sad, Serbia
{dubravka.sladic, sanjicans, miro.govedarica, dusan.jovanovic, przulj}@gmail.com

Abstract. This paper presents the application of ontologies in the field of real estate cadastre. Ontologies can be seen as a form of metadata that provide a higher level of interoperability and integration within the Spatial Data Infrastructure, not only on the syntax level but on the semantic level as well. The application of ontologies in this domain is based on domain ontology for cadastre developed on top of the Land Administration Domain Model defined in ISO 19152 standard. The use of ontologies is shown on the several examples including data integration of the Serbian national cadastre and the INSPIRE cadastral parcels, and integration of OGC based geospatial services and other Web services in cadastral systems. The introduction of semantics in the cadastral systems provide many opportunities in terms of cadastral data and services integration on national and international level, and also in connecting with many other organizations that are users of such systems. These opportunities are reflected in the fact that terms are given well-defined explicit meaning and when based on formal ontology automatic reasoning can be used to infer the new knowledge.

Keywords: ontologies, cadastre, LADM, SDI.

1. Introduction

In the modern Spatial Data Infrastructures (SDI) [24] the key issue is finding appropriate data and services and their integration into single usable information. For this purpose, catalogue services are used which store and serve metadata about geospatial resources, with different catalogue information models, i.e. metadata formats [12]. Problems appear because of interoperability issues, where the usability of information created in one context is often of limited use in another context, due to insufficient means for meaningful interpretation [4]. This problem is known as semantic heterogeneity. The standards in the field of GIS increase interoperability at syntactic and structural level, since they standardize data structure and service interfaces, but these standards do not solve semantic problems. Searching for information is often affected by low recall and precision [25]. Low recall means that some relevant information sources may not be discovered, while low precision means that some of the discovered information may not be relevant. Semantic heterogeneity is caused by different conceptualizations of real world facts and can be divided into *cognitive heterogeneities* in which the same names are given for the different real world objects (homonyms) and *naming heterogeneities* in which different names are given to the same real world objects (synonyms) [6].

The problem of semantic heterogeneities may be solved using technologies of the Semantic Web [5]. The Semantic Web is an extension of the World Wide Web in which information is given well-defined explicit meaning through the use of ontologies which are used to communicate a shared and common understanding (between people and computers) of some domain of discourse, because they represent an explicit formal specification of a shared conceptualization of the domain [14]. Ontologies provide semantic representations about knowledge of the real world allowing users to define a set of concepts, relationships between concepts, and rules of inference on a particular domain. Ontologies on the Semantic Web are represented using Web Ontology Language (OWL) [2] a W3C standard built on top of RDF (Resource Description Framework) [35]. The technologies of Semantic Web are used because the goal of SDI is to facilitate spatial data dissemination via World Wide Web, and for that goal the service-oriented architecture is used. Geospatial web services are mostly based on OpenGIS consortium (OGC) implementation specifications of service interfaces for geospatial data access and processing.

Ontologies are used to describe a certain domain and to reason about the properties of that domain by inferring the new knowledge from the asserted facts. Its role is to provide a shared vocabulary within a certain domain such as the land administration. The term *land administration* is described as "the process of determining, recording and disseminating information about the relationship between people and land"[23]. This term is more general than the term *real estate cadastre* (shortly cadastre), which is only one aspect of land administration expressed through rights (mainly ownership rights) on real estates (land, buildings and part of buildings). In Serbia land administration is organized as the real estate cadastre, while the old organization called land cadastre (concerned only with rights on land) is completely abandoned, although in some countries in the region still exists. The Land Administration Domain Model (LADM) specified in ISO 19152 international standard [23] provides a base for building ontologies in land administration domain to enable involved parties, both within one country and between different countries, to communicate, based on the shared vocabulary (ontology) implied by the model. Therefore, the core ontology for the real estate cadastre should be developed according to this domain model in order to achieve the intended goal of the standard, while domain ontology for cadastral systems in different countries should be based on this core ontology. Once the domain ontology for cadastre is established it can be used to link the variety of data models and services that reside in cadastral systems and in that way provide semantic interoperability in cadastral systems. This link is provided through the use of application ontologies that describe individual data sets and services and reference domain ontology. This approach has been used in the paper to solve problems that arise from semantic heterogeneities in cadastral systems.

The main contribution of this paper is to show the practical use of ontologies and Semantic Web technologies in cadastral systems, the topic rarely covered in literature, to obtain semantic interoperability which is significant not only within a single country for different kind of users of cadastral data and services, but for a cross border real estate market, as well. The gain from this methodology is that it can be used to connect variety of data sets through Web services, since the aim is to move cadastral system from the monolith closed system to the open distributed system, in order to provide easy access for everyone. In this context, implementing Web services without semantics is significant step forward, but adding semantics improve usability of these services through explicating concepts that are known only to a small group of domain experts.

This paper is organized as follows: Section 2 presents related works in the field of research. Then, the ontology architecture in the domain of the real estate cadastre has been presented in Section 3. The purpose of this Section is to describe how domain ontology for the national cadastre can be developed, shown on the example of Serbian real estate cadastre using LADM as the basis for the development of the core ontology for cadastre. Section 4 presents the case study of semantically enhanced discovery process based on developed ontology. After that conclusions are discussed in Section 5.

2. Related Work

The importance of ontologies for solving semantic problems during discovery, retrieval and integration of geospatial data and services has been widely recognized in geospatial community. The concept of Geospatial Semantic Web has been introduced in [10]. The importance of Geospatial Semantic Web is also recognized by the OpenGIS Consortium (OGC) [34] where there are several OGC initiatives considering development of the Geospatial Semantic Web. In [29] the attempts to extend existing OGC services, encodings, and architectures with Semantic Web technologies in order to achieve semantic interoperability are presented. In [32] semantic annotations at three different levels are discussed: geospatial service metadata, data models and process descriptions, and actual data instances in the database. In [47] a proposal for OGC catalogue service based on catalogue information model of RDF, RDF Schema and OWL elements is described. OGC has also developed GeoSPARQL - A Geographic Query Language for RDF Data, an extension to the SPARQL query language for processing geospatial data [36].

Some researches in this area are focused on the development process of ontologies itself, proposing different ontology architectures for the geospatial ontologies [26] or domain ontologies for different fields of application such as environment, land cover and topography, observations and measurements and land administration [33, 48]. Other researchers are focused on the application of ontologies in the discovery and retrieval, composition and integration of geospatial resources [1].

These research results provide a significant input for the application of ontologies in the field of real estate cadastre. They are either general for geospatial domain or are focused on specific domains such as environment, but there are few results in the field of land administration, especially considering the use of current standards. In this paper the authors present a model and implementation of ontologies in cadastral systems based on LADM using case study for Serbian cadastre, whose main application is the integration of existing spatial data and services through an automated discovery and integration process of cadastral resources.

A recent research in [45] also uses LADM to build ontologies in this domain, but it is mostly focused on representing roles in land administration and is not based on upper ontology which is a difference with presented approach. The authors believe that without using upper level ontology, semantic heterogeneities still exist but are only shifted from application level to the domain level. The paper [44] presents a conceptual framework of representing semantics for 3D cadastre. 3D cadastre is not yet implemented in Serbia, therefore it is out of the scope of research. Several other papers are concerned with *Linked Data* approach, which is a new research area in geospatial domain. Ref. [7] presents Linked Data approach to the land administration domain as a Core Immovable Property Vocabulary. Papers [8, 39] describe Linked Data approach for cadastral data integration. Linked Data is defined as “a term used to describe a recommended best practice for exposing, sharing, and connecting pieces of data, information, and knowledge on the Semantic Web using URIs and RDF” [30]. It is a different approach based on RDF, while presented approach is based on OWL. Both approaches use different methodologies with the same goal and it would be necessary to perform thorough analysis which of them has better applicability in real world scenarios.

Ontology model for the real estate cadastre based on LADM and other geospatial standards has been presented in [41, 43], while this paper considers its applicability in common cadastral problems such as issuance of ownership sheet through the usage of web services (e.g. *Right Service* described in Section 4). Paper [40] discusses different forms of geospatial metadata including semantic metadata and its applicability in cadastral domain. It also makes comparisons among them to analyze their advantages and disadvantages.

To our knowledge there are still not real applications of usage of Semantic Web in cadastral domain and all attempts are in research domain, but once the right solution is established it will make cadastral data more open to the general public, whereas now the semantics of the domain is known only by domain experts.

3. Ontology Model

Based on the degree of generality, ontologies can be divided into three levels [15]: top-level ontologies, domain ontologies and application ontologies. Top-level ontology or upper level ontology defines generic concepts such as space and time that are independent of the domain. Domain ontology defines domain specific concepts in a domain such as land administration, while application ontologies define concepts used in specific applications and they reference general concepts from domain ontology. According to this classification the authors developed the ontology model that consists of four layers as described in [41]. The model proposed in [41] is considered as domain ontology for the Serbian cadastre, while additional steps with respect to the ontology modelling are taken on the application level. This includes concepts used in Web services such as those described in next Section (e.g. *Rights Inquiry* and *Rights Inquiry Response*).

This paper gives the overview of the model with more practical examples of its use in distributed environment. The first layer is an upper level ontology that is used to connect ontologies from different domains. The next layer is the ontology that describes concepts in the geospatial domain, such as feature, geometry, topology, etc. The third layer contains ontology of basic concepts related to the real estate cadastre used in different countries and is based on ISO 19152 international standard. The final layer is the ontology that describes concepts related to the cadastre in a specific country. Each layer contains more specific concepts that are derived from the concepts in the previous layer. Comparing to the classification given in [15], the first layer of the proposed ontology model is the top-level ontology, while next three layers comprise domain ontology for cadastre. Application ontologies in [15] are not part of the ontology model for cadastral domain. They are derived from the concepts from the domain ontology and are used in different applications. Some of the applications are described in Section 4.

The proposed ontology is a knowledge model in the field of real estate cadastre for a specific country. It specifies the concepts that should be referenced by the concepts from the application ontology. Application ontologies are used in different applications to describe the specificity of the application and are mapped to domain ontology. The reason for such a proposal is to achieve the appropriate level of granularity at each layer, so that concepts are not too specific or too generic for use in real applications. This allows better acceptance of the proposed ontology by users and also facilitates the maintenance of ontology.

The authors used an open source ontology editor Protégé [27] for the development of cadastral ontology. Protégé allows the specification of ontologies in the OWL and OWL 2 language. It also allows automated reasoning systems using inference engine. The proposed ontology for the real estate cadastre has been implemented using OWL.

3.1. Upper Level Ontology

Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [31] has been used as an upper level ontology since it best suits the application in a web environment for the information discovery and retrieval. Its advantages are also relatively small number of basic concepts and implementation in the OWL language. Legal ontology [11] developed on top of the Description and Situation ontology (DnS) – an extension of DOLCE, also provides a good basis for the development of the ontology for the real estate cadastre since the land administration represent lawful relationship between people and land.

3.2. Geospatial Feature Ontology

The second layer of the ontology for the real estate cadastre is the ontology that describes concepts in the geospatial domain, such as feature, geometry, topology, etc. This ontology is called Geospatial Feature Ontology and it is based on ISO 19100 series of standards [20]. These standards define the basic structure and semantics of geospatial data and services to enable interoperability between different GIS systems. The basic concept of ISO 19100 series is a *feature* representing an abstraction of a real world phenomenon which has spatial and non-spatial characteristics. The spatial characteristics are geometry and topology of objects in some coordinate system related to the Earth, while the non-spatial characteristics can be thematic or temporal.

3.3. Core Ontology for Cadastre

The third layer of the ontology architecture is the Core Ontology for Cadastre. It contains ontology of basic concepts related to the real estate cadastre used in different countries and is based on ISO 19152 international standard. The focus of this standard is on that part of land administration that is interested in rights, responsibilities and restrictions affecting land, and the geometrical (spatial) components. Central part of the LADM model are four classes: *LA_Party* representing the property owner or the person that is given certain rights over real estate; *LA_RRR* representing rights, restrictions and responsibilities; *LA_BAUnit* containing administrative data on spatial units with equal rights, restrictions and responsibilities; *LA_SpatialUnit* representing territorial units, parcels, buildings, etc. Concepts in the core ontology for cadastre follow the meaning of these classes defined in the standard.

The concept *Party* represents a party i.e. a person or organization that plays a role in a rights transaction. The concept *RRR* represents legal aspects over real estates. Its subclasses are rights, restriction and responsibilities. Rights are formal or informal entitlement to own or to do something. Restrictions are entitlement to refrain from doing something. Responsibility is an obligation to do something. The concept *Basic Administrative Unit* represents an administrative entity consisting of zero or more spatial units against which unique and homogeneous rights**,** responsibilities and restrictions are associated to the whole entity. The concept *Spatial Unit* represents an area of land or a volume of space structured in a way to support the creation and management of basic administrative units. These four concepts are subsumed by the concepts from DOLCE and DnS ontology.

3.4. Domain Ontology for Serbian Cadastre

The final layer of the ontology contains concepts present in the real estate cadastre system of the specific country and it is the domain ontology for the national cadastre. In Serbia this layer contains concepts related to geodetic reference, cadastral parcels, parts of cadastral parcels according to land use, buildings, network utilities, spatial units, elevation model of terrain and topography [28]. Since cadastral system contains many data sets and services it is necessary to introduce concepts from a national cadastre in domain ontology while the link between cadastres in different countries will be established via Core Ontology for Cadastre with similar approach described in [16, 17].

Cadastral data in Serbia are organized according to the conceptual model in Figure 1 [49, 50]. Real estates include parcels, buildings and parts of buildings, such as apartments and offices. Over each real estate, rights are defined so that the total sum of shares is equal to one. Homogenous rights over an individual real estate (parcel, building or part of building) are gathered in a real estate folio. Holders of rights are physical and legal entities that have certain rights over real estate. Standardized domain model of real estate cadastre in Serbia was formed on the basis of a comparison of the basic LADM classes and conceptual model for Serbia.

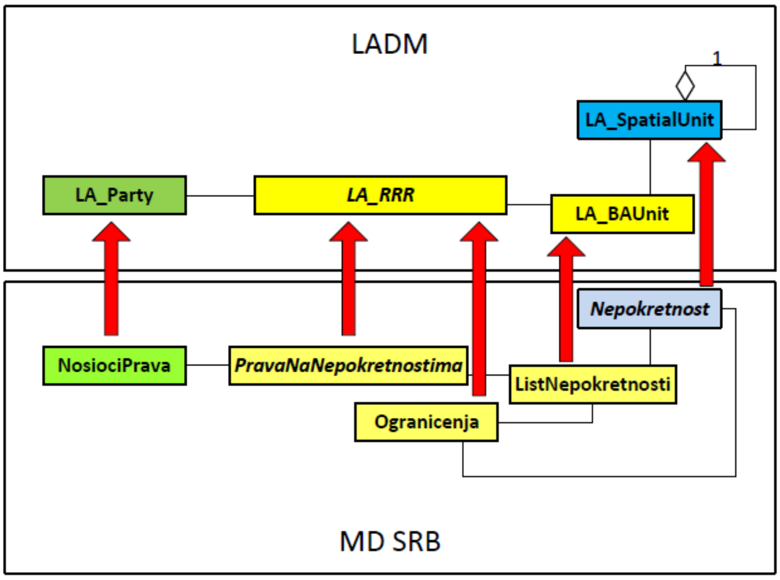

Fig. 1. Mapping of concepts from Serbian cadastre to LADM

Table 1 shows the basic mapping of LADM classes to classes from the conceptual model for Serbia. As being more formal than terms and definitions in [28], conceptual model for cadastre in Serbia is used as a base for ontology development.

Table 1. Summary of the basic concepts from LADM and cadastre in Serbia

LADM concepts	LADM profile concepts
LA_SpatialUnit	RS_Parcel
LA_SpatialUnit	RS_PartOfParcel
LA_LegalSpaceBuildingUnit	RS_Building
LA_LegalSpaceBuildingUnit	RS_PartOfBuilding
LA_SpatialUnitGroup	RS_CadastralMunicipality
LA_SpatialUnitGroup	RS_AdministrativeMunicipality
LA_SpatialUnitGroup	RS_City
LA_SpatialUnitGroup	RS_Country
LA_Party	RS_RightHolder
LA_BAUnit	RS_RealestateFolio
LA_Right	RS_Ownership
LA_Restriction	RS_Restriction

3.5. Ontology Example

Figure 2 shows an example from all layers of ontology containing concepts related to the roles in legal affairs related to land administration and to legal aspects of land administration. To achieve visual clarity, ontologies are represented informally in UML class diagrams, assuming description logic semantics: classes are interpreted as concepts, generalization is interpreted as formal subsumption, and association is interpreted as a binary relation. Concepts from different layers can be distinguished by different colors and different prefixes: prefix *DnS* represents concepts from the upper level ontology (grey color), prefix GFO represents concepts from the geospatial feature ontology (blue color), prefix LADM represents concepts from the core ontology for cadastre (yellow) and RS is used for concepts in Serbian cadastre (green). The concept *LADM:RRR* is a *DnS:Description* that *defines* concepts: *LADM:Party* and *LADM:Basic Administrative Unit* (relation *edns:defines* is specified in extended DnS based on DOLCE). In this way the relationship between people and land linked by (ownership) rights is expressed as it is established in land registry or cadastre. *LADM:Party* is a *DnS:Role* played by the *DnS:Agentive Figure* which can be a person (the concept *DnS:Natural Person*) or organization (*DnS:Legal Person*). The role of the party can also play a basic administrative unit. *LADM:Basic Administrative Unit* is a role played by *LADM:Spatial Unit* (parcel or building) subsumed by *GFO:Geospatial Feature.* The holder of the right (*RS:Holder of Right*) is a natural or a legal person that has acquired a right over a real estate. Real estate includes land, buildings and part of buildings. The concept *RS:Real Right* is subsumed by the concept *LADM:Right*, the concept *RS:Right Holder* is subsumed by *LADM:Party*, and the concept *RS:Real Estate* is subsumed by *LADM:Basic Administrative Unit*. Real right defines holders of the rights and real estates the same way as right defines parties and basic administrative units in LADM. Real right includes ownership rights and rights of usage. The entire ontology is implemented in OWL using DOLCE+.owl [9] as a basis to introduce new concepts.

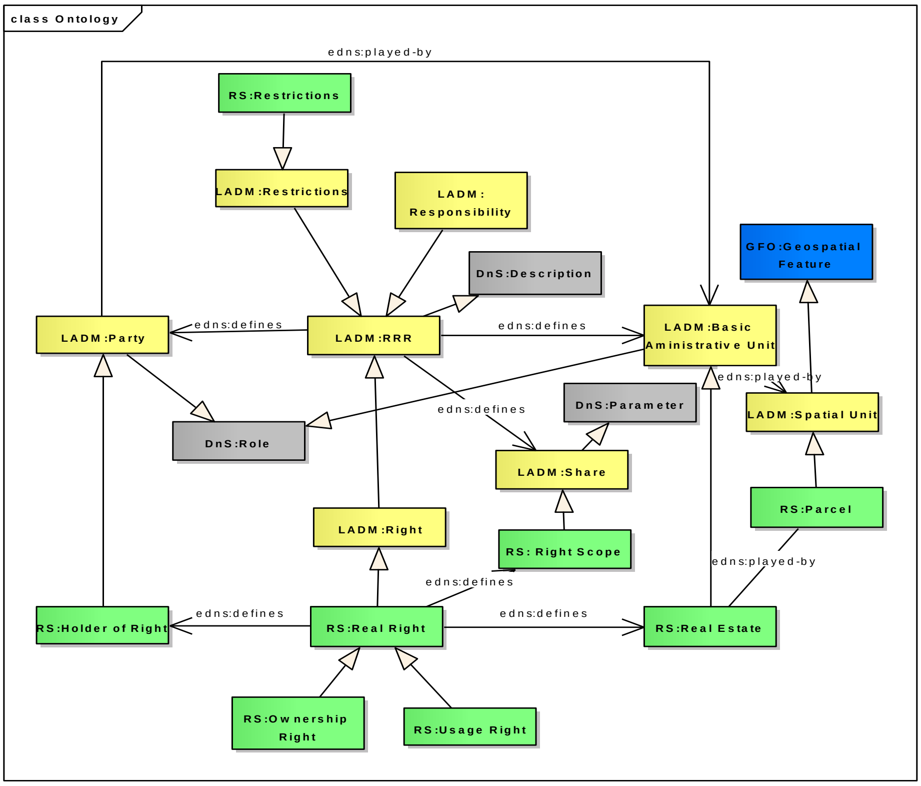

Fig. 2. The basic cadastral concepts

4. Application of Domain Ontology for Cadastre

4.1. Integration with INSPIRE

The use of ontologies in cadastral systems can be shown in the process of integration and harmonization of Serbian national cadastre with the cadastral model of the INSPIRE directive [18] using domain ontology for cadastre based on LADM**.** INSPIRE directive defines data specifications for various themes to facilitate cross-border discovery and access of data in European countries, which are primarily intended for users in the field of environment. Cadastral parcels are one of the datasets which are harmonized in INSPIRE and they serve as a generic information locator for environmental applications, such as discovery and retrieval of other spatial information [19]. INSPIRE data model for cadastral parcels has been developed in parallel with LADM model, which has resulted in concept consistency and compatible definitions of common concepts. In that way the consistency of these models is provided. The difference arises from the different scopes and targeted application areas. INSPIRE focuses on the application in the field of environmental protection, whereas LADM has a multi-purpose character such as providing support to legal certainty, the formation of taxes, planning, real estate valuation, etc. , which is beyond the scope of INSPIRE. The basic concepts related to cadastral parcels in INSPIRE are *Cadastral Parcel*, *Basic Property Unit*, *Cadastral Boundary* and *Cadastral Zoning*. These concepts are subsumed by the concepts: *Spatial Unit*, *Basic Administrative Unit*, *Boundary Face String* and *Spatial Unit Group*, respectively.

Table 2 shows a comparative review of the names and attributes of *feature types* that represent a land parcel according to three different data models including national cadastre in Serbia, INSPIRE and LADM. Feature, in ISO 19100 series, is defined as abstraction of real world phenomenon. It is considered as an instance of feature type, a class of features that usually contains spatial and non-spatial attributes. Features are delivered through Web Feature Service (WFS). WFS is a geospatial Web service (shortly called geo-service) whose interface is standardized by OpenGIS Consortium and it is used to accesses geospatial data in vector format [51]. Features are delivered in GML format, according to GML application schema, an XML based schema standardized by OGC [37].

Table 2. Comparative review of feature types that represent a land parcel

WFS output	SERBIAN CADASTRE	INSPIRE	LADM
Feature type name	Parcel	CadastralParcel	SpatialUnit
Number	number	nationalCadastralReference	X
Subnumber	subnumber	nationalCadastralReference	X
Geometry	geometry	geometry	ass. class
Area	area	areaValue	area
Land use	wayOfUse	ass. class	ass. class
Unique identifier	X	inspireID	suID
Dimension	X	X	dimension
Description	description	label	label
Reference point	X	referencePoint	referencePoint
External address	address	X	extAddressID

Feature types in Table 2 represent outputs from WFS services. These feature types are comprised of different attributes, as well as similar attributes but with different names. Keyword-based search is not able to determine the relationship between these three outputs from WFS. But if these WFS services are semantically annotated, it is possible to perform semantic search and determine the correct relationship among them. The usage of semantic annotations with geospatial Web services is described in detail in [42]. To summarize, semantic annotations can be implemented on three different levels: service metadata (*Capabilities* document that describes WFS service capabilities), data model level (feature types) and data level (feature instances). We used model reference and domain reference from SAWSDL standard [38] to semantically annotate WFS outputs. Model reference is used to link a feature type with its *Feature Type Ontology* (application ontology), while domain reference links application ontology to domain ontology, as shown in Figure 3.

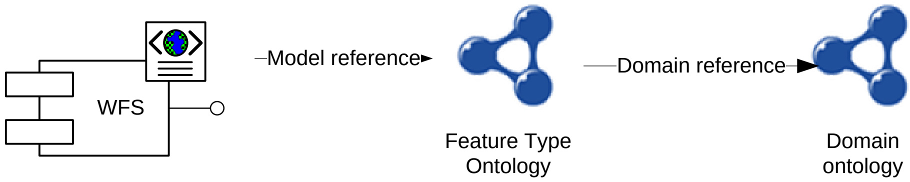

Fig. 3. Semantic annotation of feature types

In order to harmonize data about cadastral parcels in INSPIRE and national cadastre it is necessary to semantically annotate feature types *Parcel* (Listing 1) and *CadastralParcel*. Semantic annotations of the feature type *Parcel* reference the *ParcelFeatureType* application ontology, whereas semantic annotations of the feature type *CadastralParcel* reference the *CadastralParcelFeatureType* application ontology. These two application ontologies semantically describe the output from WFS services delivering data according to national cadastre and INSPIRE schema.

```
<xsd:element name="Parcel" substitutionGroup="gml:_Feature"
type="kn:parcelType" sawsdl:modelReference="&cadastre;Parcel"/>
<xsd:complexType name="parcelType">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element maxOccurs="1" minOccurs="0" name="the_geom"
nillable="true" type="gml:MultiSurfacePropertyType"
sawsdl:modelReference="&cadastre;geometry"/>
        <xsd:element maxOccurs="1" minOccurs="0" name="number"
nillable="true" type="xsd:int"
sawsdl:modelReference="&cadastre;number"/>
        <xsd:element maxOccurs="1" minOccurs="0" name="subnumber"
nillable="true" type="xsd:int"
sawsdl:modelReference="&cadastre;subnumber"/>
        <xsd:element maxOccurs="1" minOccurs="0" name="area"
nillable="true" type="xsd:int"
sawsdl:modelReference="&cadastre;area"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
```

Listing 1. Semantically annotated feature type Parcel

Application ontologies *ParcelFeatureType* and *CadastralParcelFeatureType* are subsumed by the concepts from domain ontology for cadastre. *ParcelFeatureType* is subsumed by the concept *Parcel*, whereas a *CadastralParcelFeatureType* is subsumed by *SpatialUnit*. Listing 2 shows the application ontology for the feature type *Parcel* that references concepts from domain ontology for cadastre.

```
kn:ParcelFeatureType
   a       owl:Class ;
   rdfs:subClassOf owl:Thing , kn:Parcel ;
   rdfs:subClassOf
            [ a owl:Restriction ;
            owl:allValuesFrom <http://www.owl-
ontologies.com/OntologyISO19107.owl#GM_Object>;
            owl:onProperty default:hasGeometry
            ] ;
   rdfs:subClassOf
            [ a owl:Restriction ;
            owl:cardinality "1"^^xsd:int ;
            owl:onProperty default:hasNumber
] ;
      ...
 rdfs:subClassOf
[ a         owl:Restriction ;
            owl:onProperty default:hasGeometry ;
            owl:someValuesFrom <http://www.owl-
ontologies.com/OntologyISO19107.owl#GM_Object>
] .
```

Listing 2. Application ontology for the feature type *Parcel*

The result of subsumption reasoning [3] on application ontologies shows that application ontologies *ParcelFeatureType* and *CadastralParcelFeatureType* are both sub concepts of the concept *SpatialUnit* from the domain ontology. In this way the link between WFS services whose output are these feature types is established during the semantic search.

4.2. Implementation of Example Web Services

While WFS services are mainly used for distribution of spatial data i.e. geometries such as boundaries of parcels and other spatial units, there are plenty of other Web services in cadastral systems that are concerned not only to geometric characteristics of real estates, but also rights, holders of rights, and other non-spatial data. Those services are mainly implemented using WSDL and it is necessary to make link to WFS services and other geospatial services, which are mainly OGC based RESTful services, to obtain full interoperability.

Suppose that, in order to ensure interoperability of cadastral system with other stakeholders, it is necessary to provide a service for retrieving all of the rights of a specified party. That service can be called *RightsService* and its operation that will provide the functionality *GetRights*. Modelling the service includes an XML schema definition, that will describe the types that are also concepts of domain model (in this case real estate cadastre) and the WSDL file to describe the service, operation, message type and protocol that will ensure the transfer of data in XML format between the service consumer and the provider.

Listing 3 shows the XML schema that defines the types that constitute the basis for defining the types of messages whose exchange service should provide. These types are semantically annotated to reference application ontologies that reference the same domain ontology so they can be linked to corresponding WFS services. Complex types are modelled according to the LADM classes, specified in ISO 19152. In addition to the complex and simple types that describe the domain, XML schema contains the types *RightsInquiryType* and *RightsInquiryResponseType* which model the consumer request and service provider response, respectively. Finally, XML schema contains elements *rightsInquiry* and *rightsInquiryResponse* that facilitate the use of the elements of the specified type in the WSDL definition.

```
<?xml version="1.0" encoding="UTF-8"?>
...
  <element name="rightsInquiry" type="tns:RightsInquiryType"
sawsdl:modelReference="&cadastre;rightsInquiry></element>
  <element name="rightsInquiryResponse"
type="tns:RightsInquiryResponseType"
sawsdl:modelReference="&cadastre;rightsInquiryResponse></element>
  <complexType name="RightsInquiryType">
    <sequence>
      <element name="partyId" type="int" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;partyid></element>
    </sequence>
  </complexType>
  <complexType name="RightsInquiryResponseType">
    <sequence>
      <element name="rights" type="tns:RightType"
maxOccurs="unbounded" minOccurs="0"
sawsdl:modelReference="&cadastre;rights></element>
    </sequence>
  </complexType>
  <complexType name="RightType">
<sequence>
      <element name="party" type="tns:PartyType" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;party></element>
      <element name="spatialUnit" type="tns:SpatialUnitType"
maxOccurs="1" minOccurs="1"
sawsdl:modelReference="&cadastre;spatialUnit></element>
<element name="right" type="tns:RightEnumType" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;right></element>
      <element name="shareNumerator" type="int" maxOccurs="1"
minOccurs="1"
sawsdl:modelReference="&cadastre;numerator></element>
      <element name="shareDenominator" type="int" maxOccurs="1"
minOccurs="1"
sawsdl:modelReference="&cadastre;denominato></element>
   </sequence>
  </complexType>
  <complexType name="PartyType">
    <sequence>
      <element name="partyId" type="string" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;partyid></element>
```

```
      <element name="name" type="string" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;name></element>
      <element name="role" type="string" maxOccurs="1"
minOccurs="0" sawsdl:modelReference="&cadastre;role></element>
      <element name="type" type="string" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;type></element>
    </sequence>
  </complexType>
<complexType name=" LAUnitType">
    <sequence>
      <element name="id" type="string" maxOccurs="1" minOccurs="1"
sawsdl:modelReference="&cadastre;uid></element>
      <element name="name" type="string" maxOccurs="1"
minOccurs="0" sawsdl:modelReference="&cadastre;name></element>
      <element name="units" type="SpatialUnitType"
maxOccurs="unbounded" minOccurs="1"></element>
    </sequence>
  </complexType>
  <complexType name="SpatialUnitType">
    <sequence>
      <element name="id" type="string" maxOccurs="1" minOccurs="1"
sawsdl:modelReference="&cadastre;suid></element>
      <element name="area" type="double" maxOccurs="1"
minOccurs="1" sawsdl:modelReference="&cadastre;area ></element>
      <element name="address" type="string" maxOccurs="1"
minOccurs="0" sawsdl:modelReference="&cadastre;address></element>
      <element name="label" type="string" maxOccurs="1"
minOccurs="0" sawsdl:modelReference="&cadastre;label></element>
    </sequence>
  </complexType>
...
```

Listing 3. XML schema CadastreSRB.xsd

WSDL definition describes the web service for finding all of the rights for specified party id specified in the request. The content is given in Listing 4.

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<wsdl:definitions xmlns:cada="http://www.example.org/CadastreSRB"
...
name="RightsService"
targetNamespace="http://www.example.org/RightsService/">
  <wsdl:types>
    <xsd:schema
targetNamespace="http://www.example.org/RightsService/">
      <xsd:import namespace="http://www.example.org/CadastreSRB"
        schemaLocation="CadastreSRB.xsd"></xsd:import>
    </xsd:schema>
  </wsdl:types>
  <wsdl:message name="GetRightsRequest">
    <wsdl:part element="cada:rightsInquiry"
  name="rightsInquiry"/>
  </wsdl:message>
  <wsdl:message name="GetRightsResponse">
    <wsdl:part element="cada:rightsInquiryResponse"
name="rightsInquiryResponse"/>
  </wsdl:message>
```

```
    <wsdl:portType name="RightsService">
      <wsdl:operation name="GetRights">
        <wsdl:input message="tns:GetRightsRequest"/>
        <wsdl:output message="tns:GetRightsResponse"/>
      </wsdl:operation>
    </wsdl:portType>
    ...
  </wsdl:definitions>
```

Listing 4. RightsService.wsdl

Using WSDL, a contract between the provider and the consumer of the service is defined, as well as the types of messages that will be exchanged in their interaction. Defined this way, the web service can be used only if the service consumer knows the semantics of the concepts of the real estate cadastre, which represent the content of the exchanged messages. An example SOAP request to RightsService is shown in listing 5.

```
<soapenv:Envelope
  xmlns:cada="http://www.example.org/CadastreSRB"
  xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
            <soapenv:Header>
            </soapenv:Header>
            <soapenv:Body>
              <cada:rightsInquiry>
                <cada:partyId>123456</q0:partyId>
              </cada:rightsInquiry>
            </soapenv:Body>
</soapenv:Envelope>
```

Listing 5. Examples of SOAP requests to RightsService

4.3. Semantic Search Using SPARQL

Another example how ontologies and the semantic search can be useful in cadastral systems is creating party portfolio defined in ISO 19152. This standard defines interface classes whose purpose is to generate and manage products and services. Interface classes represent views on aggregated data from other classes, and do not contain data themselves. An example of such an interface class is *PartyPortfolio* that contains overview of all rights, restrictions and responsibilities, all basic administrative units and all spatial units for one specific party. This concept is similar to the real estate deed in Serbian real estate cadastre that contains data about real estates and real rights on them for one specific holder of the rights. Real estate deed contains all the data about real estates belonging to the same party. Other kind of real estate deed contains data concerning one specific real estate and it is similar to the interface class containing the overview of all parties, rights, restrictions and responsibilities and all basic administrative units for one specific spatial unit.

In order to create party portfolio it is necessary to perform a semantic search on all real estates, which may be in different cadastral municipalities, and real rights on them for a specific person. Concerning land ownership, the semantic search is done similar to the previous example. During the semantic search, subsumption reasoning is used to infer the hierarchy of concepts representing WFS outputs and to determine the relationship between them.

While a subsumption reasoning is a kind of type reasoning, i.e. reasoning on description logic concepts (or OWL classes) that inheres a hierarchy of concepts, there is also the instance reasoning using the query language SPARQL [46] whose purpose is to retrieve individuals of certain OWL classes. Using SPARQL, it is not only possible to discover appropriate WFS service containing data but it is also possible to retrieve data itself.

In order to use SPARQL to create party portfolio it is necessary to convert data from database relational model into RDF graph model (e.g. using *DataMaster* plugin for *Protégé*). Cadastral systems are highly transactional systems involving many changes/updates and real time conversion is not justified. However, this approach can be used to analyze data in some period of time. As a demo example a database from a software package *eTerrasoft* for the area of cadastral municipality Voždovac is used [13]. Listing 6 shows a SPARQL query that retrieves data for the party portfolio, i.e. all properties (parcels, buildings, parts of buildings...) on which the party has certain rights (ownership, co-ownership, the right of use...). The convenience about this kind of distributed query is that it collects data from different sources using general concepts to obtain individuals of all their sub concepts (e.g. all individuals of a Spatial Unit will be parcels, sub parcels, buildings, networks...), so that only one query is enough instead of many. The result is shown in Figure 4.

```
PREFIX db:
<http://biostorm.stanford.edu/db_table_classes/DSN_jdbc.oracle.
thin.@localhost.1521.orcl#>
PREFIX edns:<http://www.loa-cnr.it/ontologies/ExtendedDnS.owl#>
PREFIX ladm: <http://www.owl-ontologies.com/LADM.owl#>
SELECT ?rrr ?baunit ?spatialunit
WHERE {
?rrr rdf:type ladm:RRR.
?baunit rdf:type ladm:BAUnit.
?rrr edns:defines ?baunit.
?spatialunit rdf:type ladm:SpatialUnit.
?baunit edns:played-by ?spatialunit.
?rrr edns:defines db: V_N_RS_OWNER_Instance.
}
```

Listing 6. SPARQL query

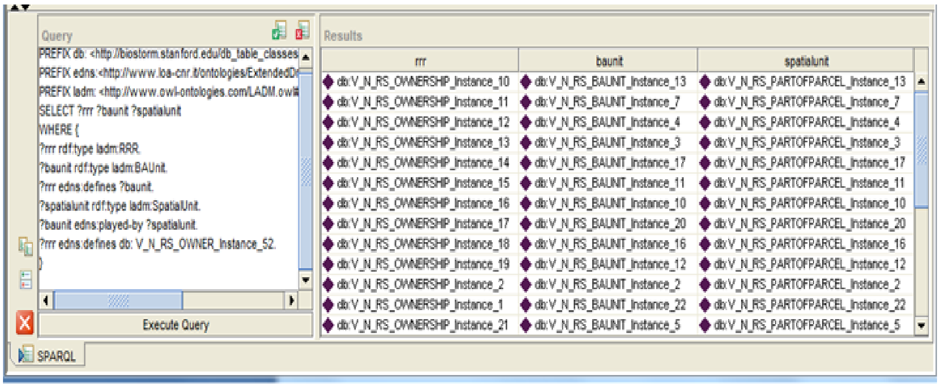

Fig. 4. Query result in Protégé

5. Conclusion

This paper presents ontology model for the real estate cadastre in Serbia and the use of ontologies to obtain semantic interoperability in national and international context. Ontologies are useful for data integration and harmonization with other cadastral systems using standard based domain ontology for cadastre on national and international level. Domain ontology for cadastre is based on the upper level ontology to avoid semantic ambiguities on the domain level and it is coordinated with standards in the geospatial domain, since they precisely define concepts (terminology) in geospatial domain and their relations with other concepts. The core ontology for cadastre is based on international standard ISO 19152 to provide reference for domain ontologies of national cadastres and achieve semantic interoperability between cadastral systems. This can improve discovery, retrieval and integration of data and services in cadastral information systems, and raise it from the syntactic to the semantic level.

Semantic search and integration of cadastral data based on the developed ontology model has been tested using data from Serbian real estate cadastre. Proposed ontology model has been verified on several examples, including integration with international frameworks such as INSPIRE, integration of spatial and non-spatial data, semantic search based on reasoning to find party portfolio, and distributed queries in SPARQL to retrieve data. Future work will include the alignment with the emerging standard for geospatial ontologies – ISO 19150 [21, 22] that defines the framework for semantic interoperability of geographic information and rules for geospatial ontologies, where one of the parts of this standard should address semantic operators and service ontology, once the work on it starts. Therefore, our further research will be focused on semantic integration and composition of cadastral Web services, aligned with standards.

References

1. Andrei, M., Berre, A., Costa, L., Duchesne, P., Fitzner, D., Grcar, M., Hoffmann, J., Klien, E., Langlois, J., Limyr, A., Maue, P., Schade, S., Steinmetz, N., Tertre, Vasiliu, L., Zaharia, R., Zastavni, N.: SWING: An Integrated Environment for Geospatial SemanticWeb Services, The Semantic Web Research and Applications, 3, 767-771. (2008)
2. Antoniou, G., Van Harmelen, F.: Web ontology language: OWL. In: Staab, S., Studer, R. (editors), Handbook on Ontologies. Springer, 91–110. (2009)
3. Baader, F., McGuinness, D., Nardi, D., Patel-Schneider, P.F.: Description Logic Handbook: Theory, Implementation and Applications. Cambridge University Press, 574 pages. (2002)
4. Bernard, L., Einspanier, U., Haubrock, S. Hubner, S., Kuhn, W., Lessing, R., Lutz, M., Visser, U.: Ontologies for intelligent search and Semantic Translation in Spatial Data Infrastructures. Photogrammetrie-Fernerkundung-Geoinformation 6, 451–462, (2003)
5. Berners-Lee, T., Hendler, J., Lassila, O.: The Semantic Web. Scientific American 184 (5), 34–43. (2001)
6. Bishr, Y.: Overcoming the semantic and other barriers to GIS interoperability. International Journal of Geographical Information Science 124, 299–314. (1998)
7. Çağdaş, V., Stubkjær E.: Core immovable property vocabulary for European linked land administration. Survey Review, in press
8. Díaz, A. A., Vilches-Blázquez, L.M.: Cadastral Linked Data According to INSPIRE. INSPIRE Conference, Aalborg (2014).
9. DOLCE-2.1-Lite-Plus, [Online]. Available: http://www.loa.istc.cnr.it/old/DOLCE.html (current October 2014)
10. Egenhofer, M. J.: Toward the semantic geospatial web. Proceedings of the 10th ACM International Symposium on Advances in Geographic Information Systems. ACM Press, New York, 1–7. (2002)
11. Gangemi, A., Sagri, M., Tiscornia, D.: A Constructive Framework for Legal Ontologies. International Semantic Web Conference – ISWC, 97-124. (2003)
12. Govedarica, M., Bošković (Sladić), D., Petrovački, D., Ninkov, T., Ristić, A.: Metadata Catalogues in Spatial Information Systems. Geodetski list, 64 (87) 4, 313-334. (2010)
13. Govedarica, M., Ristić, A., Sladić, D., Pržulj, Đ.: LADM profil za Republiku Srpsku. Kongres o katastru u BiH, Sarajevo, Bosna i Hercegovina. (2011)
14. Gruber, T.R.: A translation approach to portable ontology specifications. Knowledge acquisition 5, 199–220. (1993)
15. Guarino, N. Formal ontology and information systems. Proceedings of the First International Conference on Formal Ontologies in Information Systems. FOIS'98, Trento, Italy, pp. 3–15. (1998)
16. Hess, C., Schlieder, C.: Ontology-based verification of core model conformity in conceptual modeling. Computers, Environment and Urban Systems, vol. 30, 543–561. (2006)
17. Hess, C., de Vries, M.: From models to data: A prototype Query Translator for the cadastral domain. Computers, Environment and Urban Systems, vol. 30, 529–542. (2006)
18. INSPIRE, [Online]. Available: http://inspire.jrc.ec.europa.eu/ (current October 2014)
19. INSPIRE Data Specification on Cadastral Parcels D2.8.I.6 – Guidelines, [Online]. Available: http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_CP_v3.0.1.pdf, (current October 2014)
20. ISO / TC211 Geographic Information / Geomatics, [Online]. Available: www.isotc211.org, (current October 2014)
21. ISO/TS 19150-1:2012, Geographic information - Ontology - Part 1: Framework, http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=57465, (current January 2015)

22. ISO/DIS 19150-2, Geographic information - Ontology - Part 2: Rules for developing ontologies in the Web Ontology Language (OWL), http://www.iso.org/iso/catalogue_detail.htm?csnumber=57466, (current January 2015)
23. ISO 19152:2012 Geographic information – Land Administration Domain Model (LADM), http://www.iso.org/iso/catalogue_detail.htm?csnumber=51206, (current October 2014)
24. Nebert, D., 2004. Developing Spatial Data Infrastructures: The SDI Cookbook. [Online]. Available: http://www.gsdi.org/docs2004/Cookbook/cookbookV2.0.pdf, (current October 2014)
25. Klein, M., Bernstein, A.: Toward high-precision service retrieval. IEEE Internet Computing 8 (1), 30–36. (2004)
26. Klien, E., Probst, F.: Requirements for Geospatial Ontology Engineering. 8th Conference on Geographic Information Science. Portugal, 251-260. (2005)
27. Knublauch, H., Fergerson, R.W., Noy, N.F., Musen, M.A.: The Protégé OWL Plugin: an open development environment for semantic web applications. Lecture Notes in Computer Science 3298. Springer, 229-243. (2009)
28. The Law on State Survey and Cadastre (Zakon o državnom premeru i katastru), [Online]. Available: http://www.rgz.gov.rs/web_preuzimanje_datotetka.asp?FileID=321, (current October 2014)
29. Lieberman, J.: Geospatial Semantic Web Interoperability Experiment Report, OGC 06-002r1. Open Geospatial Consortium, Inc. 70 pages, (2006)
30. Linked Data - Connect Distributed Data across the Web, http://linkeddata.org/, (current January 2015)
31. Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A.: Ontology Infrastructure for the Semantic Web. WonderWeb Deliverable D18, IST WonderWeb Project 2001-33052. 349 pages. (2003)
32. Maué, P.: Semantic annotations in OGC standards, OGC 08-167r1. Open Geospatial Consortium, Inc. 50 pages. (2009)
33. van Oosterom, P., Zlatanova, S.: Creating Spatial Information Infrastructures: Toward the Spatial Semantic Web. Taylor & Francis. 216 pages. (2009)
34. OpenGIS Consortium, [Online]. Available: http://www.opengeospatial.org/, (current October 2014)
35. Pan, J. Z.: Resource Description Framework. In: Staab, S., Studer, R. (editors), Handbook on Ontologies. Springer, 71-90. (2009)
36. Perry M, Herring J.: OGC GeoSPARQL - A Geographic Query Language for RDF Data, Version 1.0. OGC 11-052r4. Open Geospatial Consortium, Inc. pp. 57. (2012)
37. Portele, C.: Geography Markup Language (GML) Encoding Standard, Version 3.2.1. OGC 07-036. Open Geospatial Consortium, Inc. pp. 437. (2007)
38. Semantic Annotations for WSDL, [Online]. Available: http://www.w3.org/TR/wsdl20/, (current October 2014)
39. Saavedra, J., Vilches-Blázquez, L.M., Boada, A.: Cadastral data integration through Linked Data. Proceedings of the AGILE 2014 International Conference on Geographic Information Science. Castellón, (2014)
40. Sladić, D., Govedarica, M., Jovanović, D., Petrovački, D.: Spatial Metadata and Ontologies in Cadastral Systems. International Conference on Methodologies, Technologies and Tools Enabling e-Government - MeTTeG12, 11-22 (2012)
41. Sladić, D., Govedarica, M., Pržulj, Đ, Radulović, A., Jovanović, D.: Ontology for Real Estate Cadastre. Survey Review, Vol. 45 No. 332, 357-371. (2013)
42. Sladić, D., Govedarica, M., Ristić, A., Petrovački, D.: Semantičko označavanje OGC baziranih geoservisa. InfoM, 42, 29-36. (2012)
43. Sladić (Bošković), D., Ristić, A., Govedarica, M., Pržulj, Đ.,: Ontology Development for Land Administration. 8th International Symposium on Intelligent Systems and Informatics (SISY), Subotica, 437 – 442 (2010)

44. Soon, K., H.: A Conceptual Framework of Representing Semantics for 3D Cadastre in Singapore. 3rd International Workshop on 3D Cadastres, Shenzhen, China, 361-380 (2012)
45. Soon, K., H.: Representing Roles in Formalizing Domain Ontology for Land Administration. 5th Land Administration Domain Model Workshop, Kuala Lumpur, Malaysia, 203- 222. (2013)
46. SPARQL Query Language for RDF, [Online]. Available: http://www.w3.org/TR/rdf-sparql-query/, (current October 2014)
47. Stock, K.: Catalogue Services – OWL Application Profile of CSW, OGC 09-010. Open Geospatial Consortium, Inc. 70 pages. (2009)
48. Stuckenschmidt, H., Stubkjær, E., Schlieder, C.: The Ontology and Modelling of Real Estate Transactions. Ashgate Publishing, 170 pages. (2004)
49. Radulović (ex Ristić), A., Govedarica, M., Pržulj, Đ., Sladić, D.: European cadastre in Serbia – domain model. International Scientific Conference and XXIV Meeting of Serbian Surveyors, Kladovo. Proceedings ISBN 978-86-7518-135-4: 45-49. (2011)
50. Radulović (ex Ristić), A., Govedarica, M., Pržulj, Đ.,Ristić,A.: Experience in Implementing ISO 19152 Standard in Cadastral Systems. International Conference on Methodologies, Technologies and Tools Enabling e-Government-MeTTeG12, Beograd. ISBN: 978-86-7892-413-2. (2012)
51. Vretanos, P., Web feature service (WFS) implementation specification. Version 1.1.0. OGC 04-094. Open Geospatial Consortium, Inc. 131 pages. (2005)

Dubravka Sladić received the PhD degree in 2013 at Faculty of technical sciences, Novi Sad. From 2008she is full time employee at Faculty of technical sciences, and from 2013she works as assistant professor of information technologies and geoinformatics. Her current research interests include research in the area of geoinformatics and service oriented geospatial information systems with the main focus on the cadastral systems.

Aleksandra Radulović received MSc degree in 2007 at Faculty of Technical Sciences, Novi Sad. Since 2011 she is teaching assistant at Faculty of Technical Sciences. She published 45 papers in international and national journals and conferences. She is PhD candidate and her research work include geoinformatics and service oriented information systems.

Miro Govedarica received the PhD degree in 2001 at Faculty of technical sciences, Novi Sad. From 1994 he is full time employee at Faculty of technical sciences, and from 2012 he works as professor of information technologies, geomatics and geoinformatics. He published more than 100 papers in journals and scientific conferences proceedings and he is reviewer in several journals. His current research interests include research in area of geomatics, geoinformatics and development of service oriented geospatial information systems.

M.Sc. Dušan Jovanović, since Aug, 2004 is a teaching assistant and Ph.D. student at Faculty of Technical Sciences, University of Novi Sad, Serbia. He has published several papers in international and national journals and conferences, including 4 paper in international journals, more than 20 papers on international conferences and more than 20 papers on Serbian national journals and conferences. He has also participated in several research projects concerning geospatial technologies and systems. He has 10

years' experience with lead software in the field of geographic information systems and technologies, such as ERDAS Imagine, ArcGIS, TerraSolid, MicroStation, CAD, and others. His areas of interest include remote sensing, airborne laser scanning, and GIS.

Ph.D. Đorđe Pržulj full employee at Faculty of Technical Sciences, University of Novi Sad, Serbia since November 1999. Since October 2013 he is an assistant professor at Faculty of Technical Sciences on several subjects in area of object oriented programming, software development and reengineering, geospatial information systems and spatial databases. He has published several papers in international and national journals and conferences. His current research interests are in area of service oriented architecture, design patterns and application of those concepts in geospatial information systems.

Received: October 31, 2014; Accepted: April 14, 2015.