A standards-based portal for integrated Land Administration information

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1 Introduction

Linking systems with official land administration information is crucial for attaining national-level land tenure security. Land administration is the process of identifying, recording, and sharing information about the relationship between entities and land. This definition broadly encompasses geographical spaces covering land and water, both above and below the surface (ISO, 2012)(Lemmen et al., 2021). Land administration systems are structured to support the four main functions of land administration: land tenure, land value, land use, and land development, as noted by Williamson (2001). Each country must establish an efficient, effective, and secure land administration system to support sustainable development and good land management practices (Dale and McLaughlin, 1999).

Responsibilities and tasks related to land administration may be distributed among different organizations and authorities. If so, they are likely to deal with different administrative areas and have different administrative aspects, such as how information is provided, processed and retrieved. The efficient practice of land administration is anticipated to organize these registries for the provision of cross-sector and cross-border land administration services. Such a system should provide fundamental data regarding land without requiring access to individual registries or distinct land administration systems (Çağdaş and Stubkjær, 2014). The Land Administration Domain Model (LADM) standard facilitates the effective implementation of land administration, according to Van Oosterom and Lemmen (2015). The model, which has five parts that deal with land, property, and entities, is presented in LADM Edition II. Additionally, it includes land administration terminology, serving as the foundation for regional and national profiles, and enabling the combination of land administration information from different sources (ISO, 2012). Providing a shared ontology is crucial for effective communication among professionals and for facilitating the exchange and management of data quality. The LADM provides a flexible conceptual schema, that can facilitate the exchange of data to and from different land administration systems (Van Oosterom and Lemmen, 2015).

1.1 Problem statement

The second Edition of LADM defines *Land* as the spatial extent to be covered by rights, restrictions and responsibilities, encompassing the wet and dry parts of the earth surface, including all space above and below the surface (ISO, 2023). Currently, information related to land in the Netherlands can be accessed through various platforms due to the country's disaggregated Land Administration Systems (LASs). These platforms include PDOK (pdo), Ruimtelijkeplannen (rui), WOZwaardeloket (woz), Bagviewer (bag), and Kaartenvannederland (Kadaster, b). The information systems acquire their data from distributed sources, including registries maintained by various organizations such as the Waarderingskamer, municipalities, and Kadaster. This can create challenges for users seeking specific information. Additionally, the platforms utilize different approaches for information delivery, processing, and retrieval, leading to difficulties in achieving interoperability between them. Due to this, there seems to be a necessity for an integrated land information system, such a system can be structured by a data model that clearly identifies the attributes of these registries and the relationships between them (Çağdaş and Stubkjær, 2014).

LADM as a conceptual model has multiple purposes. Firstly, it establishes a common ontology enabling users to communicate effectively. Secondly, it supports the development of land administration systems, particularly within an organized environment involving multiple organizations, by integrating them into a Spatial Data Infrastructure (SDI) for efficient data organization and accessibility. A SDI is about the facilitation and coordination of the exchange and sharing of spatial data between stakeholders from different jurisdictional levels in the spatial data community (Rajabifard and Williamson, 2001). Lastly, LADM supports the creation of application software with the data model at its core, and allows for the exchange of land administration data. This capability must exist within a SDI to allow for exchange between cadastres, land registries, and municipalities. The ultimate objective is to aid in data quality management. With the above-mentioned objectives, LADM holds the promise of being a potential solution when responsibilities and tasks related to land administration are distributed among different branches of government or organizations (Lemmen et al., 2015b).

National mapping agencies are exploring the potential of publishing official government data utilizing Linked Data (Ronzhin et al., 2019). By adhering to linked data principles, geospatial data can seamlessly link together, facilitating access and navigation. Linked Data, a technique based on standardized web technologies, can implement and enhance the capabilities of a SDI. In summary, linked data principles are highly relevant to the development of application software with LADM at its core. These principles augment the data model's capabilities by making data more interconnected, improving interoperability, and enabling efficient data exchange, all of which are important in land administration, where multiple organizations and information systems need to work together.

The Kadaster registers all land information on behalf of the Dutch government, including ownership and rights. Due to this central role, they manage crucial land administration systems and registries throughout the Netherlands. It is worth noting that despite these important responsibilities, Kadaster does not use the international standard LADM for creating an integrated national system (Hagemans et al., 2022). One may wonder why, but even the Kadaster does not have an answer to this question. In theory, the application of LADM appears logical, but the question is, does this application actually provide a solution in practice? This study examines the application and implementation of LADM in the Netherlands, utilizing a SDI approach and Linked Data. The study adopts the ISO 19152 standard LADM Edition II. Subsequently, a prototype will be created by utilizing Linked Data technologies to implement the country profile conceptual model of the Netherlands. After which use cases will be compared and evaluated to analyze the advantages and disadvantages of the application and implementation of LADM.

1.2 Scientific relevance

Countries with disaggregated land administration systems fail to take advantage of the opportunities that may exist in their disparate land administration systems to address national needs (Bennett et al., 2012). This results from potential misunderstandings between organizations due to the lack of shared concepts and terminology. Therefore, it is essential to establish concepts and terminology based on a standardized national model, such as the LADM (Zulkifli et al., 2015a). The term *national* is extensively used in current influential literature on land administration to convey the requirement for a unified national approach. The United Nations Integrated Geospatial Information Framework (UN-IGIF) also emphasizes the need for cross-sectoral and multidisciplinary collaboration on data that support people's activities and their interaction with the built and natural environment (Krizanovic et al., 2023). Considering the broader international context, the implementation of an international standard at the national level would represent a significant advance toward achieving interoperability between countries. This study will analyze the implementation of LADM Edition II in the Dutch context and its potential benefits and drawbacks. As LADM Edition II is still under development, the findings of this thesis can provide feedback and recommend possible changes to further optimize the revised version before it is officially adopted. The study will assess the implementation using case studies and offer recommendations for future developmental work.

2 Research objectives

2.1 Research questions

The main research question of this thesis is:

How can the Land Administration Domain Model (LADM) Edition II be applied and implemented in the context of the Netherlands?

The aim of this thesis is to research the potential of applying and implementing LADM in the context of the Netherlands. In order to answer the main question, the following sub-questions are relevant:

1. What are relevant use cases to demonstrate the potential added value of applying the LADM Edition II within the context of the Netherlands?
2. What is the state of the art on the LADM Edition II?
3. How can the country profile of the Netherlands be conceptually modelled as it pertains to parts 1, 2, 4 and 5 of the LADM Edition II, and what are the intended and unintended consequences in this modelling?
4. How can Linked Data be employed to implement the conceptual model of the country profile of the Netherlands based on LADM Edition II, and what are the intended and unintended consequences in this implementation?
5. What are the advantages and disadvantages following the LADM-based approach in the use cases as demonstrated through the developed prototype?

2.2 Scope

This research will exclusively addresses land administration pertaining to the Dutch territory, with further spatial constraints limiting consideration to only 2-dimensional data. The study utilizes the base register of addresses and buildings (BAG), the base register of large-scale topography (BGT), the base register of topography (BRT), the base land register (BRK), the public law restrictions (PB), the WOZ-value, WOZwaardeloket, PDOK, and Ruimtelijkeplannen as the foundation.

The scope of this study does not include 3-dimensional land administration data related to the context of the Netherlands, nor will it include land administration data related to foreign cases. In addition, datasets concerning underground infrastructure networks (IMKL) (KLIC), underground geology and soil (BRO) and maritime areas (Part 3 of LADM Edition II) are excluded. Furthermore, the focus of this research will be on data dissemination, i.e. the provision of the requested information to the user. It does not address the process of data registration, which serves to add new information to a register (Krizanovic et al., 2023). Finally, this thesis will not address privacy and authorization issues that may arise.

3 Related work

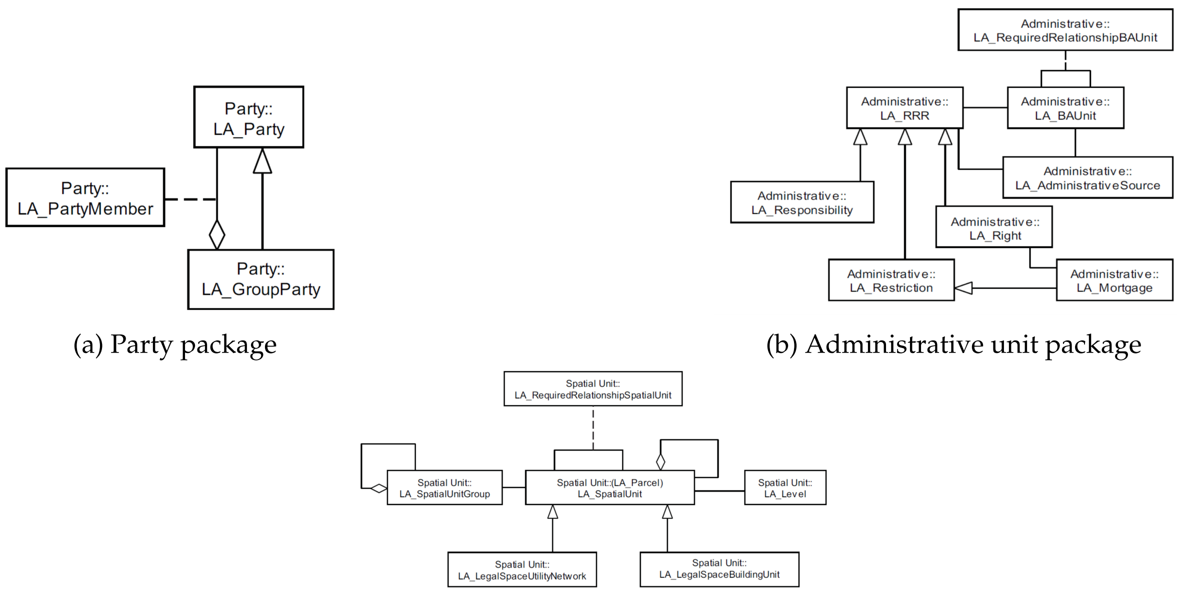
This chapter discusses work related to the topic of this thesis. Firstly, the Land Administration Domain Model is explained, after which the main (geo)portals in the Netherlands are described. Thirdly, the development of a country profile is elaborated on. Finally, the principles of Linked Data are explained, as well as the relation to the Kadaster Knowledge Graph and open dataset.

3.1 Land Administration Domain Model

The Land Administration Domain Model (ISO 19152) is a conceptual model based on a practical approach. It describes the data contents and relationships of Land Administration in general and can be extended and adapted to specific situations. The international standardized LADM includes land registration and cadastre in the widest sense. It includes land, and elements above and below the surface of the earth, and agreements on data about administrative and spatial units, land rights and source documents (Lemmen et al.)(Çağdaş et al., 2016). The main packages of the first edition of LADM are:

- The Party package (parties are persons, groups of persons or juridical persons, that make an identifiable single (legal) entity), represents legal and natural people.
- The Administrative package (rights, restrictions and responsibilities), deals with the registering units of land administration.
- The Spatial Unit package (based on a point or line representing a single area or multiple areas of space), defines spatial units and their geometric and topological representation.

Figure 1 shows the three main packages of the first edition of LADM (Çağdaş et al., 2016). Figure 2 shows a general overview of LADM (Lemmen et al., 2015a), both in the Unified Modelling Language (UML).



(a) Party package

(b) Administrative unit package

(c) Spatial unit package

Figure 1: Main packages first edition of LADM

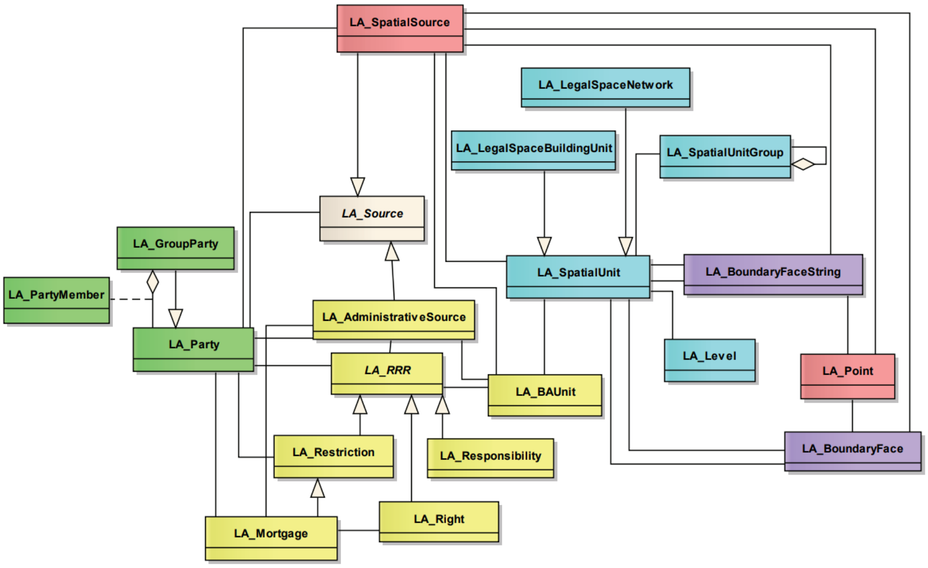


Figure 2: The Land Administration Domain Model

The functionality included in the first edition of LADM is also included in the second edition of LADM (Van Oosterom et al., 2022). The revised version of LADM is projected to be published as a multipart, containing five parts, each part having a prefix that identifies the UML package in which a class is defined (see table 1). Each part constitutes separate standards, and each part will go through the full standardization process. Although the revised version is still under development, it is stable enough to be used as the basis for this thesis. The five parts of LADM Edition II are briefly explained below.

Part	**Prefix**
Part 1 - Generic conceptual model	LA
Part 2 - Land registration	LA
Part 3 - Marine georegulation	MG
Part 4 - Valuation model	VM
Part 5 - Spatial plan information	SP

Table 1: Prefixes of UML classes

3.1.1 Part 1 - Generic Conceptual Model

Part 1 provides a general overview of the model and serves as an overarching standard that supports Parts 2 to 5 and is backward compatible with the first edition of LADM. It defines the basic components and relationships common to all land administration objects, and provides an overview of all parts, including those over water and land, and elements above and below the earth's surface (Van Oosterom et al., 2022). This part also provides a terminology for land administration, a basis for national and regional profiles and enables land administration from different sources to be combined (Body et al., 2022). Figure 3 shows the sub-packages in Part 1. A subpackage is a group of classes with a degree of cohesion.

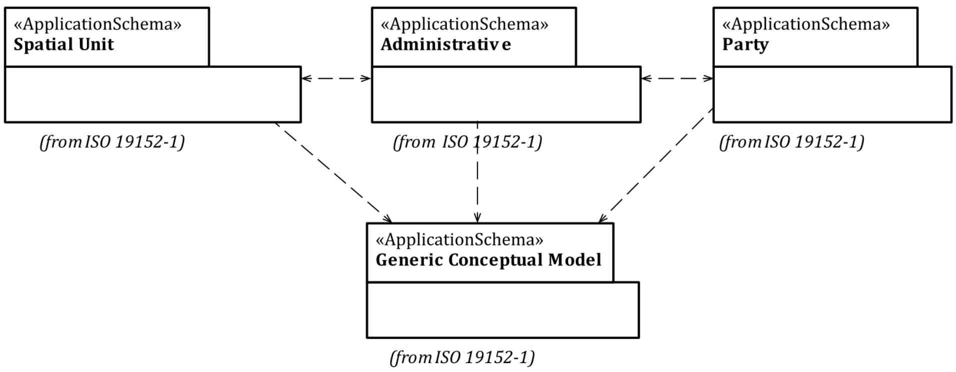


Figure 3: Part 1 sub-packages

Part 1 is based on six basic classes, all inheriting from VersionedObject (and associated to LA_Source):

- Class LA_Party. Instances of this class are parties (people and organisations).
- Class LA_RRR. Instances of sub-classes of LA_RRR are rights, restrictions or responsibilities.
- Class LA_BAUnit. Instances of this class are basic administrative units.
- Class LA_SpatialUnit. Instances of this class are spatial units.
- Class LA_Source. Instances of this class are sources (i.e. administrative and spatial).
- Class VersionedObject. This class is an abstract class and instances of subclasses of VersionedObject are all LADM classes (except LA_Source and its subclasses).

Figure 4 shows the basic classes of the core LADM. These classes cover both event-based and state-based modelling (Oukes et al., 2021).

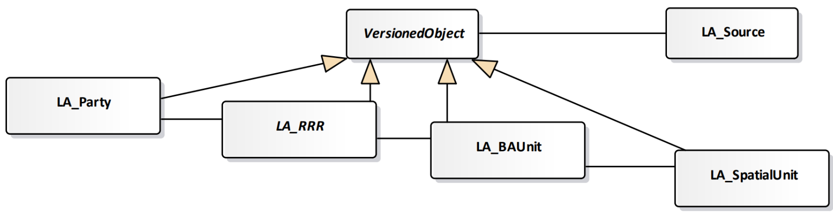


Figure 4: Classes of core LADM

3.1.2 Part 2 - Land Registration

Land registration is covered in Part 2, some of the existing parts of the first edition are refined with the aim of adding more semantics to the LADM. Part 2 is extended with a Survey and Representation package, which includes a new class LA_SpatialSource, as well as support for different observation types, accompanied by several new features and corresponding code lists (Van Oosterom et al., 2022)(Body et al., 2022). The concept of *integrated source* is introduced and modelled as an association between the Administrative and Spatial Source classes. A semantically enriched, structured (thesaurus/ontology) and versioned code list is also part of the refinement. These refinements are visualised in Figure 5, which shows the classes of Part 2 (Lemmen et al., 2021).

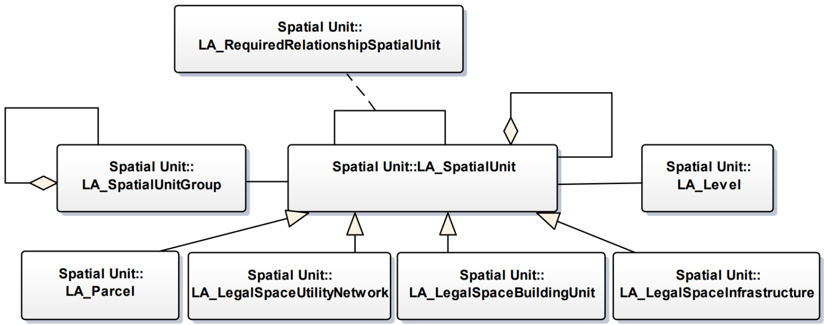


Figure 5: Classes of Part 2

3.1.3 Part 3 - Marine Georegulation

This part provides the structure and concepts for standardisation of georegulation in the marine space. It focuses on the information structure related to legal spaces, marine living and non-living resource management areas, and marine protected areas and their rights and obligations. It provides a model that represents the rights, restrictions and responsibilities related to marine space. The main classes are MG_SpatialUnit, MG_Administrative, MG_PartyGroup and MG_SourceGroup (Body et al., 2022).

3.1.4 Part 4 - Valuation Information

Part 4 specifies the semantics and characteristics of the valuation information (Kara et al., 2021). The valuation model is a conceptual scheme that facilitates all stages of administrative property valuation (Body et al., 2022). In particular, the identification of properties, the valuation of properties, the recording of the transaction price and the presentation of sales statistics, and finally the handling of appeals (Kara et al., 2021). All this includes the input and output data in valuation processes (Body et al., 2022).

The main classes are: VM_ValuationUnit, VM_SpatialUnit, VM_Building, VM_CondominiumUnit and VM_ValuationUnitGroup. These classes represent their characteristics and objects of valuation (Kara et al., 2021). Figure 6 shows the main classes that are included in this package (Lemmen et al., 2019). In addition, Figure 7 shows the main classes of the valuation information model in relation to the other classes of LADM (Kara et al., 2021).

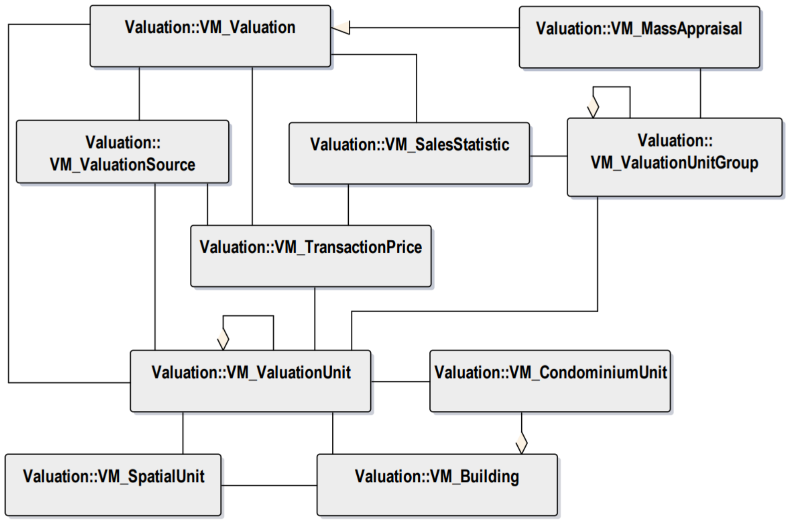


Figure 6: Classes of Part 4

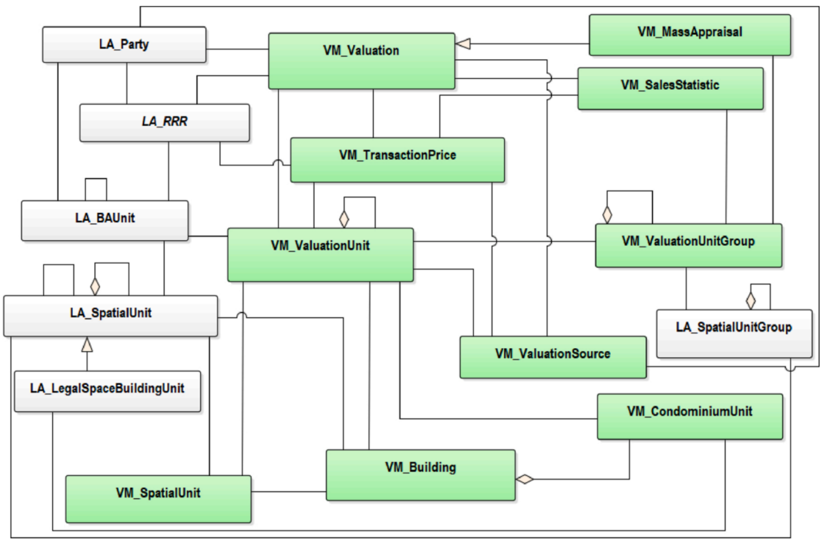


Figure 7: Relationships of valuation classes

3.1.5 Part 5 - Spatial Plan Information

The last part defines a general schema for spatial plan information. It proposes planned land use to be converted into rights, restrictions and, responsibilities (RRR) (Van Oosterom et al., 2022). It contains three main classes: SP_PlanningBlock, SP_PlanningUnit, and SP_PlanningGroup (Lemmen et al., 2019). The LA_SpatialUnit is used in this part to facilitate RRRs from land administration and spatial planning processes. Figure 8 and Figure 9 visualize the Spatial Plan Information package and its relationships with other packages (Lemmen et al., 2019).

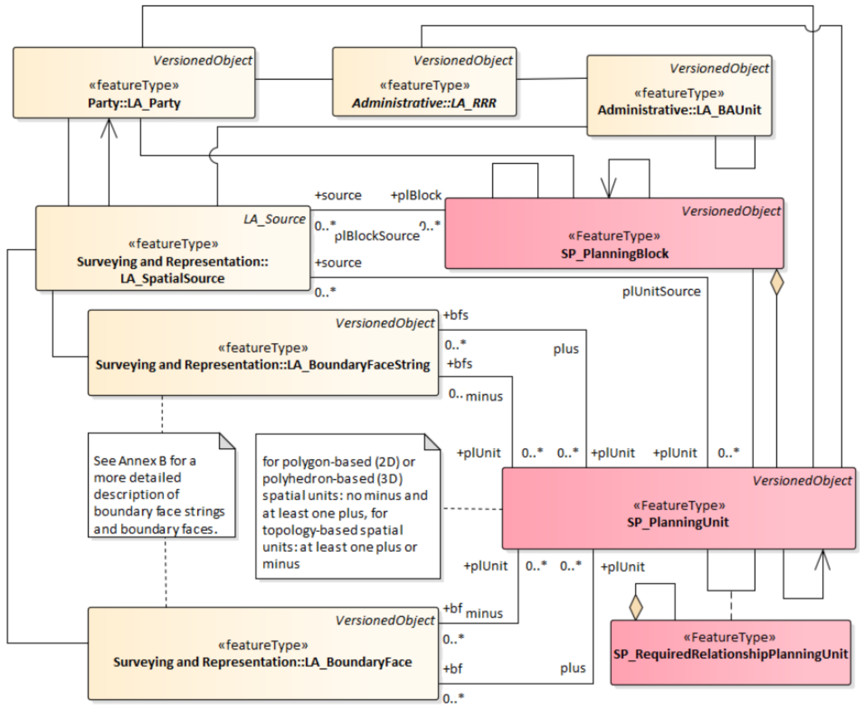


Figure 8: Classes of Part 5

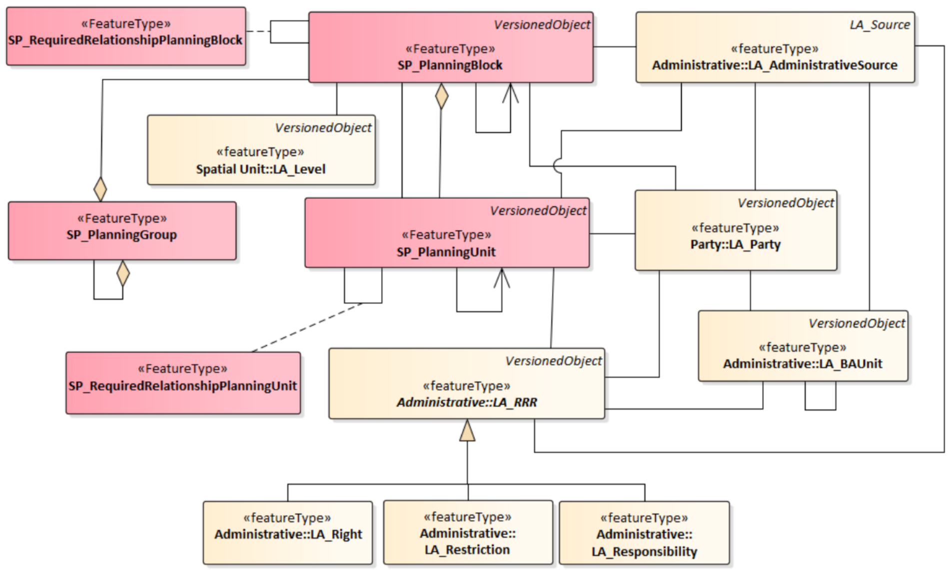


Figure 9: Correlation of LA_RRR and the classes of Part 5

3.2 (Geo)Portals in the Netherlands

Land information in the Netherlands is mainly held by Land Administration Systems (LAS). The information in these systems are each structured and formatted according to the specific data (registers) they manage, which leads to cross-sector interoperability problems when trying to link these different LAS. It is therefore important to have an integrated information system that clearly identifies the registered units within the registries and their core attributes, as well as their interrelationships. The following sections describe the main (geo)portals through which information from LASs is delivered in the Netherlands.

3.2.1 PDOK

Publieke Dienstverlening Op de Kaart (PDOK) is a platform that enables access to geodatasets from the Dutch government (pdo). These datasets are both up-to-date and reliable for the public and private sector. The Kadaster manages this platform and makes this open digital geoinformation freely available to everyone in the form of data services and files. These datasets are accessible via geo web services and downloadable for easy use. PDOK delivers data in a standardized way so that it can be processed automatically and generically. See Figure 10 for details on data, services, and standards provided by the PDOK platform.

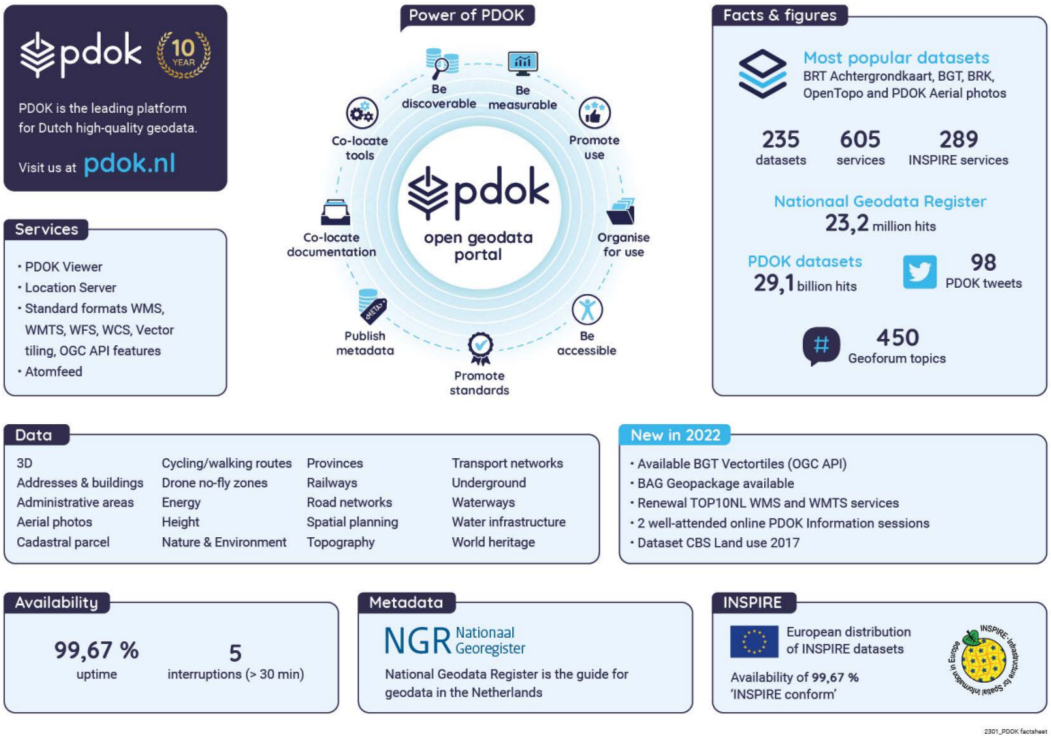


Figure 10: Factsheet PDOK 2022 PDOK (2022)

PDOK serves as the Dutch SDI to a significant degree, in part because it contains a substantial number of crucial registries. PDOK contains the registers, BAG (addresses and buildings), BGT (large-scale topography), BRK (cadastre, only the spatial parts), BRO (subsurface), BRT (topography) and BRT-A (topography background), these registries are further elaborated on in 3.5.1. Data on PDOK can be retrieved in standard formats such as Web Map Service (WMS), Web Map Tile Service (WMTS), Web Feature Service (WFS), Web Coverage Service (WCS), vector tiling and Application Programming Interface (API). A user can also share the URL link to a map showing the currently visible layers at a particular zoomed-in location.

3.2.2 Ruimtelijkeplannen

Ruimtelijkeplannen (spatial plans) is the result of a collaboration between the national government, Kadaster, Geonovum, Interprovinciaal Overleg and the Association of Dutch Municipalities (rui). It serves as the national portal for spatial plans, which include zoning plans, structural visions and general rules set by municipalities, provinces and the national government. These plans provide objective information on government spatial planning. The platform's viewer offers various backgrounds for user orientation. These backgrounds and detailed digital maps rely on the BRT and BGT (see 3.5.1) and are displayed using open standards for geographic web services. The platform also offers a viewer service to display plan map information. The system offers multiple types of geospatial services, including WMS, WFS, and tiled services. Additionally, users have the option to request a plan or point location through a deep link that contains parameters. Furthermore, users may use the print function to save a map image in PDF format.

Municipalities, provinces and the government are the source holder of data on this platform. They provide spatial plans by offering a complete and validated set of plan files in a manifest. Manifests can be offered in accordance with defined standards. Furthermore, Ruimtelijkeplannen is connected to PDOK. This means that the spatial plans are also made available via PDOK as WMS or as a download. Multiple map layers of Ruimtelijkeplannen are accessible in PDOK. These include Figure, Area Designation, Letter Designation, Plan Area, Zoning Plan Area, Plan Area, Provincial Complex, Provincial Area, Provincial Plan Area, 9 Decision Areas, and 8 Structure Visions.

3.2.3 WOZwaardeloket

WOZ-waardeloket contains information on the Waardering Ontroerende Zaken (WOZ) (Base-register of real estate values), which is a key register in the Netherlands (woz). The WOZ value is the estimated market value of a property determined on the assessment date (1 January). The WOZwaardeloket is intended for consultation of individual houses for citizens and not for mass or automated downloading and/or extraction of data. Municipalities are source holders of the data and must provide it annually. De Waarderingskamer (Council for Real Estate Assessment) is an independent administrative body that oversees the taxation, the platform itself is maintained by the government. In addition to the WOZ values, the platform displays the following data:

- Identification (WOZ-object number)
- Use purpose
- Attributes (from the BAG)
  - Year of construction
  - Purpose of use
  - Surface area
  - Addressable object
  - Number designation

A user can find information about a property by, searching an address, clicking on an element on the map, filtering in the properties visible on the map, using map layers (through information from the BAG), or zooming in and out.

3.2.4 Bagviewer

The Bagviewer represents data from the Basic Register of Addresses and Buildings (BAG). which includes all official addresses, buildings, residential units, stands, and berths assigned on Dutch territory (bag). Specific object types and attribute values are defined in the Bagviewer.

Known object types in BAGviewer are:

- Number designation
- Public space
- Residence
- Property
- Accommodation
- Stand
- Berth

Municipalities are responsible for maintaining the BAG as source holders, including the addition and quality of data. The National Provision BAG (LV BAG) centrally provides data on addresses and buildings. The Kadaster offers this data to various users in different ways, such as through the PDOK and the BAG Viewer. The viewer offers background maps from the BRT, BGT, and aerial photographs. Moreover, users can download data by selecting the desired objects and attributes, and exporting them as a PDF. The Bagviewer also provides a glossary that defines and describes technical terms and their abbreviations.

3.2.5 Kaartenvannederland

Kaartenvannederland provides access and allows use of data from the BGT and the BRT (Kadaster, b). It includes a legend, scale, and features to measure distances on the map, draw on it, and print it in PDF format, as well as options for selecting different background maps. The viewer is managed by the government, in collaboration with Kadaster.

The table below shows which (geo)portals relate to which parts of LADM Edition II.

Land Administration System	**Part 1**	**Part 2**	**Part 3**	**Part 4**	**Part 5**
PDOK					
PDOK - cadastral map		x			
Ruimtelijkeplannen					x
WOZwaardeloket				x	
Bagviewer					
Kaartenvannederland					

Table 2: Part of LADM covered by (geo)portal

3.3 Country profile

The implementation of LADM in a country involves developing a country profile (e.g. UML application schema) (Kara et al., 2021). The creation of a country profile based on LADM and efforts to apply LADM in land administration systems have so far been carried out by several countries, such as Czech Republic (Janečka and Souček, 2017), Croatia (Mađer et al., 2015) (Vučić et al., 2013), Turkey (Kara et al., 2021), Malaysia (Zulkifli et al., 2015b), China (Zhuo et al., 2015) and Poland (Bydłosz, 2015). The results of these reports can be used as a guide and example for the creation of a country profile.

3.3.1 Methodology

Kalogianni et al. (2021) propose a methodology for developing LADM country profiles, which consists of three phases, including:

- Phase I - Scope definition
- Phase II - Profile creation (modelling)
- Phase III - Profile testing (implementation)

Phase I involves defining the model's scope, which encompasses describing the type of situation the model will depict: the LASs, classes, and code lists. In Phase II, the country profile is modelled using UML based on the first phase's analysis. To undertake conceptual modeling, it is recommended to follow the subsequent steps:

1. Inheritance from LADM core classes into the relevant country-specific classes using a prefix denoting the country.
2. Explicit schema mapping between the country profile and LADM classes in case inheritance is not used.
3. Create new classes serving the specific needs that are not supported in the LADM, if needed.
4. Add new attributes to address country specific needs and requirements.
5. Introduce new associations based on country specific needs.
6. Adjust multiplicities according to if needed, and define relevant constraints to be imposed.
7. Add new values to existing code lists, and new code lists, if required, for new attributes.
8. Introduce external classes to link the model with the current external registries.
9. Test conformity.

The final stage involves testing the country profile by translating the UML conceptual model into the respective database schema and implementing it with technical encodings. This proposed methodology can serve as a guideline for the development of the country profile of the Netherlands.

3.3.2 The Netherlands

In the first publication of LADM, the country profile of the Netherlands was developed, as shown in Figure 11. Furthermore Kara et al. (2019) have developed a valuation information model based on the country profile of the Netherlands as can be seen in Figure 12.

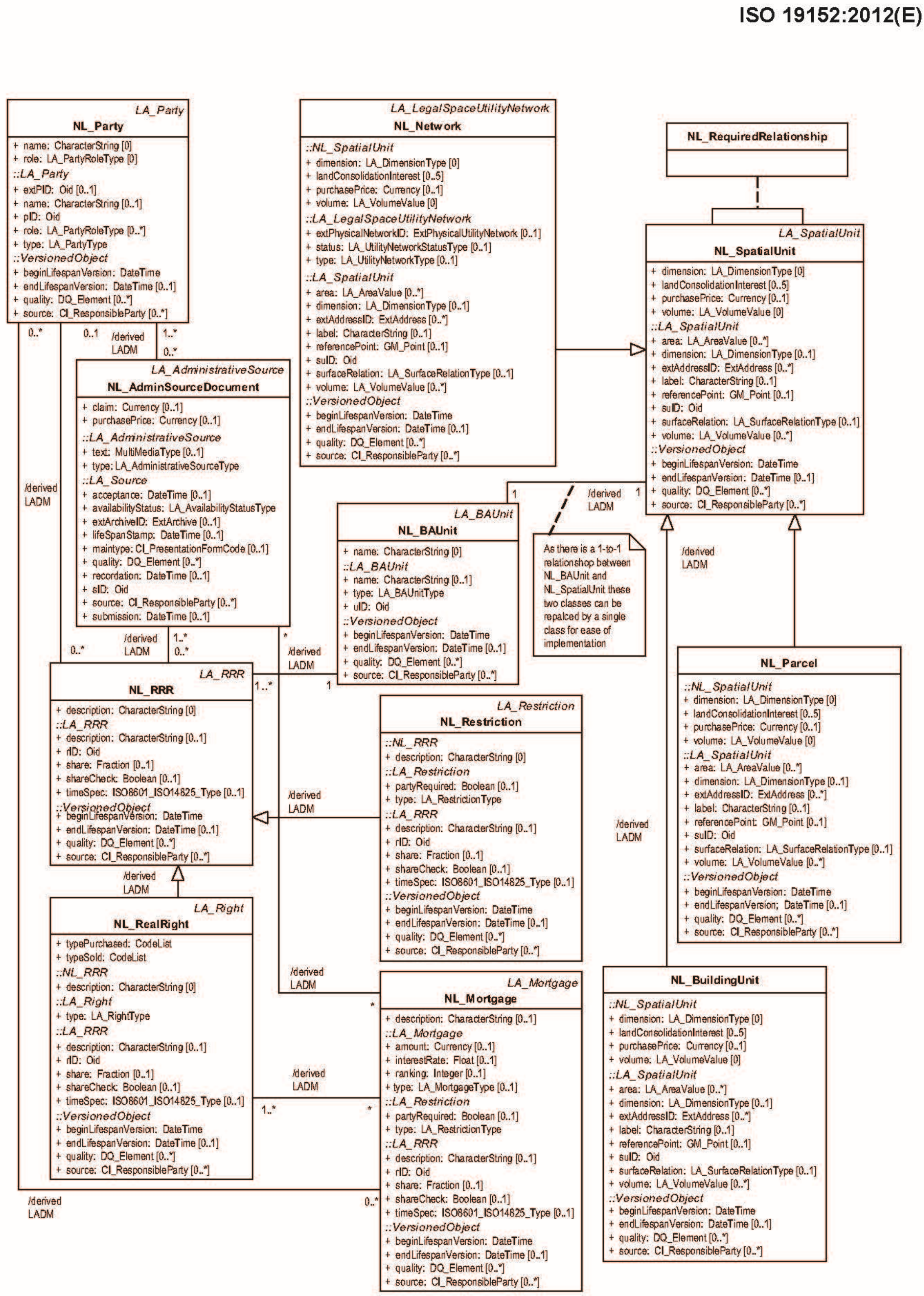


Figure 11: Country profile of the Netherlands

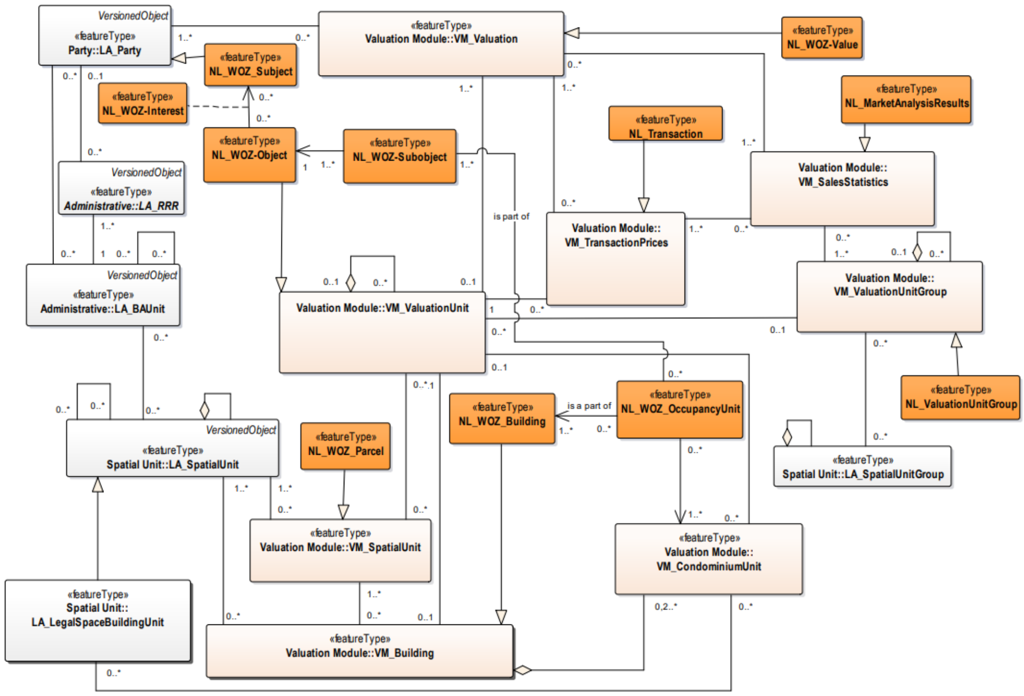


Figure 12: Overview of LADM valuation model on the country profile of the Netherlands

3.4 Linked Data

As mentioned in the introduction of this thesis, Linked Data allows data to be linked and used within a SDI to improve data interoperability and accessibility. Linked Data can be a way to implement a LADM-based country profile by establishing relationships between multiple registries and LASs, making it easier to access and navigate data.

Linked Data is about using the Web to create links between data (Bizer et al., 2009). More specifically, it's about using the Resource Description Framework (RDF) and the Hypertext Transfer Protocol (HTTP) to link data published on the Web from different sources (Bizer et al., 2008). Linking data this way allows users to navigate between different data sources by following RDF links. Simply said, a RDF link indicates that a piece of data has some relationship to another piece of data (Bizer et al., 2008). Bizer et al. (2009) defined a set of rules for linked data on the Web:

1. Use Uniform Resource Identifiers (URIs) as names for things.
2. Use HTTP URIs so that people can look up those names.
3. When someone looks up an URI, provide useful information, using the standards (RDF, SPARQL).
4. Include links to other URIs, so that they can discover more things.

Data must be published in RDF links, known as triples, which allow an element to be linked to other elements (Çağdaş and Stubkjær, 2014). These triples consists of three components:

1. Subject: an URI that represents a thing.
2. Predicate: an URI that indicates the relationship.
3. Object: an URI or literal that identifies another thing.

Figure 13 shows an example of an RDF triple where a cadastral parcel (subject) has four cadastral boundary parts (objects), and its relationship is represented by the boundary itself (predicate).

```
  <http://location.data.eu/so/cp/Cadastral
Parcel/12345><http://cadastralvocabulary.
org/land/#boundary><http://location.data.
eu/so/cp/CadastralBoundary/67890>
  <http://location.data.eu/so/cp/Cadastral
Boundary/78906>
  <http://location.data.eu/so/cp/Cadastral
Boundary/89067>
  <http://location.data.eu/so/cp/Cadastral
Boundary/90678>
```

Figure 13: Example RDF triple
(subject in blue, predicate in orange, and object(s) in green)

SPARQL is the standardized query language for linked data that allows querying and combining data from multiple linked datasets (Kadaster, 2013). In the context of this research, the linked data approach can enable easy integration of registries and information systems maintained by different organizations. However, this approach requires a Knowledge Organization System (KOS) in the form of controlled vocabularies, taxonomies, thesauri, or ontologies that provide shared descriptions of domain concepts and the relationships between these concepts (Çağdaş and Stubkjær, 2014).

Çağdaş and Stubkjær (2014) conducted a research that contributed to the linked data approach by developing a conceptual model and RDF schema that can be used to represent land administration data as linked data. More about this research can be found in Appendix section 8.1.

3.5 Kadaster Knowledge Graph

As previously mentioned, implementing the linked data approach in a domain requires controlled vocabularies, taxonomies, thesauri or ontologies that describe the domain-specific classes and their relationships, solving semantic interoperability problems (Çağdaş and Stubkjær, 2014). This aspect is critical for semantic resource identification, classification, and the shared description of domain concepts and their relationships (Çağdaş and Stubkjær, 2015). One method to accomplish this is through the use of a knowledge model.

A knowledge model is a collection of interlinked descriptions of concepts, entities and relationships of general world knowledge (Ronzhin et al., 2019). A Knowledge Graph (KG) contextualizes data through linking and semantic metadata, presenting a network of world real entities and their relationships. This information is typically stored in a graph database and visualized in a graph structure, hence the name Knowledge *Graph*. A KG comprises three primary components:

- Nodes: any object, person or place.
- Edges: defines the relationship between two nodes.
- Labels: to classify nodes.

This structure may seem familiar since KGs are represented in a RDF. As previously explained in section 3.4, this framework illustrates the relationships between entities by using triples: subject, predicate, and object. Leveraging a KG as a foundation and subsequently employing the linked data approach in a particular domain could prove to be an effective method.

In most cases, KGs are constructed from datasets originating from diverse sources, often with varying structures. The structure of a KG is formed through the integration of information models, which serve as the framework for the KG, identities that allow for appropriate categorization of underlying nodes, and context (wha). Ontologies are frequently referenced in this context as a blueprint for organizing information within a knowledge domain. It establishes the composition of data, with categories, attributes, connections, and contextual knowledge such as definitions, associations, and regulations (Union). An ontology provides a foundation for Knowledge Graph instances to attain data coherency and to ensure an unambiguous comprehension of the data system. Simply put, an ontology can be thought of as the data schema of the KG (Technologies) (Ontotext, 2023). There is an ongoing discussion regarding the differentiation between ontologies and KGs. This discussion is motivated by the fact that both ontologies and KGs utilize nodes and edges to describe relationships between entities, commonly represented by RDF triples. Consequently, they may seem comparable, particularly when presented visually.

The Kadaster has created the Kadaster Knowledge Graph (KKG), a KG customized for the Netherlands, which adheres to national and international standards for linked data as defined by W3C. The KKG enables the linking of disparate datasets, simplifying the process of requesting information for users, whether they be citizens or experts, by allowing them to ask a single question with all required criteria, eliminating the need for sub-querying individual datasets. The KKG is compatible with the SPARQL query language and draws on data from open sources: BAG, BGT, BRT, BRK and Public Law Restrictions (PB). In addition, the KKG includes a glossary with definitions for KKG-specific terminology, which can be conveniently ordered alphabetically, hierarchically or by group. This obviates the need to consult a catalog when encountering unfamiliar terms. Additionally, the KKG offers datasets, narratives, queries, and examples of a SPARQL endpoint (Kadaster, a). The KG can be observed in Figure 14, depicting the connections and nodes between each other. Users can refine the visualization by filtering it by relationship types, datasets, and types, or by conducting a direct search. Kadaster has developed a chatbot named *Loki* based on the KKG, which stands for Location-Based Land Registry Information. This chatbot is available at https://labs.kadaster.nl/ and showcases the capability to provide geospatial information related answers in a comprehensible language to the general public (Ronzhin et al., 2019).

3.5.1 Open data sources

The section will provide an explanation of the datasets that are available as open data in the KKG.

Basisregistratie adressen en gebouwen (BAG)
(English translation: Base register of addresses and buildings)

The BAG contains information about all addresses and buildings in the Netherlands. Municipalities are source holders of the BAG, meaning they are responsible for including the data and its quality. The data is made available through the LV BAG (National Provision BAG), which is maintained by the Kadaster. Users of the LV BAG who have a public task are obliged

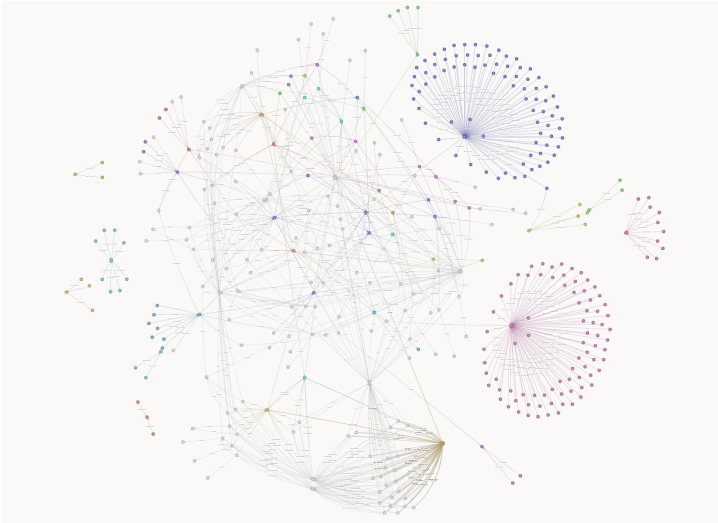


Figure 14: Visualization Kadaster Knowledge Graph (Rowland and Kadaster)

to use this data. The BAG consists of information of various object types and attributes, which are described in more detail in the Appendix 8.2. The BAG is part of the government's system of basic registrations and is therefore a key register in the Netherlands (Overheid, 2022).

Basisregistratie Grootschalige Topografie (BGT)
(English translation: Base register of large-scale topography)

The BGT is a digital map of the Netherlands on which buildings, roads, waterways, terrains and railroad lines are unambiguously recorded. The map shows the layout of the physical environment accurate to 20 centimeters. Municipalities, provinces, water management, the Ministry of LNV (Rijksdienst voor Ondernemend Nederland), the Ministry of Defense (Rijksvastgoedbedrijf), the Ministry of I&W (Rijkswaterstaat) and ProRail are responsible for maintaining their data, and deliver the information consequently to the Kadaster according to standardized agreements. The Kadaster manages the register in one national system, PDOK. Through this system, the data is made available to users. The BGT can also be viewed on the Kaartenvannederland viewer (see 3.2.5). Ministries, provinces, water management, municipalities and other government services are obliged to use the BGT in all work processes that require a map. The BGT consists of information of different object types, which are described in more detail in the Appendix 8.2. The BGT is part of the government's system of basic registrations and is therefore a key register in the Netherlands (Overheid, 2022).

Basisregistratie topografie (BRT)
(English translation: Base register of topography)

The BRT consists of digital topographic files at various scales. Both the formatted maps and the object-oriented files are available as open data. The Kadaster is the holder of the BRT, and makes these data files available free of charge and with minimal delivery requirements. The BRT consists of TOPRaster, TOPnames, BRTbackgroundmaps, TOPNL and NL maps, which are described in more detail in the Appendix 8.2. The BRT is part of the government's system of basic registrations and is therefore a key register in the Netherlands (Overheid, 2022).

Basisregistratie Kadaster (BRK)
(English translation: Base land register)

The BRK contains information on parcels, property, mortgages, restricted rights (such as leasehold, superficies and usufruct) and pipe networks. It also contains cadastral maps with parcel, parcel number, area, cadastral boundary and state, provincial and municipal boundaries. The Kadaster manages the BRK and makes the data available to organizations with public tasks and institutions. The Kadaster links the BRK with the BAG, the Commercial Register and the BRP (Basic Registration of Persons), so there exists a transfer of data. The BRK consists of the Cadastral Register and the Cadastral Map, which are described in more detail in the Appendix 8.2. The BRK is part of the government's system of basic registrations and is therefore a key register in the Netherlands (Overheid, 2022).

Publiekrechtelijke bepalingen (PB)
(English translation: Public law restrictions)

Public law restrictions refer to restrictions imposed by the government that determine what a person may or may not do with land. Ministries, provinces, water authorities, and municipalities are the source holders for PB, which are subsequently registered by the Kadaster. There are 48 restrictions recorded in the cadastre, varying from specific to general, the most common being: designation as a national or municipal monument, notification for home improvement, municipal right of first refusal, expropriation order, municipal permission to subdivide into apartment rights, public law anti-speculation clause (e.g. self-occupancy or prohibition of resale), soil remediation order or benefit tax. For additional information regarding how public law limitations are presented in an owner's report, see the Appendix 8.2. Public law restrictions are part of the BRK.

The table below shows which open data sources are included in which (geo)platform.

LAS	**BAG**	**BGT**	**BRT**	**BRK**	**PB**
PDOK	x	x	x	x	x
Ruimtelijkeplannen	x	x	x		
WOZwaardeloket					
Bagviewer	x				
Kaartenvannederland		x	x		

Table 3: Open data sources included in (geo)platforms

4 Methodology

This Chapter describes the methodology to answer the main research question and sub-research questions previously defined in 2.1. Subsection 4.1 shows the general approach, and subsection 4.2 will elaborate on this by breaking the general approach down into more detailed steps.

4.1 Approach

This research will follow a general approach as shown in Figure 15. This general approach consists of six steps which include the identification of use cases, describing the current state of the use cases, conceptual modelling of the country profile, implementation of the conceptual model, querying and evaluation. As indicated in the Figure 15 are the conceptual modelling and implementation iterative steps. These six steps can be put into a methodology with the most relevant steps being: identifying relevant use cases, mapping the LADM Edition II, developing a country profile, implementing the conceptual model and, querying and evaluating the use cases.

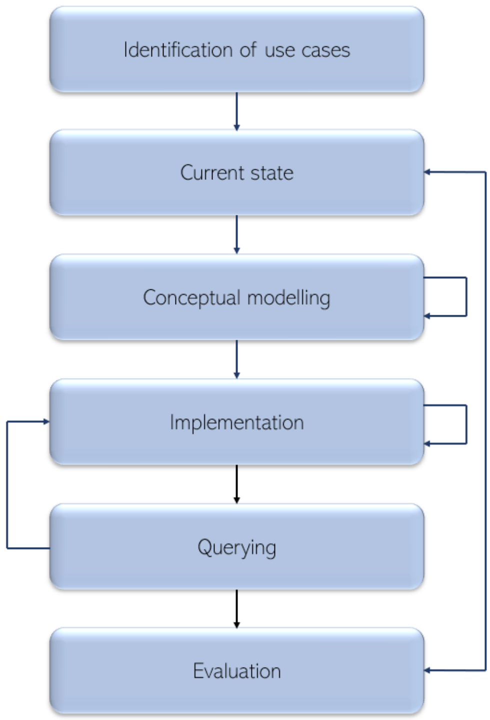


Figure 15: General approach

4.2 Research methodology

4.2.1 Use cases

A case study approach will be utilized, as case studies centre on specific examples rather than one-time cross-sectional studies of many individuals. Importantly, case studies allow for generalizations to be drawn, in this case on the application and implementation of LADM within the Netherlands (Bennett et al., 2012). As described in Chapter 3, land administration in the Netherlands is distributed among several platforms with data from different sources. The use cases that will be identified must depict a process in which users are obligated to collect data from multiple platforms or registries in order to fulfill a specific goal (Krizanovic et al., 2023).

Possible use cases that fulfil this are, for example, use cases related to real estate transactions and spatial planning, as will be explained below.

Real estate transaction
In this scenario, a potential real estate buyer (typically a non-professional citizen) seeks to explore his or her options before finalizing the purchase. The buyer seeks information about property rights and restrictions, local zoning laws, and surrounding property values. The transfer of rightful ownership requires the involvement of a notary during the purchase process, which also involves new information to be processed. Several different situations can arise during a real estate transaction. For example, in more complicated scenarios, a homeowner's death may create additional challenges. The first step is to confirm the individual's passing, followed by identifying the legal heir who will inherit any assets and property. As a result, real estate transactions can be classified as either simple or complex.

Building permit
When applying for a building permit in the context of spatial planning, one may have to deal with the municipality and potential land use limitations. Currently, it is understood that applicants do not receive a comprehensive information file when submitting their application. The implementation of the LADM may demonstrate that it is possible to overlay different data sets so that the complete file of limitations will be known.

Process models are considered to provide a better understanding of processes, enabling improved communication between stakeholders, to optimise current procedures and/or process elements and, finally, to predict the impact of changes in dissemination strategies, such as the introduction of new technologies (Krizanovic et al., 2023). The current state of the examined use case will be modelled as a process model with actors, activities and resources (Krizanovic et al., 2023), additionally process components can subsequently be matched with the LADM classes which can be used to denote identified process components. Clarifying the authority and responsibility for each activity and identifying the necessary resources to be accessed. (Zevenbergen and Stubkjaer, 2005).

4.2.2 LADM Edition II

The second edition of the LADM has yet to be officially published. To map the second edition of the model, information available must be utilized. This process requires mapping all classes and attributes per part, which establishes the foundation for the next phase of creating the country profile.

4.2.3 Country profile

Several studies propose a methodology for creating a country profile. As a guideline, the methodology outlined by Kalogianni et al. (2021) will be used to develop the country profile for the Netherlands. The following steps will be executed in this process:

1. Examine the extent of existing LASs and datasets, and describe them comprehensively (objects, attributes and relationships). A thorough investigation of the current LAS is necessary, as their data models and concepts must be taken into account when creating a LADM profile.
2. Create the conceptual model. This step can be divided in subsequent steps:
    a) Provide explicit schema mapping between the country profile and LADM classes. A schema mapping document should be created that explicitly links the entities

and attributes in the country profile to the corresponding LADM classes. For each entity and attribute in your country's data, specify which LADM class it relates to (i.e. explain the conformance by either: using inheritance of LADM classes or explicit table showing how classes and attributes in the country profile are mapped to LADM). This mapping should be comprehensive and unambiguous. This is the most important as there is not always a one-to-one relationship.

b) Create new classes serving the specific needs that are not supported in the LADM.

c) Add new attributes to address the country's specific needs and requirements.

d) Introduce new associations based on country's specific needs.

e) Adjust multiplicities according to if needed and define relevant constraints to be imposed.

f) Add new values to existing code lists, and new code lists if required for new attributes. In practice this appears one of the more complex tasks.

g) Introduce external classes to link the model with the current external registries.

4.2.4 Implementation

Implementing the conceptual model aims to create a prototype that can demonstrate the application of the LADM-based approach through use cases. This implementation will utilize a linked data strategy that employs ETL (Extraction, Transformation, and Load). First, data will be extracted from a database, then transformed into the conceptual model, and finally loaded into a new LADM compliant database, based on the integrated information model.

The development of the country profile of the Netherlands results in an UML model, which serves as the ontology in the implementation. The objective is to convert this UML model (the ontology) into a Linked Data model. This is feasible by transforming the data to RDF triples at both the instance and data level. instance level refers to individual records or data points within a dataset or database. Data level deals with the broader perspective of data, considering the entire dataset. At the instance level, relationships in the UML model are transformed into RDF language, i.e., triples that describe the model (relationships between object types are identified). At the data level, the same RDF language is utilized for the data itself. This means that the relationships between object types are applied to the values of the data.

As an example, the ontology shows that 'Pand' in BAG and 'Addressable Object' in WOZ are equal to 'LA_LegalSpaceBuildingUnit' in LADM. To achieve this equivalence, BAG and WOZ data must be transformed into this ontology using RDF at both the instance and data level. Then, a URI is utilized to indicate that 'Pand' in BAG is equal to 'Addressable object' in WOZ. In this way, the URI establishes a path that links these two entities. Next, the datasets need to be reconstructed to enable this path to be also based on the values of the data. Following this step, SPARQL can be utilized to perform queries. The methodology of implementing LADM consists of the following steps:

- Develop an ontology,
- Extract the data,
- Transform the data conform the ontology with RDF triples,
- Design URIs,
- Load the data into a linked data store,
- Query with SPARQL to retrieve information.

4.2.5 Querying and Evaluation

The purpose of the querying process is to assess the effects of applying and implementing LADM, examining its advantages and disadvantages. To evaluate the use cases, a benchmarking approach will be followed, identifying various metrics to evaluate the performance of the prototype compared to the current situation (the benchmark) (Gurumurthy and Kodali, 2008). The following metrics can be identified:

- Performance metrics
  - Efficiency, measuring the time to complete certain tasks or processes.
  - Efficiency, measuring the resources required to complete certain tasks or processes.
  - Latency, evaluating the time delays in processing and delivering information.
- Data quality metrics
  - Data accuracy, measuring the level of correctness and precision of data returned.
  - Completeness, evaluating how well the use case captures all the relevant data and information.
  - Consistency, assessing the uniformity and absence of contradictions in the data.
- User experience metrics
  - Usability, evaluating the ease of use and intuitiveness of the system.
  - Accessibility, ensuring that the system is accessible to all types of users.
- Resource metrics
  - Resource efficiency, assessing the optimal use of resources such as personnel and technology.
- Scalability metrics
  - Scalability, determining whether the use case can handle an increasing volume of transactions or data without a significant decrease in performance.
- Cost metrics
  - Total cost, calculating the costs to execute certain tasks or processes.

5 Schedule

This graduation project will be carried out in the academic years 2023-2024 and 2024-2025.

5.1 Deadlines

The most important deadlines during this thesis are presented in table 4. The exact dates are to be determined.

Deadline	**Date**
P2 - Graduation plan	17-11-2023
P3 - Midterm progress meeting	08/01/2024 - 19/01/2024
P4 - Go / no-go (formal assessment)	04/03/2024 - 15/03/2024
P5 - Public presentation and final assessment	08/04/2024 - 19/04/2024

Table 4: Deadlines

5.2 Schedule

The schedule for carrying out this research is presented in a Gantt chart table shown in Figure 16. This chart table focuses on the progression of deadlines P2, P3, P4 and P5 of this thesis. Included are the deadlines, meetings with supervisors and absences due to vacation periods.

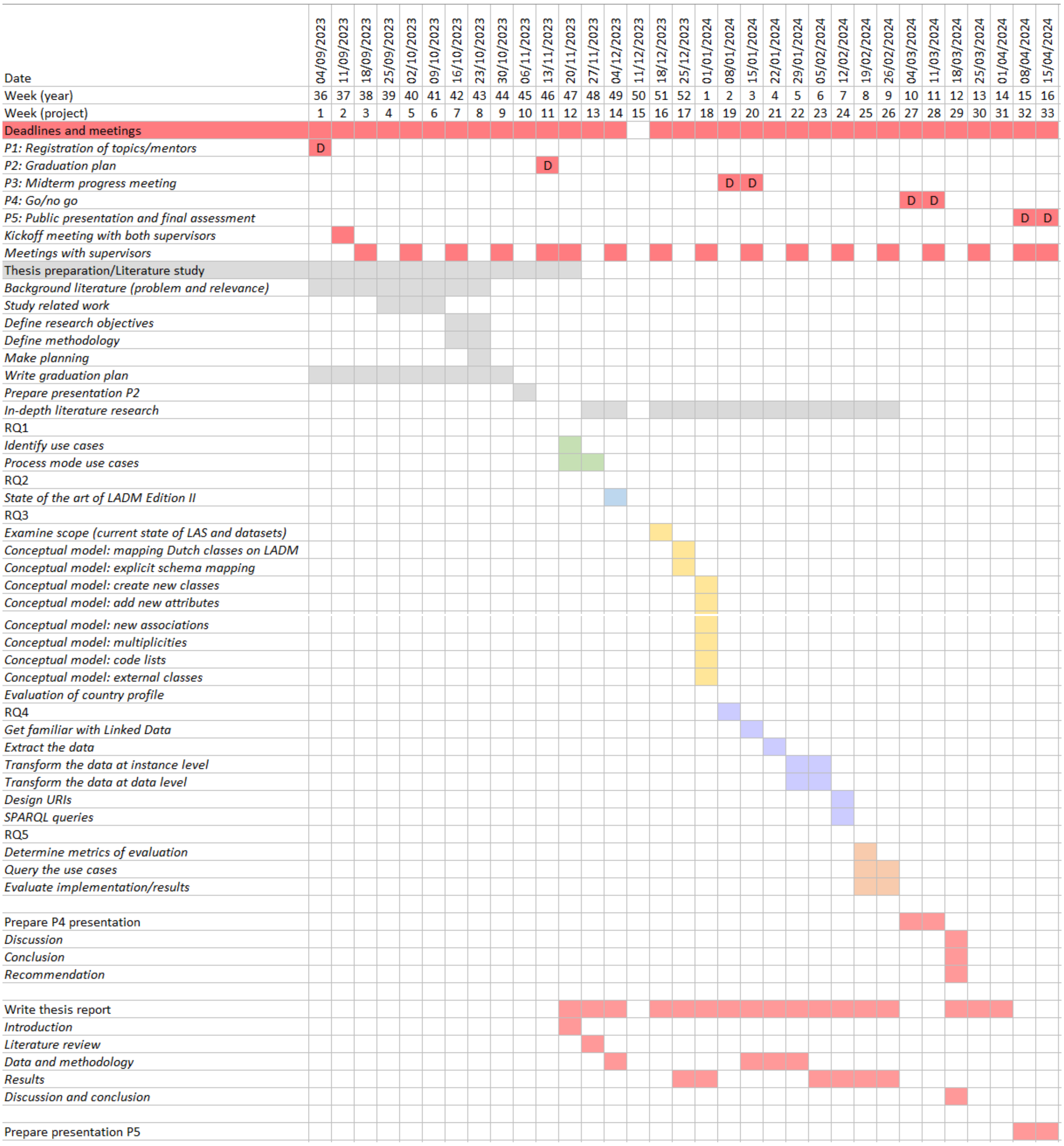


Figure 16: Schedule graduation plan

6 Datasets and tools

6.1 Datasets

The data that will be used are: the base register of addresses and buildings (BAG), the base land register (BRK), the public law restrictions (PB), the WOZ value and Ruimtelijkeplannen. These have been previously explained in 3.2.3, 3.5.1 and, 3.2.2. Further details about the BAG, BRK and PB can be found in the Appendix 8.2. Since the data on the WOZ value is not managed by Kadaster but by the WOZwaardeloket, a request will have to be made to allow (part of) this data to be used for this study. Should permission not be granted, it is possible to perform the use cases using fake data of the WOZ value.

6.2 Tools

UML Modelling
There are various tools for modeling in the UML language. Sparx Systems Enterprise Architect is a widely used tool at Kadaster and by ISO/TC211 for standards development. It is a visual design and modeling tool based on the UML language.

Linked Data implementation
There are various tools available for deployment that offer many options and choices. Due to the lack of experience with linked data, it is recommended to use Visual Studio Code as a development environment for the Turtle syntax. Before implementation, familiarization with linked data will be done using the book *Learning SPARQL* by DuCharme (2011).

7 Supervisors

The supervisors for this thesis project are:

Delft University of Technology:

- First mentor: Peter van Oosterom
- Second mentor: Hendrik Ploeger

This thesis project is executed in cooperation with Kadaster:

- First external supervisor: Erwin Folmer
- Second external supervisor: Lexi Rowland

7.1 Meetings

Meetings with the first mentor will be held approximately every two weeks, the second mentor will be present if he is available. One day before the meeting, the student will send an email with the progress of the last weeks, and what will be done the next weeks, following the structure of a progress monitor.

The student will be present weekly on Thursdays at the Kadaster office. There will be weekly contact with the Kadaster supervisors to discuss progression and provide substantive guidance as needed.

Every 4 to 6 weeks joint (online)meetings will be held with the supervisors of the TU Delft and Kadaster.

References

IMX-Geo: Informatiemodel voor cross-domein databevragingen – Geo-informatie. URL https://geonovum.github.io/IMX-Geo/.

BAG Viewer. URL https://bagviewer.kadaster.nl/lvbag/bag-viewer/?zoomlevel=1.

Home - PDOK. URL https://www.pdok.nl/.

Ruimtelijkeplannen.nl. URL https://www.ruimtelijkeplannen.nl/landing.

What is a Knowledge Graph? . URL https://www.ibm.com/topics/knowledge-graph.

WOZ-waardeloket. URL https://www.wozwaardeloket.nl/.

MIM - Metamodel informatie modellering, 2 2022a. URL https://docs.geostandaarden.nl/mim/mim/#niveau-1-model-van-begrippen.

MIM - Metamodel informatie modellering, 2 2022b. URL https://docs.geostandaarden.nl/mim/mim/#niveau-2-conceptueel-informatiemodel.

MIM - Metamodel informatie modellering, 2 2022c. URL https://docs.geostandaarden.nl/mim/mim/#niveau-3-logisch-informatie-of-gegevensmodel.

IMX-Geo — Semantisch model basis- en kernregistraties, 7 2023. URL https://www.geonovum.nl/geo-standaarden/imx-geo-semantisch-model-basis-en-kernregistraties.

R. Bennett, A. Rajabifard, I. Williamson, and J. Wallace. On the need for national land administration infrastructures. *Land Use Policy*, 29(1):208–219, 1 2012. doi: 10.1016/j.landusepol.2011.06.008. URL https://doi.org/10.1016/j.landusepol.2011.06.008.

C. Bizer, T. Heath, K. Idehen, and T. Berners-Lee. Linked data on the web (LDOW2008). *WWW 2008 / Workshop Summary*, 1 2008. doi: 10.1145/1367497.1367760. URL https://doi.org/10.1145/1367497.1367760.

C. Bizer, T. Heath, and T. Berners-Lee. Linked Data - The Story So Far. *International Journal on Semantic Web and Information Systems*, 5(3):1–22, 7 2009. doi: 10.4018/jswis.2009081901. URL https://doi.org/10.4018/jswis.2009081901.

C. Body, C. Lemmen, A. Kara, and P. van Oosterom. Progress Report on the Revision of the Land Administration Domain Model (LADM), 2022. URL https://ggim.un.org/meetings/2022/4th-EG-LAM/documents/2.2_Chris_Body.pdf.

J. Bydłosz. The application of the Land Administration Domain Model in building a country profile for the Polish cadastre. *Land Use Policy*, 49:598–605, 12 2015. doi: 10.1016/j.landusepol.2015.02.011. URL https://doi.org/10.1016/j.landusepol.2015.02.011.

E. Commission. *E-Government Core Vocabularies Handbook*. 1 2015.

P. F. Dale and J. D. McLaughlin. *Land Administration*. Spatial Information Systems, 1 1999.

B. DuCharme. *Learning SPARQL: querying and updating with SPARQL 1.1*. 1 2011. URL http://ci.nii.ac.jp/ncid/BB13342438.

A. Gurumurthy and R. Kodali. Benchmarking the benchmarking models. *Benchmarking: An International Journal*, 15(3):257–291, 5 2008. doi: 10.1108/14635770810876593. URL https://doi.org/10.1108/14635770810876593.

E. Hagemans, E.-M. Unger, P. Soffers, T. Wortel, and C. Lemmen. The new, LADM inspired, data model of the Dutch cadastral map. *Land Use Policy*, 117:106074, 6 2022. doi: 10.1016/j.landusepol.2022.106074. URL `https://doi.org/10.1016/j.landusepol.2022.106074`.

ISO. Geographic information — Land Administration Domain Model (LADM) . *ISO*, 2012. URL `https://www.iso.org/standard/51206.html`.

ISO. Geographic information — Land Administration Domain Model (LADM) — Part 1: Generic conceptual model. *ISO 2023*, 2023.

K. Janečka and P. Souček. A country profile of the Czech Republic based on an LADM for the development of a 3D cadastre. *ISPRS international journal of geo-information*, 6(5):143, 5 2017. doi: 10.3390/ijgi6050143. URL `https://doi.org/10.3390/ijgi6050143`.

Kadaster. Kadaster Labs, a. URL `https://labs.kadaster.nl/thema/Knowledge_graph`.

B. . Kadaster. Kaarten van Nederland, b. URL `https://www.kaartenvannederland.nl/#?geometry.x=160000&geometry.y=455000&zoomlevel=3`.

H. Kadaster. Linked Open data, 7 2013. URL `https://www.youtube.com/watch?v=eWqRB-_HFxI`.

E. Kalogianni, K. Janečka, M. Kalantari, E. Dimopoulou, J. Bydłosz, A. Radulović, N. Vučić, D. Sladić, M. Govedarica, C. Lemmen, and P. Van Oosterom. Methodology for the development of LADM country profiles. *Land Use Policy*, 105:105380, 6 2021. doi: 10.1016/j.landusepol.2021.105380. URL `https://doi.org/10.1016/j.landusepol.2021.105380`.

A. Kara, R. Kathmann, P. van Oosterom, and C. Lemmen. Towards the Netherlands LADM Valuation Information Model Country Profile. *ResearchGate*, 4 2019. URL `https://www.researchgate.net/publication/335105316_Towards_the_Netherlands_LADM_Valuation_Information_Model_Country_Profile`.

A. Kara, V. Çağdaş, U. Isikdag, P. Van Oosterom, C. Lemmen, and E. Stubkjær. The LADM Valuation Information Model and its application to the Turkey case. *Land Use Policy*, 104: 105307, 5 2021. doi: 10.1016/j.landusepol.2021.105307. URL `https://doi.org/10.1016/j.landusepol.2021.105307`.

D. Kitsakis, E. Kalogianni, and E. Dimopoulou. Public Law Restrictions in the context of 3D Land Administration—Review on legal and technical approaches. *Land*, 11(1):88, 1 2022. doi: 10.3390/land11010088. URL `https://doi.org/10.3390/land11010088`.

J. Krizanovic, M. Roic, and D. Pivac. Modeling data dissemination processes as part of the future LADM development. *Interational FIG Land Administration Domain Model / 3D Land Administration Workshop*, 10 2023. URL `http://www.gdmc.nl/3DCadastres/workshop2023/programme/3DLA2023_paper_B.pdf`.

C. Lemmen, P. Van Oosterom, H. Uitermark, J. Zevenbergen, and A. K. Cooper. Interoperable domain models: The ISO land administration domain model LADM and its external classes, volume = XXXVIII-4/C21, year = 2011, doi = 10.5194/isprsarchives-xxxviii-4-c21-31-2011, url = https://doi.org/10.5194/isprsarchives-xxxviii-4-c21-31-2011,. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, pages 31–40, 8 .

C. Lemmen, P. Van Oosterom, and R. Bennett. The Land Administration Domain Model. *Land Use Policy*, 49:535–545, 12 2015a. doi: 10.1016/j.landusepol.2015.01.014. URL `https://doi.org/10.1016/j.landusepol.2015.01.014`.

C. Lemmen, P. Van Oosterom, and R. Bennett. The Land Administration Domain model. *Land Use Policy*, 49:535–545, 12 2015b. doi: 10.1016/j.landusepol.2015.01.014. URL https://doi.org/10.1016/j.landusepol.2015.01.014.

C. Lemmen, P. Van Oosterom, A. Kara, E. Kalogianni, A. Shnaidman, A. Indrajit, and A. Alattas. The scope of LADM revision is shaping-up. *International FIG workshop*, pages 1–36, 10 2019. URL https://repository.tudelft.nl/islandora/object/uuid%3Ade054473-e64a-4c6c-8dce-ccdb85381db1.

C. Lemmen, A. Alattas, A. Indrajit, E. Kalogianni, A. Kara, P. Oukes, and P. Van Oosterom. The Foundation of Edition II of the Land Administration Domain Model. *ResearchGate*, pages 1–17, 6 2021. URL https://research.utwente.nl/en/publications/the-foundation-of-edition-ii-of-the-land-administration-domain-mo.

M. Mađer, H. Matijević, and M. Roić. Analysis of possibilities for linking land registers and other official registers in the Republic of Croatia based on LADM. *Land Use Policy*, 49:606–616, 12 2015. doi: 10.1016/j.landusepol.2014.10.025. URL https://doi.org/10.1016/j.landusepol.2014.10.025.

Ontotext. What is a Knowledge Graph? — Ontotext Fundamentals, 5 2023. URL https://www.ontotext.com/knowledgehub/fundamentals/what-is-a-knowledge-graph/.

P. Oukes, M. Van Andel, E. Folmer, R. Bennett, and C. Lemmen. Domain-Driven Design applied to land administration system development: Lessons from the Netherlands. *Land Use Policy*, 104:105379, 5 2021. doi: 10.1016/j.landusepol.2021.105379. URL https://doi.org/10.1016/j.landusepol.2021.105379.

D. Overheid. 10 basisregistraties Stelsel van basisregistraties - Digitale Overheid, 2 2022. URL https://www.digitaleoverheid.nl/overzicht-van-alle-onderwerpen/stelsel-van-basisregistraties/10-basisregistraties/.

PDOK. PDOK factsheet (ENG), 2022. URL https://www.pdok.nl/documents/1901824/4016976/2301_PDOK+factsheet+ENG.pdf/763c527c-5101-6c44-29cc-8a8c1beb63d6?t=1675318986668&download=true.

A. Rajabifard and I. Williamson. Spatial Data Infrastructures: Concept, SDI Hierarchy and Future Directions. *Geomatics Conference*, 1 2001. URL https://minerva-access.unimelb.edu.au/bitstream/handle/11343/33897/66253_00001151_01_4_01Raj_Iran.pdf?sequence=1.

S. Ronzhin, E. Folmer, P. Maria, M. Brattinga, W. Beek, R. Lemmens, and R. Van 't Veer. Kadaster Knowledge Graph: Beyond the fifth star of open data. *Information*, 10(10):310, 10 2019. doi: 10.3390/info10100310. URL https://doi.org/10.3390/info10100310.

A. Rowland and Kadaster. Weaver - The user-friendly way to structure your information. URL https://kadaster.wvr.io/kadaster-knowledge-graph?tab=home&branch=main.

E. Stubkjaer and V. Cagdas. Cadastre and Land Administration Thesaurus - CALATHE. URL http://cadastralvocabulary.org/.

O. S. Technologies. What is an Ontology? URL https://www.oxfordsemantic.tech/faqs/what-is-an-ontology.

S. Union. What is a Knowledge Graph. URL https://www.stardog.com/knowledge-graph/.

P. Van Oosterom and C. Lemmen. The Land Administration Domain Model (LADM): Motivation, standardisation, application and further development. *Land Use Policy*, 49:527–534, 12 2015. doi: 10.1016/j.landusepol.2015.09.032. URL https://doi.org/10.1016/j.landusepol.2015.09.032.

P. Van Oosterom, E.-M. Unger, and C. Lemmen. The second themed article collection on the land administration domain model (LADM). *Land Use Policy*, 120:106287, 9 2022. doi: 10.1016/j.landusepol.2022.106287. URL https://doi.org/10.1016/j.landusepol.2022.106287.

N. Vučić, D. Markovinović, and B. Mičević. LADM in the Republic of Croatia – Making and Testing Country Profile. *ResearchGate*, 1 2013. URL https://bib.irb.hr/datoteka/650224.LADM_in_the_Republic_of_Croatia__Making_and_Testing_Country_Profile.pdf.

I. Williamson. Land administration "best practice" providing the infrastructure for land policy implementation. *Land Use Policy*, 18(4):297–307, 10 2001. doi: 10.1016/s0264-8377(01)00021-7. URL https://doi.org/10.1016/s0264-8377(01)00021-7.

J. Zevenbergen and E. Stubkjaer. Real Property Transactions: Challenges of Modeling and Comparing. *FIG Working Week*, 4 2005. URL https://www.fig.net/resources/proceedings/fig_proceedings/cairo/papers/ts_11/ts11_04_zevenbergen_stubkjaer.pdf.

Y. Zhuo, Z. Ma, C. Lemmen, and R. Bennett. Application of LADM for the integration of land and housing information in China: The legal dimension. *Land Use Policy*, 49:634–648, 12 2015. doi: 10.1016/j.landusepol.2015.09.005. URL https://doi.org/10.1016/j.landusepol.2015.09.005.

N. A. Zulkifli, A. A. Rahman, and P. Van Oosterom. An overview of 3D topology for LADM-based objects. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-2/W4:71–73, 10 2015a. doi: 10.5194/isprsarchives-xl-2-w4-71-2015. URL https://doi.org/10.5194/isprsarchives-xl-2-w4-71-2015.

N. A. Zulkifli, A. A. Rahman, P. Van Oosterom, L. C. Tan, H. M. Jamil, C. H. Teng, K. S. Looi, and K. L. Chan. The importance of Malaysian Land Administration Domain Model country profile in land policy. *Land Use Policy*, 49:649–659, 12 2015b. doi: 10.1016/j.landusepol.2015.07.015. URL https://doi.org/10.1016/j.landusepol.2015.07.015.

V. Çağdaş and E. Stubkjær. Core immovable property vocabulary for European linked land administration. *Survey Review*, 47(340):49–60, 4 2014. doi: 10.1179/1752270614y.0000000093. URL https://doi.org/10.1179/1752270614y.0000000093.

V. Çağdaş and E. Stubkjær. A SKOS vocabulary for Linked Land Administration: Cadastre and Land Administration Thesaurus. *Land Use Policy*, 49:668–679, 12 2015. doi: 10.1016/j.landusepol.2014.12.017. URL https://doi.org/10.1016/j.landusepol.2014.12.017.

V. Çağdaş, A. Kara, P. Van Oosterom, C. Lemmen, U. Isikdag, R. Kathmann, and E. Stubkjær. AN INITIAL DESIGN OF ISO 19152:2012 LADM BASED VALUATION AND TAXATION DATA MODEL. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-2/W1:145–154, 10 2016. doi: 10.5194/isprs-annals-iv-2-w1-145-2016. URL https://doi.org/10.5194/isprs-annals-iv-2-w1-145-2016.

8 Appendix

8.1 LADM and Linked Data

Çağdaş and Stubkjær (2014) conducted a research that contributed to the linked data approach, by developing a conceptual model and RDF schema that can be used for presenting land administration data as linked data, as an extension of Government Core Vocabularies (Commission, 2015) which provides a generic approach for a data model based on core vocabularies. This extension enables the representation of the datasets kept in the registries.

In a later study, Çağdaş and Stubkjær (2015) developed a KOS in the form of a thesaurus for the domain of cadastre and land administration to further contribute to linked data administration. The thesaurus is mainly derived from the terms of the Land Administration Domain Model, and should provide a basis for further ontology development initiatives. The interrelated core domain terms of the developed thesaurus are supposed to improve finding and retrieval of information, thereby organizing domain knowledge. The development of the Cadastre and Land Administration Thesaurus (CaLaThe) was accomplished using the 2005 Guidelines for the Construction, Format, and Management of Monolingual Controlled Vocabularies, following the steps: term selection, identification of semantic relationships, and specification of these relationships. The resulting CaLaThe is based on Simple Knowledge Organization System (SKOS), structured in RDF format and available online at the website Cadastre and Land Administration Thesaurus - CaLAThe (cadastralvocabulary.org) as an enriched and terminologically specified version of the LADM ISO standard that presents and relates core terms of the cadastral domain in SKOS format (Semantic Web) (Stubkjaer and Cagdas).

8.2 Open data sources

Basisregistratie adressen en gebouwen (BAG)
(English translation: Base register of addresses and buildings)

Each object type contains the following standard attributes:

  - Documentdatum (Document date)
  - Documentnummer (Document number)
  - Geconstateerd (Observed)
  - Status (Status)
  - Identificatie (Identification)

- NUMMERAANDUIDING (NUMBER DESIGNATION)
  - Postcode (Postalcode)
  - Huisnummer (House number)
  - Huisletter toev. (House letter (if applicable))
  - Huisnummer toev. (House number addition (if applicable))
  - Type adresseerbaar object (Type of addressable object)
- OPENBARE RUIMTE (PUBLIC SPACE)
  - Naam (Name)

- WOONPLAATS (RESIDENCE)
  - Naam (Name)
  - Geometrie (Geometry)
- PAND (PROPERTY)
  - Oorspronkelijk bouwjaar (Original year of construction)
  - Geometrie (Geometry)
- VERBLIJFSOBJECT (ACCOMMODATION)
  - Gebruiksdoel (Use purpose)
  - Oppervlakte (Surface area)
  - Geometrie (Geometry)
- STANDPLAATS (STAND)
  - Geometrie (Geometry)
- LIGPLAATS (BERTH)
  - Geometrie (Geometry

Basisregistratie Kadaster (BRK)
(English translation: Base land register)

The BRK consists of:

- The cadastral registration of immovable property and rights with information on parcels, ownership, parties who have RRRs with spatial units, mortgages, leasehold, superficies, usufruct, limited rights and cable and pipeline networks. The exact location of cables and pipelines is not in the BRK, but is registered in KLIC.
- The cadastral map. This shows the location of the cadastral parcels (including parcel number) and the boundaries of the state, provinces and municipalities from the BRK. This map shows:
  - The global location of cadastral boundaries in relation to the surrounding area
  - Parcel numbers, names of streets and watercourses
  - The main construction of house numbers
  - (In the open dataset) the quality labels

  The cadastral map can be viewed on PDOK in 3 forms: via a viewer, web services (WFS/WMS/WMTS) or download in GML format.

Publiekrechtelijke bepalingen (PB)
(English translation: Public law restrictions)
Legislation regulates the ownership status and use of land by imposing Public Law Restrictions (PLRs). These restrictions cover different areas and different legal frameworks, such as the protection of archaeological sites, the protection and maintenance of underground infrastructure and utilities, environmental protection, etc. (Kitsakis et al., 2022). Public law restrictions are listed in an owners' report, which is ownership information from the Kadaster that someone can request. The ownership report states:

- Property information Kadaster
- Current owner plot or property
- Last known purchase price
- Real right and share
- Surface area of parcel
- Any notes such as monument or ground lease
- Public law restrictions

8.3 IMX-Geo

LADM is an international standard that structures land administration data. Kadaster has developed a different model to structure Dutch land administration data. The IMX-Geo model incorporates spatial relationships between object types. Relationships between objects from different data registries are not known. However, these relationships are necessary to answer queries that require information from different registers. However, not every relationship needs to be defined, only those that are of value to the user of a model. The IMX-Geo is an overarching information model that defines geospatial data from different government sources (BAG, BRT, BRK, BGT, BRO, Spatial Plans and Administrative Areas) by describing the relationships of the object types. The information model is designed to enable data queries that require data from different registers, also called cross-domain data queries. The model makes it possible to answer these cross-domain queries without requiring modifications to the data at the source (core registry). This is possible because the model is a Knowledge Graph based on linked data standards. One of the requirements during the development of the model was that it must be user-friendly. This implies in this case that developers must be able to understand the model in order to figure out the connections between the different registries needed to answer cross-domain data queries (IMX) (IMX, 2023).

The design of the model started with a concept diagram (MIM level1) in Simple Knowledge Organization System (SKOS), this level describes the reality within the domain through terms (concepts) and their relationships to each other (MIM, 2022a). Subsequently, a conceptual information model (MIM level2) was created, this level describes the reality within the domain through a description of what information plays a role (classes), it is about the 'what' (MIM, 2022b). Last is the logical model (MIM level 3) which describes how the concepts are used in the interaction between different sources, it is thus about the 'how' (MIM, 2022c). To test and evaluate the information model, 21 use cases were collected.