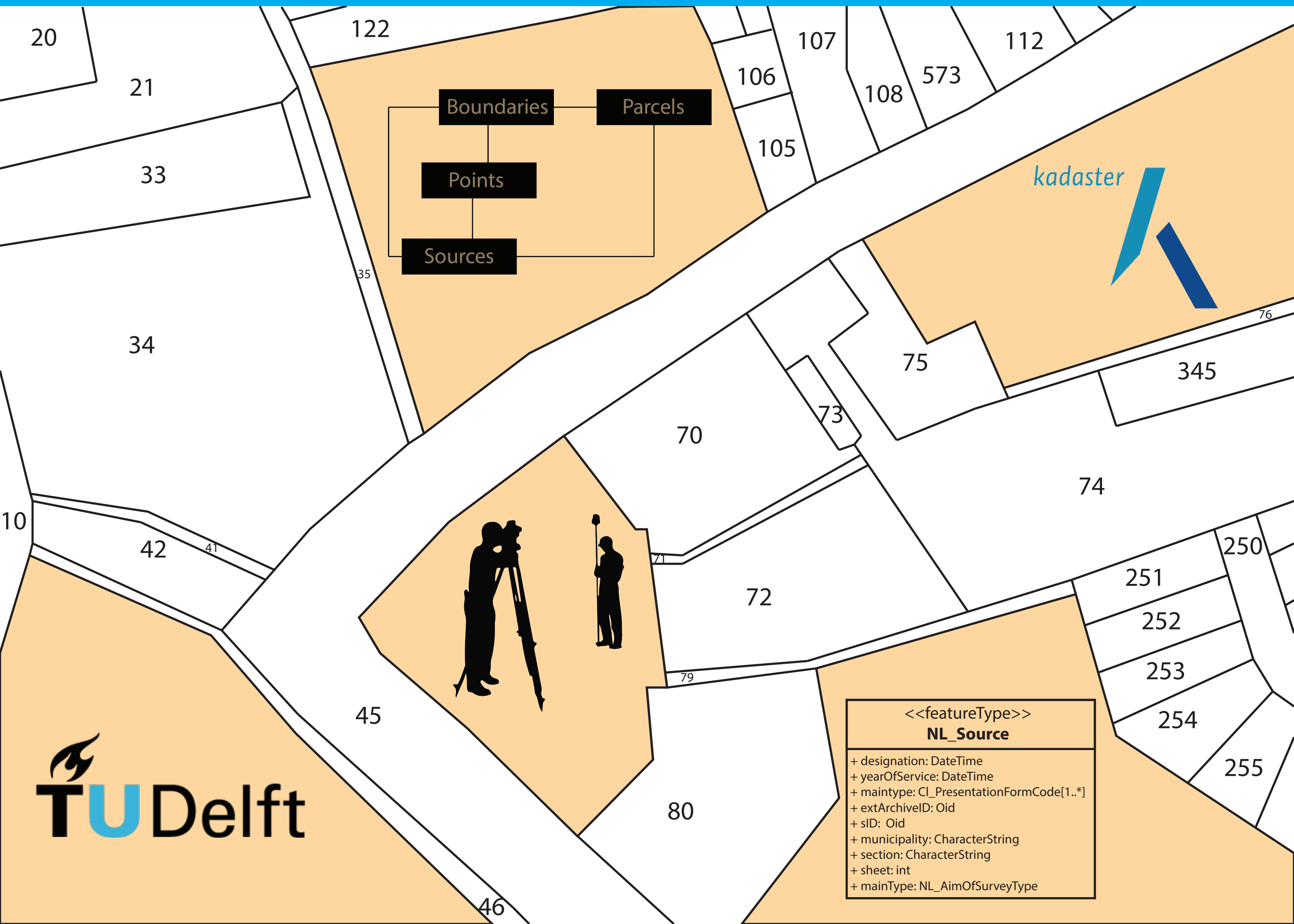
MSc thesis in Geomatics for the Built Environment

Designing an integrated future data model for survey data and cadastral mapping

Pieter Soffers

2017



DESIGNING AN INTEGRATED FUTURE DATA MODEL FOR SURVEY DATA AND CADASTRAL MAPPING

A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of

Master of Science in Geomatics for the Built Environment

by

P.J.J.F. Soffers

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Supervisors: Prof.dr.ir. P.J.M. van Oosterom
ir. E. Verbree
ir. H.J. Hagemans & dr.ir. C.H.J. Lemmen
Co-reader: Dr. S. Zlatanova

ABSTRACT

For nearly 200 years the Netherlands' Cadastre, Land Registry and Mapping Agency – in short 'Kadaster' has been the organization that registers and maintains all legal rights concerning property in the Netherlands. An elementary part of its activities is the spatial description of parcels that are built up by boundaries which are surveyed in the field and depicted on the Dutch cadastral map. Nowadays this is an open source digital map which provides an overview of the cadastral situation for the entire country. The map exists of unique representations of all cadastral boundaries and parcels. It must be pointed out though that these locations are only depicted by approximation, which is caused by several factors. The most precise location of a boundary still remains the original survey data in the field, which is documented on separate survey documents. In the Dutch cadastral map every parcel has its own number, which is the link to original survey documents. Relating the boundary on the map to the correct survey data happens by intuition. This is feasible when cadastral situations are documented from scratch. However the Dutch cadastral situation is dynamic; parcels can split and merge, which results in new numbers and extra survey documents. As a result searching for survey data is getting more and more complex. Additionally the Kadaster has used different survey techniques over time offering different meta data, administration and accuracy. The survey data have been stored at different locations. Also boundary reconstructions lead to extra survey documents for one boundary.

This thesis presents a research to design a data model which relates all survey data directly to its boundaries in the Dutch cadastral map instead of parcel numbers. As a starting point for this data model requirements are defined, which are based on preliminary investigation of the Dutch cadastral work flow. The requirements are establishing a link between survey data and the Dutch cadastral map, incorporating all survey methods, assuming more elements in the Dutch cadastral map as entities in their own right, the maintenance of topology, the maintenance of quality and the use of ISO standards. The design of the data model uses the Land Administration Domain Model as template. This data model was adjusted to the situation of the Kadaster. This is a common method applied by cadastral organizations to improve their work flow. The Land Administration Domain Model (LADM) template offers solutions for generally upcoming cadastral issues as well as a data organization that is clearer and more accessible for externals. Nevertheless there are multiple approaches to solve the issues of the Kadaster by this template. This research will discuss several options to meet the stated requirements and deliberate on the best choice. Real Dutch cadastral cases are used to demonstrate how the final data model operates. At last a comparison is made with related cadastral systems abroad to reflect on its drawbacks and benefits.

The final model can support the current work flow of the Kadaster by assuming boundaries as own entities. A direct link to its related survey data saves time, labour and expert knowledge. The model places similar objects in similar classes in order to increase overview. The data model may be a starting point for improvement of the Dutch cadastral map.

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Another special thanks goes to the land surveyors of the Kadaster, Peter Winterswijk and Quintin Qualm, for the very interesting and exciting training. In addition the author would like to thank as well the interviewed persons of the Kadaster for their input; Klaas van der Hoek, Hans Swarts, Ron Bloksma, Herman de Koning, Arjen Santema and Noreisha Niamat. Furthermore a special thanks to all the colleagues of the department product- and processinnovation of the Kadaster in Apeldoorn for answering all my spontaneous questions and for all the discussions about the Kadaster in general during lunch breaks. At last the author would like to thank Irene de Vreede and Adrie Rovers for all the coffee breaks and mental support.

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ACRONYMS

GLOSSARY

BOUNDARY is a set that represents the limit of an entity.[ISO 19152, 2012]

BAG is the Dutch national registration system for adresses and buildings.

BGT is a registration system to record the Dutch topography in an unilateral way.

BOUNDARY FACE STRING is a boundary forming part of the outside of a spatial unit.[ISO 19152, 2012]

BUILDING UNIT is a component of a building (the legal, recorded or informal space of the physical entity).[ISO 19152, 2012]

DEED is a document written by a notary as legal proof of ownership.

DELIMITATION is the indication of an existing cadastral boundary taking the accuracy and circumstances in account at that time.

RIJKSDRIEHOEKSNET is a national geodetic coordinates system for the Netherlands, which is the basis for geographic marks and files.

DSDM is a method for software development on the basis of a framework of timeboxes.

DVA is the archive of field sketches at the Kadaster.

DRA is the archive of numerical survey coordinates at the Kadaster.

GEO DBMS is a system of databases which stores, protects and manages spatial data.

LAND ADMINISTRATION is a process of determining, recording and disseminating information about the relationship between people and land. [ISO 19152, 2012]

LADM is an international standard for land administration. [ISO 19152, 2012]

LKI is an internal system for survey and cartographic information at the Kadaster.

MOSCOW ANALYSIS is a method for software engineers to set priorities.

OCR is the technique to transform data on paper into processable digital data by pattern recognition.

PDOK is the national Dutch SDI; a central facility for unlocking geodatasets of national importance.

PPI is a department of the Kadaster, specialized in process and product innovation.

RELAAS VAN BEVINDINGEN is a document on which the survey results are recorded by the land surveyor.

SOURCE is a document providing legal and/or administrative facts on which the land administration object right, restriction, responsibility, basic administrative unit, party or spatial unit is based.[ISO 19152, 2012]

SPATIAL SOURCE is a source with the spatial representation of one (part of) or more spatial units.[ISO 19152, 2012]

ANALOGUE SPATIAL SOURCE is an umbrella term for all survey documents written on paper.

SPATIAL UNIT is a single area (or multiple areas) or land and/or water, or a single volume (or multiple volumes) of space.[ISO 19152, 2012]

TERRESTRIC REGISTRATION is a registration which enables to overview all cadastral survey data of a certain boundary via a central place.

1 INTRODUCTION

Land administration is an essential precondition for economic development of a country; Controlling and maintaining property is important for sectors like agriculture, urban planning, government, development and management of infrastructure. Land administration offers a legal protection for property owners and investors. [Bogaerts and Zevenbergen, 2001]
Land administration in the Netherlands is done by the Cadastre, Land Registry and Mapping Agency - in short 'Kadaster'. This is a non-departmental public body under the political responsibility of the Minister of Infrastructure and the Environment. Its main activities are registration of real estate, providing information about national facilities like *Basisregistratie Adressen en Gebouwen* (BAG) and *Basisregistratie Grootschalige Topografie* (BGT), offering data selection to authorities for spatial development plans. The Kadaster also collaborates and shares knowledge with countries that request it. [Kadaster, 2016]
An essential part of land administration is the description of properties. In the Netherlands properties are described in two ways. First by a deed, drafted by a notary (a deed is the legal proof of ownership). Secondly by the Kadaster's description of the spatial extent of a property using a Dutch cadastral map and spatial sources. Spatial sources are the result of surveying cadastral boundaries in the field. Surveying seems a logical step to describe a boundary, yet other ways are possible: in the United Kingdom for instance boundaries are documented by a descriptive text [Grover, 2014].

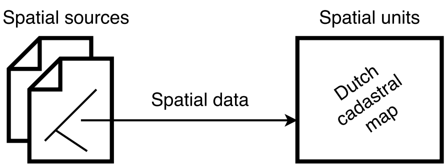

Figure 1.1: The difference between spatial sources, spatial data and spatial units.

The information, written down in the spatial source, is called spatial data. This is processed by several procedures at the Kadaster and subsequently implemented in the Dutch cadastral map. This is a digital map, which is freely available at the *Publieke Dienstverlening Op de Kaart* (PDOK). It depicts an up-to-date overview of the cadastral situation of the entire country. The cadastral situation is shaped by parcels and boundaries, which are called spatial units. In figure 1.1 the relation between spatial sources, spatial data and spatial units is clarified.
The Dutch cadastral map is a planar partition and ensures that a spatial unit fits correctly with respect to its cadastral environment. The relation between survey data and spatial units is as follows: Survey data attempts to describe a cadastral object as accurately as possible. A spatial unit is a unique representation of this cadastral object in the Dutch cadastral map. Therefore inconsistency exists between the location of spatial sources and

spatial units; The Dutch cadastral map merely has an index function without claiming that it depicts the location of spatial units in its legal position. This creates the unique problem of trying to adjust the more accurate surveyed spatial data of new boundaries to the less accurate spatial units of the cadastral map. This is an undesirable situation, since this will not increase the quality of the Dutch cadastral map. Furthermore society expects the cadastral map to depict the correct locations of spatial units.
What is actually a boundary in the Dutch cadastral map? This requires a strict definition in order to avoid confusion. A boundary in the Dutch cadastral map is a line with one parcel at the left and one parcel at the right. Furthermore it is running from one node to another (see the red line in figure 1.2). A boundary in the Dutch cadastral map can be either or drawn as a circular arc and may contain middle points (see other boundaries in figure 1.2).

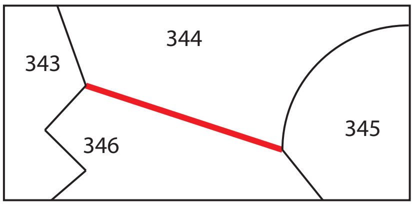

Figure 1.2: Definition of a boundary in the Dutch cadastral map.

1.1 PROBLEM STATEMENT

The cadastral situation in the Netherlands is constantly changing by the exchange of (parts of) properties. The Dutch cadastral map is therefore dynamic (see figure 1.3).

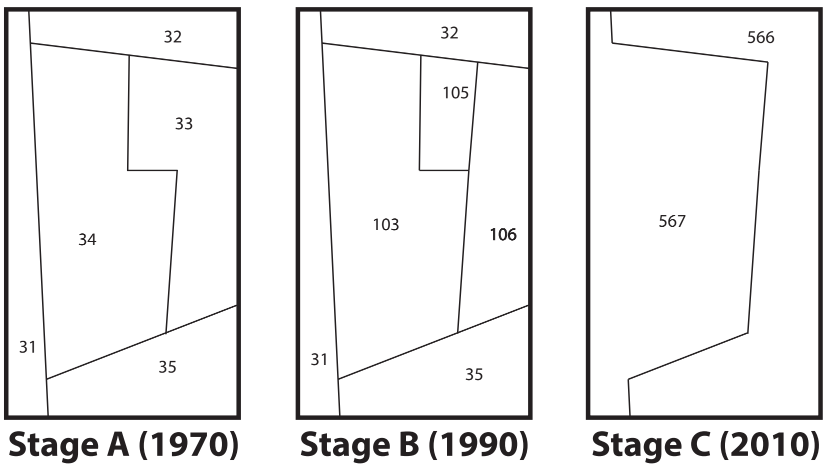

Figure 1.3: Boundary dynamics in the Dutch cadastral map

This causes problems since there is no one-on-one relation between spatial units and spatial sources. One spatial source may represent the boundary of

multiple parcels when implemented in the Dutch cadastral map. This situation is demonstrated in figure 1.3 (Stage A); The collinear boundary between parcel 31, 32, 34 and 35 has only one spatial source, whereas it describes multiple boundaries. The formation of new parcels and the disappearance of expired parcel influence boundaries enormously: new boundaries appear, other boundaries split in two, two separate boundaries merge into one or expired boundaries disappear. Today related spatial sources only refer to parts of a boundary or even to two split parts (see stage B & C in figure 1.3). This being said, one boundary may have multiple spatial sources, both describing a part of this boundary (See stage C in figure 1.3). It can be concluded that the dynamics in the Dutch cadastral map result in an increasing fragmentation within the relation between spatial sources and spatial units. This fragmentation doesn't have to be a problem per se, but there is an additional problem. There is no direct link between spatial sources and boundaries such, as spatial units. The registration of spatial units in the Kadaster is based on parcels, whereas survey data describe boundaries in the first place. In order to find out which spatial data belongs to which boundary, merely depends on interpretation and expert knowledge. If a parcel had only 4 boundaries, this would not be a delicate job. But it is getting more complicated with complex parcels with a lot of boundaries.
On top of this, not all spatial data of a parcel are documented within the same spatial source. When a new parcel is created, the related spatial source only describes the changes in the cadastral situation, such as the new boundaries. Other boundaries of the parcel, which already existed before, are described on previous spatial sources. In order to link both spatial sources to each other, the new and expired parcel numbers are noted. This is demonstrated in figure 1.4, where the red line indicates new boundaries and the red letters indicate new parcel numbers. The blue letters are the reference to the former parcel. In case that the spatial source of the encircled boundary is requested, it will take three steps (from E to B to A) (see figure 1.4). Such situations are appearing very often.

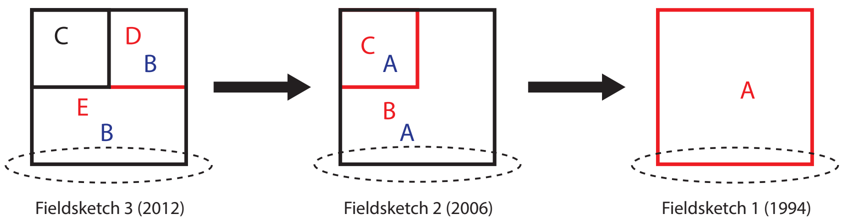

Figure 1.4: Referencing between different spatial sources

In the Kadaster all spatial sources are stored in a database, called Digitaal Veldwerk Archief (DVA). This includes all analogue spatial sources, which are digitally scanned. Nevertheless the survey data on the spatial sources are not readable for the computer. All spatial sources can be traced by a special ID or the combination of municipality name / section letter / parcel numbers. However there is no automated searching system to traverse this network of parcel-referenced spatial sources in a rapid manner. The spatial data, which in some cases also have a less readable handwriting, has to be interpreted by humans. The search process itself is a non-automated process with a parent-child structure. It is clear that this process is labour intensive and time-consuming. Furthermore, since there is no direct link between spatial sources and spatial data, this work flow asks expert knowledge and is susceptible to misinterpretation. This expert knowledge is in danger by the quickly approaching retirement of many involved land surveyors. If nothing happens existing knowledge about interpreting spatial sources may well disappear. [Hagemans et al., 2016]

Initially it may seem that all spatial units have one spatial source, but this is not the case. The amount of spatial sources per spatial unit varies from zero to multiple since spatial sources from before 1900 have been thrown away. They were assumed to be useless [VIG, 2003] and a part of the cadastral administration has been lost by fires, like the cadastral office in Arnhem during WWII [Verheijen, 2014]. Also a spatial unit may have multiple sources. For instance when this spatial unit is described by two adjacent spatial sources. Furthermore customers may ask the Kadaster to reconstruct a boundary of their property in the field. This reconstruction is documented as well, which creates an additional spatial source.

Over time the Kadaster has used various survey techniques to describe cadastral objects; from measure tape to GPS equipment. This has resulted in different sort of spatial data and a different measurement quality. Analogue field sketches contain distances information and in general present a poor quality compared to GPS measurements which provided coordinates. Some boundaries were established recently and have been measured by high-accurate equipment. Other boundaries exists since the foundation of the Kadaster. A simple solution would be to (re)measure all cadastral boundaries in the Netherlands again with high-accurate equipment. The huge amount of around 8 million parcels, built up by around 28 million cadastral boundaries, registered by the Kadaster, would present a serious obstacle though [de Koning, 2016]. Let's presume that it will take half an hour (which is a tight schedule!) to reconstruct and measure a boundary by high-accurate GPS equipment; the total operation would take 14 million hours. This would mean that based on an eight hour working day, the job will be finished by one person in 1,75 million days or around 6700 years. This is not only way too much work even for a group of people, but such a project would also take a disproportional share of the budget. The need of more accurate boundaries does not outweigh these costs. Also cost-effectiveness varies from one region to the other. For instance in Amsterdam the land value is much higher than in rural areas with less land value. Therefore higher accuracy would be more cost-effective in Amsterdam.

Lastly, it is currently difficult to get an complete overview of spatial sources in the Dutch cadastral database, called *Landmeetkundig Kartografische Informatie (LKI)*. The spatial data are stored in multiple places, as well as in different data-storage media (paper, files, etc.). This makes it difficult to get an clear view on the survey quality of the Kadaster.

The fragmented relation between spatial sources and spatial data, having no direct link between them, the required expert knowledge, the time-consuming and labour intensive searching time, the different amount of spatial sources, the different survey techniques that are used as well as the different places were spatial data is stored in the Kadaster system, causes issues in the relation between survey data and the Dutch cadastral map is. This reveals that there is room left for improvements in the work flow of the Kadaster.

A couple of employees of the Kadaster, consulted on this matter, agreed mostly with these drawbacks. Nevertheless in general they were hesitant on

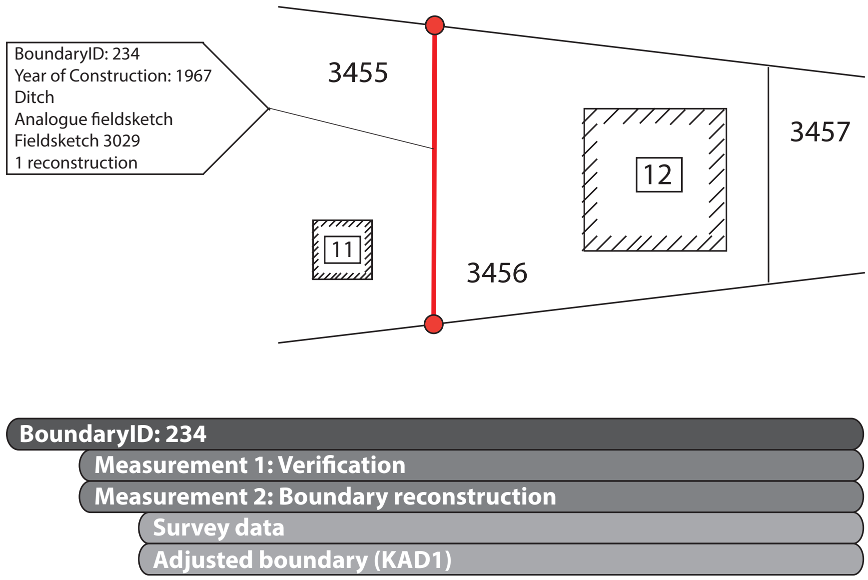

Figure 1.5: Aim of the research (created by the author)

changes in the work flow;

"The current system is functional and works sufficiently. We haven't heard any major complains. Why would one want to change it? "

Changes in the work flow cost a lot of time and investments. The only desire expressed by these employees was to create a more efficient search for spatial data and spatial sources by clicking on a boundary in the Dutch cadastral map.

1.2 THE AIM OF THE RESEARCH

Not all employees of the Kadaster agree on the stated opinion in the last paragraph. The project *Terrestric Registration* of the Kadaster has the aim to improve the current work flow. Establishing a link between spatial sources and spatial data will improve the transparency and accessibility of survey data. The project is initiated by the Product- and Processinnovatie (PPI) department of the Kadaster, but involves people from all over the organization. The research presented in this thesis will contribute to the project by the proposal of a data model design. Data modelling stimulates proper communication between professionals and organizations about data management by using standard language and structure [Lemmen et al., 2015]. A data model demonstrates a plan to structure data in a Geo Database Management System (Geo DBMS). This has technical considerations like software, data formats and database technology and institutional elements like stakeholders and public demand for services. [Kalantari et al., 2015]

The data model of this research attempts to connect all the different spatial sources with their related spatial units (see figure 1.5). The design of which will be based on existing expertise on this discipline. This expertise exists of LADM, which is an international conceptual standard model for Land Administration [van Oosterom and Lemmen, 2015] and comparable cadastral issues abroad. The research analyses in which way existing expertise can contribute to a data model that improve the work flow at the Kadaster. This will save the organization from re-inventing the wheel [van Oosterom and Lemmen, 2015]. The data model, presented in this research, is given the name Dutch Survey and Representation Data Model (NLSRDM).

1.3 RESEARCH QUESTIONS

In the problem statement it is clearly explained that the work flow between survey data and cadastral mapping at the Kadaster is sub-optimal. The aim of this research is to develop a data model, which should improve this situation. Among others the data model considers conceptual approaches and the used terms and relations between different components. The main question of the research is:

Can the newly designed integrated data model between survey data and cadastral mapping improve the Dutch cadastral work flow?

The development of the data model is based on requirements to secure the improvement. Nevertheless different requirements have a different impact on the improvement and some requirements are diametrically opposed. The first sub question therefore is:

Which of the stated requirements can be implemented in the data model?

The expertise of the LADM is used to support the development process. The LADM could potentially already meet several requirements. To what extent the LADM is incorporated is covered by the following sub question:

To which extent does the Land Administration Domain Model present a useful template for managing survey and boundary data within the Kadaster?

1.4 SCOPE OF THE PROJECT

The primary aim of the research in this thesis is about data modelling between survey data at the Kadaster and the Dutch cadastral map. It must be stated, though, that this research is part of the project *Terrestric Registration*, and that this project involves more components, which are not a part of this particular research. At first reading and transferring the spatial data on analogue spatial sources to digital spatial data in the Geo DBMS of the Kadaster. This can be achieved by the use of *Optical Character Recognition (OCR)*, which involves line detection and number/symbol detection. This process is a research in itself. Most spatial data in analogue spatial sources are related to

features, like buildings or ditches in the landscape. At a certain moment in time, all buildings have been replaced or broke down and all ditches filled up. The information on the analogue spatial sources will be useless at some point [Hagemans et al., 2016]. Although the data model will facilitate the incorporation of the spatial data, the digitalization of analogue spatial sources itself falls out of the scope of this project.
In addition this research do not provide any software implementation or database prototypes. The data flow of the model is shown by demonstrating original cadastral cases.
Moreover the provided data model of this research is a first step in many things, which are out of the scope of this project, like improvement of the quality of the Dutch cadastral map and a more positive Kadaster.
At last the Kadaster has the ambition to incorporate 3D registration in its cadastral administration. In the current dynamic world 3D registration is of increasing importance because of the construction of multi_storey buildings, tunnels, etc. 3D is not in the scope of this project, but the data model should be extensible to include 3D. The chapter *future work* will elaborate on the possibilities of data models between survey data and the Dutch cadastral map.

1.5 THESIS OUTLINE

The survey processes of the Kadaster are using very specific Dutch terms in some cases, which are delicate to translate into English without decreasing their meaning and understanding. Therefore the original Dutch terms are written between parentheses and an English translation between brackets afterwards, for instance: 'kadastrale legger' (*land tax register*).
Many of the current issues at the Kadaster are not directly related to ignorance or limited budget, but are a result of constantly improving cadastral products and methods. This generates new insights. For instance the absence of a proper relation between spatial sources and spatial units is only an issue, because the Kadaster realizes that this is a new step in cadastral administration.
The research is done in several steps. At first the order of these steps is discussed in the chapter *Research Approach*. This will also elaborate on the reasons for these steps to be taken. The chapter *Survey data and cadastral mapping at the Kadaster* will explain the history and the current procedures of the Kadaster in this discipline. A good overview of this work flow will reveal its issues. The chapter *Related work* will talk about the project *Terrestric Registration* and the content of the LADM. Both involve a lot of research, which is to the benefit of the research in this thesis. The chapter *Comparable cadastral issues abroad* will discuss three foreign cadastral systems, which differ in essential. The aim of this chapter is to gain a more considered view on requirements and approaches of cadastral systems in general.
The chapter *Requirements* elaborates on the requirements the data model have to satisfy in order to be of any improvement to the Kadaster. These stated requirements are based on insights, gained during the preliminary investigation, discussed in chapter *Survey data and cadastral mapping at the Kadaster*. The chapter *Development of the data model* will discuss the development of an extended LADM-based model that represents survey data and the Dutch cadastral map in one integrated manner. Furthermore it will discuss

the considerations in this development. The actual data flow of the model is explained by several real cadastral cases in the chapter *Demonstration cases*. The chapter *Conclusion and discussion* will formulate the final conclusions of this thesis and its considerations. Moreover the paragraph *Future work* will philosophize on the possibilities this research provides for future developments at the Kadaster.

2 RESEARCH APPROACH

Designing a data model for survey data and cadastral mapping is not an one minute job. Solving these challenges requires a structured approach. This chapter will explain the steps to be taken in order to answer the stated research questions. The structured approach is clarified in scheme 2.1, which divides the research in four different phases.

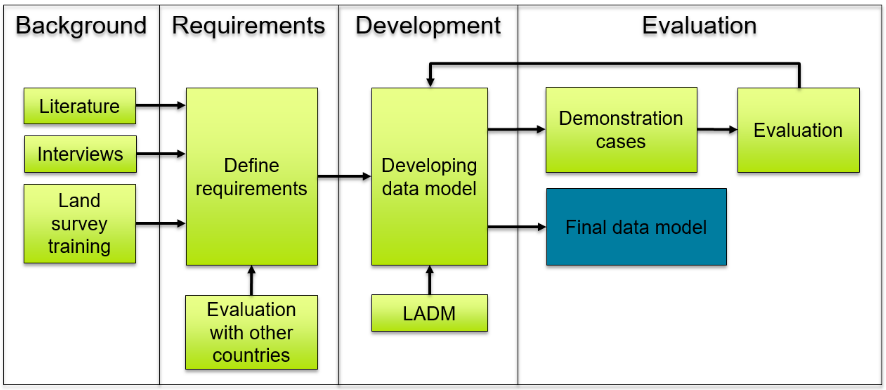

Figure 2.1: Schematic overview of the research approach

2.1 BACKGROUND

The first phase of the research involves a background investigation on the current work flow of the Kadaster. The aim of this research is to improve the current work flow of the Kadaster concerning the relation between survey data and cadastral mapping at the Kadaster by designing a new data model. The preliminary investigation will reveal the current issues of the work flow of the Kadaster by a literature research, interviews and a training in land surveying.
The consulted literature exists of internal manuals and reports, which are listed in the bibliography of this thesis. An important document is the 'Handleiding voor de Technische Werkzaamheden van het Kadaster' [Polman and Salzmann, 1996]. This book describes the procedures which are the basis for all survey activities executed by the Kadaster.
Further several employees of the Kadaster are interviewed. These conversations reveal different opinions and considerations on how prescribed procedures turn out in practice. All the involved persons have a different role in the field of survey data and cadastral mapping at the Kadaster.
At last the author got a training in surveying by Peter Winterswijk (see figure 2.2); a land surveyor of the Kadaster, specialized in boundary reconstructions. This training includes the preliminary research at the office, the actual boundary reconstruction in the field and processing of the obtained

survey data in the Dutch cadastral database. The main focus of this training involved the search and interpretation of field sketches to reconstruct a boundary and the different survey techniques used in the field, like GPS equipment, a tachymeter and the options for quality checks.

Figure 2.2: Training of land surveyor

2.2 REQUIREMENTS

After the preliminary investigation requirements are stated, which are based on the encountered issues during this research phase. The requirements are the guidelines for the design of the data model in order to achieve an improved work flow. The different requirements are of different importance and have a different impact. Therefore a subdivision is made by a MoSCoW analysis. This is a often used method in software engineering projects to define the priorities. MoSCoW analysis is part of Dynamic Systems Development Method (DSDM) [Wikipedia, 2008]. In order to get a more considered overview of cadastral systems and their requirements in an additional chapter three foreign cadastral systems are discussed. This chapter will discuss the impacts of requirements on cadastral systems.

2.3 DEVELOPMENT OF THE DATA MODEL

This part of the research describes the design process of the new data model. A data model can meet requirements in several ways. This thesis discusses these several approaches and will choose the best solution for the Kadaster. For the design of the new data model the subpackage *Survey and Representation* of the LADM will be used as template. This data model does meet already certain requirements, but need adjustments to meet others. The considerations of these adjustments will be discussed.

2.4 EVALUATION

In a final step this thesis present several real cadastral cases. The aim of this chapter is to demonstrate how the new data model operates. The cases are real cases from the Kadaster and chosen by purpose to cover the broad spectrum of challenges of survey data and cadastral mapping of the Kadaster. The demonstration cases both come from the survey data side and the cadastral mapping side. The data flow of the test cases will be drawn by sketches and a data model. This will clarify the approach and solutions by this data model.

2.5 SOFTWARE AND TOOLS

The NLSRDM is designed by Unified Modelling Language (UML). This is an object-oriented modelling language, which is tool for architects and developers to communicate a data model into vivid software. A model is an abstraction of a certain real-word problem and an object is any person, place, thing, concept, event, screen or report applicable to your system. The problem and its related model could get very complicated. This requires proper communication between the persons who design a solution for this problem and the persons who to develop tools to execute this solution. UML is a standardized language, which enables everyone, from business analyst to designer to programmer a common vocabulary to talk about software design. [Miller, 2004]
UML models consists of objects, which have attributes and operations. Operations describes how objects behave and attributes are elements an object can have. The values of an object determine its state. Different objects interact with each other by messages. [Miller, 2004]
There exists various modelling diagrams in UML, like a sequence diagram and a activity diagram [Miller, 2004]. For this research the use case diagram and the class diagram will be used. A use case diagram is a description what a system does from an external observer's point of view. A class diagram displays what interacts but not what happens when they do interact.

3 SURVEY DATA AND CADASTRAL MAPPING AT THE KADASTER

3.1 THE ORIGIN OF THE KADASTER

Till the end of the 18th century there was no organized system of land administration in the Netherlands. This changed by the foundation of the unitary state 'The Netherlands' in 1798. By French influence it was tried to raise property tax in a fair way and an administrative organization was established. In 1810 the Netherlands came under the authority of Napoleon. As a result the French cadastral laws were applied in the Netherlands. After the downfall of Napoleon, the process of land administration continued and in 1832 the Kadaster was founded.
At the start of the Kadaster properties were described on cadastral maps, which offers a general impression of the cadastral situation per municipality or section of municipality. These cadastral maps were created by land surveyors. In cooperation with the local major they first defined the boundaries of a municipality, mainly based on natural features. These boundaries were measured in a so-called 'driehoeksnet' (*triangulation network*); a local geodetic network, which commonly used the local church as central point. Since the municipal boundaries were measured separately, they didn't match with adjacent municipal boundaries.
Afterwards the land surveyor visited all individual land owners. They had to assign the extent of their property. If the owners were absent, this assignment was done by a third party. Every piece of land with a similar land use and a similar land owner was considered to be separate parcel. Nevertheless the amount of parcels on the map was stimulated by the fact that land surveyors were paid per defined parcel. The parcels were identified by a specific parcel number, which was written on the cadastral map. Roads, water bodies and other public pieces of land didn't got a parcel number, since they had no owner to pay taxes. These parcels are numbered in a later phase. [Verheijen, 2014]
The extent of parcels were measured with special chains in the field and later in the office drawn in the cadastral map. The work of the land surveyor was later verified by an engineer. There are significant differences in accuracy, scale and reliability of these maps.
From every parcel the area was calculated, in order to determine the amount of property tax. To avoid conflicts with the owners, these calculations were mainly rounded downwards. Confusing is the fact that land surveyors used local measure units like 'bunder', 'are' and 'el' for the parcel areas. [Verheijen, 2014].
When a cadastral map was completed and all calculations were finished, the related survey data was assumed to be useless and thrown away. New insights at the end of the 19th century resulted in the maintenance of survey data from that point on. [Koen and Schipper, 1979]
Cadastral maps which describe the starting point of the Dutch cadastral situation are called the 'kadastrale minuuttoestand' (*cadastral field documents*). These documents had a legal value and it was only allowed to change them

in highly exceptional cases [Verheijen, 2014]. Most of the 'kadastrale minuuttoestand' (*cadastral field documents*) reflect the cadastral situation of 1 October 1832, as this is the day the Kadaster took over from Napoleon. However there are some exceptions like the new created province Flevoland. Further land consolidation projects create a new 'kadastrale minuuttoestand' (*cadastral field documents*). All cadastral maps are stored in the 'cartografisch gegevensbestand' (*cadastral database*), currently known as LKI. [Verheijen, 2014]

Properties were also administrated by the 'kadastrale legger' (*land tax register*). This register contains the properties of an individual owner per municipality. If a person had different legal rights, like lease, in the same municipality, this was documented in a separate 'kadastrale legger' (*land tax register*). The document administrated the parcel number, the calculated surface, the land use and the taxability of a property. All the 'kadastrale leggers' (*land tax registers*) were stored in the 'kadastrale boekhouding' (*cadastral administration*). The system is used till June 1990, when it was replaced by the *Automatisering Kadastrale Registratie (AKR)*. [Verheijen, 2014]

Changes in the cadastral situation were documented by 'hulpkaarten' (*supportive maps*). On these documents the changes were indicated by field sketches, including the survey data of the new boundaries. The changes were added to the 'kadastrale legger' (*land tax register*) and the 'hulpkaarten' (*supportive maps*) were stored in the 'veldwerkarchief' (*field sketch archive*). [Verheijen, 2014]

In the Netherlands the legal prove of ownership is not a 'kadastrale legger' (*land tax register*) or a cadastral map, but a deed, drafted by a notary. The deeds are stored in the 'openbare registers' (*property register*). [Koen and Schipper, 1979]

Together with the 'cartografisch gegevensbestand' (*cadastral database*), the 'kadastrale boekhouding' (*cadastral administration*) and the 'veldwerkarchief' (*field sketch archive*), the 'openbare registers' (*property register*) is the core component of Land Administration at the Kadaster (see figure 3.1). [Koen and Schipper, 1979]

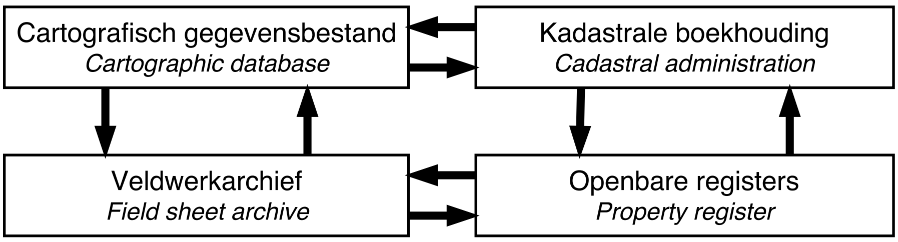

Figure 3.1: The organisation of the Kadaster [Koen and Schipper, 1979]

3.2 THE REVISION OF CADASTRAL DATA

Since the establishment of the 'kadastrale minuuttoestand' (*cadastral field documents*), the cadastral situation in the Netherlands have been changed constantly. This resulted in new spatial units with related spatial sources. Therefore the Kadaster is continuously updating their administration. Changes of the Dutch cadastral situation appear by the so-called 'grens- and perceelsvorm-

ing' (*boundary- and parcel creation*). This exists of the following activities; 'verificatieposten' (*verification*), 'splitsen' (*splits*), 'ruilverkaveling' (*land consolidation*), 'gemeentelijke herindeling' (*communal redivision*) and 'grensreconstructie' (*boundary reconstruction*) (see figure 3.2).
The activities 'kavelruil' (*exchange of parcels*) and 'gemeentelijke herindeling' (*communal redivision*) involves the exchange of entire parcels to others, which maintains the current outline of the Dutch cadastral map. There are no changes in the extent of spatial units and no new parcel numbers are generated. The changes are only recorded by deeds.

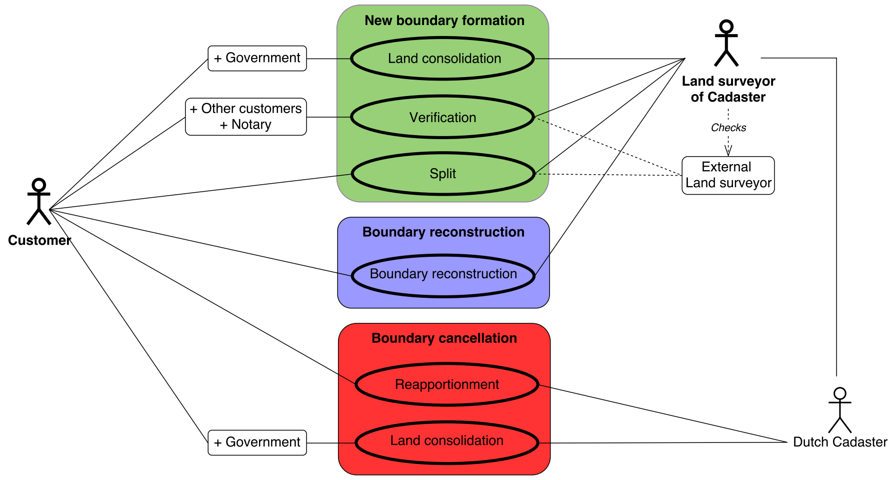

Figure 3.2: Survey processes at the Kadaster

This is different for 'verificatieposten' (*verification*) and 'splitsen' (*splits*), where new spatial units will be created. 'Verificatieposten' (*verification*) means that one party transfers a part of its parcel to another party. Therefore they go together to a notary, where their agreement is drafted in a deed. The notary is authorized to draw a provisional line in the Dutch cadastral map via a special software called Splits. This provisional line, called the *Voorlopig Kadastrale Grens (VKG)*, corresponds to the agreement, but is indicative. In the Dutch cadastral map the VKG is coloured brown and its location is mainly based on area calculations or the position of other spatial units. The implementation of a VKG generates immediately new parcel numbers.
The final location of the new boundary have to be defined in the field. Therefore a land surveyor of the Kadaster arranges a meeting with the involved parties at the location of the new boundary. This meeting is called the 'aanwijs' (*designation*). Both parties assign the agreed location of the boundary in the landscape. The land surveyor measures this assigned boundary and later he checks at the office if it corresponds to the officials areas of the related parcels. These official areas are noted in the deeds, stored in the AKR. Nevertheless deviation is not exceptional. The land surveyor documents the 'aanwijs' (*designation*) on a 'relaas van bevindingen' (*official statement of observations*) (for an example see appendix A.1). This statement includes the names of the involved parties, the related deed and possible related 'relaas van bevindingen' (*official statement of observations*), the day of the 'aanwijs' (*designation*), the day of the measurements and the reason for the mutation. An added 'hulpkaart' (*supportive map*) clarifies the new cadastral situation, including the new and expired parcel numbers. The 'relaas van bevindingen' (*official statement of observations*) has legal value and will be used as

reference in case of conflicts. The 'aanwijs' (*designation*) takes in most cases place 12 to 18 months after the preparation of the deed, depending on the terrain. After this meeting the land surveyor processes the new cadastral situation in the Dutch cadastral map. [VIG, 2003]
The 'splitsen' (*splits*) activity is almost similar to the 'verificatieposten' (*verification*), but it involves only one party without a VKG. This is mainly done to exclude another party from influence on the position of a new boundary. The related measurements can even be done by externals or by the involved party himself/herself. Nevertheless the survey procedure have to meet certain criteria. These are described in a guideline and checked afterwards by the Kadaster. The observations of a 'splitsen' (*splits*) are documented on a 'relaas van bevindingen' (*official statement of observations)* too and at the end the Kadaster implements the new cadastral situation in the Dutch cadastral map. (Hagemans, Winterswijk, personal communication, 2016)
A special case is the boundary reconstruction, where the Kadaster is asked by customers to visualize an already determined boundary in the field. Boundary reconstructions do not create a new cadastral situation, but they do generate new spatial sources of an existing spatial unit. [Polman and Salzmann, 1996]
For this boundary reconstruction a land surveyor consults all related spatial sources. He/she has a special interest in the most original sources, since these are the legal descriptions of a boundary. This quest could go back till the 'kadastrale minuuttoestand' (*cadastral field documents*). When all spatial sources are collected, the land surveyor will do first a preliminary investigation in the field. He checks if the topography on the spatial sources still corresponds to the features in the landscape (see figure 3.3). When this is the case, the land surveyor reconstructs the boundary, marks it by posts and informs the customer. In some cases the actual location of the boundary could only be traced back to a wider zone or the original spatial sources are missing. This appears for instance when the boundary is defined as a ditch, but this ditch is 1 meter wide. In such a situation the land surveyor choose the most logical location for the boundary, like the middle of the ditch. This process is called *delimitation*. [Nagtzaam, 2016] [Schut, 2016]

Figure 3.3: Land surveyors of the Kadaster reconstructing a boundary (photo taken by the author)

Afterwards the land surveyor remeasures the reconstructed boundary by modern survey equipment. This survey data will however not be implemented in the Dutch cadastral map, but only stored in the *Digitaal Reconstructie Archief (DRA)*. The DRA will be explained later. (Winterswijk, personal communication, 2016)
A last situation where the cadastral situation changes is 'ruilverkaveling' (*land consolidation*). These are projects, which reorganize the cadastral situation of a certain region. The aim of this redivision is to have a more efficient land use by relocating properties near the residence of the land owner. This relocating happens on basis of exchange. Further it tries to decrease the amount of parcels as much as possible. Parcels of the same owner and the same legal rights are merged into one new parcel. In most cases 'ruilverkaveling' (*land consolidation*) involves only rural areas. The cadastral situation after the 'ruilverkaveling' (*land consolidation*) is declared as new 'kadastrale minuuttoestand' (*cadastral field document*). In the past all boundaries in this new 'kadastrale minuuttoestand' (*land consolidation*) were measured. Due to a lack of time and money only the new boundaries are remeasured.
Customers could also merge adjacent parcel by own initiative if they have similar conditions. This is however hardly done due to the expenses, which have to be paid by the customer himself/herself. This activity is called 'vereniging van percelen' (*reappointment of parcels*). [Polman and Salzmann, 1996]

3.3 SURVEYING AT THE KADASTER

When a survey is conducted by a land surveyor, this is done in a survey project by the Kadaster staff. A survey project means a set of measurements in the same local measurement system. The survey data in this project is related to each other. There are two ways for measuring cadastral boundaries; Coordinate Geometry and straight coordinates.
Coordinate Geometry (COGO) is a method to transform written descriptions of cadastral features into a digital map. These written descriptions, like line length and directions, refer to an original key feature, like control points on field sketches. The coordinates of these control points are known, which enables to calculate the location of the cadastral features by the information of the written descriptions. The basic elements of COGO are points, spirals, lines and curves. Straight lines have distance and direction. Curves have a radius, angle, arc length and a direction. The main advantage of COGO is that the relative position of features is described. On survey documents of the Kadaster the boundaries are referred to control points or fixed features in the landscape, like walls, roads or corners of houses. [Wiki.GIS.com, 2011]
Alternatively it is possible too to calculate coordinates straight via communication with satellites. These coordinates places the features independently in the environment with no reference to other features in the vicinity. The Kadaster is a 2D system, measuring only the X-coordinate and Y-coordinate. It need to be highlighted that a boundary is not always measured by its start point, end point or intersection point with another boundary. Two or more points are chosen on a random spot on the boundary. Although it is preferred to measure spots spread all over the boundary. Later in the digital cadastral map these the final boundary is drawn between these spots and extended to the intersecting boundary. The intersection points are calcu-

lated in this digital cadastral map and assumed to be the start point and end point of the related boundary.
Both for COGO and straight coordinates topography is measured as reference to the environment and as quality check for survey project. Topography could be for instance corners of buildings or a ditch. The global coordinates of this topography is known and can be implemented in the survey project. Relating measurements to topography in the field is called 'idealisatie' (*idealisation*). The precision of survey data can never be better than its 'idealisatie' (*idealisation*) points. For fixed features used for 'idealisatie' (*idealisation*), different standard precision classes are defined (see figure 3.4). It need to be mentioned that all topography are temporal; at some moment in time topography is removed, replaced or modified. This causes issues for boundary reconstructions.

klasse	klasse-indeling idealisatie([cm])	standaardafwijking idealisatie([cm])	
		beschrijving uitwisseling beoordeling	aansluiting
grenssteen, muur (harde topografie)	0 - 2	2	1
kant verharding, straatmeubilair, put	1 - 3	3	2
hek	2 - 5	5	3.5
heg, greppel	5 - 10	10	7.5
sloot	10 - 20	20	15
niet geklasseerde punten	> 20	32	20

Figure 3.4: Class division, after [Polman and Salzmann, 1996]

The Kadaster defines a difference between 'harde topografie' (*solid topography*), like buildings and walls, and 'zachte topografie' (*soft topography*), for instance ditches, road edges and shrubbery. The 'harde topografie' (*solid topography*) are the main source for control points, but by a lack of it 'zachte topografie' (*soft topography*) is used. This is often the case in rural areas, where patterns of ditches are used as topography. For a reliable reference to the environment, a survey project needs at least 3 control points, but 4 to 5 control points are preferred. A boundary could also be described by its geometrical relation with respect to other boundaries or topography. Examples of geometrical relations are collinearity, perpendicularity, and parallelism. [Polman and Salzmann, 1996]
Over time the Kadaster used four different survey techniques; GPS, a tachymeter, photogrammetry and measure tape [Polman and Salzmann, 1996].
GPS is a global navigation system, which can define a location on earth by communicating with a network of satellites. There exists different sorts of GPS techniques, which work with a reference system. A reference point enables to derive high accuracy of several centimetres. Both the reference point and the rover, the actual GPS equipment of a land surveyor, have a receiver. With this receiver they both can communicate with the satellite network. The reference is placed on a point with known coordinates. This allows him to determine the deviation. This deviation is communicated to the rover via a telephone or radio connection. A rover is long stick with the GPS receiver on top. For a measurement the bottom side of the stick have to

be placed on the actual measure point, while it is kept levelled (see figure 3.5). The rover is able to define his position accurately by receiving information about his position with respect to the different satellites and deviation information from the base station. For a proper measurement, the GPS receivers need contact with at least 4 satellites. (Verbree, lecture Positioning & location awareness, 2014) [GEO/PPB, 2010]
The advantage of GPS measuring is that the location of a point is immediately determined by global coordinates. This makes that the quality of the different measurements is dependent on each other. This is in contrast with tachymeter and measure tape measurements. GPS is especially useful for measuring in rural areas. A drawback of GPS is that the communication with satellites could be disrupted by foliage, buildings or other features. This is annoying for urban areas. Another disadvantage is that in some cases it is impossible to place the instrument on top a point like the corner of a building. This could be solved by a 'V-meting' (*V-measurement*), where two other points with a similar distance to the actual point are measured. [Polman and Salzmann, 1996]

Figure 3.5: A GPS receiver (photo taken by the author)

The second survey technique, which is currently used, is the tachymeter. This is a theodolite with an electronic distance measurement system [Polman and Salzmann, 1996]. A theodolite is a precision instrument for measuring angles in the horizontal and vertical planes. [Polman and Salzmann, 1996]. The tachymeter is placed levelled on a known point in space, an 'opstelpunt' (*base spot*). It is preferred to place the tachymeter on such a place that is have a straight view to all or as much as possible points to be measured. The land surveyor places a stick with a prism on the measured points and the tachymeter observes the angles and distances of the prism with respect to itself (see figure 3.7). This enables the tachymeter to calculate the position of the measure point. The tachymeter of the Kadaster was equipped with a GPS receiver to determine its own position and it is automatically following the prism. Therefore measurements can be done by one person (Winterswijk, personal communication, 2016).

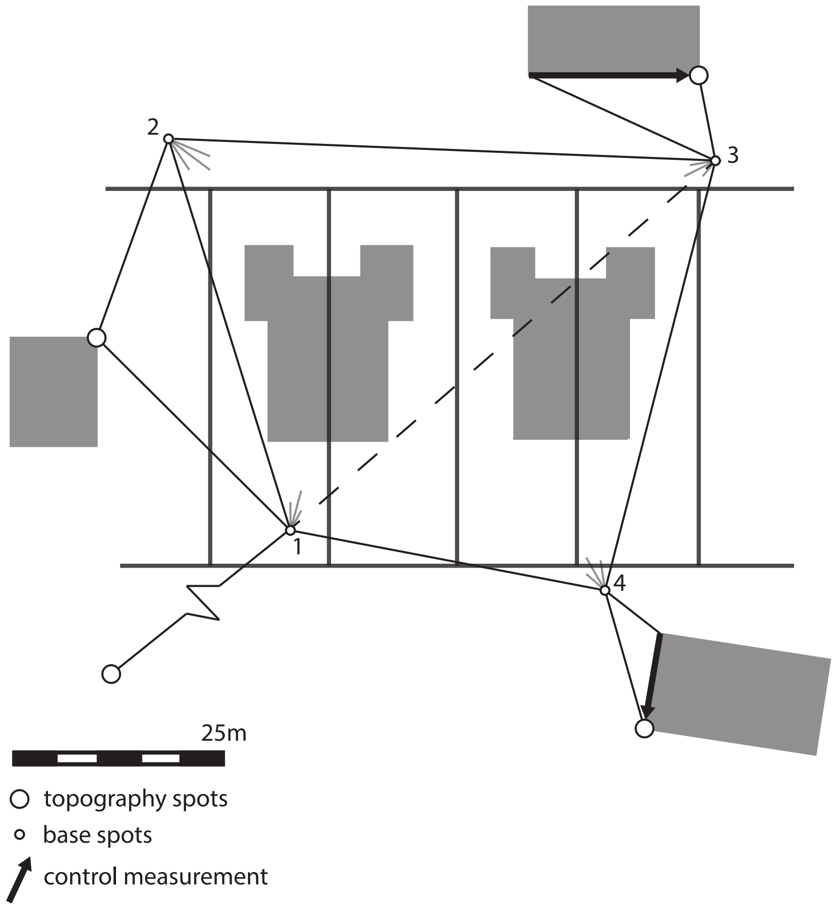

Figure 3.6: Schematic overview of a survey project with a tachymeter (after [Polman and Salzmann, 1996])

For measuring fixed topography like walls, where it is difficult to put a prism on, the tachymeter is able to survey point without the prism. This is however less accurate and it is only possible on surface with sufficient reflection, a so-called Lambertian reflectance (Lemmens, lecture Sensing technologies for the built environment, 2014). The quality of tachymeter measurements are better when the amount of 'opstelpunten' (*base spots*) is limited to the minimum. Then all measure points have the same reference point, which increases the coherence between of the survey project. Buildings, vegetation or other features could block a straight view between the instrument and the prism. In this case extra 'opstelpunten' (*base spots*) are inevitable. Extra 'opstelpunten' (*base spots*) cost extra time too [Polman and Salzmann, 1996]. This situation is demonstrated in figure 3.6 where there is no straight view between 'opstelpunten' (*base spots*) 1 and 3. 'Opstelpunt' (*base spot*) 4 is added to connect both.

Figure 3.7: A tachymeter with a prism (photo taken by the author)

GPS and the tachymeter are both terrestric survey methods. These are currently used at the Kadaster for measuring new boundaries and boundary reconstruction. Terrestric survey methods are common used in relatively small areas. In an area with many buildings a tachymeter is more effective, since it can reach more difficult points.
All measurements of a terrestric survey project are measured twice by a different surveys for a quality check. As an alternative, measure tape could be used as well. Nevertheless in this case the tachymeter or GPS measurements are the primary measurements. Measure tape is currently only used for control measurements. In the past it was the only method for cadastral surveying. Measure tape is for instance used to measure the distance between two measured points as control measurement (see figure 3.3). Measure tape is the basis for the former 'meetlijnmethode' (*aligning base method*), which is used for analogue field sketches. It holds that straight lines of fixed features, like a façade of a house, are used to measure the distance to other fixed features or boundaries. This extension need to be limited to twice the length of the façade With the 'orthogonaal methode' (*orthogonal method*) points will be placed perpendicular to a measure line with the help of a pentaprism. The distance of the measured point to the perpendicular line should be limited to certain tens of meters. [Polman and Salzmann, 1996]
A special category in surveying is photogrammetry. This technique exists of taking images from the involved area in an aerial vehicle. These images are merged into one orthophoto by least square adjustment. This orthophoto is referenced by ground control points. In this orthophoto the cadastral boundaries can be drawn, while its coordinates are immediately obtained. The technique can only be used when the fixed features are clearly visible on the orthophoto and relevant as cadastral boundaries. (Lemmens, lecture Sensing technologies in the built environment, 2014)
Although photogrammetry is mainly used for mapping topography, in some cases it is used as well for relatively bigger survey projects in rural areas, like land consolidation projects. In rural areas the striking features, which indicate a cadastral boundary, are clearly visible, like ditches. This technique is less accurate than terrestric survey methods, but this is more allowed in such areas. It is inevitable that some parts of the photogrammetric map are invisible by vegetation or buildings, a photogrammetric survey is never

complete. Missing parts have to be added by terrestric surveying. [Polman and Salzmann, 1996]
A recent inventory of the spatial data in Kadastrale Perceelsvorming (KPV) demonstrated that 44% of the boundaries at the Kadaster have analogue spatial sources, 36% is measured with terrestrical survey techniques (tachymeter or GPS) and 6% of the boundaries at the Kadaster are measured via photogrammetry (mainly at land consolidation projects). From 12% of the boundaries is its spatial source unknown and 2% are administrative and VKG boundaries. [de Koning, 2016]
The quality of measurements are indicated by the precision and reliability. Good precision doesn't mean a good reliability. Together these components are called the 'nauwkeurigheid' (*accuracy*). Precision describes the distribution of random points with respect to their average. Precision of one element is described by its standard deviation, for more elements it is described by the covariance matrix. Further it can also be described by ellipses. The reliability describes the sensitivity for deviations in the coordinates as a result of errors in the measurements. [Polman and Salzmann, 1996]

3.4 GEODETIC REFERENCE SYSTEMS

At the Kadaster several geodetic reference systems are important. In most cases the Rijksdriehoek (RD) system is used. This is a network of fixed points spread over the entire Netherlands. These fixed points are maintained by the 'bijhoudingsdienst der Rijksdriehoeksmeting'. The origin of this network is based on the top of a church in Amersfoort. At the start this origin got the coordinates (0,0), but this resulted in negative coordinates and confusing between X-coordinates and Y-coordinates. Therefore the (0,0) have been replaced to an imaginary point close to Paris. The RD-points can be used as control points for surveying, but however they are to less distributed and extra control points are required. [Polman and Salzmann, 1996]
GPS-systems have the ability to measure in RDNAPTRANS2008. Other used reference systems are WGS84, ED50 (offshore measurements) and the ETRS89 system, which is used to exchange and compare geometric data in Europe. [Polman and Salzmann, 1996]
In some applications it is necessary to know the relation between the different reference systems. This is achieved by the help of a datum transformation parameters. At the Kadaster this is mainly appearing between the RD/NAP system and the ETRS89 system. [Polman and Salzmann, 1996]

3.5 FIELD SKETCHES

A field sketch is a document drafted by a land surveyor of the Kadaster to sketch and describe a changed cadastral situation. Until 2008 these documents were written on paper, but currently they are manufactured digitally [Polman and Salzmann, 1996]. An example of an paper field sketch is given by figure A.4 and a digital example in figure A.1. The information written on a paper field sketch is various. At first about the document itself. Every field sketch has an unique 'archiefnummer' (*archive number*) and a cadas-

tral municipality name, a section letter and a sheet number to relate it to the cadastral map. The term cadastral municipality appeared after the start of municipal redivision; The expired names of municipalities who joined others maintained separately at the Kadaster to avoid mistakes [Verheijen, 2014]. The 'jaar' (*document creation year*) gave the document a timestamp. Every field sketch has a 'dienstjaar' (*year of service*), which is one year later than the 'jaar' (*document creation year*). Further is the orientation indicated by a north arrow. Scattered text offers additional information like adjacent field sketches, related deeds, street names and the name of the land surveyor, including his signature. [Christodoulou and de Koning, 2016]
The new cadastral situation is indicated by the generation of new parcels numbers. These new parcel numbers in red. The former, but expired parcel numbers are written in blue. Parcel numbers of unchanged parcels are written in black. Further the field sketches of the former and future cadastral situation of the involved area are noted. The outline of these parcels are drawn by different lines; continuous red lines describes new parcel boundaries and continuous black/grey line describes existing/untouched parcel boundaries. Other special boundaries on a field sketch, but used on cadastral maps as well, are the sheet boundary, section boundary, municipality boundary, province boundary and the national boundary. These are depicted in figure 3.8.

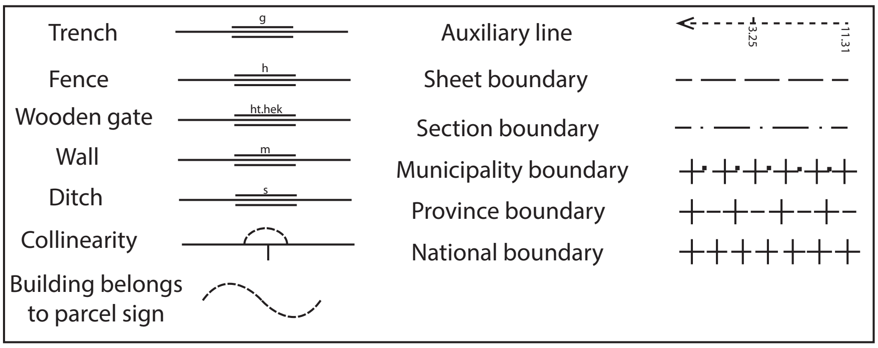

Figure 3.8: Symbology on field sketches, after [Verheijen, 2014]

Besides parcels there are mainly buildings drawn on the field sketch to refer cadastral boundaries to topography. Buildings are identified by an encircled number for identification and its outline is marked by a continuous line shade elements (see figure 3.9). A special symbol clarifies to which parcel a building belongs, if it is located on the parcel boundary (see figure 3.8). Other fixed features on a field sketch are walls or fences, which both could be assigned as boundary or used as topography with a certain distance to a boundary (see figure 3.8). The distance of topography to the actual boundary is drawn by a dashed auxiliary line, which includes the measured distance (see figure 3.9). If more cadastral points are located on one auxiliary line, there distance is given cumulatively with respect to the start of the auxiliary line (see figure 3.8). When a boundary is curved, auxiliary lines pointing the curve and their measured distance suggests the radius of the curve. The location of boundaries with respect to topography could also be indicated by geometrical relations, like collinearity and parallelism. There are special signs for these geometrical relations (see figure 3.8). In many cases scattered text on the field sketch describes the land use (e.g. 'garden'), feature information ('house'), the name of parcel owners and the physical appearance of boundaries. [Christodoulou and de Koning, 2016]

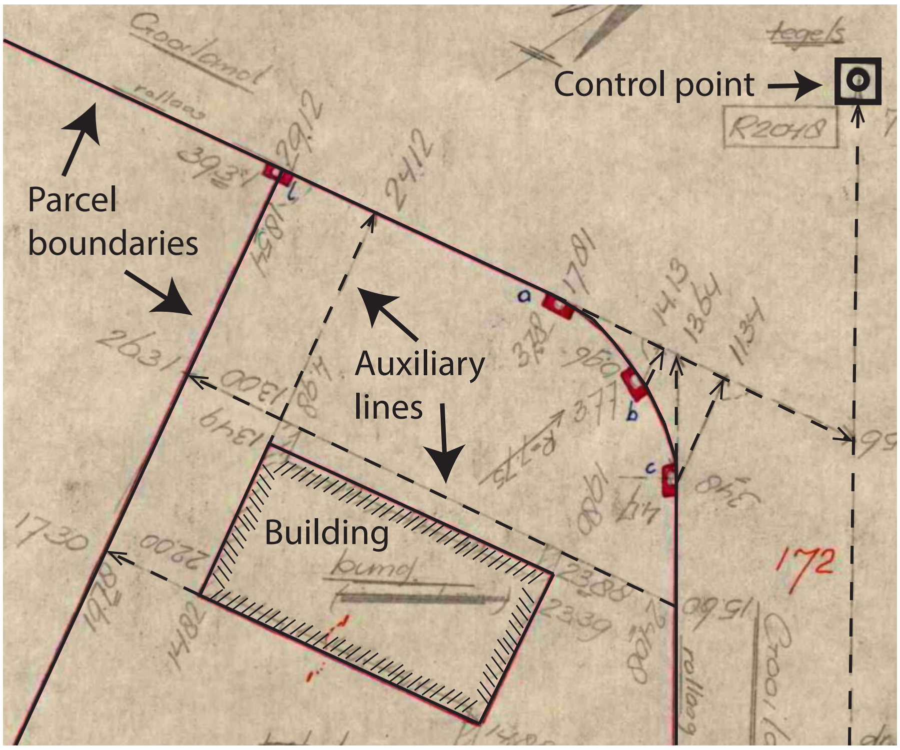

Figure 3.9: Details of a field sketch. For a complete field sketch, see appendix A.4

A special category of fixed features are control points (see figure 3.9). These are points in the field, marked by special RD posts. The coordinates of these control points are measured by the Kadaster. On a field sketch these control points are drawn in a square and a number. With this number the corresponding coordinates can be found on a special list. Control points enables to related the field sketch straight to the environment. It is preferred for a field sketch to have at least 2 control points, but the more the better. However a lack of control points is not exceptional. In that case the field sketches need to be orientated by matching the outline with the outline of adjacent field sketches.

The drawings on the field sketches are indicative and not scaled. However the field sketches indicates clearly the adjacent boundaries of a certain boundary. Sometimes measured lines are even drawn curved to not overlap other features, but keep the topological information intact. If they supposed to be straight the text 'recht' (*straight*) is added. In other cases parcel lines and building lines overlap an continuing auxiliary line. It is up to the reader to detect this error.

It seems that a field sketch is a quite standardized document, but there are many exceptions and various notations. This depends on the work habits of the involved land surveyor. An internal inventory by the Kadaster identified 29 ways of drawing a line, 20 ways to draw points, 12 ways to document measurements and 40 different sorts of other information, like scattered text, symbols and parcel and building information [Christodoulou and de Koning, 2016].

Currently all the field sketches are scanned and digital available via a database.

The field sketches are traceable by their 'archiefnummer' (*archive number*) or by their municipality name, section letter and parcel numbers. (Peter Winterswijk, personal communication, 2016)

3.6 PROCESSING OF SURVEY DATA AT THE KADASTER

Currently there are two different work flows in the Kadaster to process survey data (see figure 3.10). The distinction of both work flows has historical reasons. In the past all survey information was written on an analogue field sketch. By the introduction of digital survey equipment a second work flow was introduced to manage spatial data in file formats, which were readable for survey equipment. Field sketches are stored in DVA and in DRA the survey data is stored in numerical coordinates. A special element in the work flow is Splits and AKR. The VKG in Splits are together with the official area noted in the deeds are the source for 'verificatieposten' (*verification*) for a land surveyor.
Field sketches are generated by the software program Bluebeam in a intuitive way by implementing the related DRA coordinates. Together with the data of the 'aanwijs' (*designation*), a document in pdf-format is created by eRelaas and stored in the DVA. This is a database for all 'relazen der bevindingen' (*official statements of observations*) (see figure 3.10).
In the other work flow the survey data, obtained in the field, is subjected to a couple of processes and at the end implemented in the Dutch cadastral map (see figure 3.10). These processes are executed by the software *Terrestrische Inwinning en Reconstructie (TIR)/MOVE*. This is a software package, which checks and adjusts the quality of spatial data by least squares, reliability and precision. [Polman and Salzmann, 1996]

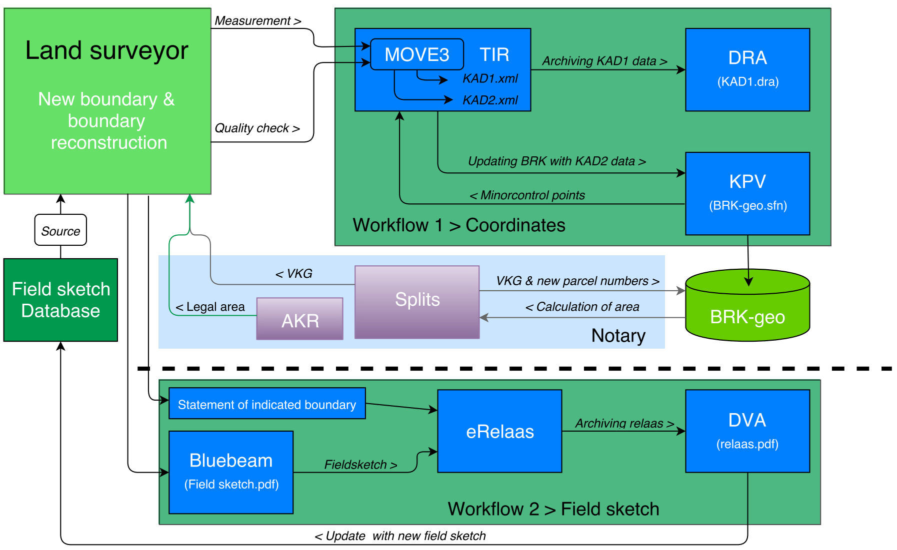

Figure 3.10: Work flow overview of the Cadastral survey process

The first process of the work flow is called the 'eerste vereffening' (*first adjustment*) or KAD1 (see figure 3.11). This process tests the quality of the spatial data by its related control measurements. These tests look at collinearity, parallelism, perpendicular, distances between points and corresponding sizes of fixed features. Errors implicate equipment failure or wrong procedures. The 'eerste vereffening' (*first adjustment*) involves only all spatial data of one survey project in an own local system. When the spatial data is approved, it will be stored in the DRA per point. This is a database where all KAD1 data is stored by numerical RD coordinates. KAD1 spatial is assumed to be the best estimation of a point.

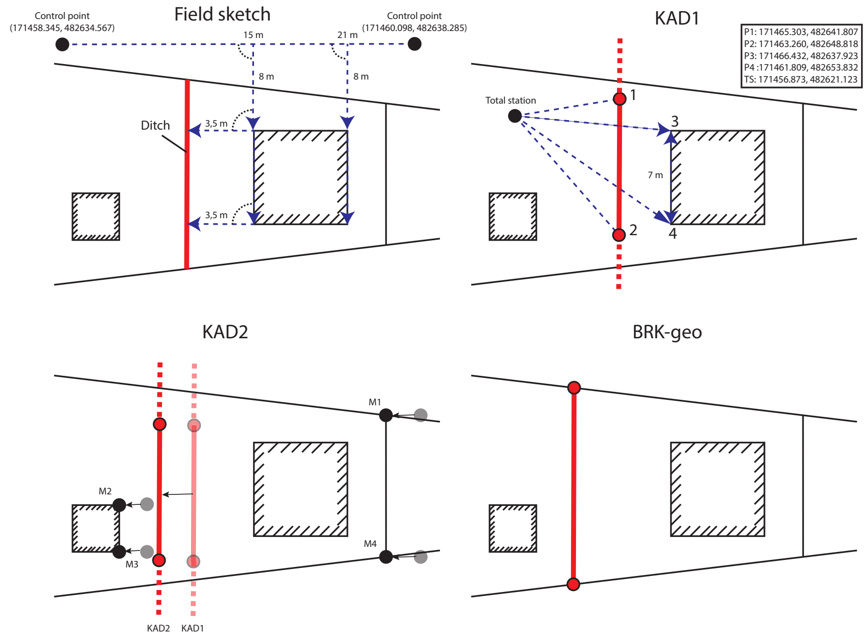

Figure 3.11: Processing of spatial data by the Kadaster

If spatial data doesn't have to be implemented in the Dutch cadastral map, like boundary reconstruction, the 'eerste vereffening' (*first adjustment*) is the final step. Otherwise a second process is subjected to the spatial data, called the 'tweede vereffening' (*second adjustment*) or KAD2. By this process the KAD1 data is adjusted to the environment by matching them with 'aansluitingspunten' (*minorcontrol points*) (see figure 3.11). These are points of topography, which are measured in the survey project and already existing in the Dutch cadastral map. This adjustment is based on least square adjustment. This 'tweede vereffening' (*second adjustment*) is controversial since high accurate spatial data is adjusted to less accurate topography. When the 'tweede vereffening' (*second adjustment*) is finished, the coordinates are stored in the KPV. This is a Geographic Information System (GIS)-based software program that transforms the surveyed points into a line. This line is extended till it intersects with adjacent boundaries. The line is then stored as line string, based on the intersection points, and implemented in the Dutch cadastral map (see figure 3.11). [Polman and Salzmann, 1996]
In the KPV system all constructed boundaries get a quality code, based on their survey method; The 'D' is for the digitized boundaries of analogue spatial sources, which are implemented in the Dutch cadastral map. The quality of the boundaries depends on the original map scale The 'T' is for Terrestric spatial data, varying form 'T1' (good) to 'T6' (bad). Photogrammetric spatial data are indicated by the code 'F0' to 'F6', depending on the quality of the flight. If the quality is unknown the spatial data get the code

'X' [de Koning, 2016]. Other codes in the KPV are 'V' for VKG, 'Z' for administrative boundaries. [de Koning, 2016]
The Kadaster uses the file formats NEN1878-format/NEN1878- measurement-format (both with extension .SFN) and .SUF2 (with extension .SF2, precursor of .SFN) to transport the measurements of survey equipment to the computer for processing (NEN1878-measurement format), the exchange of spatial data to customers and as reference for measurement reconstruction (NEN1878-format). The NEN1878-measurement format stores all relevant spatial data and related metadata in different records. [VIG, 2003]

```
         1         2         3         4         5         6
1234567890123456789012345678901234567890123456789012345678901234

0101204_55    V      199504        1 1S04VOORBEELD_NEN1878    01
020102150201         0         0         1         0         101
07NKADASTER CONCERNSTAF/VIG                                   00
07AHOFSTRAAT                 110                   P7311KZ    00
07WAPELDOORN                                                  01
03MM01      G010111   D 19930427BAPD01 1                      00
04I1        X100101700Y531065536Q  2  1  0                    00
05F912      X100101700Y531065536                              00
06A28T102      10CM ONDER MAAIVELD                            01
03MQ21      G010101   D 19940424B1994  0                      00
```

Figure 3.12: Output of a NEN1878 file [VIG, 2003]

Figure 3.12 demonstrates the output of an NEN1878-measurement file This file covers various coded information, like general information in lines starting with '01', meta data about used reference system (line starts with '02'), meta data of the user (line starts with '07'), non-geometrical characteristics of the object (line starts with '03'), geometrical characteristics of the object (line starts with '04'), data of the text and symbols (line starts with '05') and the actual text (line starts with '06'). [VIG, 2003]

3.7 THE DUTCH CADASTRAL MAP

The Dutch cadastral map is called the BRK-geo. This is an up-to-date digital map, which covers the cadastral situation of the entire country and can be consulted via PDOK. The map depicts primary parcel boundaries and parcel. Nevertheless street names, house numbers and water bodies are added for orientation, buildings (derived from the BGT are included for idealisation, control points and orientation). Other topography, like statues and sculptures, are added if they improve the orientation.
The Dutch cadastral map is built up by line objects, which are straight or arc-shaped. Per line object it is registered which parcel is located at the left and which parcel is located at the right. Software secures that parcels are closed areas. [VIG, 2003]
For customers this map offers an cartographic overview of the division, shape and location of parcels. This secures their legal unique entity. All parcels on the map are numbered with a parcel number as a reference to the 'openbare register' (*property register*). The Dutch cadastral map is mainly used as template for own projections, like municipal development plans. For the Kadaster it is required that the map is a planar partition. The cadastral map is used for area calculation of parcels and by a lack of other spatial

sources boundary reconstructions are based on the Dutch cadastral map [VIG, 2003]. In order to improve the orientation, houses of the BGT and semantic information, like house numbering is added.

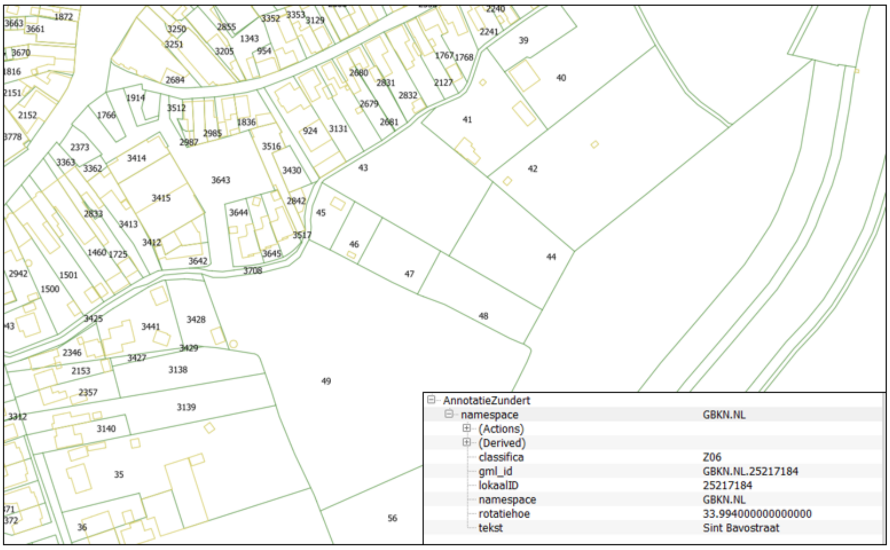

Figure 3.13: Part of the Dutch cadastral map, including annotation

The coordinate system of the map is the RD system and the map has a precision $\sqrt{2}$ x 20 cm of in urban areas and $\sqrt{2}$ x 40 cm in rural areas. It have to be noted that the Dutch cadastral map is pure indicative, the locations of the spatial units are given by approximation. This is the result of how it is manufactured; All analogue spatial sources were digitalized and made together (Klaas van der Hoek, personal communication, 2016). The various quality of the different spatial sources required a lot of compromises and results in a less accurate Dutch cadastral map in specific areas. Currently the high accurate measurements of new boundaries are adjusted to the less accurate Dutch cadastral map and the boundary reconstructions are not even implemented. The accuracy of the Dutch cadastral map won't improve by this way. [Polman and Salzmann, 1996]
A screen shot of the including semantic data is demonstrated in figure 3.13. The quality of the Dutch cadastral map differs as well on different locations. An urban area has a better accuracy than rural area. Urban areas have more topography in the vicinity for idealisation than rural. However the current used GPS equipment have more issues in urban areas, since the signal is disturbed by all the buildings and foliage. Buildings and vegetation could also disturb the line of sight of a tachymeter, which have to position on more locations. Further when the Dutch cadastral map was established, old analogue cadastral maps were used. These maps were a scale of 1:1000 in urban areas and on a scale of 1:2000 in rural areas. [de Koning, 2016].

3.8 3D REGISTRATION AT THE KADASTER

The Kadaster administrates cadastral objects in a 2D dimension. In general this approach is sufficient to cover the Dutch cadastral situation. Neverthe-

less there are occasions were it is preferred to have a cadastral registration in a 3D environment. An example is ownership in a building with apartments on top of each other. Currently such situations are solved by projecting them on a 2D parcel map where the 2D parcels are divided into small parcels. This procedure leads to unclear fragmentation. [Stoter et al., 2016]
In order to achieve a better representation of the actual cadastral situation, the Kadaster established in march 2016 their first 3D registration. This 3D registration concerned the new combined structure of the city hall and underground railway station in the town of Delft. The 3D registration was such chosen that it fitted in the existing cadastral and legal framework. The operation had the aim to gain experience for building a more fundamental solution in the future.
The implementation has been conducted in several phases. At first the real rights were secured in a common deed, then the architect converted the 3D drawing of the construction into six legal volumes in consultation with the stakeholders and in a last step the 3D representations of the rights were translated into a PDF file. This file included a deed which was supplementary to the original deed. In the cadastral registration was a 3D complex ID generated and the different rights have been assigned to unique indices.
The major advantage of the 3D registration is that it is a better representation of complex ownership situations and it is more cost effective. Detailed descriptions for complex situations in 2D is not necessary any more. A drawback is that the 2D Dutch cadastral map doesn't depict the actual registered situation. This requires adaptation of the cadastral legislation and procedures. This change is a delicate job and there is still a lot of work and research to do before 3D registration is a feasible component for the Kadaster. [Stoter et al., 2016]

4 RELATED WORK

4.1 PROJECT *terrestric registration*

Terrestric Registration is a project of several departments (including PPI) of the Kadaster [Schouten, 2016]. The start of this project is motivated by the desire to establish a Dutch cadastral map in which the graphical location of spatial units corresponds more precise to the cadastral reality. Currently the Dutch cadastral map indicates only rough the location of spatial unit. But this is not an ideal situation: The Kadaster uses survey methods with high accuracy, but the derived spatial data are now adjusted to less accurate spatial data and they appear less accurate in the Dutch cadastral map as they could be. An opposite process would be better. In order to improve the geometrical quality of the Dutch cadastral map, all spatial sources need to be related to their spatial units, indicating the accuracy of the spatial units [Schouten, 2016]. The project is assumed to be the next step in achieving a cadastral map which has similar accuracy as its spatial sources. The different process steps for a final improved map are shown in figure 4.1.

Figure 4.1: Process steps to a cadastral map corresponding to its spatial sources

The step taken by the project consists of the design of a new Geo DBMS; The so-called *Terrestric Registration*. This Geo DBMS has the aim to store as much as possible the spatial sources and its processed data in a structured way. Other steps will be the vectorisation of all analogue spatial sources of the Kadaster and the actual improvement of the accuracy of spatial units in the Dutch cadastral map. Since the Kadaster has an archive of survey documents, the process could be redone for all documents. [Hagemans et al., 2016]
Nevertheless there are more reasons for a *Terrestric Registration*. The current systems for spatial data at the Kadaster leaves space for improvements. Extra functionality have to be added to stay suitable for future needs . The main issues are the ambiguity and incompleteness of spatial source storage and the labour intensive retrieve of spatial sources [Hagemans et al., 2016]. In the end the Kadaster doesn't have a central place where the spatial sources and spatial data of a measurement are stored and offers an overview of the entire survey history of a certain spatial unit [Schouten, 2016].

For the project several requirements are stated to which the new *Terrestric Registration* should satisfy;

1. More efficiency in gaining spatial sources by surveying .

2. An improved registration of spatial source by a proper reduction to changes and visualisation of the accuracy and meta data of spatial units.

3. Using a secured Geo DBMS to increase the availability and reliability of spatial data.

4. A better portal to spatial data by relating them to their geographical location and easing the access to spatial sources.

5. Creating a fundament for future development, like vectorisation of analogue spatial sources and storage for 3D spatial data.

The final result of the project *Terrestric Registration* is a portal and an inventory of all spatial sources, spatial data and spatial units of the current. This will be a tool for applying improvement methods on the Dutch cadastral map. Besides it will save time to collect spatial sources of a certain spatial unit, it will decrease the required expert knowledge for interpreting spatial sources and treated topography and spatial data will be maintained in the Dutch cadastral system. This is a huge improvement for the internal work flow at the Kadaster. Externally the *Terrestric Registration* will lead to more reliable and useful cadastral products for customers; Areas can be calculated more precise and a representation of the spatial data can be delivered custom-made. [Hagemans et al., 2016]
In order to develop the *Terrestric Registration* expert knowledge from the entire Kadaster organisation will be used. The project structure involves many stakeholders. Currently the project is in its initial phase by writing the business case, which explains the used methodology, the planning and the expenses. [Hagemans et al., 2016]

4.2 THE LAND ADMINISTRATION DOMAIN MODEL

All around the world much research have been taken place on effective and efficient land administration. Since land administration differs per country or even per region (see chapter *cadastral systems abroad*), various systems have been developed. Although cadastral organizations try to solve often similar cadastral issues. In order to prevent that multiple researchers take place over and over again on these similar cadastral issues, knowledge and cadastral organization structures need to be shared. A standardised data model for cadastral organization enables GIS and data providers to develop applications and for cadastral organizations is it a useful tool to manage their systems in a more efficient way. [van Oosterom and Lemmen, 2015]
In order to fulfil this need, the Land Administration Domain Model is developed by more then fifty experts (scientists and national cadastral organizations) from around 20 countries. It is a conceptual scheme, covering basic information-related components of land administration [ISO 19152, 2012]. LADM is flexible and applicable on a wide range of different types of cadastral cases. The model provides for land administration a shared ontology by defining a terminology, it is a support for developing application software and data quality management and LADM enables data exchange between different cadastral systems [Lemmen et al., 2015]. The development of the LADM started with a congress of the International Federation of Surveyors in 2002 and it is supported by the organizations UN-Habitat, the Food and

Agricultural Organization of the United Nations, the Joint Research Centre of the European Union and the International Organization for Standarization (ISO). [van Oosterom and Lemmen, 2015].
LADM is an ISO/TC211 standard and it used several other ISO geo-standards, like the ISO 19107:2003, *Geographic information - Spatial schema* [ISO 19107, 2003] and the ISO 19156:2011, *Geographic information -Observations and measurements* [ISO 19152, 2012].
LADM have already been used as a template for many countries all over the world like Portugal, Indonesia, Russian Federation and Hungary. The adoption to a country specific data model is enabled by the addition of country specific elements like attributes, operators or even new classes. On the other hand parts of the LADM could also be omitted. [ISO 19152, 2012]
The flexible framework of LADM meets also future needs in cadastral organizations and permits system growth and change [Lemmen et al., 2015].

LADM is built up by many classes and associates as it is shown in appendices B.1, B.2, B.3, B.4 and B.5. In general the structure is based on four basic classes (figure 4.2);

- **Class LA_Party**; This class represents parties. Parties are natural or non natural persons, or group of persons or juridical persons that compose an identifiable single (legal) entity. A juridical person may be a company, a municipality, the state or a farmers cooperation or church community. A 'group party' is any number of parties, forming together a distinct entity. [van Oosterom et al., 2011]

- **Class LA_RRR**; This is an abstract class, which doesn't have instances by its own. Only the subclasses of the abstract class have instances. The class LA_RRR has the subclasses rights, restrictions or responsibilities. A right is *an action, activity or class of actions that a system participant may perform on or using an associated resource*, for instanced ownership right, tenancy right or possession. A restriction is *a formal or informal obligation to refrain from doing something*, for instance 'it is not allowed to build within 200 meters of a fuel station'. A responsibility is *a formal or informal obligation to do something*, for instance cleaning the ditch. [ISO 19152, 2012] [van Oosterom et al., 2011]

- **Class LA_BAUnit**; This class represents a basic administrative unit. This is *an administrative entity consisting of zero or more spatial units (parcels) against which (one or more) rights (e.g. an ownership right or a land use right), responsibilities or restrictions are associated, as included in a Land Administration system*. It represents a group of spatial units with the same rights, restrictions and responsibilities. An example for this situation is an apartment with a garage and a rural parcel. [van Oosterom et al., 2011]

- **Class LA_SpatialUnit**; This class represents a spatial unit (parcels and the legal space of buildings and utility networks). A spatial unit can be *a point (or, multi-point), a line (or, multi-line), representing a single area (or, multiple areas) of land (or water) or, more specifically a single volume of space (or, multiple volumes of space)*. The LA_SpatialUnit class is given in appendix B.1. [van Oosterom et al., 2011]

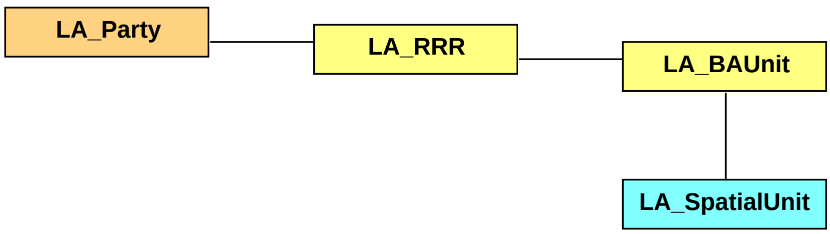

Figure 4.2: The general structure of LADM [ISO 19152, 2012].

In the LADM different types of spatial units are supported; 'sketch based', 'text based', 'point based', 'line based', 'polygon based' (in 2D and in 3D) and 'topological based'. [van Oosterom et al., 2011]
Many LADM classes are subclasses of the superclass *VersionedObject*. This is an umbrella class to manage and maintain historical and quality data for the complete contents of the data model. [van Oosterom et al., 2011]
The spatial package has a specific sub package, called the *Survey and Representation* subpackage. This sub package manages data collection and presentation of surveys and derived coordinates. It covers both 'fixed' boundaries (coordinate-based), 'general' boundaries (based on physical features) and boundaries generated from aerial photo's or satellite images. [van Oosterom et al., 2011]
The *VersionedObject* class, the *Survey and Representation* sub package and the *SpatialUnit* package will be used as template for the NLSRDM. Their contents and the (im)possibilities for implementation on the Dutch cadastral system will be discussed in detail during the development chapter later in this thesis.

5 COMPARABLE CADASTRAL ISSUES ABROAD

All over the world exist different cadastral systems for land administration. The different purposes causes a wide variety in these systems. In the meanwhile some are highly developed, while others are still at the start. This chapter discusses the cadastral systems of Malaysia, the United Kingdom and Austria in order to get an impression on the differences in cadastral systems.

5.1 MALAYSIA

Malaysia is a country in the South-Eastern region of Asia. The area covers about 329,758 square kilometres and 7,2 million parcels, consisting of two parts: Peninsular Malaysia, bordering Thailand and Singapore, and a part on the island Borneo, bordering Brunei and Indonesia. Peninsular Malaysia consists of 11 states and the Bornea part consists of the states Sabah and Sarawak. Besides Malaysia has 3 federal territories. The country is populated by about 30 million people. In 1963 it became an independent federation, but before it was a colony of the British Empire. [Department of Survey and Mapping Malaysia, 2012]

In 1966 the National Land Code (NLC) was introduced in Malaysia to enable the transfer of land titles to the Torrens system. This system means that the register is the leading element in ownership. Therefore a valid and accurate description of boundaries is necessary. The Torrens system originally comes from Australia. This register records person's titles or interests after prescribed registration procedures. This person is the indefeasible owner or interest holder to the exclusion of all others. Land transfers in Malaysia can take place by alienation, dealings or inheritance. [Zulkifli et al., 2014]

On an organizational level, the Malaysian Cadaster exists of two components; the Cadastral Survey (JUPEM) and the Land Registration. JUPEM is an organization operating on national level. The Malaysian Cadaster is based on fixed boundaries. Therefore certified land surveyors are required by law to survey and demarcate a parcel in order to get a land title approved. It is up to this organization to decide the scope of survey projects and its standards of accuracy to the validity of the type of title. A survey plan need to be approved by the Director of Survey before it becomes official. Only after this approval other transactions, like amalgamation and splitting of parcels can take place [Nordin, 2016]. It is permitted in the Malaysia to let do official survey activities by certified non-government surveyors. [Chai, 2006]

The cadastral map of Malaysia is completely digitalized and it can be consulted via a geoportal. This map contain an overview of the geometry of all land parcels and their identifiers. [Chai, 2006]

The Land Registration component operates on district level by separate land

offices. Its most important element is the type of title for by the system of land tenure and the nature of Government guarantee. The Land Registration system enables the registration of indefeasible title or interest, except for certain occasions like fraud. To get a final title the Land Registry delivers Register Documents of Title (RDT). This document contains information about ownership, identification, restrictions, responsibilities and conditions. [Nordin, 2016]
Currently the RDT's are stored in the so-called eLand system. This is the successor of the Computerised Land Registration System (CLRS), which wasn't able to integrate with the system of the Cadastral Survey, the so-called eKadaster. [Nordin, 2016] Both systems are linked to each other by using a Unique Parcel Identifier (UPI). This UPI is given to every different cadastral object. [Zulkifli et al., 2014]
This eKadaster has the aim to simplify the delivery system for land title survey. Therefore survey processes follow a complete digital work flow and its data is stored in a National Digital Cadastral Database (NDCDB). This national survey database contain a spatial accuracy of less than 5 centimetres in urban areas and less than 10 centimetres in semi-urban and rural areas. This accuracy is achieved by the development of a dense control infrastructure grid of 0.5 km spacing in urban areas and 2.5 km spacing in rural areas. This infrastructure uses lease square adjustments and GPS positioning on GDM2000 geocentric datum. [Department of Survey and Mapping Malaysia, 2012]
Currently the land administration system in Malaysia doesn't support full history management.[Zulkifli et al., 2014]

5.2 UNITED KINGDOM

United Kingdom is a country subdivided into four constituent units; England, Scotland, Wales and Northern Ireland. All together they cover an area of around 242.495 km2. The population of the United Kingdom is around 64 million people. [Eulis, 2008]
The registry of land in the United Kingdom is a task of the HM Land Registry, however the country doesn't have a Cadaster. It have never been invaded by Napoleon and currently there is no public interest to introduce such a system due to its high costs. The expenses of the Land Registration system are fully covered by the revenue from their services and they don't get any governmental funding. The main goal of the land registration system is to support the efficient operation of the land market by facilitating low cost, reliable transfers of land and therefore protection of property rights. [Grover, 2014]
The Land Registration in the United Kingdom is since 1926 on compulsory basis and is based on title registration. This registration includes a property register, a proprietorship register and a charges register. The property register identifies the location and the extent of land and the rights that benefit the land, supported by a title plan. The proprietorship register specifies the quality of the title, the names and addresses of the legal owners, restrictions on land and the sum of money reported to have been paid by the current proprietor. The charges register describes details of mortgages and financial burdens. [Grover, 2014]
There are no fixed boundaries, but general boundaries. The position of

these boundaries are described by text. In the title plan the boundaries are described by their relation to physical features on the ground displayed on a Ordnance Map. The ordnance map contain around 440 million individual objects. The government doesn't guarantee private boundaries and there is no involvement of the private sector in the Land Registry system. [Eulis, 2008]
Land registration is the responsibility of three different regional bodies. For England and Wales, this is the Land Registry and in Northern Ireland this is organized by the Land & Property Services. In Scotland land registration is the responsibility of Registers of Scotland, which maintain 14 registers, including the Register of Sasines and the Land Register. [Grover, 2014]
Mapping and surveying is the responsibility of the governmental organization Ordnance Survey, which was originally a military organization and later switched to civil service. This organization maps the official boundaries of public bodies, but no private boundaries. They maintain there data in a Master map geo-spatial database. They have the only surveyors in the country. [Grover, 2014]
Boundaries in the United Kingdom are described by the metes and bounds method. This method used physical features together with directions and distances to describe the boundaries of a parcel. When an owner want to sell a part of his parcel, he is responsible for describing the newly created boundaries in words. Therefore inaccuracy is commonly appearing since this work is done by laymen. Nevertheless the buyer need to do research to it, since the principle caveat emptor (let the buyer beware) applies. Theft of land is not covered by law in Great Britain. [Maynard, 2015]
There are different ways in the United Kingdom to describe new boundaries. At first by single building plots along the road where its depth back from the road is given. The purchaser is required to mark the boundaries by fences. A second method occurs when a single person buys a large area. In this case a reference to the field numbers of the Ordnance map is used. Its boundaries where identified as the boundaries of the parcel. Although on the map they only represent physical features. In another occasion boundaries can be described by a reference to the development plan and when a small area of a parcel is transferred to an adjoining parcel, this is described by demarcation. [Maynard, 2015]

5.3 AUSTRIA

Austria is located in the centre of Europe and it adjoins 8 different countries. It is a member of the European Union. The size of the country is around 83,878 km2 and it has a population of circa 8,5 million people. [Eulis, 2016]
Since 1817 Austria raises taxes on real estates. This taxation was the first systematic registration of parcels based on field survey covering the entire country, for which a national Cadaster was founded. Currently this Cadaster has a full coverage of the country with about 2,6 million real estates and around 10,5 million parcels. [Eulis, 2016]
The system is based on 'title registration'. This means that the owner, registered in the land register, has the public trust of being the owner of a parcel. Parcels are mainly defined with fixed boundaries. These boundaries are marked by monuments and their coordinates are measured in national coordinates and depicted on the cadastral maps (numeric Cadaster). Surveys of

boundaries are described in survey documents. These surveys can only be executed by certified land surveyors, who are specifically educated. Their delivered survey documents need the approval of the national Cadaster before become official. [Zevenbergen, 2002]
The Land administration in Austria involves two different systems; the Land Registry System (Grundbuch) ad the Cadaster (Kadaster). In the Land Registry System all legal data for real estate is stored. A legal registered entity is identified by a property number consisting of one or more parcels. Per entity information about the object, the owner or ownership and information about rights, restrictions or responsibilities is stored [Schennach, 2014]. Only this system is considered to have valid data about property rights and therefore it is important to be kept up-to-date. Changes can only be accomplished by a notary deed. [Eulis, 2016]
The Cadaster system is an organization of 41 Cadastral Offices. These offices are responsible for the registration and maintenance of real estate, in specific land. Since the establishment of 'Cadaster of boundaries', Austria guarantees the geometry of parcel boundaries. This 'Cadaster of boundaries' means that boundaries are not sensitive for prescription. In order to achieve this, a qualitative attribute is added that secures the rights of the boundaries. This attribute requires a precise survey of the boundary lines of the entire parcel and the agreements with the owners of adjacent parcels. Currently 8 procent of the parcels have been converted to the boundary cadaster and parcels of both types of cadaster are displayed on the same cadastral map. [Zevenbergen, 2002]
The land Registry System and the Cadaster System are independent organizations, but share a common database. This database exists since 1980 and it combines the information of both systems in one digital format, replacing the analogue cadastral registration. It is accessible via web based services. Since 2012 there exists different parts for land registration and cadastral surveys, which both are updated simultaneously. This database contains basic register units, like cadastral unit identifier and parcel identifier, and cadastral attributes like area of parcel, address of parcel and boundaries of parcels. [Schennach, 2014]
In general the current information about real estate in the database is available for public. Searching by its ID, information of real estates are presented in pdf or HTML files. Nevertheless it is able to restrict information to specific owners or to a specific part of the information. Besides the system enables searching for historic data as well on address, name or by the cadastral map. [Muggenhuber et al., 2011]
Analysing the Austrian Cadaster, it turns out that it works properly, but its expenses of the system are very high to maintain it. Further it is quite bureaucratic and relatively slow. The cadastral organization is over-decentralized by the many local cadastral offices. This system is less applicable on countries, which are less used to good corporation between organizations. [Zevenbergen, 2002]

6 REQUIREMENTS

For the development of a data model it is an unavoidable step to define requirements. These requirement form the guideline to achieve the main goal of a research. There are several ways to define requirements for a data model depending on what actually need to be solved, for example a market operation to indicate the missing needs of users or organizing brain storm sessions with stakeholders [Lemmen, 2012]. This research will derive its requirements via a preliminary investigation on the internal work flow of the Kadaster. In an ideal situation the data model meets all the requirements. Although there is a certain hierarchy in the impact of requirements on the project. Some requirements take precedence over others. This distinction is made by a MoSCoW analysis, which will be discussed at the end of this chapter.

6.1 REQUIREMENTS

Requirement 1: The NLSRDM is the link between all spatial sources and the Dutch cadastral map.

In the chapter *Survey data and cadastral mapping at the Kadaster* it is explained that many survey methods have been used over time. In some cases boundaries are measured multiple times or have additional spatial information, for instance a boundary reconstruction. The measured spatial data is adjusted to the map according to a certain protocol in order to fit the cadastral objects correctly with respect to the cadastral environment. This results in a deviation between the location of cadastral objects in the Dutch cadastral map and the original survey data. Due to legal aspects, it is however important to record how a boundary is constructed. An additional reason is the more and more fragmented relation between survey data and the Dutch cadastral map, caused by cadastral dynamics.

Figure 6.1: The data model have to be the link between spatial sources and the spatial units in both directions

This makes original survey data of (partly) expired cadastral boundaries still relevant for the Kadaster. The survey data of an expired cadastral boundary is currently not traceable via the Dutch cadastral map; There is no automated link to all relevant survey data on a certain boundary. Therefore the NLSRDM has to give a complete overview of all survey data related to a certain spatial unit in the Dutch cadastral map, including all above mentioned aspects. In the opposite way the NLSRDM has to be the link as well from the spatial source to the Dutch cadastral map in order to see which cadastral object is described by a random survey document. This is depicted in figure 6.1.

Requirement 2: The NLSRDM considers boundaries as own entities.

Currently the Dutch cadastral database can be traversed via by municipality number, section number and parcel numbers or archive numbers, written on spatial sources. There is no option to search through the cadastral database via other relevant cadastral information. This makes the quest for this data complicated, since changes in the cadastral situation generates new parcel numbers and extra spatial sources. This results in an additional step in the search process for other relevant data, like survey data of a boundary. The parcel based approach seems therefore not the best solution for the Kadaster. The parcel based approach has its origin in the fact that the Kadaster administrates properties and not the boundaries. For a solid spatial description of a property an increasing amount of survey documents need to be consulted and since the survey data is not unilateral related to the cadastral boundaries, searching and interpreting the spatial sources requires expert knowledge.

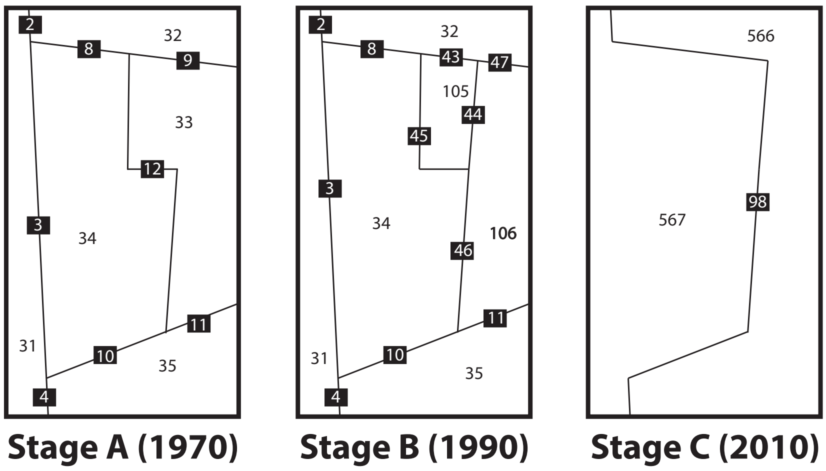

Figure 6.2: Considering cadastral boundaries as own entities

The solution would be to let the Dutch cadastral map index as well the boundaries of parcels (see figure 6.2). This enables detection of a certain boundary and its survey history at a glance. This solution is described in [Lemmen, 1995] and partly implemented in the KPV. In this system all boundaries have an unique ID. Further it contain the attributes shape (metric information), adjacent boundaries and parcels, a bounding box and time stamps [van Oosterom, 1997]. However the ID of the boundary is not applicable beyond KPV and able to link the specific survey data for a boundary to it. Further contains the cadastral database more elements then only boundaries; other present line elements are auxiliary lines and topography, which are relevant survey data. The identification of cadastral boundaries in the current KPV system exists of the parcel numbers of their left and right side. However in some cases this leads to confusion, as it is demonstrated in figure 6.3. In case 1 new parcels are created, while the geometry of the encircled boundary doesn't change at all. In case 2 two encircled boundaries have both similar adjacent parcels, but are actually different boundaries them selves. These two cases proves that the KPV method for identification is not optimal. Nevertheless, if an ID of a boundary doesn't have a relation to its cadastral environment, this will decrease the ability to verify errors. A consideration which have to taken into account in the NLSRDM.

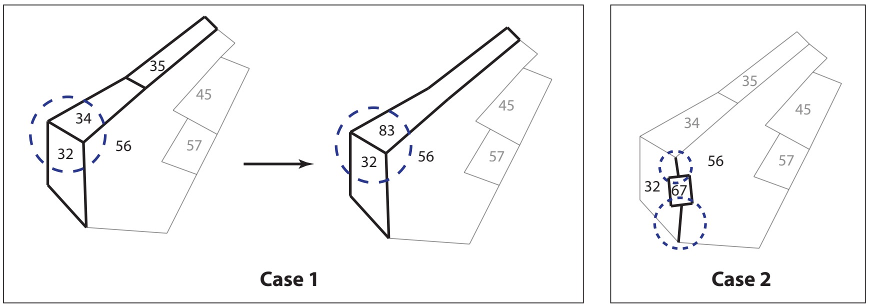

Figure 6.3: Two cases of confusing boundary identification by parcel number

The NLSRDM have to consider boundaries as own entities in the cadastral database. Then the survey data can be unilateral linked to it. This will remove ambiguity in the cadastral database and will store the survey information at the place where it actually belongs; the boundary.
Nevertheless this causes some issues, for instance how to handle the the split of cadastral boundaries, when a new boundary is created. In this new situation there are two child boundaries, which relate to one similar parent boundary. An example in figure 6.2 are child boundaries 45 and 46, which must relate to parent boundary 12. On the other hand different cadastral boundaries could also merge into a single new one. In this case the NLSRDM have to maintain the relation between both different spatial sources. An example in figure 6.2 is boundary 98, which is related to boundary 2, 8, 43, 44, 46, 10 and 4. A benefit of this approach is the possibility to implement the description of geometrical relations between boundaries and reference to other objects. At the Kadaster boundaries are often described by their distance to other boundaries or topography, as it is demonstrated in figure 6.4. In addition the status of unique boundaries can be described. In

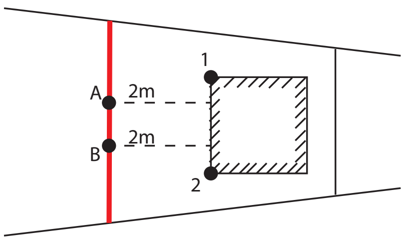

Figure 6.4: Boundary described by distance from a building façade

the Dutch cadastral map boundaries described the edge of a parcel. Some of these boundaries indicates as well the edge of a municipality, province or country. In figure 3.8 it is demonstrated how these special boundaries are noted on field sketches. The status of these boundaries appear in a hierarchy; A national boundary is by definition a province boundary and a province boundary is by definition a municipality boundary [van Oosterom and Lemmen, 2001]. Another special category in boundary status is the Voorlopig Kadastrale Grens, which do not have a survey source, but only a legal source. They are indicated in the Dutch cadastral map by a red line. Further the data model could tell which edges of buildings are also defining a boundary of a parcel. This situation is depicted in figure 6.5.

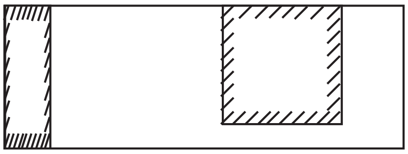

Figure 6.5: Building boundaries could also be part of parcel boundaries

Further this approach enables to relate attributes to the boundaries between parcels. The parcel approach leads to data redundancy, since boundaries are stored in both parcels and it results in inconsistencies like gaps and overlap. [van Oosterom and Lemmen, 2001]

Requirement 3: The NLSRDM considers points as own entities.

Following the consideration of boundary entities the NLSRDM have to differentiate points in own entities; There are many different points present in the Dutch cadastral system; control points, topography points, auxiliary points, survey points and intersection points. These different points have different functions and some of them are related to other points, for instance to define a boundary (survey points and intersection points, while other are individual points (control points). All these different points are relevant for survey data in various ways. A distinction in these points is therefore beneficial to the storage of survey data.

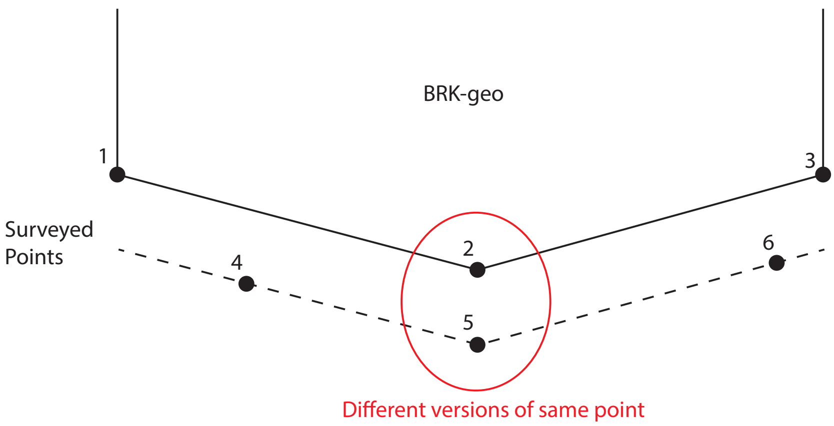

Figure 6.6: Different versions of a same point.

As it is explained in the chapter *Survey data and cadastral mapping at the Kadaster*, it is important to realize that some survey points and their related intersection do not describe the same point. This occasion appears at start and end points of a surveyed boundary. An example is demonstrated in figure 6.6, where point 4 is the surveyed point and point 1 is an intersection point. This is different for middle points where the surveyed point describes the same point as it is depicted on the Dutch cadastral map. In figure 6.6 this is demonstrated by surveyed point 5 and cadastral map point 2. In some cases different points turn out to describe an identical point in space when they are described on two different spatial sources. Further the NLSRDM have to take into account that in some cases the KAD1 are so accurate that they don't need to be further adjusted. In this case the KAD1 data is declared as being KAD2 data as well.

Requirement 4: The NLSRDM is suitable for the various survey methods at the Kadaster.

All the different survey methods used by the Kadaster over time describes spatial data in a different way. Nevertheless in the end they are all based on the principle of COGO, but they have different expressions for the different survey methods. Some are expressed in coordinates and their position in relation to satellites, other spatial data are described by distances and bearings, related to near topography or control points. This result in many different sorts of data. Only an ID, year of measurement and some other shared meta data are common data on every spatial source. Therefore the NLSRDM have to enable the implementation of all the different spatial sources and spatial data. Special attention need to be paid on the process of making analogue spatial sources digital readable. This is a delicate, but inevitable step. Methods for automated field sketch scanning is out of the scope of this research, but the NLSRDM have to facilitate registration of the status in relation to this process, something like processed or not processed.

Requirement 5: The NLSRDM maintains the topology of cadastral objects.

The spatial sources of the Kadaster do not only describe spatial data in a geometrical way. They also reflect the relative position of spatial units to other cadastral objects. By sketches, it is clearly indicated what the left and right neighbours of a boundary is (see figure 6.7).

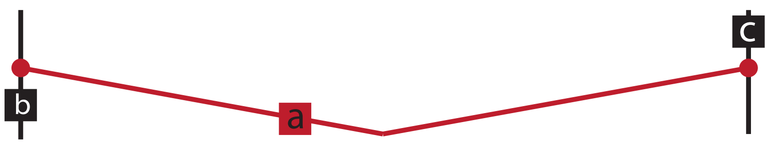

Figure 6.7: Topology: Boundary A adjoins boundary B and C

This is important information, since there exists more surveyed versions of a cadastral boundary. It is told in this research that some map improvement have taken place [Hoekstra, 1997] and that more map improvement is necessary to achieve similar quality between the survey data and the Dutch cadastral map. This means that boundaries will move with respect to each other. In that case it would be a solution to store the left and right parcel, the left and right adjacent boundary at the start en end point of a boundary [Thompson et al., 2016]. A consideration would be to store all the geometrical information at point level and further create a topological model, which refer points to other points in order to create boundaries and parcels. The main advantages of this approach is a reduction of cadastral data storage and consistency in the Dutch cadastral map. [Thompson et al., 2016]

Requirement 6: The NLSRDM registers the quality of cadastral objects.

The different used survey methods of the Kadaster do not only provide different descriptions of spatial data, they also have a different quality. Analogue spatial sources described survey methods with chains and measure tape. The only information is an auxiliary line which indicates a distance from topography to the boundary. In many cases this topography and/or boundaries are described by features in the field, like ditches or walls. However a ditch is 2 meters wide and a wall around 30 centimetres

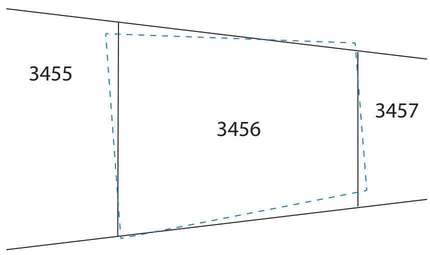

Figure 6.8: Differences of the parcel in the Dutch cadastral map and the surveyed parcel.

Nevertheless analogue spatial sources do not have a similar accuracy as modern techniques, like GPS and a tachymeter. These are described by their 'puntprecisie' (*point precision*), this means the relative precision of coordinates of points as result of the total survey- and processing procedures. The quality is expressed in a standard deviation. When spatial data is implemented in the Dutch cadastral map their position is adjusted to the surrounding topography.

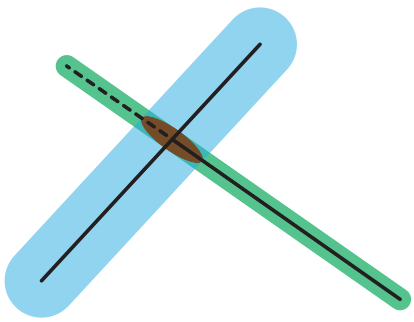

Figure 6.9: Accuracy

This 'idealisatie precisie' (*idealisation precision*) can never be more accurate than the idealisation precision of the related topography [Polman and Salzmann, 1996]. Although it results that the surveyed parcels deviate from the parcels in the Dutch cadastral map (see figure 6.8). Representing the quality of survey data is a complicated topic and a complex job for the NLSRDM. At least NLSRDM have to take quality into account and facilitate all different quality descriptions of survey data. Besides it have to contain a manner of for a harmonized quality description of spatial units in the Dutch cadastral map. A possible solution is drawn in figure 6.9. Reliability strips, which indicate the precision, can be drawn of the separate cadastral boundaries. The quality per intersection point can then be derived by an ellipse. This ellipse describes the quality by both the standard deviation of the intersection boundaries and their angles compared to the north for orientation. An improvement to the Dutch Kadaster is the harmonization of quality descriptions.

Requirement 7: The NLSRDM uses ISO standards as much as possible.

ISO standards are used all over the world for many geographic issues. Using standards will make geographic issues clear for more people and they offer solutions for specific cases. Standardization is important component in the field of land administration, which can cover a complete cadastral organization. It involves work flows, documents, persons, organization of tables, interaction between tables, coding of administration. A standardized model in the land administration domain leads to the *establishment of a shared ontology*, it supports *the development of the application software for land administration*, it facilitates *cadastral data exchange with and from a distributed land administration system* and it supports *data quality management in land administration*.[Lemmen, 2012]
For land administration there exists the ISO standard LADM [ISO 19152:2012]. The NLSRDM has to use this ISO standard as a template for its own design. The question will be, which solutions offers the LADM for the Kadaster and the data model? And in which way can it be implemented in the NLSRDM? The implementation of this template must not only be focussed on the structure of LADM. Standardized terminology is of similar importance since it stimulates the understanding of the NLSRDM. Therefore the data model have to strive to transform specific Dutch cadastral terms into standard terms, defined in the LADM. If the LADM doesn't provide the correct terms, other ISO standards need to be consulted. Some of the Dutch cadastral terms have clear standardized equivalents. Others will loose too much of their meaning or there is not even a related standard term available. In this case these specific Dutch cadastral terms will be maintained in the model.

Requirement 8: The NLSRDM enables history management.

The Dutch cadastral map exists of many cadastral boundaries, which are measured at different moments in time. The survey data of these boundaries are noted on different spatial sources. As it is explained in chapter *Survey data and cadastral mapping at the Kadaster*, this survey data can be traced via parcel numbering. This is a time-consuming system. Further a part of these boundaries disappear as well at a certain moment in time, although they are still relevant, as they are a part of existing boundaries. In requirement 2 it is stated that boundaries have to be assumed as own entities, but in addition to this a temporary aspect need to be added. This can achieve by giving each boundary a t_min and t_max attribute [van Oosterom and Lemmen, 2001]. Each boundary has then at least a t_min value, expressing the day this boundary is added to the Dutch cadastral map. If there is no t_max value, this means that the boundary is still present in the Dutch cadastral map. If there is a t_max value, this means that the boundary is expired. This system of a t_min and t_max enables intuitive search through the history of cadastral boundaries.

Requirement 9: The NLSRDM incorporates COGO data.

As it is explained in chapter *Survey data and cadastral mapping at the Kadaster*, there are various ways to describe boundaries. For instances via coordinates, via relation to topography or via angles and distances. All these survey data are noted on spatial sources. COGO software is the data conversion process from written descriptions to a digital map. These written descriptions are different in sort, like a combination of angles and distances to specify a point, angles and bearings to specify a point or distances from two points to specify a point. This requirement reflects the consideration to implement COGO in the NLSRDM. [Autodesk AutoCad Map 3D, 2017]

Requirement 10: The NLSRDM refers the survey data to either topography or cadastral boundaries.

In the survey data at the Kadaster many of the cadastral boundaries are described by their relative position with respect to topography, like corners of buildings, walls or ditches. Therefore topography is an essential element in survey data. The NLSRDM have to enable to store this topography and to relate the cadastral boundaries to its topography. Special attention in this need to be paid to the idealisation. The idealisation precision of cadastral boundaries can never be more precise then the idealisation precision of the related topography. A simple start of this would be to add a selection code, which mentions geographic data as topography or cadastral object. [van Oosterom, 1997]

Requirement 11: The NLSRDM incorporates 3D cadastral data.

As it it explained in the preliminary investigation of this research, the cadastral database is 2D-based. Properties, which are located on top of each other, like apartment complexes, have in fact a 3D component. Currently these case are solved by adding extra notifications in the floor level parcel. However there is research taken place, which has the aim to implement 3D data as 3D data in the cadastral database [Stoter et al., 2016]. Therefore the NLSRDM have to take this development into account by making the data model adaptable to these new situations.

6.2 MOSCOW ANALYSIS

In order to set priorities in the requirements, the MoSCoW analysis is used. This method is often used by projects of software engineers. The MoSCoW analysis divides requirements in four different categories, which are pro-

cessed in its name. The categories are *must have*, *should have*, *could have* and *won't have*. [Wikipedia, 2008]
The requirements of the *must have* category all have to be implemented in the system. If one is not, the project is assumed as failed. The requirements of the category *should have* are very important for the success of a project, but the project is not assumed as failed if these requirements are not implemented. The category *could have* is for requirements, which are desirable for the project, but not necessary. These requirement could improve the project, but are excluded by a lack of time and resources. The last category of requirements is the *won't have* category. This category indicates the requirements which are assumed as not appropriate for the project at that time. [Wikipedia, 2008]
The requirements of this research can be placed in the following categories:

'Must have' category

- *Requirement 1: The NLSRDM is the link between all spatial sources and the Dutch cadastral map.*
  This requirement covers the main goal of the research.

- *Requirement 2: The NLSRDM considers boundaries as own entities.*
  This requirement reflects the main encountered issue in the preliminary investigation. In the KPV boundaries are already an own entity, this model tries to achieve this for the entire cadastral system due to its benefits.

- *Requirement 3: The NLSRDM considers points as own entities.*
  The survey data of the Kadaster involves many sorts of points, which all have a different role. If a more intimate relation between survey data and the Dutch cadastral map needs to be achieve. It is unavoidable that the NLSRDM takes points as own entities into account.

- *Requirement 4: The NLSRDM is suitable for the various survey methods at the Kadaster.*
  The different survey methods result in different survey data. If the they all need to be linked to the cadastral objects, it is necessary to enable the link for all these survey methods.

- *Requirement 8: The NLSRDM enables history management.*
  The cadastral database is dynamic, but all survey documents are still relevant for current objects and for the legality. Proper history management ensures that cadastral database can be traversed more easily. Therefore this requirement is an absolute must for the NLSRDM.

- *Requirement 9: The NLSRDM incorporates COGO data.*
  COGO is a method to process written descriptions of cadastral objects in a digital map. This method is highly applicable on the Kadaster, since its system contains analogue spatial sources, which define a digital cadastral map. Therefore it is a must to implement this method into the NLSRDM.

- *Requirement 10: The NLSRDM refers the survey data to either topography or cadastral boundaries.*
  Survey data exists of many different elements, like it is explained with points in requirement 3. it contains not only information about cadastral boundaries, but as well about topography. It is important that the NLSRDM enables to make a distinction between these different elements.

'Should have' category

- *Requirement 5: The NLSRDM maintains the topology of cadastral objects.*
  Topology is an important aspect for the Dutch cadastral map, but not unavoivable for a link to the original survey data. Therefore this requirement is placed in this category.

- *Requirement 7: The NLSRDM uses ISO standards as much as possible.*
  The LADM is however a template, which is adaptable to every country. For these adaptations other ISO standards can be used, but custom maded solutions as well. Therefore this category is placed in this category instead of the 'must have' category.

'Could have' category

- *Requirement 6: The NLSRDM registers the quality of cadastral objects.*
  The question on how to maintain the survey quality in an unilateral way in the Kadaster is a research by itself. It is important for a better link between survey data and the cadastral map and the NLSRDM have to take the future implementation of quality descriptions in account.

- *Requirement 11: The NLSRDM incorporates 3D cadastral data.*
  Due to the fact that 3D implementation is still in an experimental phase and relevant for the future of the Kadaster, there is still too less decided on how to this should be implemented. This creates too less basis for implementation in the NLSRDM. Nevertheless it should be kept in mind that the NLSRDM in the future should be adaptable for these future inventions.

'Won't have' category

- None

7 DEVELOPMENT OF THE DATA MODEL

7.1 INTRODUCTION

This chapter will present the design of a data model, which attempts to cover all the stated requirements according to the MoSCoW analysis. This data model is called the Dutch Survey and Representation Data Model NLSRDM and it will use the sub package *Survey and Representation* as template for its design. Designing a data model for this research is a complex operation, which involves a lot of processes and objects. Although the strength of a proper data model is to keep it as simple as possible to keep it understandable and feasible. A simple data model can support complex data processes. However a complex data model doesn't solve per se a complex data process. In order to simplify a data model to a simple structure several considerations have to be taken.
The benefit of using a part of the LADM as a template is that it contains already solutions. This chapter will discuss which of these solutions are applicable on the Kadaster and which one are not. Specific challenges of the Kadaster requires specific adaptation and addition of the LADM template. These changes represent different approaches. This chapter will consider the approaches for the NLSRDM. The design of the NLSRDM will be created in UML. This chapter will first explain how UML works.

7.2 HOW DOES UML MODELLING WORK?

For the development of a data model, the class diagram of UML modelling will be used. This diagram is built up by square blocks, representing the different classes. Classes are a template for an object. There exists also abstract classes without an instance. They are a base class, where the other classes inherit from. Abstract classes are marked by an italicized class name.
Classes consist of three parts; *a class name*, *attributes* and *operations/methods*, as can be seen in figure 7.1. In some cases a fourth part *constraints* is added.

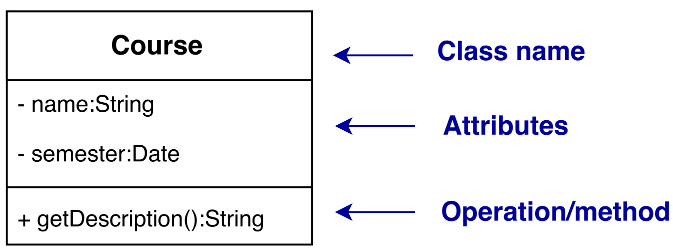

Figure 7.1: An example of a class, after [Miller, 2004]

It is optional to add a *stereotype* to the class. A *stereotype* is written in the format <<stereotype>>. *Stereotypes* extend the semantics, but not the structure of pre-existing UML elements (classes, attributes, operations, constraints, associations, roles, packages). There exist many different *stereotypes*. In table 7.1 the *stereotypes*, appearing in the LADM, are explained;

stereotype	Function
<<datatype>>	Classifier, which instances are identified by only their values.
<<featureType>>	A spatial object type.
<<code List>>	Identifier of collections of enumerated values that may also have relationships .

Table 7.1: Different stereotypes

The information about an object is stored in the *Attributes* and *operations/methods* describes the behaviour of an object. They are described in the form: *<access ><specifiername >(<parameter list >): <return type >*. The access could be specified as *public (+)*, *private (-)* or *protected(#)*. [Miller, 2004]

The classes are connected by associations. These relationships are in some cases labelled to clarify the relation and have in general one or two arrows to show the direction a relationship can be traversed or queried. This is the so-called *navigability*.
At the edges of connecting optionally several elements are mentioned, as can be seen in figure 7.2. At first the role clarifies the nature of a relation. Further a *constraint* (written in the format {constraint description}) is a condition that every implementation of the design must satisfy. It is optional to add this *constraint* to a class or an association. At every side of an association numbers are written which indicates the *multiplicity*; the number of possible instances of a class associated with a single instance of the other end. [Miller, 2004]

Figure 7.2: Notation for associations, after [Ambler, 2004]

Multiplicities are single numbers or ranges of numbers as can be seen in table 7.2. [Miller, 2004]

Multiplicities	Meaning
0..1	zero or one instance. The notation ***n..m*** indicates ***n*** to ***m*** instances.
0..* *or* *	no limit on the number of instances (including none).
1	exactly one instance
1..*	at least one instance

Table 7.2: Examples of different multiplicities

Different arrows and lines suggesting different types of association, as can be seen in figure 7.3. [Miller, 2004]

- *Association* is the most general link between two classes, the nature of the relationship is sometimes identified by a label and the involved classes with a role name.

- *Aggregation* is a relationship in which one class belongs to a collection. There is also an option self-aggregation.
- *Generalization* is an inheritance link indicating one class is a superclass of the other.
- *Composition* is a strong association in which the part can belong to only one whole. the part cannot exist without the whole.
- *Dependency* is a relation between two classes in which a change in one may force changes in the other.

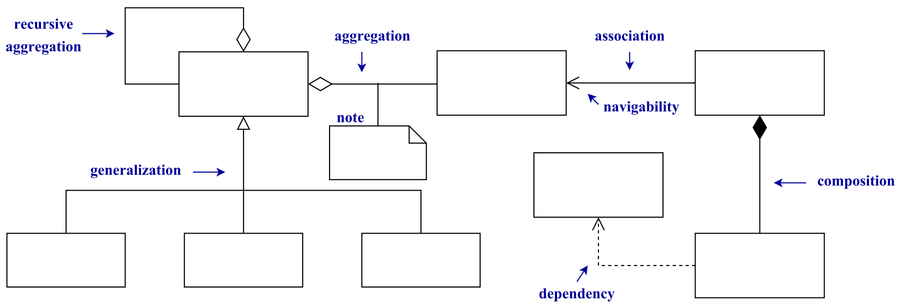

Figure 7.3: Different relationships between classes

Besides all the classes, the additional element *note* can be placed in the data model. A *note* is a text inside a dog-eared rectangle, which clarifies a certain element of the data model. [Miller, 2004]

7.3 THE SUBPACKAGE *survey and representation*

As a starting point of Dutch Survey and Representation Data Model the sub package *Survey and representation* will be used as template. This sub package is part of the package SpatialUnit. An overview of the sub package *Survey and Representation* is given by the figure B.2. This sub package is built up by four different classes; LA_SpatialSource, LA_Point, LA_BoundaryFaceString and LA_BoundaryFace. They all adhere to ISO/TS 19103 stereotype class featureType [ISO 19152, 2012].
The LA_SpatialSource class is a subclass of the more general abstract class LA_Source, as it is demonstrated in figure B.5. LA_Source has a second subclass, called LA_AdministrativeSource, which represents the deeds or other legal source documents. The spatial sources are represented by LA_SpatialSource of survey projects. Further is LA_SpatialSource related to the class LA_Party, which represents the involved land surveyor of a survey project and all stakeholders at the 'aanwijs' (*designation*). [ISO 19152, 2012]
An unique aspect of the LA_SpatialSoure with respect to the other class of the sub package *Survey and Representation* is that it not inherits to the superclass *VersionedObject* (see figure B.4). Survey data updates the cadastral database, but are a single event by itself. LA_SpatialSource is associated directly to all other classes of the sub package and as well to the class

LA_SpatialUnit. By the multiplicities of the different associations it is defined that an instance of LA_SpatialSource is at least associated to an instance of LA_Point. Otherwise a source wouldn't contain any information and is it no source. Together with LA_Point, LA_SpatialSource represents the survey part of the sub package [ISO 19152, 2012].
LA_Point represents the spatial data on the spatial sources. It inherits to the superclass *VersionedObject*, which enables to store multiple versions of a points, like the transformation to another coordinates system. The association to LA_SpatialUnit enables the representation of parcels by only one point in the parcel. [ISO 19152, 2012]
LA_BoundaryFace and LA_BoundaryFaceString are the representation part of the sub package Instances of LA_BoundaryFace are faces in a 3D environment and instances of LA_BoundaryFaceString are line strings consisting of two or more points. In both classes instances could be defined by geometry or text. Their associations with LA_SpatialUnit represents the left and right side of the spatial unit.
In the end all associations of the sub packages lead to the class LA_SpatialUnit. This class has a child-parent aggregation to itself; a parcel could be part of a cluster of parcels. Further it has a second self-association, explained by the class LA_RequiredRelationshipSpatialUnit. [ISO 19152, 2012]
Several attributes in various classes uses components from other standards, like the use of GM_Point and OM_Observations. The sub package is designed in such a way that it could be applicable on multiple cadastral cases. In the next part of the chapter the implementation of the sub package *Survey and Representation* on the Dutch cadastral system is explained.

7.4 THE DESIGN OF THE DUTCH SURVEY AND REPRESENTATION DATA MODEL

7.4.1 The general structure

The design of the Dutch Survey and Representation Data Model is demonstrated in figure 7.4. This data model is highly related to the design of the sub package *Survey and Representation*. This sub package is depicted in appendix B.2. This chapter will explain per adaptation/addition its consideration for implementation.
The classes in the sub package *Survey and Representation* correspond to a certain extent to the components of the Kadaster. These components are spatial sources, points, lines and parcels. Nevertheless in the Kadaster 3D objects are not represented as volumes [Stoter et al., 2012]. Therefore the class LA_BoundaryFace is omitted in the model.
The other classes are implemented and since they apply on the Kadaster they will be marked by the prefix NL_. This results in four different classes, including NL_Parcel. NL_Parcel is related to the LADM class LA_SpatialUnit. The benefit of this structure is that it creates overview of the presence of the different objects in the Kadaster. In every class the instances are identified by an unique ID number. This number exists of the datatype Oid. Oid is built up in two parts; the localId and the namespace. The localId is a character string given by the data provider and should unique. The namespace is a character string too and identifies the data source of an object [ISO

19152, 2012]. This identification turns every instance (point, source, line, parcel) in the sub package into an individual entity. Related instances like 'vereffende' (*adjusted*) points got a same Oid. These are separated by the superclass *VersionedObject*, which gives every instance a time span by the attributes beginLifeSpanVersion and endLifeSpanVersion. The values oid and endLifeSpanVersion are the unique identifiers for every object in space and time [van Oosterom, 1997].

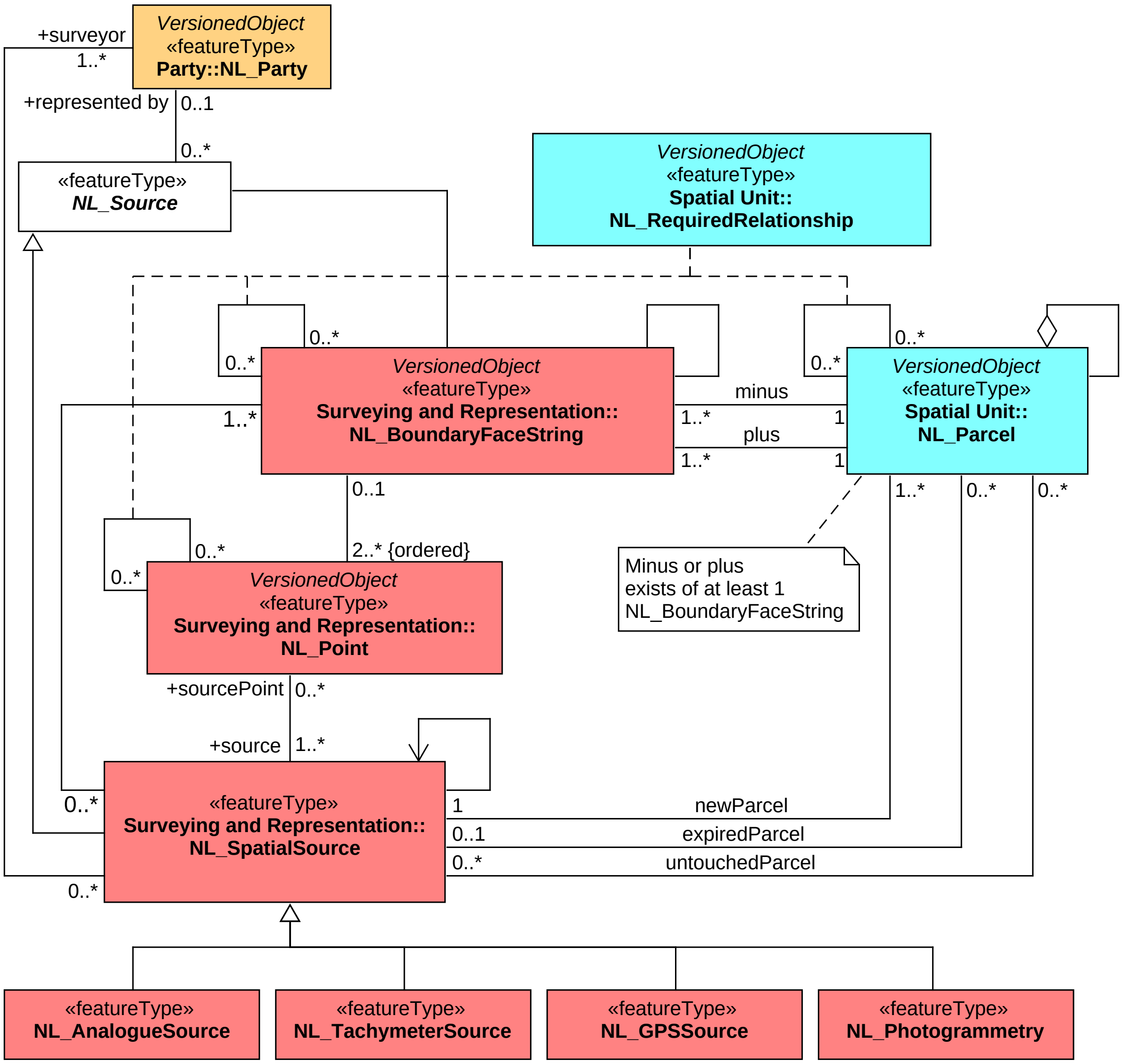

Figure 7.4: The Dutch Survey and Representation Data Model

In an simple situation, cadastral objects are built up by points, which forms lines. These lines forms parcels. This composition is demonstrated in figure 7.5. This topological structure is common for a part of the Dutch cadastral sources, especially on analogue spatial sources. Nevertheless in other cases, a cadastral boundary is described by two random points on this boundary, as it is demonstrated in figure 7.6. In the Dutch cadastral map these random points are extended till they intersect with other boundaries. This results in intersection points, which defines a cadastral boundary together with mid points. The situation appears in many cases. This situation is always the case for current survey techniques, but on analogue spatial sources this appears as well.

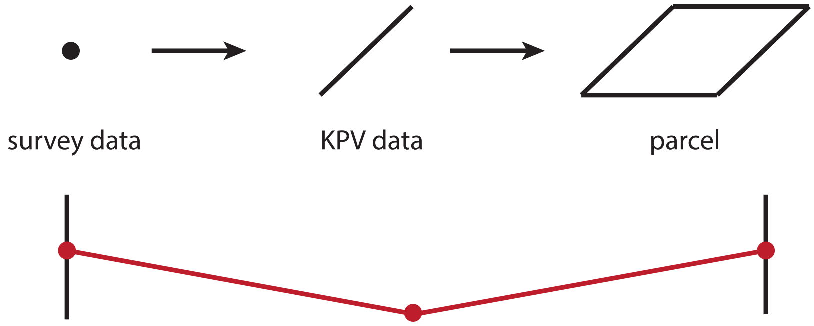

Figure 7.5: The simple composition of cadastral boundaries

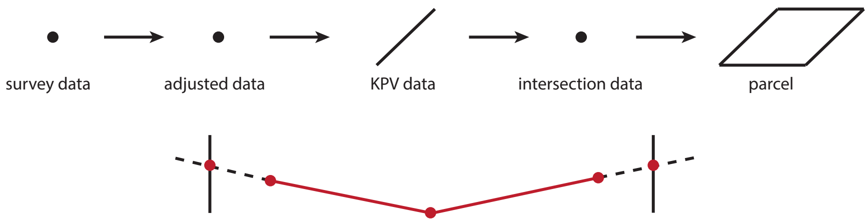

Figure 7.6: The composition of cadastral boundaries manner 1

The sub package *Survey and Representation* allows text based descriptions of spatial units. Since such descriptions are not appearing in the Kadaster, this ability is omitted in the NLSRDM. The NLSRDM have some changes specific related to classes. In the next sections these changes are discussed.

7.4.2 NL_Source

In the sub package spatial sources are represented by the LA_SpatialSource. This is a subclass of LA_Source (see figure B.5). The other subclass is LA_AdministrativeSource, which represents the deeds [van Oosterom et al., 2011]. LA_Source represents general data of a source, like specific dates (acceptance, lifeSpanStamp, recordation and submission) and the CI_PresentationFormCode. This is a code list from the ISO standard 19115 [ISO 19152, 2012], which contain values like documentDigital and documentHardcopy. Further the extArchiveID represents the ID of a source in an external registration and the sID is the identifier of the source. Both are described by the value Oid. In the NLSRDM this is turned into the class NL_Source. The spatial sources of the Kadaster contain only the year of 'aanwijs' (*designation*) and a 'dienstjaar' (*year of service*). Later spatial sources also contained the month (and day) of 'aanwijs' (*designation*). The format of the spatial sources could be represented by the CL_PresentationFormCode. In some occasions a spatial source could be partially digital and partial on paper. Therefore this attribute could have more than one option. The extArchiveID can be used for the 'archiefnummer' (*Archive Number*) and the sID for an separate ID in the data model.

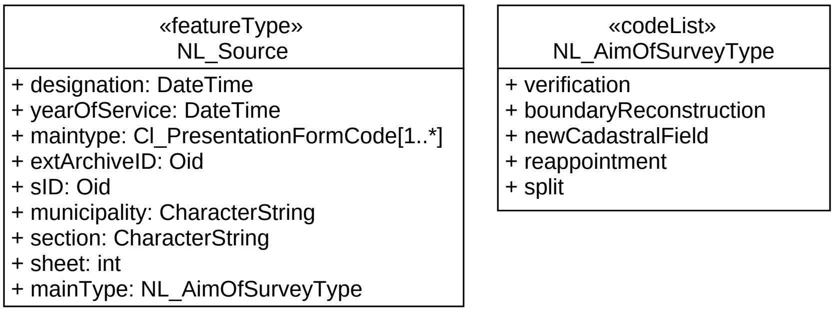

Figure 7.7: The class NL_Source

Additional required elements are the municipality, the section letter, sheet number, the new created parcel numbers and the expired parcel numbers. In the BGT there exists a special coding for municipalities. It would be a must to implement these in the system. However the Kadaster administrates cadastral municipalities, which deviates from the BGT coding. Further the aim for a spatial source need to be mentioned by the code list NL_AimOfSurveyType. This code list has the values verification, split, new cadastral field, reappointment or boundary reconstruction. This result in the class as it is depicted in figure 7.7.
The involved land surveyor and the stakeholders of the 'aanwijs' (*designation*) are recorded via an association to the NL_Party class. This class is completely inherited from the LADM.

7.4.3 NL_SpatialSource

The LA_SpatialSource itself has three attributes; measurements are represented by the featureType OM_Observations, which contain temporal and quality aspects of a survey (see figure B.9). The procedure of the survey is described by the value OM_Process, like an instrument, a sensor, a human observer, etc. Both are a part of the ISO standard 19156 [ISO 19152, 2012]. A third attribute is the code list LA_SpatialSourceType explaining the survey technique used.
The quality of OM_Observation is described by DQ_Element. This is an abstract class with several subclasses describing various ways of quality, like completeness, logical consistency, positional accuracy, temporal accuracy, thematic accuracy. DQ_Element is a part of the ISO standard 19115.
As it is described in the chapter survey data and cadastral mapping, there are different survey techniques used at the Kadaster. This requires a consideration for the implementation. All different spatial sources could be

an instance of one NL_SpatialSource class, but the survey techniques have different spatial data and different quality descriptions. This would result in many different attributes with many optional none values. A better approach would be to split up all the spatial sources of the different survey techniques and let them all inherit to a general super class NL_SpatialSource. This would give a proper overview of all different survey techniques. Nevertheless it need to be remembered that spatial sources uses different survey techniques for control measurements.

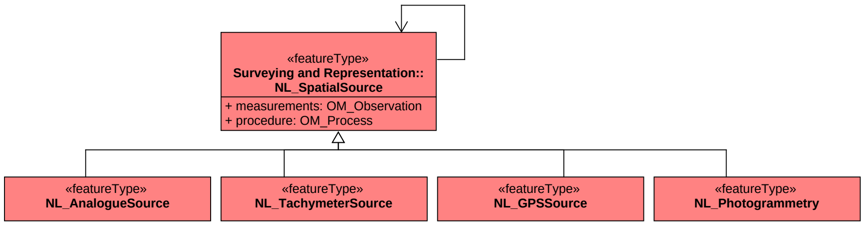

Figure 7.8: The class NL_SpatialSource

Finally the NL_SpatialSource class is considered as a superclass, which is inherited by different subclasses, representing the different survey techniques. The measurements are still described by OM_Observation and OM_Process. This is demonstrated in figure 7.8. The NL_SpatialSource class has a self association as well, since they refer to other spatial sources. Further it has three different associations with LA_Parcel; newParcel, expiredParcel and untouchedParcel. There content will be explained later.

7.4.4 NL_Point

The next class in the NLSRDM is NL_Point. This class corresponds to the LA_Point class. LA_Point has the attributes interpolationRole to describe the position of a point on the boundary, like end or mid, and the monumentation, which explains the physical appearance in the field. Both are represented by a code list (NL_InterpolationType and NL_MonumentationType). The originalLocation attribute describes the point itself by GM_Point. GM_Point describes the X and Y coordinates of a point and its coordinate reference system (see figure B.6). GM_Point is part of the ISO standard 19107 [ISO 19152, 2012]. Other attributes of LA_Point are pID, described by Oid, pointType, defined by the code list LA_PointType, the attribute aimOfPoint, describes by the code list NL_AimOfPoint and productionMethod. The last one is described by LI_Lineage. This is part of the ISO standard 19115. Further the LA_Point class contains the attribute transAndResult, which is described by LA_Transformation. LA_Transformation is a datatype with two attributes, describing the transformed point and the method of transformation. The operation GetTransResult generates a new point from the original one. The LA_Point class inherits the superclass *VersionedObject*, giving it a timestamp and a quality stamp by DQ_Element.
The Kadaster involves three different points; KAD1 points, KAD2 points and non-processed points. The NL_Point (see figure 7.9) class involves three different kind of points; KAD1 points, KAD2 points and non-processed points. KAD1 and KAD2 points are derived from modern survey tech-

niques, while there are as well non-processed points, which come from analogue spatial sources. These non-processed points are derived by the support of auxiliary points. These auxiliary points could be refer to more than one point. This situation only appears on analogue spatial sources.

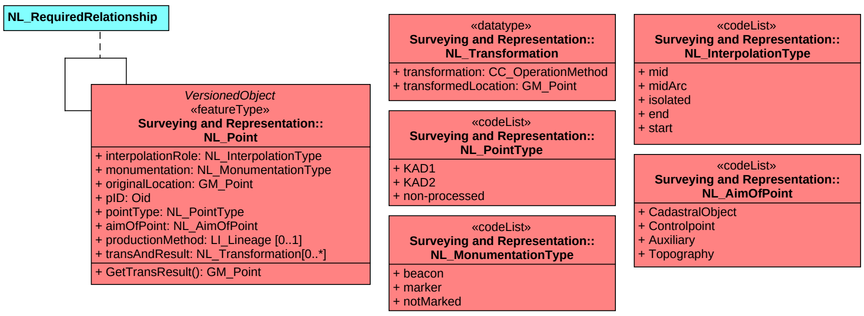

Figure 7.9: The class NL_Point

In the Kadaster there are also intersection points, which are derived by extending a boundary till it intersects with an adjacent boundary in the cadastral map. When a measured point, KAD1 or non-processed point, represents a midpoint of a boundary, they represent the same point in space in the cadastral map. If a measured point represents the start or end of a boundary, this is not the case. Therefore the attribute NL_InterpolationType defines the position of the point on a boundary by a code list. This code list could also defined if the boundary is an arc. Most of these codes seem clear, but there is a difference between the indicative point and the end and start points. The indicative point describes the points, measured by tachymeter or gps measurements, that indicate the run of a boundary. While points on analogue spatial data and photogrammetric sources indicate the real start and end point of a boundary.
The intersection points are maintained in the line string of the NL_BoundaryFaceString. In a last case a point could also be represent an isolated point in space, like a control point. The attribute transAndResult and the operation GetTransResult are used for the different stage in the 'vereffening' (*designation*). These different versions of the same instance are stored by the superclass *VersionedObject*.
Not all objects in the NL_Point class have a similar pattern. The non-processed points doesn't have a successor and not all KAD1 data have a successive KAD2 version. For instance boundary reconstructions, which are not implemented in the Dutch cadastral map. In other cases the KAD1 object has sufficient quality and is declared as KAD2 survey data without further processing.
This *VersionedObject* enables also the storage of quality. At the Kadaster the quality of cadastral objects are expressed in precision and reliability [Polman and Salzmann, 1996]. This quality depends on many aspects, which is explained in the chapter *Survey data and cadastral mapping at the Dutch Kadaster*. The precision can be expressed by one number (precision of the measure point, expressed by its standard deviation), 2 numbers (precision of the x and y coordinate, expressed by the standard deviation) or 3 numbers (precision expressed in the standard ellipse, existing of an a and b part and a φ).
NL_Point has a special self association, which also appear at NL_BoundaryFaceString class and the NL_Parcel class. The self association illustrates that different

points in the Kadaster could describe a similar point. A example for this situation is a point on two adjacent spatial sources.
The meaning of the self association is defined by the NL_RequiredRelationshipSpatialUnit. This class is copied from the LADM. NL_RequiredRelationshipSpatialUnit has one attribute called relationship. This is described by a ISO 19125_Type. This class allows for creating instances of relationships between spatial units, for instance ST_Within. [ISO 19152, 2012]
An object in the NL_Point class is involved with only zero or one boundary. If it is related to zero boundaries, it means it is an isolated point or a boundary reconstruction.

7.4.5 NL_BoundaryFaceString

NL_BoundaryFacestring (see figure 7.10) is corresponding to LA_BoundaryFacestring. LA_BoundaryFaceString has three different attributes. The bfsID got the value Oid, the geometry is described by GM_MultiCurve and at last the locationByText is described by a character string. The class is inheriting from *VersionedObject*.

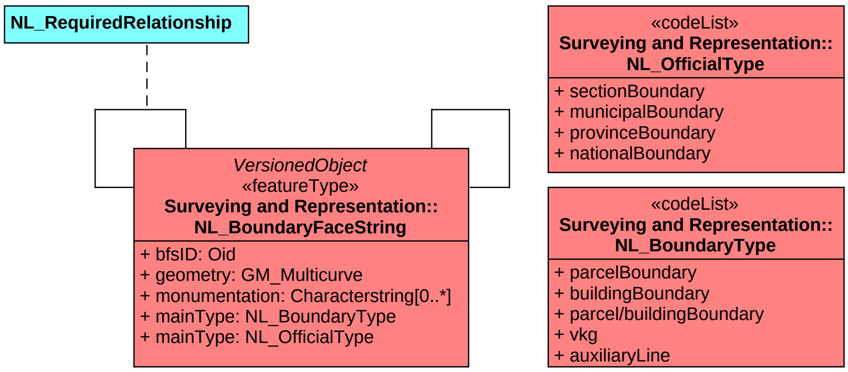

Figure 7.10: The class NL_BoundaryFacestring

For the NL_BoundaryFaceString the locationByText is omitted. Further the other two attributes are maintained. The attribute NL_BoundaryType is added to express the line type. This attribute could be a parcel boundary, a building boundary, both, a VKG or an auxiliary line. The officialType attribute contains optional extra elements about a parcel boundary; is it a municipality boundary, a national boundary, etc. The values of NL_OfficialType appear in a hierarchy; a national boundary is automatically a province boundary, a province boundary is automatically a municipal boundary. An extra attribute is monumentation to describe the physical appearance of a boundary. This is represented by a characterstring, like 'ditch'. A BoundaryFaceString is defined by two or more points [ISO 19152, 2012]. Further the class has two associations with itself. The first association illustrates the dynamics in the Dutch cadastral map. A boundary could be a part of a former boundary or two former boundaries could be associated to the same current boundary. The dynamics of the boundaries in the Dutch cadastral map could be recorded by the *VersionedObject* class. This enables history search. A second association is defined by again the NL_RequiredRelationship class. This association means that two different boundaries, described by two different spatial sources. This situation appears when it turned out that a boundary is described on two adjacent spatial sources or with a boundary reconstruction. This association indicates that both spatial sources with their own processed spatial data are described the same point. Additionally this enables the description of boundaries derived from a certain distance from another boundary.

7.4.6 NL_Parcel

The last class of the NLSRDM is NL_Parcel (see figure 7.11). In the LADM LA_SpatialUnit could represent different ways, like points, multipoints, line, multilines, parcels and multiparcels. This class is the centre of its own Spatial Unit package (see figure B.1). The attributes of LA_SpatialUnit are able to describe the area, dimension, surface relation and volume. Further this class has an attribute for an external ID (extAddressID) and an internal ID (suID). The referencePoint enables to describe a parcel by one point. The label attribute enables to add a short description of a spatial unit.

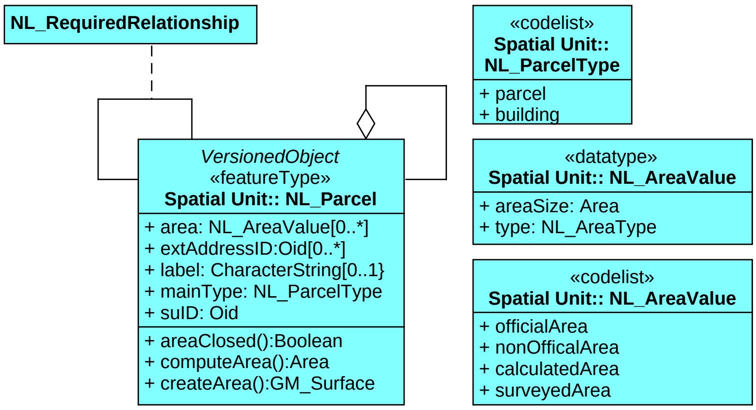

Figure 7.11: The class NL_Parcel

LA_SpatialUnit may be associated to zero or more basic administrative units. Associated to zero or more spatial unit groups. It can be spatially related, through a required relationship, to zero of more other spatial units. They can be associated to zero or more spatial sources. They can further be specialized into building units or utility networks. [ISO 19152, 2012]
A special thing is that the area attribute is able to store multiple areas, which is useful in case of map improvement and new areas are calculated. The extAddresID involves information, like city, street and postal code. The suID involves a internal Oid. The label attribute is used for extra description, like land use, and the NL_ParcelType describes the sort of parcel.
The NL_SpatialSource is associated to one or more NL_SpatialUnits. This association appears in three different manners; A source could describe it as a newParcel, an oldParcel or an untouchedParcel. The NL_SpatialUnit should at least be associated as newParcel to NL_SpatialSource, because only one SpatialSource describes the arise of a new parcel (1).

8 DEMONSTRATION CASES

In this chapter the data flow of the NLSRDM is demonstrated. This is done by 5 different cases, which are based on real cadastral sources and issues. These cases involve both the input and output case of the The cases that will be treated are the implementation of a spatial source, the implementation of an analogue spatial source, the cadastral dynamics in three stages, multiple sources for a similar boundary and a boundary reconstruction.

8.1 CASE 1: IMPLEMENTATION OF A SPATIAL SOURCE

The first case is about the implementation of a spatial source. This involves a spatial source, which depicts a current survey, which is drawn digitally and contains digital coordinates, stored in the DRA. This spatial sources (see figure 8.1) is chosen randomly from the cadastral database. In the tables 8.1, 8.2 and 8.3 it is documented which survey data is derived from this spatial source and on which class of the NLSRDM it is applicable.

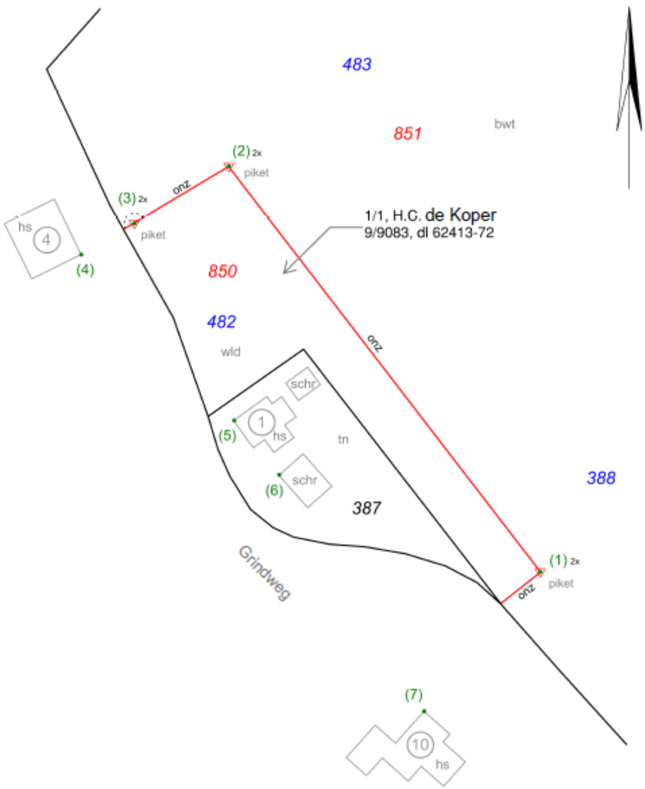

Figure 8.1: The survey data of a spatial source

NL_Point						
pID	Interpolation	Monumentation	X	Y	PointType	AimOfPoint
Point 1	Mid	Piket	204000.769	500534.509	kad1	Boundary
Point 2	Mid	Piket	204046.769	500573.887	kad1	Boundary
Point 3	End	Piket	203950.189	500565.990	kad1	Boundary
Point 4	Isolated	End B2 of BL4	204010.851	500497.873	kad1	Topography
Point 5	Isolated	End B10 of BL1	204035.715	500564.498	kad1	Topography
Point 6	Isolated	End B4 of schr	204001.075	500549.707	kad1	Topography
Point 7	Isolated	End B3 of BL10	204005.975	500543.340	kad1	Topography

Table 8.1: Case 1: The survey data for the NL_Point class

NL_Boundary	
Boundary 1	From point 3 to point 2 to point 1 to end Boundary B (south point parcel 387)
Boundary 1	Boundary is invisible

Table 8.2: Case 1: The survey data for the NL_Boundary class

NL_Parcel	
Parcels	850, 851, 482, 483, 388
NewParcels	850, 851
ExpiredParcels	482, 483, 388
UntouchedParcels	387, 1, 4, 10
Buildings	1, 4, 10
Parcel 850 is wld (Meadow)	
Parcel 387 is tn (Garden)	
Building 1 is hs (House)	
Building 4 is hs (House)	
Building 10 is hs (House)	

Table 8.3: Case 1: The survey data for the NL_Parcel class

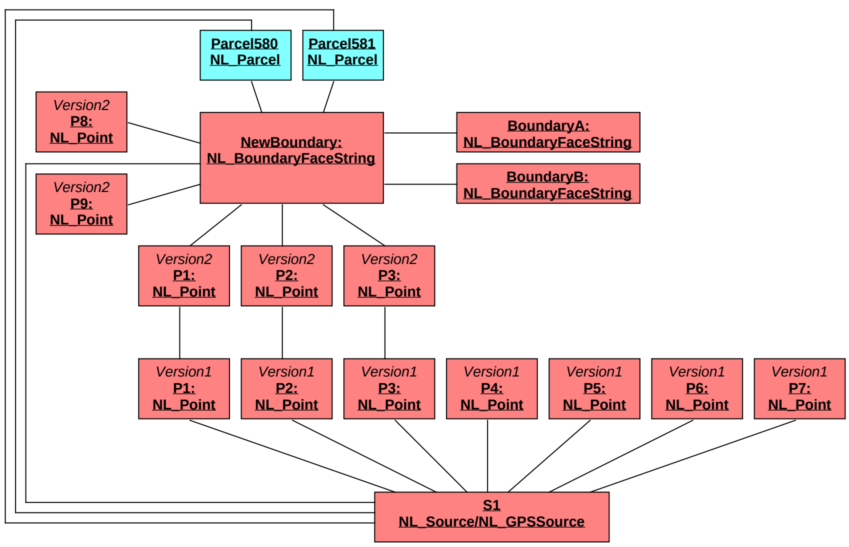

Figure 8.2: The data flow of a spatial source

The case results in the following data flow, as it is demonstrated in figure 8.2. In this demonstration case it is shown that all survey points are processed to KAD1 (as it is depicted as well in figure 8.1). This data flow continues with the processing of the boundary points into KAD2 data. Points 8 and 9 are intersection points derived via extending point 1, 2 and 3 in the Dutch cadastral map. Point 8 and 9 defines the intersection points with boundaries A and B in the cadastral map. Together with point 2, they are the final new created boundary. This new boundary results in the new parcels 580 and parcel 581.

8.2 CASE 2: IMPLEMENTATION OF AN ANALOGUE SPATIAL SOURCE

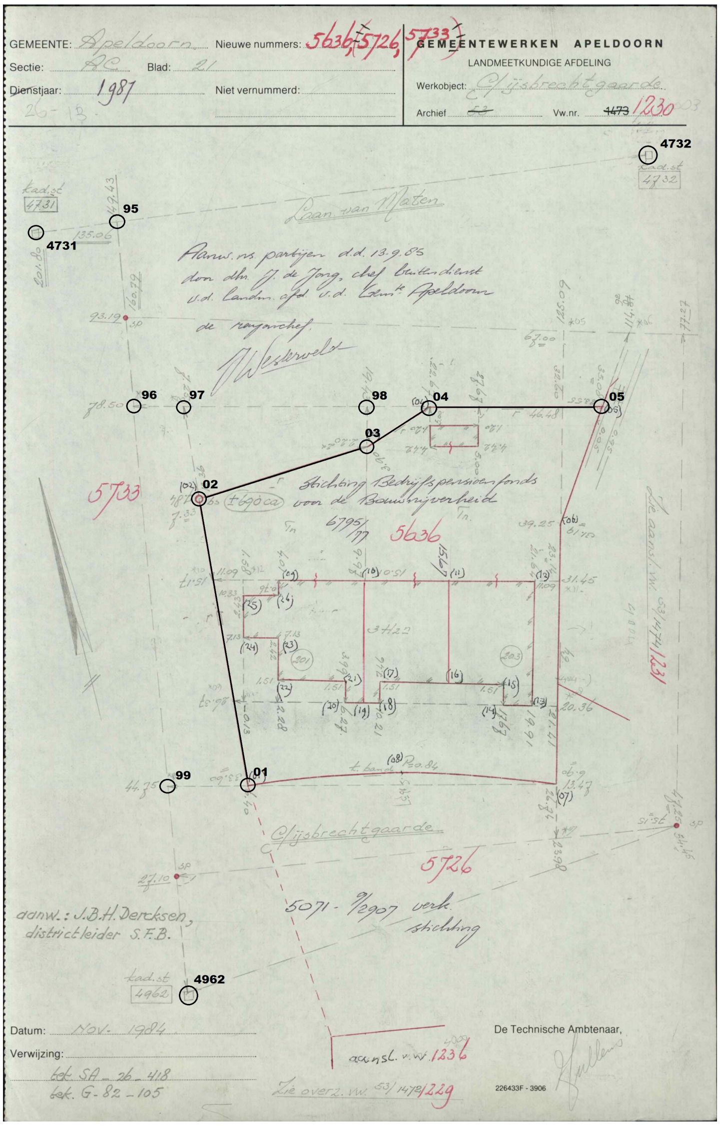

Figure 8.3: The spatial data on an analogue spatial source

The second case is about implementing an analogue spatial source (see figure 8.3); A written document with measurements done with distances with respect to control points. This is done with the support of auxiliary lines. Only a sample of the survey data is taken to avoid data redundancy. This sample is enough to demonstrate the data flow in the NLSRDM. The survey data is given per class in table 8.4, 8.5 and 8.6.

NL_Point					
Point	Intpol.	Mon.	Position	PointType	AimOfPoint
Point 4731	Isolated	-	(X,Y)	non-processed	controlpoint
Point 4732	Isolated	-	(X,Y)	non-processed	controlpoint
Point 4962	Isolated	-	(X,Y)	non-processed	controlpoint
Point 01	Start	-	33,69 meter from point 97 and 6,40 meter from point 99	non-processed	Boundary
Point 02	Mid	-	7,84 meter from Point 97	non-processed	Boundary
Point 03	Mid	-	2,20 meter from Point 98	non-processed	Boundary
Point 04	Mid	-	22,67 meter from Point 96	non-processed	Boundary
Point 05	End	-	35,08 meter from Point 96	non-processed	Boundary
Point 95	Start	-	135,06 meter from Point 4962 and 149,43 meter from Point 4732	non-processed	Auxiliary
Point 96	Start	-	78,50 meter from Point 4962	non-processed	Auxiliary
Point 97	Mid	-	7,95 meter from Point 96	non-processed	Auxiliary
Point 98	Mid	-	19,43 meter from Point 96	non-processed	Auxiliary
Point 99	Mid	-	44,75 meter from Point 4962	non-processed	Auxiliary
Point 4962, 99, 96 and 95 run collinear					
Point 96, 97, 98, 04 and 05 run collinear					
Point 01, 02, and 97 run collinear					
Point 4731, 95 and 4732 run collinear					

Table 8.4: Case 2: The survey data for the NL_Point class

NL_Boundary
Boundary runs from Point 01 to 02 to 03 to 04 to 05

Table 8.5: Case 2: The survey data for the NL_Boundary class

NL_Parcel	
newParcel	5733, 5636, 5726

Table 8.6: Case 2: The survey data for the NL_Parcel class

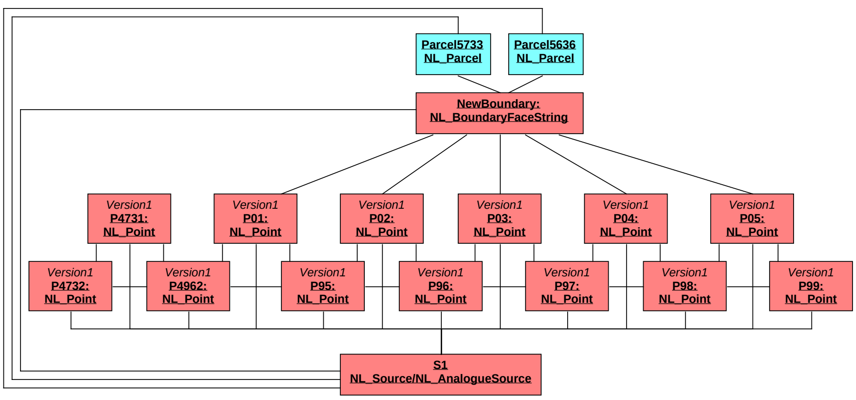

Figure 8.4: The data flow of an analogue spatial source

The survey data of the analogue spatial source is processed in the data flow scheme of figure 8.4. This data flow shows that all points (control points, auxiliary points and boundary points) are related to each other in order to define the correct position of the final boundary. The boundary is measured at his start, mid and end position. Therefore there are no intersection points involved. Further non of these points are processed in KAD2 and therefore there is no second version of each instance.

8.3 CASE 3: CADASTRAL MAP DYNAMICS IN THREE STAGES

A next case demonstrates the dynamics of the Dutch cadastral map in three stages. These different stages are depicted in figure 8.5. In this figure both the parcels and the boundaries got an ID and its relations per stage is shown in figures 8.6, 8.7 and 8.8.

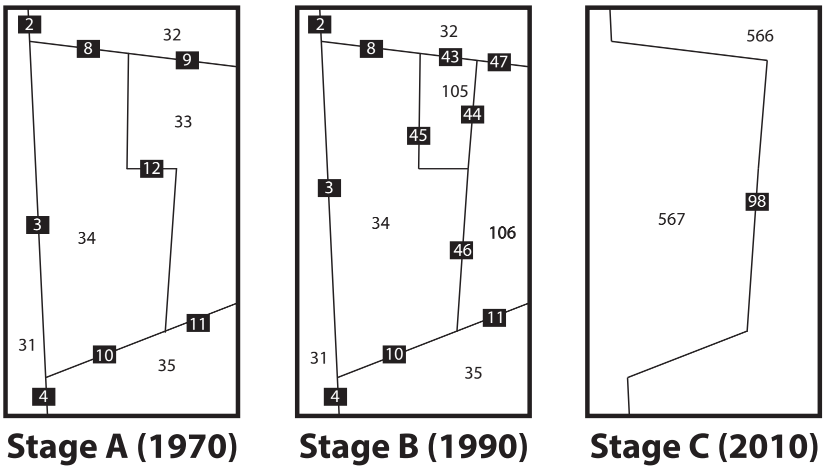

Figure 8.5: Boundary dynamics of the Dutch cadastral map in three stages

Stage A is a cadastral situation from scratch. The relation between sources, parcels and boundaries are simple. The stage exists of 4 sources, which all relate to one or more boundaries and these boundaries relates to two parcels. Most parcels are built up from three boundaries, only parcel 34 has 4 boundaries. It need to be mention that the relation between the sources and the parcels is not depicted in these schemes.

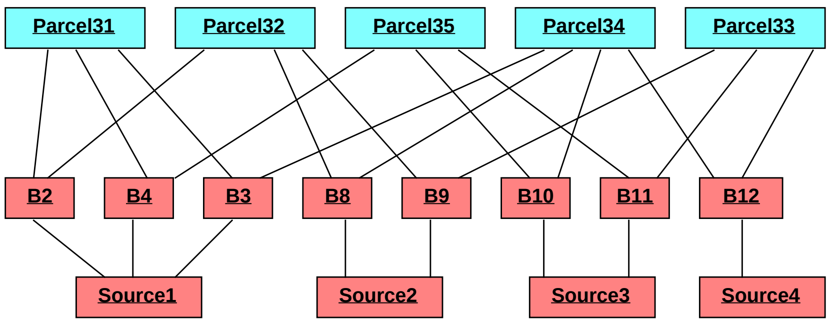

Figure 8.6: Boundary dynamics stage A

In stage B the cadastral situation changed. An extra boundary is added, which split parcel 33. This results in the new parcels 105 and 106. In the data flow of figure 8.7 it is demonstrated that this change does not only affect the relations of parcel 33. At first the boundaries 9 and 12 are split into the new boundaries 43, 45, 46 and 47. All the involved boundaries have now actually two spatial sources, namely the original survey source and the source, which defines the split. There also appears a third change in relation; parcels 32 and 34 do not change in shape at all, but since boundary 9 and 12 are split in new boundaries with new ID's, the parcels 32 and 34 are related to the new boundaries as well.

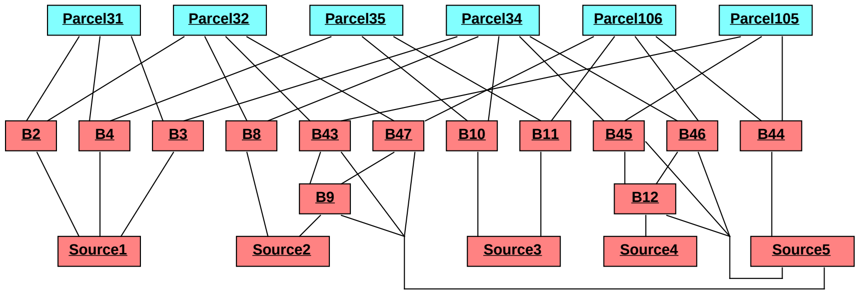

Figure 8.7: Boundary dynamics stage B

In the last stage C all the boundaries are affected by a land consolidation. A part of the boundaries are expired and gone, while others are merged into boundary 98. This result in a new source for all the cadastral objects. At a glance boundary 98 seems an simple line, but if a land surveyor traverses its survey history, it turned out that it involves many sources. Even the boundaries 2 and 4 of stage A, which where at that point part of one surveyed boundary with one spatial source, are disconnected in Stage C, but still belong to the similar surveyed boundary.

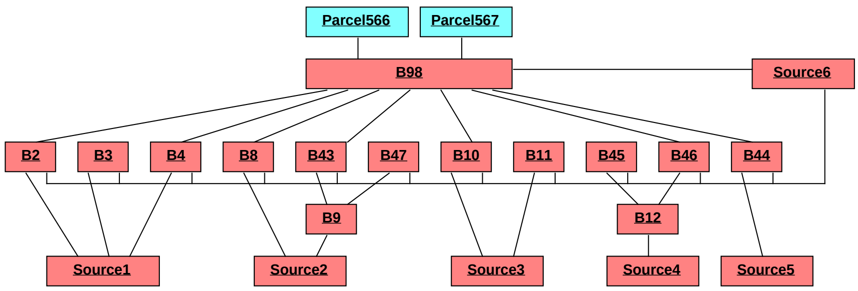

Figure 8.8: Boundary dynamics stage C

8.4 CASE 4: MULTIPLE SOURCES FOR SIMILAR BOUNDARY

This case demonstrates how the model reacts on the fact when a cadastral boundary has two original survey documents, as it is depicted in figure 8.9. This duplication is caused by the fact that both spatial sources describe an adjacent cadastral situation. The boundaries at the borders have in that case two original survey data. The data flow in figure 8.10 shows that in that case, both boundaries can be processed separately in the cadastral system.

At the end of this process both boundaries get an individual ID, but their relation is described via the class NL_RequiredRelationship.

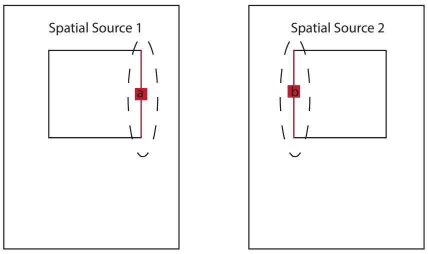

Figure 8.9: Two adjacent sources (1 and 2) with a similar boundary (A equals B)

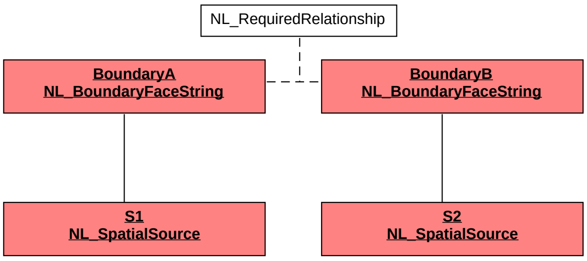

Figure 8.10: The data flow for a boundary reconstruction

8.5 CASE 5: BOUNDARY RECONSTRUCTION

In a last case the data flow of the NLSRDM is described when a boundary reconstruction is added to the cadastral database. The test case reveals a special case in this, as it is shown in figure 8.11; Boundary C is reconstructed, which is a merge of the two separate boundaries A and B. Both have a different spatial source, while boundary C will result in another spatial source. The scheme of figure 8.12 demonstrates that there are two different data flows; one for the original survey data and one for the boundary reconstruction. In this situation there are two separate boundaries created in the cadastral database and there reciprocal relation is described by the class NL_RequiredRelationship.

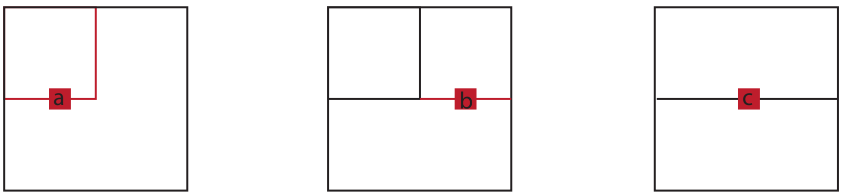

Figure 8.11: The sketch for a boundary reconstruction

A boundary reconstruction can be assumed as new spatial source, if the survey methods used are more accurate then the survey methods used in the original spatial sources or/and the related topography has changed/-gone (for instance a ditch is filled up).

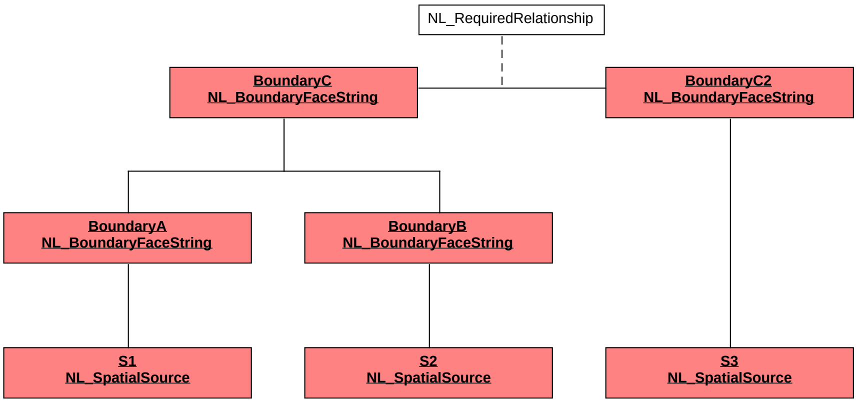

Figure 8.12: The data flow for a Boundary Reconstruction

9 CONCLUSION AND DISCUSSION

9.1 CONCLUSION

This thesis presents a data model, which connects the spatial units of the Dutch cadastral map to its related survey data. This data model is called the Dutch Survey and Representation Data Model NLSRDM and its design is based on the sub package *Survey and Representation* from the LADM. The research attempted to answer the stated research questions of the introduction chapter. The main research question was:

Can the newly designed integrated data model between survey data and cadastral mapping improve the Dutch cadastral work flow?

The cadastral database at the Kadaster has a focus on parcels by the Kadaster. This research has explained that this approach leaves space for improvements for the work flow. The Dutch Survey and Representation Data Model presents a couple of solutions. At first the model enables a better connection between survey data and the Dutch cadastral map. The model considers points and lines as own entities and this enables to store survey data to the actual object it is describing. This is beneficial to the work flow in many ways; survey data of a certain object can be derived much more quicker and unilateral, there is less expert knowledge necessary for interpreting the spatial sources and it enables history management via the superclass *VersionedObject*. The structure of the NLSRDM monitors the origin of spatial units. This enables a deliberated decision-making tool to increase the quality of the Dutch cadastral map. The overview provide as well the ability to check the completeness of the survey dataset.
As the survey data in the Kadaster is based on various survey techniques with different survey data and quality, this NLSRDM is a first step in a more integrated cadastral dataset. However developing and improving a work flow is an ongoing process and this NLSRDM doesn't challenge all the issues of the Kadaster. Therefore future research is still recommended.

Which of the stated requirements can be implemented in the data model?

In this research 11 requirements are stated, based on a preliminary investigation. By the use of a MoSCoW analysis a distinction is made in different priorities. Seven of the requirements were placed in the category 'Must have", meaning that they have to be implemented in the NLSRDM for sure.
The first requirement stated that there have to be a link between all spatial sources and the Dutch cadastral map. This is achieved by the NLSRDM, since it provides place for sources and cadastral objects and they are connected to each other via the NL_SpatialSource, NL_Point and NL_BoundaryFaceString classes. A special attention in this have to be by the self-association on the different classes specified by the NL-RequiredRelationship class. These includes similar objects with a different spatial source or instances with addi-

tional spatial sources, like a boundary reconstruction. The NLSRDM has an additional aspect on a more strict relation between spatial sources and the Dutch cadastral map by the explicit relations of newParcel, expiredParcel and untouchedParcel between the classes NL_SpatialSource and NL_Parcel. In a second and third requirement it was stated that boundaries and points have to be considered as own entities. This is achieved by different classes for boundaries and points. Additionally all instances of these classes are giving a Oid. It was stated that the beneficial element of an own entity is the fact that many attributes can be attached to these objects, like descriptions and time. This can be established via the NLSRDM. The next requirements of the 'must have' category stated that the NLSRDM need to be suitable for various survey methods and it must incorporate COGO data. In the NLSRDM the different survey methods can be implemented as instance of the umbrella class NL_Source class and the NL_SpatialSource class, which contains the attributes measurements and procedures. A distinction in the different survey methods is given by the subclasses NL_AnalogueSource, NL_TachymeterSource, NL_GPSSource and NL_Photogrammetry. These different classes involves different implementation of COGO data. A more specified way of implementing these COGO data needs future investigation. Another requirement is about managing history data. This is achieved by the use of the superclass *VersionedObject*, which has the attributes beginLifespanVersion and endLifespanVersion. These involves the start time and end time of an object. A second element of history management contains of self-associations of the classes NL_SpatialSource and NL_BoundaryFaceString in which they refer to related instances of the past. A last requirement in the category 'Must have' states that the NLSRDM must refer survey data to both cadastral boundaries and topography. This is achieved by linking the class NL_SpatialSource to the related classes. The distinction between topography and cadastral boundaries are made via code lists in every class.
In the next category of the MoSCoW analysis ('should have') states that the model should incorporate topology and ISO standards. The NLSRDM doesn't explicitly stored topological relations between cadastral objects. Further the NLSRDM is based on the sub package *Survey and Representation* of the LADM. This standard provides a structure for managing cadastral data. Besides the *Survey and Representation* sub package contains several other ISO standards. The left over requirement of implementing 3D data in the cadastral system is not concerned in the NLSRDM, but will be discussed in the future work paragraph of this chapter.

To which extent does the Land Administration Domain Model present a useful template for managing survey and boundary data within the Kadaster?

For the design of the NLSRDM the sub package turned out to be a very useful template. The general structure is taken over by using the four classes spatial sources, points, boundaryfacestrings and boundaryfaces. Only the LA_BoundaryFace class was omitted, but this class will be for sure useful if 3D data implementation will be an issue. Further the superclass *VersionedObject* turned out to be very useful for history management.
Nevertheless the NLSRDM is custom made to the Kadaster. Therefore several adaptations on the sub package have been taken place. The most basic change is the assumption that a spatial sources should involve at least one boundary instead of one point. This resulted in a change of relations. Further the different survey methods are divided in different sub-

classes of the general NL_SpatialSource class. The classes NL_SpatialSource and NL_BoundaryFaceString got an extra self-association and the classes NL_Point and NL_BoundaryFaceString an additional association, explained by the class NL_RequiredRelationship. Further the relation between NL_Parcel and NL_SpatialSource is made more explicit.
Due to the result of this research there are several recommendations to make for the design of a new LADM. At first it should develop general classes for the different spatial sources and the different survey methods. A second recommendation is to implement specific related spatial sources, which are not the original survey data, like boundary reconstructions. A last recommendations is how to handle with a phenomenon like intersection points, since they results in a different data flow.

9.2 DISCUSSION

One of the main conclusion of this research is to consider boundaries as own entities. This seems an easy solution on paper, but it is a labour intensive operation to implement in the current system. The Dutch cadastral map have already been subjected to many developments and the relation between the spatial units and its spatial sources is fragmented. Referencing is therefore a delicate job and it need consideration about how the NLSRDM should be implemented. There are three options: (1) implementation all at once, (2) implementation in phases or (3) implementation by the occasion. Implementation all at once requires a lot of coordination and work. The advantage is that the data structure is maintained unilateral. However it is difficult to adjust the procedures by progressive insights. The implementation in phases involves an approach per certain area. This is beneficial to adjust the implementation to progressive insights, but this results in a less unilateral dataset. A third option would be to implement this data model by the occasion. When a new request for boundary reconstruction comes, the land surveyor could establish the link between the spatial sources and spatial units. This is the most cheapest and simple approach, but it takes probably ages before the entire cadastral dataset is adjusted to the NLSRDM. It is even possible that existing boundaries will never be involved in boundary reconstruction or land consolidation. It is up to the Kadaster to decide and expenses will probably the main consideration. In the opinion of the author of this research implementation in phases seems the best option, since it is ensured that all cadastral data will be adjusted to the NLSRDM, while the impact of it is in proportion.
Currently many spatial data is written on analogue spatial sources. In order to fully implement the NLSRDM in the Kadaster, it is an inevitable step to transform it to digital spatial data. In the design of NLSRDM it is assumed that this digitalization process already have been taken place. Actually this is not the case. The digitalization is a complex and labour intensive procedure, since the paper spatial sources are not completely standardized. Every land surveyor had his own handwriting and own habits in documentation. This leads to many exceptions and different interpretations. The digitalization could be achieved by Optical Character Recognition (Lemmen, personal communication, 2016). This is a mechanical or electronic conversion of images of typed, handwritten or printed text into machine-encoded text, whether from a scanned document, a photo of a document, a scene-

photo (for example the text on signs and billboards in a landscape photo) or from subtitle text superimposed on an image (for example from a television broadcast). It is a common method of digitising printed texts so that they can be electronically edited, searched, stored more compactly, displayed online and used in machine processes . This process will be probably taking a couple of years, which turns the spatial source class for analogue spatial sources into a versioned object. This will reveal the phase of a spatial source in this process.

In the data model of this thesis, it have been attempted to incorporate standard terminology as much as possible to stimulate a wider understanding of the data model. Although in some cases it is still a challenge. The Kadaster doesn't have a dictionary with unilateral translations of terms. When the author inquired about this documentation, three different employees send him a different list of translated words. One of these lists was made in 1983 by an old fashion typewriter. In order to stimulate international cooperation and exchange of knowledge, the Kadaster need to work on a dictionary with well-defined and translated terminology into the common European languages English, French, German and Spanish.

9.3 FUTURE WORK

As it is discussed in the conclusion, the NLSRDM is an improvement for the internal work flow of the Kadaster. However its serves extra opportunities. This paragraph will elaborate on the most elementary of them.

At first this data model could support more effective boundary reconstruction for customers. At this moment many time and effort is spent on searching and interpreting spatial sources. This labour is reflected in the customers rate. Many people quit after receiving the estimated quotation. Nevertheless in many cases the offered price is hardly covering all costs made by the Kadaster. The rate is standardized to keep boundary reconstructions at least a bit affordable. Besides currently it takes 12 to 18 months before a requested boundary reconstruction can be executed due to the many requests. It is clear that both for the Kadaster and the customers this situation is unsatisfactory. To decrease the expenses for a customer, currently the Kadaster provides extra information about the approximate boundary location. This extra information could be a list of coordinates or reference to topography, like '3 meters from the dormer' (Zoreisha Niamat (Marketing Kadaster), personal communication, 2016). For customers these high rates and prudence about the exact boundary location are difficult to comprehend. The survey in the field by the land surveyor mainly exists only of a couple of measurements, done within an hour. Further the Dutch cadastral map is free available on PDOK with clear lines for boundaries. Understanding survey data requires expert knowledge and it is Chinese for laymen. Besides providing raw survey data to customers is dangerous, since it reveals the margins of the property descriptions of the Kadaster. This could only lead to legal proceedings which results in more work instead of less. The best for the Dutch cadastral map would be to strive to an exact location of boundaries instead of suggesting only an approximation. The Dutch cadastral map have been already subjected to an improvement initiative in 1997. This project compared the boundaries in LKI (this is the precursor of KPV) to the topography of the Grootschalige Basiskaart Nederland (GBKN). The GBKN is the precursor of the BGT. Local geometric accurate cadastral bound-

aries were aligned to less accurate topography of the GBKN. This resulted in many adjustments, but the outcome was variable depending on the GBKN quality. In some cases the map wasn't improved, but deteriorated according to some people of the Kadaster [Boersema, 2015].
The data model of this thesis could be a start for a new map improvement. The model reveal the original survey data per spatial unit and therefore it could serve as source for new map improvements algorithms. These have to be created in the future phase and they have to use the NLSRDM as source. This approach is better then the project in 1997, since it uses original survey data instead of processed data.
As an alternative for immediate map improvement, this data model enables the production of more custom-made spatial sources; Requested spatial units can be depicted in the centre of a map with relevant survey data added, like coordinates or distance to existing topography. Currently the only reference there is are the original spatial sources. They have dispersed and ambiguous information.
The map improvement initiative and the data model could be the starting point for a more positive approach for the Kadaster. Currently the Kadaster is considered to be negative system. This means that customers can not get an legal guarantee about the extent of their property by the registers of the Kadaster. In a negative system it is the court of justice who finally decides about property and property conflicts. For the Kadaster it means that they decide in the field what the actual cadastral situation is. In a negative Kadaster cases like prescription are possible. In a positive system the legal property is according to the actual cadastral situation at the Kadaster (Lemmen, personal communication, 2016). Customers have to respect this situation by any time. An example of a positive system is the Torrens system in Australia [Mitchell, 2010]. A positive cadastral system involves unilateral areas of parcels and source data of spatial units. [Zevenbergen, 2002]
For a couple of years the Kadaster is preparing for the implementation of 3D registration [Stoter et al., 2012]. At this moment the first 3D registration is achieved by the train station in Delft and 3D implementation is in an experimental phase. The NLSRDM is however focussed on the existing 2D implementation of the Kadaster. If 3D registration is generally implemented, it is recommended to adjust the data model to this situation. The LADM provides also a class called LA_BoundaryFace, which is designed for 3D implementation. Adding and adjusting this class into the NLSRDM would be the main work.

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A SPATIAL SOURCES OF THE KADASTER

kadaster

Relaas van bevindingen

Gemeente
HARDERWIJK

Sectie D
Archiefnummer 2271

Blad
1 van 2

Opgemaakt op: 01-11-2012 door Mark Slomp, Landmeter
Naar aanleiding van: grensreconstructie, aangevraagd door Mevrouw E.S.I.H. Lups, ordernummer 5000531202

Gegevens van belanghebbenden

Gegevens van de verschenen belanghebbenden of vertegenwoordiging

mw. E.S.I.H. Lups, geboortedatum 10-12-1968, aanvrager en eigenaar, verschenen op 01-11-2012.

Alle opgeroepen belanghebbenden zijn verschenen dan wel vertegenwoordigd.

Gegevens van de niet-verschenen belanghebbenden of vertegenwoordiging

Omschrijving van de aangewezen kadastrale grenzen

onzichtbare grens midden tussen de zijgevels van Dennenlaan 22 en 24 aangegeven middels twee ijzeren buizen en twee krijtstrepen.

Aanwijzingen

Aantekeningen

Opmerkingen

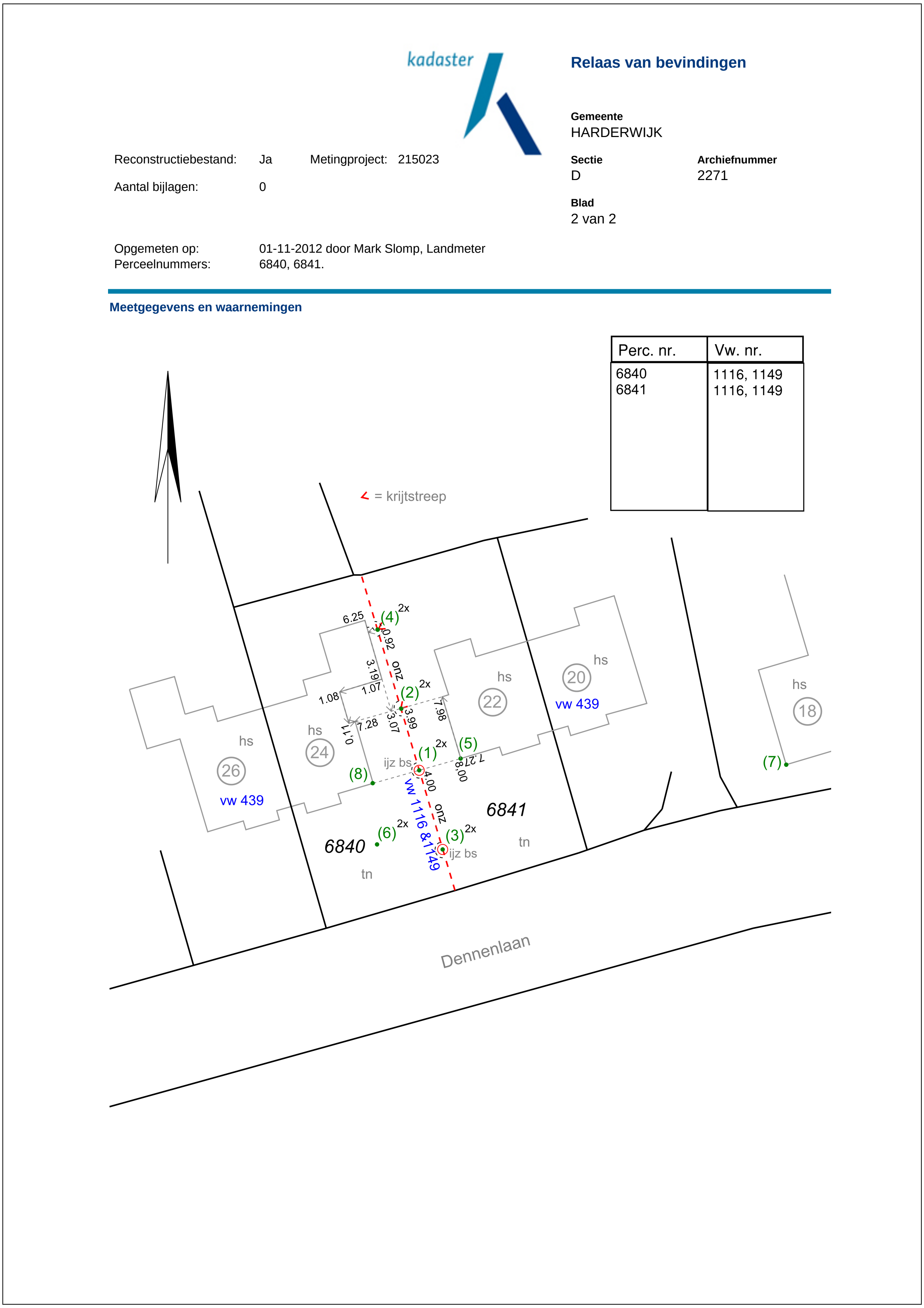
Vervolgprocedure

Overige opmerkingen

Informatie over de ligging van de grens is in ontvangst genomen door aanvrager.

Ondertekening

Figure A.1: A 'relaas van bevindingen' (*official statement of observations*) part 1



kadaster

Relaas van bevindingen

Gemeente
HARDERWIJK

Sectie
D

Archiefnummer
2271

Blad
2 van 2

Reconstructiebestand: Ja   Metingproject: 215023

Aantal bijlagen: 0

Opgemeten op: 01-11-2012 door Mark Slomp, Landmeter
Perceelnummers: 6840, 6841.

Meetgegevens en waarnemingen

Perc. nr.	Vw. nr.
6840	1116, 1149
6841	1116, 1149

Figure A.2: A 'relaas van bevindingen' (*official statement of observations*) part 2

Dienst voor het Kadaster en de openbare registers

Gemeente:	HARDERWIJK	Archiefnummer(s)	: 2271
Sectie:	D		
Datum:	02-11-2012	Pagina	: 1/1

Reconstructiecoördinaten
Coördinatenstelsel : **RDNAPTRANS**

Nr	X	Y	Nr	X	Y
-----	----------	----------	-----	----------	----------
1	171465.303	482641.807			
2	171463.260	482648.818			
3	171466.432	482637.923			
4	171461.809	482653.832			
5	171469.126	482642.975			
6	171462.871	482638.099			
7	171527.473	482651.987			
8	171461.466	482640.675			

Figure A.3: Coordinates overview, part of 'relaas van bevindingen' (*official statement of observations*)

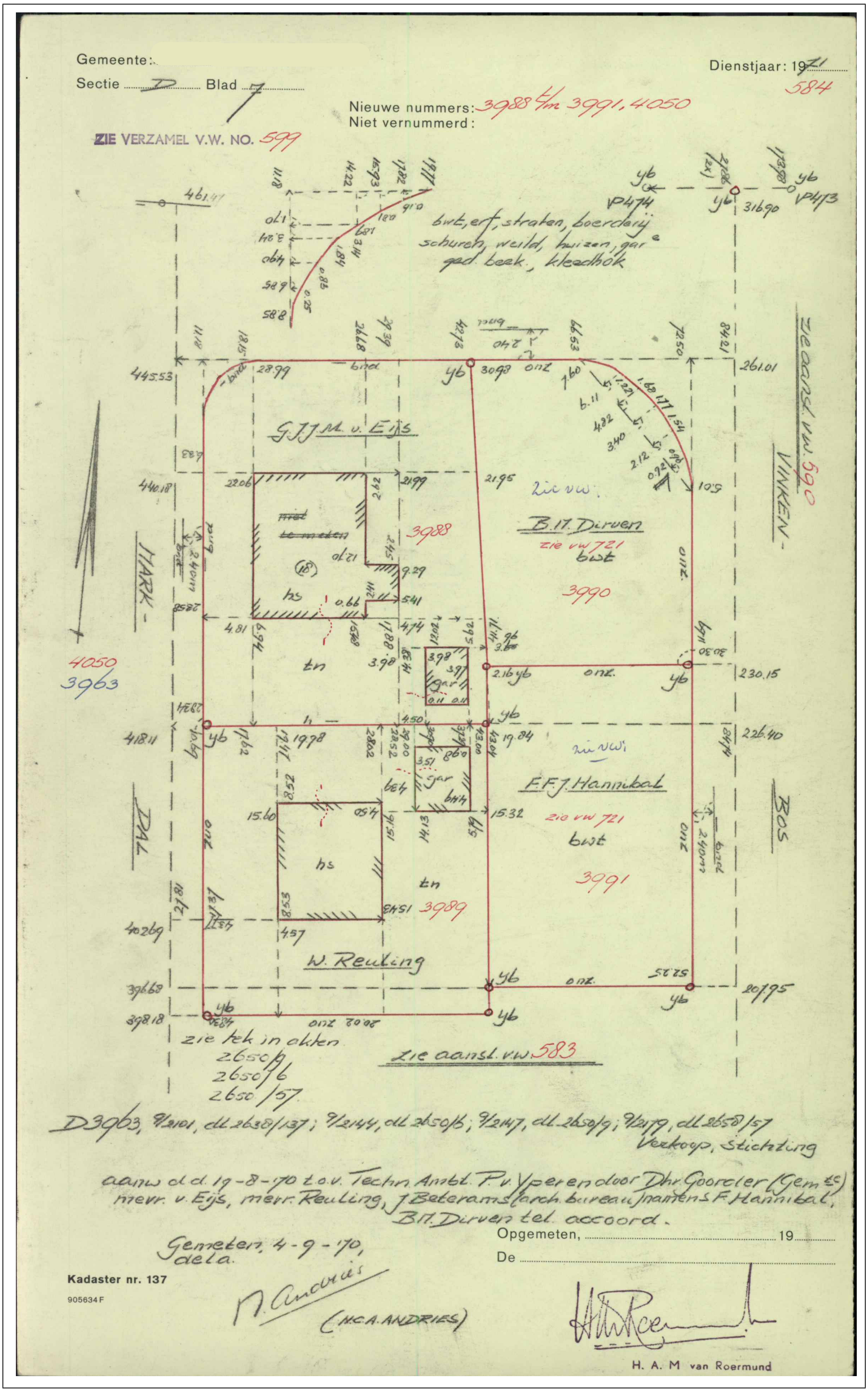


Figure A.4: A field sketch of the Kadaster from 1976

B PACKAGES OF LADM

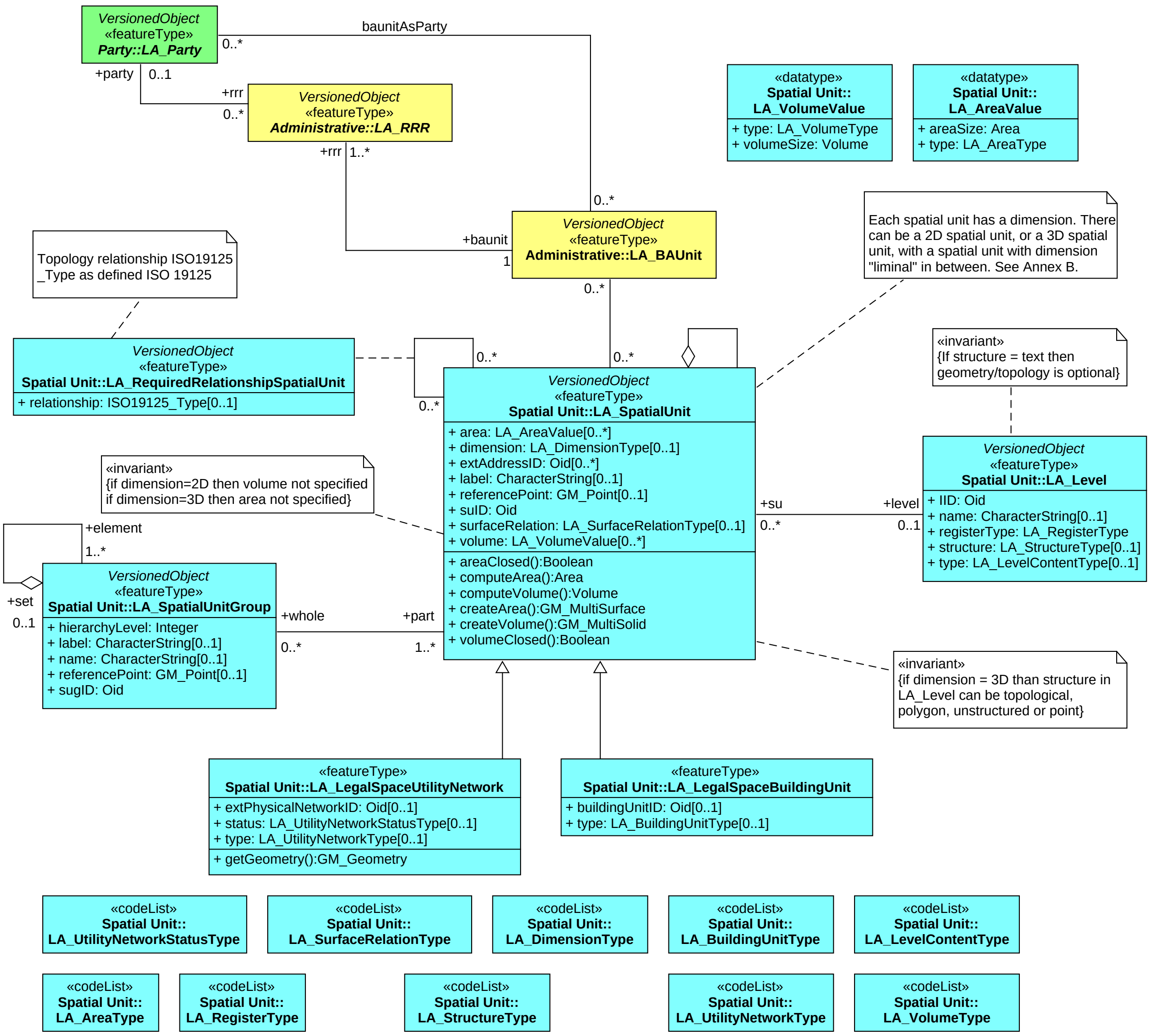


Figure B.1: LA_SpatialUnit [van Oosterom et al., 2011]

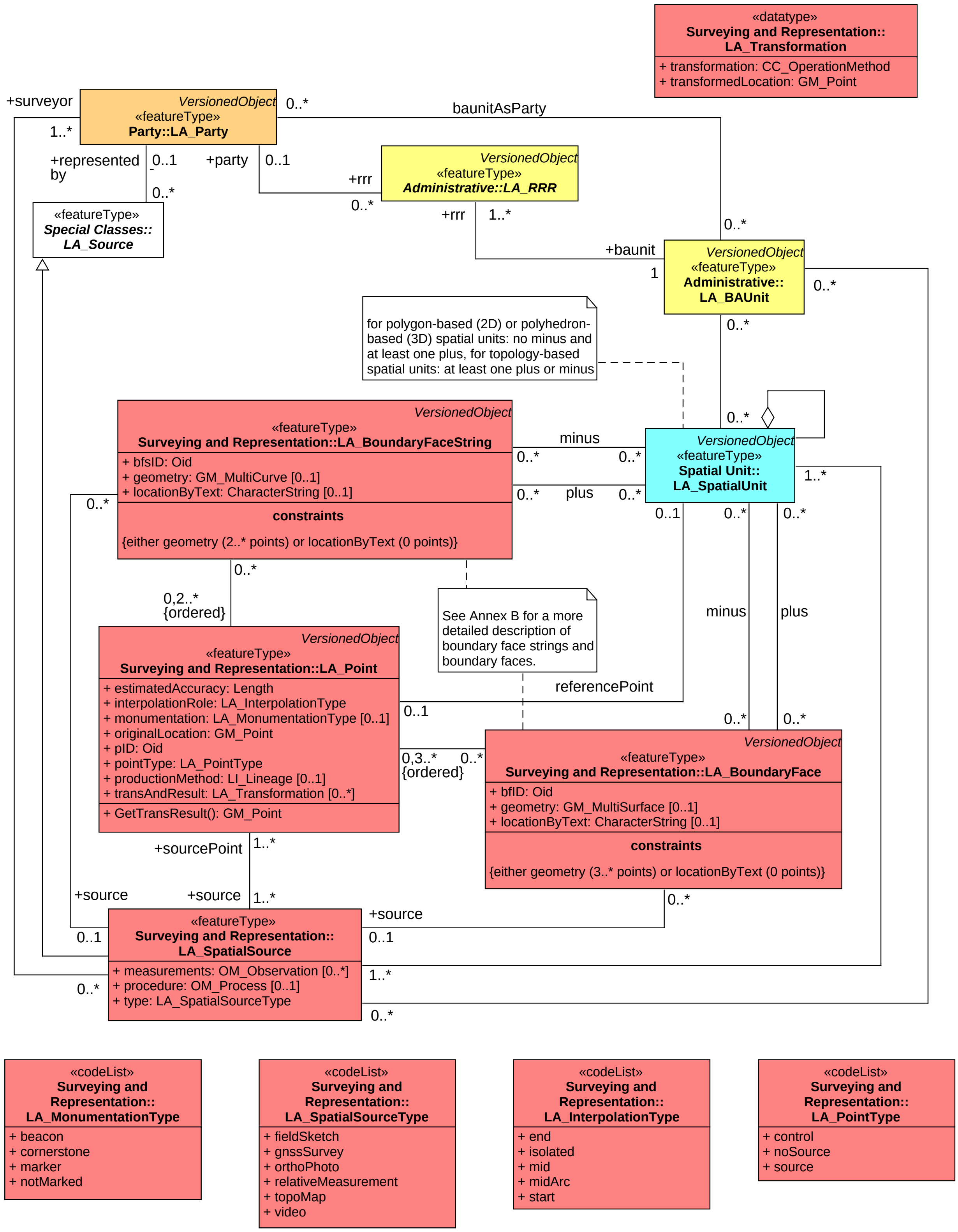


Figure B.2: Survey and Representation sub package [van Oosterom et al., 2011]

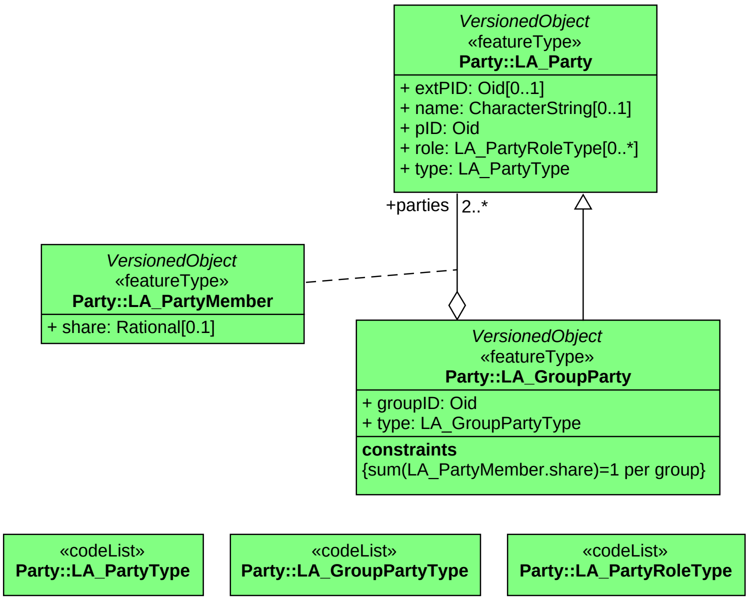


Figure B.3: LA_Party [van Oosterom et al., 2011]

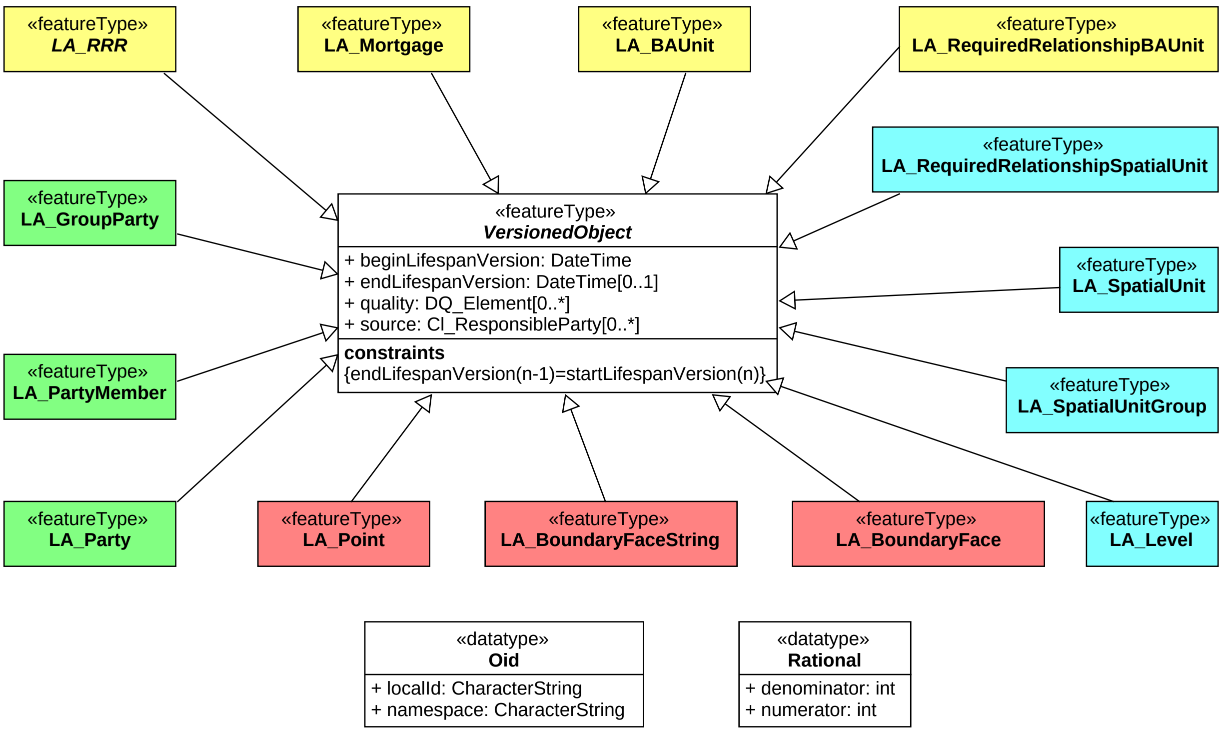


Figure B.4: VersionedObject [van Oosterom et al., 2011]

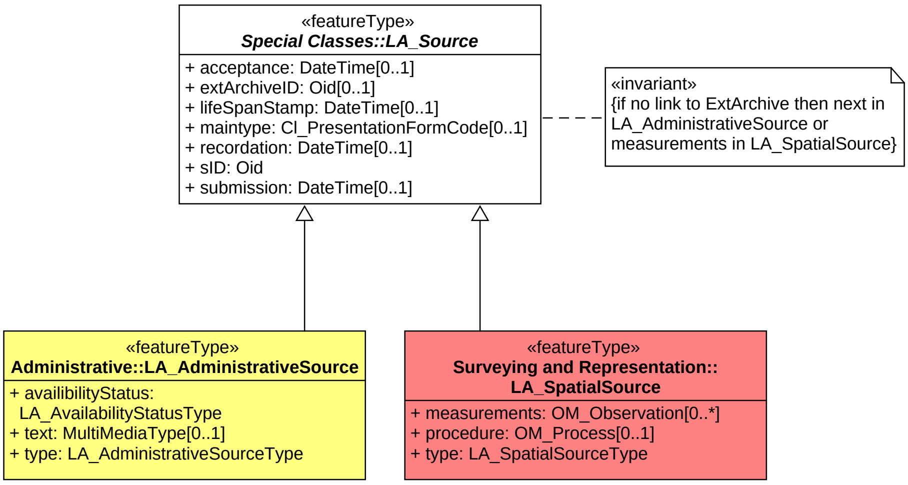


Figure B.5: LA_Source [van Oosterom et al., 2011]

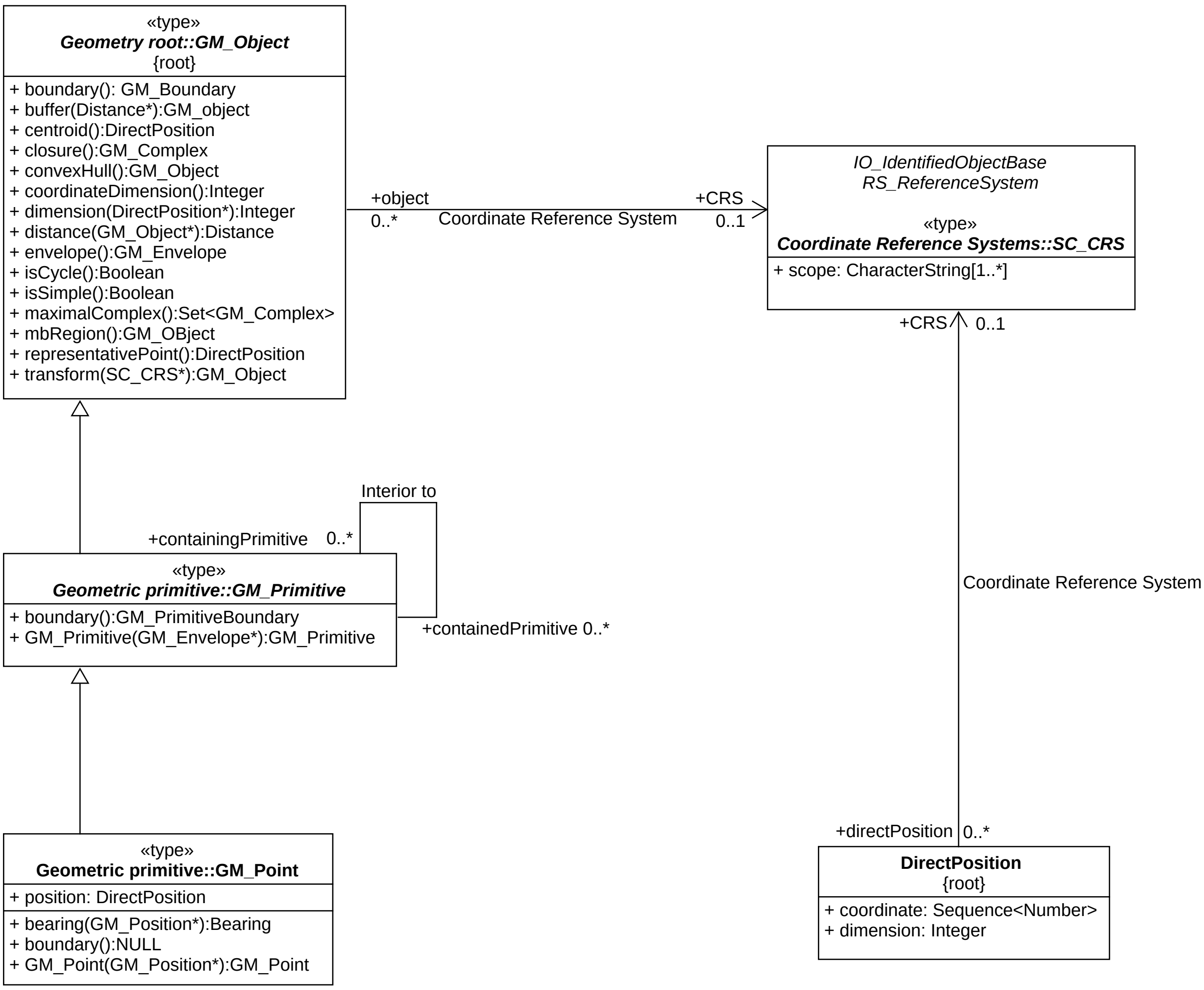


Figure B.6: GM_Point [van Oosterom et al., 2011]

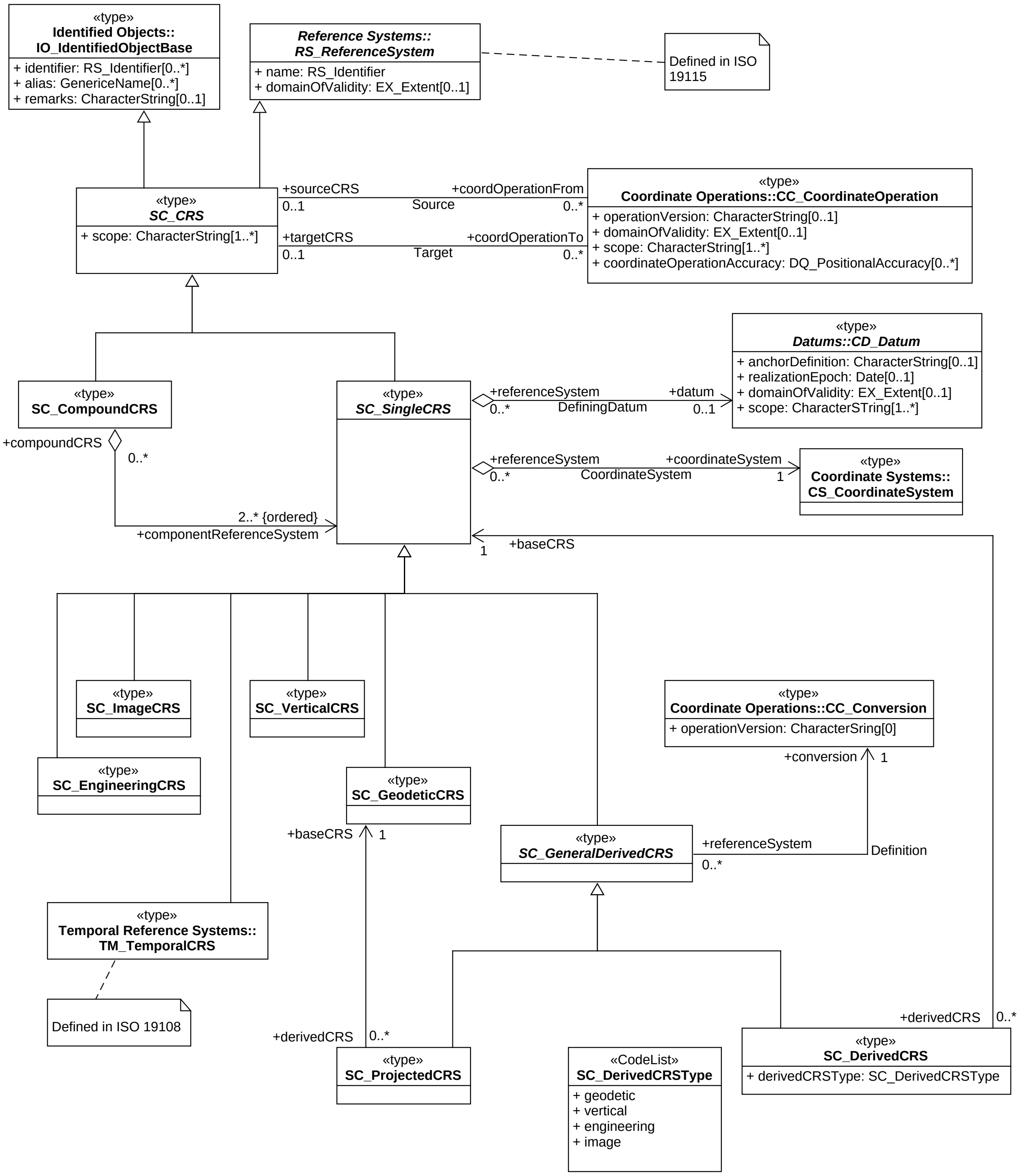


Figure B.7: SC_CRS [van Oosterom et al., 2011]

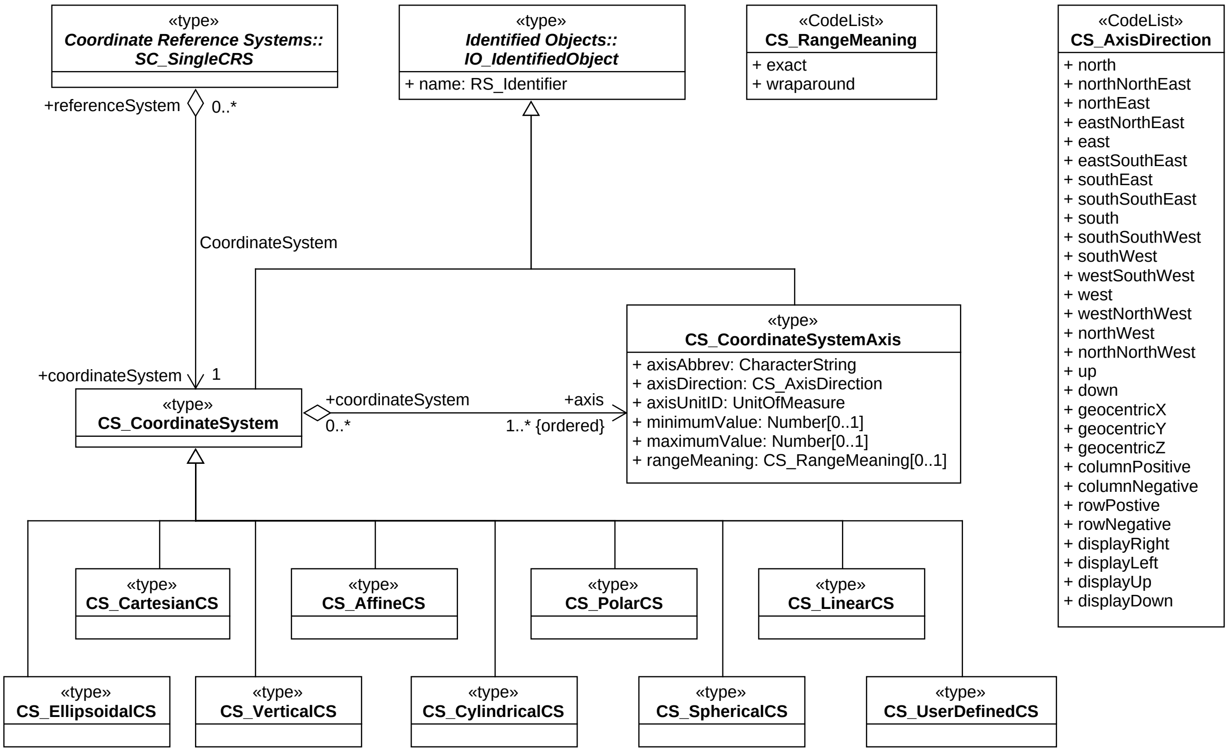


Figure B.8: SC_CoordinateSystem [van Oosterom et al., 2011]

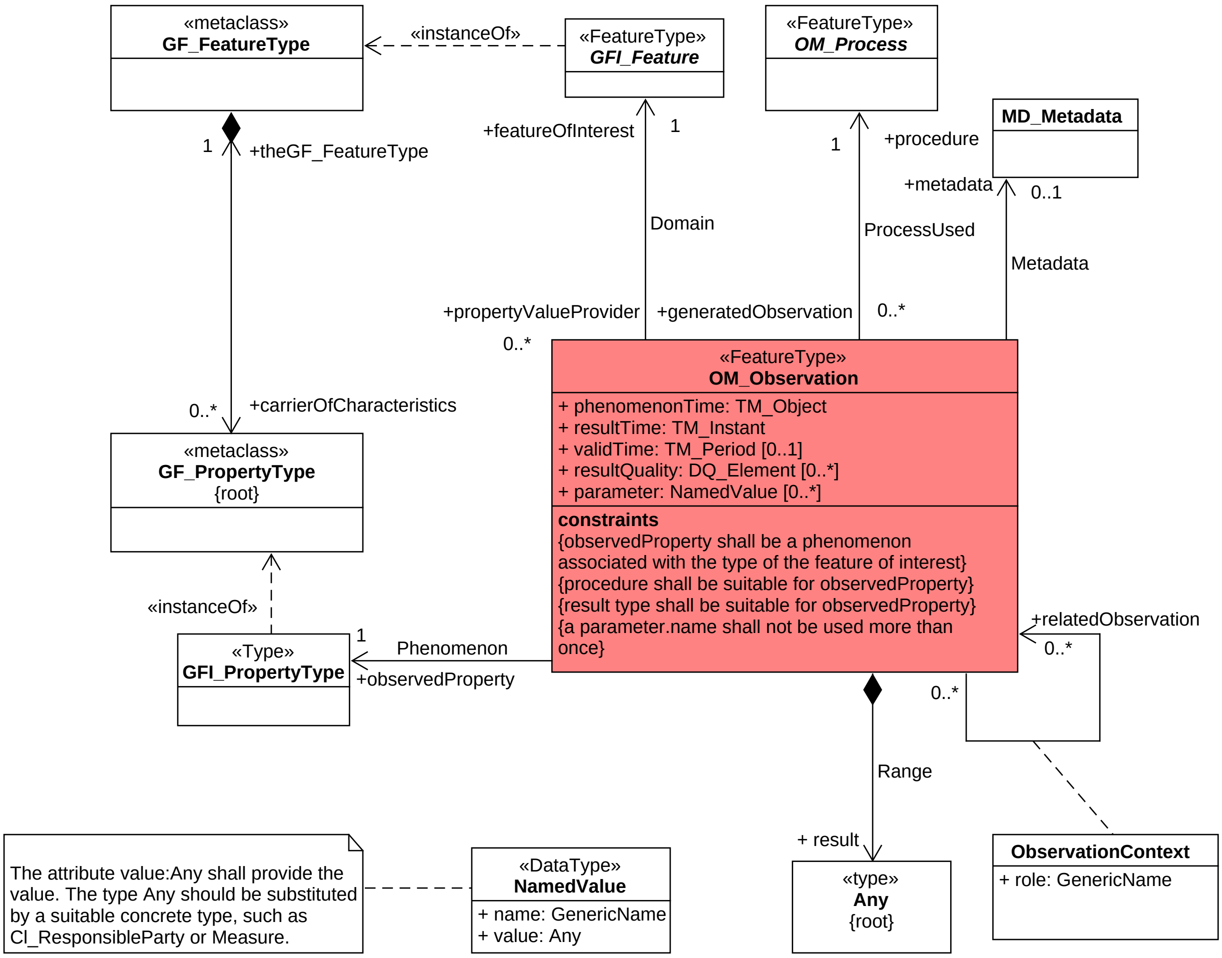


Figure B.9: OM_Observation [van Oosterom et al., 2011]

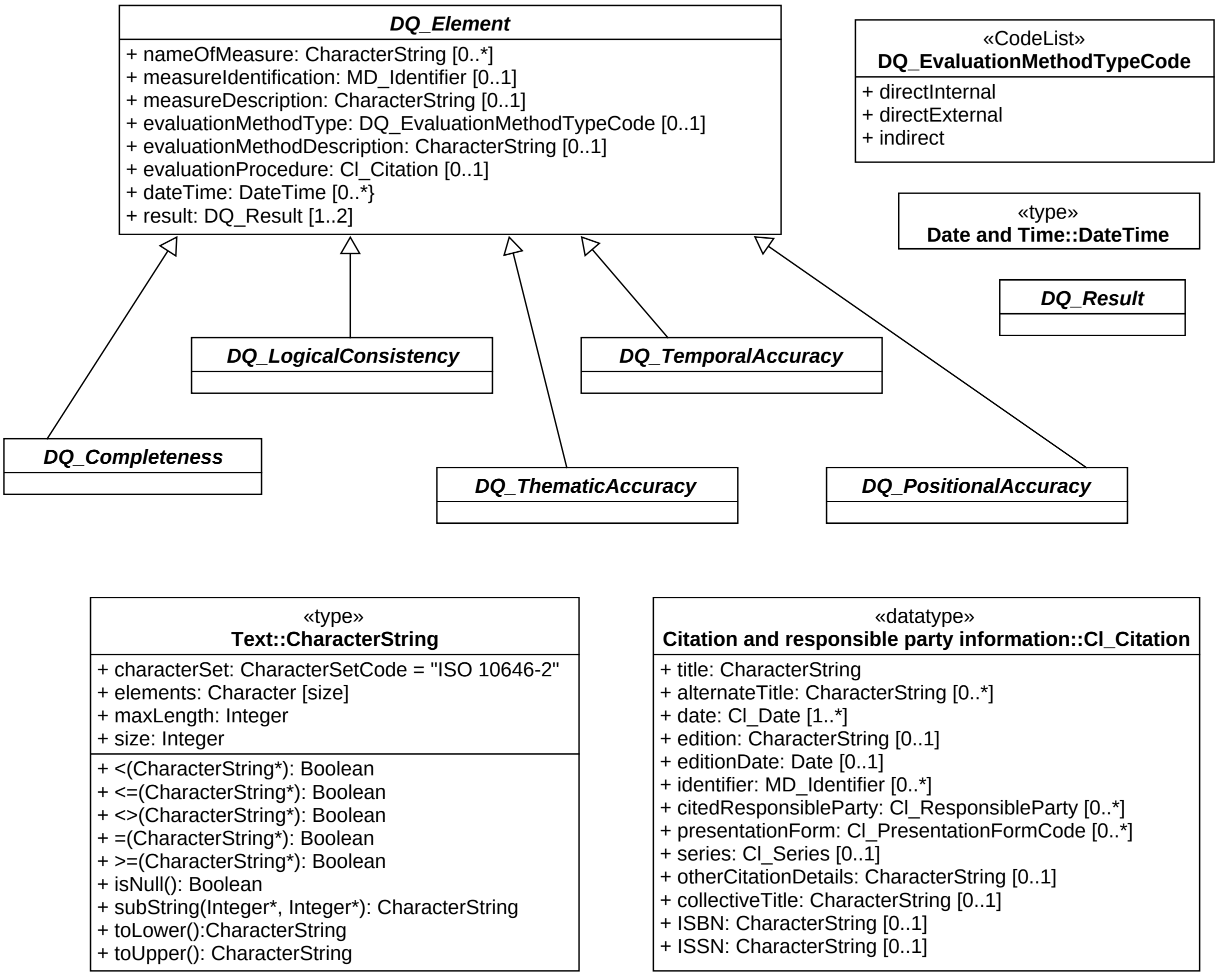


Figure B.10: DQ_Element [van Oosterom et al., 2011]

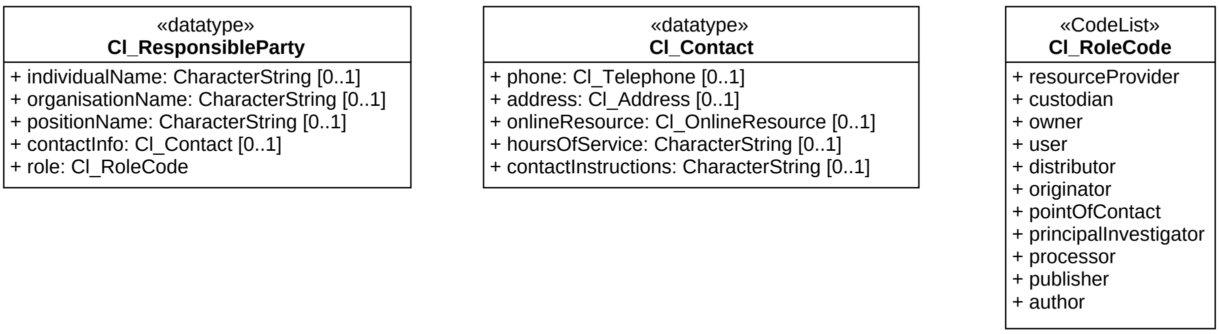


Figure B.11: CI_ResponsibleParty [van Oosterom et al., 2011]

C REFLECTION

For almost 200 years the Kadaster is the organization for land administration in The Netherlands. An elementary part is surveying boundaries. Over time different survey techniques were used; from chains to dGPS, with different metadata, administration and accuracy. Besides all these data are stored in a different manner, like field sketches and coordinate databases. In order to provide customers an rough overview of parcels for the entire country, an open cadastral map is available in PDOK. But there is no link from the boundaries of this map to its survey information. This research presents a data model design which relates all history survey data to its related boundary in the Dutch cadastral map. This model is based on the LADM; an international standard model for land administration.

The relationship between the methodical line of approach of the Master Geomatics and the method chosen by the student in this framework.
The general approach of this research was based on three elements; a preliminary investigation of the organization by reading literature, a training of a land surveyor and interviews with employees. This analysis provided insight in the drawbacks and benefits of the current organization and the abilities for improvements. The research stated requirements for improvements and designed a data model in UML to offer a solution for the current cadastral cases. This data model was tested by the use of test cases and foreign cadastral systems. This approach is corresponding to the methodical line of approach by the master Geomatics.

The relationship between the conducted research and application of the field geomatics.
According to its website, the study *Geomatics for the Built Environment* is concerned with the acquisition, analysis, management and visualisation of geographic data. It has the aim of gaining knowledge and a better understanding of the built and natural environments. The research presented in this thesis involves data management of survey data as main part. It had the aim to design a proper and straight link between survey data and the Dutch cadastral map. This management requires the use of UML and an deliberated analysis of the organization of data at the Kadaster.

Scientific relevance
The survey process at the Kadaster is complex with many involved datasets and data flows. For a long tim, this was an acceptable situation. But in a world with more and more data and software available on the internet, it is necessary to improve the cadastral survey system to make a next step to itself and its customers. But before starting to develop supportive software, it is a must to create a data model. this eases the understanding of a computer system before construction begins. In order to have a unified language between data architects and software developers, UML modelling

is a tool used all over the world.

The relationship between the project and the wider social context.
Designing a data model is not only in favor of the Kadaster itself, but as well on for its customers. A more unilateral retrieval of survey data, will supports customers to have a better defined and more secured extent of their property. Further this data model decrease the amount of work for boundary reconstructions. This limits the rate for certain operations and makes this tool accessible fror more people. A second element, which is of profit in a wider social context, is the fact that the gained knowledge by this research can more easily shared with other cadastral organizations by the use standards.

COLOPHON

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