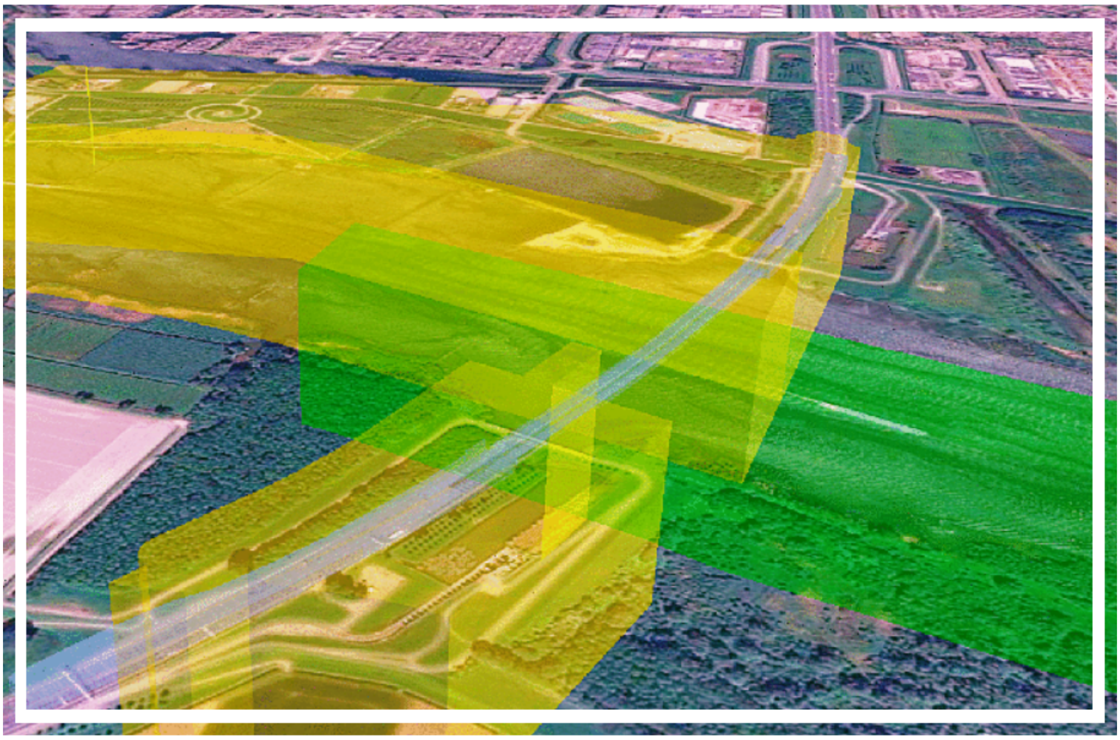
Modelling the legal spaces of 3D underground objects in a 3D LAS



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June 2022

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MODELLING THE LEGAL SPACES OF 3D UNDERGROUND OBJECTS IN A 3D LAS

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

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June 2022

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Acknowledgements

This research could not have been completed without my supervisors Eftychia Kalogianni and Peter van Oosterom. I would like to thank them for their guidance, support and feedback throughout the research. I would also like to thank Hendrik Ploeger (Delft University of Technology) for being the co-reader of my thesis.

During this research I held meetings with stakeholders in order to understand the challenges and needs of these stakeholders with regards to using models of underground objects and the current approach to the construction of objects below the surface. Next to this, several organisations provided models of underground objects, which was also helpful in my research. I would therefore like to thank the following persons: Abdullah Kara (Delft University of Technology), Jan Verbrugge, Melina de Boer and Tessa Eikelboom (Rijkswaterstaat); Bram Corneliszen, Niels Reyngoud, Alysha van de Meer and Mariska van der Steeg (Province of Gelderland); Jelle Gulmans, (Province of North Holland), Ronald Andringa (Province of Groningen); Klaas Schouten, Marco Scheffers and Jasper Vallentgoed (Engineering bureau of the municipality of Amsterdam); Peter Doorduin (Municipality of Rotterdam), Andries Nolles (Municipality of Groningen); Gerry de Koning and Tom Lonnee (Municipality of Almere); Valerie Dresscher and Rachel van der Auwera, (Evides); Peter Horst and Hans Joosten (PWN Water company); Corné Helmons and Eric Oosterom (RIONED); Maria Klonner (Swisstopo); Kilian Reyer, (Canton Basel-Stadt), Kean Huat Soon and Richard Loo (Singapore Land Authority); Behnam Atazadeh (University of Melbourne); Robbert van ‘t Veer and Jorrit de Jong (Antea Group); Michael Richtert (TenneT), Ties de Ruyter Wildt (Prisma Groep); George Floros and Anita Soni (Skanska UK).

Summary

Urbanisation and a lack of available construction land has led to the increased development of underground space which can contribute to the development of the urban areas by providing space for the construction of (infra)structural objects and networks necessary for a city to function and provide services to its citizens. The main challenge in developing the underground space is registering the RRRs of the underground objects into Land Administration Systems (LASs). Registering the RRRs of these underground objects in 3D can facilitate a better understanding, as well as a more efficient registration and clear visualisation of the RRRs.

To register the objects below the surface in a 3D LAS, 3D physical data as well as 3D legal data need to be registered and integrated into one model. BIM/IFC models can be (re)used as input data to register the 3D physical data. To register the 3D legal data in an efficient way, the ISO 19152:2012 Land Administration Domain Model (LADM) standard can be applied. The motivation for linking the BIM/IFC models with the LADM is that the geometry of the BIM/IFC models can be reused from design for the registration of the legal spaces in LASs or that BIM/IFC models can serve as a technical encoding for the exchange of data in LASs and thereby connect the workflows from the (AECOO) community. In this research the mapping of the basic classes of the LADM to IFC entities is presented to support the linkage of these two data models.

Research to investigate the implementation of the LADM in a 3D LAS, with the use of BIM/IFC models as input for 3D objects on the surface such as apartment buildings and infrastructure objects has been carried out. The result of this research was that the RRRs of objects on the surface can easily be determined by applying the legal information from the enriched BIM/IFC model. No research has been done in implementing the LADM in a 3D LAS, with the use of BIM/IFC models as input for 3D objects below the surface. This research will therefore complement the earlier related work, thereby supporting the modelling of legal information of all 3D objects, below as well as on the surface.

To solve the challenges that currently prevent the implementation of 3D objects below the surface in LASs and to harmonise the different (technical and semantic) requirements for LASs a standardised workflow was developed and is presented in this thesis. The standardised workflow shall provide more insight into the modelling of the legal spaces of 3D objects below the surface, stimulate the exchange of data across the AECOO community, and promote the use and development of 3D LASs.

Two case studies were conducted, where objects (pipes) from the sewage system and a tunnel were used. The tunnel was a BIM/IFC model, while the sewage pipes were converted to an BIM/IFC model. The models from both cases were stored according to the LADM standard in a 3D LAS, represented by a 3D database and a 3D geospatial visualisation platform. The main results are that the technical part of the proposed workflow supports the registration of 3D underground objects in 3D LAS and that for underground objects the legal spaces from the 2D parcels that are extruded to 3D volumetric parcels, are sufficient enough to describe the RRRs of the objects.

Samenvatting

Verstedelijking en een gebrek aan land om op te kunnen bouwen heeft ertoe geleid dat er een toename is in de ontwikkeling van de ondergrondse ruimte, voor de infrastructuur en netwerken die noodzakelijk zijn voor een stad om te functioneren en de inwoners van dienst te kunnen zijn. De voornaamste uitdaging in het ontwikkelen van de ondergrondse ruimte is het registreren van de rechten, beperkingen en verantwoordelijkheden (*Engels: Right, Restrictions and Responsibilities, RRRs*) van ondergrondse objecten in Land Administratie Systemen (LASs). Het registreren van de 'RRRs' van van deze ondergrondse objecten in 3D leidt tot een betere begrip en efficiënte registratie en visualisatie van de 'RRRs'.

Om deze ondergrondse objecten te registreren in een 3D LAS, moet 3D fysieke en 3D juridische data worden geregistreerd en geïntegreerd in één model. BIM/IFC modellen kunnen worden hergebruikt om de fysieke data te registreren. De juridische data kan worden geregistreerd volgens de ISO standaard 19152:2012 Land Administration Domain Model (LADM). De motivatie om the BIM/IFC modellen te koppelen aan het LADM is dat aan één kant de geometrie van de al ontworpen BIM/IFC modellen kan worden hergebruikt en aan de andere kant dat BIM/IFC modellen kunnen dienen als een technische encodering voor het uitwisselen van data in LASs en daarmee de workflows van de AECOO (*Engels: Architecture, Engineer, Constructor, Owner / Operator*) kunnen verbinden. In dit onderzoek zullen de basisklassen van het LADM aan de IFC entiteiten worden gekoppeld om de verbinding tussen de twee data modellen te ondersteunen.

De implementatie van het LADM in een 3D LAS met gebruik van BIM/IFC modellen als invoer voor 3D objecten op het (aard)oppervlak, zoals een appartementencomplex, is reeds onderzocht. Wat volgde uit dit onderzoek is dat de 'RRRs' van objecten op het (aard)oppervlak makkelijk bepaald kunnen worden door het toepassen van de juridische informatie van het BIM/IFC model dat verrijkt was met deze informatie. Er is echter geen onderzoek gedaan naar het implementeren van het LADM in een 3D LAS met het gebruik van BIM/IFC modellen voor 3D objecten onder het (aard)oppervlak. Het eerder gedane onderzoek zal met het onderzoek in deze thesis worden gecomplementeerd, waardoor het modelleren van juridische informatie van alle 3D objecten, zowel onder als boven het (aard)oppervlak zal worden ondersteund.

Om de uitdagingen die de implementatie van 3D objecten onder het (aard)oppervlak in LASs verhinderen en om de verschillende (technische en semantische) vereisten voor LASs te harmoniseren, is er een gestandaardiseerde workflow ontwikkeld die wordt gepresenteerd in deze thesis. De gestandaardiseerde workflow zal meer inzicht bieden in het modelleren van de juridische ruimtes (de RRRs) van 3D objecten onder het (aard)oppervlak, de uitwisseling van data stimuleren in de AECOO gemeenschap en het bevorderen van het gebruik en de ontwikkeling van 3D LASs.

Twee case studies zijn uitgevoerd waarbij één studie leidingen van een riolering gebruikt waren en bij de andere studie een tunnel gebruikt was. De tunnel was een BIM/IFC model en de rioolleidingen waren geconverteerd naar BIM/IFC modellen. De BIM/IFC modellen van beide case studies werden opgeslagen volgens de LADM standaard in een 3D LAS, vertegenwoordigd door een 3D database en een 3D visualisatie platform. The voornaamste resultaten zijn dat het technische deel van de voorgestelde workflow het registreren van ondergrondse objecten in een 3D LAS ondersteund en dat voor ondergrondse objecten de juridische ruimte van de 2D percelen, die zijn geconverteerd naar 3D volumetrische percelen, geschikt zijn om de 'RRRs' van de ondergrondse objecten te kunnen beschrijven.

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Acronyms

AECOO - Architect, Engineer, Constructor, Owner / Operator

BIM - Building Information Model

BRK - Basisregistratie Kadaster (*English: Cadastral registry)*

CRS - Coordinate Reference System

EPSG - European Petroleum Survey Group

ETL - Extract, Transform, Load

IFC - Industry Foundation Classes

ISO - International Organization for Standardization

LADM - Land Administration Domain Model

LAS - Land Administration System

NEN - Nederlandse Normalisatieinstituut (*English: Dutch standardisation institute)*

OGC - Open Geospatial Consortium

OID - Object identifier

PDOK - Publieke Dienstverlening Op de Kaart (*English: Public service on the map*)

PLR - Public Law Restriction

RRRs - Rights, Restrictions, Responsibilities

WGS - World Geodetic System

1. Introduction

In this chapter, the challenges facing the development of the underground space as well as the methods to solve these challenges are given. The objectives to solve the challenges and the research questions derived from these objectives are then presented, followed by the scope and the relevance of this research. The chapter concludes with the outline of the thesis.

1.1 Background

Urbanisation, caused by the migration of people from rural to urban areas as well as population growth in general, has led to the rapid development of cities around the world (Kookana et al., 2020). The lack of available construction land within these urban areas has resulted in an increase in the development of the multi-level properties and the underground space (Kim et al., 2015, Zhen, 2019).

The multi-level properties can consist of multiple spatial units with different owners. Registering the Rights, Restrictions, and Responsibilities (RRRs) of these spatial units in 2D might result in registrations that are not readable and understandable and thereby not helpful (Stoter et al., 2016). The multi-level properties should therefore be registered as 3D objects, since registering objects in 3D can provide a better understanding and clear visualisation of the RRRs of the spatial units (Kim et al., 2015, Atazadeh et al., 2018, 2019).

Developing the underground space can contribute to the further development of urban areas by providing space for the construction of (infra)structural objects and networks necessary for a city to function and provide services to its citizens. Utilising the underground space will help cities cope with urbanisation and provide support for sustainable development (Broere, 2016, Peng et al., 2021). Objects in the underground space should also be registered as 3D objects since these objects can be part of multi-level properties, for example, an underground parking garage that is part of a building on the surface, but which might have a different owner. Also, even though there are many objects in the underground space that are not part of a multi-level property, these objects can still be connected, directly or indirectly (below another property), to objects on the surface and should thus be registered as 3D objects in LASs.

To digitally represent a physical model of the 3D objects, a Building Information Model (BIM), which comprises the geometry and the semantic information of an object during the whole building lifecycle, can be used (Kalogianni et al., 2020a). The most commonly used BIM format is the Industry Foundation Classes (IFC), ISO 16739:2018. IFC is an open standard developed to stimulate interoperability of different types of BIM models (ISO, 2018). Enhanced interoperability facilitates data sharing and integration and stimulates the reuse of the data, especially from the design stage. A need for data exchange and interoperability within the Architecture, Engineering, Construction, Owner Operator (AECOO) community, as well as the rapid demand and even mandate from industry and the governments around the world has resulted into the increasing use of BIM/IFC models (Kalogianni et al., 2020a).

1.2 Research motivation

The main challenge in developing the underground space is defining and registering the RRRs of the objects present in the underground space into LASs (Peng et al., 2021). The implementation of objects in the underground space requires the use of 3D objects. However, most LASs in countries around the world register objects on and below the surface in 2D. When objects below the surface are registered in 2D, the relations between objects below and on the surface are not explicitly provided (Yan et al., 2019). Figure 1 shows a 2D model of an underground utility network, where it is not clear how the utility pipelines below the surface are related to objects above the surface. It is also not clear how the pipelines below the surface are related to each other, since the depth cannot be visualised in 2D. LASs that register these objects in 3D can clearly define the relationships between the RRRs and the spatial units (3D objects), while the registration of the objects in the third dimension (3D) facilitates a better understanding, as well as a more efficient registration and clear visualisation of the RRRs (Kim et al., 2015, Atazadeh et al., 2018, 2019). Figure 2 shows a schematic image of a 3D LAS, where the relations between the objects below and above the surface are more clear.

To register the objects below the surface in a 3D LAS, 3D physical data as well as 3D legal data need to be registered and integrated into one model, which can be challenging (Atazadeh et al., 2018). BIM/IFC models can be (re)used as input data to register the 3D physical data. To register the 3D legal data in an efficient way, the ISO 19152:2012 Land Administration Domain Model (LADM) standard can be applied. The LADM is an international standard, a flexible conceptual model that provides a formal language for describing both the spatial and non-spatial information in the land administration domain. Compliance with this standard leads to a more efficient LAS, where data can be exchanged and the quality of data ensured, sustained and effectively managed (Lemmen et al., 2015). To achieve an integrated model, the classes of the LADM should be mapped to the elements of the BIM/IFC model (Atazadeh et al., 2018).

One of the two scenarios for linking the LADM classes to the IFC entities in this research is that the geometry from BIM/IFC models can be reused from design for the registration of the legal spaces in LASs. The other scenario is that BIM/IFC models can be reused from design to serve as a technical encoding for the exchange of data in LASs and thereby connect the workflows from the AECOO community.

Another challenge is that LASs around the world vary, since they depend on various aspects, such as socioeconomic situation, scope of the LAS, existing situation on land registration, data availability, standards, vision for future LAS, etc. This mosaic results in different requirements for the collection, validation, registration and visualisation of 3D underground (cadastral) data.

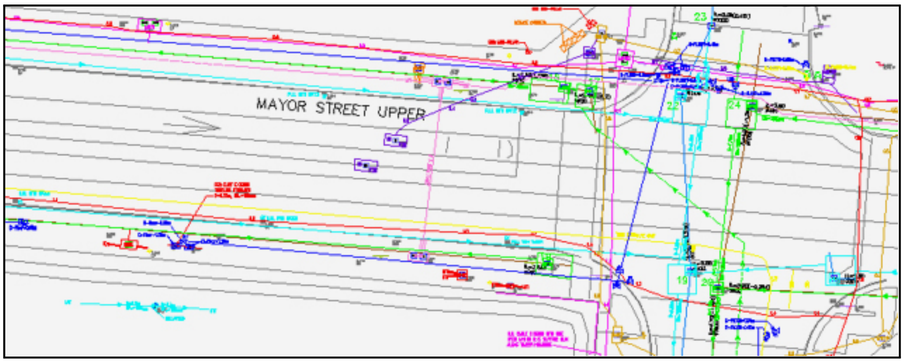


Figure 1. 2D model of an underground utility network (IndiCOMET, 2017)

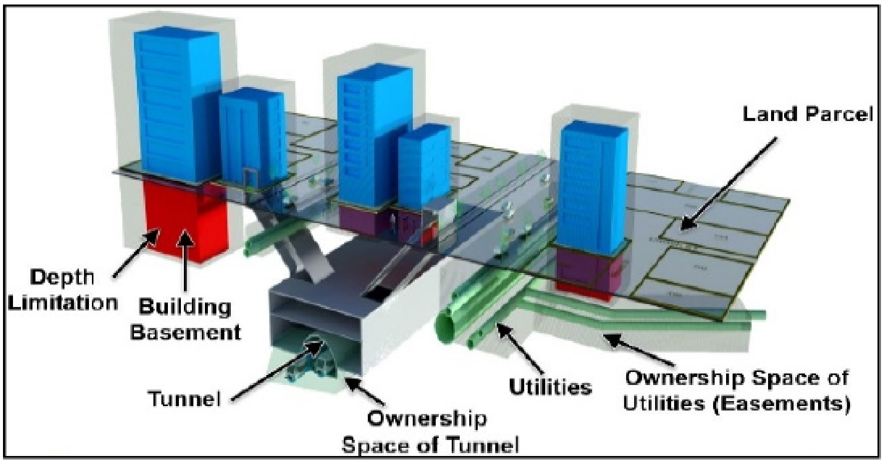


Figure 2. Schematic image of a 3D LAS (Saedian, et al., 2021)

1.3 Objective

To solve the challenges that currently prevent the implementation of 3D objects below the surface in LASs and to harmonise the different (technical and semantic) requirements for LASs a standardised workflow will be developed and presented in this thesis in order:

- to collect, process, store, visualise, disseminate and query 3D underground data in a 3D LAS according to ISO 19152:2012 (LADM standard)
- to model the relations between underground objects and their legal spaces
- to model the relations between underground legal spaces and the 2D parcels on the surface (that will be modelled as 3D volumetric columns)
- to connect the workflows from AECOO where BIM/IFC models (ISO 16739:2018) are used as a data input for 3D LAS

The standardised workflow shall provide more knowledge and insight into the modelling of the legal spaces of 3D objects below the surface, stimulate the exchange of data across the AECOO community, industry and government, promote the use and development of 3D LASs and contribute to the decision-making process of the development of the underground space.

1.4 Research questions

In order to achieve the objective, the main research question is formulated, which is:

How can the legal spaces of 3D objects below the surface be modelled in 3D Land Administration Systems based on ISO 19152:2012 in the context of reusing BIM/IFC models from design?

From this main research question the following sub-questions are derived:

1. *Which 3D objects below the surface are there and how are they currently modelled in LAS?*

2. *How does the current legislation in the Netherlands support the registration of 3D underground objects in LASs and how can the legislation be improved?*

3. *Who are the stakeholders in registering the 3D objects below the surface in LASs?*

4. *What are the requirements (technical and semantic) to register BIM/IFC models of 3D objects below the surface?*

5. *How can the legal spaces of 3D objects below the surface be efficiently stored, visualised and disseminated?*

6. *How can the effectiveness of the proposed workflow be evaluated?*

1.5 Scope

This research focuses on modelling the legal spaces of 3D objects below the surface in LASs. The primary 3D objects below the surface of which the legal spaces will be modelled are tunnels and utilities. These objects are chosen since tunnels and utilities comprise the largest part of the underground space. The utilities are defined as the gas, water, sewage, drainage pipes, electricity and telecommunication cables and networks below the underground space.

The tunnels and utility objects should be modelled according to the most recent ISO standard for IFC (ISO 16739:2018), IFC 4. If there are not enough or no IFC 4 models collected, then tunnels and utilities modelled according to the previous ISO standard of IFC 2x3 (ISO/PAS 16739:2005) will be used. If there are not enough or no IFC models collected, then non-IFC models of tunnels and utilities will be used. The non-IFC models will then be converted to IFC models.

1.6 Relevance

Research to investigate the implementation of the LADM in a 3D LAS, with the use of BIM/IFC models as input for 3D objects on the surface such as apartment buildings and infrastructure objects has recently been carried out (Broekhuizen, 2021). The result of this research was that the RRRs of objects on the surface can easily be determined by applying the legal information from the enriched BIM/IFC model. This is especially important when the physical models and their legal spaces need to be compared and be consistent, as could be the case with complex built structures (Atazadeh et al., 2018).
However, there has been no research done in implementing the LADM in a 3D LAS, with the use of BIM/IFC models as input for 3D objects below the surface. This research will therefore complement the earlier related work, thereby supporting the modelling of legal spaces of all 3D objects, below as well as on the surface.

1.7 Thesis outline

The first chapter provides the problem statement and states the objective to solve the challenges presented in the problem statement. The research questions that are formulated to achieve the objective are also given in the first chapter. Chapter two, Theoretical framework, gives an introduction into LASs and Public Law Restrictions (PLR's) and presents an overview of the current situation of the (modelling of the) legal spaces of 3D objects below the surface in countries around the world. The second chapter also provides information on standardised data models and the integration of legal and physical models. Hereafter, the methodology is presented in the third chapter where the literature research, data collection and tools used in this research are discussed. Chapter three also provides an alternative workflow to register objects below the surface. The fourth and fifth chapter present the result of this research. In chapter four the mapping of the LADM classes to the IFC elements is provided and in chapter five the implementation of the prototype and visualisation of the two case studies is presented. The sixth and final chapter, provides the answers to the research questions, a discussion on the research, gives recommendations based on the research and provides suggestions for future research.

2. Theoretical framework

In this chapter, first, an introduction into Land Administration Systems (LASs) and Public Law Restrictions (PLR's) is given. Then, the current situation with regards to the registration of 3D objects below the surface in countries around the world is presented. Hereafter, standardised data models, in particular the LADM and BIM/IFC, will be discussed. This section concludes with recent research on the integration of legal and physical models for registering the RRRs of 3D objects below the surface. This chapter provides the information needed to better understand the area of research, which will contribute to answering the research questions formulated in Chapter 1. Introduction.

2.1 Land Administration Systems

A Land Administration System (LAS) is a system where land administration policies are implemented with the use of an (spatial) information infrastructure. Land administration is the set of processes used to register the Rights, Restrictions and Responsibilities (RRRs) associated with the land. The 'Rights' deal with the ownership, use and tenure of the land. The use of the land can be limited by 'Restrictions'. The 'Responsibilities' concern obligations to maintain the land according to social and environmental standards (Enemark, 2009).

Land can be registered in a LAS through a deed or a title. If land is registered through a system of deed registration, the deed is the document that describes the transaction of the property. With a deed registration, however, there is no proof of the ownership rights of the parties in the transaction. The deed merely proves the fact that a transaction took place without the guarantee that the party claiming to be the owner of the land that is to be transferred is actually the owner (Henssen, 1995, Zevenbergen, 2002).

In a system with title registrations, the transfer of the land with its associated rights is not registered, but the consequence of this transfer of rights. This consequence, meaning the right of ownership of the land, as well as the name of the owner and the land itself are registered, thereby creating the title. With a system of title registration the ownership of a property is correctly registered and guaranteed by the state (Henssen, 1995, Zevenbergen, 2002).

If land administration policies are well designed and implemented, then this shall result in security of land tenure and sustainable development of the land, thereby contributing to the welfare of the people (Enemark et al., 2021). In LASs, the land parcels as well as the RRRs associated with these parcels are both registered. Most LASs around the world register the parcels and other objects where RRRs can be associated with, in 2D (FIG, 2018).

2.2 Public Law Restrictions

In order to restrict the ownership and use of spatial units for the public interest, Public Law Restrictions (PLR's) are created and applied in specific cases. These restrictions are based on the interpretation of public law. Public law deals with the relations between the government and individuals and between individuals if the relations between individuals are of importance for the government or the community. Due to urbanisation, there is less available land and more development of structures in the underground space. This trend has resulted in more PLR's restricting the rights of ownership and use, in order to make it able to use the space for the benefit of society (Kitsakis et al., 2021). A system where land administration and PLR's are integrated has been proposed by several academics (Indrajit et al., 2021).

2.3 Registration of 3D objects below the surface in LASs worldwide

Due to urbanisation, there has been an increase in the development of multi-level properties and the underground space. Cities around the world are being extended below ground and develop their underground spaces for optimal usage. A review of how countries around the world currently model (specific) 3D objects below the surface and the associated legal spaces in LASs and registries, as well as the recent research that is being carried out in order to improve this registration, is presented in this section.

2.3.1 The Netherlands

2.3.1.1 Ownership and use of the land in the Netherlands

According to article 20 of book 5 of the Dutch Civil Code (*Dutch: Burgerlijk Wetboek*), ownership of the land in the Netherlands is defined as the land on the surface as well as all the ground layers below, groundwater that is brought to the surface by a pump or a well, water that is on the surface and is not connected to water on land of a different owner, structures on and below the land surface as long as these structures are not part of a property with a different owner, space above the surface and all the plants that are connected to the land (principle of superficies solo cedit).

An exception to this definition is the ownership of a network consisting of multiple cables and pipes used to transport gaseous, liquid or solid substances, energy, and information, that is constructed above or below the surface of the land of the landowner. The ownership of the network belongs to the party that constructed the network and the eventual legal successor(s) (Overheid.nl, 2018).

Article 21 of book 5 of the Dutch Civil Code states that the owner of land is authorised to use the land as well as the space above and below the surface. Other parties can use the land owned by a different owner if the use is so high above or so low below the surface of the land that the owner does not have any interest in objecting to this use (Overheid.nl, 2018).

The owner of the land also does not have aviation rights in the space above the surface of the land (Overheid.nl, 2018).

Book 5 of the Dutch Civil Code also describes other (limited) rights that apply to the ownership and use of land which are the right of superficies (*Dutch: opstalrecht)*, the right of long lease (*Dutch: erfpacht*) and easements (*Dutch: erfdienstbaarheid*). The right to superficies provides the right to construct buildings or other structures above or below other structures or land that is owned by someone else. The right of long lease gives the right to use an object but unlike the right of superficies, the entitled party (the lessee) is not the legal owner thereof. The long lease can apply to (parts of) a property or space, for example, the parking garage can be leased but not the building that is built on top of it. An easement is a burden on a parcel, where another parcel has certain rights over. An example is the extension of a tunnel located on one parcel to another parcel owned by a different owner that is burdened with the easement (Stoter et al., 2012, Overheid.nl, 2018).

The ownership (and extraction) of minerals under the surface are regulated by the Dutch Mining Law (*Dutch: Mijnbouwwet*). In general, all minerals on as well as below the surface are owned by the state. However, the Dutch Mining Law states that the law only applies to minerals extracted lower than 100 metres below the surface. The Dutch government has the right to sell licences to entities, such as mining companies, that will use the land of a different owner to extract the minerals located at lower than 100 metres below the surface of the land. The ownership of geothermal heat by the state starts at lower than 500 metres below the surface (Overheid.nl, 2022a).

The Telecommunication Law (*Dutch: Telecommunicatiewet*) states in article 5.1 that owners of public or private land, where the private land does not form one whole with an inhabited property, will need to tolerate the construction, maintenance and removal of cable and connection points of electronic communication networks. Owners of private land where the inhabited property does form one whole, will need to tolerate the construction, maintenance and removal below and above the surface of the land and in buildings constructed on the land if these objects are necessary to connect users to the electronic communication network (Overheid.nl, 2022b).

The Electricity Law (*Dutch: Elektriciteitswet*) states that the connections to buildings from an electricity network are owned by the company that owns the network. For other utility networks, the Dutch Law does not state that the connections to the home are owned by the owner of the network. Ownership of the connections to buildings from utility networks varies across Dutch municipalities (Janssen, 2010). An example is the demarcation of the ownership between the part of the sewage and drainage system that is publicly owned and the part that is privately owned. A number of Dutch municipalities state that the private ownership of the sewage connections to the homes ends at the parcel boundary or near the parcel boundary where the blow-off valve (*Dutch: ontstoppingsstuk*) is located. Other municipalities state that the ownership ends at the connection to the main sewer or at 50 cm from the building facade (which is the border between sewage systems inside and outside of a building, according to Dutch national guidelines) (Janssen, 2010).

The Removal of Impediments Law (*Dutch: Belemmeringenwet Privaatrecht*) states that the Dutch minister of Infrastructure and Water Management can impose an ‘obligation to consent’ on a privately owned parcel, where the private owner has to accept that, for example, a utility company constructs part of their network on the private owner’s land. The Removal of Impediments Law will only be used if no agreement has been reached between the private owner and, for example, the utility company (Overheid.nl, 2010).

2.3.1.2 The Dutch LAS

In the Netherlands, the Dutch Cadastre (*Dutch: Kadaster*) is, according to the Law on the Cadastre (*Dutch: Kadasterwet*), responsible for the registration of the three types of cadastral objects: parcels, apartments and utility networks. Utility networks are registered as legal objects in the Dutch Cadastre separate from the parcels (Stoter et al., 2012, Overheid, 2021a). The Dutch Cadastre registers these cadastral objects in 2D.

Physical objects, for example, tunnels, are not considered legal objects but their property rights should still be registered with the use of limited rights on 2D parcels: the right of superficies, the right of long lease and easements (Stoter et al., 2012).

To register the legal spaces of the 3D objects (below the surface) with the attached limited rights, the Dutch Cadastre adheres to the ‘*specialty principle*’. *‘The principle of specialty implies that in land registration, and consequently in the documents submitted for registration, the concerned subject (man) and object (i.e. real property) must be unambiguously identified’* (Hensen, 1995). This means that if a limited right is attached to a part of a parcel then the whole parcel needs to be divided in a manner that no parcel with the limited right intersects with parcels that do not have the same right attached to it. Applying the specialty principle can result in the occurrence of many small parcels (Stoter et al., 2016; 2017).

Next to registering the (limited) rights of objects above and below the surface, the Dutch Cadastre also registers the Public Law Restrictions (PLR's). Examples of these PLR's are restrictions associated with monuments, living environment and soil protection (Kadaster, 2022a).

The Law on Cadastre states that the Dutch Cadastre is responsible for making clear where cable and pipes are located which is reaffirmed in the Law on information exchange of aboveground and underground networks (*Dutch: Wet informatie-uitwisseling bovengrondse en ondergrondse netten en netwerken*) (Overheid.nl, 2019, 2021b). This responsibility is executed by the Kabels en Leidingen Informatie Centrum (KLIC), a department of the Dutch Cadastre. The KLIC does not register the location (or the RRRs) of the cables and pipes, but exchanges the data of the utilities from and between different utility network companies (Kadaster, 2022b).

2.3.1.3 3D LAS in the Netherlands

A workflow has been developed by Stoter et al. (2017), regarding the registration of multi-level properties with objects below the surface in 3D. In this workflow, legal volumes were created from BIM models which were then validated. With the use of a 2D cadastral map a 3D-PDF was created for the visualisation of the legal volumes and was used as a legal source document. Figure 3 and 4 show the visualisation of the legal volumes of Delft Station and the congress Hotel Maritim respectively. The 3D geometry of the legal volumes created from the BIM models were also stored in the Dutch Cadastre which could be used to update the legal source document in the future (Stoter et al., 2017). It is however not possible to extract coordinates from a 3D PDF, thus, the use of BIM/ IFC models is preferred.

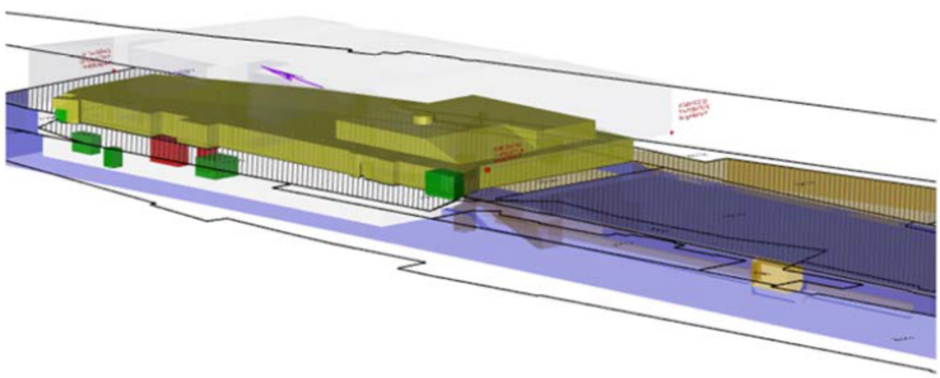


Figure 3. Visualisation of the different legal spaces of Delft station, The Netherlands (Stoter et al., 2017)

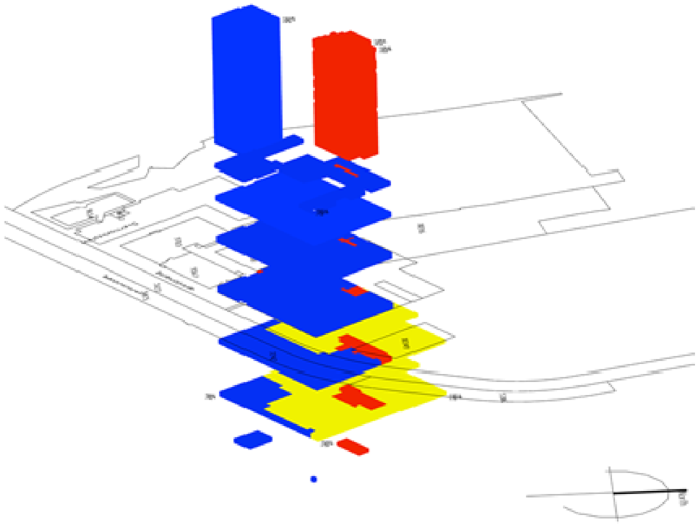


Figure 4. Visualisation of the different legal spaces of the congress hotel Maritim, Amsterdam, The Netherlands. Red: residential building, blue: congress centre; yellow: underground parking garage (Stoter et al., 2017).

2.3.2 Poland

In Poland, the current cadastral system consists of two registers: one for the location and the geometry of the land (legal spaces) and buildings and one for the legal information (Bieda et al., 2020). The registration of 3D objects below the surface can be complicated, since these objects can have different owners than those of the objects on the surface. The 3D objects below the surface therefore need to be registered separately.

A new method is proposed to extend the current cadastral conceptual model with new classes to support a 3D cadastre. One of these new classes represents the 3D objects below the surface (EGB_BuildingBlockUnderground3D), while another class represents the 3D objects on the surface (EGB_BuildingBlockAboveground3D). The class that represents the legal space (EGB_BuildingLegalSpace3D) is composed of these two classes (Bieda et al., 2020). Figure 5 shows the proposed conceptual 3D cadastral model.

The “object-oriented spatial plot” is a concept proposed in Poland to register underground objects. In this concept the 3D object below the surface, as well as the spatial plot that it occupies, are described and separately registered in three dimensions. It is highlighted that amendments in the Polish real estate law are necessary to implement this concept (Matuk, 2019). Figure 6 shows an example of the proposed object-oriented spatial plot.

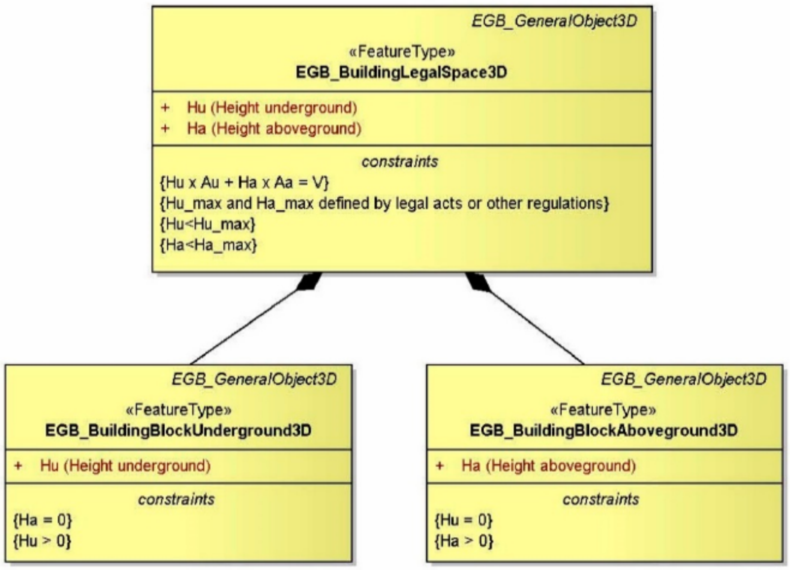


Figure 5. Conceptual 3D cadastral model (Bieda et al., 2020).

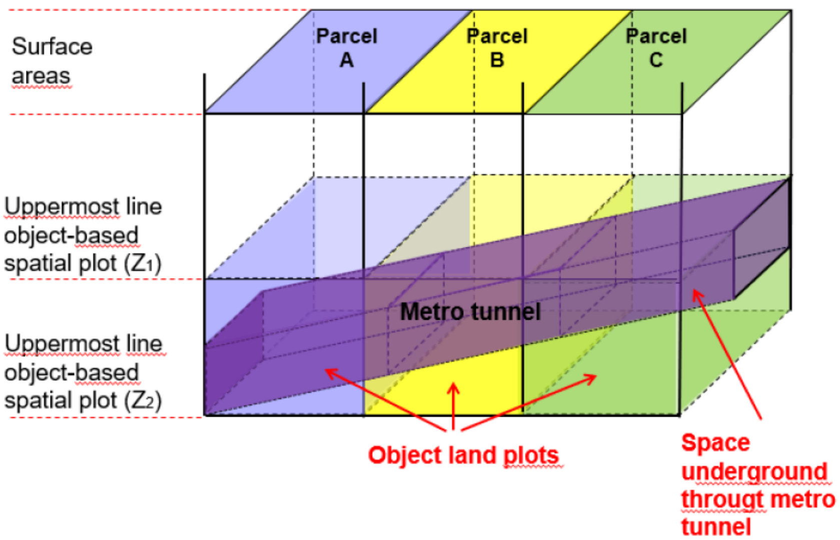


Figure 6. Example of the proposed object-oriented spatial plot (Matuk et al., 2018).

2.3.3 South Korea

Moreover, in Korea, land administration is based on a 2D cadastral system and on the ISO 19152:2012 LADM standard that registers the boundaries and other geometries of the cadastral objects, while a real property registration system registers the legal information. Due to its two-dimensional character the cadastral system is not able to register 3D objects below the surface. The real property registration system can register these objects by defining certain extents of the legal space under the surface. In order to prepare the system for 3D objects below the surface, Kim et al. (2017) propose to extend the cadastral model with two packages: one for the surveying and mapping of the underground objects and one for the 3D underground parcels. Figure 7 shows the data model of the newly proposed surveying and mapping packages. The cadastral model will also be integrated with the LADM in order to register the RRRs.

Research by the same authors presents a framework in which 3D underground parcels can be registered. In this framework the parcel is prepared by collecting data from surveying and existing 2D maps. Then, the 3D underground parcel is defined by modelling the legal spaces and taking into account the absolute or relative height. At the end, the legal rights to the 3D underground parcel are registered. To make this framework possible, Korean law does need to be altered (Kim et al., 2019). Figure 8 shows the registration framework for 3D underground parcels.

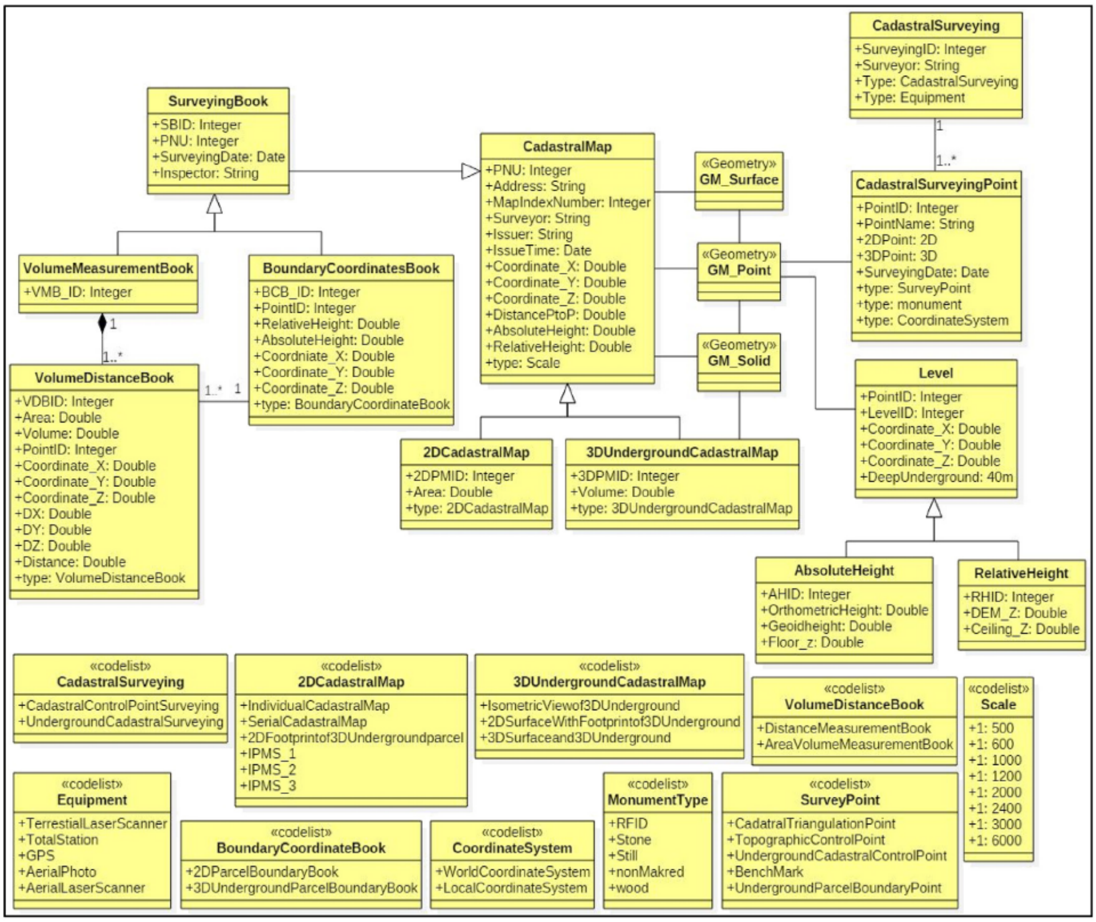


Figure 7. Data model of the newly proposed surveying and mapping packages (Kim et al. 2017).

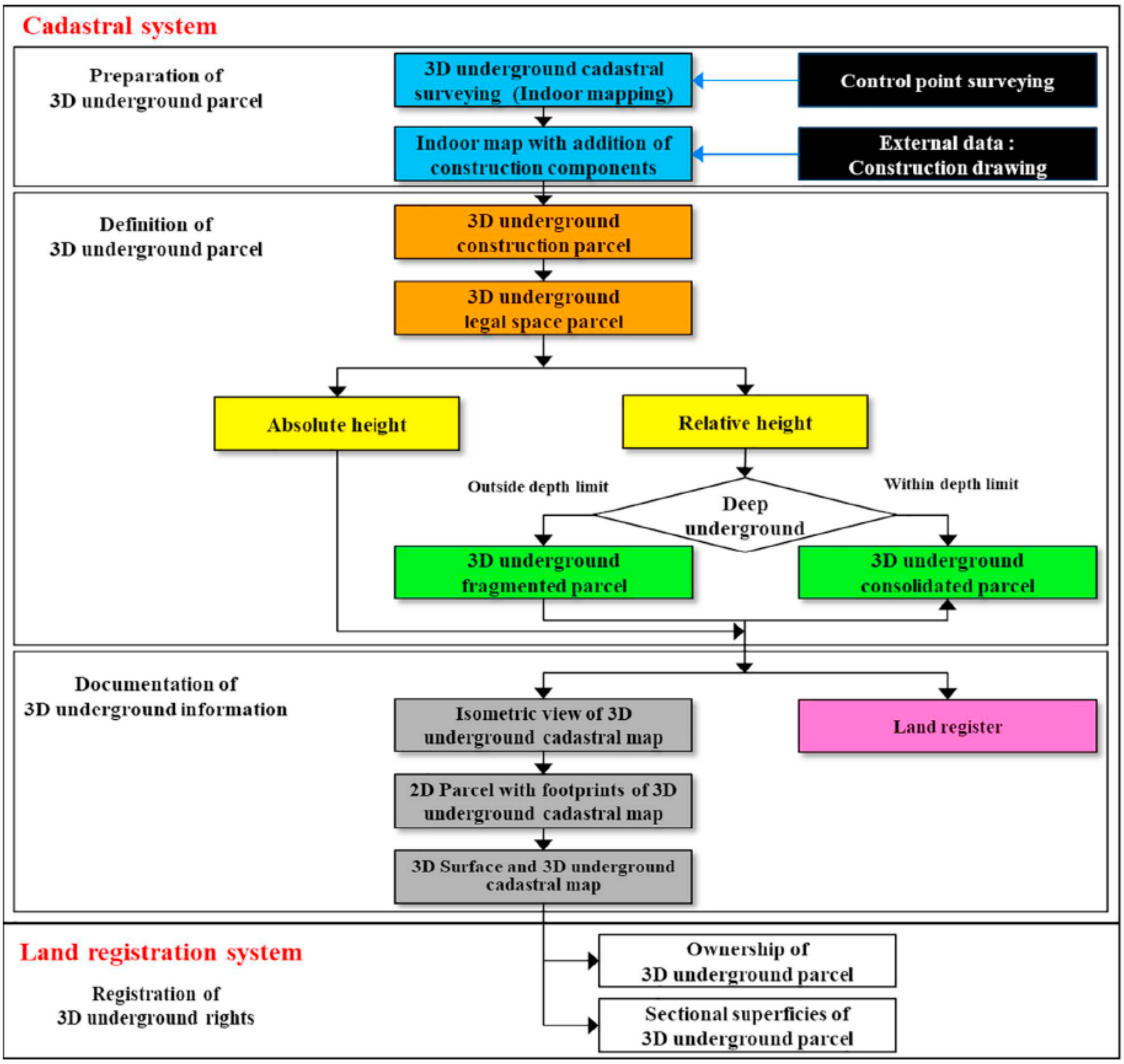


Figure 8. Registration framework for 3D underground parcels (Kim et al. 2019).

2.3.4 Singapore

In Singapore, land owners in general own the land up to 30 metres below the mean sea level, although the law makes it possible to acquire a specific part of underground space if necessary (Yan et al., 2019). The underground spaces are registered in the cadastre as subterranean lots based on the 2D drawings. Additional surveys can take place which are registered in 2D with the addition of the elevation relative to the mean sea level. Due to the complexity and overlap of the 2D drawings of the lots, there is a need for a 3D cadastre (Khoo, 2011). With regards to the utilities, an underground utility 3D data model based on the LADM is currently being developed in order to better register and manage the utilities and their networks in Singapore (Yan et al., 2019, 2021).

2.3.5 Croatia

Croatia does not register tunnels in its cadastral system, while utilities are separately registered in the Utility Cadastre. In this cadastre the horizontal and vertical location of the utility lines are registered, although the legal relations are registered in land books (Vucic, N. et al., 2011). Since 2016, however, a new law has been adopted to retrieve information on the space that utilities occupy and to incorporate the Utility Cadastre into the Croatian LAS (Vucic, N. et al., 2017).

2.3.6 Slovakia

In Slovakia, 3D objects below the surface are registered in a 2D paper-based cadastre. A new method has been proposed in order to register underground objects where the Land Administration Domain Model (LADM) is taken into account (Janečka et al., 2018). In this research a 3D wire-frame model of a wine-cellar was made from the points of the dataset with the use of specific software. To register the 3D model of the wine-cellar topology-based encoding was used. The 2D parcels were modelled according to the principle of the LADM class 'LA_BoundaryFaceString'. The 3D boundaries of the wire-frame were modelled according to the LADM class 'LA_BoundaryFace'. Both models were then integrated in a spatial database and visualised (Janečka et al., 2018). Figure 9 shows the side view of the model where boundary face strings and boundary faces are both used to determine bounded and unbounded 3D volumes.

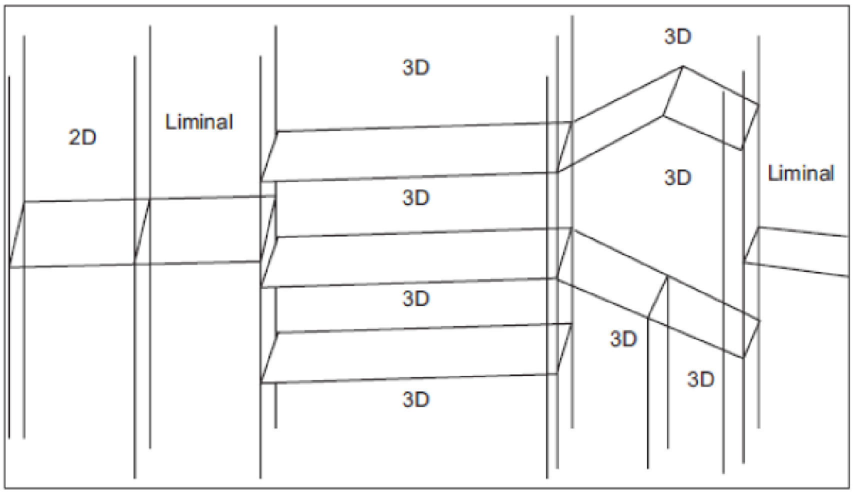


Figure 9. Side view of the model where boundary face strings and boundary faces are both used to determine bounded and unbounded 3D volumes (Janečka et al., 2018).

2.3.7 Serbia

The Serbian cadastre registers 3D objects below the surface that are part of a building, as building units. These building units are not visible on the cadastral map but data and attributes are stored in the database. 3D objects below the surface that are independent of a building or other structure are linked to the parcel on which the entrance to the object is located. For the registering of utilities, there exists a separate cadastre.

The existence of these two cadastres prevent the overlapping of information on cadastral maps (Visnjevac, N. et al., 2018). However, both cadastres use different semantics, software, data storage etc. resulting in a lack of interoperability and slow information processing.
Research has been done in developing a country based LADM profile that will be extended with utility network elements to create a unified data model for both cadastres, solving the lack of interoperability (Radulovic et al., 2019). Figure 10 shows a part of the unified data model via an instance-level diagram used for the registration of ownership and the lease of the use of underground chambers in a fortress.
A 3D cadastre has been proposed in which the two cadastres can be integrated into one system, and where, due to the three-dimensional aspect, the overlapping of information would not be a problem to visualise (Visnjevac et al., 2018).

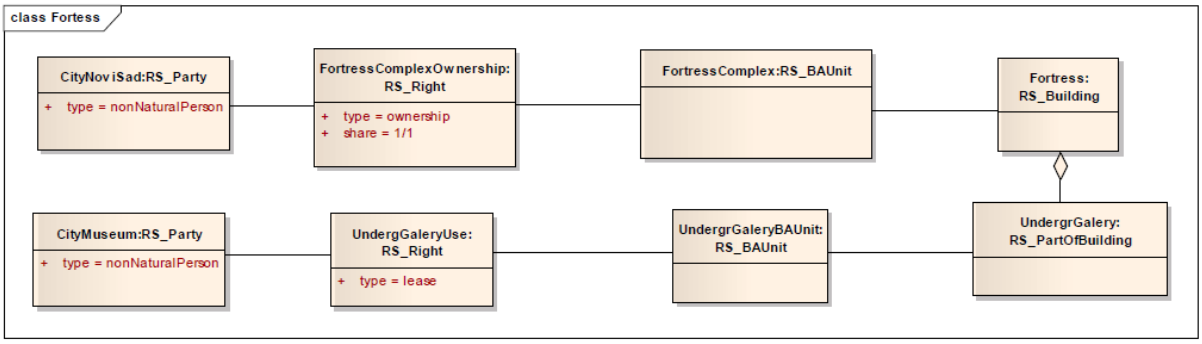


Figure 10. Instance-level diagram for the registration of ownership and the lease of underground chambers in a fortress (Radulovic, A. et al., 2019).

2.3.8 Australia

In Australia, land administration policies differ by state. The states of Queensland and Victoria lead the way in registering the RRRs in 3D of objects above the surface. In Queensland, for example, volumetric 3D parcels are surveyed and registered. In Victoria, the legislation facilitates the registration of RRRs in 3D. However, for registering the RRRs of objects below the surface, 2D survey plans are still used in Victoria (FIG, 2018). A new framework has been proposed to outline the direction that the current LAS should take in order to develop a system to integrate 3D underground cadastral data (Saeidian et al. 2021). A conceptual data model based on the LADM standard that aims to facilitate the integrated management of 3D underground objects through the linkage of legal and physical properties has been developed for the state of Victoria (Saeidian et al., 2022). Figure 11 shows the conceptual data model for underground land administration in Victoria.

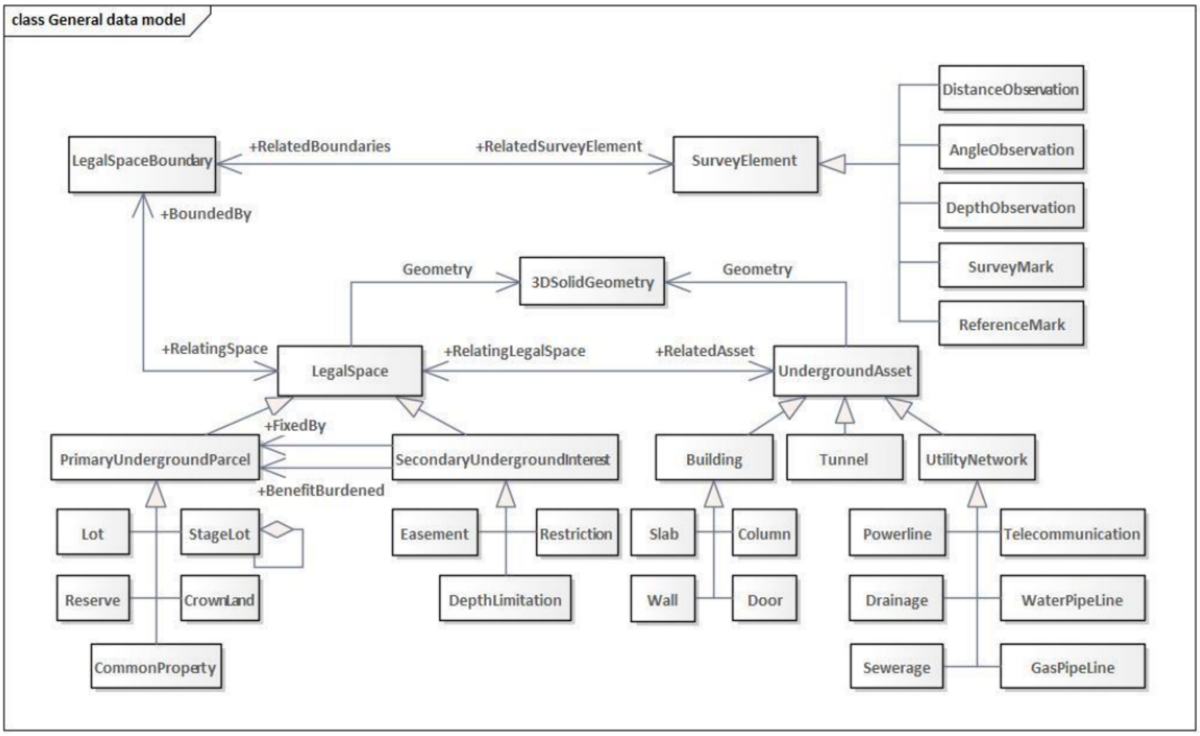


Figure 11. Conceptual data model for underground land administration in Victoria

2.4 Standardised data models for objects below the surface in the GeoBIM discourse

Data standardisation is the process of setting the standards for the structure and organisation of the data. Standardisation of data can reduce the time and costs, since there are no or less technical and semantic differences in the data, making the data more understandable, interoperable and suitable for exchange (Gal et al., 2019). A standardised data model is an abstract model through which data can be structured and organised in a standardised manner.

2.4.1 Types of standardised data models

There are several types of data models used to standardise the modelling of (specific types of) 3D objects below the surface. The information model for cables and pipes (*Dutch: Informatiemodel Kabels en Leidingen, IMKL*) is a Dutch data model for all types of utilities where each utility network is described by the location and the topology of the network elements (Den Duijn, 2018). The INSPIRE Data Specification on Utility and Government Services is the European application schema for utility networks where the focus lies on defining a 2D topological relationship between the network elements. Another data model is MUDDI, the Model for Underground Data and Integration. MUDDI consists of a standard part for the geometry of underground objects, where other modules can be connected to for specific use cases or for interoperability with other data models (Lieberman et al., 2020). CityGML, an open data model used for the storing and exchange of 3D city models. CityGML describes the geometry and attributes of typical 3D objects, for example, buildings, roads, tunnels, that are present in cities as well as the relations between these objects.

The Application Domain Extensions (ADEs) of CityGML are extensions which can be used to adjust the model to fit certain use cases. One of these ADEs is the Utility Network ADE which is used to store data on the geometry of the utilities, the relations between them and other information with regards to the use and operation of the utilities (Biljecki et al., 2021). In this subsection however, the data models used in this thesis, the LADM and IFC, will be presented, while research carried out towards their integration will be discussed. Table 1 provides a list of the data models with the scope, origin, use and the area where the models are applicable.

Table 1. Standardised data models

Name	Origin	Scope	Use	Area
IMKL	NEN	Utility network objects	Exchange	The Netherlands
INSPIRE Data Specification on Utility and Government Services	EU	Utility network objects	Exchange	European Union
MUDDI	OGC	Underground objects	Exchange	Worldwide
CityGML	OGC	City objects	Storage, exchange and visualisation	Worldwide
CityGML Utility Network ADE	OGC	Utility network objects	Storage, exchange and visualisation	Worldwide
LADM	ISO	Land, building, infrastructure and utility network objects	Exchange	Worldwide
IFC	ISO	Building, infrastructure and utility network objects	Storage, exchange and visualisation	Worldwide

2.4.2 ISO 19152:2012 Land Administration Domain Model (LADM)

The Land Administration Domain Model (LADM) is a conceptual data model and ISO standard (ISO 19152:2012) offering a core structure and vocabulary to be used as fundamental of any Land Administration System, which can be extended with classes and attributes that are specific to each country (ISO, 2012, Lemmen et al., 2015).

The LADM covers all basic aspects of land administration including those over water and land, and elements above and below the surface of the earth. These aspects concern the Rights, Restrictions and Responsibilities (RRRs), but also all the legal, administrative and spatial information. The LADM consists of three main packages: party; administrative and spatial, as well as a subpackage of surveying and representations. Figure 12 shows the overview of the basic packages and classes of the LADM.

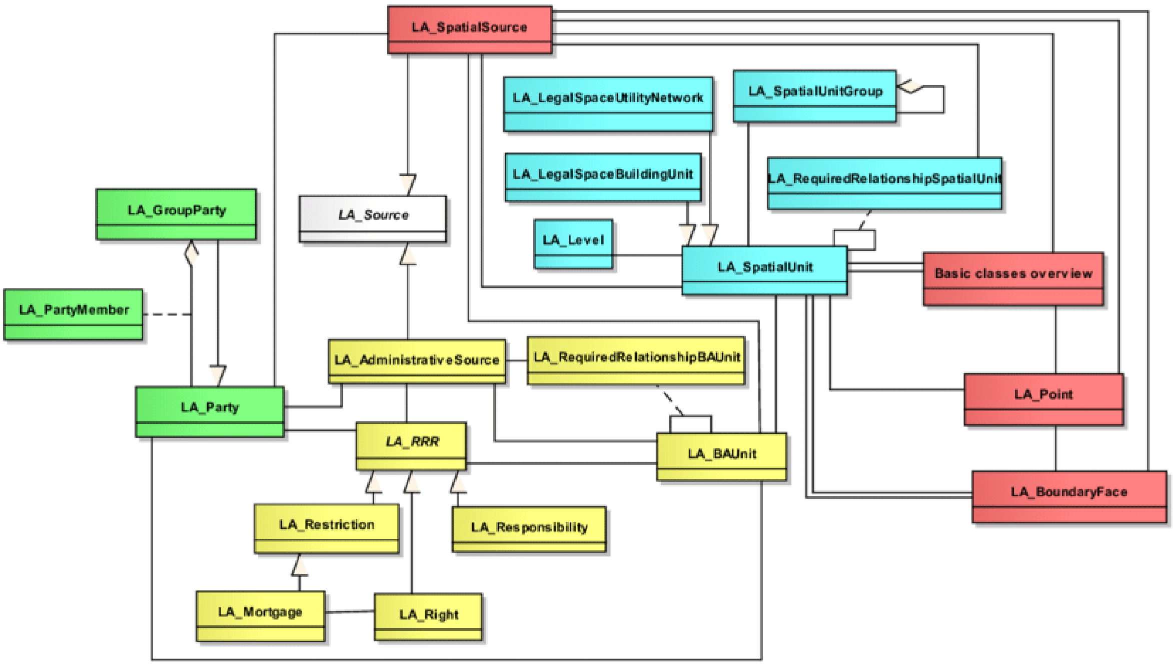


Figure 12. The Land Administration Domain Model. Green: party package, yellow: administrative package, blue: spatial package and red: surveying and representations subpackage (Lemmen et al., 2015).

Currently, the revision of its first edition is ongoing in order to improve and refine the modelling of the land and property rights, as well as to widen the scope of the standard (Lemmen et al., 2019). An important aspect of this revision is that first, the definition of land administration will change to: ‘*Land administration is the process of determining, recording and disseminating information about relationships between people and land - informal, customary and formal use and property rights - and about value and use of land*.’ (Lemmen et al., 2020).

What is more, the following aspects are included in the revision: (1) the extension of the scope, (2) the improvement and refinement of the current conceptual model, the (3) the inclusion of technical models and (4) the integration of processes (Lemmen et al., 2019; 2020). The scope will be extended by, among other things, adding more information related to the valuation domain through a Valuation Package, facilitating the link between the legal and physical objects and increasing the support for different types of legal spaces, (i.s. utilities). Indicatively, the improvement of the conceptual model of the LADM Edition I will be through the enrichment of the semantics of LADM codeLists and by extending the survey model to support multiple surveying techniques. Some of the technical models that are considered to be included in the revised version of LADM are: BIM/IFC, CityGML and InfraGML. Processes that will be integrated in the new model will deal with the updating of maps, the survey procedures and the transaction of real estate. Next to this, there will also be a methodology incorporated to develop LADM country profiles (Lemmen et al., 2019, 2020).

The revised LADM will consist of six parts: (1) Land Administration Fundamentals (generic conceptual model), (2) Land Registration, (3) Marine Space Georegulation, (4) Valuation Information, (5) Spatial Plan Information and (6) Implementation Aspects. Part 1 (Land Administration Fundamentals) and part 2 (Land Registration) will integrate the ISO 19152:2012 LADM standard, making the revised version backwards compatible (Lemmen et al., 2019, 2020). It is expected that the new edition of the LADM will be ready and published in 2024 - 2025.

In the current version of LADM the legal spaces of spatial units are represented by the classes LA_LegalSpaceBuildingUnit and LA_LegalSpaceUtilityNetwork that inherit from the class LA_SpatialUnit. In the revised version of LADM two new (possible) classes to model spatial units are added: LA_LegalSpaceParcel and LA_LegalSpaceInfrastructure (Figure 13) (Lemmen et al., 2021). LA_LegalSpaceParcel represents the legal space of a (type of) parcel, while LA_LegalSpaceInfrastructure represents the legal space of a (type of) infrastructure. For modelling the legal spaces of underground objects there are two options: LA_LegalSpaceUtilityNetwork and LA_LegalSpaceInfrastructure. However, LA_LegalSpaceParcel can still be used to model the legal spaces of parcels that border, intersect or contain underground objects, while LA_LegalSpaceBuildingUnit can be used to model the legal spaces of buildings above and/or connected to the underground objects.

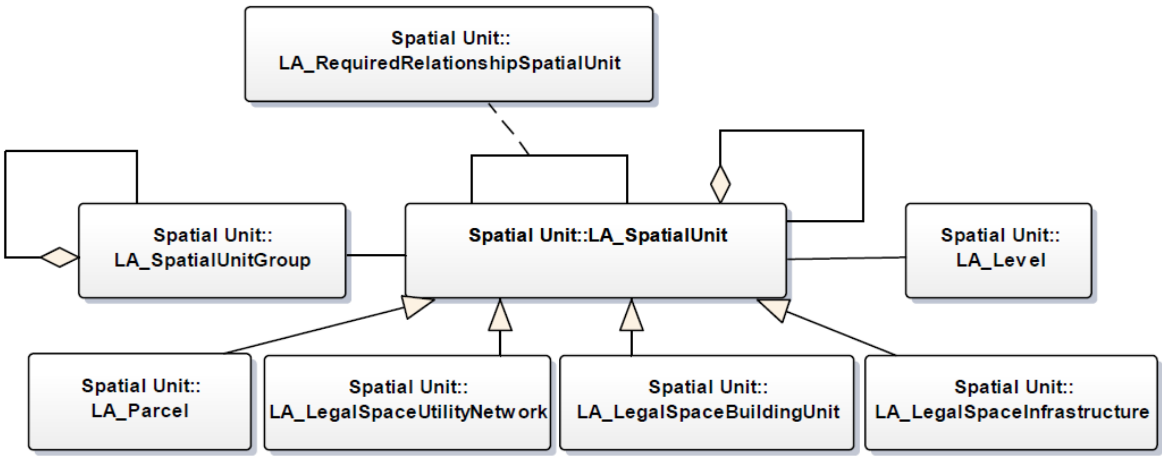


Figure 13. Possible classes in the Spatial Unit Package of the revised LADM

2.4.3 ISO 16739-1:2018 Industry Foundation Classes (IFC)

A Building Information Model (BIM) is a model where information on buildings and other (infra)structures is created, stored and maintained for the design, construction, operation and other processes and applications (Kalogianni et al., 2020a). The Industry Foundation Class (IFC) is an ISO standard (ISO 16739-1:2018) for BIM data and developed to stimulate interoperability in the construction industry. IFC contains requirements for data applied to buildings throughout their life cycle. The standard is encoded in the EXPRESS and XML schema's (ISO, 2018). The IFC standard consists of many classes to store and exchange data of buildings, for instance, IfcSpace that is used to model the volume inside an object (Atazadeh et al., 2019). Figure 14 shows the upper levels of the IFC model's spatial hierarchy.

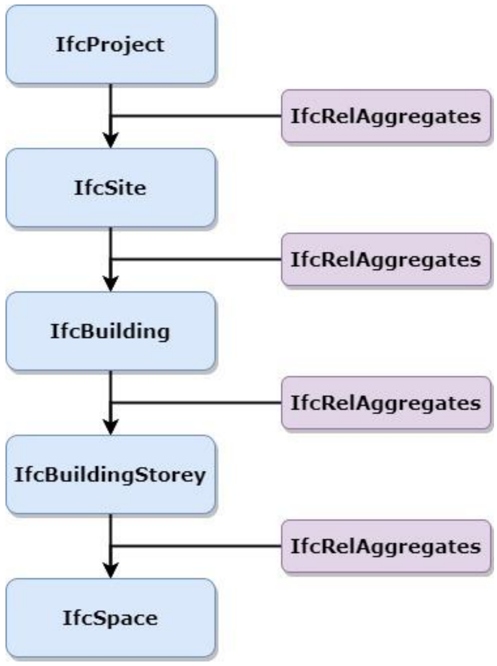


Figure 14. Upper levels of IFC spatial hierarchy. IfcRelAggregates indicates an aggregation relationship.

Due to the increased use of BIMs by the AECOO community, explained by the advantages of a reduction in cost and better management of buildings throughout their life cycle, but also because in certain countries BIMs are mandated to be used by the governments for public projects, more BIM/IFC models are produced (Kalogianni, et al., 2020a, Oti-Sarpong, et al., 2020). These IFC models made during the design phase of constructing a building or other structures could be reused for land administration purposes, since they contain geometrical and other data that is necessary for registering property rights. If the IFC models were to be shared throughout the building lifecycle among all stakeholders of the AECOO community, then this would lead to a reduction in costs, higher efficiency and better decision-making (Kalogianni et al., 2020b).

The current ISO standard certified version of IFC is IFC 4 (ISO 16739-1:2018). This version is a revised version of the ISO 16739:2013 standard (ISO, 2018). The revision of the current version of IFC is ongoing. The motivation for this update was to improve the representation of infrastructure objects, for instance, roads, railways, ports, waterways and the shared infrastructure that comprise elements that can apply to all types of infrastructure objects, for example, earthworks (buildingSMART, 2022a).

In the revised version, IFC 4x3, several additions of new elements are made, two of them being IfcFacility and IfcFacilityPart. IfcFacility is an element that is derived from the IfcSpatialStructureElement (buildingSMART, 2022b). Spatial structure elements are used to outline the spatial structure (buildingSMART, 2022b). An IfcFacility can be a building but it can also be a tunnel. IfcFacilityPart describes the structural parts of an IfcFacility object (buildingSMART, 2022b). Also, in IFC 4x3, multiple elements are depreciated, one of them is IfcBuildingElementProxy (buildingSMART, 2022a). IfcBuildingElementProxy is currently used to model all (or part of) the geometry information of models made in IFC 4 (as well as IFC 2x3). IfcBuildingElementProxy is an element that is used to model building elements, without it having to be a specific type of building element (buildingSMART, 2022c). If IfcBuildingElementProxy is depreciated, alternatives must be used to model the same elements. IfcFacilityPart could be one of the alternatives. IFC 4x3 is currently under development and will be published in the middle of 2022 (buildingSMART, 2022d).

2.5 Integration of legal (LADM) and physical (BIM/IFC) models

The integration of the LADM with a BIM/IFC model makes it possible for BIM/IFC models to describe legal spaces, where several types of IFC elements are selected to represent the legal spaces. The most important of these IFC elements is IfcSpace. IfcSpace is defined as: *'A space represents an area or volume bounded actually or theoretically.'* (buildingSMART, 2022c). Legal spaces are volumetric spaces in which the legal information is stored. IfcSpace is, according to the definition of the entity, able to store volumes and thereby thus the legal spaces. Examples of other IFC elements that can be used to register legal information are IfcSite for a land parcel, IfcExternalSpatialElement for the outdoor legal space and IfcZone for multiple IfcSpaces.
One workflow to add legal data to a BIM/IFC model consists of six steps: (1) Model the object based on 2D drawings, (2) Define the legal boundaries, (3) and the legal spaces, (4) group the same legal spaces into one zone, (5) add the RRRs to this zone and (6) export the data to an IFC file (Atazadeh et al., 2018; 2019).
In a different workflow, BIM/IFC models of apartment complexes were enriched with legal data where the IFC element IfcSpace was used to connect this data. Figure 15 shows a part of an apartment complex with the legal space enriched IfcSpace in yellow. Then, the enriched BIM/IFC was stored, together with cadastral data in a database management system, after which it was visualised through a 3D geospatial visualisation platform (Meulmeester, 2019).

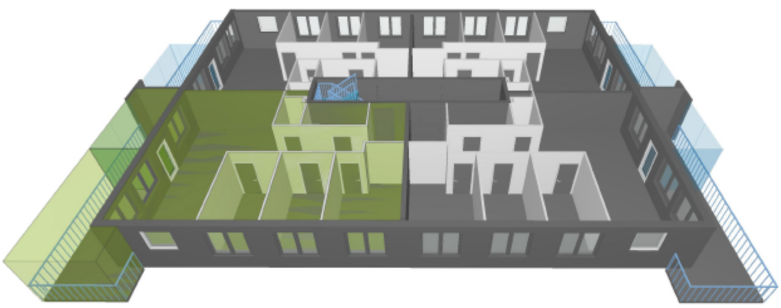


Figure 15. Part of an apartment complex with the legal space in yellow (Meulmeester, 2019)

Research to investigate the implementation of the LADM in a 3D LAS, with the use of BIM/IFC models for objects above the surface such as apartment buildings and infrastructure objects has recently been carried out. The BIM/IFC models that were enriched with legal spaces according to the LADM were stored in a spatial database and visualised through an online 3D geospatial visualisation platform (Broekhuizen, 2021). Figure 16 shows the visualisation of an enriched BIM model in the visualisation platform.

Figure 16. Enriched BIM/IFC model visualised in an online visualisation platform (Broekhuizen, 2022)

Next to enriching the BIM/IFC models with legal spaces it is possible to combine the LADM with standards for new classes where physical information can be stored. Combining both approaches is also an option (Alattas et al., 2021).

The permanent extension of the IFC model with elements to store the legal information according to LADM has recently been researched with promising results (Petronijevic et al., 2021).

A framework has been proposed where LADM, BIM/IFC as well as CityGML are all used together in order to stimulate data sharing. In this framework there are five steps that need to be executed to have a combined model to represent 3D buildings: (1) Create a LADM file with the legal data, (2) define the property geometry in the IFC model, (3) integrate the LADM with the IFC model, (4) convert the IFC model to the CityGML model and (5) integrate the CityGML model with the LADM (Sun et al., 2019). Figure 17 shows the framework for the integration of BIM/IFC models with LADM and CityGML.

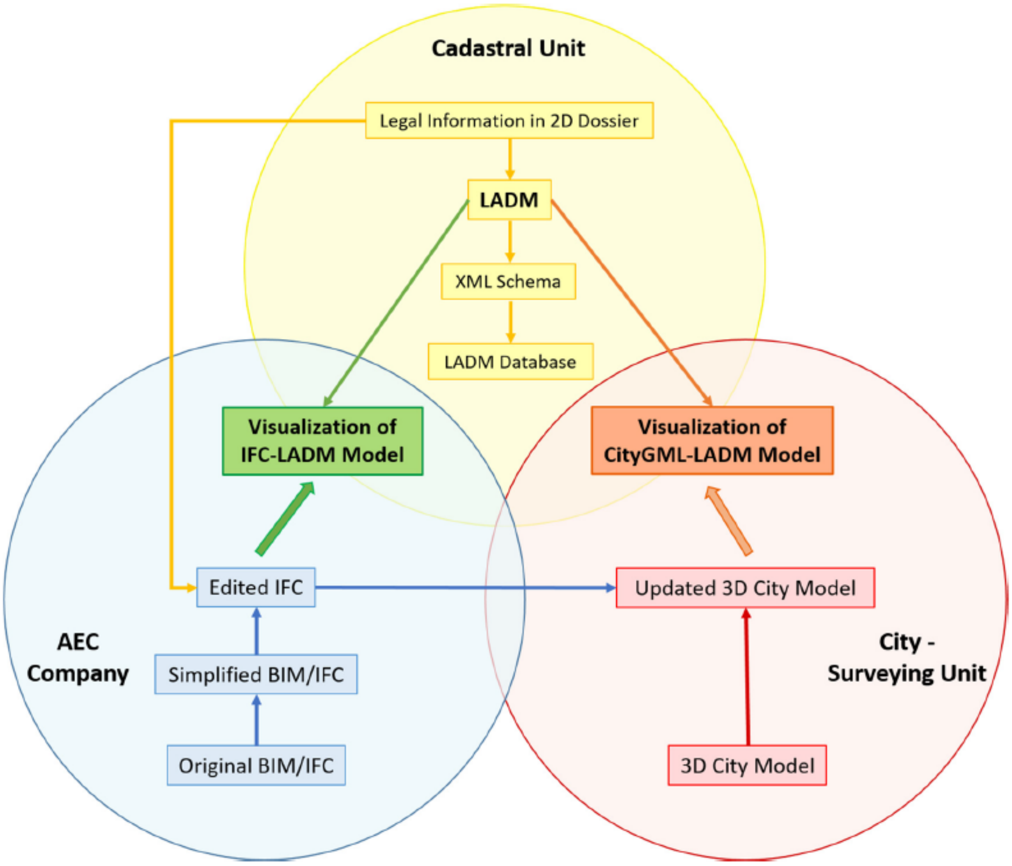


Figure 17. Framework for the combined use of BIM/IFC models with LADM and CityGML (Sun et al., 2019)

3. Methodology

In this chapter the methodology of this research is provided. The methodology is divided into four parts: literature research, input from stakeholders, data collection and the workflow generation (Figure 18). The input from stakeholders and the literature research contributed to the generation of the workflow. Based on the literature research, the information in Chapter 2. Theoretical framework was written and the method for the generic model mapping of the LADM classes to the IFC entities was developed. The data collection provided the data for the implementation of the prototype and visualisation of the case studies. This chapter also presents the tools, system architecture, data flow and how the workflow should be evaluated.

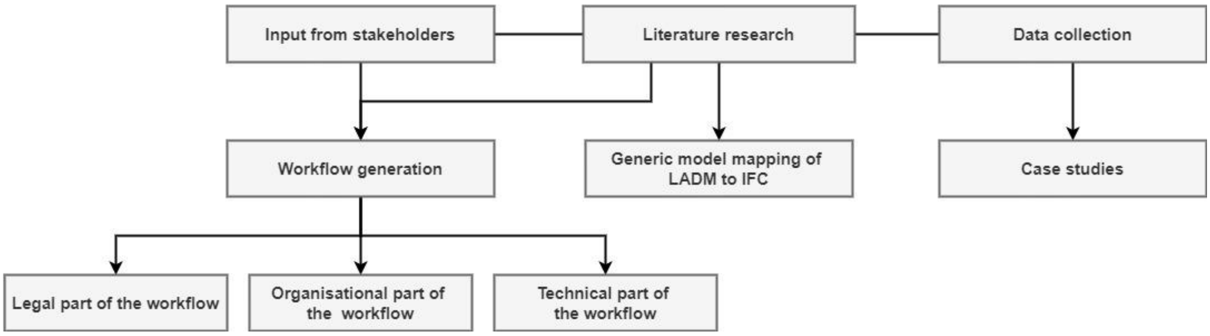


Figure 18. Flowchart of the methodology

<u>3.1 Literature research</u>

In order to search for information with regards to the modelling of the legal spaces of underground objects in 3D Land Administration Systems (LASs) a literature review was performed. The results from the literature review are provided in Chapter 2. Theoretical framework. With the knowledge gained from the literature review more insight was provided into the following eight concepts:

1. The current state of development of 3D cadastres in the Netherlands and countries around the world
2. Type of 3D underground objects
3. Registration of 3D underground objects in a LAS in the Netherlands and countries around the world
4. The stakeholders involved in the registration of the RRRs of 3D underground objects
5. The Land Administration Domain Model (LADM) (current and revised version)
6. The Industry Foundation Classes (IFC) (current and revised version)
7. Semantic and technical requirements and standards required for BIM/IFC models to register the RRRs according to the LADM
8. Storage, visualisation and dissemination of the 3D legal spaces in the LAS.

Articles were retrieved by conducting an online search through relevant journals (e.g. International Journal of Geo-Information), educational and research repositories (e.g. TU Delft Education and Research repository). Articles were also supplied by the supervisors.
The articles were selected by assessing their relevance to this research. The first selection of the articles was done based on the titles and abstracts. Then, after reviewing the full-text versions of the selected articles, those with the highest relevance, meaning articles that provided insight into the aforementioned concepts, were selected. The references of these articles were also evaluated and if the articles from the references were deemed to be relevant, then these articles were also included.
From the 153 articles that were collected, 42 were used to write Chapter 2. Theoretical framework. Next to this, the Dutch governmental websites Overheid.nl and Kadaster.nl, and the websites from the organisations of international standards, ISO and buildingSMART, were also used to write Chapter 2.

<u>3.2 Input from stakeholders</u>

The stakeholders involved in the process of registering and using 3D underground objects in LASs are governmental organisations, utility network companies and operators, engineering companies and professional bodies. These stakeholders provided insight into the current methods of registration of 3D underground objects as well as the problems they have in doing so. The stakeholders also communicated their needs with regards to which type of information, legal or physical, of the 3D underground objects in LASs they would require for use. Meetings and interviews with stakeholders were held and the insights gained with regards to legal and organisational aspects as well as technical and semantic challenges and requirements, were used in the development of the workflows. Appendix A - Stakeholders provides an overview of the stakeholders that responded to the request for meetings or interviews.

<u>3.3 Data collection</u>

In order to collect BIM/IFC models of objects below the surface, governmental organisations, utility network companies and operators, engineering companies and professional bodies were approached. From the organisations that did respond to the request for BIM / IFC models, 14 organisations provided data (which were not always BIM / IFC models), while 35 declined to do so.
The reasons given by the 35 organisations to not provide BIM / IFC models were that the organisations did not have any BIM / IFC models of objects below the surface and if they did, they could not share the models due to issues regarding intellectual property, confidentiality and cybersecurity.
The 14 organisations that did provide datasets were the:

- Dutch municipalities
- Dutch provinces
- Dutch national executive agency Rijkswaterstaat
- Dutch utility network companies
- Swiss Canton of Basel-Stadt
- Swiss national mapping agency Swisstopo
- Engineering companies

From the 44 datasets provided by the organisations, 13 were IFC 2x3 or IFC 4 models.

The other datasets were in the following data formats:

- 2D/3D CAD (DWG/DXF)
- CityGML
- Shapefile (SHP)
- Geopackage (GPKG)
- Revit 3D (RVT)
- Navisworks Document (NWD)

Table 2 shows the count of data formats of provided datasets per organisation. The national agency Rijkswaterstaat and the municipality of Rotterdam provided multiple datasets of the same objects in different data formats.
Table 3 shows the count of the type of object in the provided IFC 2x3 and IFC 4 models.
The IFC models of bridges (from the municipality of Groningen and Canton Basel-Stadt) and the petrochemical pipes (from Prisma Groep) consist of a part that is below the surface. The underpass (from the municipality of Amsterdam), consisting of two IFC files with parts of the structure, is not below the surface but the utility network below the area of the underpass (provided in 2D CAD format) is. The IFC models of buildings and surroundings from Rijkswaterstaat are connected to the IFC model of a tunnel.
Specifications on all the provided data are given in Appendix B - Data inventory. The inspection of the IFC models is provided in Appendix C - IFC model inspection.

Table 2. Count of data formats of provided datasets per organisation

		Data formats							
		IFC 2x3	IFC 4	DWG/ DXF	CityGML	SHP	GPKG	RVT	NWD
Code	**Name of organisation**								
D	Municipality of Almere						2		
D	Engineering bureau of the municipality of Amsterdam	2		1					
D	Municipality of Groningen				2				
D	Municipality of Rotterdam			20					
D	Province of Gelderland							1	
D	Province of Groningen	1							
D	Province of North-Holland					2			
D	National executive agency Rijkswaterstaat	3		6					5

D	PWN					1			
S	Canton of Basel-Stadt		1						
S	Swisstopo		3						
E	Ballast-Nedam								1
E	Prisma Groep	1							
E	Skanska UK	2							

Codes: D = Dutch organisation; S = Swiss organisation; E = Engineering company

Table 3. Categorisation of the collected objects based on the IFC version

	Data formats	
	IFC 2x3	IFC 4
Type of object		
Tunnel	3	
Utilities / (part of a) utility network		3
Bridge	1	1
Petrochemical pipes	1	
Underpass	2	
Building	1	
Surroundings	1	

3.4. Alternative workflows to register 3D objects below the surface

For this research three workflows (legal, organisational and technical) were developed in order to register the 3D underground objects, through enriching a BIM/IFC model with legal spaces with unique ID’s according to the LADM standard, in LASs. The workflows will also support the storage, visualisation and dissemination of the 3D LAS with underground legal spaces derived from the BIM/IFC models.

3.4.1 Legal workflow

The legal workflow consists of all the legal aspects that should be dealt with when registering the RRRs of 3D underground objects (Figure 19). The workflow is divided in two parts: (1) Investigate current legislation, standards and guidelines and (2) Change the current legislation (Figure 15). The workflow starts first with the investigation of the current

legislation, standards and guidelines with regards to registering the legal information of 3D underground objects in a LAS.
First, it should be researched if the current legislation adequately defines the legal concepts of (1) underground space, (2) parcels and (3) objects. If this is not the case, then these concepts should be defined and legally mandated.
Then, it should be investigated whether the current legislation is able to define the legal information of objects in the underground space. Aspects of this ownership that require special attention during the investigation are: (1) the types of underground objects, (2) the boundaries of underground spaces, (3) the rights, (4) the restrictions and (5) the responsibilities. If these aspects are not well defined, then definitions should be drawn up to effectively reflect the legal concepts of ownership of the underground space and are legally mandated.
Finally, it should be researched how the legal information of the underground space is registered and if this is sufficient. Aspects to consider are: (1) what parties are involved in the registration of the ownership of the underground space and what their roles are, (2) how the 3D underground parcels or objects are registered, (3) which data models should be used for the registering of the underground parcels and objects, (4) which data format should be used in order to stimulate the exchange of data and (5) how the registration of the underground space is visualised and disseminated. If the registration of the RRRs of objects in the underground space is currently not effective, then new legal policies need to be defined and mandated. These policies should make it clear that the legal information of 3D underground parcels or objects should be registered in a LAS. Part of these policies will be defined in the organisational workflow by the stakeholders involved in the registration and use of the legal information of 3D underground objects.

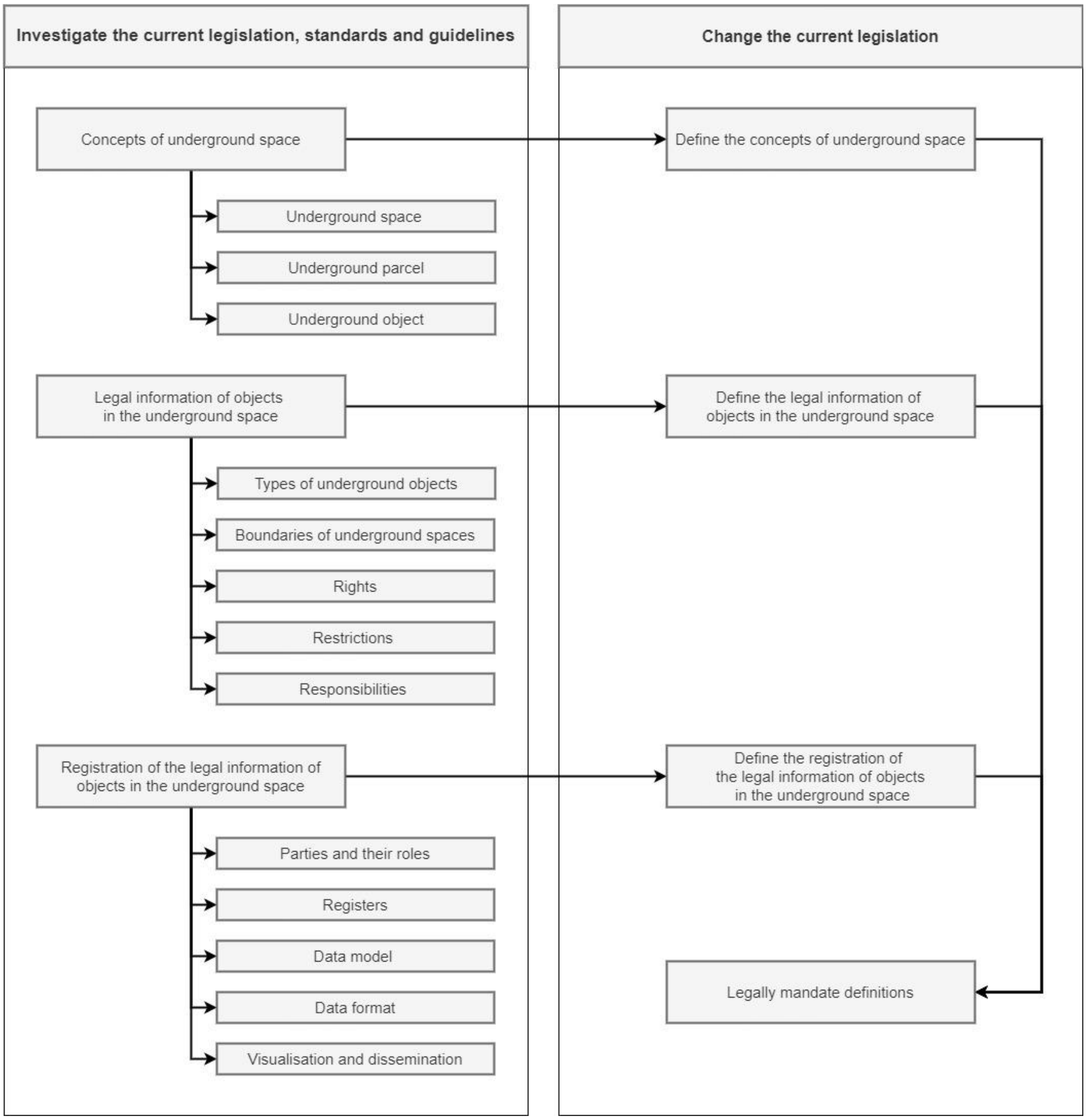


Figure 19. Legal workflow

3.4.2 Organisational workflow

In the organisational workflow, the stakeholders involved in the registration of the RRRs of 3D underground objects and the stakeholders are identified (Figure 20).

After identifying the stakeholders, use cases are defined for each stakeholder. Based on these use cases, the function and role that a stakeholder has in registering the RRRs of 3D underground objects can be defined. Hereafter, it will be assessed if the current function of a stakeholder is sufficient to support the registration of the RRRs of 3D underground objects. If this is the case, nothing will change with regards to the function and role of the stakeholder in the process of registration. If the current function is not sufficient to support registration of the legal information of 3D underground objects, then function requirements needed for a stakeholder to be able to support the registration will be added to the function of the

stakeholder. The needs of the stakeholders will be defined from which policy, semantic and technical requirements can be derived (Figure 21).
As a final step, the new framework for the registration of the legal information of 3D underground objects will be made. The policy, semantic and technical requirements that were earlier derived from the needs of stakeholders will be agreed upon by the stakeholders. Part of the requirements can be translated to and guaranteed by standards. These standards should also be agreed upon by the stakeholders. The requirements and standards that stakeholders agreed on as well as the legal mandates that resulted from the legal workflow, will be part of the plan to create a new framework for the registration of the legal information of 3D underground objects (Figure 22).

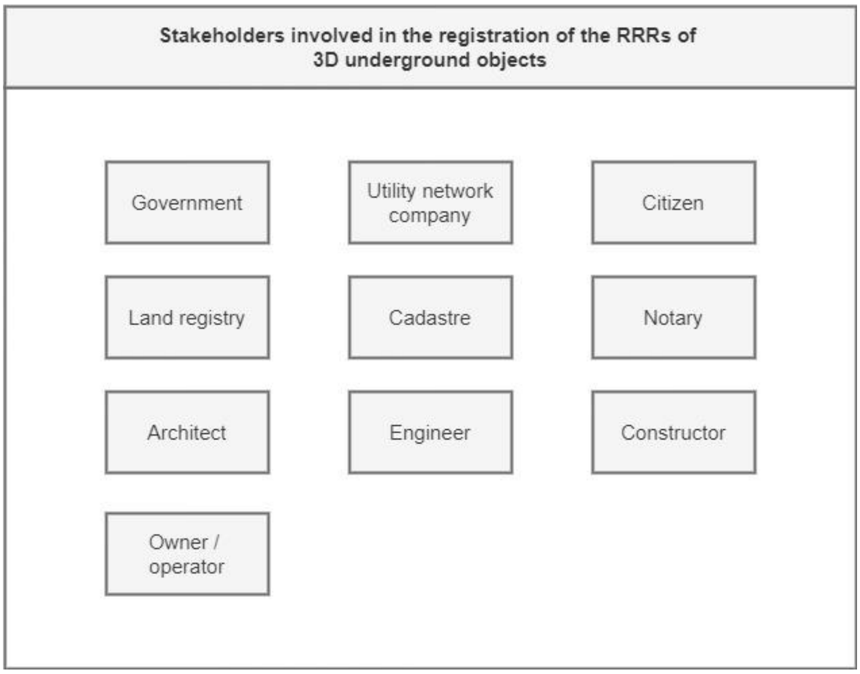


Figure 20. Organisational workflow - the stakeholders

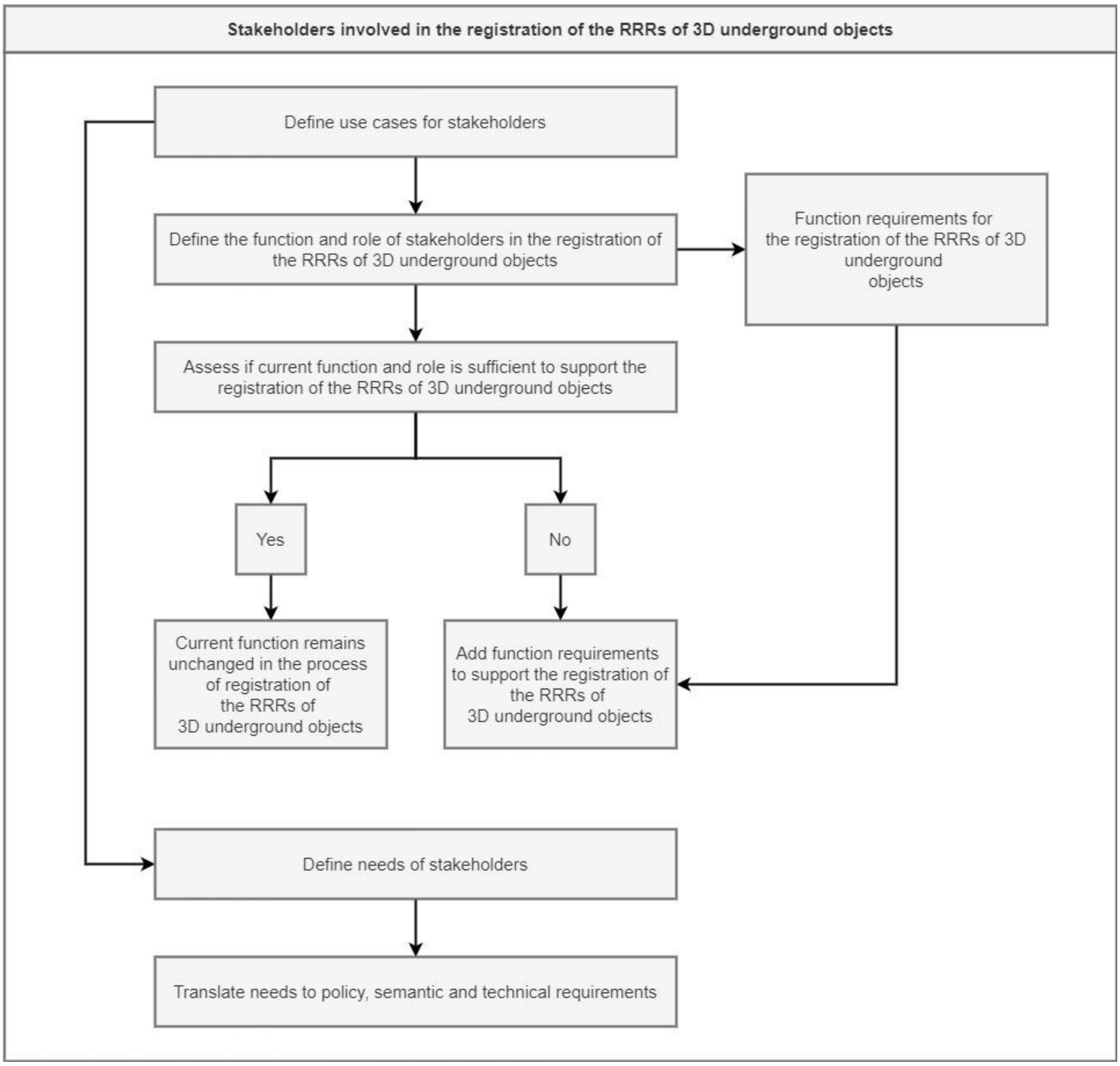


Figure 21. Organisational workflow - stakeholders involved in registration of the RRRs of 3D underground objects

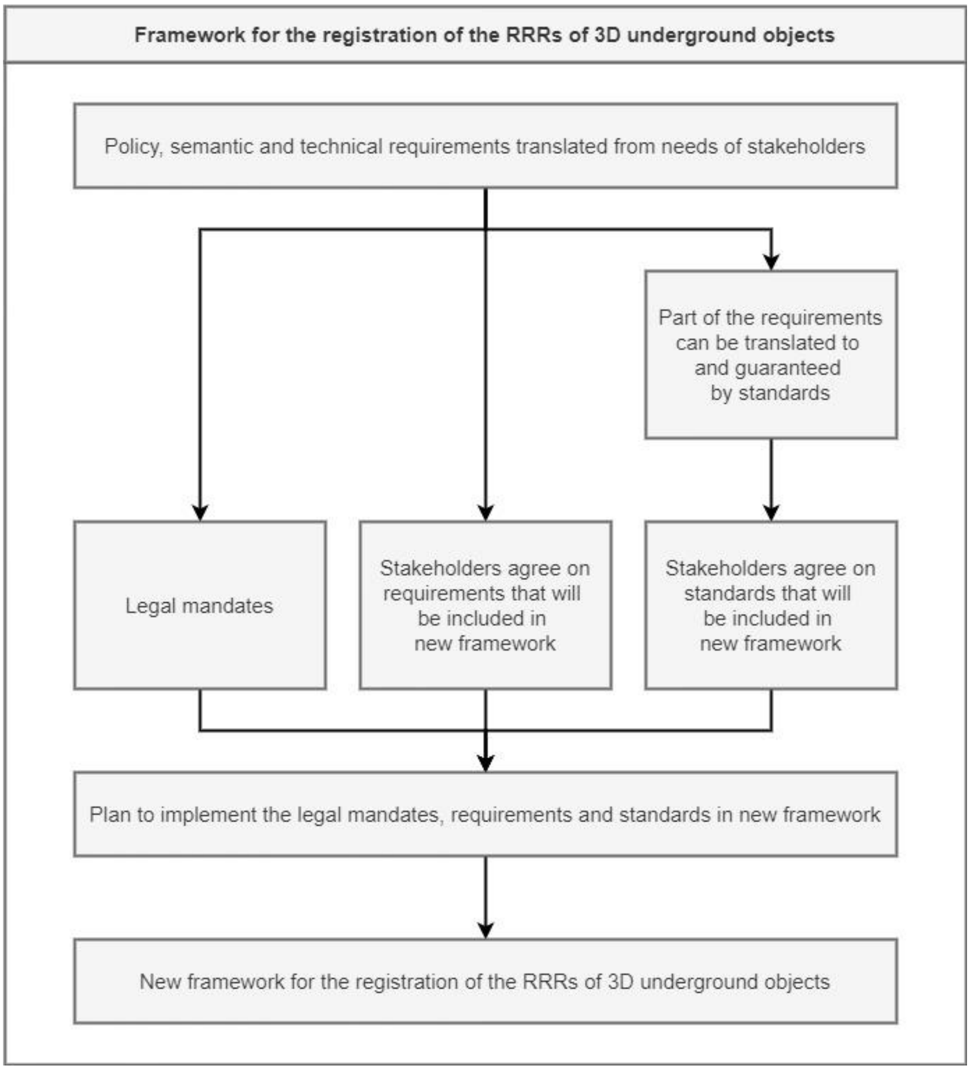


Figure 22. Organisational workflow - framework for the registration of the RRRs of 3D underground objects

3.4.4 Technical workflow

The technical workflow provides the technical implementation of registering the 3D underground objects (Figure 23). An IFC model of an underground object is first geometrically validated and correctly georeferenced, when needed.

Then, two methods could be executed in order to add the RRRs according to the LADM to the IFC model: (1) Modelling of the 3D volumes in IfcSpace and (2) Modelling the geometry of the object in IfcSpace.

For the modelling of the 3D volumes with IfcSpace, it is first investigated if IfcSpace(s) are present, used to describe the legal spaces, and if the spaces have unique IDs. Objects below the surface, however, in general do not have apartments in buildings and therefore IfcSpace is most always not present. If IfcSpace(s) are present, then the If the IfcSpace(s) are not present, then IfcSpace(s) should be created (with each a unique ID), which can be done with the use of architectural software that enables the creation and editing of IFC models. The geometrical dimensions of the volume(s) represented by the IfcSpace(s) can be defined from the RRRs of the underground objects(s) or from laws, standards, and guidelines.

The modelling of the geometry of the object in IfcSpace can be done if there is no 3D volumetric legal space around the object, because only the object itself is owned. It is first investigated if IfcSpace(s) are present. If IfcSpace(s) are present, then the geometry of the object can be added to the IfcSpace(s). If IfcSpace(s) are not present, then the geometry of the object can be written to a newly created IfcSpace(s), where each IfcSpace has a unique ID. The IfcSpace(s) can be created with the use of architectural software that enables the creation and editing of IFC models, but also with Extract, Transform and Load (ETL) software that supports the IFC data format.

After one of the methods (or both) have been executed, then the 3D volume(s) in IfcSpace(s) that represent the legal space(s) or the geometry of the object modelled in IfcSpace(s), are stored in the 3D LAS.

The 3D LAS is represented in this research by a 3D LADM spatial database management system (DBMS) (and the 3D geospatial visualisation platform).

The 2D parcels that represent the objects above the surface should first be extruded to 3D and then converted to an IFC model with the use of architectural or ETL software. The geometry of the 3D volumetric parcels is then written to IfcSpace(s), where each IfcSpace has a unique ID, and subsequently stored in the 3D LAS.

Hereafter, the RRRs of the IFC models of the objects above and below the surface are modelled according to the LADM and are then added to the IfcSpace(s) in the 3D LAS to enrich the IFC model(s).

The result is visualised in a 3D geospatial visualisation platform, where other databases (such as a topography database or a 3D city model) can be added to enrich the result.

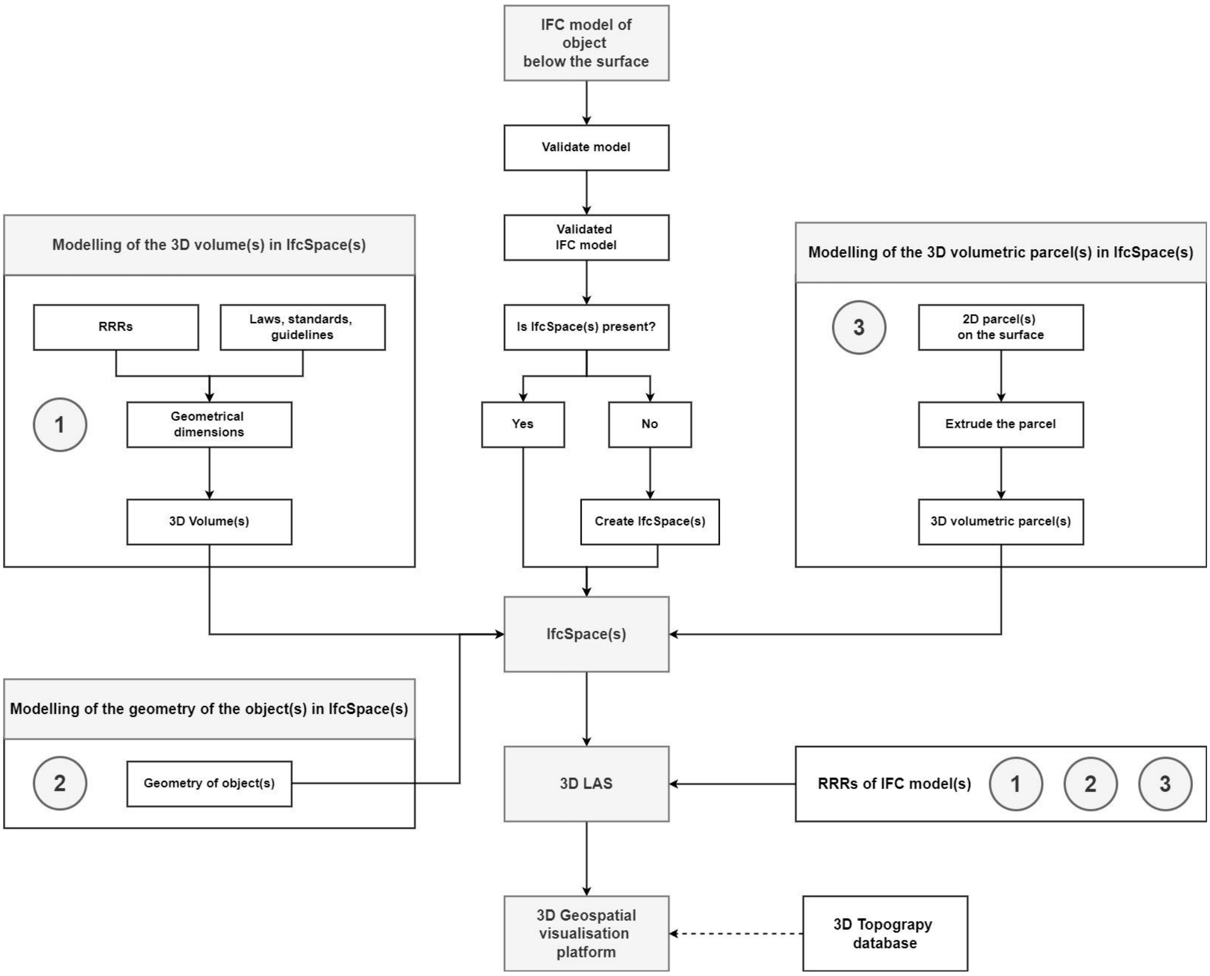


Figure 23. Technical workflow

3.5 Tools

The following tools were used to execute this research:

- BIMvision 2.25.3
- Feature Manipulation Engine (FME) 2022.0
- QGIS 3.16.10
- PostgreSQL 13.0
- PostGIS 3.1
- pgAdmin4
- Cesium ion
- Cesium JS 1.94

BIMvision is an IFC model viewer that can be used to view and inspect the IFC models.
FME is a data integration platform where, among other things, spatial data can be extracted, transformed, loaded, converted, validated and integrated with the use of readers, transformers and writers.
QGIS is an open GIS platform that makes it able to view, analyse, edit and export different

types of geospatial data.
PostgreSQL is an open relational database management system to store, manipulate and query data with the use of the SQL language. With the PostGIS extension, the PostgreSQL database can be spatially-enhanced to support geographic data. pgAdmin4 is used as a graphical user interface (GUI) for the PostgreSQL database.
Cesium is an open 3D geospatial platform used to create geospatial applications. From this platform Cesium ion, CesiumJS and Cesium Sandcastle were used. Cesium ion was used to upload and tile the data as 3D Tiles. CesiumJS is an open-source JavaScript library that was used to visualise 3D geospatial data on the Internet through the live-coding application of Cesium JS: Sandcastle.
Figure 24 shows the system architecture where all the tools are included in.

3.6 Data flow

There are three flows of data that can be distinguished in this research (Figure 24):

1. Flow with the IFC model as input data
2. Flow with the data retrieved from the Web Feature Service (WFS) of PDOK as input data
3. Flow with a shapefile as input data

The first flow of data is as follows:

1. The IFC model is used as input data (1)
2. The IFC model is viewed and inspected in BIMVision (2)
3. The IFC model is read into FME and processed there (3)
4. The IFC model is stored into the PostgreSQL / PostGIS database (4)
5. The data in the PostgreSQL / PostGIS database is viewed, queried, populated with valued (5)
6. The data in the PostgreSQL / PostGIS database is read into FME, where it is written to Cesium 3D Tiles (3)
7. The Cesium 3D Tiles are uploaded to the Cesium ion platform and visualised with the live-coding application of Cesium JS: Sandcastle (6)

The second flow of data is as follows:

1. In QGIS a connection is made with the WFS of PDOK (8)
2. The data from the WFS of PDOK is read, viewed and processed in QGIS, after which the data is saved as a shapefile (7)
3. The shapefile is read into FME where it is converted to an IFC model (1)

The next steps of the second flow of data are the same as the steps from the first flow of data.

The third flow of data starts with the third step from the second flow of data after which the steps from the first flow of data are followed.

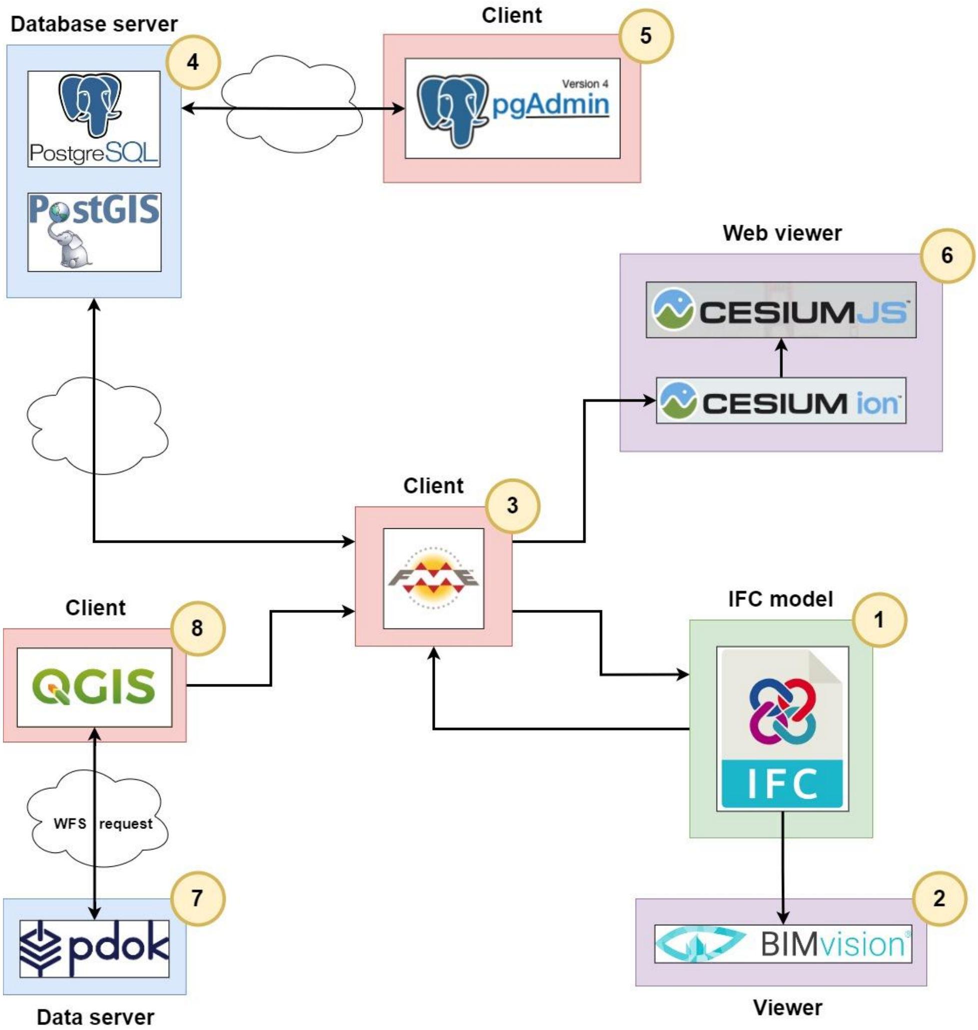


Figure 24. System architecture

3.7 Evaluation of the workflow

The three parts of the workflow (legal, organisational and technical) should be evaluated in order to test the effectiveness of the whole workflow (and if needed further refined and improved).

The evaluation of the legal workflow should focus on the completeness of the workflow, that is, in how far the workflow covers all the legal aspects that are needed to facilitate and mandate the registration of the RRRs of 3D underground objects.

The evaluation of the organisational workflow should focus on the involvement of the stakeholders, where it should be evaluated if all the stakeholders are identified and if the part that the stakeholders will play in the establishment of the framework developed in order to register the RRRs of 3D underground objects is sufficiently defined.

The evaluation of the technical workflow should focus on the technical processes and tools used to register the RRRs of 3D underground objects, where it should be evaluated if the technical processes and tools are suitable and effective in order to register these objects.

This evaluation can be done by the stakeholders as well as legal, organisational and technical experts through the establishment of a working group, with the stakeholders and experts as members of the group. The working group will hold meetings and workshops to discuss the aspects of the legal, organisational, technical workflows, where the stakeholders and experts can provide their input with regards to the workflow. With the input from the stakeholders and experts, the legal, organisational and technical workflows can be refined. If multiple meetings and workshops are held, a proposal on the workflows can be made, after which the members will vote on the proposal. If the proposal is accepted, then this workflow shall be the standard through which countries can register the RRRs of 3D underground objects in a 3D LAS. If the proposal is not accepted, then suggestions should be made by the members in order to modify the workflow until it is accepted.

In this research only the technical workflow will be evaluated through case studies (see Chapter 5. Case studies).

4. Mapping the basic classes of LADM to IFC entities

In this chapter, the basic classes of LADM to IFC elements are mapped. This is done based on literature research as stated in Chapter 3. Methodology. First, the versions of the LADM and IFC standard used for the mapping will be discussed. Then, the scenarios for linking the LADM classes to the IFC entities are provided. Hereafter, a subsection is presented on general rules for the mapping with regards to multiplicity, Versioned Objects and data types. Then, classes from each package of LADM (Party, Administrative, Spatial) and the Surveying and Representations subpackage will be mapped to the IFC entities.

4.1 LADM and IFC versions

In this chapter, the revised LADM model from up until October 2021 is used (ISO/TC 211, 2021) for the mapping of LADM classes to the IFC 4 (ISO 16739-1:2018) entities (buildingSMART, 2022c). The LADM consists of three main packages: Party; Administrative and Spatial, as well as a subpackage of surveying and representations (ISO/TC 211, 2021). The LADM classes, attributes, types, relations and (adapted) descriptions are all retrieved from ISO/TC 211, 2021.
The previous version of IFC, IFC 2x3 as well as the draft version of IFC 4x3 (buildingSMART, (2022)b) were also evaluated to see if there are any differences between IFC 4 and IFC 2x3 or IFC 4x3 with regards to the mapping of the LADM classes to the IFC elements. With regards to the mapping of the LADM classes to the IFC entities, no differences were found between IFC 2x3 and IFC 4. The main difference between IFC 4 and IFC 4x3 is that the entity IfcBuildingElementProxy will be deprecated.

4.2 Scenarios for linking LADM classes to the IFC entities

In section 1.2 Research motivation, the two scenarios for linking the LADM classes to the IFC entities were presented, which are:

1. Reusing the geometry from BIM/IFC models from design for the registration of legal space in LASs
2. Reusing the BIM/IFC models from design to serve as a technical encoding for the exchange of data in LASs

In the first scenario, the ‘Party’ and ‘Administrative’ classes do not need to be mapped, since the information stored and structured in these classes can be obtained from the deed of a property. In the second scenario, however, the classes from all LADM packages (Party, Administrative, Spatial) need to be mapped to IFC entities, in order to have a complete exchange of data. In this chapter, it was decided to map the classes from all basic LADM packages.

4.3 General rules for the mapping of LADM classes to IFC entities

4.3.1 Multiplicity and Versioned Objects

In mapping the basic classes of LADM to IFC entities, a number of general rules apply with regards to multiplicity and Versioned Objects:

1. The multiplicity of attributes will be mapped with an addition to the attribute name of an underscore and which number it is. For example: role_1, role_2, etc.
2. Attributes inherited from a Versioned Object will be mapped with an addition to the attribute name of an underscore, version abbreviated to 'v' with the version number written behind it. For example: role_v1, role_v2, etc.
3. Attributes that have a multiplicity and are inherited from a Versioned Object will have an addition to the attribute name of an underscore, which number it is, another underscore, version abbreviated to 'v' with the version number written behind it. For example: role_1_v1, role_1_v2, role_2_v1, etc.

4.3.2 Mapping of LADM types to IFC data types

In mapping the basic classes of LADM to IFC entities, the LADM types should be mapped in a consistent manner to the IFC data types. Table 4 shows the general mapping of the LADM types to the IFC data types.

Table 4. General mapping of the LADM types to the IFC data types

LADM Type	IFC Data Type	Description
Oid	IfcGloballyUniqueID	For external unique identification
Oid	IfcIdentifier	For internal system identification
CharacterString	IfcLabel	For naming purposes
CharacterString	IfcText	For descriptive purposes
Code list Type	IfcInteger	For Code lists with integer values
Code list Type	IfcLabel	For Code lists with name values
Integer	IfcInteger	For integer numbers
Fraction	IfcRatioMeasure	For fractions
Boolean	IfcBoolean	For indicating whether a constraint applies or not
Currency	IfcMonetaryMeasure	For the value of the amount of money
Float	IfcNumericMeasure	For the numeric value of a physical quantity
Area	IfcAreaMeasure	For the value of the area
Volume	IfcVolumeMeasure	For the value of the volume
Point	IfcCartesianPoint	For a point defined in a 2D or 3D Cartesian coordinate system

ISO type	IfcText	For the input according to the ISO standard
-	IfcURIReference	For the location of a document on the Internet

4.4 LA_Source

The classes LA_AdministrativeSource from the administrative package and LA_SpatialSource from the surveying and representations subpackage both inherit from the class LA_Source. LA_Source is a LADM class that contains the document(s) that provide administrative and spatial information of the (underground) object that is being modelled (ISO/TC 211, 2022). LA_Source will not be mapped to IFC, but the subclasses LA_AdministrativeSource and LA_SpatialSource will.

4.5 Party package

The LADM classes from the Party package that are mapped to IFC entities are: LA_Party, LA_GroupParty, LA_PartyMember. Figure 25 shows the mapping of the LADM classes of the Party Package to the IFC entities. Figure 26 shows the association of the IFC property sets with LADM classes for the Party package.

4.5.1 LA_Party

LA_Party is the LADM class where a party is defined. A party can be a natural person, organisation or basic administrative unit that is involved in the rights, restrictions and responsibilities of the spatial units (ISO/TC 211, 2022). The entity IfcActor defines the actors that are involved in a project, or in this case the registration of the RRRs. The actors can be persons and organisations (buildingSMART, 2022c). This makes IfcActor a suitable entity to map the LA_Party class to. A new property set can be made to be applied to the IfcActor entity: Pset_LA_Party. Table 5 provides the LADM information of the LA_Party class and the new IFC property set: Pset_LA_Party. The attributes fingerprint, photo and signature with the LADM Type: MultiMediaType are not mapped to IFC, since there is no equivalent or comparable IFC element for this LADM type. To keep the relation between the classes LA_Party and LA_RRR new attributes are introduced: list_rightID, list_restrictID and list_respoID, all with data type IfcLable. These attributes each contain a list with the IDs of the Rights, Restrictions and Responsibilities (see Chapter 4.6 Administrative Package) since a party can have multiple RRRs. Another new attribute is introduced: list_groupID with data type IfcLable. This attribute contains a list with the IDs of the group parties, since a party can be a member of multiple groups.

Table 5. LADM information of the LA_Party class and the IFC property set Pset_LA_Party

LADM information LA_Party class			Pset_LA_Party (of IfcActor)		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
extPID	Oid	-	extPID	IfcGloballyUniqueID	External identifier
fingerprint	MultiMediaType	-	-	-	-
gender	GenderType	1 - Male 2 - Female 9 - doesNotApply 0 - unknown	gender	IfcInteger	Gender (only for natural persons)
name	CharacterString	-	name	IfcLabel	Name of party
photo	MultiMediaType	-	photo	-	-
pID	Oid	-	pID	IfcIdentifier	Identifier of party
role	LA_PartyRoleType	citizen employee employer farmer proxy	role	IfcLabel	Role of the party in the whole registration process
signature	MultiMediaType	-	-	-	-
type	LA_PartyType	baunit group naturalPerson nonNaturalPerson	type	IfcLabel	Type of the party
-	-	-	list_rightID	IfcLabel	List with identifiers of the Rights (rightID)
-	-	-	list_restrictID	IfcLabel	List with identifiers of the Restrictions (restrictID)
-	-	-	list_respoD	IfcLabel	List with identifiers of the Responsibilities (respoID)
-	-	-	list _groupID	IfcLabel	List with identifiers of the group parties

4.5.2 LA_GroupParty

The LADM LA_GroupParty class is a group of separately registered parties that form a distinctive entity (ISO/TC 211, 2022). The IFC entity IfcGroup is a collection of non-geometrical objects, which the entity IfcActor is (buildingSMART, 2022c). This characteristic of IfcGroup makes it possible for the entity to map the LA_GroupParty class to. The IFC entity IfcRelAssignsToGroup assigns the object, for instance, the IfcActor entity to the IfcGroup entity (buildingSMART, 2022c). A new property set can be made to be applied to the IfcGroup entity: Pset_LA_GroupParty. Table 6 provides the LADM information of the LA_GroupParty class and the new IFC property set Pset_LA_GroupParty.

Table 6. LADM information of the LA_GroupParty class and the new IFC property set: Pset_LA_GroupParty.

LADM information			**Pset_LA_GroupParty (of IfcGroup)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
groupID	Oid	-	groupID	IfcIdentifier	Identifier of the group party
type	LA_GroupPartyType	association baunitGroup family tribe	type	IfcLabel	Type of the group party

4.5.3 LA_PartyMember

The LADM LA_PartyMember association class defines the share of party members which are separate parties registered as a component of a group party (ISO/TC 211, 2022). There is no suitable IFC entity to map the LA_PartyMember class to. Since the LA_PartyMember class is optional and in general contains one attribute (more if inherited attributes from Versioned Objects are included), a possible solution would be to create a new property set: Pset_LA_PartyMember. This property set can then be added to the IfcActor entity. Table 7 provides the LADM information of the LA_PartyMember class and the new IFC property set Pset_LA_PartyMember. A new attribute is introduced: groupID with data type IfcIdentifier. This attribute makes it able to link the party to the group it is a part of, together with the share the party has in the group.

Table 7. LADM information of the LA_PartyMember class and the new IFC property set Pset_LA_PartyMember

LADM information			Pset_LA_PartyMember (of IfcActor)		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
share	Fraction	-	share	IfcRatioMeasure	Fraction of the whole group
-	-	-	groupID	IfcIdentifier	Identifier of the group party

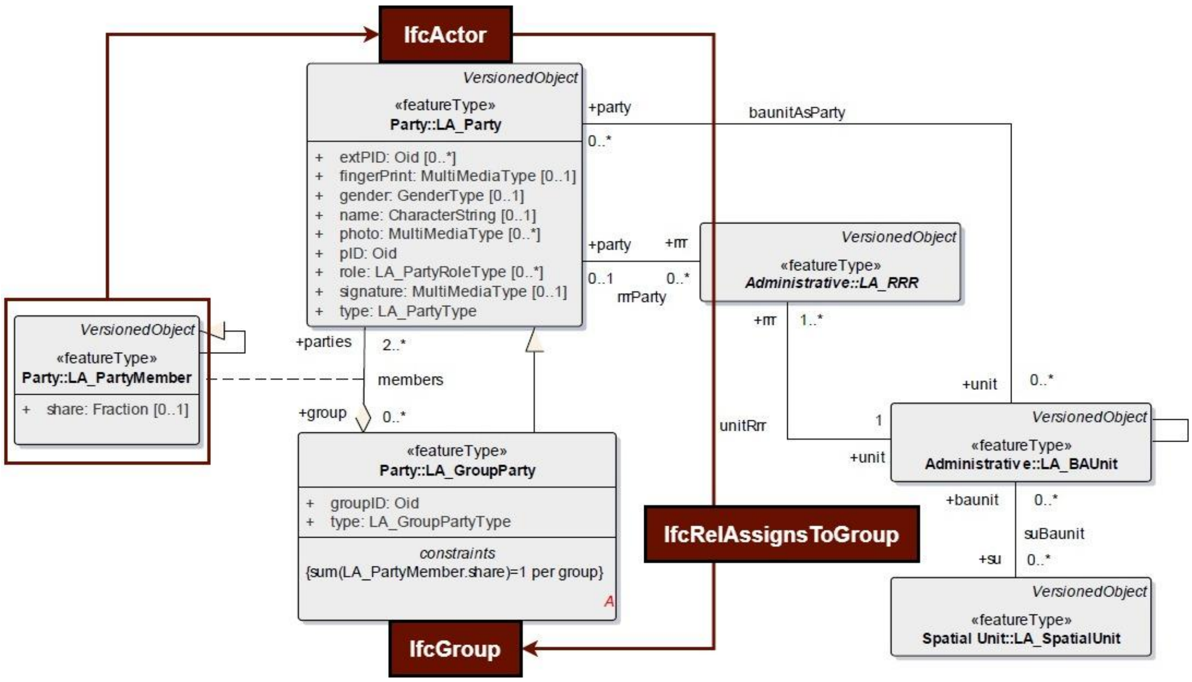


Figure 25. Mapping of the LADM classes to the IFC entities for the Party package (adapted from ISO/TC 211, 2021)

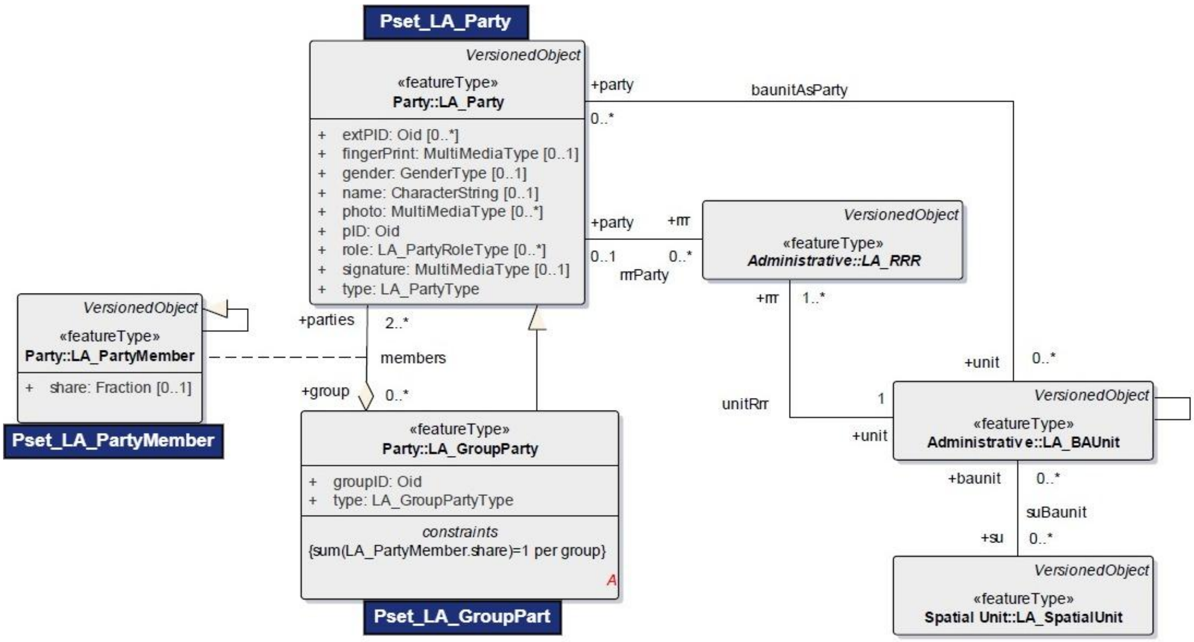


Figure 26. Association of the IFC property sets with LADM classes for the Party package (adapted from ISO/TC 211, 2021)

4.6 Administrative package

The LADM classes from the Administrative package that are mapped to IFC entities are: LA_BAUnit, LA_RequiredRelationshipBAUnit, LA_RRR, LA_Right, LA_Restriction, LA_Mortgage, LA_Responsibility and LA_AdministrativeSource. Figure 27 shows the mapping of the LADM classes of the Administrative Package to the IFC entities. Figure 28 shows the association of the IFC property sets with LADM classes for the Administrative package.

4.6.1 LA_BAUnit

LA_BAUnit (basic administrative unit) is a LADM class that consists of zero or more spatial units where one or more rights, restrictions and/or responsibilities applicable to all spatial units in the BAUnit is attached to (ISO/TC 211, 2022). A (subclass of a) spatial unit can be modelled as IfcSpace (see 4.7 Spatial package). Multiple IfcSpaces can be grouped together in the entity IfcZone through the relationship IfcRelAssignsToGroup (buildingSMART, 2022c). IfcZone is thus a suitable entity to map LA_BAUnit to. A new property set can be made: Pset_LA_BAUnit. Table 8 provides the LADM information of the LA_BAUnit class and the new IFC property set Pset_LA_BAUnit. To keep the relation between the classes LA_BAUnit and Rights, Restrictions, Responsibilities from the LA_RRR class, new attributes are added: list_rightID, list_restrictID and list_respoID, all with data type IfcLable. These attributes will each contain a list with the IDs of the Rights, Restrictions and Responsibilities. This is because LA_BAUnit can have multiple RRRs. To keep a relation between the classes LA_BAUnit and the LA_RequiredRelationshipBAUnit another attribute was added: reqrel_uID with data type IfcIdentifier.

Table 8. LADM information of the LA_BAUnit class and the new IFC property set Pset_LA_BAUnit

LADM information			**Pset_LA_BAUnit (of IfcZone)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
name	CharacterString	-	name	IfcLabel	Name of the BA unit
type	LA_BAUnitType	basicPropertyUnit leasedUnit rightOfUseUnit	type	IfcLabel	Name of the BA unit
uID	Oid	-	uID	IfcIdentifier	Identifier of the BA unit
-	-	-	list_rightID	IfcLabel	List with identifiers of the Rights (rightID)
-	-	-	list_restrictID	IfcLabel	List with identifiers of the Restrictions (restrictID)
-	-	-	list_respoD	IfcLabel	List with identifiers of the Responsibilities (respoID)
-	-	-	reqrel_uID	IfcIdentifier	Identifier of the group containing the BA Units with the required relationships

4.6.2 LA_RequiredRelationshipBAUnit

LA_RequiredRelationshipBAUnit is a LADM association class that provides the required relationship(s) between the basic administrative units (ISO/TC 211, 2022). Since the required relationship can concern multiple units, an IfcGroup can be made that contains all the basic administrative units with an explicit relationship. The IfcZone to which the LA_BAUnits are mapped to will be related through the relationship IfcRelAssignsToGroup. A new property set can be made: Pset_LA_RequiredRelationshipBAUnit. Table 9 provides the LADM information of the LA_RequiredRelationshipBAUnit class and the new IFC property set Pset_LA_RequiredRelationshipBAUnit. A new attribute reqrel_uID with data type IfcIdentifier can be added to the property set to provide an identification to the group.

Table 9. LADM information of the LA_RequiredRelationshipBAUnit class and the new IFC property set Pset_LA_RequiredRelationshipBAUnit

LADM information			**Pset_LA_RequiredRelationshipBAUnit (of IfcGroup)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
-	-	-	reqrel_BAUnitID	IfcIdentifier	Identifier of the group
relationship	CharacterString	-	relationship	IfcText	Description of the required relationship

4.6.3 LA_RRR, LA_Right, LA_Restrictions, LA_Responsibilities

LA_RRR is a LADM abstract class that contains information on the rights, restrictions and responsibilities (RRRs) of the basic administrative unit(s) (ISO/TC 211, 2021). The LADM class LA_Right provides the type of rights associated with one or multiple basic administrative units (ISO/TC 211, 2021). LA_Restriction is a LADM class that provides the type of restrictions associated with one or multiple basic administrative units (ISO/TC 211, 2021). The LADM class LA_Responsibility provides the type of responsibilities associated with one or multiple basic administrative units (ISO/TC 211, 2021). IfcResource is an entity where the information of the object (in this case the BA_Unit) in a process (in this case registering the RRRs) can be represented. This characteristic of IfcResource makes it able to map the three classes LA_Right, LA_Restriction and LA_Responsibility to the entity. Three new property sets can be made, one for each LADM class. In each of these property sets the attributes of the class LA_RRR as well as the attributes of each of the classes LA_Right, LA_Restriction and LA_Responsibility will be listed. The LADM class LA_Mortgage, a subclass of LA_Restriction, provides the type of mortgages associated with one or multiple basic administrative units (ISO/TC 211, 2021). The attributes of the subclass of LA_Mortgage can be listed under the attributes of LA_Restriction. Since LA_Mortgage can also be associated with a right, a new attribute will be added to attributes of LA_Mortgage: mortgageRight. The attribute mortgageType has data type IfcBoolean where 0 means that the mortgage is not associated with a right and 1 means it does. The new attribute mortgageRight_ID is added to LA_Right and LA_Mortage to indicate which rights the mortgage is associated with.

Table 10, 11 and 12 provide the LADM information of the LA_Right, LA_Restriction and LA_Responsibility classes and the equivalent property sets Pset_LA_Right, Pset_LA_Restriction and Pset_LA_Responsibility.

Table 10. LADM information of the LA_Right class and the new IFC property set Pset_LA_Right

LADM information			**Pset_LA_Right (of IfcResource)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
LA_RRR.description	CharacterString	-	description	IfcText	Description of the RRRs
LA_RRR.rID	Oid	-	rightID	IfcIdentifier	Identifier of the Rights from the RRRs
LA_RRR.share	Fraction	-	share	IfcRatioMeasure	Share in the instance of a subclass of LA_RRR
LA_RRR.shareCheck	Boolean	-	shareCheck	IfcBoolean	Indicates whether the constraint in LA_BAunit can be applied
LA_RRR.timeSpec	ISO 8601 type of ISO 14825 type	-	timeSpec	IfcText	Use of RRRs in time sharing
type	LA_RightType	agriActivity commonOwnership customaryType fireWood fishing grazing informalOccupation lease occupation ownership ownershipAssumed superficies usufruct waterrights tenancy	type	IfcLabel	Type of right
-	-	-	mortgageRight_ID	IfcIdentifier	Identifier of the mortgage

Table 11. LADM information of the LA_Restriction and LA_Mortgage classes and the new IFC property set Pset_LA_Restriction

LADM information			**Pset_LA_Restriction (of IfcResource)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
LA_RRR.description	CharacterString	-	description	IfcText	Description of the RRRs
LA_RRR.rID	Oid	-	restrictID	IfcIdentifier	Identifier of the Restrictions from theRRRs
LA_RRR.share	Fraction	-	share	IfcRatioMeasure	Share in the instance of a subclass of LA_RRR
LA_RRR.shareCheck	Boolean	-	shareCheck	IfcBoolean	Indicates whether the constraint in LA_BAunit can be applied
LA_RRR.timeSpec	ISO 8601 type of ISO 14825 type	-	timeSpec	IfcText	Use of RRRs in time sharing
partyRequired	Boolean	-	partyRequired	IfcBoolean	Indicated if a party is required in the association with LA_Party
type	LA_RestrictionType	adminPublicServitude monument monumentPartly mortgage noBuilding servitude servitudePartly	type	IfcLabel	Type of restriction
-	-	-	mortgageRight	IfcBoolean	Indicates if the mortgage is associated with a right
-	-	-	mortgageRight_ID	IfcIdentifier	Identifier of the mortgage
amount	Currency	-	amount	IfcMonetaryMeasure	Amount of money of the mortgage
interestRate	Float	--	interestRate	IfcNumericMeasure	Interest rate of the mortgage
ranking	Integer	-	ranking	IfcInteger	Ranking order of mortgages

					(if applicable)
type	LA_MortgageType	levelPayment linear microcredit	type	IfcLabel	Type of the mortgage

Table 12. LADM information of the LA_Responsibility class and the new IFC property set Pset_LA_Responsibility

LADM information			**Pset_LA_Responsibility (of IfcResource)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
LA_RRR.description	CharacterString	-	description	IfcText	Description of the RRRs
LA_RRR.rID	Oid	-	respoID	IfcIdentifier	Identifier of the Responsibilities from the RRRs
LA_RRR.share	Fraction	-	share	IfcRatioMeasure	Share in the instance of a subclass of LA_RRR
LA_RRR.shareCheck	Boolean	-	shareCheck	IfcBoolean	Indicates whether the constraint in LA_BAunit can be applied
LA_RRR.timeSpec	ISO 8601 type or ISO 14825 type	-	timeSpec	IfcText	Use of RRRs in time sharing
type	LA_Responsibility Type	monumentMaintenance waterwayMaintenance	type	IfcLabel	Type of responsibility

4.6.4 LA_AdministrativeSource

LA_AdministrativeSource is a LADM class that contains the original information on the parties, rights, restrictions, responsibilities and basic administrative units (ISO/TC 211, 2022). LA_AdministrativeSource will be mapped to the IFC entity IfcResource. A new property set was made: Pset_LA_AdministrativeSource. Table 13 provides the LADM information of the LA_AdministrativeSource class and the new IFC property set Pset_LA_AdministrativeSource. The LADM attribute text contains the content of the document. However, the LADM type: MultMediaType of the attribute text has no equivalent or comparable IFC element. Therefore, the attribute text is replaced by four attributes that provide metadata on the document. The attribute location provides information on where the document is located on the Internet. The attribute reqrel_uID with data type IfcIdentifier can be added to the property set to provide an identification to the group of basic administrative units with their required relationships. To keep the relation with the LA_Party class (mapped to the IFC entity IfcActor), the identifier of the party, pID, can be added to the attribute list. LA_AdministrativeParty is a LADM association class that provides the role of the party in the administrative part of the registration process (ISO/TC 211, 2021). Due to its relevance, it was decided to add the contents of the codeList of the LA_AdministrativePartyRoleType as an attribute in the property set Pset_LA_AdministrativeSource.

Table 13. LADM information of the LA_AdministrativeSource class and the new IFC property set Pset_LA_AdministrativeSource

LADM information			**Pset_LA_AdministrativeSource (of IfcResource)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
text	MultiMediaType	-	-	-	-
			aID	IfcIdentifier	Identifier of document
-	-	-	name	IfcLabel	Name of document
-	-	-	description	IfcText	Description of document
-	-	-	location	IfcURIReference	Location of document on the Internet
type	LA_Administrative SourceType	agriConsent agriLease agriNotaryStatement deed mortgage title	type	IfcLabel	Type of document
role	LA_Administrative PartyRoleType	bank conveyancer notary moneyProvider registrar stateAdministrator	role	IfcLabel	Role of the party in the whole registration process
-	-	-	reqrel_uID	IfcIdentifier	Identifier of the group containing the BA Units with the required relationships
-	-	-	pID	IfcIdentifier	Identifier of the party

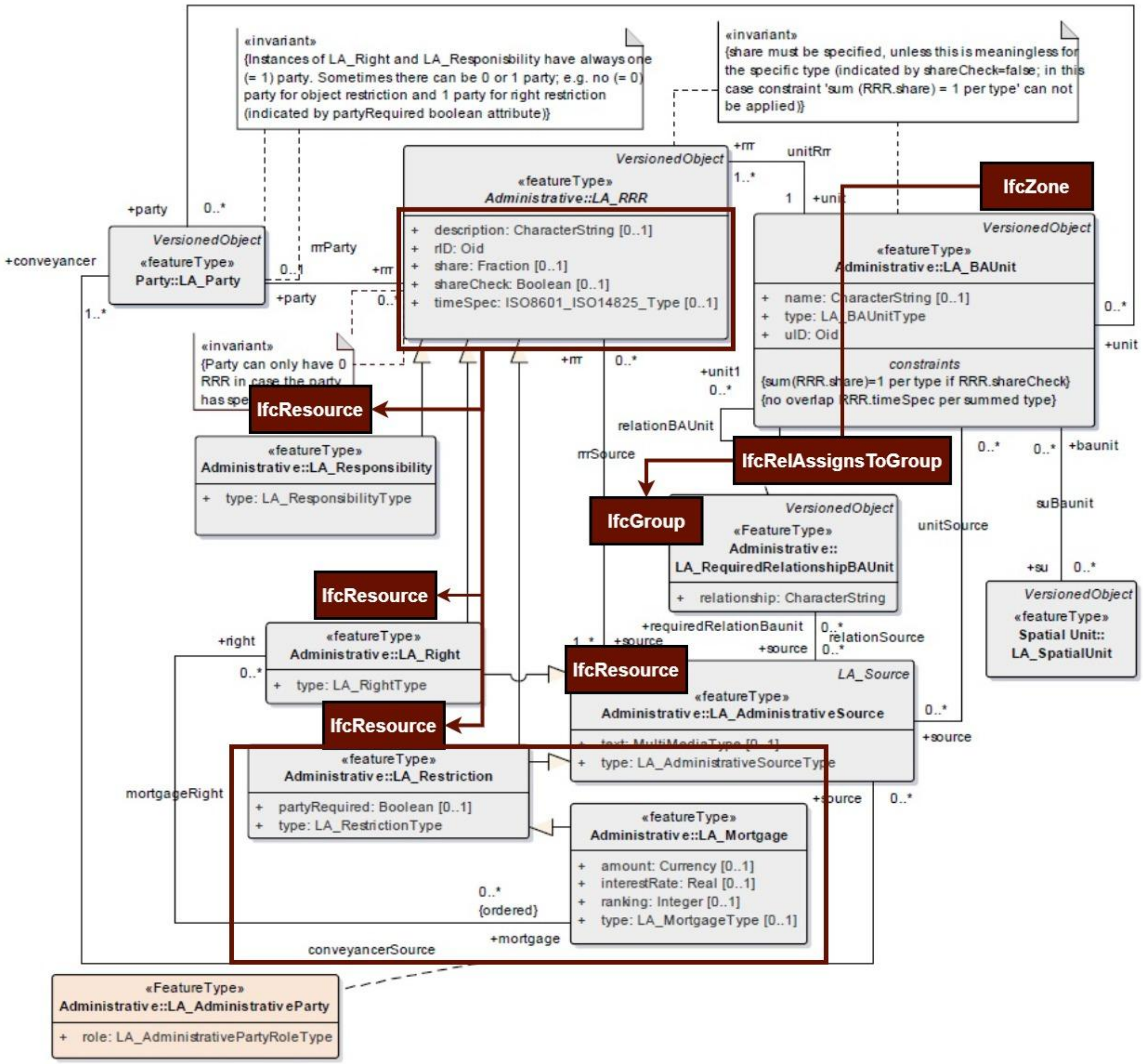


Figure 27. Mapping of the LADM classes of the Administrative Package to the IFC entities (adapted from ISO/TC 211, 2021)

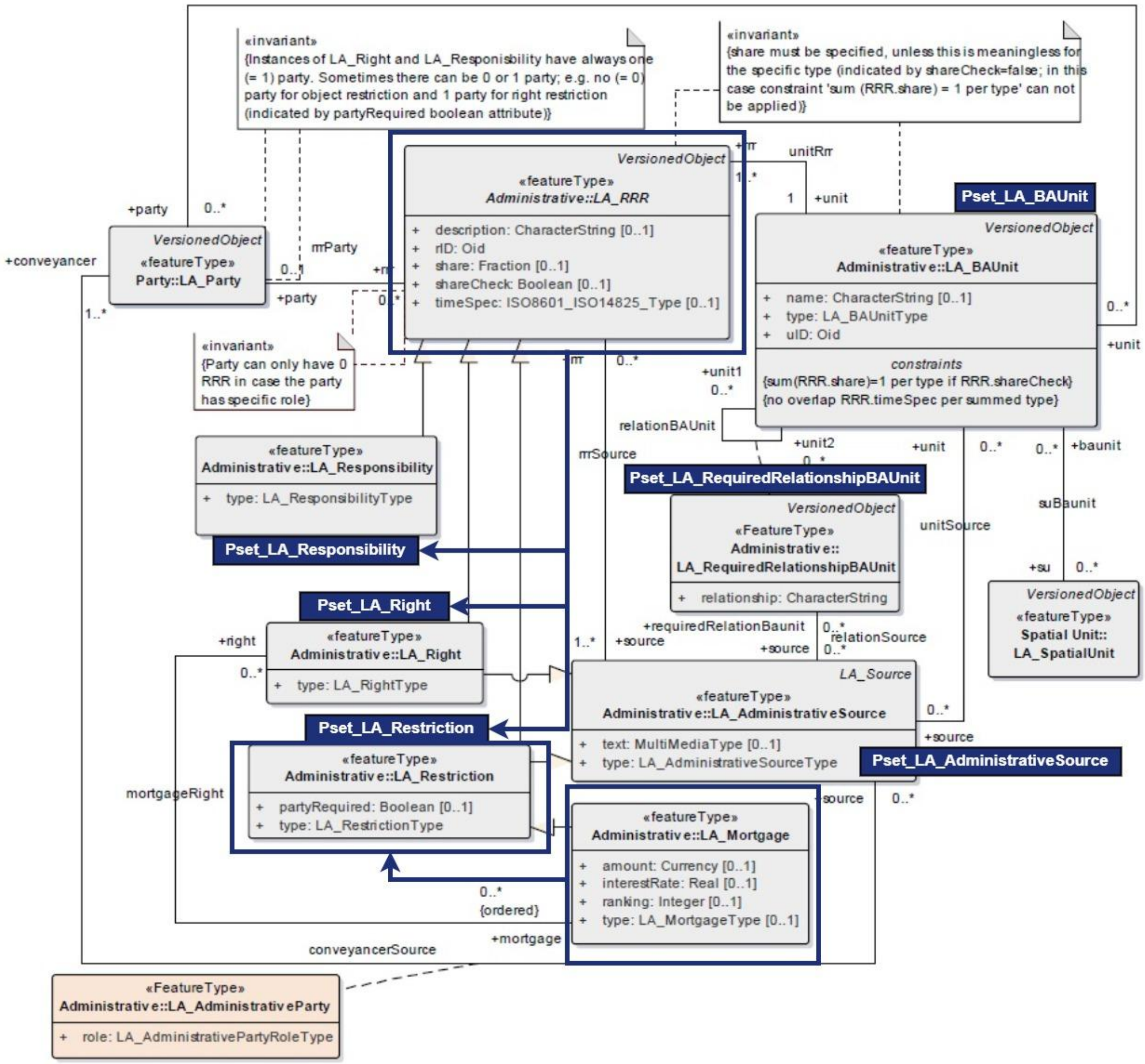


Figure 28. Association of the IFC property sets with LADM classes for the Administrative package (adapted from ISO/TC 211, 2021)

4.7 Spatial package

The LADM classes from the Spatial package that are mapped to IFC entities are: LA_SpatialUnit, LA_LegalSpaceParcel, LA_LegalSpaceBuildingUnit, LA_LegalSpaceUtilityNetwork, LA_LegalSpaceInfrastructure, LA_Level, LA_SpatialUnitGroup, LARequiredRelationshipSpatialUnit. Figure 29 shows the mapping of the LADM classes of the Spatial Package to the IFC entities. Figure 30 shows the association of the IFC property sets with LADM classes for the Spatial package.

4.7.1 LA_SpatialUnit

A spatial unit is an area of land or water or a volume of space that is associated with a basic administrative unit and is represented by the LADM class LA_SpatialUnit (ISO/TC 211, 2022). IfcSpace is defined as: *'A space represents an area or volume bounded actually or theoretically.'* (buildingSMART, 2022c). This makes IfcSpace the suitable IFC entity to map

the class LA_SpatialUnit to. A property set containing the attributes of LA_SpatialUnit will also be created and associated with the IfcSpace entity to which LA_SpatialUnit is mapped to. There are four subclasses of LA_SpatialUnit: LA_LegalSpaceParcel for the legal spaces of parcels, LA_LegalSpaceBuildingUnit for the buildings, LA_LegalSpaceUtilityNetwork for the utilities and LA_LegalSpaceInfrastructure for the infrastructural objects (ISO/TC 211, 2021). The four subclasses will each have their own property set. The property sets will each consist of the attributes from a subclass and will be associated with the IfcSpace that the class SpatialUnit is mapped to.
If IfcSpace is to be used for modelling, then four attributes are recommended to be included (if these attributes are not already present) (buildingSMART, 2022c). Table 14 provides the recommended attributes for IfcSpace.

Table 14. Recommended attributes for IfcSpace

Attribute name	**Description**
Name	Unique name of number of the space
Description	Description of the space
LongName	Full name of the space
ObjectType	Type (function) of the space

Some changes have been made in the attribute list of LA_SpatialUnit. In LA_SpatialUnit the attribute name area has Type: LA_AreaValue. LA_AreaValue is a data type consisting of the attribute areaSize and type. Both these attributes were modelled as separate IFC elements. The name of the attribute type was changed to areaType. Also, in the LA_SpatialUnit class, the attribute volume is listed with Type: LA_VolumeValue. LA_VolumeValue is a data type consisting of attribute volumeSize and type. Both the attributes were modelled as separate IFC elements. The name of the attribute type was changed to volumeType. To keep the relation with the LA_BAUnit class, LA_Level and LA_SpatialUnitGroup, the identifiers of these classes, uID, lID, sugID can be added to the list of attributes. To keep the relation between the classes LA_SpatialUnit and the LA_RequiredRelationshipSpatialUnit another attribute was added: reqrel_suID with data type IfcIdentifier.
Table 15 - 19 provides the LADM information of the LA_SpatialUnit, LA_LegalSpaceParcel, LA_LegalSpaceBuildingUnit, LA_LegalSpaceUtilityNetwork, LA_LegalSpaceInfrastructure class and the equivalent IFC property sets Pset_LASpatialUnit, Pset_LA_LegalSpaceParcel, Pset_LA_LegalSpaceBuildingUnit, Pset_LA_LegalSpaceUtilityNetwork and Pset_LA_LegalSpaceInfrastructure.

Table 15. LADM information of the LA_SpatialUnit class and the IFC property set Pset_LA_SpatialUnit

LADM information			Pset_LA_SpatialUnit (of IfcSpace)		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
-	-	-	Name	IfcLabel	Name of the space
-	-	-	Description	IfcText	Description of the space
-	-	-	LongName	IfcLabel	Full name of the space
-	-	-	ObjectType	IfcLabel	Type (function) of space
area	LA_AreaValue	-	-	-	-
areaSize	Area	-	areaSize	IfcAreaMeasure	Area of 2D spatial unit
type	LA_AreaType	calculatedArea nonOfficalArea officialArea surveyedArea	areaType	IfcLabel	Type of area
dimension	LA_DimensionType	0D 1D 2D 3D liminal	dimension	IfcLabel	Dimension of the spatial unit
extAddressID	Oid	-	extAddressID	IfcGloballyUniqueID	Link to external address(es) of the spatial unit
.label	CharacterString	-	label	IfcText	Description of the spatial unit
geometry	Geometry	-	geometry	IfcText	Geometry of the spatial unit
referencePoint	Point	-	referencePoint	IfcCartesianPoint	Coordinates of a point inside the spatial unit
suID	Oid	-	suID	IfcIdentifier	Identifier of the spatial unit
surfaceRelation	LA_LevelType / LA_SurfaceRelationType	above below mixed onSurface	surfaceRelation	IfcLabel	Indicates if the spatial unit is above or below the surface
volume	LA_VolumeValue	-	-	-	-
volumeSize	Volume	-	volumeSize	IfcVolumeMeasure	Volume of the 3D spatial unit

type	LA_VolumeType	calculatedArea nonOfficalArea officialArea surveyedArea	volumeType	IfcLabel	Type of volume
uID	Oid	-	uID	IfcIdentifier	Identifier of the BA unit
lID	Oid	-	lID	IfcIdentifier	Identifier of the level
sugID	Oid	-	sugID	IfcIdentifier	Identifier of the spatial unit group
-	-	-	reqrel_suID	IfcIdentifier	Identifier of the group of the spatial units with the required relationships

4.7.1.1 LA_LegalSpaceParcel

Table 16. LADM information of the LA_LegalSpaceParcel class and the IFC property set Pset_LA_LegalSpaceParcel

LADM information			**Pset_LA_LegalSpaceParcel (of IfcSpace)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
type	LA_ParcelUseType	agricultural industrial mixed other residential vacant	type	IfcLabel	Type of the parcel

4.7.1.2 LA_LegalSpaceBuildingUnit

Table 17. LADM information of the LA_LegalSpaceBuildingUnit class and the IFC property set Pset_LA_LegalSpaceBuildingUnit

LADM information			**Pset_LA_BuildingUnit (of IfcSpace)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
extPhysicalBuildingUnitID	extPhysicalBuildingUnit	-	extPhysicalBuildingUnitID	IfcGloballyUniqueID	Identifier of the building unit
type	LA_BuildingUnitType	individual shared	type	IfcLabel	Type of building unit

4.7.1.3 LA_LegalSpaceUtilityNetwork

Table 18. LADM information of the LA_LegalSpaceUtilityNetwork class and the IFC property set Pset_LA_LegalSpaceUtilityNetwork

LADM information			**Pset_LA_LegalSpaceUtilityNetwork (of IfcSpace)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
extPhysicalUtilityNetworkID	ExtPhysicalUtility Network	-	extPhysicalUtilityNetworkID	IfcGloballyUniqueID	Identifier of the physical description of the utility network
status	LA_StatusType	inUse outOfUse planned	status	IfcLabel	Status of the utility network
type	LA_UtilityNetwork Type	chemicals electricity gas heating oil telecommunication water	type	IfcLabel	Type of the utility network

4.7.1.4 LA_LegalSpaceInfrastructure

Table 19. LADM information of the LA_LegalSpaceinfrastructure class and the IFC property set Pset_LA_LegalSpaceinfrastructure

LADM information			Pset_LA_LegalSpaceInfrastructure (of IfcSpace)		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
extPhysicalInfrastructureID	ExtPhysicalInfrastructure	-	extPhysicalInfrastructureID	IfcGloballyUniqueID	Identifier of the physical description of the infrastructure
status	LA_StatusType	inUse outOfUse planned	status	IfcLabel	Status of the infrastructure
type	LA_InfrastructureType	bridge tunnel other	type	IfcLabel	Type of the infrastructure

4.7.2 LA_Level

The LADM class LA_Level defines a group of spatial units that are coherent in a geometrical, topological and/or thematic manner (ISO/TC 211, 2022). IfcSpace can also be part of another IfcSpace with the use of the entity IfcRelAggregates (buildingSMART, 2022c). A new property set can be made: Pset_LA_Level. Table 20 provides the LADM information of the LA_Level class and the new IFC property set Pset_LA_Level.

Table 20. LADM information of the LA_Level class and the IFC property set Pset_LA_Level

LADM information			Pset_LA_Level (of IfcSpace)		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
-	-	-	name_space	IfcLabel	Name of the space
-	-	-	Description	IfcText	Description of the space
-	-	-	LongName	IfcLabel	Full name of the space
-	-	-	ObjectType	IfcLabel	Type (function) of space
lID	Oid	-	lID	IfcIdentifier	Identifier of the level

name	CharacterString	-	name_level	IfcLabel	Name of the level
registerType	LA_RegisterType	all forest mining publicSpace rural urban	registerType	IfcLabel	Register type of the content of the level
structure	LA_StructureType	point polygon text topological unstructuredLine sketch	structure	IfcLabel	Structure of the level geometry
type	LA_LevelContentType	building customary mixed network primaryRight responsibility restriction informal	type	IfcLabel	Type of the content of the level

4.7.3 LA_SpatialUnitGroup

The LADM class LA_SpatialUnitGroup defines a group of spatial units that have the same administrative or zoning region, but do not need to be continuous. As for the class LA_Level, the IFC entity IfcSpace can also be used to map the class LA_SpatialUnitGroup. The IfcSpaces of the subclasses of LA_SpatialUnit will be associated with the IfcSpace of LA_SpatialUnitGroup through the entity IfcRelAggregates. A new property set can be made: Pset_LA_Level. Table 21 provides the LADM information of the LA_SpatialUnitGroup class and the new IFC property set Pset_LA_SpatialUnitGroup.

Table 21. LADM information of the LA_SpatialUnitGroup class and the IFC property set Pset_LA_SpatialUnitGroup

LADM information			**Pset_LA_SpatialUnitGroup (of IfcSpace)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
-	-	-	Name	IfcLabel	Name of the space
-	-	-	Description	IfcText	Description of the space
-	-	-	LongName	IfcLabel	Full name of the space
-	-	-	ObjectType	IfcLabel	Type (function) of space

hierarchyLevel	Integer	-	hierarchyLevel	IfcInteger	Level in the hierarchy of a division
label	CharacterString	-	label	IfcText	Description of the spatial unit group
name	CharacterString	-	name	IfcLabel	Name of the spatial unit group
referencePoint	Point	-	referencePoint	IfcCartesian Point	Coordinates of reference point in a group
sugID	Oid	-	sugID	IfcIdentifier	Identifier of the spatial unit group

4.7.4 LARequiredRelationshipSpatialUnit

LA_RequiredRelationshipSpatialUnit is a LADM class that provides the required relationship(s) between the basic administrative units (ISO/TC 211, 2022). Since the required relationship can concern multiple units, an IfcGroup can be made that contains all the basic administrative units with an explicit relationship. The IfcSpaces to which the subclasses of LA_SpatialUnit are mapped to will be related through the relationship IfcRelAssignsToGroup. A new property set can be made: Pset_LA_RequiredRelationshipSpatialUnit. A new attribute reqrel_suID with data type IfcIdentifier can be added to the property set to provide an identification to the group in order to keep the relation between the classes LA_SpatialUnit and the LA_RequiredRelationshipSpatialUnit. Table 22 provides the LADM information of the LA_RequiredRelationshipSpatialUnit class and the new IFC property set Pset_LA_RequiredRelationshipSpatialUnit.

Table 22. LADM information of the LA_RequiredRelationshipSpatialUnit class and the IFC property set Pset_LA_RequiredRelationshipSpatialUnit

LADM information			**Pset_LA_RequiredRelationshipSpatialUnit (of IfcGroup)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
-	-	-	reqrel_suID	IfcIdentifier	Identifier of the group
relationship	ISO 19107_Type	-	relationship	IfcText	Description of the required relationship

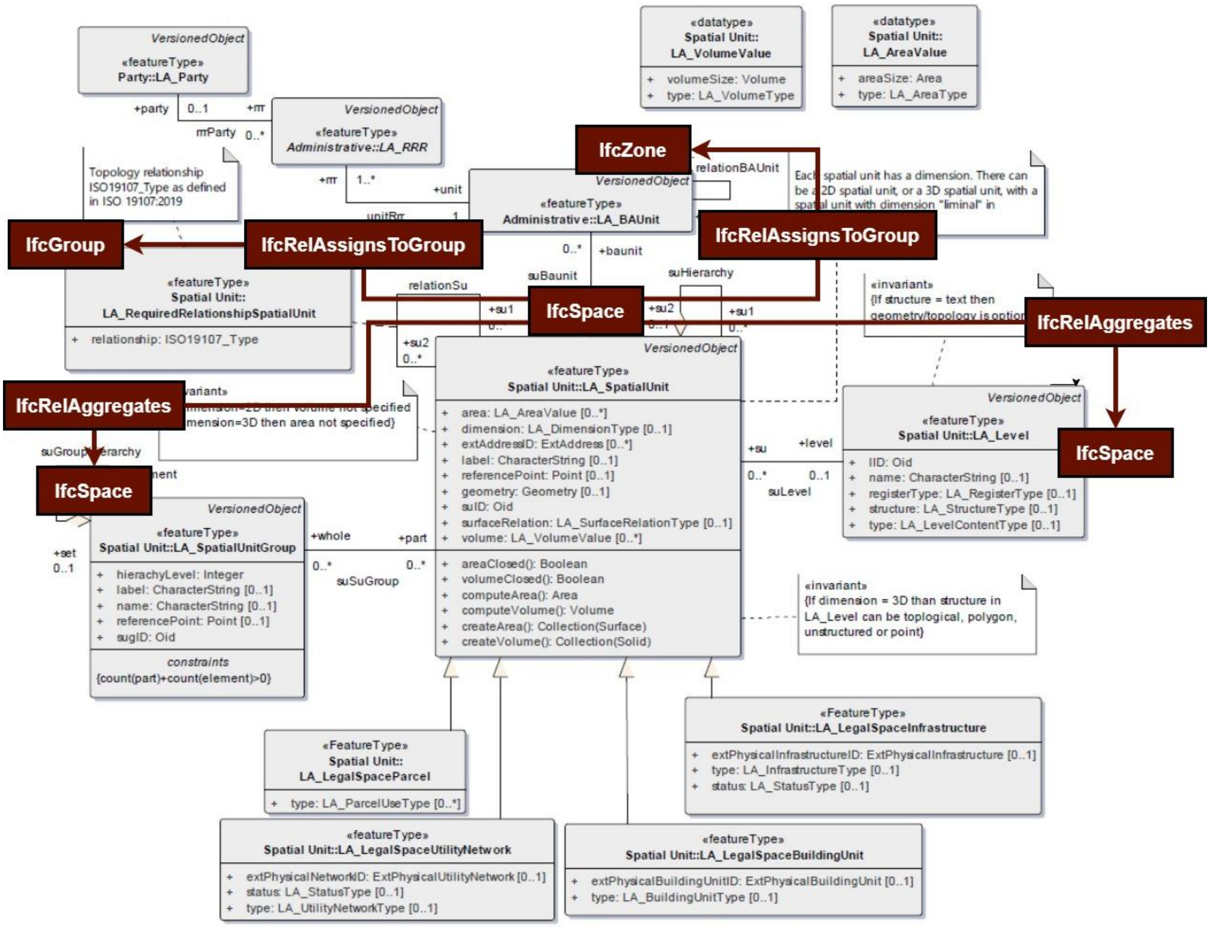


Figure 29. Mapping of the LADM classes of the Spatial Package to the IFC entities

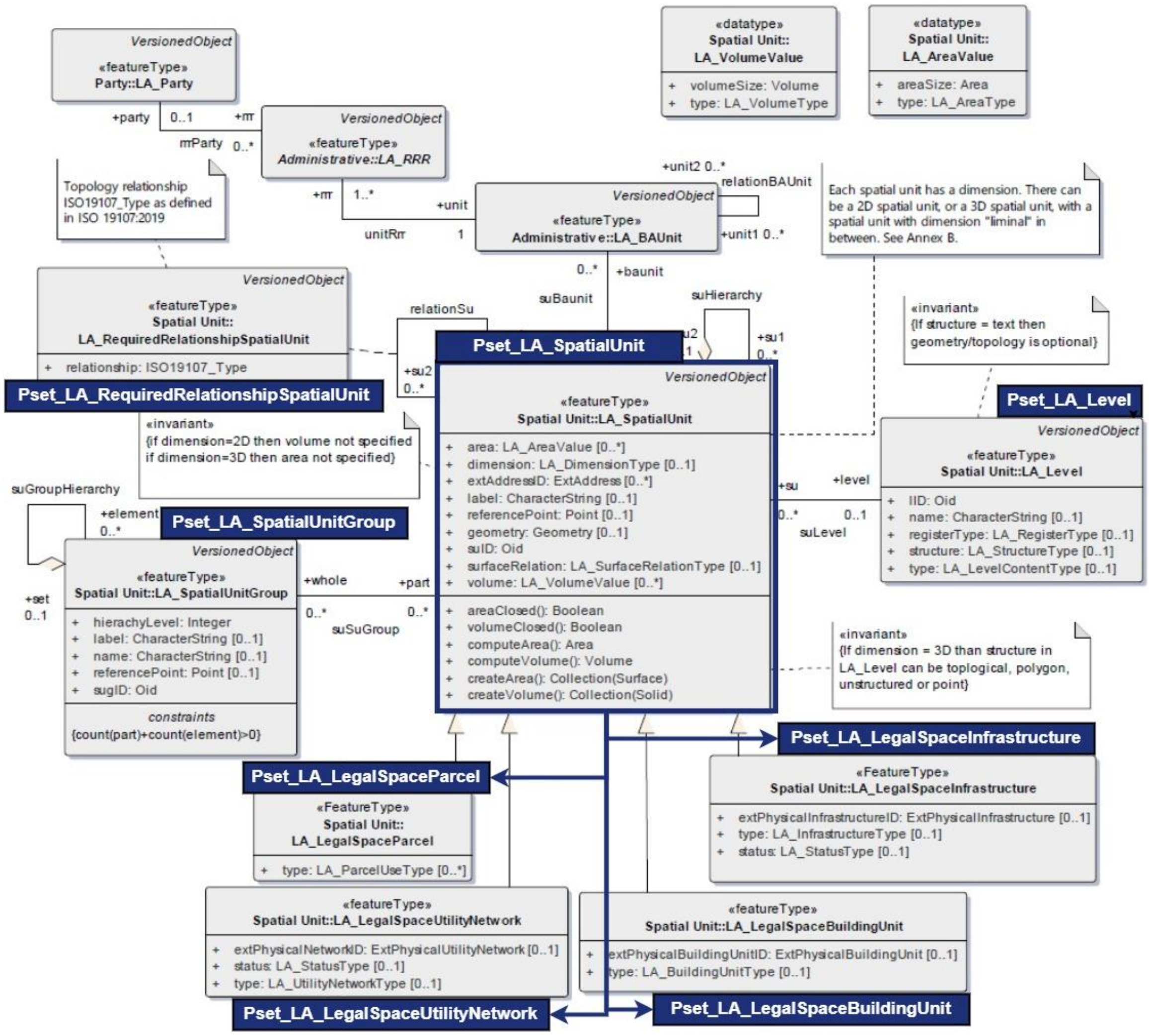


Figure 30. Association of the IFC property sets with LADM classes for the Spatial package.

4.8. Surveying and representations subpackage

In a cadastre, 2D spatial units are represented by points along a boundary that form a boundary string (curve). 3D spatial units are represented by (3D) points along a boundary that form a boundary face (surface) (ISO/TC 211, 2021). The LADM classes from the Surveying and representations subpackage that are mapped to IFC entities are: LA_Point, LA_BoundaryFaceString, LA_BoundaryFace, LA_SpatialSource, LA_DesignSource and LA_SurveyParty. Figure 31 shows the mapping of the LADM classes of the Surveying and Representations subpackage to the IFC entities. Figure 32 shows the association of the IFC property sets with LADM classes for the Surveying and Representations subpackage.

4.8.1 LA_Point

The LADM class LA_Point represents a point. The IFC entity IfcCartesianPoint defines a geometric point. This characteristic makes the IfcCartesianPoint entity suitable to map LA_Point to. A new property set can be made: Pset_LA_Point. Table 23 provides the LADM information of the LA_Point class and the new IFC property set Pset_LA_Point. Since the boundary face strings and boundary faces are composed of points, two new attributes are added: bfs_groupID and bf_groupID both with data type IfcIdentifier. These attributes are added to keep the relation between the class LA_Point and the classes LA_BoundaryFaceString and LA_BoundaryFace through the use of IfcGroups.

Table 23. LADM information of the LA_Point class and the IFC property set Pset_LA_Point

LADM information			**Pset_LA_Point**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
estimatedAccuracy	AbsolutePositionalAccuracy	-	estimatedAccuracy	IfcRatioMeasure	Estimated accuracy of a point
interpolationRole	LA_InterpolationType	midArc start end mid isolated	interpolationType	IfcLabel	Role of point in the structure of a straight line of curve
monumentation	LA_MonumentationType	beacon cornerstone marker notMarked	monumentation	IfcLabel	Type of monumentation
originalLocation	Point	-	originalLocation	IfcCartesian Point	Calculated coordinates
pID	oid	-	pID	IfcIdentifier	Identifier of the point
pointType	LA_PointType	control noSource source	pointType	IfcLabel	Type of the point
productionMethod	LI_Lineage	-	lineage	IfcLabel	The lineage
transAndResult	LA_Transformation	-	-	-	-
transformation	OperationMethod	-	transformation	IfcLabel	Transformation method used to associate location value
transformedLocation	Point	-	transformedLocation	IfcCartesian Point	Location obtained from transformation method
-	-	-	bfs_groupID	IfcIdentifier	Identifier of the group of boundary face strings
-	-	-	bf_groupID	IfcIdentifier	Identifier of the group of boundary faces

4.8.2 LA_BoundaryFaceString

The LADM class LA_BoundaryFaceString is used for the representation of 2D spatial units through line strings and 3D spatial units where the line strings are to be seen as vertical faces (ISO/TC 211. 2022). IfcPolyLine is an IFC entity that is a curve consisting of lines made up by (Cartesian) points (buildingSMART, 2022c). This characteristic of IfcPolyLine makes it suitable to map LA_BoundaryFaceString to it. A new property set can be made: Pset_LA_BoundaryFaceString. Table 24 provides the LADM information of the LA_BoundaryFaceString class and the new IFC property set Pset_LA_BoundaryFaceString. The attribute bfs_groupID was added to the IFC attributes to keep the link between LA_BoundaryFaceString and LA_point through the use of an IfcGroup.

Table 24. LADM information of the LA_BoundaryFaceString class and the IFC property set Pset_LA_BoundaryFaceString

LADM information			**Pset_BoundaryFaceString (of IfcPolyline)**		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
bfsID	Oid	-	bfsID	IfcIdentifier	Identifier of the boundary face string
geometry	Collection (Curve)	-	geometry	IfcPolyline	Boundary represented via a curve on ground level
locationbyTest	CharacterStrin g		locationbyTest	IfcText	Boundary represented in text
-	-	-	bfs_groupID	IfcIdentifier	Identifier of the group of boundary face strings

4.8.3 LA_BoundaryFace

The LADM class LA_BoundaryFace is used for the representation of 3D spatial units through faces that create volumes that are to be seen as legal spaces (ISO/TC 211, 2022). IfcSurface is an IFC entity that can represent a surface through connected points. (buildingSMART, 2022c). This characteristic of IfcSurface makes the entity suitable to map LA_BoundaryFace to. A new property set can be made: Pset_LA_BoundaryFace. Table 25 provides the LADM information of the LA_BoundaryFace class and the new IFC property set Pset_LA_BoundaryFace. The attribute bf_groupID was added to the IFC attributes to keep the link between LA_BoundaryFace and LA_point through the use of an IfcGroup.

Table 25. LADM information of the LA_BoundaryFace class and the IFC property set Pset_LA_BoundaryFace

LADM information			Pset_BoundaryFace (of IfcSurface)		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
bfID	Oid	-	bfsID	IfcIdentifier	Identifier of the boundary face
geometry	Collection (Surface)	-	geometry	IfcSurface	Boundary represented via a surface on ground level
locationbyTest	CharacterString		locationbyTest	IfcText	Boundary represented in text
-	-	-	bf_groupID	IfcIdentifier	Identifier of the group of boundary faces

4.8.4 LA_SpatialSource

LA_SpatialSource is the LADM class that gives information on the spatial representation of the object (ISO/TC 211, 2022). The IFC entity IfcResource can be used as a container for the attributes of LA_SpatialSource. A new property set can be made: Pset_LA_SpatialSource. Table 26 provides the LADM information of the LA_SpatialSource class and the new IFC property set Pset_LA_SpatialSource. The attribute reqrel_suID was added to the IFC attributes to keep the link between LA_SpatialSource and LA_RequiredRelationshipSpatialUnit through the use of an IfcGroup. The attributes (and the contents of the codeLists, if applicable) of the LADM classes LA_DesignSource and LA_SurveyParty were added to the attribute list of LA_SpatialSource since these attribute were relevant to the spatial source and to the registering of the RRRs of spatial units.

Table 26. LADM information of the LA_SpatialSource, LA DesignSource and LA_SurveyParty classes and the IFC property set Pset_LA_SpatialSource

LADM information			Pset_SpatialSource		
LADM Attribute name	**LADM Type**	**LADM codeList**	**IFC Attribute name**	**IFC Data Type**	**Description**
type	LA_SpatialSourceType	GNSS totalStation LiDAR RADAR levelling mobileMapping photogrammetry analogueMapping	type	IfcLabel	Technique of the survey used

		tacheometry CADDesgn chainSurveying BIM Design			
media	LA_MediaType	sketch pointCloud image scannedMap digitizedMap DB video	media	IfcLabel	Type of source media
automationL Level	LA_Automation LevelType	automatic manual semiAutomatic	automationL evel	IfcLabel	The process automation level
surveyPurpo se	LA_SurveyPurp oseType	landConsolidation division split deedRegistration boundaryDelineation controlMeasurements boundaryReconstruction asMaidMeasurements titleRegistration amalgamation constructionPermit spatialPlanning	surveyPurpo se	IfcLabel	Purpose of the survey
lifecyclePha se	LA_LifecyclePh aseType	asBuilt buildingPermit design	lifecyclePhas e	IfcLabel	Lifecycle phase of the object
sourceFileTy pe	LA_SourceFile Type	dwg dxf ifc shapefile other	sourceFileTy pe	IfcLabel	Format type of the source file
designObje ctType	LA_DesignObje ctType	residentialBuilding commercialBuilding school hospital terminal road tunnel bridge other	designObject Type	IfcLabel	Type of object or spatial unit from the design
fileCreatorR ole	LA_FileCreator RoleType / LA_DesignFile CreatorRoleTyp e	architect constructor municipality designer other	fileCreatorRo le	IfcLabel	Role of the designer
role	LA_SurveyPart yRoleType	licensedSurveyor supervisingSurveyor volunteer	role	IfcLabel	Role of the surveyor
-	-	-	reqrel_suID	IfcIdentifier	Identifier of the group containing spatial units with the

					required relationships

Several classes, data types and codeLists do not need to be used for the mapping of LADM classes to IFC entities for the Surveying and Representations subpackage. The primary reason for not using these LADM classes, data types and codeLists is because they represent detailed information on surveying. In scenario 1, where the geometry is reused from BIM/IFC models from design for the registration of legal spaces in LASs, details on surveying are not needed. In scenario 2, where the BIM/IFC models from design serve as a technical encoding for exchange of data in LASs, detailed information on surveying could be useful, but it was decided, for this research, to only map the main classes of the Surveying and Representations subpackage and leave the details to future work. Table 27 provides the LADM classes, data types and codeLists that were not used for mapping to IFC entities.

Table 27. LADM classes, data types and codeLists that were not used for mapping to IFC entities

Class	Data type	codeLists
LA_SurveySource LA_SurveyRelation LA_DistanceObservation LA_LevelObservation LA_AngularObservation LA_ImageObservation LA_TPSObserbvation LA_PointCloudObservation LA_GNSSObservation LA_GNSSCorrections	LA_Transformation LA_SSR_Error_Components	LA_InterpolationType LA_MonumentationType LA_MediaType LA_AutomationLevelType LA_PlatformType LA_SurveyMethodType LA_SpatialTransactionType LA_DistanceType LA_AngularType LA_SatelliteSystemType LA_GNSSSurveyType LA_ObservationsAccuracyType LA_GNSSFrequencyType LA_CorrectionServiceType LA_GNSSReferenceStationsNetworkType LA_GNSSReferenceStationsNetworkScale

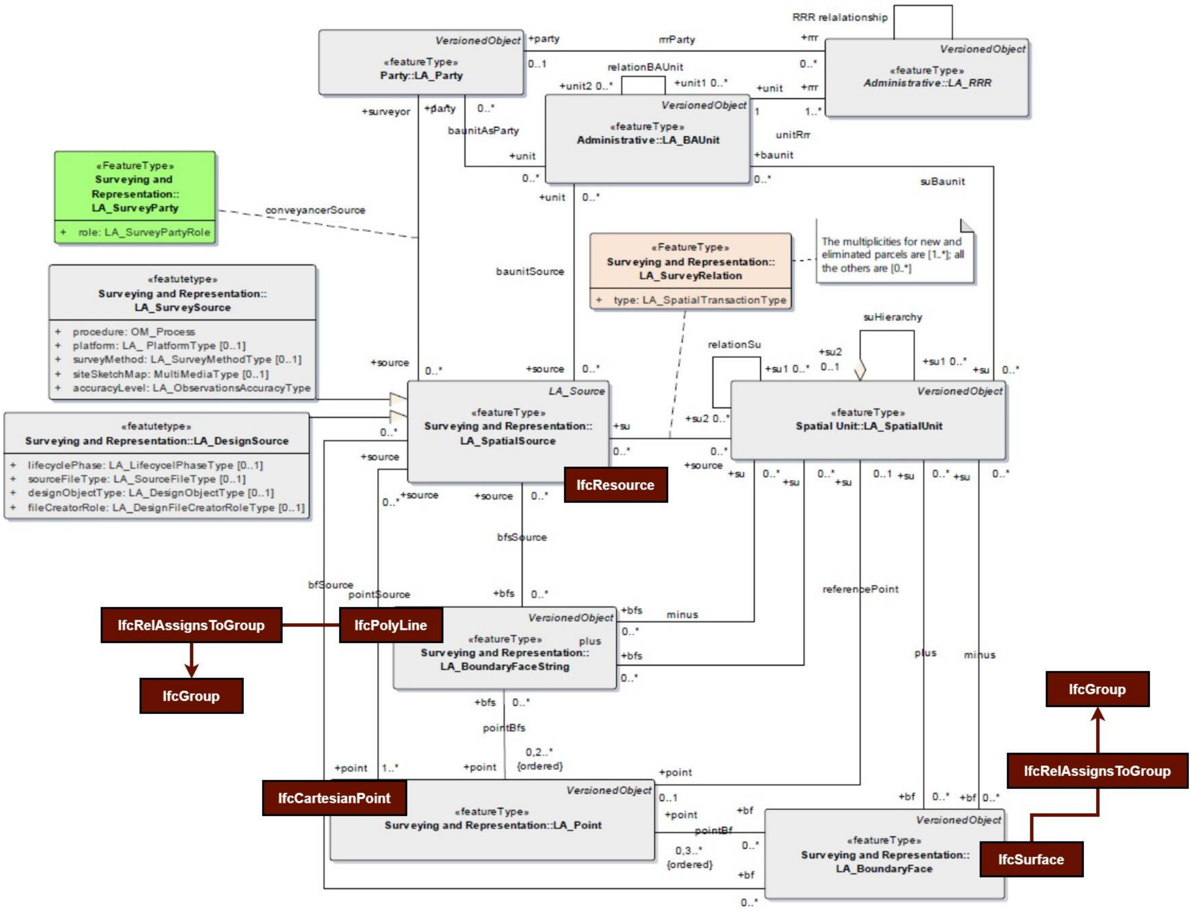


Figure 31. Mapping of the LADM classes of the Surveying and Representations subpackage to the IFC entities

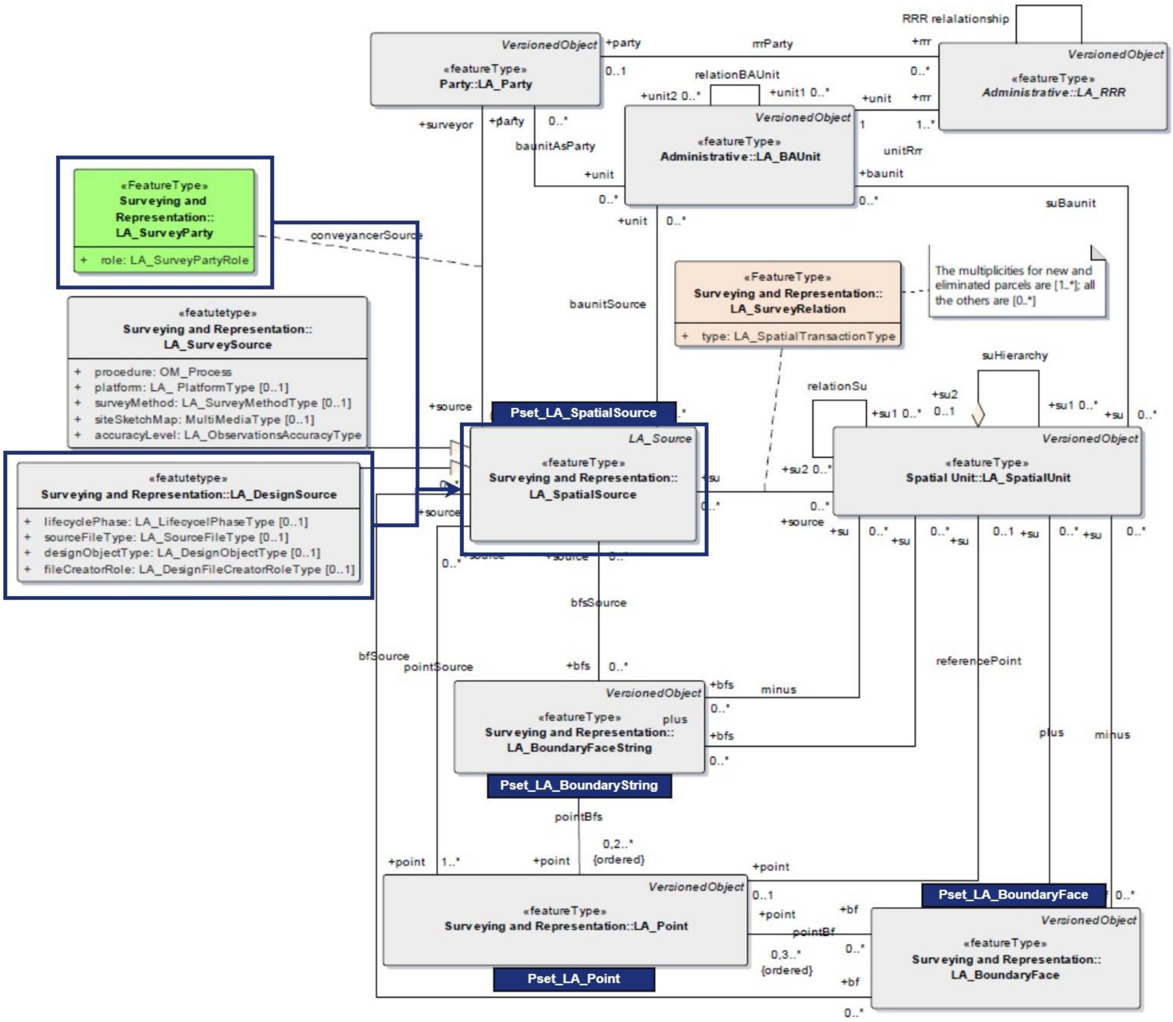


Figure 32. Association of the IFC property sets with LADM classes for the Surveying and Representations subpackage

5. Case studies

This chapter presents the implementation of the technical workflow from subsection 3.4.4 through two case studies, where the RRRs of objects below the surface and the parcels above the surface will be registered, stored in a PostgreSQL database and visualised on the 3D geospatial visualisation platform CesiumJS. The first case study is of a utility segment and the second case study is of a tunnel. Almost all the files used and created in these two case studies can be found on the public Github repository:
https://github.com/rohitramlakhan/thesis.

5.1 Selection of input data for case studies

The input data of the objects below the surface used in the case studies were chosen due to the result of a process of elimination. The other data that was collected was not chosen because of one or more of the following reasons:

- The data could not be read, viewed or processed
- The data collected was not from objects below the surface
- The data was not an IFC model, and could not be converted to an IFC model
- The data was not or incorrectly georeferenced and could not be correctly georeferenced
- The data had no available or accessible data on the ownership of the corresponding parcels above the surface

After this process of elimination, datasets with utilities from three providers (the province of North-Holland, the municipality of Almere and the water company PWN) and datasets with tunnels from two providers (Rijkswaterstaat and Ballast-Nedam) were left.
The datasets from the utilities were all shapefiles or a geopackage and would need to be converted to an IFC model. The utility datasets were all viewed in QGIS, where also a WFS request was made to PDOK for the Cadastral registry (*Dutch: Basisregistratie Kadaster, BRK)* dataset that contains the cadastral parcels of the Netherlands. Then, the data was inspected and compared to the cadastral parcels, to see if there were interesting cases with, for example, different owners or specific restrictions. The dataset from the sewage pipes from the municipality of Almere was eventually chosen, since there were multiple owners in the selection from the dataset that was made.
The dataset from the tunnels were an IFC model and a Navisworks model (NWD). The IFC model was chosen, because even though the NWD could be converted to an IFC model, the result was a file with a large file size, larger than that of the IFC model. With regards to ownership of the tunnels, there was no difference, since both tunnels are owned and maintained by the Ministry of Infrastructure and Water Management.

5.2 Case study 1: Sewage pipes

In the first case study of this research, the legal spaces from the sewage pipes of the main sewage of the Dutch municipality of Almere, as well as the pipes that are connected to the homes there, were modelled. In the Netherlands, the main sewage pipes of the sewage network are owned by the municipality, which also has the responsibility to maintain the sewage system. The ownership of cables and pipes in the Netherlands does not involve a volumetric space of the object or around it. The ownership is limited to the object itself.
The main sewage pipes are (usually) located under the land owned by the municipality.
The municipality is thereby the owner of the land and the network under the land. The legal spaces of the main sewage pipes are thus the 2D parcels on the surface that are extruded to 3D parcels.
For the pipes that are connecting the main sewage pipes to the homes, the situation is a bit different, because the ownership of the connections end at the border of the parcels. The RRRs of the pipes that connected the homes to the main sewage pipes are divided between the public and private parties. However, the legal space of these pipes can be modelled in the same manner as the legal spaces from the main sewage pipes, that is, by using the 2D parcels and extruding them to 3D.
The legal spaces were modelled through the following steps:

1. Select pipe segments from the sewage network
2. Convert the pipe segments to IFC models
3. Select the parcels under which the pipe segments lie
4. Convert the parcels to an IFC model
5. Store the pipe segments and the parcels in the 3D DBMS
6. Add the RRRs to the 3D DBMS
7. Write the data from the 3D DBMS to Cesium 3D Tiles
8. Visualise the Cesium 3D Tiles

5.2.1 Select pipe segments from the sewage network

The main sewage pipe segments were selected in QGIS from the GeoPackage with the sewage network (MA_main_sewage_pipes.shp) (Figure 33). The selected feature was saved as a separate shapefile: main_sewage_almere.shp with the CRS: EPSG:4326 - WGS 84. The pipe segments connecting the main sewage pipe to the homes (the home connections) were selected in QGIS from the GeoPackage with the home connections (MA_sewage_home_connections) (Figure 33).

Figure 33. Selected pipe segments from the sewage network in Almere. Blue: main sewage pipes, orange: home connections

5.2.2 Convert the pipe segments to IFC models

The selected main sewage pipe segments and home connections were converted to IFC models (main_sewage_almere..ifc, home_connections_almere.ifc) with the use of the FME Workspace cs1_shp2ifc_(1).fmw and cs1_shp2ifc_(2).fmw (see Appendix D, Figure D1, D2). The 2D pipe segments should be 'buffered' to 3D, which is why the transformer 'Bufferer' is present. The main sewage pipes and the home connections both had a value for the diameter, but with the home connections, the value was expressed in mm. That is why the value was manually inserted in the 'Bufferer' transformer. The home connections also did not have a depth value. It was decided to use an 'Ofsetter' transformer to manually insert a value for the depth, which was the average of the values of the depths of the main sewage pipes to which the home connections are connected to. The geometry of the pipe segments was stored in IfcSpace(s). The shapefile were then written to IFC 2x3. The model could also be written to IFC 4 or IFC 4x3, but then the property sets did not show. It was not clear what caused this problem, and it was decided not to write the shapefile model to IFC 4 or IFC 4x3. Figure 34. shows the IFC models of the main sewage pipes and the home connections.

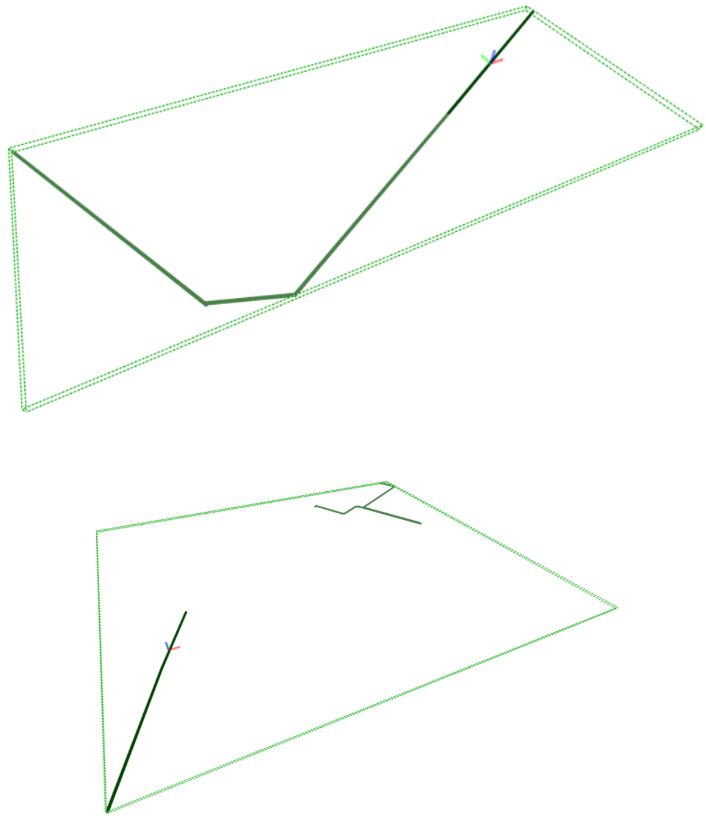


Figure 34. IFC models of the main sewage pipes (top) and the home connections (bottom)

5.2.3 Select the parcels under which the pipe segments lie

The parcels under which the pipe segments lie were selected in QGIS where a connection was made to the PDOK Web Feature Service (WFS) for the Cadastral Registrations (*Dutch: Basisregistratie Kadaster, BRK)* dataset that contains the cadastral parcels of the Netherlands. The selected parcels were then saved as a new shapefile as 'parcels_almere.shp' with the CRS: EPSG:4326 - WGS 84. Figure 35. shows the two selected parcels overlaid on OpenStreetMap.

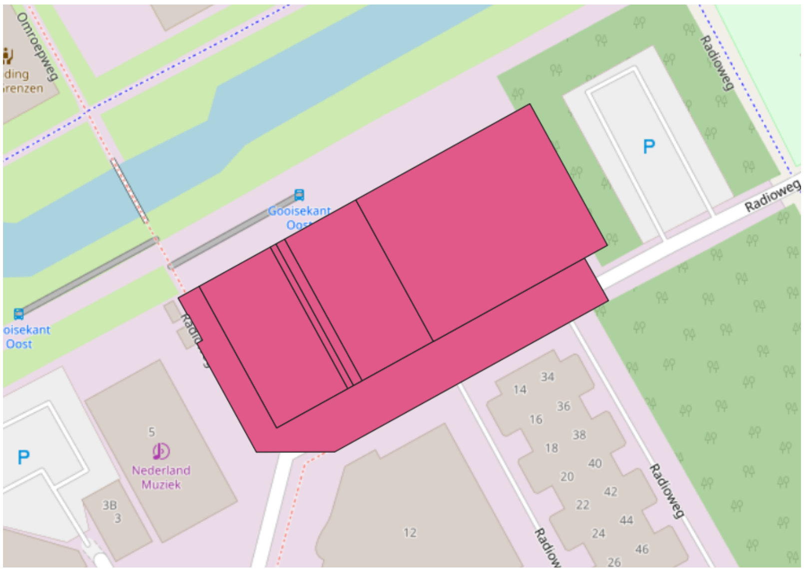


Figure 35. Selected parcels from the municipality of Almere

5.2.4 Convert the parcels to an IFC model

The shapefile with the selected parcels was converted to an IFC model with the use of the FME Workspace cs1_shp2ifc_(3).fmw (Appendix D, Figure D3). In this workspace, there are two transformers: ‘Extruder’ and ‘Offsetter’ that were added to extrude the two parcels for 100 metres above and below the surface of the 2D parcel in order to create a 3D parcel. Although the ownership of a parcel in the Netherlands extends further than 100 metres above and below the surface, this value was chosen since this was deemed enough to show the parcels extending above and below the surface. The geometry of the parcels was stored in IfcSpace. The shapefile model was then written to IFC 2x3. Figure 36 shows the IFC model of the two selected parcels.

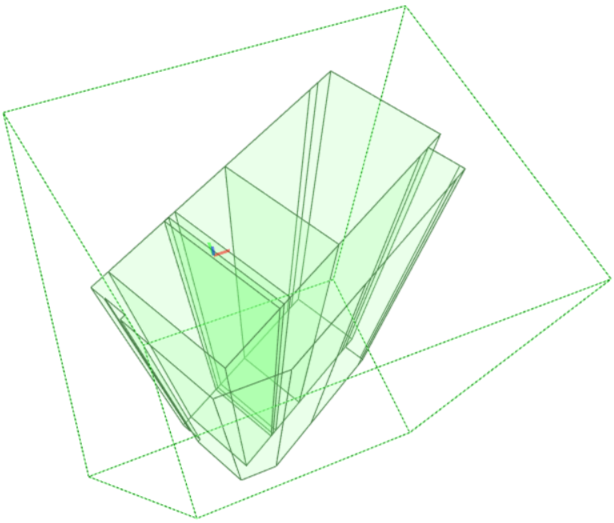


Figure 36. IFC model of the selected parcels from the municipality of Almere

5.2.5 Store the pipe segments and the parcels in the 3D DBMS

The IFC models with the sewage pipe segments, home connections and parcels were stored in the 3D DBMS through the use of the FME workspace cs1_ifc2postgis_(4).fmw (Appendix D, Figure D4) and the DBMS PostgreSQL extended with PostGIS spatial extension, accessed through the web-based client pgAdmin.

In the workspace, first, the IFC models were read into FME. In the 'Parameters' section the 'Read IfcSpace Geometries' was changed from 'No' to 'Yes'. In the 'Select Feature Types' pop-up only IfcSpace was selected from the Object List, since IfcSpace contains the geometry of the cable segments. Then, the names of the attributes were changed to lowercase letters in order to write the values of the attributes to the 3D DBMS. The transformer 'AttributeManager' was used to change the names of the attributes to lowercase letters since the transformer 'StringCaseChanger' did not work.

Hereafter, a database was created in PostgreSQL: 'case_almere'. Then, the database was extended with PostGIS by executing the SQL query: `CREATE EXTENSION POSTGIS;`. In the FME workspace the PostGIS writer was selected. A new database connection was made: 'case_almere'. The host was 'localhost', the port: 5432 and the database was 'case_almere'. In the 'Feature Type' section of the PostGIS writer, the 'Table Names' were 'main_sewage_almere', 'home_connections_almere', 'parcels_almere'. The 'Table Handling' was changed from 'Create If Needed' to 'Drop and Create' in order to drop the tables with older values and create new tables when executing the FME workspace multiple times.

5.2.6 Add the RRRs to the 3D DBMS

The RRRs were added to the pipe segments and parcels by first adding the columns 'Party', 'Rights', 'Restrictions', 'Responsibilities' to the table 'parcels_almere'. This was done through the execution of the SQL query:

```
ALTER TABLE parcels_almere
ADD COLUMN Party VARCHAR,
ADD COLUMN Rights VARCHAR,
ADD COLUMN Restrictions VARCHAR,
ADD COLUMN Responsibilities VARCHAR;
```

Hereafter, the columns of the table 'parcels_almere' were populated with the values of the Parties and the RRRs retrieved from the Dutch Cadastre (Appendix F).

For the parcels with numbers '3147', '3148' and '3303' the 'Party' is 'Rijnhomij B.V.'. The 'Rights' are 'Ownership' and the 'Restrictions' are 'Obligation to consent (Liander N.V.)'. There are no known 'Responsibilities'. The SQL query for updating the 'Party', 'Rights' and 'Restrictions' columns is:

```
UPDATE parcels_almere
SET Party = 'Rijnhomij B.V.', Rights = 'Ownership', Restrictions =
'Obligation to consent (Liander N.V.)'
WHERE name = '3147';

UPDATE parcels_almere
SET Party = 'Rijnhomij B.V.', Rights = 'Ownership', Restrictions =
'Obligation to consent (Liander N.V.)'
WHERE name = '3148';
```

```
UPDATE parcels_almere
SET Party = 'Rijnhomij B.V.', Rights = 'Ownership', Restrictions =
'Obligation to consent (Liander N.V.)'
WHERE name = '3303';
```

For the parcel with the number ‘3302’, the ‘Party’ is ‘G.N. Wijngaard B.V.’. The ‘Rights’ are ‘Ownership’ and the ‘Restrictions’ are ‘Obligation to consent (Liander N.V.)’. There are no known ‘Responsibilities’. The SQL query for updating the ‘Party’, ‘Rights’ and ‘Restrictions’ columns is:

```
UPDATE parcels_almere
SET Party = 'G.N. Wijngaard B.V.', Rights = 'Ownership', Restrictions =
'Obligation to consent (Liander N.V.)'
WHERE name = '3302';
```

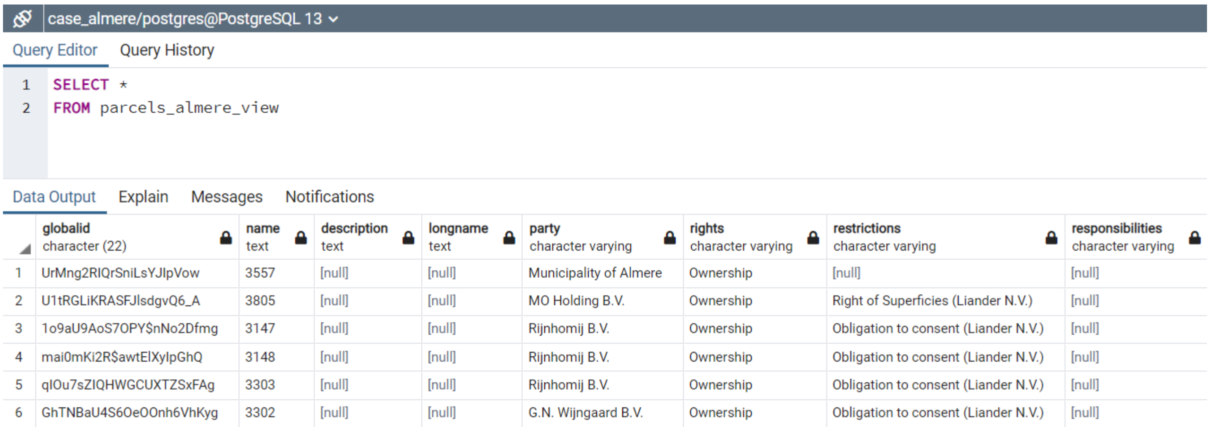
For the parcel with the number ‘3557’, the ‘Party’ is the ‘Municipality of Almere’. The ‘Rights’ are ‘Ownership’. There are no known ‘Restrictions’ and ‘Responsibilities’. The SQL query for updating the ‘Party’ and ‘Rights’ columns is:

```
UPDATE parcels_almere
SET Party = 'Municipality of Almere', Rights = 'Ownership'
WHERE name = '3557';
```

For the parcel with the number ‘3805’, the ‘Party’ is the ‘MO Holding B.V.’. The ‘Rights’ are ‘Ownership’ and the ‘Restrictions’ are ‘Right of superficies (Liander N.V.)’ There are no known ‘Restrictions’ and ‘Responsibilities’. The SQL query for updating the ‘Party’ and ‘Rights’ columns is:

```
UPDATE parcels_almere
SET Party = 'MO Holding B.V.', Rights = 'Ownership', Restrictions = 'Right of
Superficies (Liander N.V.)'
WHERE name = '3805';
```

Figure 37 shows a view of selected columns of the table of the parcels. These columns were selected since they contain the GUID, the recommended attributes for IfcSpace, the Party, and the RRRs.



case_almere/postgres@PostgreSQL 13

Query Editor | Query History

```
SELECT *
FROM parcels_almere_view
```

Data Output | Explain | Messages | Notifications

	globalid character (22)	name text	description text	longname text	party character varying	rights character varying	restrictions character varying	responsibilities character varying
1	UrMng2RIQrSniLsYJlpVow	3557	[null]	[null]	Municipality of Almere	Ownership	[null]	[null]
2	U1tRGLiKRASFJlsdgvQ6_A	3805	[null]	[null]	MO Holding B.V.	Ownership	Right of Superficies (Liander N.V.)	[null]
3	1o9aU9AoS7OPY$nNo2Dfmg	3147	[null]	[null]	Rijnhomij B.V.	Ownership	Obligation to consent (Liander N.V.)	[null]
4	mai0mKi2R$awtElXylpGhQ	3148	[null]	[null]	Rijnhomij B.V.	Ownership	Obligation to consent (Liander N.V.)	[null]
5	qlOu7sZIQHWGCUXTZSxFAg	3303	[null]	[null]	Rijnhomij B.V.	Ownership	Obligation to consent (Liander N.V.)	[null]
6	GhTNBaU4S6OeOOnh6VhKyg	3302	[null]	[null]	G.N. Wijngaard B.V.	Ownership	Obligation to consent (Liander N.V.)	[null]

Figure 37. View of selected columns from the table parcels_almere

5.2.7 Write the data from the 3D DBMS to Cesium 3D Tiles

The data from the 3D DBMS was written to Cesium 3D Tiles with the use of the FME Workspace cs1_postgis2cesium3dtiles_(5).fmw. In this workspace, the data was read into FME with the PostGIS reader, where in the 'Parameters' section both tables, drainage_koggenland and parcels_koggenland, were selected from the schema public. For both readers a GeometryColorSetter was attached, where the rainwater drainage pipe segment was given the colour light blue, while the parcels were given the colour yellow. The alpha for the parcels was set at 0.4, to make the parcels transparent and thereby able to see objects below the surface such as telecommunication cable segments. Then, the Cesium 3D Tiles writers were attached for both readers. In the 'Feature Type' section of the Cesium 3D Tiles writer, the 'Geometry' was set for both writers to: 'cesium_3d_object'. The folders with the 3D Tiles were then zipped, in order to easily import the files into Cesium ion.

5.2.8 Visualise the Cesium 3D Tiles

To visualise the 3D Tiles, code was written in Cesium Sandcastle (https://sandcastle.cesium.com/). Parts of the code were adapted from the following code examples of Cesium Sandcastle: 'Globe Translucency', 'Montreal Point Cloud' and '3D Tiles Feature Picking'. The code was saved to the JavaScript file: 'case_almere.js' and the CSS file: 'case_almere.css'. Figure 38. shows the top view of the location of the selected parcels in the municipality of Almere. Figure 39. shows the selected parcels in the municipality of Almere. Figure 40. Shows the sewage pipes in the municipality of Almere.

Figure 38. Top view of the location of the parcels in the municipality of Almere

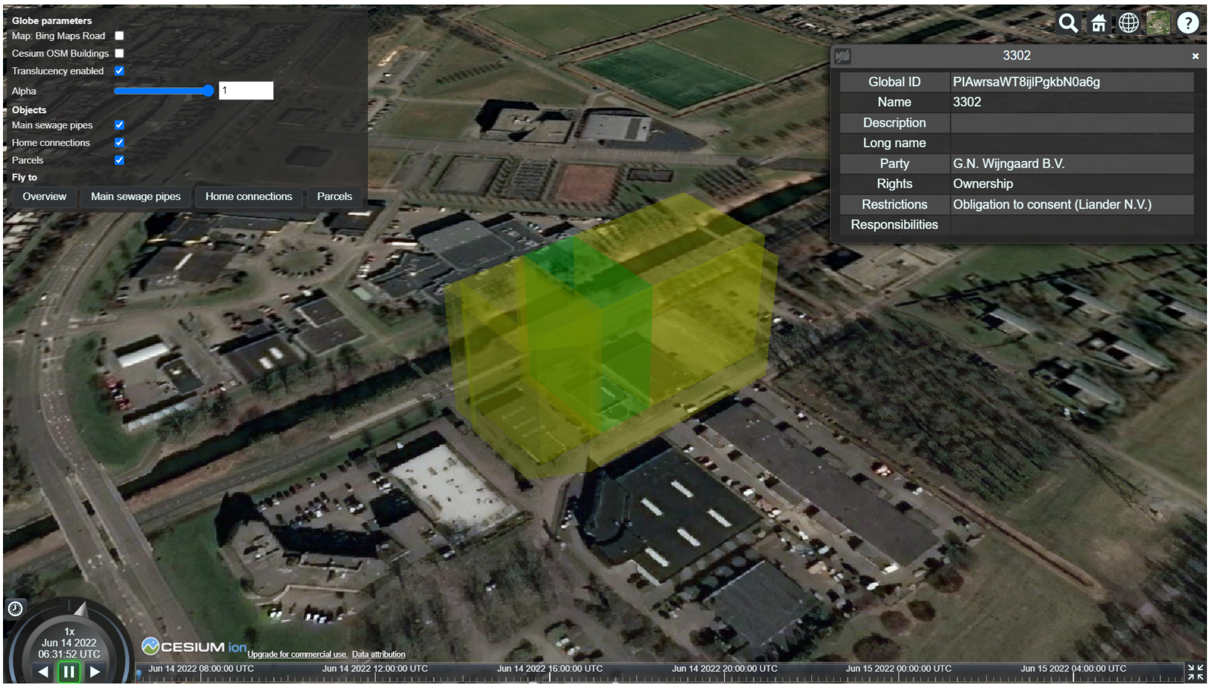


Figure 39 Selected parcels in the municipality of Almere

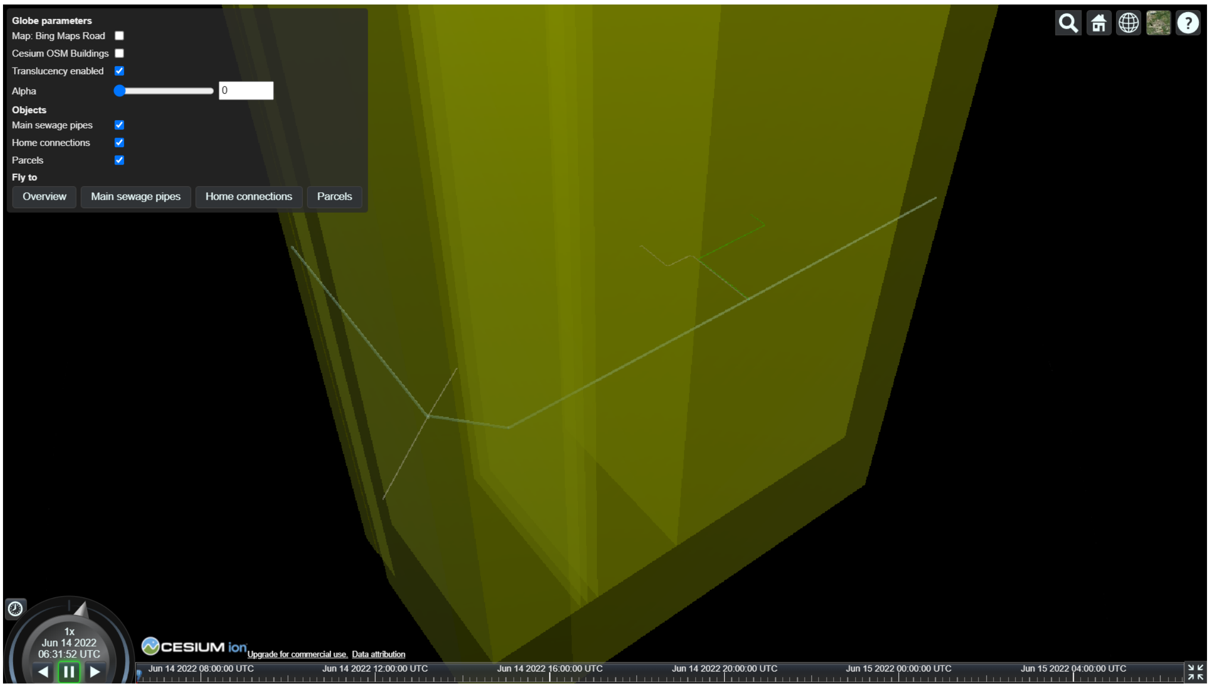


Figure 40. Main sewage pipes and home connections in the municipality of Almere

5.3 Case study 2: Heinenoord tunnel

In the second case study, the legal space of the Heinenoordtunnel, a traffic tunnel located in the municipalities of Heinenoord and Barendrecht that goes under the river the 'Oude Maas'., was modelled. The Heinenoordtunnel is owned and maintained by the Dutch ministry of Infrastructure and Water Management. The four parcels under which the Heinenoordtunnel lies are also owned by this ministry (except for one, where it is not sure who owns the parcel, since the ownership information could not be retrieved), meaning that there is (for the three parcels) no conflict. However, it could be in the case of other tunnels, such as the Sijtwendetunnel in the municipality of Leidschendam-Voorburg, that there are multiple different owners. Therefore it is still important to model the legal spaces of the Heinenoordtunnel, so that it can serve as an example for other tunnels that do have different owners of (parts of) the tunnel or the land above it.
In this case study, the 2D parcels on the surface were extruded to 3D volumetric parcels and used to describe the RRRs of the tunnel through the following steps:

1. Simplify the IFC model of the tunnel
2. Select the parcels under which the tunnel lies
3. Convert the parcels to an IFC model
4. Store the simplified IFC model and the parcell in the 3D DBMS
5. Add the RRRs to the 3D DBMS
6. Write the data from the 3D DBMS to Cesium 3D Tiles
7. Visualise the Cesium 3D Tiles

5.3.1 Simplify the IFC model of the tunnel
The IFC model of the Heinenoordtunnel is shown in Figure 41. This model, however, is very large in size and contains objects that are not necessary for modelling the legal spaces. It was therefore decided that the model was to be simplified. The simplification of the model was done with the use of the IFC workspace cs2_ifc2ifc_(1).fmw (Appendix E, Figure E1) by selecting only the elements (based on their unique ID) that comprise the outer structure of the tunnel (Figure 42). The elements from the outer structure of the tunnel were stored in entities of the entity IfcSpace. Since the model of the Heinenoordtunnel was in IFC 2x3, the simplified model was also written to IFC 2x3, in order to be consistent.

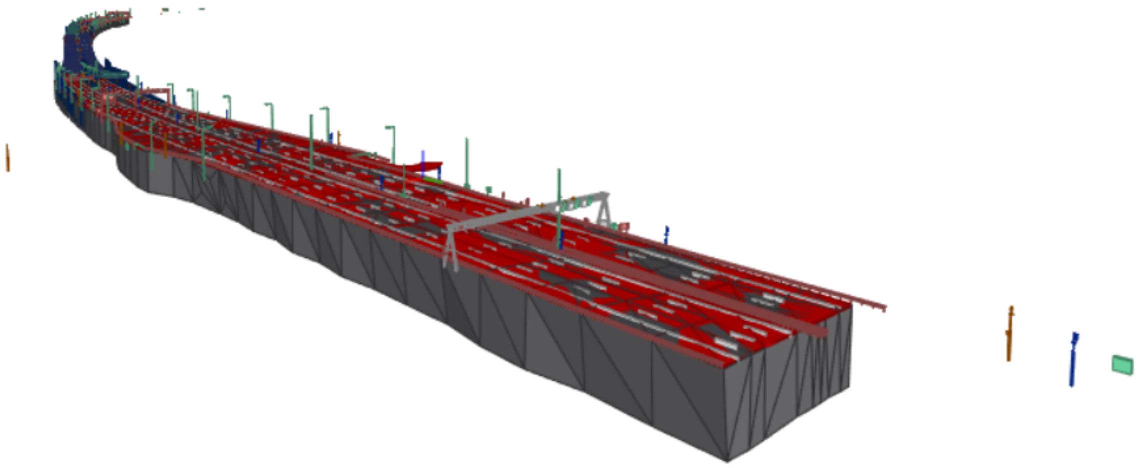


Figure 41. IFC model of the Heinenoordtunnel

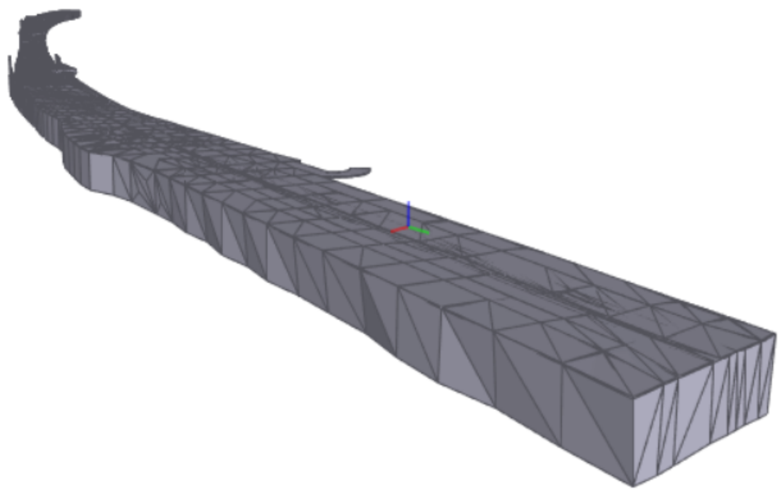


Figure 42. Simplified IFC model of the Heinenoordtunnel

5.3.2 Select the parcels under which the tunnel lies

The parcels under which the tunnel lies were selected in QGIS where a connection was made to the PDOK Web Feature Service for the Cadastral Registrations (*Dutch: Basisregistratie Kadaster, BRK)* dataset that contains the cadastral parcels of the Netherlands. The two selected parcels were then saved as a new shapefile as 'parcels_heinenoord.shp' with the CRS: EPSG:4326 - WGS 84. Figure 43 shows the four selected parcels overlaid on OpenStreetMap.

Figure 43. Selected parcels from the municipalities of Heinenoord and Barendrecht

5.3.3 Convert the shapefile of the parcels to an IFC model

The shapefile with the selected parcels under which the Heinenoordtunnel lies was converted to an IFC model with the use of the FME Workspace cs2_shp2ifc_(3).fmw (Appendix E, Figure E2) . In this workspace, there are two transformers: 'Extruder' and 'Offsetter' that were added to extrude the two parcels for 100 metres above and below the surface of the 2D parcel in order to create a 3D parcel. Although the ownership of a parcel in the Netherlands extends further than 100 metres above and below the surface, this value was chosen since this was deemed enough to show the parcels extending above and below the surface. The geometry of the parcels was stored in IfcSpace. This was done because the RRRs were added to the geometry of the parcels in IfcSpace. The shapefile model was then written to IFC 2x3. Figure 44 shows the IFC model of the four selected parcels.

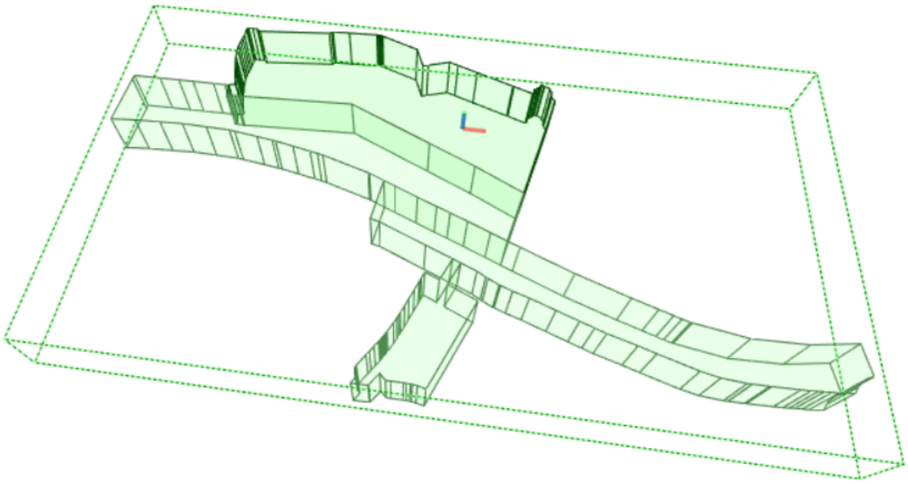


Figure 44. IFC model of selected parcels from the municipalities of Heinenoord and Barendrecht

5.3.4 Store the simplified IFC model and the parcels in the 3D DBMS

The simplified IFC model of the Heinenoordtunnel and the selected parcels were stored in the 3D DBMS through the use of the FME workspace cs2_ifc2postgis_(3).fmw (Appendix E, Figure E3) and the DBMS PostgreSQL extended with PostGIS spatial extension, accessed through the web-based client pgAdmin.

In the workspace, first, the IFC model was read into FME. In the ‘Parameters’ section the ‘Read IfcSpace Geometries’ was changed from ‘No’ to ‘Yes’. In the ‘Select Feature Types’ pop-up only IfcSpace was selected from the Object List, since IfcSpace contains the geometry of the tunnel.

Since the model of the tunnel was not georeferenced correctly, it was decided to georeference it manually with the use of the transformers ‘Scaler’, ‘LocalCoordinateSystemSetter’ and ‘Offsetter’. Then, the names of the attributes were changed to lowercase letters in order to write the values of the attributes to the 3D DBMS. The transformer ‘AttributeManager’ was used to change the names of the attributes to lowercase letters since the transformer ‘StringCaseChanger’ did not work.

Hereafter, a database was created in PostgreSQL: ‘case_heinenoord’. Then, the database was extended with PostGIS by executing the SQL query: `CREATE EXTENSION POSTGIS;`. In the FME workspace the PostGIS writer was selected. A new database connection was made: ‘case_heinenoord’. The host was ‘localhost’, the port: 5432 and the database was ‘case_heinenoord’. In the ‘Feature Type’ section of the PostGIS writer, the ‘Table Name’ was ‘tunnel_heinenoord’ and ‘parcels_heinenoord’. The ‘Table Handling’ was changed from ‘Create If Needed’ to ‘Drop and Create’ in order to drop the table with older values and create a new table when executing the FME workspace multiple times.

5.2.7 Add the RRRs to the 3D DBMS

The RRRs were added to the parcels by first creating the columns ‘Party’, ‘Rights’, ‘Restrictions’, ‘Responsibilities’ to the table ‘parcels_heinenoord’.

```
ALTER TABLE parcels_heinenoord
ADD COLUMN Party VARCHAR,
ADD COLUMN Rights VARCHAR,
ADD COLUMN Restrictions VARCHAR,
ADD COLUMN Responsibilities VARCHAR;
```

The ownership information is retrieved from the Dutch Cadastre (see Appendix F). The Dutch government owns and maintains the Heinenoordtunnel and the three out of the four parcels that are located above the area where the tunnel is situated (Rijkswaterstaat, 2022). From the fourth parcel no ownership information could be retrieved. A Public Law Restriction (PLR), in this case concerning a listed natural monument, is attached to parcels with numbers ‘911’ and ‘979’.

The SQL query for updating the parcel with number 911 is:

```
UPDATE parcels_heinenoord
SET Party = 'Ministry of Infrastructure and Water Management', Rights =
'Ownership', Restrictions = 'Listed natural monument'
WHERE name = '911';
```

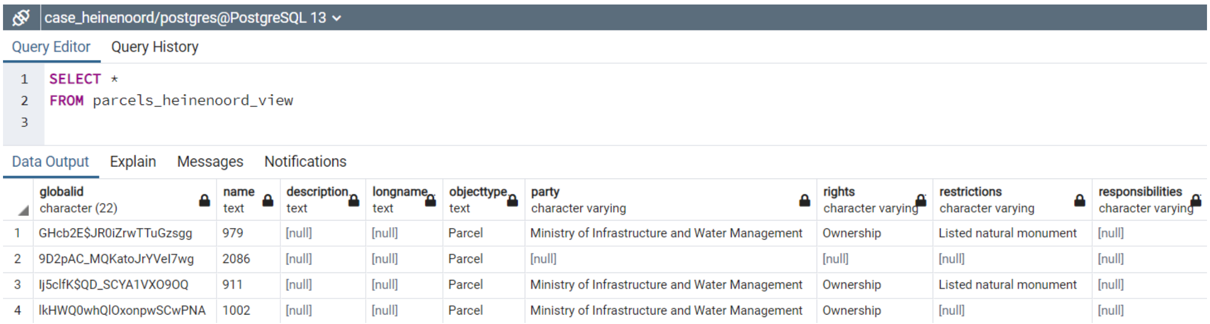
The SQL query for updating the parcel with number 979 is:

```
UPDATE parcels_heinenoord
SET Party = 'Ministry of Infrastructure and Water Management', Rights =
'Ownership', Restrictions = 'Listed natural monument'
WHERE name = '979';
```

The SQL query for updating the parcel with number 1002 is:

```
UPDATE parcels_heinenoord
SET Party = 'Ministry of Infrastructure and Water Management', Rights =
'Ownership'
WHERE name = '1002';
```

Figure 45 shows a view of selected columns of the parcels. These columns were selected since they contain the GUID, the recommended attributes for IfcSpace, the Party, and the RRRs.



case_heinenoord/postgres@PostgreSQL 13

Query Editor | Query History

```
SELECT *
FROM parcels_heinenoord_view
```

Data Output | Explain | Messages | Notifications

	globalid character (22)	name text	description text	longname text	objecttype text	party character varying	rights character varying	restrictions character varying	responsibilities character varying
1	GHcb2E$JR0iZrwTTuGzsgg	979	[null]	[null]	Parcel	Ministry of Infrastructure and Water Management	Ownership	Listed natural monument	[null]
2	9D2pAC_MQKatoJrYVel7wg	2086	[null]	[null]	Parcel	[null]	[null]	[null]	[null]
3	Ij5clfK$QD_SCYA1VXO9OQ	911	[null]	[null]	Parcel	Ministry of Infrastructure and Water Management	Ownership	Listed natural monument	[null]
4	lkHWQ0whQlOxonpwSCwPNA	1002	[null]	[null]	Parcel	Ministry of Infrastructure and Water Management	Ownership	[null]	[null]

Figure 45. View of selected columns from the table parcels_heinenoord

5.2.9 Write the data from the 3D DBMS to Cesium 3D Tiles

The data from the 3D DBMS was written to Cesium 3D Tiles with the use of the FME Workspace cs2_postgis2cesium3dtiles_(4).fmw (Appendix E).. In this workspace, the data was read into FME with the PostGIS reader, where in the 'Parameters' section both tables, tunnel_heinenoord and parcels_heinenoord, were selected from the schema public. For both readers a GeometryColorSetter was attached, where the rainwater drainage pipe segment was given the colour light blue, while the parcels were given the colour yellow. The alpha for the parcels was set at 0.5, to make the parcels transparent and thereby able to see objects below the surface such as telecommunication cable segments. Then, the Cesium 3D Tiles writers were attached for both readers. In the 'Feature Type' section of the Cesium 3D Tiles writer, the 'Geometry' was set for both writers to: 'cesium_3d_object'. The folders with the 3D Tiles were then zipped, in order to easily import the files into Cesium ion.

5.2.10 Visualise the Cesium 3D Tiles

To visualise the 3D Tiles, code was written in Cesium Sandcastle (https://sandcastle.cesium.com/). Parts of the code were adapted from the following code examples of Cesium Sandcastle: 'Globe Translucency', 'Montreal Point Cloud' and '3D Tiles Feature Picking'. The code was saved to the JavaScript file: 'case_rotterdam.js' and the CSS file: 'case_rotterdam.css'. Figure 46. shows the top view of the location of the selected parcels in the municipalities of Heinenoord and Barendrecht. Figure 47. shows the selected parcels in the municipalities of Heinenoord and Barendrecht. Figure 48. Shows the Heinenoordtunnel in the municipalities of Heinenoord and Barendrecht.

Figure 46. Top view of the location of the parcels in the municipalities of Heinenoord and Barendrecht

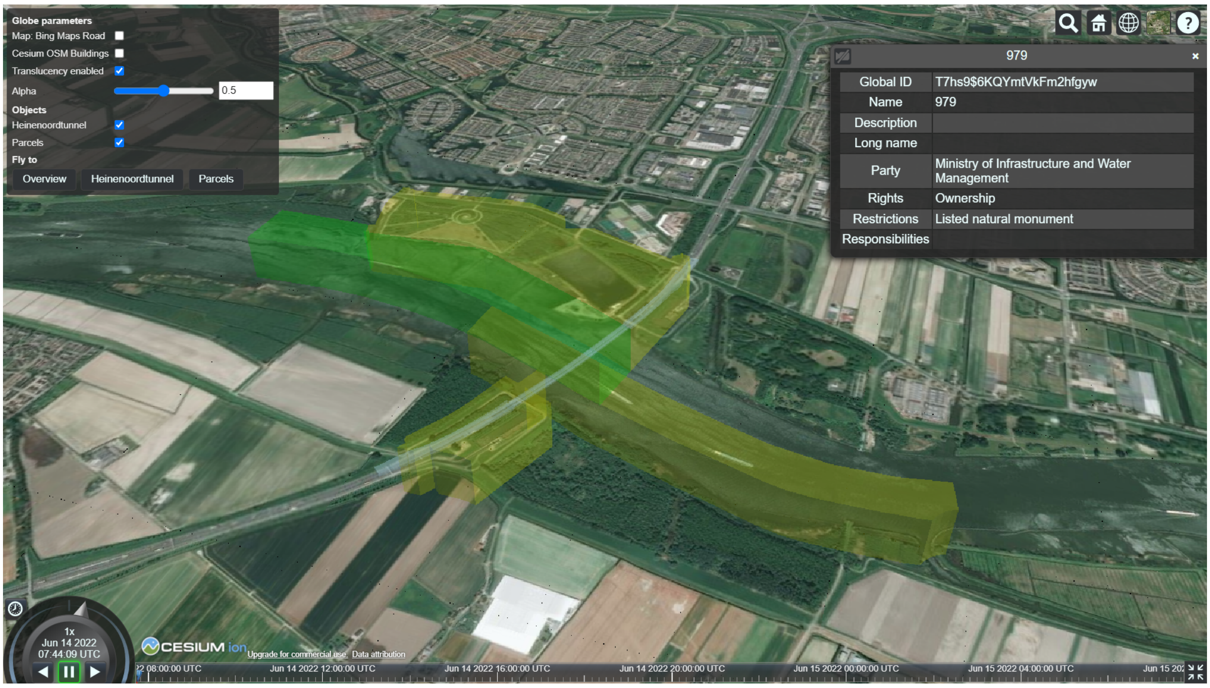


Figure 47. Selected parcels in the municipalities of Heinenoord and Barendrecht

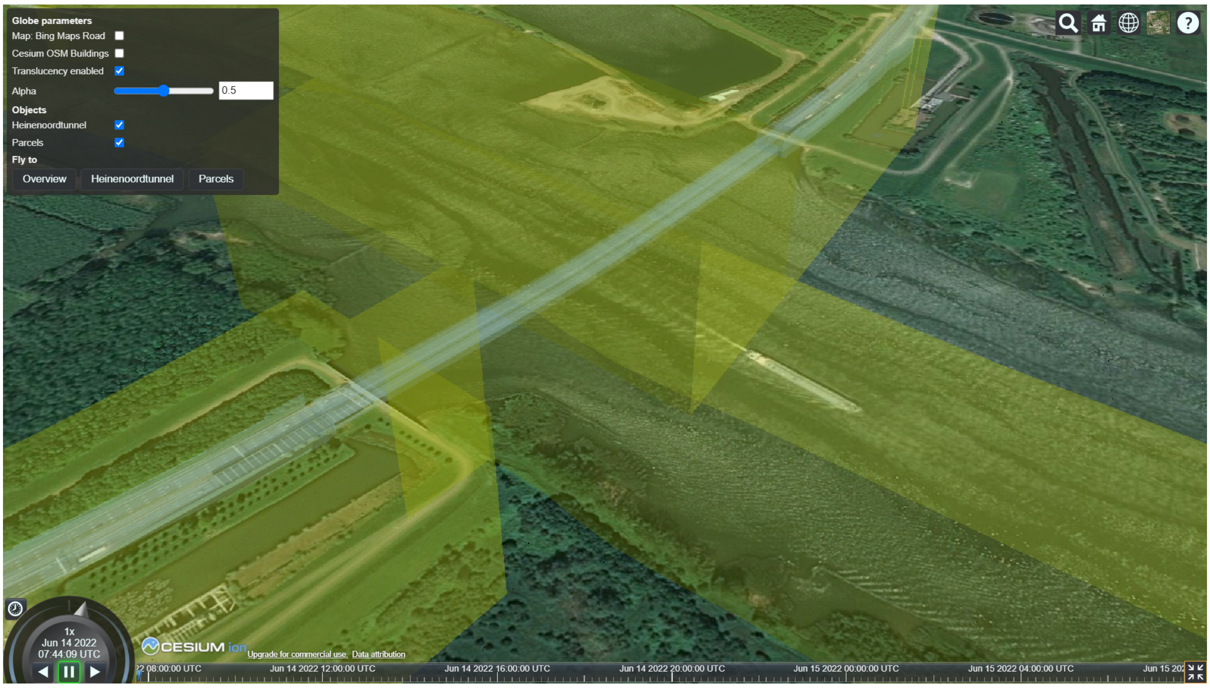


Figure 48. Heinenoordtunnel in the municipalities of Heinenoord and Barendrecht

6. Conclusions

The main objective of this thesis was to develop a workflow through which the challenges that prevent implementation of 3D objects below the surface in 3D LASs (section 1.2 Research motivation) and to harmonise the different (technical and semantic) requirements for LASs. The objective was achieved through the answering the main research question and the sice sub-questions that were derived from the main research question. The developed workflow consists of a legal, organisational and technical part. Two case studies were implemented to evaluate the technical part of the workflow. In this chapter the answers to the research questions are provided as well as a reflection on the implementation of the case studies. This is followed by a discussion of the research, recommendations that were derived from the research and future work.

6.1 Research questions

The main research question, as stated in section 1.4, that has been answered in this research was:

How can the legal spaces of 3D objects below the surface be modelled in 3D Land Administration Systems based on ISO 19152:2012 in the context of reusing BIM/IFC models from design?

This question was answered through the following five research questions:

1. Which 3D objects below the surface are there and how are they currently modelled in LAS?

One type of 3D objects below the surface are the utilities which are:

- Gas pipes, connections between the gas pipes and gas networks
- Water pipes, connection between the water pipes and electricity networks
- Electricity cable and electricity networks
- Sewage and drainage pipes, connections between the sewage and drainage pipes and sewage and drainage networks
- Waste management facilities and networks below the surface,

Other types of 3D objects below the surface are petrochemical installations, tunnels, cellars and parking garages and other structures below the surface.
In most LASs, objects below the surface are modelled in 2D. For example, an underground pipe or cable is drawn as a line in 2D on cadastral maps, where the depth of the pipe can be attached as an attribute (section 3.1 elaborates on the literature research based on which this question was answered).

2. How does the current legislation in the Netherlands support the registration of 3D underground objects in LASs and how can the legislation be improved?

Although the current legislation of the Netherlands allows the registration of 3D underground objects, it does not support it. Several amendments to the Dutch are needed to be made to support registration of 3D underground objects. Standards and guidelines shall be investigated to assess if the concepts of the underground space and the legal information of 3D objects in the underground space are defined and if the process of the registration of objects in the underground space is supported through these standards and guidelines. If this is the case, then these standards and guidelines can serve as a blueprint for a proposal where the objective is to amend and enrich the legislation to support and mandate the registration of objects in the underground space and define the manner in which this needs to be done (sections 3.1 and 3.2 elaborate on the literature research and the input from stakeholders, respectively, based on which this question was answered).

3. Who are the stakeholders in registering the 3D objects below the surface in LASs?

The stakeholders involved in registering the underground assets in LASs are usually:

- governmental organisations
- land registry organisations
- cadastral organisations
- utility network companies
- notaries
- architects
- engineers
- constructors
- owners / operators
- citizens

Each one of these stakeholders have a different role and responsibility in the registration of the underground assets (sections 3.1 and 3.2 elaborate on the literature research and the input from stakeholders, respectively, based on which this question was answered).

4. What are the requirements (technical and semantic) to register BIM/IFC models of 3D objects below the surface?

In order to register the legal information of 3D underground objects modelled in BIM/IFC and in line with the ISO 19152: 2012 LADM standard there are several technical and semantic requirements that need to be fulfilled to adequately register the legal information.

These requirements are that:

- The data should be complete
- The depth values of the 3D underground objects should be included in the data
- The data should be accurate
- The data should be correctly georeferenced
- The data should be geometrically valid

- It is important to choose the appropriate IFC entities(s) to store the legal information. One of these entities could be IfcSpace. IfcSpace is defined as: *'A space that represents an area or volume bounded actually or theoretically'*. Legal spaces are volumetric spaces in which the legal information is stored. IfcSpace, is therefore, according to the definition of the entity, able to store volumes and thereby thus the legal spaces.
- The legal spaces should have unique IDs, to be able to identify them
- There should be no overlap between the legal spaces,
- The same semantics should be used throughout the whole process of registering 3D underground objects to prevent confusion and mistakes, for example, that one name of a parameter is written in a certain way by one person and in a different manner by another person.
- There should be sufficient metadata making it able for others to know who made the data, when the data was made, which software was used etc.
- All versions of the data should be stored, making it able to review earlier versions if this is needed

(section 3.1, 3.2, 3.3 elaborate on the literature research, the input from stakeholders, the data collection respectively, based on which this question was answered)

5. How can the legal spaces of 3D objects below the surface be efficiently stored, visualised and disseminated?

The BIM/IFC models of 3D underground objects are enriched with legal information structured according to the LADM and they are stored in a spatial database, where in one table the legal information is stored and in a respective table the physical information is stored. The model can best be visualised on a 3D geospatial visualisation platform, where querying is supported.

6. How can the effectiveness of the proposed workflow be evaluated?

This effectiveness can be done by the stakeholders as well as legal, organisational and technical experts through the establishment of a working group, with the stakeholders and experts as members of the group. The working group will hold meetings and workshops to discuss the aspects of the legal, organisational, technical workflows, where the stakeholders and experts can provide their input with regards to the workflow. With the input from the stakeholders and experts it can be evaluated how effective the legal, organisational and technical workflows are (section 3.7 elaborates on the evaluation of the workflow).
The effectiveness of the proposed (technical) workflow can be evaluated through case studies. There were two case studies in this research: (1) Utilities below the surface with parcels above the surface and (2) A tunnel with parcels on the surface. For each step of the technical workflow, the efficiency of this workflow has been evaluated and tested for the different types and combinations of underground objects.

6.2 Case studies

In the first case study of this research, the legal spaces from the sewage pipes of the main sewage of the Dutch municipality of Almere and the pipes that are connected to the homes there, were modelled. The legal spaces of the main sewage pipes as well as the pipes connecting the homes to the main sewage pipe are the 2D parcels on the surface that are extruded to 3D parcels.
From this case study it can be concluded that a legal space does not always have to be made separate from the existing (or potential) legal spaces (2D parcels extruded to 3D volumetric parcels). It could be that the existing (or potential) legal spaces are adequate enough to describe the RRRs of other objects present in these legal spaces.
In the second case study, the legal space of the Heinenoordtunnel, located in the municipalities of Heinenoord and Barendrecht, was modelled. In this case study, the 2D parcels on the surface were extruded to 3D volumetric parcels and used to describe the RRRs of the tunnel.
From this case study the same conclusions can be drawn as in the first case study, that is, that a legal space does not always have to be made separate from the existing (or potential) legal spaces (2D parcels extruded to 3D volumetric parcels). It could be that the existing (or potential) legal spaces are adequate enough to describe the RRRs of other objects present in these legal spaces.
From both case studies it can be concluded that the technical workflow supports the use of 2D parcels that are extruded to 3D volumetric parcels and modelled in IfcSpace.

6.3 Discussion

In this research a workflow to register 3D underground objects in a LADM-based 3D LAS is presented together with two case studies that were used to test the (technical part of the) workflow.
In both case studies, IFC 2x3 models of underground objects were used and made from models with data formats other than IFC, such as a shapefile. This was because most of the models of objects supplied by organisations were not IFC models of tunnels or utilities. The models that were IFC models, were from the previous standard, IFC 2x3. The two organisations that did supply IFC 4 models, provided models that were experimental and not correctly georeference or where the ownership information could not be retrieved. Therefore it was decided to use IFC 2x3 models and to convert models of underground objects with data formats other than IFC to an IFC 2x3 model. The models were not converted to IFC 4 or IFC 4x3 in FME, because then the property set did not appear. It was also not necessary to convert the model to IFC 4 or IFC 4x3 since all the IFC entities used were entities that are present in all these three versions of IFC. The lack of IFC 4 models from underground objects was a limiting factor of this research.
The case studies were implemented with IFC models located in the Netherlands. Literature research was done on the legal background of the RRRs of underground objects in the Netherlands. However, no case studies with IFC models of underground objects or literature research on the legal background on the RRRs of underground objects countries have been done. The conclusions derived from the case studies and literature research shall therefore mainly apply to the Netherlands. It cannot be estimated how (parts of) the proposed workflow applies to countries other than the Netherlands.

6.4 Recommendations

Through this research, and in the legal and organisational workflows, international, open standards are used and also recommended. Next to using the two ISO standards, the IFC models for the physical model and the LADM for structuring the legal information, other standards or standardised procedures can also be used. For instance, for the georeferencing of IFC models, the classification of LoGeoRef proposed by Clemen et al. (2019) can be used. The international OGC Simple Feature Access standard can be used for the geometrical validation of the 3D objects (OGC, 2022, ISO, 2022a).

Moreover, apart from the workflow, this research provides the general mapping of LADM concept and classes (based on the ongoing revision of the standard) to IFC entities (IFC 4). Although the revised version of IFC 4 (IFC 4x3) is expected to be published in late 2022 and the revision of the LADM has a planned duration of 4 years, this model mapping method can still be used when the revised IFC version is standardised (buildingSMART, 2022a, ISO, 2022b) and can be revised accordingly where needed. This is because all IFC 4 entities, except one, that were used for the model mapping method will also be included in IFC 4x3 with the same definitions. The one entity that is deprecated in IFC 4x3 is IfcBuildingElementProxy (buildingSMART, 2022a). IfcBuildingElementProxy is an element that is used to model building elements, without it having to be a specific type of building element (buildingSMART, 2022c). In IFC 4x3, the new entities IfcFacility and IfcFacilityPart will be included. An IfcFacility can be a building, but it can also be a tunnel, bridge, railway or road (buildingSMART, 2022b). IfcFacilityPart describes the structural parts of an IfcFacility object (buildingSMART, 2022b). When IfcBuildingElementProxy is deprecated, the entity could be replaced by IfcFacilityPart.

It is also recommended to use 3D volumetric parcels (that were made by extruding the 2D parcels on the surface) to describe the RRRs of underground objects. 3D volumetric parcels are sufficient to describe the RRRs of underground objects, as was concluded from the case studies.

6.5 Future work

In this research two case studies were performed with IFC models of utilities. As a next step more case studies could be done of IFC models of tunnels and other underground objects that shall be tested.

What is more, the two case studies of IFC models are located in one country, the Netherlands. Future research can include the testing of IFC models located in other countries, and specifically where the legislative frameworks are different than those of the Netherlands with regards to the registration of underground objects. More case studies with IFC models of different underground objects in different countries would contribute to better validate the workflow.

IfcSpace is used in this research as the IFC entity to store the legal information of underground objects. Although IfcSpace is the most suitable entity to store volumetric spaces, it can be investigated if other IFC entities are also acceptable for storing the RRRs of underground objects, for example, IfcExternalSpatialElement.

In this research, IfcSpace was used to attach the RRRs, where IfcSpace can represent the volumetric parcels used to model the 3D legal spaces. However, in the Netherlands it could be that ownership of objects is limited to the objects themselves. For example, the owner of a network of cables or pipes, only owns the network and no volume around it. The RRRs

could therefore be attached to the cable / pipe or the line that represents these objects. More investigation can be done to determine if geometrical primitives are good enough to attach RRRs to them.
In the mapping of LADM classes to IFC entities, only the LADM classes and the attributes were mapped, but not the operations. To complete the mapping of the main classes of LADM to IFC, the operations should also be mapped.

In this research IFC models were used to register the legal spaces according to the LADM. There are, however, more possibilities to use IFC models where more work can be done:

- IFC models can be used to update the registration of the legal information of the objects
- IFC models can be extended with LADM classes for better exchange of data
- IFC models can serve as a technical encoding for the LADM data exchange. In this case not only the main classes of LADM should be mapped to IFC entities, but all classes and subclasses.

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Appendix A. Stakeholders

Appendix A provides table A1 in which the stakeholders are listed that were contacted for meetings and interviews and responded (as described in section 3.2). The type of organisation, which country the organisation is (mainly) located and what the role of the organisation is in the registration of RRRs of 3D objects below the surface.

Table A1. Stakeholders who responded to the request for meetings and interviews

Name	Type of organisation	Country	Stakeholder role
Rijkswaterstaat	National executive agency	The Netherlands	Government
Province of Gelderland	Province	The Netherlands	Government
Province of North-Holland	Province	The Netherlands	Government
Municipality of Almere	Municipality	The Netherlands	Government
Engineering bureau of the municipality of Amsterdam	Municipal engineering organisation	The Netherlands	Government
RIONED	Umbrella organisation for municipal water management	The Netherlands	Government
TenneT	Transmission system operator company (government-owned)	The Netherlands	Government, Engineer
Evides	Water company	The Netherlands	Utility network company
PWN	Water company	The Netherlands	Utility network company
Antea Group	Engineering company	The Netherlands	Engineer
Swisstopo	National mapping agency	Switzerland	Government
Singapore Land Authority	National land registration organisation	Singapore	Land registry, Cadastre

Appendix B. Data inventory

Appendix B presents table B1 in which the collected data, first described in section 3.3, is listed with the data formats, description of the data, the location and the year the data was made.

Table B1. Inventory of the collected data

#	Name	Data format	Description	Location	Year
Municipality of Almere [MA]					
1.1	MA_main_sewage_pipes.gpkg	Geopackage	Main sewage pipes and sewers	Municipality of Almere, the Netherlands	-
1.2	MA_sewage_home_connections.gpkg	Geopackage	Sewage connections to homes	Municipality of Almere, the Netherlands	-
Municipality of Amsterdam [MAM]					
2.1	MAM_main_part_underpass.ifc	IFC 2x3	Main part of the underpass 'Amstelstroomlaan'	Municipality of Amsterdam, the Netherlands	2020
2.2	MAM_top_part_underpass.ifc	IFC 2x3	Top part of the underpass 'Amstelstroomlaan'	Municipality of Amsterdam, the Netherlands	2020
2.3	MAM_utilities_underpass.dwg	2D/3D CAD	Utilities located underground in the region of the location of the underpass 'Amstelstroomlaan'	Municipality of Amsterdam, the Netherlands	-
Municipality of Groningen [MG]					
3.1	MG_Steentilbrug.gml	CityGML	Traffic bridge over the canal 'Schuitendiep'	Municipality of Groningen, the Netherlands	-
3.2	MG_KLIC_tracé.gml	CityGML	Trace of cables and pipes underground in the region of the 'Steentilbrug'	Municipality of Groningen, the Netherlands	-
Municipality of Rotterdam [MR]					
4.1	MR_city_heating_pipes.dwg	2D/3D CAD	Heating pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.2	MR_drinking_water_pipes.dwg	2D/3D CAD	Drinking water pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.3	MR_electricity_cables.dwg	2D/3D CAD	Electricity cables located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.4	MR_gas_pipes.dwg	2D/3D CAD	Gas pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-

4.5	MR_mixed_sewage_pipes.dwg	2D/3D CAD	Mixed sewage pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.6	MR_other_utilities.dwg	2D/3D CAD	Other utilities located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.7	MR_pressure_sewage_pipes.dwg	2D/3D CAD	Pressure sewage pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.8	MR_rainwater_drainage_pipes.dwg	2D/3D CAD	Rainwater drainage pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.9	MR_telecommunication_cables.dwg	2D/3D CAD	Telecommunication cables located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
4.10	MR_waste_water_pipes.dwg	2D/3D CAD	Waste water pipes located underground in the region of the subway station 'Beurs'	Municipality of Rotterdam, the Netherlands	-
Province of Gelderland [PG]					
5	PG_underpass.rvt	Revit 3D model	Underpass in the town of 'Dieren'	Municipality of Rheden, the Netherlands	-
Province of Groningen [PGR]					
6	PGR_animal_tunnel.ifc	IFC 2x3	Tunnel under a road to let small animals cross (*Dutch: Faunaduiker)*	The Netherlands	2021
Province of Noord-Holland [PNH]					
7.1	PNH_electricity_cables.shp	Shapefile	Electricity cable network of the province of 'Noord-Holland'	Province of Noord-Holland, the Netherlands	-
7.2	PNH_rainwater_drainage_pipes.shp	Shapefile	Rainwater drainage pipeline network of the province of 'Noord-Holland'	Province of Noord-Holland, the Netherlands	-
National agency Rijkswaterstaat [NAR]					
8.1.1	NAR_Heinenoordtunnel.ifc	IFC 2x3	Traffic tunnel under the river 'de Oude Maas'.	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	2020
8.1.2	NAR_Heinenoordtunnel.nwd	Navisworks Document	Traffic tunnel under the river 'de Oude Maas'.	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.2	NAR_Heinenoordtunnel_ground_radar.dwg	2D/3D CAD	Ground radar trace of the Heinenoordtunnel	Municipality of Heinenoord and municipality of	-

				Barendrecht, the Netherlands	
8.3.1	NAR_Heinenoordtunnel_service_building_north.dwg	2D/3D CAD	Service building on the north side of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.3.2	NAR_Heinenoordtunnel_service_building_north.ifc	IFC 2x3	Service building on the north side of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	2020
8.3.3	NAR_Heinenoordtunnel_service_building_north.nwd	Navisworks Document	Service building on the north side of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.4.1	NAR_Heinenoordtunnel_service_building_south.dwg	2D/3D CAD	Service building on the south side of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.4.2	NAR_Heinenoordtunnel_service_building_south.nwd	Navisworks Document	Service building on the south side of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.5.1	NAR_Heinenoordtunnel_surroundings.dwg	2D/3D CAD	Surroundings of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.5.2	NAR_Heinenoordtunnel_surroundings.ifc	IFC 2x3	Surroundings of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	2020
8.5.3	NAR_Heinenoordtunnel_surroundings.nwd	Navisworks Document	Surroundings of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.6	NAR_Tweede_Heinenoordtunnel.nwd	Navisworks Document	Second (slow) traffic tunnel under the river 'de Oude Maas' (built to the right side of the Heinenoordtunnel)	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
8.7	NAR_Local_DTM.dwg	2D/3D CAD	DWG file with a C3D surface of the local DTM in the area of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-

8.8	NAR_Utilities.dwg	2D/3D CAD	Trace of the utilities of the Heinenoordtunnel	Municipality of Heinenoord and municipality of Barendrecht, the Netherlands	-
Water company PWN [WCP]					
9	WCP_water_pipelines.shp	Shapefile	Water pipelines in a part of the municipality of Haarlem	Municipality of Haarlem, the Netherlands	-
Canton of Basel [CB]					
10	CB_Gellertstrassenbruecke.ifc	IFC 4	Traffic bridge that goes over a (city) highway with an utility tunnel underground	City of Basel, Switzerland	2021
National agency Swisstopo [NAS]					
11.1	NAS_electricity_cables.ifc	IFC 4	Electricity cable network located in a city in Switzerland	Switzerland	2021
11.2	NAS_water_pipes.ifc	IFC 4	Water pipe network located in a city in Switzerland	Switzerland	2021
11.3	NAS_sewage_pipes.ifc	IFC 4	Sewage pipe network located in a city in Switzerland	Switzerland	2021
Company Ballast-Nedam [CBN]					
12	CBN_Maasdeltatunnel.nwd	Navisworks Document	Traffic tunnel being built under the river 'het Scheur'	Municipality of Vlaardingen and municipality of Rotterdam, the Netherlands	-
Company Prisma Groep [CP]					
12	CP_piping_petrochemical.ifc	IFC 2x3	Part of the piping of a petrochemical complex	Unknown	2021
Company Skanska UK [CSU]					
14.1	CSU_bridge.ifc	IFC 2x3	A bridge	Unknown	2021
14.2	CSU_two_tunnels.ifc	IFC 2x3	Two tunnels	No real location. The model is a template.	2018

Appendix C. IFC model inspection

Appendix C provides table C1 in which several characteristics of the IFC models are listed with the result of the evaluation of the IFC models (as described in section 3.3) if these characteristics are present in the IFC model.

Table C1. Inspection of collected IFC models

#	Name	Object	IFC schema	IFC model spatial hierarchy	Global Unique ID	IfcSpace	IfcBuildingElementProxy use	IfcProperty Set use	Georeferencing
Municipality of Amsterdam [MAM]									
1.1	MAM_main_part_underpass.ifc	Underpass (main structure)	IFC 2x3	Correct	Yes	No	Partial	No	LoGeoRef20
1.2	MAM_top_part_underpass.ifc	Underpass (top structure)	IFC 2x3	Correct	Yes	No	Partial	No	LoGeoRef20
Province of Groningen [PGR]									
2	PGR_animal_tunnel.ifc	Tunnel	IFC 2x3	Correct	Yes	No	Yes	No	LoGeoRef20
National agency Rijkswaterstaat [NAR]									
3.1	NAR_Heinenoordtunnel.ifc	Tunnel	IFC 2x3	Incorrect, IfcSite is missing	Yes	No	Yes	No	n.a.
3.2	NAR_Heinenoordtunnel_service_building_north.ifc	Building	IFC 2x3	Incorrect, IfcSite is missing	Yes	No	Yes	No	n.a.
3.3	NAR_Heinenoordtunnel_surroundings.ifc	Surroundings	IFC 2x3	Incorrect, IfcSite is missing	Yes	No	Yes	No	n.a.
Canton of Basel [CB]									
4	CB_Gellertstrassenbruecke.ifc	Bridge	IFC 4	Correct	Yes	No	Partial	Partly	LoGeoRef20
National agency Swisstopo [NAS]									
5.1	NAS_electricity_cables.ifc	Utility network	IFC 4	Correct	Yes	No	Partial	No	n.a.
5.2	NAS_water_pipes.ifc	Utility network	IFC 4	Correct	Yes	No	Partial	No	n.a.

5.3	NAS_sewage_pipes.ifc	Utility network	IFC 4	Correct	Yes	No	Partial	No	n.a.
Company Prisma Groep [CP]									
6	CP_piping_petrochemical.ifc	Petrochemical pipes	IFC 2x3	Incorrect, IfcSite is missing.	Yes	No	Yes	No	n.a.
Company Skanska UK [CSU]									
7.1	CSU_bridge.ifc	Bridge	IFC 2x3	Correct	Yes	No	Partial	No	LoGeoRef20
7.2	CSU_two_tunnels.ifc	Tunnel	IFC 2x3	Correct	Yes	No	Yes	No	LoGeoRef10

IfcBuildingProxyElementUse: Yes: All geometry information is modelled within this class; Partial: Geometry information is modelled within different classes.

Georeferencing: Levels of georeferencing according to Clemen et al., 2019.

Appendix D. Case study 1

Appendix D provides the FME Workspaces used in the implementation of the first case study of the sewage pipes in Almere (section 5.2).

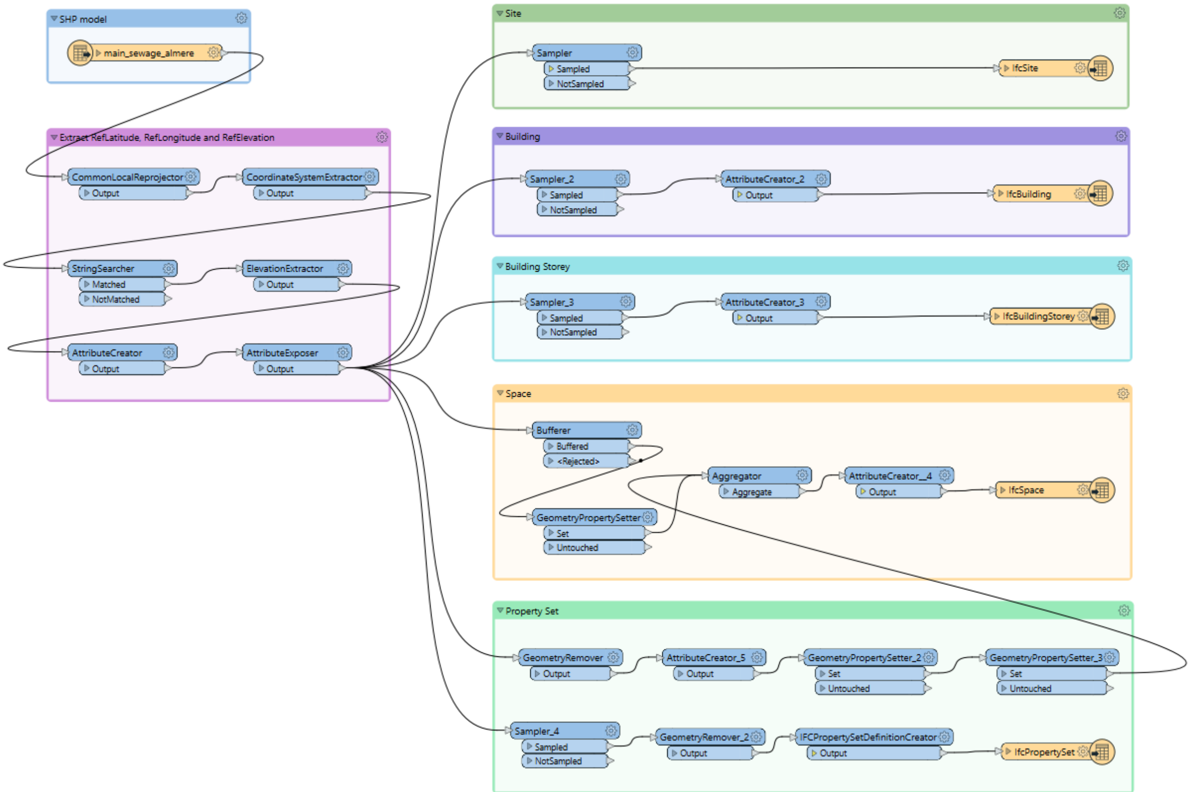

Figure D1. FME Workspace cs1_shp2ifc_(1)

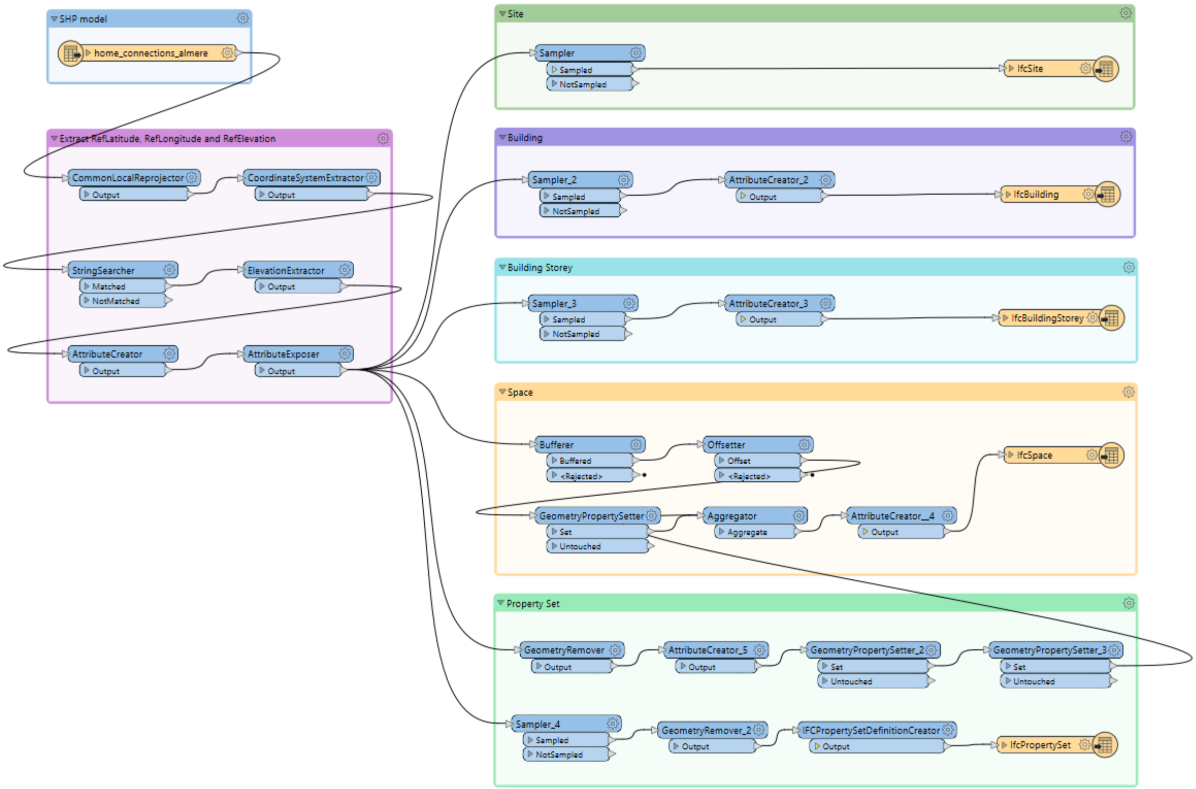

Figure D2. FME Workspace cs1_shp2ifc_(2)

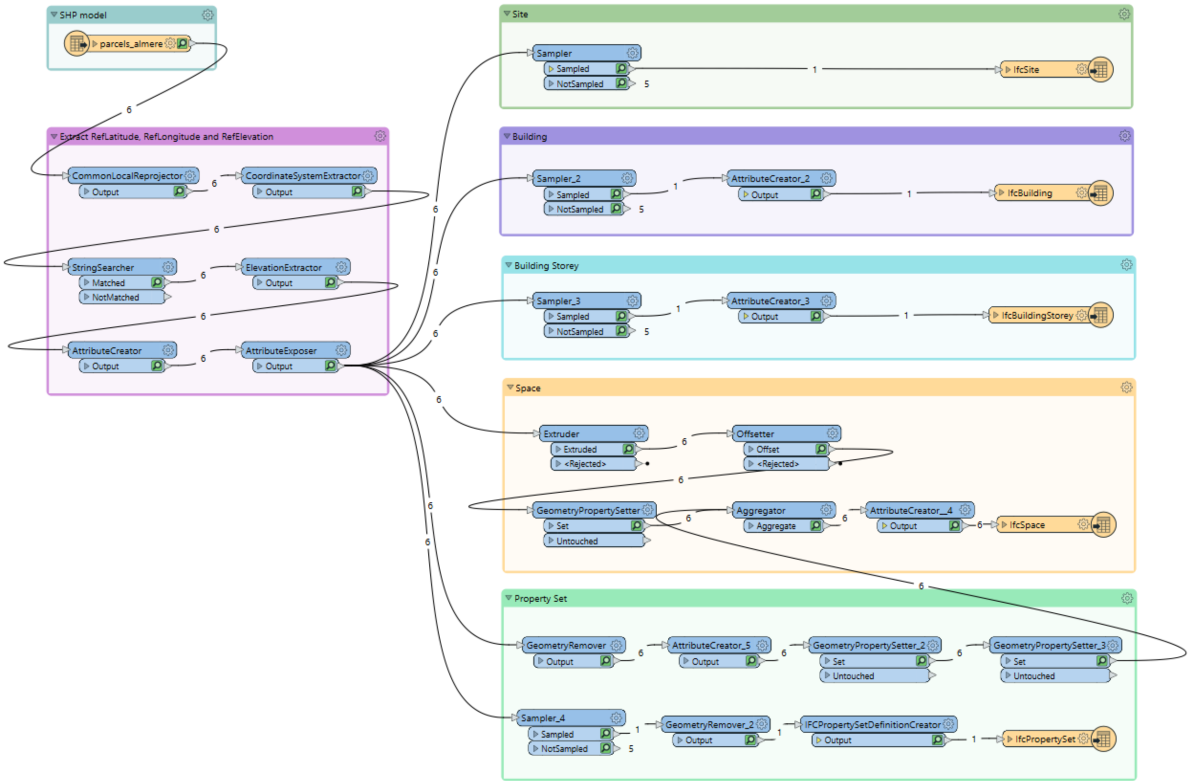

Figure D3. FME Workspace cs1_shp2ifc_(3)

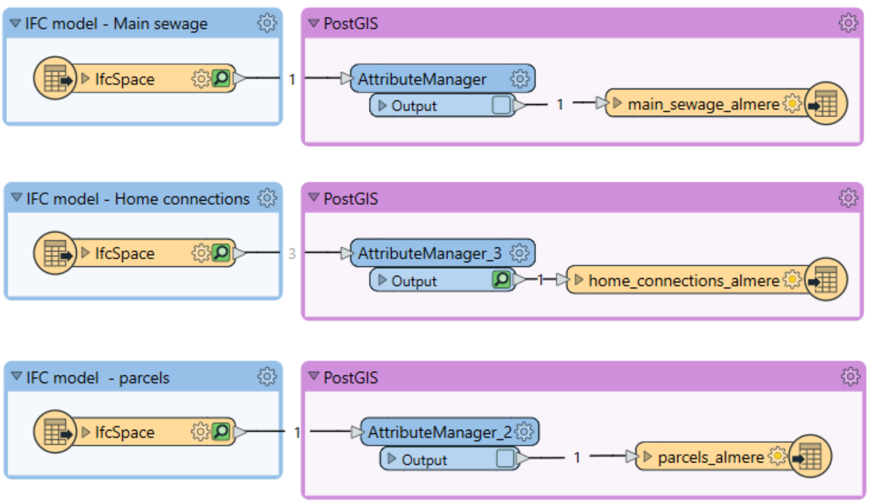

Figure D4. FME Workspace cs1_ifc2postgis_(4)

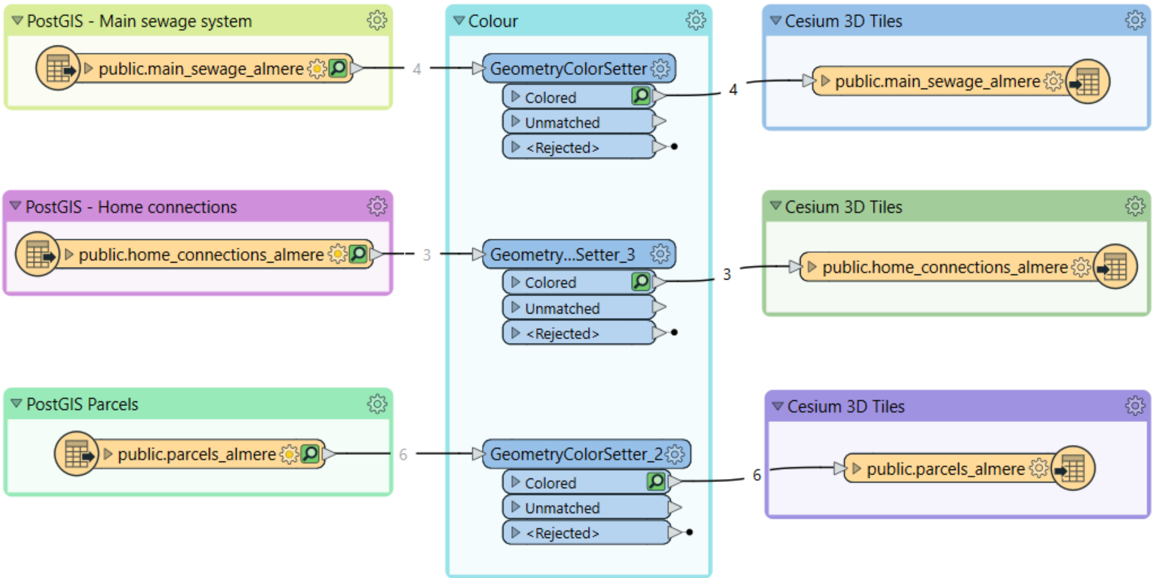

Figure D5. FME Workspace cs1_postgis2cesium3dtiles_(5)

Appendix E. Case study 2

Appendix E provides the FME Workspaces used in the implementation of the second case study of the Heinenoordtunnel (section 5.3).

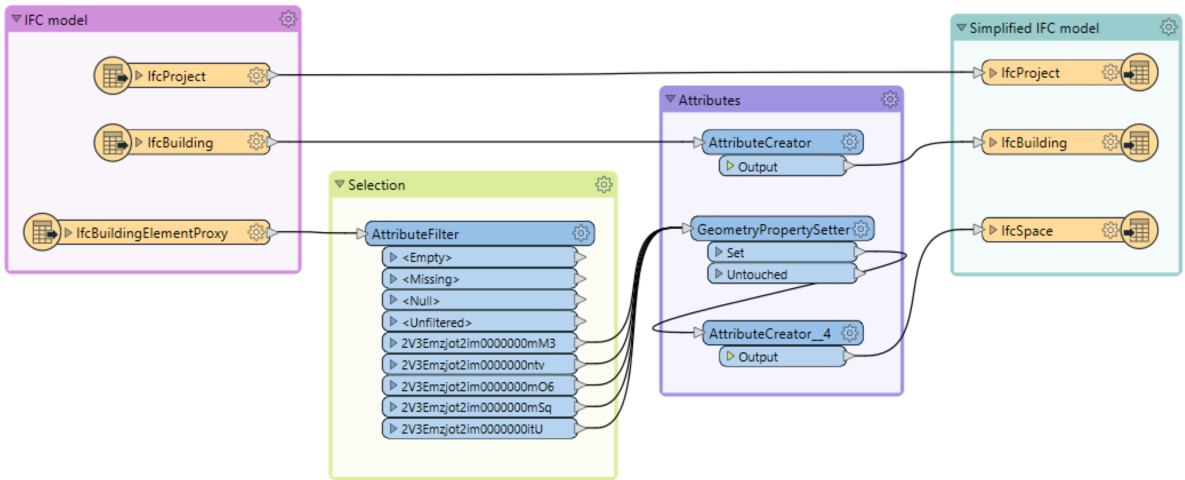

Figure E1. FME Workspace cs2_ifc2ifc_(1)

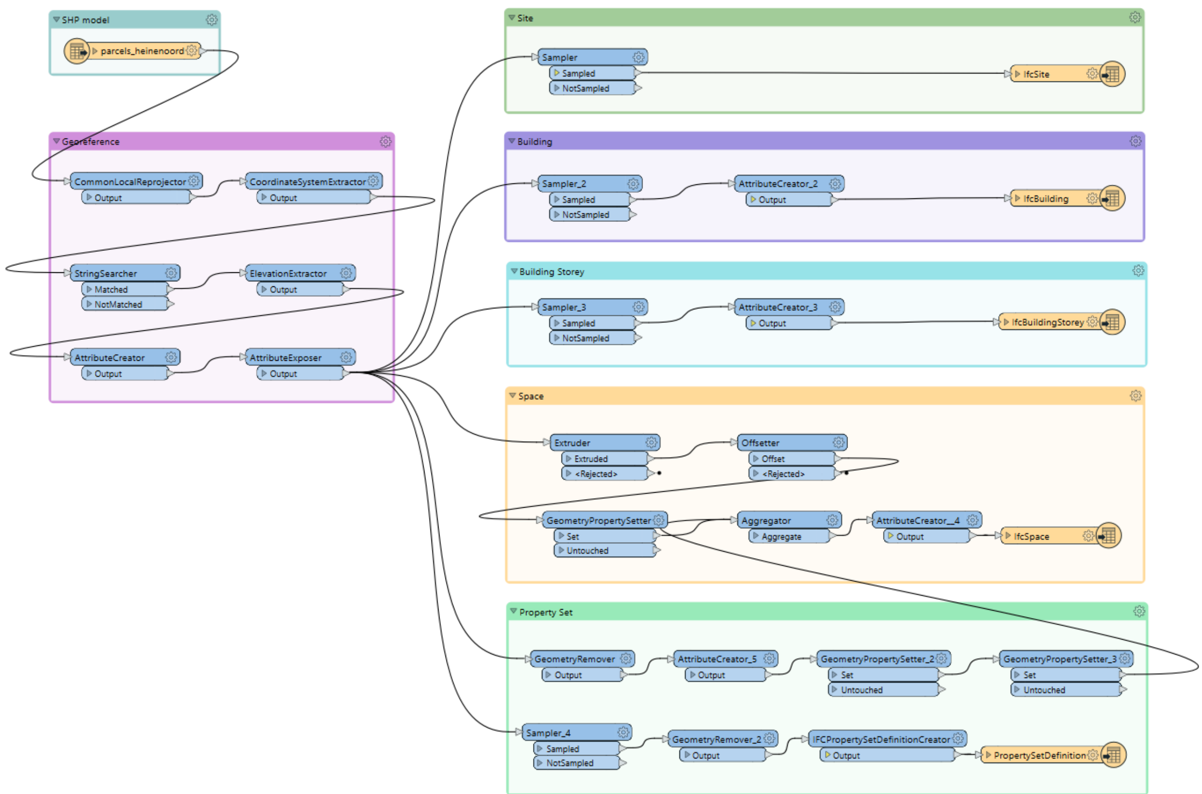

Figure E2. FME Workspace cs2_shp2ifc_(2)

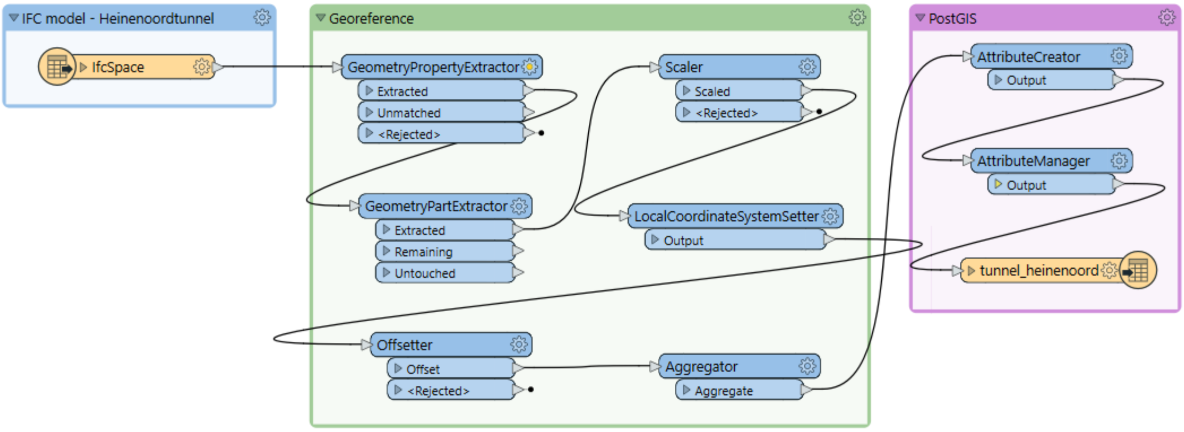

Figure E3. FME Workspace cs2_ifc2postgis_(3)

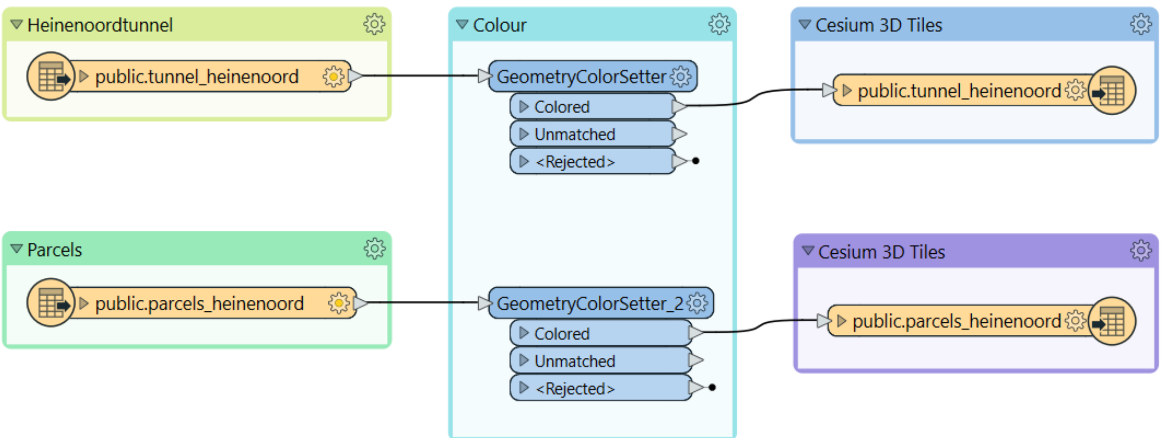

Figure E4. FME Workspace cs2_postgis2cesium3dtiles_(4)

Appendix F. Ownership information

Appendix F provides the ownership information on the parcels retrieved from the Dutch Cadastre used in the case studies of section 5.2 and 5.3.

kadaster

BETREFT Almere K 3147	
UW REFERENTIE 2170972_2	
GELEVERD OP 13-06-2022 - 21:29	PRODUCTIEORDERNUMMER S11129559287
VOLLEDIG GESIGNALEERD T/M 13-06-2022 - 14:59	VOLLEDIG BIJGEWERKT T/M 13-06-2022 - 14:59
BLAD 1 van 2	

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Almere K 3147 Kadastrale objectidentificatie : 088920314770000
Locatie	Radioweg 11 1324 KW Almere Locatiegegevens zijn ontleend aan de Basisregistratie Adressen en Gebouwen Verblijfsobject ID: 0034010000018205
Kadastrale grootte	1.238 m²
Grens en grootte	Vastgesteld
Coördinaten	141893 - 485223
Omschrijving	Bedrijvigheid (industrie)
	Erf - tuin
Ontstaan uit	Almere K 274

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom belast met Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht (zie 1.1)**		
Soort recht	Eigendom (recht van)		
Afkomstig uit stuk	Hyp4 6236/43 Zwolle	**Ingeschreven op**	05-04-1989
Naam gerechtigde	Rijnhomij B.V.		
Postadres	Radioweg 11 1324 KW ALMERE		
Statutaire zetel	ZEIST		
KvK-nummer	32051399 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister		

1.1	**Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht**
Afkomstig uit stuk	Hyp4 4767/59 Zwolle
Naam gerechtigde	Liander N.V.

Figure F1. Almere K 3147

kadaster

BETREFT	Almere K 3148
UW REFERENTIE	2170972_3
GELEVERD OP	13-06-2022 - 21:30
PRODUCTIEORDERNUMMER	S11129559292
VOLLEDIG GESIGNALEERD T/M	13-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	13-06-2022 - 14:59
BLAD	1 van 2

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Almere K 3148 Kadastrale objectidentificatie : 088920314870000
Kadastrale grootte	99 m²
Grens en grootte	Vastgesteld
Coördinaten	141893 - 485239
Omschrijving	Bedrijvigheid (industrie)
Ontstaan uit	Almere K 274

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom belast met Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht (zie 1.1)**		
Soort recht	Eigendom (recht van)		
Afkomstig uit stuk	Hyp4 6423/36 Zwolle	**Ingeschreven op**	11-10-1989
Naam gerechtigde	Rijnhomij B.V.		
Postadres	Radioweg 11 1324 KW ALMERE		
Statutaire zetel	ZEIST		
KvK-nummer	32051399 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister		

1.1	**Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht**
Afkomstig uit stuk	Hyp4 4767/59 Zwolle
Naam gerechtigde	Liander N.V.
Adres	Utrechtseweg 68 6812 AH ARNHEM
Postadres	Postbus 50 6920 AB DUIVEN
Statutaire zetel	ARNHEM

Figure F2. Almere K 3148

BETREFT	Almere K 3302
UW REFERENTIE	2170972_5
GELEVERD OP	13-06-2022 - 21:30
PRODUCTIEORDERNUMMER	S11129559312
VOLLEDIG GESIGNALEERD T/M	13-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	13-06-2022 - 14:59
BLAD	1 van 2

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Almere K 3302 Kadastrale objectidentificatie : 088920330270000		
Locatie	Radioweg 13 1324 KW Almere Locatiegegevens zijn ontleend aan de Basisregistratie Adressen en Gebouwen Verblijfsobject ID: 0034010000018210		
Kadastrale grootte	1.238 m²		
Grens en grootte	Vastgesteld		
Coördinaten	141899 - 485261		
Omschrijving	Bedrijvigheid (industrie)		
	Erf - tuin		
Koopsom	€ 350.000	**Koopjaar**	2012
Ontstaan uit	Almere K 3149		

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom belast met Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht (zie 1.1)**		
Soort recht	Eigendom (recht van)		
Afkomstig uit stuk	Hyp4 62116/170	**Ingeschreven op**	07-11-2012 om 14:52
Naam gerechtigde	G.N. Wijngaard B.V.		
Adres	Palmpolstraat 50 1327 CH ALMERE		
Statutaire zetel	ALMERE		
KvK-nummer	39075746 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister		

1.1	**Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht**
Afkomstig uit stuk	Hyp4 4767/59 Zwolle
Naam gerechtigde	Liander N.V.

Figure F3. Almere K 3302

kadaster

BETREFT	Almere K 3303
UW REFERENTIE	2170972_4
GELEVERD OP	13-06-2022 - 21:30
PRODUCTIEORDERNUMMER	S11129559302
VOLLEDIG GESIGNALEERD T/M	13-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	13-06-2022 - 14:59
BLAD	1 van 2

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Almere K 3303 Kadastrale objectidentificatie : 088920330370000
Kadastrale grootte	148 m²
Grens en grootte	Vastgesteld
Coördinaten	141892 - 485246
Omschrijving	Wonen
Ontstaan uit	Almere K 3149

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom belast met Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht (zie 1.1)**		
Soort recht	Eigendom (recht van)		
Afkomstig uit stuk	Hyp4 58/32 Lelystad	**Ingeschreven op**	05-11-1990
Naam gerechtigde	Rijnhomij B.V.		
Postadres	Radioweg 11 1324 KW ALMERE		
Statutaire zetel	ZEIST		
KvK-nummer	32051399 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister		

1.1	**Zakelijk recht als bedoeld in artikel 5, lid 3, onder b, van de Belemmeringenwet Privaatrecht**
Afkomstig uit stuk	Hyp4 4767/59 Zwolle
Naam gerechtigde	Liander N.V.
Adres	Utrechtseweg 68 6812 AH ARNHEM
Postadres	Postbus 50 6920 AB DUIVEN
Statutaire zetel	ARNHEM

Figure F4. Almere K 3303

kadaster

BETREFT	Almere K 3557
UW REFERENTIE	2170972_1
GELEVERD OP	13-06-2022 - 21:29
PRODUCTIEORDERNUMMER	S11129559284
VOLLEDIG GESIGNALEERD T/M	13-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	13-06-2022 - 14:59
BLAD	1 van 1

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Almere K 3557 Kadastrale objectidentificatie : 088920355770000
Kadastrale grootte	2.052 m²
Grens en grootte	Vastgesteld
Coördinaten	141929 - 485224
Omschrijving	Wegen
Ontstaan uit	Almere K 3151

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom (recht van)**
Afkomstig uit stuk	84 AMR04/12004 LLS
Naam gerechtigde	Gemeente Almere
Adres	Stadhuisplein 1 1315 HR ALMERE
Postadres	Postbus 200 1300 AE ALMERE
Statutaire zetel	ALMERE
KvK-nummer	32164984 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister

Figure F5. Almere K 3557

kadaster

BETREFT	Almere K 3805
UW REFERENTIE	2170972_6
GELEVERD OP	13-06-2022 - 21:30
PRODUCTIEORDERNUMMER	S11129559323
VOLLEDIG GESIGNALEERD T/M	13-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	13-06-2022 - 14:59
BLAD	1 van 2

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Almere K 3805 Kadastrale objectidentificatie : 088920380570000		
Locaties	Radioweg 15 1324 KW Almere Locatiegegevens zijn ontleend aan de Basisregistratie Adressen en Gebouwen Verblijfsobject ID: 0034010000018211		
	RADIOWG 17 1324 KW ALMERE		
Kadastrale grootte	3.022 m²		
Grens en grootte	Vastgesteld		
Coördinaten	141947 - 485288		
Omschrijving	Bedrijvigheid (industrie)		
	Erf - tuin		
Koopsom	€ 625.000	**Koopjaar**	2017
Ontstaan uit	Almere K 1171		
	Almere K 3300		
	Almere K 3301		

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom belast met Opstalrecht Nutsvoorzieningen op gedeelte van perceel (zie 1.1)**		
Soort recht	Eigendom (recht van)		
Afkomstig uit stuk	Hyp4 72215/178	**Ingeschreven op**	20-12-2017 om 12:09
Naam gerechtigde	MO HOLDING B.V		
Adres	Da Costakade 8 H 1052 SJ AMSTERDAM		
Statutaire zetel	DRONTEN		
KvK-nummer	39084005 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister		

Figure F6. Almere K 3805

kadaster

BETREFT	Almere K 3805
UW REFERENTIE	2170972_6
GELEVERD OP	13-06-2022 - 21:30
PRODUCTIEORDERNUMMER	S11129559323
VOLLEDIG GESIGNALEERD T/M	13-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	13-06-2022 - 14:59
BLAD	2 van 2

1.1 Opstalrecht Nutsvoorzieningen op gedeelte van perceel

Afkomstig uit stuk	Hyp4 513/12 Lelystad	**Ingeschreven op**	16-09-1994
Aanvullend stuk	Hyp4 827/11 Lelystad Is aanvulling op Hyp4 513/12 Lelystad	**Ingeschreven op**	11-07-1996
Naam gerechtigde	Liander N.V.		
Adres	Utrechtseweg 68 6812 AH ARNHEM		
Postadres	Postbus 50 6920 AB DUIVEN		
Statutaire zetel	ARNHEM		
KvK-nummer	08021677 (Bron: Handelsregister) Voor de meest actuele naam, zetel en adres, raadpleeg het Handelsregister		
Vermeld in stukken	Hyp4 79165/00021 Naamswijziging rechtspersoon	**Ingeschreven op**	01-10-2020 om 11:28
	Hyp4 69849/00097 Naamswijziging rechtspersoon	**Ingeschreven op**	06-01-2017 om 10:10
	Hyp4 60879/00069 Naamswijziging rechtspersoon	**Ingeschreven op**	16-12-2011 om 09:00
	Hyp4 55903/00133 Naamswijziging rechtspersoon	**Ingeschreven op**	03-12-2008 om 09:00
	Hyp4 30279/00087 Arnhem Naamswijziging rechtspersoon	**Ingeschreven op**	12-06-2003 om 09:00
	Hyp4 07358/00017 Arnhem Naamswijziging rechtspersoon		
	Hyp4 04664/00048 Zwolle Naamswijziging rechtspersoon		
	Hyp4 03659/00036 Arnhem Naamswijziging rechtspersoon		

Figure F6. Almere K 3805

kadaster

BETREFT	Heinenoord H 911
UW REFERENTIE	2166786_2
GELEVERD OP	09-06-2022 - 10:08
PRODUCTIEORDERNUMMER	S11129253941
VOLLEDIG GESIGNALEERD T/M	08-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	08-06-2022 - 14:59
BLAD	1 van 2

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Heinenoord H 911 Kadastrale objectidentificatie : 017260091170000
Kadastrale grootte	303.900 m²
Grens en grootte	Vastgesteld
Coördinaten	95130 - 427224
Omschrijving	Water
Ontstaan uit	Heinenoord H 446

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Besluit op basis van artikel 9.1 Wet Natuurbescherming		
Betrokken bestuursorgaan	De Staat (Landbouw, Natuur en Voedselkwaliteit)		
Vermeld in stukken	Hyp4 72869/00136 Naamswijziging rechtspersoon	**Ingeschreven op**	29-03-2018 om 09:00
	Hyp4 65061/152 Naamswijziging rechtspersoon	**Ingeschreven op**	22-10-2014 om 09:00
Afkomstig uit stuk	Hyp4 59694/00009	**Ingeschreven op**	16-03-2011 om 09:00
Overige stukken	Hyp4 61814/00165	**Ingeschreven op**	06-08-2012 om 14:20
	Hyp4 59694/00107	**Ingeschreven op**	16-03-2011 om 12:00
	Hyp4 59694/00106	**Ingeschreven op**	16-03-2011 om 11:59

RECHTEN

1	**Eigendom (recht van)**		
Afkomstig uit stukken	Hyp4 69470/122	**Ingeschreven op**	23-11-2016 om 09:09
	Hyp4 65061/152	**Ingeschreven op**	22-10-2014 om 09:00
	84 HNO02/1786 RTD		
Aanvullend stuk	Hyp4 69620/170 Is aanvulling op Hyp4 69470/122	**Ingeschreven op**	13-12-2016 om 11:59
Naam gerechtigde	De Staat (Infrastructuur en Waterstaat)		
Adres	Korte Voorhout 7 2511 CW 'S-GRAVENHAGE		
Postadres	Postbus 16169 2500 BD 'S-GRAVENHAGE		

Figure F7. Heinenoord H 911

kadaster

BETREFT	Barendrecht C 979
UW REFERENTIE	2166786_1
GELEVERD OP	09-06-2022 - 10:08
PRODUCTIEORDERNUMMER	S11129253904
VOLLEDIG GESIGNALEERD T/M	08-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	08-06-2022 - 14:59
BLAD	1 van 2

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Barendrecht C 979 Kadastrale objectidentificatie : 015470097970000
Kadastrale grootte	411.050 m²
Grens en grootte	Vastgesteld
Coördinaten	93916 - 427856
Omschrijving	Water

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Besluit op basis van artikel 9.1 Wet Natuurbescherming		
Betrokken bestuursorgaan	De Staat (Landbouw, Natuur en Voedselkwaliteit)		
Vermeld in stukken	Hyp4 72869/00136 Naamswijziging rechtspersoon	**Ingeschreven op**	29-03-2018 om 09:00
	Hyp4 65061/152 Naamswijziging rechtspersoon	**Ingeschreven op**	22-10-2014 om 09:00
Afkomstig uit stuk	Hyp4 59694/00009	**Ingeschreven op**	16-03-2011 om 09:00
Overige stukken	Hyp4 61814/00165	**Ingeschreven op**	06-08-2012 om 14:20
	Hyp4 59694/00107	**Ingeschreven op**	16-03-2011 om 12:00
	Hyp4 59694/00106	**Ingeschreven op**	16-03-2011 om 11:59

RECHTEN

1	**Eigendom (recht van)**		
Afkomstig uit stukken	Hyp4 69470/122	**Ingeschreven op**	23-11-2016 om 09:09
	Hyp4 65061/152	**Ingeschreven op**	22-10-2014 om 09:00
	84 BRD00/2511 RTD		
Aanvullend stuk	Hyp4 69620/170 Is aanvulling op Hyp4 69470/122	**Ingeschreven op**	13-12-2016 om 11:59
Naam gerechtigde	De Staat (Infrastructuur en Waterstaat)		
Adres	Korte Voorhout 7 2511 CW 'S-GRAVENHAGE		
Postadres	Postbus 16169 2500 BD 'S-GRAVENHAGE		
Statutaire zetel	'S-GRAVENHAGE		

Figure F8. Barendrecht C 979

kadaster

BETREFT	Heinenoord H 1002
UW REFERENTIE	2166786_3
GELEVERD OP	09-06-2022 - 10:09
PRODUCTIEORDERNUMMER	S11129253988
VOLLEDIG GESIGNALEERD T/M	08-06-2022 - 14:59
VOLLEDIG BIJGEWERKT T/M	08-06-2022 - 14:59
BLAD	1 van 1

Eigendomsinformatie

ALGEMEEN

Kadastrale aanduiding	Heinenoord H 1002 Kadastrale objectidentificatie : 017260100270000
Locatie	Tunnelpad 2 Heinenoord Verblijfsobject ID: 1963010002126898
Kadastrale grootte	94.380 m²
Grens en grootte	Vastgesteld
Coördinaten	94470 - 427070
Omschrijving	Wegen
Ontstaan uit	Heinenoord H 768

AANTEKENINGEN

Publiekrechtelijke beperking Basisregistratie Kadaster	Er zijn geen beperkingen bekend in de Basisregistratie Kadaster.

RECHTEN

1	**Eigendom (recht van)**		
Afkomstig uit stuk	Hyp4 1599/1 Dordrecht	**Ingeschreven op**	13-12-1972
Naam gerechtigde	De Staat (Infrastructuur en Waterstaat)		
Adres	Korte Voorhout 7 2511 CW 'S-GRAVENHAGE		
Postadres	Postbus 16169 2500 BD 'S-GRAVENHAGE		
Statutaire zetel	'S-GRAVENHAGE		
Vermeld in stukken	Hyp4 72869/00136 Naamswijziging rechtspersoon	**Ingeschreven op**	29-03-2018 om 09:00
	Hyp4 59220/00014 Naamswijziging rechtspersoon	**Ingeschreven op**	08-12-2010 om 12:40

Figure F9. Heinenoord H 1002