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Modelling the legal spaces of 3D underground objects in 3D land administration systems

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ABSTRACT

One of the significant challenges in current 2D Land Administration Systems (LAS) is defining and registering the Rights, Restrictions and Responsibilities (RRRs) attached to the underground objects. A 3D LAS can facilitate a better understanding, as well as a more efficient registration and clear visualisation of the RRRs than a 2D LAS, through 3D digital modelling of the legal ownership of underground objects below the surface. To register the objects below the surface in a 3D LAS, 3D physical data as well as 3D legal data shall either be registered and integrated into one model, or the physical and legal models shall be linked effectively. In the context of this paper, the IFC (ISO 16739:2018) is used to register the 3D physical data, while the Land Administration Domain Model (LADM, ISO 19152:2012) is used to structure the legal data. To achieve the link of the respective legal and physical data, the classes of the LADM are mapped to the elements of the IFC. A standardised workflow is presented in this paper where the inclusion of the legal, organisational and technical aspects of modelling the legal ownership results in a comprehensive approach to solve the challenges that currently prevent the registration of the RRRs of 3D objects below the surface in LASs. This paper also provides a general method for mapping the LADM classes to the IFC entities. Two case studies were conducted to assess the technical aspect of the workflow, where the RRRs of objects below the surface and the parcels above the surface were registered and visualised on the 3D geospatial visualisation platform CesiumJS.

1. Introduction

Developing the underground space can contribute to the optimal use of land in urban areas by providing the space for the construction of (infra)structural objects and networks vital for a city or country faced with urbanisation challenges and provide support for sustainable development (Broere, 2016; Peng et al., 2021). The main challenge in developing the underground space is defining and registering the RRRs of the objects in the underground space in current 2D LASs (Peng et al., 2021). Most objects below the surface are currently registered in 2D, making it not easy to identify their attached RRRs (Yan et al., 2019). Research shows that with the registration of the below-surface objects in 3D, the relationships between the RRRs and their physical parts can clearly be defined, understood and visualised (Kim et al., 2015; Atazadeh et al., 2018, 2019).

To register the objects below the surface in a 3D Land Administration Systems (LAS), 3D physical data, as well as 3D legal data shall either be registered and integrated into one model (Atazadeh et al., 2018) or the legal and physical models shall be linked effectively. To register the 3D physical data, IFC (ISO 16739:2018) models can be used. IFC is an open standard developed to stimulate interoperability and exchange of BIM models (ISO, 2018). To register the 3D legal data, the ISO 19152:2012 Land Administration Domain Model (LADM) standard can be used (ISO, 2012). The LADM is 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 the LADM standard

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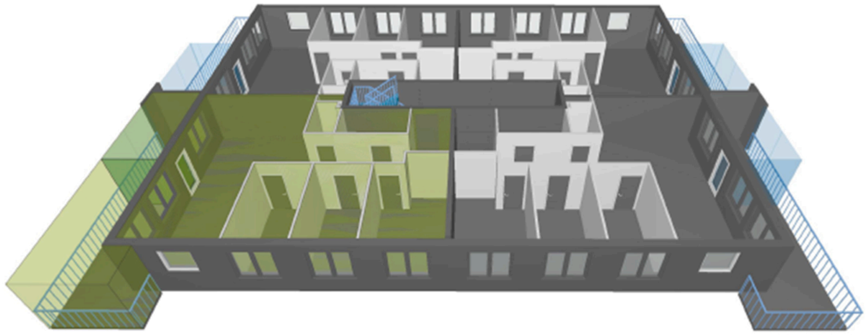

Fig. 1. Part of an apartment complex with the legal space enriched IfcSpace in yellow (Meulmeester, 2019).

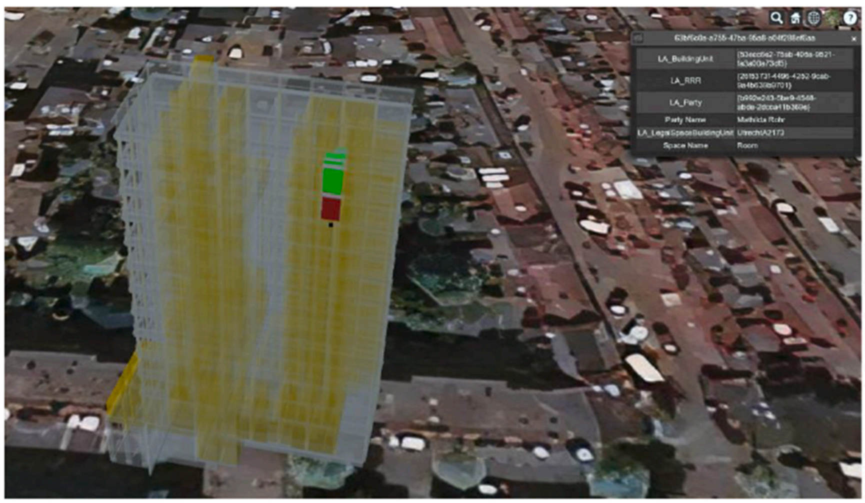

Fig. 2. Visualisation of the enriched BIM/IFC model (Broekhuizen et al., 2021).

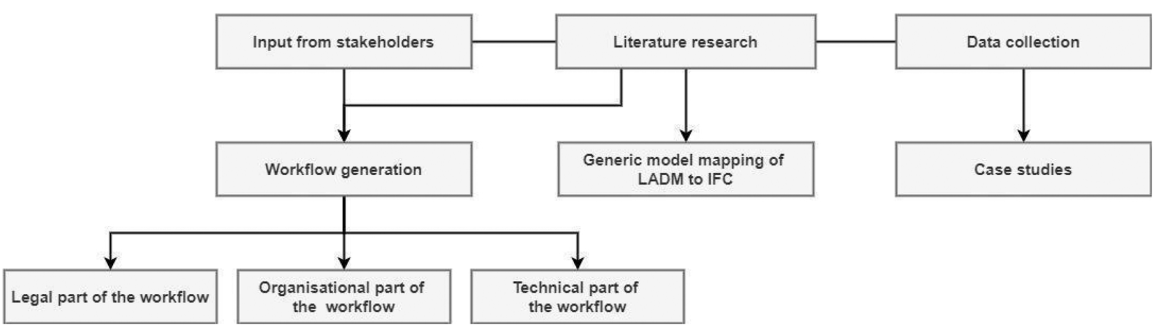

Fig. 3. Flowchart of the methodology.

leads to a LAS, where data can be exchanged and the quality of data ensured, sustained, and effectively managed (Lemmen et al., 2015). To achieve the link of the respective legal and physical data, the classes of the LADM should be mapped to the elements of the IFC.

To address the challenges that currently prevent the registration of the RRRs of the below-surface 3D objects in LASs a standardised workflow is developed and presented in this paper aiming to achieve the following:

1. collection, processing, storage, visualisation, dissemination and querying of 3D underground data in a 3D LAS according to ISO 19152:2012 LADM,
2. modelling the relations between underground objects and their legal spaces,
3. link the workflows from Architect, Engineer, Constructor, Owner Operator (AECOO) industry to 3D LAS using BIM/IFC models (ISO 16739:2018).

The standardised workflow is expected to provide more knowledge and insight into modelling the legal spaces of 3D underground objects, 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 when planning, developing and managing underground environments.

This paper is structured as follows: Section 2 provides a critical review of the existing research in underground land administration at an international level and the integration of legal and physical models. The research methodology, including the legal, organisational and technical

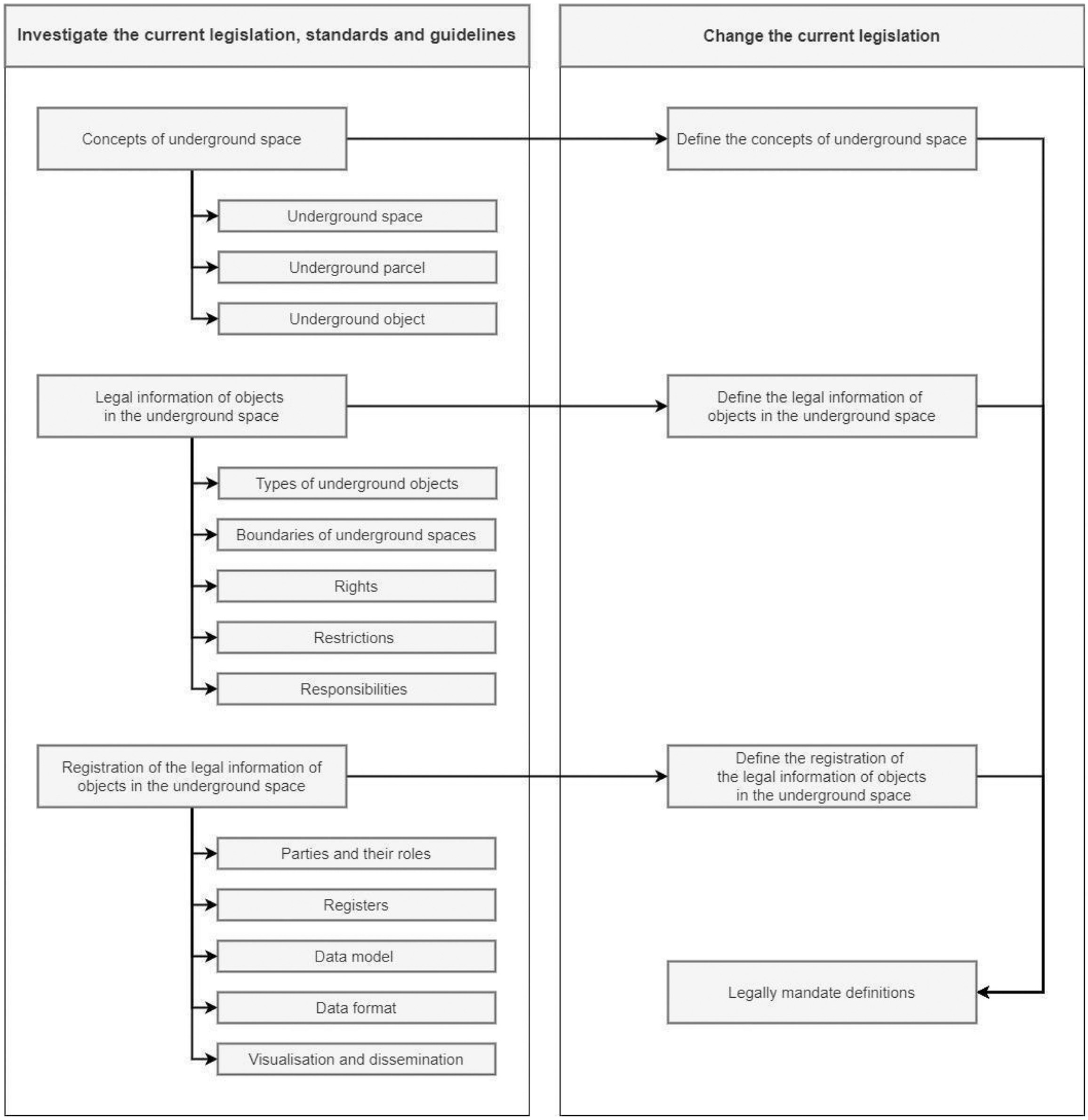

Fig. 4. Legal workflow.

part of the workflow, is presented in Section 3, while Section 4 provides the results of the generic model mapping of LADM classes to IFC entities with case studies that implement the technical aspect of the workflow. Finally, the paper concludes with discussion and conclusions on the workflow and recommendations for future work.

2. Related work

2.1. Registering underground objects worldwide

In countries around the world, research is carried out to further develop the LASs to model the RRRs of 3D underground objects, or specific registries are developed to register them. To name a few, in Poland it is proposed to extend the current cadastral conceptual model with new classes to support a 3D LAS. One of them refers to the 3D objects below the surface, while another models the 3D objects on the surface (Bieda et al., 2020). The "object-oriented spatial plot" is a concept suggested in Poland to register the below-surface objects together with the spatial plot that it occupies. To achieve it, legal amendments at the Polish real estate law are needed (Matuk, 2019).

Moreover, in Korea, Kim and Joon (2017, 2019) proposes to extend the cadastral model with two packages based on LADM: one for the surveying and mapping of the underground objects and one for the 3D underground parcels, with the necessary amendments on the legislative framework. While, in Singapore, 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 (Yan et al., 2019, 2021).

Croatia does not register tunnels in its cadastral system, while utilities are separately registered in the Utility Cadastre, where the horizontal and vertical location of the utility lines are registered, while the legal relations are registered in land books (Vucic 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 et al., 2017). In Slovakia, a new method has been proposed to register 3D underground objects, based on topology. The 2D parcels were modelled according to the principle of the LADM class 'LA_BoundaryFaceString', while the 3D boundaries based on the 'LA_BoundaryFace' class. Both models were stored in a spatial database and visualised (Janečka et al., 2018).

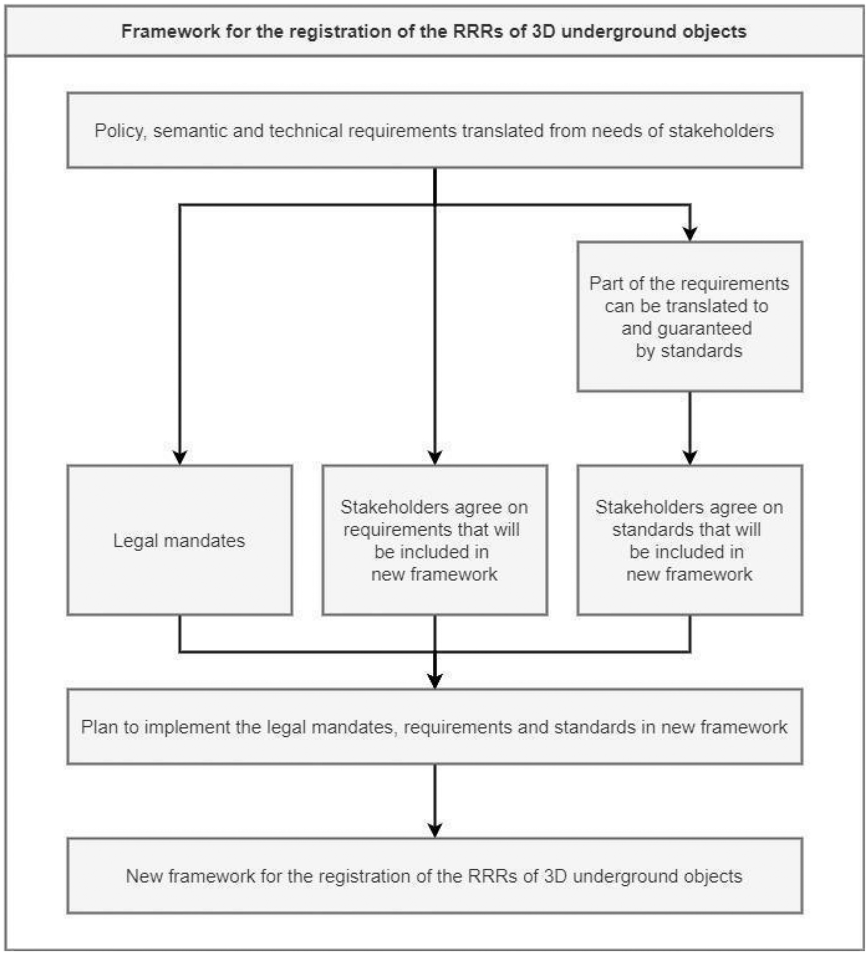

Fig. 5. Organisational workflow - framework for the registration of the RRRs of 3D underground objects.

The Serbian cadastre registers 3D objects below the surface that are part of a building, as building units, while the utilities are registered at a separate cadastre (Visnjevac et al., 2018). Research has been carried out in developing a country profile based on LADM, 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). A 3D cadastre has been proposed in which the two registries can be integrated into one system (Visnjevac, N. et al., 2018).

In Australia, 2D survey plans are a common form of representation used to manage the extent of ownership of underground objects, however this representation cannot effectively link the underground ownership boundaries and RRRs in complex situations, such as intersecting underground utility networks. Therefore, 2D survey plans often create spatial problems and unclear representation of complex RRRs within subterranean environments of Australia, leading to ineffective underground data management. To address these challenges, investigations have been done to address these problems by developing new 3D data models to integrate underground cadastral information in Australia (Saeidian et al., 2021). In one of the recent studies, a conceptual data model was developed for the Victorian state of Australia by proposing a country profile for the LADM standard (Saeidian et al., 2022). This conceptual data model for underground land administration in Victoria was created by considering the critical data requirements such as primary and secondary parcels, physical elements, legal boundaries and survey data elements.

2.2. *Legal and physical models*

The link between LADM and IFC facilitates the reuse of IFC models for legal spaces of the underground spaces' registration, where the entity IfcSpace is selected to store the legal information (the RRRs), defined as 'a space that represents an area or volume bounded actually or theoretically.' (buildingSMART, 2022a), making it the most suitable entity to store the legal information based on LADM.

Atazadeh et al., (2018, 2019) presents a workflow to add legal data to a IFC model consisting of six steps: (1) Model the object based on 2D drawings, (2) Define the legal boundaries, (3) and the legal spaces, (4) group the legal spaces with the same ownership into one zone, (5) add the RRR attributes to this zone and (6) export the data to an IFC file. In another workflow, IFC of apartment complexes were enriched with legal data using IfcSpace to store this data. Fig. 1 shows part of an apartment complex with the legal space enriched IfcSpace in yellow. Then, the enriched IFC was stored, together with cadastral data in a database management system, and visualised at a 3D platform (Meulmeester, 2019).

In the same direction, research to investigate the reuse of IFC for an LADM-based 3D LAS has recently been carried out. The IFC models were enriched with legal information based on LADM, were stored in a spatial database and visualised at an online 3D platform (Broekhuizen et al., 2021), as presented in Fig. 2.

3. Research methodology

The methodology of this research is divided into four parts: literature

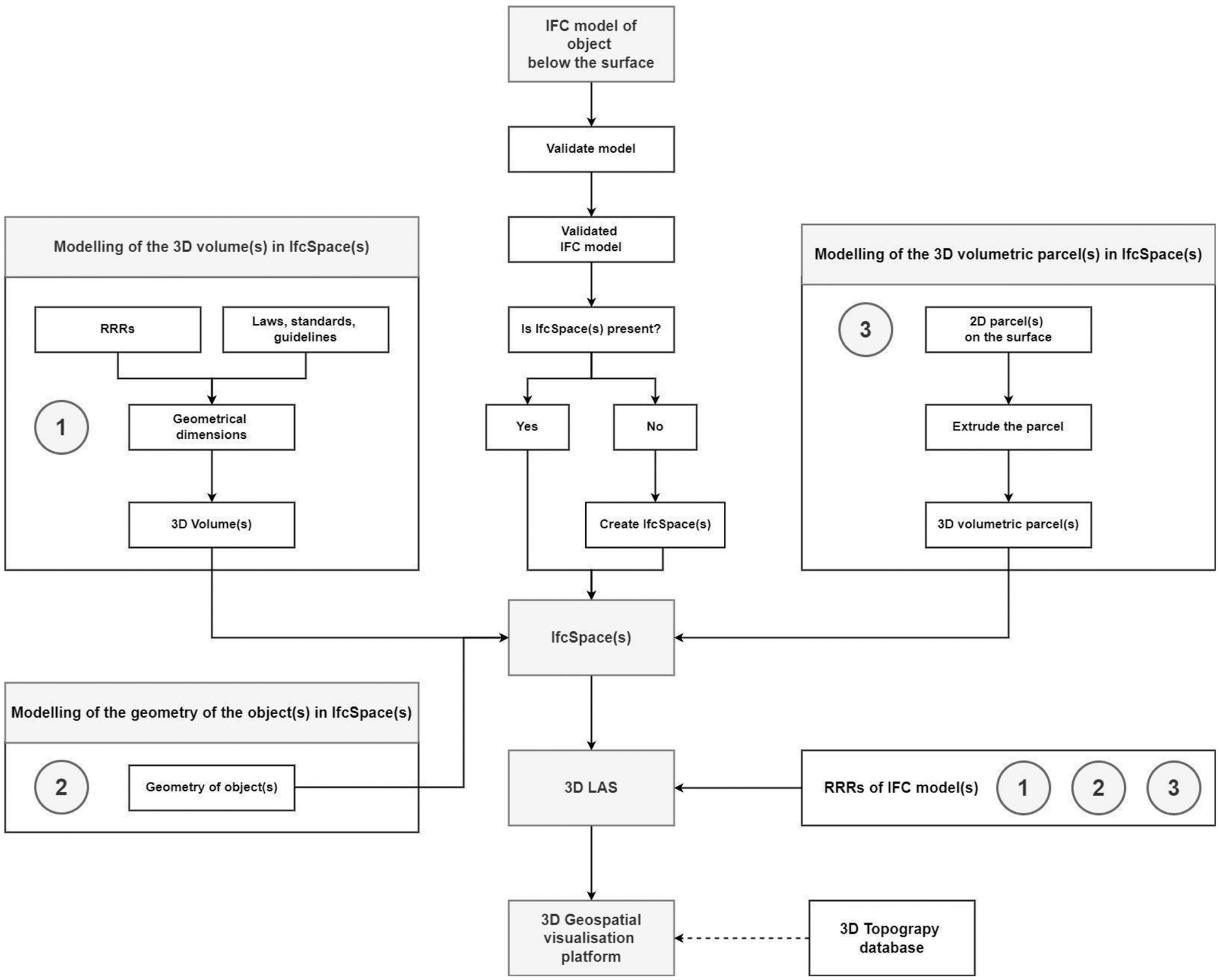

Fig. 6. Technical workflow.

research, input from stakeholders, data collection and the workflow generation (Fig. 3). The input from stakeholders and the literature research contributed to the generation of the workflow. Based on the literature research, which is presented in Section 2, the method for the generic model mapping of the LADM classes to the IFC entities was developed, while the data collection provided the data for the case studies.

3.1. Literature research

Scientific articles and other publications were retrieved by conducting an online search through journals, educational and research repositories and the documentation of standards and guidelines. The articles were selected by assessing their relevance to this research, where the requirement was that the articles provided information on: 3D cadastres, registration of 3D underground objects in LASs, Land Administration Domain Model (LADM), Industry Foundation Classes (IFC), and storage, visualisation and dissemination of IFC models. This article is based on the Master's thesis of one of the authors (Ramlakhan, 2022).

3.2. Input from stakeholders

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 were used in the development of the workflow.

3.3. Data collection

To collect the IFC models, the stakeholders were approached that are involved in the process of registering and using 3D underground objects in LASs. From the organisations that responded, 14 provided data, while 35 declined to provide any data, either because they do not use IFC models or due to intellectual property, confidentiality, and cybersecurity reasons they are not allowed to share the models. The majority of the stakeholders that provided datasets are from the Netherlands and specifically Dutch municipalities and provinces, a national agency and a utility network company, while datasets were also provided by a Swiss Canton and a Swiss national agency and three engineering companies. From the 44 datasets provided by the, 9 were IFC 2×3 models and 4 were IFC 4 models. The other datasets were in 2D/3D CAD (.dwg), CityGML, Shapefile (.shp), Geopackage (.gpkg), Revit 3D (.rvt) and Navisworks Document (.nwd) formats.

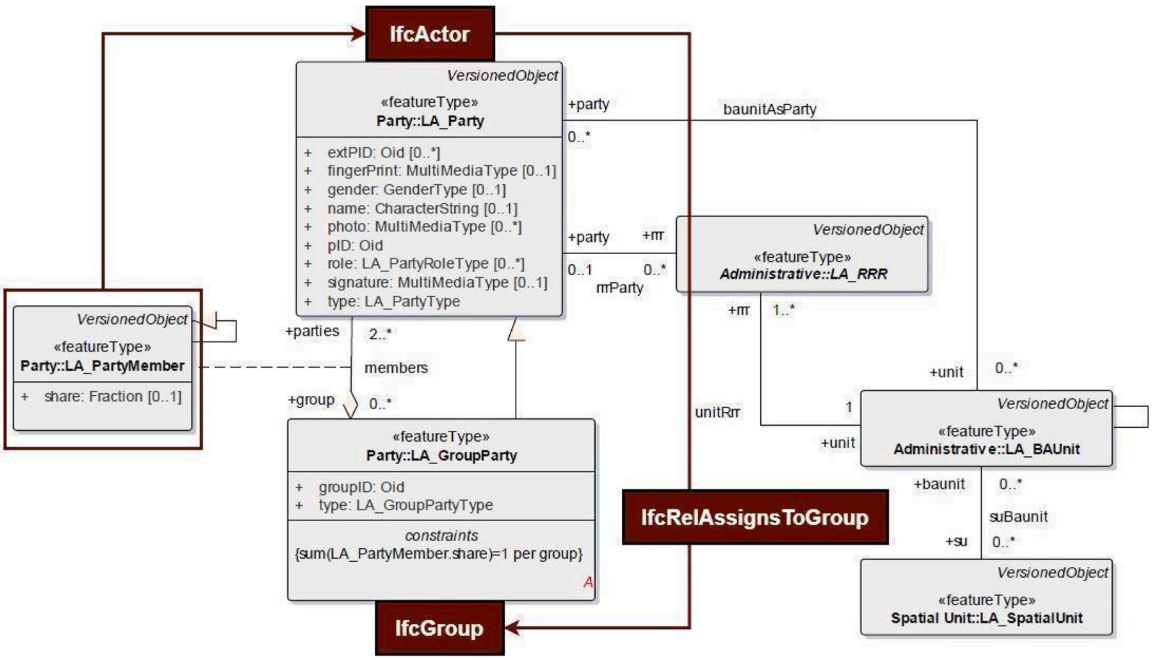

Fig. 7. Mapping of the LADM classes to the IFC entities for the Party package Adapted from ISO-TC211/HMMG (2022).

3.4. Workflow

By considering the three common aspects for implementing 3D digital cadastre, the proposed workflow in this research comprises three parts: legal, organisational and technical.

3.4.1. Legal part of the workflow

The legal workflow consists of all the legal aspects that should be dealt with when registering the legal ownership information of underground 3D objects (Fig. 4). The workflow is divided in two parts: (1) Investigate the current legislation, standards and guidelines and (2) Change the current legislation. The workflow starts with investigating whether the concepts of underground space, the legal information (the RRRs) of objects in the underground space, and the registration of the legal information of objects in the underground space are described in the legislation, standards or guidelines. If this is not the case, then these aspects need to be defined and legally mandated as can be seen in part 2: Change the current legislation.

3.4.2. Organisational part of the workflow

In the organisational workflow, the stakeholders involved in the registering of the RRRs of 3D underground objects are identified, after which use cases are defined for each stakeholder. Based on these use cases, the role that a stakeholder has in registering the RRRs of 3D underground objects can be defined. The needs of the stakeholders will be defined from which the policy, semantic and technical requirements can be derived. As a final step, a new framework for registering the RRRs of 3D underground objects is proposed. The policy, semantic and technical requirements that were earlier derived from the needs of stakeholders will be agreed upon by the stakeholders. Part of these 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 (Fig. 5).

3.4.3. Technical part of the workflow

The technical workflow provides the technical implementation of registering the 3D underground objects based on the LADM (Fig. 6).

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 method where the 3D volumes are modelled 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 almost always not present. 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 performed if there is no 3D volumetric legal space around the object, as 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 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 a 3D geospatial visualisation platform.

The 2D parcels that represent the objects above the surface should first be vertically 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. Afterwards, the

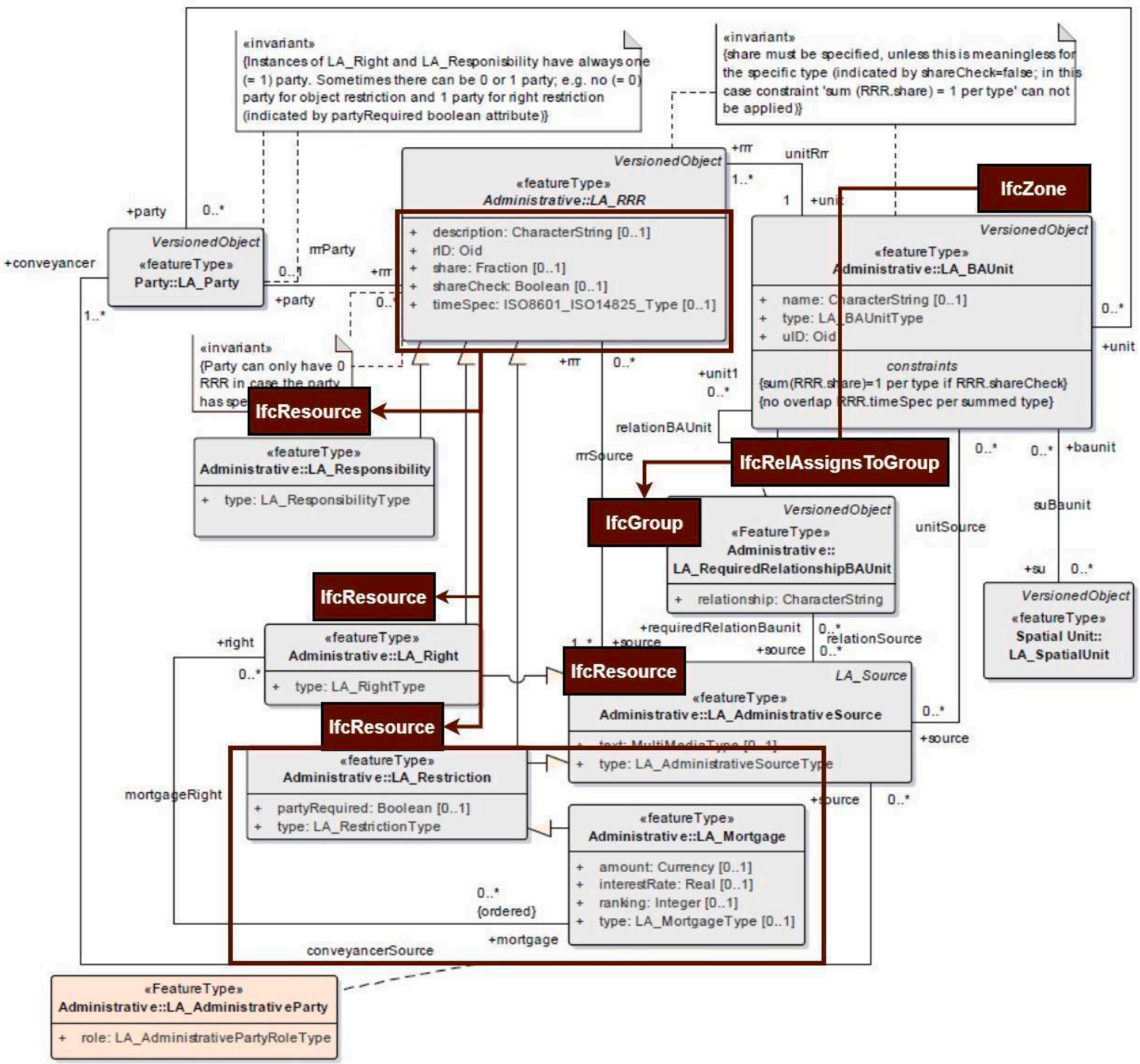

Fig. 8. Mapping of the LADM classes of the Administrative package to the IFC elements
Adapted from ISO-TC211/HMMG (2022).

legal spaces of the underground objects are subtracted from the extruded parcel and are stored separately. The RRRs, associated with the objects below the surface, are modelled based on the LADM and are then added to the IfcSpace(s) in the 3D LAS to enrich the IFC model(s). The result is finally visualised in a 3D geospatial visualisation platform, where other databases (such as a topography database or a 3D city model, etc.) and dictionaries can be added.

4. Results

4.1. Generic model mapping from LADM to IFC

The revision of the current LADM version is ongoing and its initial results are used for the purpose of this paper. Therefore, in this subsection, the revised model of the Part 2 of the LADM Edition II will be used for the mapping of LADM classes to IFC 4 entities (Lemmen et al., 2022). In the following paragraphs, the Party, Administrative, Spatial Unit packages and the Surveying and Representation subpackage are separately discussed.

4.1.1. Party package

The IfcActor entity defines the actors that are involved in a project, in this case the registration of the RRRs. The actors can be persons and organisations (buildingSMART, 2022a). This makes IfcActor a suitable entity to map the LA_Party class. The entity IfcGroup is a collection of non-geometrical objects, such as the IfcActor entity (buildingSMART, 2022a). This characteristic of IfcGroup makes it possible to map the LA_GroupParty class to this entity. The IFC entity IfcRelAssignsToGroup assigns an object, for instance, the IfcActor entity to the IfcGroup entity (buildingSMART, 2022a). The attribute of the LA_PartyMember class (denoting that a party can be a member of multiple groups and thus with different shares) can be added to the IfcActor entity, paying attention to the groups that the party belongs to. Fig. 7 shows the mapping of the LADM classes in the Party Package to their corresponding IFC entities.

4.1.2. Administrative package

A (subclass of a) spatial unit can be modelled as IfcSpace (see Section 4.1.3 Spatial package). Multiple IfcSpaces can be grouped together in the entity IfcZone through the relationship IfcRelAssignsToGroup

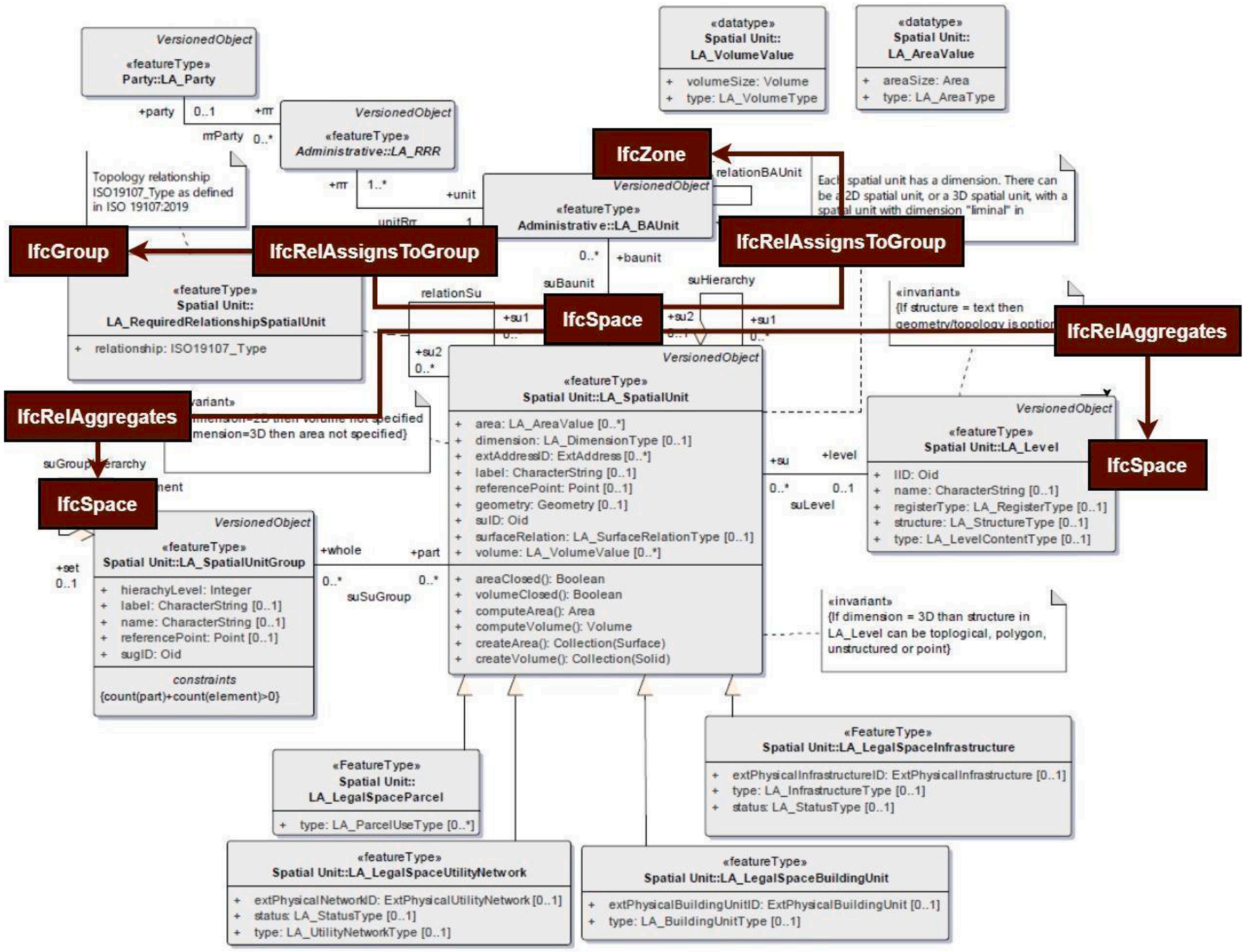

Fig. 9. Mapping of the LADM classes of the Spatial Unit package to the IFC entities
Adapted from ISO-TC211/HMMG (2022).

(buildingSMART, 2022a). IfcZone is thus a suitable entity to map LA_BAUnit to, which is a LADM class that can contain multiple spatial units. LA_RequiredRelationshipBAUnit 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 IfcZone to which the LA_BAUnits are mapped to, will be related to the IfcGroup through the relationship IfcRelAssignsToGroup. 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 possible to map the three classes LA_Right, LA_Restriction and LA_Responsibility to the entity. LA_AdministrativeSource will also be mapped to the IFC entity IfcResource. Fig. 8 shows the mapping of the LADM classes of the Administrative Package to the IFC entities.

4.1.3. Spatial Unit package

IfcSpace is defined as: 'A space represents an area or volume bounded actually or theoretically.' (buildingSMART, 2022a). This makes IfcSpace the most suitable IFC entity to map the class LA_SpatialUnit 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 (Lemmen et al., 2022). The attributes of the four subclasses will each be part of a property set that can be attached to the IfcSpace entity containing the LA_SpatialUnit class. Multiple IfcSpaces can be grouped together in the entity IfcZone through the relationship IfcRelAssignsToGroup (buildingSMART, 2022a). This property makes it possible for the spatial units to be grouped as a basic administrative unit, where the LA_BAUnit class will be mapped to the IFC entity IfcZone.

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, 2022a). The class LA_Level will be the IfcSpace where the group of (subclasses) of spatial units are aggregated to. 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 (ISO/TC, 2022). The entity IfcSpace can also be used to map the class LA_SpatialUnitGroup. The IfcSpace of LA_SpatialUnit will be associated with the IfcSpace of LA_SpatialUnitGroup through the entity IfcRelAggregates. LA_RequiredRelationshipSpatialUnit is a LADM class that provides the required relationship (s) between the spatial units (ISO/TC 211, 2022). Since the required relationship can concern multiple units, an IfcGroup can be made that contains all the spatial units with an explicit relationship. The IfcSpaces of LA_SpatialUnit will be related through the relationship IfcRelAssignsToGroup. Fig. 9 shows the mapping of the LADM classes of the Spatial Package to the IFC entities.

4.1.4. Surveying and Representation subpackage

In a cadastre, 2D spatial units are represented by points along a

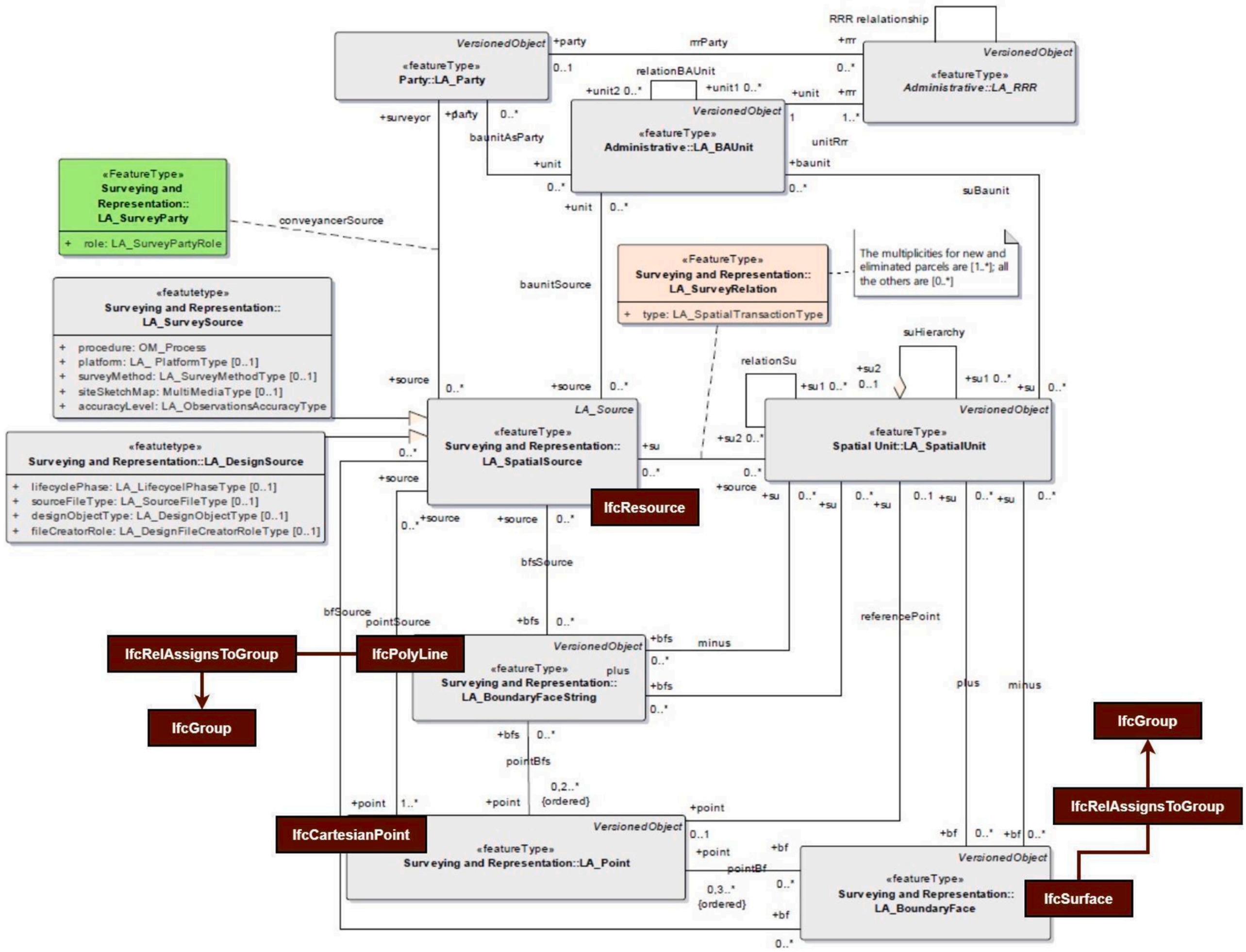

Fig. 10. Mapping of the LADM classes of the Surveying and Representations subpackage to the IFC entities. Adapted from ISO-TC211/HMMG (2022).

Fig. 11. Selected pipe segments from the sewage network in Almere. Blue: main sewage pipes, orange: home connections.

boundary that form a boundary string (curve). 3D spatial units are represented by (3D) points along a boundary that form a boundary face (surface) (Lemmen et al., n.d.). The LADM class LA_Point represents a point. The entity IfcCartesianPoint defines a geometric point. This characteristic makes IfcCartesianPoint an suitable option to map LA_Point to. The LADM class LA_BoundaryFaceString is used for the

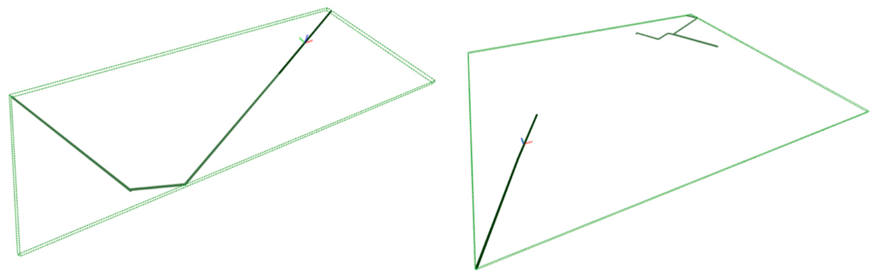

Fig. 12. IFC models of the main sewage pipes (left) and the home connections (right).

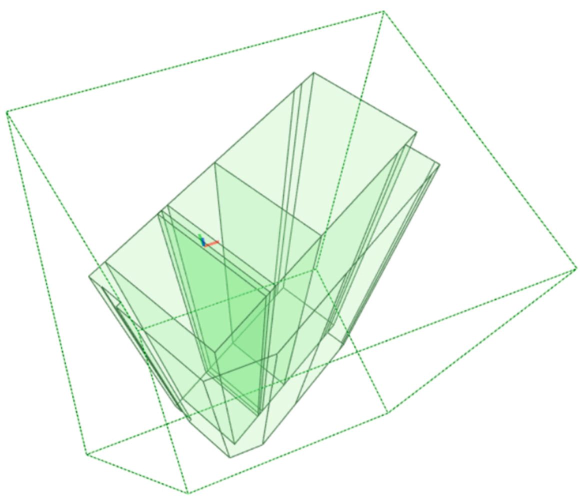

Fig. 13. IFC model of the selected parcels from the municipality of Almere.

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 entity that is a curve consisting of lines made up by (Cartesian) points (buildingSMART, 2022a). This characteristic of IfcPolyLine makes it suitable to map LA_BoundaryFaceString to it. Multiple IfcPolylines can be grouped in an IfcGroup through the entity IfcRelAssignsToGroup. The LADM class LA_BoundaryFace is used for the representation of 3D spatial units through faces that create volumes which can be the underground legal spaces (ISO/TC 211, 2022). IfcSurface is an entity that can represent a surface through connected points. (buildingSMART, 2022a). This property of IfcSurface makes it suitable to map LA_BoundaryFace to. Therefore, the IfcSurface entity can be used to define the surface geometry of underground boundaries which define the legal extent of the underground object in an IFC model. Multiple IfcSurfaces can be grouped in an IfcGroup through the entity IfcRelAssignsToGroup. LA_SpatialSource is the LADM class that provides information on the spatial representation of the object (ISO/TC 211, 2022). The entity IfcResource can be used as a container for the attributes of LA_SpatialSource. Fig. 10 shows the mapping of the LADM classes of the Surveying and Representation subpackage to the IFC entities.

4.2. Case studies

This section presents the implementation of the technical workflow from subsection 3.3. through two case studies, where the RRRs attached to the 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. The datasets used for the case studies can be found on the public repository: https://github.com/rohitramlakhan/thesis.

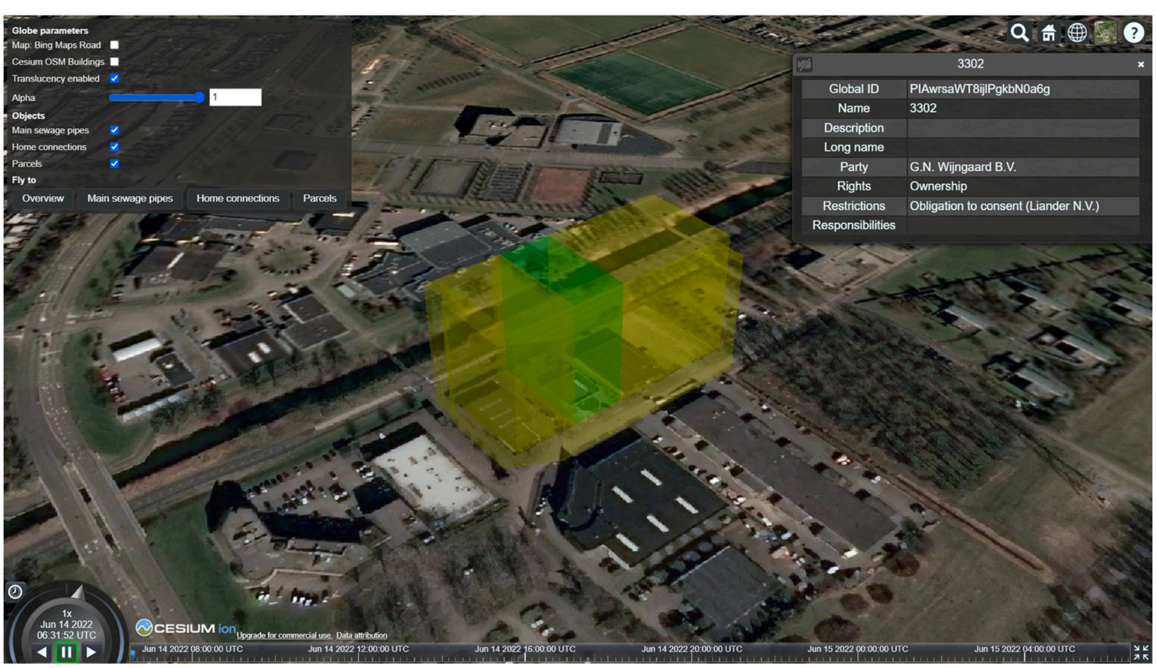

Fig. 14. Selected parcels in the municipality of Almere.

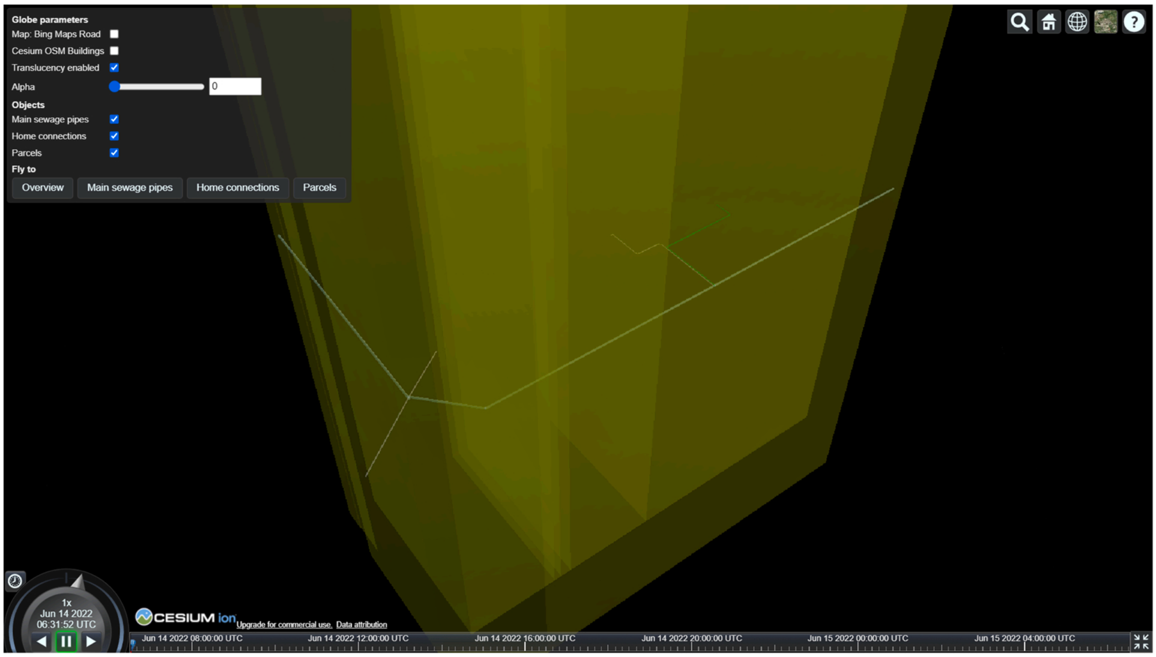

Fig. 15. Main sewage pipes and home connections in the municipality of Almere.

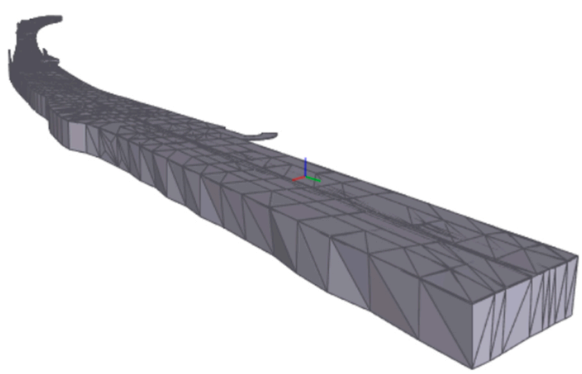

Fig. 16. Simplified IFC model of the Heinenoordtunnel.

4.2.1. 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 vertically extruded above and below the surface 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 ends at the border of the parcels. The RRRs of the pipes that connect 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 the pipe segments from the sewage network

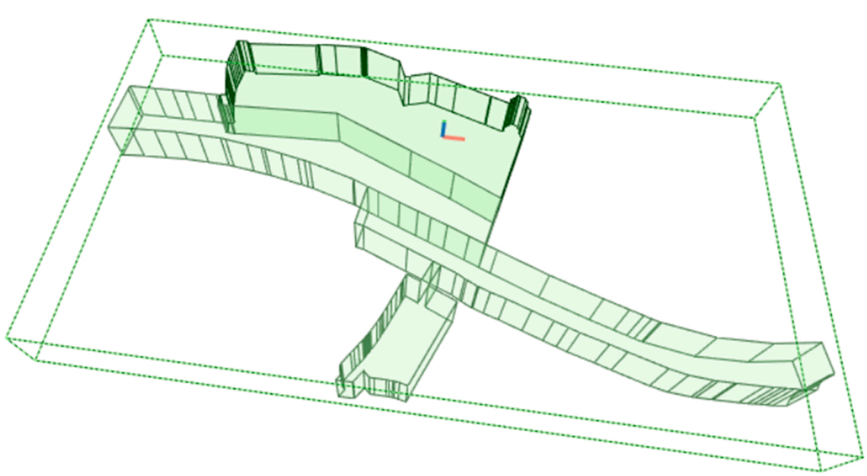

Fig. 17. IFC model of selected parcels from the municipalities of Heinenoord and Barendrecht.

Fig. 18. Selected parcels in the municipalities of Heinenoord and Barendrecht.

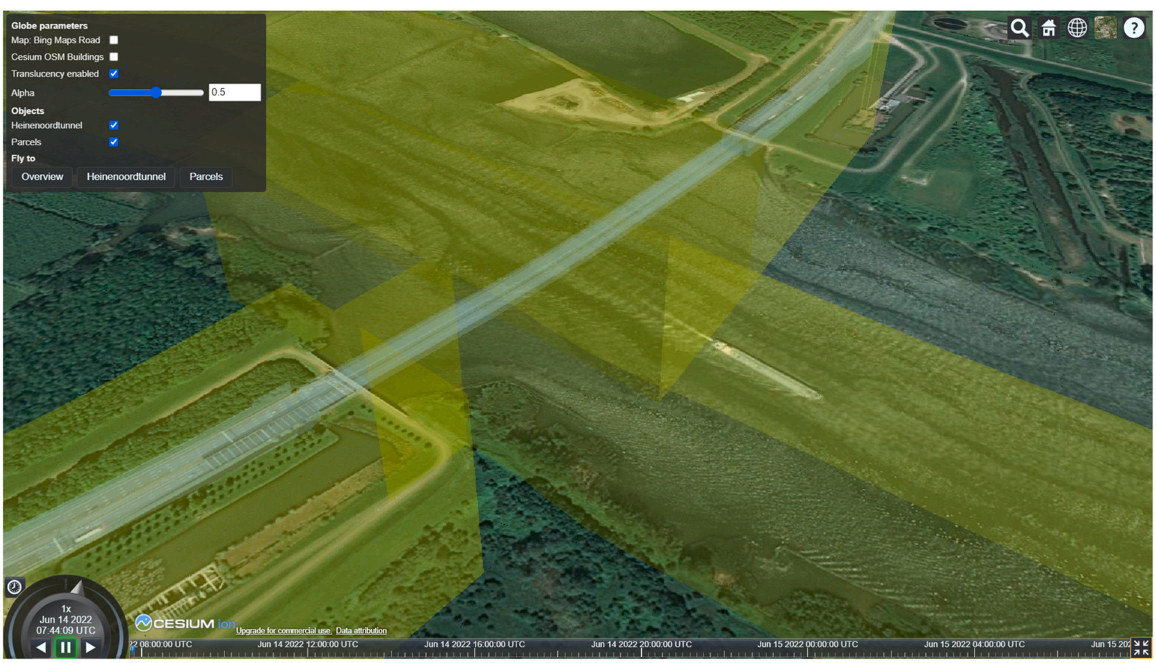

Fig. 19. Heinenoordtunnel in the municipalities of Heinenoord and Barendrecht.

2. Convert the pipe segments to IFC models
3. Select and extrude the land parcels under which the pipe segments are located
4. Extrude and convert the land parcels to an IFC model
5. Store the pipe segments and the land 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 3D data using the Cesium 3D Tiles

Fig. 11 shows the main sewage pipes and home connections below the selected parcels in Almere. Fig. 12 shows the IFC models of the main sewage pipes and the home connections separately.

Fig. 13 shows the IFC model of the two selected parcels. Fig. 14. shows the selected parcels in the municipality of Almere. Fig. 15 shows the sewage pipes in the municipality of Almere.

4.2.2. *Case study 2: Heinenoordtunnel*

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 ‘Oude Maas’ was modelled. The Heinenoordtunnel is owned and maintained by the Dutch ministry of Infrastructure and Water Management. The four land parcels, under which the Heinenoord tunnel is located, are also owned by this ministry (except for one land parcel, where there is uncertainty regarding who owns the parcel, since the ownership information could not be retrieved), meaning that there is no conflict for the other three land parcels. However, it could be in the case of other tunnels 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 vertically extruded above and below the surface 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 land parcels under which the tunnel is located
3. Extrude and convert the land parcels to an IFC model
4. Store the simplified IFC model and the land parcels 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 3D data using the Cesium 3D Tiles

Fig. 16 shows the IFC model of the simplified tunnel. Fig. 17 shows the IFC model of the four selected parcels. Fig. 18 shows the selected parcels in the municipalities of Heinenoord and Barendrecht. Fig. 19 shows the Heinenoord tunnel in the municipalities of Heinenoord and Barendrecht.

5. Discussion and conclusions

In this paper, a workflow is presented to model the RRRs of 3D underground objects, based on previous work of the authors (Ramlakhan et al., 2021). The workflow presented in this paper also includes the legal and organisational aspects, thereby creating a comprehensive approach to the modelling of RRRs attached to the 3D underground objects. Two case studies were executed to implement the technical aspect of the workflow. 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.

In both case studies, IFC 2×3 models of underground objects were used and made from models with data formats other than IFC, such as a shapefile. 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. The conclusions derived from the case studies shall therefore mainly apply to the Netherlands. It cannot be estimated how (parts of) the proposed workflow applies to countries other than the Netherlands.

Through this paper, and in the legal and organisational workflows, international, open standards are used and recommended. Next to using the IFC models for the physical model and the LADM for structuring the RRRs, other standards can also be implemented. A standard for a georeferencing format can be the 'LoGeoRef' method proposed by Clemen and Hendrik (2019). The OGC Simple Feature Access standard, which is also an ISO standard, can be used for the geometrical validation of the 3D objects (OGC, 2022; ISO, 2022a).

Moreover, apart from the workflow, this paper provides the general mapping of LADM classes (based on the revision of the standard) to IFC entities (IFC 4). Although the revised version of IFC 4 (IFC 4×3) 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 becomes standard (buildingSMART, 2022b; ISO, 2022b) and revise it 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 4×3 with the same definitions. The one entity that is deprecated in IFC 4×3 is IfcBuildingElementProxy (buildingSMART, 2022c). IfcBuildingElementProxy is an element that is used to model building elements, without it having to be a specific type of building element (buildingSMART, 2022a). In IFC 4×3, 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, 2022d). IfcFacilityPart describes the structural parts of an IfcFacility object (buildingSMART, 2022d). 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.

The workflow presented in this paper is based on previous work of the authors and there are further steps for the future. With regards to the legal part of the workflow, legal documents, standards and guidelines need to be investigated more in order to retrieve information on the legal situation of underground objects. Assessing the needs of stakeholders can also provide valuable information which can be translated to information on the legal situation of underground objects. Therefore, more involvement of stakeholders is needed. With the information on the RRRs from the laws, standards, guidelines, and based on the needs of the stakeholders, the legal spaces of the use cases of objects in the underground space can be created, the model can be stored and visualised.

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 (especially IFC 4) 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.

Data availability

The data used can be accessed through public Github repository. The link to this repository is written in the paper.

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