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Modelling 3D underground legal spaces in 3D Land Administration Systems

Rohit RAMLAKHAN, The Netherlands, Eftychia KALOGIANNI, Greece, Peter VAN OOSTEROM, The Netherlands

Key words: 3D Land Administration Systems; underground objects; LADM; BIM; IFC

SUMMARY

Two dimensional (2D) Land Administration Systems (LASs) do not adequately represent 3D underground objects. It is not easy to identify the owners of these objects and the relations between objects below and above the surface are not explicitly provided. A 3D LAS can however facilitate a better understanding, as well as a more efficient registration and clear visualisation of the Rights, Restrictions and Responsibilities (RRRs) of the 3D underground objects. To represent 3D underground objects, BIM/IFC (ISO 16739:2018) models can be used from design. The LADM (ISO 19152:2012) standard should be used to provide a formal language to register spatial and non-spatial information in LASs. In this paper a literature review is performed to develop a standardised workflow to model the legal spaces of BIM/IFC models of 3D underground objects according to the LADM in 3D LASs. With this workflow the user is provided with a general framework, where adherence to the BIM/IFC and LADM standards enhances interoperability, increases efficiency and reduces costs. More research needs to be done on validating the workflow with use cases.

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1. INTRODUCTION

Urbanisation and a shortage of accessible land has resulted in increased development of multi-level properties worldwide (Kim et al., 2015). The implementation of these properties in Land Administration Systems (LAS) requires 3D objects above and below the surface of the Earth, that 2D parcels cannot adequately support (Stoter et al., 2016). When 2D parcels are used to represent objects below the surface it is not easy to identify the owners of these objects, while the relations between objects below and above the surface are not explicitly provided (Yan et al., 2019). 3D LAS clearly defines the relationships between Rights, Restrictions, Responsibilities (RRRs) and 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).

To digitally represent a physical model of the 3D objects, a Building Information Model (BIM), which comprises the geometry and 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 Class (IFC), EN 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. The 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).

The ISO 19152:2012 Land Administration Domain Model (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). Recent research is being carried out to investigate the implementation of the LADM in a 3D LAS, with the use of BIM/IFC models as input for apartment buildings and infrastructure objects. The result is that the RRRs of underground objects can easily be determined by applying the legal aspects from the enriched BIM/IFC model. This is especially important when the physical models and their legal spaces need to be compared as could be the case with complex built structures, such as underground objects (Atazadeh et al., 2018).

The use of standards has supported the development of 3D LAS by enhancing the interoperability of the models, although several challenges and incompatibilities still remain.

3D LASs around the world may vary, since they depend on various aspects, such as the 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. For that reason, research is carried out regarding registering the legal spaces of 3D underground objects, and investigating the relation between the 3D underground objects and the affected 2D parcels on the surface of the earth (Kalogianni et al., 2020a).

In this scene, this paper investigates good practices and milestone projects for the registration of underground properties at an international level and presents a comprehensive standardised workflow that will be able to: (1) collect, process, store, validate, visualise, disseminate and query 3D underground data in a 3D LAS according to ISO 19152:2012, (2) model the relations between the underground objects and their legal spaces, (3) model the relations between the underground legal spaces and the 2D parcels on the surface and (4) connect the workflows from AECOO community to a 3D LAS via a BIM/IFC model.

The paper is structured as follows. Section one presents the introduction. Information on the modelling of underground legal spaces in the countries around the world and on standardised data models is then provided. Hereafter, the procedures that were followed in order to develop the workflow are presented. Section four presents the workflow and elaborates on the different phases. The paper concludes with the discussion and conclusions.

2. RELATED WORK

2.1 Modelling of underground legal spaces in the Netherlands

In the Netherlands, there are 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, and as physical objects by the utility network companies (Stoter et al., 2012).
Other underground objects are not legal objects but their property rights can still be registered with the use of limited rights on 2D parcels. These limited rights are the right of superficies, the right of long lease and easements (Stoter et al., 2012). The right to superficies provides the right to construct buildings or other non-utility structures above or below other structures or land that is owned by a different owner. This makes it possible to register the ownership of tunnels, parking garages and other underground objects. The right of long lease gives the right to use an object but not legally own it. 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. Examples are the extension of a tunnel from one parcel to another or prohibiting that one parcel builds pipes and cables near the other parcel (Stoter et al., 2012).

To register the legal spaces of the 3D (underground) objects with the attached limited rights, the Dutch Cadastre adheres to the '*specialty principle*'. This principle states 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 may result in the occurrence of many small parcels (Stoter et al., 2016; 2017).

A new workflow has been developed by Stoter et al. (2017), regarding the registration of multi-level properties (with underground structures) in 3D. In this workflow, legal volumes are created from BIM models and validated. With the use of a 2D cadastral map a 3D-PDF is created for the visualisation of the legal volumes and is used as a legal source document (see figures 1,2). The legal volumes created from the BIM models are also stored in the Dutch cadastre for the 3D geometry and could be updated in the future by surveying the legal volumes (Stoter et al., 2017). However, it is not possible to extract coordinates from a 3D PDF, thus, the use of BIM/ IFC models is preferred.

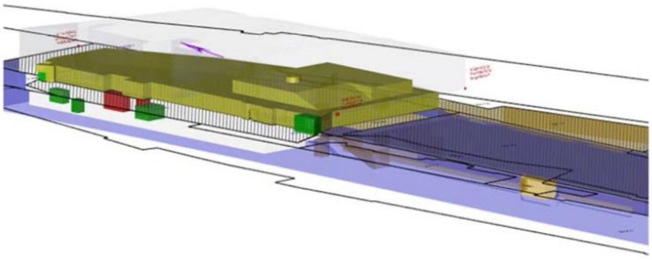

Figure 1. Visualisation of the different legal spaces of the Delft station, The Netherlands (Stoter et al., 2017)

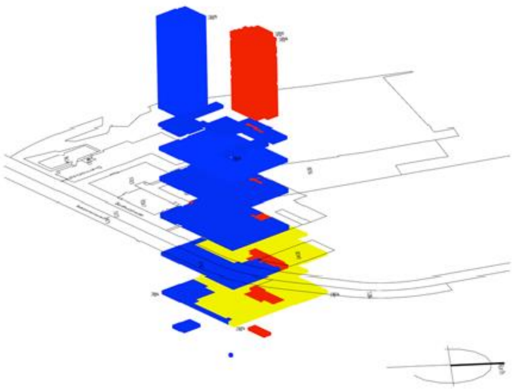

Figure 2. Visualisation of the different legal spaces of the congress hotel Maritim, Amsterdam, The Netherlands. Red: residential building, blue: congress centre; yellow: underground parking garage (Stoter et al., 2017).

2.2 Modelling of underground legal spaces worldwide

Due to urbanisation, cities around the world are being extended below ground and are developing their underground spaces for optimal usage. For example, Singapore plans to increase the use of underground space and has initiated the Digital Underground project to survey and map the subsurface utilities in order to acquire precise information of the underground space (Singapore-ETH Centre, 2019). What is more, the United Kingdom runs a similar project, the "Project Iceberg", in which, not only the subsurface utilities will be mapped, but also the conditions of the ground (BGS Research, n.d.).

A review of how selected countries around the world currently model (specific) underground objects 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.

In Poland, the current cadastral system consists of two registers: one for the location and the geometry of the land (parcels) and buildings and one for the legal information (Bieda et al., 2020). The registration of underground objects can be complicated, since these objects can have different owners than those of the objects on the surface. The underground objects therefore need to be registered separately. Bieda et al. (2020) propose to extend the current cadastral conceptual model with new classes to support a 3D cadastre. The "object-oriented spatial plot" is a concept proposed in Poland to register underground objects. In this concept the underground object, as well as the spatial plot that it occupies, is 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).

Moreover, in Korea, land administration is based on a 2D cadastral system and on ISO 19152 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 underground objects. The real property registration system can register these objects by defining certain extents of the legal space underground. In order to prepare the system for 3D underground objects, 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. Research by the same authors presents a framework in which 3D underground parcels can be registered. In this framework firstly 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).

In Singapore, land owners in general own the land up to 30 meters 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, a method has been proposed to develop an underground utility 3D data model based on the LADM in order to better register and manage the utilities and their networks in Singapore (Yan et al., 2019; 2021).

The Serbian cadastre registers underground objects, 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. Underground objects 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, A. et al., 2019). A 3D cadastre has also been proposed in which the two cadastres can be integrated to one system, and where, due to the three-dimensional aspect, the overlapping of information would not be a problem to visualise (Visnjevac, N. et al., 2018).

2.3 Standardised data models for underground infrastructure objects

There are several types of data models used to standardise the modelling of underground objects. The INSPIRE utility networks is the European application schema for utility networks where the focus lies on defining a 2D topological relationship between the network elements. The information model for cables and pipes (in 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). 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). In the next section however, the most common data models, LADM, CityGML and IFC will be discussed as well as the integration between these models.

2.3.1 ISO 19152:2012 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.

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 will 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 and the survey procedures. 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, (2) Land Registration, (3) Marine Space, (4) Land Valuation, (5) Spatial Planning and (6) Implementations. 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 2022 (Kalogianni et al., 2020a).

2.3.2 CityGML

CityGML is an open data model and XML encoded schema used for the storing and exchange of 3D city models. CityGML describes the geometry and attributes of typical 3D objects in cities, for example, buildings, roads, tunnels, 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. The Utility Network ADE is used to store data on the geometry of the utilities and the relations between them (Biljecki et al., 2021). Although CityGML is able to store the geometry of underground objects, for example, tunnels and utility networks, through the standard modules and ADEs, the models are less detailed compared to BIM/IFC models, which can be necessary for registering legal information (Arroyo Ohori et al., 2018) .
Due to a need for better usability and interoperability with other standards, CityGML is being updated. CityGML 3.0 is composed of a conceptual model and an encoding specification. The same modules used in CityGML 2.0 are part of 3.0, although some of them have been revised. New modules have been introduced, for instance, the Construction module that incorporates the classes present in the Building, Bridges and Tunnel module. CityGML 3.0 is based on several ISO standards which allows for it to automatically obtain application schema's from the conceptual data model, thereby following a model-driven approach. The conceptual model of CityGML 3.0 has already been finished, while the encoding specification has not (Kutzner et al., 2020).

2.3.3 BIM / 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 Classes (IFC) are 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 ISO 16739-1:2018 IFC standard is encoded in the EXPRESS and XML schema's and consists of many classes to store and exchange data of buildings (ISO, 2018; Atazadeh et al., 2019). Due to the increased use of BIM, explained by the advantages of a reduction in cost and better management of buildings throughout their life cycle, more BIM/IFC files are produced. These IFC files 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 files 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 version of the IFC is 4.0, while the next version, IFC 4.3, is under development. The motivation for this update was to improve the representation of infrastructure objects (buildingSMART, (n.d)a).

3. RESEARCH METHODOLOGY

In order to search for information with regards to the modelling of legal spaces of 3D underground objects in 3D Land Administration Systems (LASs), a literature review was performed. With the knowledge gained from this review, requirements for a standardised workflow to model the legal spaces of 3D underground objects, were defined.
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).
The articles were selected by assessing their relevance to this research. Important aspects here to consider were: (1) the enrichment of BIM/IFC models of underground objects with legal information according to LADM, (2) the storage of the legal and physical data of underground objects in a 3D database and (3) the visualisation of the whole integrated model. 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 were selected for further use. The references of these articles were also evaluated and if articles were deemed to be relevant, then these articles were also included.

4. RESULTS

The modelling of 3D underground legal spaces in 3D Land Administrations Systems (LASs) can be done through the execution of the workflow presented in this section and is based on earlier research by Oldfield et al., 2017, Atazadeh et al., 2018, 2019, Cemellini, 2018 and Meulmeester, 2019. An overview of the workflow is shown in figure 3. The workflow consists of three phases: (1) conceptual modelling, (2) physical modelling and (3) visualisation.

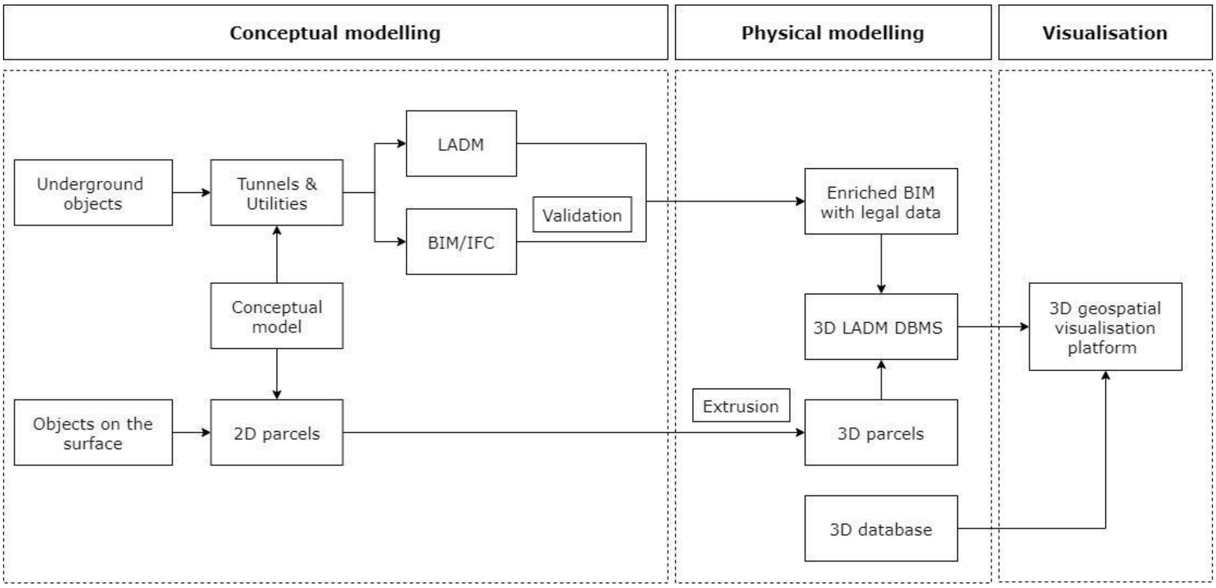

Figure 3. Overview of the workflow

4.1 Conceptual modelling

A UML model describing the relations between the underground objects, for example, tunnels and utilities and the 2D parcels is first created.

Then, BIM/IFC models of the underground objects are collected, investigated and validated. The validation of the BIM/IFC models can be done in three steps. The first step is to assess if the model complies with the IFC schema. The second step is to evaluate the BIM/IFC models according to criteria from the guidelines provided by governments (Meulmeester, 2019). Registering legal information in a cadastre requires the use of geographical coordinates. The third step is thus inspecting if *IfcSite* has (the correct) values of RefElevation, RefLatitude and RefLongitude. The parcels (2D or 3D) of which the relations to the 3D underground objects are modelled are to be retrieved from the cadastre.

After validating the BIM/IFC models, the LADM classes are mapped to the IFC elements in order to enrich the BIM/IFC models. Several types of IFC elements are selected to store the legal information of spatial units, of which *IfcSpace* is the most important (Oldfield et al., 2017; Meulmeester, 2019). *IfcSpace* is *"a space that represents an area or volume bounded actually or theoretically. Spaces are areas or volumes that provide for certain functions within a building."* (buildingSMART, (n.d)b). This property makes it possible for *IfcSpace* to store the legal information, although attributes do need to be added with the use of *IfcLabel* (Atazadeh et al., 2018). The same legal spaces can be grouped into one zone, defined by the IFC element *IfcZone* (Atazadeh et al., 2019).

4.2 Physical modelling

The relational database management system (DBMS) PostgreSQL is set up and extended with the spatial extension PostGIS, resulting in a spatial DBMS. In this DBMS the 3D parcels and the enriched BIM/IFC model will be stored.

If the objects above the surface are stored as 2D objects in the parcels then these objects first need to be extruded to 3D with the use of the data integration platform FME.

The enriched BIM/IFC models are stored in the DBMS in two tables, one for the legal model with the legal information according to the LADM and one for the physical model with the BIM/IFC data.
Another 3D DBMS can also be set up to contain a (local) Digital Terrain Model (DTM) since these are more accurate than the global terrain models that are used or a 3D city model to be used as a reference.

4.3 Visualisation

CesiumJS, a 3D geospatial visualisation platform is used for visualising the whole integrated model. 3D geospatial visualisation platforms often do not visualise the underground surface well. There are three solutions to overcome this challenge: (1) performing a ground-push, where a rectangle pushes an area of land down in order to visualise what is below, (2) creating a fake surface above the ground by copying the terrain and placing it higher than the ground surface, making it able to see what is below, and (3) making the terrain transparent to see the underground (Cemellini, 2018). The most recent releases of CesiumJS should be able to visualise the underground surface, although this is not verified by the authors of this paper.

5. DISCUSSION AND CONCLUSIONS

This paper is about initiating a discussion on the registration of 3D underground objects on 3D LAS by reusing information from previous stages of the Spatial Development Lifecycle.
Defining the ownership of underground objects has become more important due to an increase in development of underground space and multi-level properties. These developments have made it necessary to model the legal spaces of 3D underground objects in a standardised manner in a LAS. A comprehensive standardised workflow is presented in this paper that provides the user with a general framework on how to model the legal spaces of 3D underground objects in a 3D LAS, where the adherence to the BIM/IFC and LADM standards enhances interoperability, increases efficiency and reduces costs.

The upcoming revisions of the LADM and IFC standards were not taken into consideration in developing this workflow. It is thus not clear if the workflow can also be applied to revisions of the LADM and IFC standards. In order to optimally use the workflow BIM/IFC models of underground objects are needed. Although more existing underground surfaces and objects are being surveyed and mapped, most of them are not. Obtaining BIM/IFC models of existing underground objects can be challenging.

This research is a literature review and provides information and a workflow on the modelling of legal spaces of 3D underground objects in a 3D LAS. There are however no use cases provided and analysed due to a lack of adequate BIM/IFC models of underground objects, making it not possible to validate the workflow.

This workflow is an initial attempt at developing a standardised manner to model the legal spaces of 3D underground objects in 3D LAS. To further developing and improving the workflow, more research can be done by:

- validating the standardised workflow with use cases of BIM/IFC models of underground objects
- investigating the option to include data formats of 3D underground objects other than BIM/IFC in the workflow
- investigating and improving methods to convert other data formats to BIM/IFC
- assessing the impact of the revisions of the LADM and IFC standards on the workflow
- investigating how the workflow can be adapted in order to comply with the revisions of the LADM and IFC standards

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BIOGRAPHICAL NOTES

Rohit Ramlakhan is a Master student of Geomatics and the Built Environment, Faculty of Architecture, at the Delft University of Technology. His Master's thesis topic is about developing a standardised workflow in order to model the 3D underground legal spaces in 3D Land Administration Systems.

Eftychia Kalogianni is a PhD candidate in the Digital Technology Section, Department Architectural Engineering and Technology, at the Delft University of Technology. Her PhD research topic is about adopting a holistic approach to treat 3D Land Administration Systems within the Spatial Development Lifecycle, in the context of the LADM ISO 19152 revision. She holds MSc in Geoinformatics from NTUA and MSc in Geomatics from TU Delft. Since 2015, she has worked at a consulting engineering company involved in various projects carried out by European joint ventures. She is an active member of FIG Young Surveyors Network.

Peter van Oosterom obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, the Netherlands. In 1990 he received a PhD from Leiden University. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology, and head of the 'GIS Technology' group at the Digital Technologies Section, Department Architectural Engineering and Technology, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on '3D Cadastres'. He is co-editor of the International Standard for the Land Administration Domain, ISO 19152.

CONTACTS

Rohit Ramlakhan
Delft University of Technology,
Faculty of Architecture and the Built Environment
Vogelenzanglaan 53
2548 SX The Hague
THE NETHERLANDS
E-mail: R.J.K.Ramlakhan@student.tudelft.nl

Eftychia Kalogianni
Delft University of Technology, Section Digital Technologies
Faculty of Architecture and the Built Environment
10 Monis Petraki,
11521 Athens
GREECE
E-mail: E.Kalogianni@tudelft.nl

Peter van Oosterom
Professor, Delft University of Technology, Section Digital Technologies
Faculty of Architecture and the Built Environment
P.O. Box 5030
2600 GA Delft
THE NETHERLANDS
E-mail: P.J.M.vanOosterom@tudelft.nl
Website: http://www.gdmc.nl