A LADM-based 3D Underground Utility Data Model: A Case Study of Singapore

Jingya YAN, Kean Huat SOON and Siow Wei JAW, Singapore, Gerhard SCHROTTER, Switzerland

Key words: Underground utility, 3D data model, Land Administration Domain Model (LADM)

SUMMARY

Over the years, in order to meet the many and growing needs of urban development, a lot of underground spaces have been used for the public infrastructures, such as utility lines, rail lines and roads. Complex underground infrastructure and inaccurate underground information complicate the development of underground space, the ownership of underground objects is not clear for example; the interdependency of above ground and underground has not presented directly, another example. Having said that, some countries and institutions have implemented or at least conceptualized the 3D mapping of underground utility network and their management in relation to the cadastral system. The City of Zurich for instance has its own utility cadastre platform since 1999 and has set up a governance framework with the corresponding utility providers. Québec and Rotterdam begin to register underground objects for land administration as well.

A reliable 3D digital map of utility networks is crucial for urban planners to understand the impactful aspects of the underground space. In order to provide the accurate information of underground utility, Singapore Land Authority (SLA) and the Singapore-ETH Centre started the Digital Underground project to developing a roadmap for a reliable map of subsurface utilities in Singapore since 2017. Through an in-depth studying and analysis about the current states of underground utility in the world and the requirement of Singapore, together with hands-on case studies using well-known data capturing technology (i.e. Ground Penetrating Radar) and research on the 3D modelling of subsurface utilities. It can be observed that the various pieces of information that would constitute the data model exist in the data management systems of different stakeholders in Singapore. Utility networks information is managed by utility owners, land administration information is managed by Singapore Land Authority (SLA). While survey and quality metadata are currently not managed and consistently provided by utility owners.

Therefore, this work focuses on the design of 3D underground utility data model and how the data model is connected to land administration based on Land Administration Domain Model (LADM). This case study attempts to explore methods for the integration of newly collected 3D data using underground mapping technology, existing planning 2D utility data and 2D cadastre data. Based on this is a primary study of underground utility in land administration, the data model can be evaluated and improved to establish a national mapping of underground utilities in Singapore.

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1. INTRODUCTION

A digital twin can be defined as a realistic representation of something physical. To improve decision making, a reliable digital twin of the underground is required. Utilities represent a significant portion of physical assets that exists in the underground. Most of these utilities are situated in the relatively shallow layers of the underground, up to a few meters below the surface. The lack of utility information reliability and quality is a global issue.

In Singapore, the government owns a large portion of land. State land is actively managed by the various land development agencies of Singapore. The administration of state land comprises a range of processes to administer, including land ownership and conflict management, taxation, land acquisition, land lease, land use planning, land development, and land sales. In 2015, an important legislative changes clarify that surface land owners own the underground space up to 30 meters under the Singapore Height Datum. Additionally, the Land Acquisition Act has been amended to allow for the acquisition of a specific stratum of space, in order to facilitate the development of public projects. In order to understand the accurate demands of underground utility data users, a workshop was organized to learn the work process and needs of land administration in Singapore. This study includes four application domains, (i) land acquisition and purchase, (ii) planning and coordination, (iii) land transfer and sale, and (iv) land leasing. Before the return of land to the Singapore Land Authority (SLA), the owner needs to declare everything beneath the ground including utility services. The existing setup within the underground will affect future developer's design and impact on developing costs directly. Currently, most of the existing data sources are hardcopy of the utility network, 2D CAD and 2D geospatial information. There is an urgent demand of 3D geospatial information of underground utility and space to evaluate underground environment and support reallocation, land sales and the other applications. Hence, it is necessary to register the utility segments as the legal objects in the land administration system, which helps to identify the ownership of underground utility. Moreover, land parcel, as an important role in the land administration, should be connected to the underground utility (Döner et al., 2011; Pouliot & Girard, 2016).

A reliable 3D digital map of utility networks is crucial for urban planners to understand the impactful aspects of the underground space. This paper introduces the design of a 3D utility data model for land administration, which aims to bridge the gap between underground utility surveying and data management for land administration. It includes three main tasks:

• The conceptual design of LADM-based 3D underground utility data model. In order to connect 3D modelling of underground utility to land administration, some of the attributes and values of this data model are inherited from the Singapore cadastral data

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model (Soon, Tan, & Khoo, 2016) and LADM (ISO 19152) (Van Oosterom, Lemmen Christiaan, & Uitermark Harry, 2012). The LADM is a link to build a relationship between the geometric information of utility network and land administration management. Meanwhile, the geometric and spatial definitions are inherited from the spatial schema data model.

- Based on the 3D underground utility data model, a consolidated underground utility database will be developed. In this database, the underground utility data will be integrated with cadastral data. The underground utility data includes two parts: one is the existing data in the database of the government agency, which is as-build data in 2D form; the other is the newly collected data by Ground Penetrating Radar.
- A study case will be developed to query the land administration information with underground utility.

Section 2 reviews the related works include two parts: one is the existing work about underground utility in land administration in the world and general review of LADM; the other is the land administration in Singapore. Section 3 introduces the design of 3D underground utility data model for land administration. Section 4 introduces the study case, which includes the data capture by mobile based ground penetrating radar platform in Singapore and visualize the land administration information of underground utilities. At last, we conclude with a summary and an outlook on future work.

2. RELATED WORKS

2.1 Underground utility in land administration

Good standards, guidelines and practices for subsurface utility mapping are key enablers for ensuring data quality. In certain countries, standards have been introduced to formalize and standardize practices of and surrounding mapping newly built and existing buried subsurface utilities. The Department of Geomatics and Surveying of the City of Zürich (GeoZ) is responsible for surveying in the city of Zurich. The department commits to making official surveying data available as a basis for all Geo Information Systems (GIS) of the City of Zurich and as part of the Land Registry. GeoZ maintains the Leitungskataster, a consolidated map of underground utilities in the city of Zürich. Data from different utility agencies is collected by the City of Zurich in the Leitungskataster ("Utility Cadastre", LK). The LK is established using a data warehouse approach where data is collected at least once every week from all connected agencies. Although a standard for information representation is available, not every agency has (yet) opted to implement that standard. However, the data model format for data deliveries by each agency is known and agreed upon, and its definition is used to perform a basic validation by the integrating party before integration into the LK. In addition, the United Kingdom begins to the registry of underground utilities and creates a national underground assets mapping platform in 2018. Most of current standards are closely associated with the concept of subsurface utility engineering, used at the design stage of large projects to collect accurate information on subsurface utilities to mitigate risk and reduce costs.

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As an international standard, the LADM provides a flexible conceptual schema from three main aspects: organizations, rights and spatial in formations. In LADM, there is a well-developed set of classes to assist the modelling of both spatial and non-spatial sources. The integration of 2D and 3D information in the LADM can provide solutions for 3D Cadastre. LADM uses two classes (*LA_LegalSpaceUtilityNetwork* and *ExPhysicalUtilityNetwork*) to describe utility networks (Figure 1). They are simply defined the type, status and direction of utility networks and inherited from *LA_SpatialUnit*. These are not enough to describe the structure and geometric information of utility networks and support for land administration. The Netherlands developed a country profile based on LADM. In the utility network part, it is only simply customizing the LADM. Serbia extends its LADM based country profile to include utility information for utility network cadastre (Radulović, Sladić, Govedarica, Ristić, & Jovanović, 2019). Based on this data model, they develop a system to register and maintain the ownership of underground utility network. The data model describes the 3D geometric information of utility network. But they have not considered the newly collected data.



Figure 1 SpatialUnit in LADM (Van Oosterom et al., 2012)

2.2 Land administration in Singapore

Based on LADM, a Singapore-based LADM model has been developed for local use since 2014. The data model is used to manage cadastral data of land parcels, cadastral survey data and land administration data. The Singapore profile inherits LADM objects, attributes and relationships wherever relevant, and implement new items wherever necessary (Figure 2 left). The SG_SpatialUnit is contained within a SG_SurveyDistrict. The SG_Lot is inherited from LA_SpatialUnit to describe cadastral information of land parcel (Figure 2 right). The SG_Lot is associated with a multiplicity of BoundaryFaceString's (lines), if it is a 2D geometry. If it

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is a 3D lot, it is associated with a number of *BoundaryFaces*, which are just the 3D faces of a volumetric geometry. Currently, this data model has not considered the land administration of utility networks.



Figure 2 Singapore LADM overview (left) and the main extended class (right)

In Singapore, reliable information on subsurface utilities has clear benefits all throughout the life cycle of state land, resulting in efficient decision-making processes, cost savings, and additional revenues for land administration professionals. Conversely, the lack of a reliable map of subsurface utilities can lead to ill-informed decisions, costly information gathering, and missed business potential. Based on the assumption that a single lot of state land eventually passes through several stages described in Table 1, capturing reliable information of underground utilities is expected to provide a substantial return on investment, as many processes will benefit from it over time. The changes in underground ownership legislation introduced in 2015 necessitate an accurate record of the alignment of subsurface utilities in order for SLA to mitigate any underground space conflicts. Furthermore, the cadastral data model is still in 2D and the underground space has not been considered in the existing work.

To complement this, the 3D underground utility data model is developed to integrate underground objects with attributes from the cadastral data model.

Table I State faild file cycle	
Life cycle phase	Value of reliable information on subsurface utilities
Land acquisition and	Land valuation. Assessment of encumbrances present
purchase	underground that affect land value and may require land
	rejuvenation efforts.
Land rejuvenation	Assessment and location of underground encumbrances to be
	removed.
Planning & coordination	Development and evaluation of plans for underground
	development.
Interim land use	Assessment of feasibility of underground utilities to facilitate
	interim land use plans.
Land transfer and sales	Provision of correct and complete information on land for sale,
	including existing underground utilities.

 Table 1 State land life cycle

3. 3D UNDERGROUND UTILITY DATA MODEL

Our previous work presents the conceptual design of 3D underground utility data model (Yan et al, 2018), which includes geometric information of utilities, data accurate management and land administration of underground utilities. Based on the multilevel structure of utility network that is defined in our previous work (Jingya Yan, Jaw, Soon, Wieser, & Schrotter, 2019), the utility network package should describe the geometric and spatial information of utility networks. Figure 3 shows the logical design of utility network package.

The class *Utility Network* describes the attributes of the whole network at the top level, includes installation date and the type of utility network (e.g. water and gas). The class *Utility Network Node*, *Utility Network Segment* and *Utility Network Surface* are components of utility network. The class *Utility Network Node* and *Utility Network Segment* describe 2D geometric information and the other attributes of line segments and connect nodes of utility network. If the data has 3D information, the nodes and line segments are connected to the class *Utility Network Surface*. The class *Utility Network Surface* aims to describe the 3D objects of utility network, such as duct and manhole.

According to the observation of current work process and legislation of land administration in Singapore, it is clear to find the relationship of underground utilities and surface is very import in the land administration. Hence, one of the main functions of class $LA_UtilityNetworks$ is to connect LADM and utility networks (Figure 4). The LADM is an important legal framework to define and integrate concepts and terminology of Land Administration for 3D representations. In the 3D underground utility data model, the class $LA_UtilityNetworks$ connects to Utility Networks package. Meanwhile, this class connects to Singapore cadastral data model to get related land administrative information. The main objective of this class is to connect cadastral parcels and utilities through spatial relationships,

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such as contain, cross and touch. This class could support ownership management of utilities and land administrative management.



Figure 3 The logical data model of utility networks

Additionally, a series of code values are defined in the data model (Figure 5). The utility network types and material types are used in the UtilityNetwork class at top level, includes water, electricity, gas and so on. The utility connection types, utility segment types and utility surface types are used in each utility object class to describe their types. The spatial relationships are used to describe the relationship between utility objects and cadastral land parcels. The utility survey methods, which are used to identify the data source of new collected data, survey status and ground conditions are used in the UtilitySurvey package to manage the data quality. As the UtilitySurvey package is still in the conceptual design, the details have not been presented in this paper.

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Figure 4 The connection of utility networks and land administration.



Figure 5 Code values of data model

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4. THE CASE STUDY IN SINGAPORE

4.1 Study area and data source

The newly collected data is captured by the Pegasus: Stream, a mobile mapping platform. This mobile mapping platform is first time deployed in Singapore, as well as in South East Asia. This mobile mapping platform combines a Stream EM GPR and Leica Pegasus Two photo and laser scanner. The Pegasus: Stream allows the capturing of large volume underground data and imagery and point clouds of the above ground features. All the data captured by the Pegasus: Stream is geo-referenced using a combination of on-board sensors which include a GNSS receiver, an Inertial Measurement Unit (IMU), and a Distance Measurement Instrument (DMI). The Stream EM GPR uses impulse radar GPR technology. It features a large number of ground-coupled antennae, with dual frequencies (200 MHz and 600MHz). Its 40 separate antennae transmit and receive in two distinct polarizations (HH and VV), allowing it to cover wide road surfaces and to provide optimum detection for main and junction pipes at the same time. With such unique design and high numbers of antenna on board, it is expected to increase data quality and reliability of pipe detection. All acquired data were pre-processed to enhance the quality of the radargram before further interpretation. The data was exported to CAD and GIS format for further 3D modelling and visualization (Figure 8 left).

Three groups of datasets have been used in this case study:

- The existing 2D utility data from GeoSpace (Singapore NSDI) includes water supply, sewerage, drainage, telecommunication and power grid networks.
- The 2D cadastre data from SLA. Figure 6 shows the existing utility and cadastral data in Toa Payoh. The lines and points are the underground utility objects of planning data. The light pink areas are land parcels of cadastre data.
- The newly collected data using a mobile mapping platform that combines laser, photogrammetry and ground penetrating radar technology that map above and underground environments simultaneously. The data were post-processed in order to obtain digital 3D models of both the above ground environment and underground utilities in different format. After data processing, the GPR data needs to export to CAD format (Figure 7 left). Then, the data is converted to GIS format (Figure 7 right) with x, y, z value as points and lines for 3D data modelling and visualization.

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Figure 6 The existing utility and cadaster data of Toa Payoh (Data source: Singapore Land Authority)



Figure 7 GPR data of Toa Payoh from CAD (left) to GIS (right) format.

4.2 Implementation

The data model is designed by Enterprise Architect 14 using Unified Modelling Language (UML). The utility database is developed based on ArcGIS pro 2.1. Hence, the UML data model is exported as XML document and imported to ArcGIS as File Geodatabase. This work has two steps to integrate the existing utility data and newly collected data.

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First, in order to improve the attributes of newly collected data, this experiment needs to identify newly collected data from the existing utility database, which is based on spatial matching of the extracted features with other data. In order to match features, an operator overlaid the extracted features with the other data. Based on measures of spatial similarity (overlap, proximity, and visual similarity), the operator decided whether features could be positively matched. But the 2D GIS data of existing utilities imposed the following limitations: i) the lack of elevation only allows for horizontal comparison, i.e. comparison of x and y coordinates. In cases of horizontally overlapping utilities, this complicated matching and identification; ii) Identification is to take place based on horizontal overlap and proximity only. However, in many cases, the existing data did not match well with the utilities identified during data capture. This is likely due to a lack of accuracy. Additionally, it was observed that the above ground colourized point cloud data is not sufficiently detailed or suitable to confirm manhole locations, let alone identify the type of utility that is located underneath. Roughly, about 26% of the newly collected data can be identified from the existing utility database. After identification of the required information, the newly collected data is modelled in 3D. Second, the newly collected data should be loaded into the new underground utility database. The points and line segments of GPR data are stored in the feature layers UtilityNetworkNode and UtilityNetworkSegment. The 3D data is stored in the UtilityNetworkSurface. According to the pilot database, the information of underground utilities with land administration can be queried and shown in a tree hierarchy in the Figure 8. All the land parcels, which contain underground utilities in the same vertical space, are listed in the Land Parcel of the tree. All of related utility segments are shown in the tree as children nodes of land parcel. When we click the number of objects, the details of each object are shown in the right window. After 3D modelling, Figure 9 shows an example of 3D visualisation of underground utilities and land parcels with land administration information. Obviously, the 3D data and visualisation help to provide more reliable underground information for land administration.



Figure 8 Examples of land administration information querying. Land administration information of land parcel (left) and details of utilities (right)

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Figure 9 An example of 3D visulisation of utilities and land parcels.

5. CONCLUSION

This work aims to develop a study case to organise 3D underground utility data for land administration. As we know, lack of accurate and reliable underground information is a significant issue to develop digital twins city for urban planning, land administration and the other applications. Most of the existing works focus on general 3D geometric description of underground utility network. Based on the urgent needs of Singapore land administration, this work designed a logical model to integrated newly collected (mobile GPR) 3D underground utility data and the 2D cadastre data for land administration. A demo of consolidated database is developed based on the schema of ArcGIS pro. Because of the limitation of current data information, we need to integrate new collected data and the existing planning utility data to improve the information (e.g. material and diameter of pipeline). This case study presents the connection between underground utility and land administration based on a 3D underground utility data model. When we check the land administrative information of each land parcel, the related underground utilities can be displayed that are located at same vertical space of land parcel.

This case can be concluded that a combination of GPR and cadastral data is only a primary attempt. It is not sufficient to improve the accuracy of information on existing underground utilities. For the next step, resources are not only required to build a comprehensive 3D underground utility database, but also to develop a feasible approach to integrate existing and newly collected data. Moreover, the 3D underground utility data model connects underground utilities to cadastral parcel, which could help to identify the ownership of underground utility in land administration. However, the cadastral data is in 2D, which may not be accurate to

identify the spatial relationship of underground utilities and land parcel in vertical space. In the future, we will collaborate with selected agencies to evaluate and improve the 3D utility data model. Their recommendations could help to extend data model include other underground infrastructures and develop the platform of underground space management to support various applications in Singapore.

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BIOGRAPHICAL NOTES

Jingya YAN is a postdoctoral researcher in the Singapore-ETH Centre, which was established in 2010 by ETH Zurich - The Swiss Federal Institute of Technology and Singapore's National Research Foundation (NRF), as part of the NRF's CREATE campus. She obtained an MSc in Geomatics in 2011 from The Hong Kong Polytechnic University. And she received her Ph.D in Geomatics from Naval Academy Research Institute (IRENav) of France in 2014. Her work focuses on 3D underground utility data modelling and data management in Digital Underground project. Her research interests are 3D geospatial data modelling, ontology engineering, cartography, and computer science.

Kean Huat SOON is Senior Principal Surveyor at the Survey and Geomatics Division of Singapore Land Authority. He is involved in the development of the new cadastral system in the Division to support automated cadastral processing using SG LandXML. He also takes part in the 3D National Mapping project, which is primarily based on CityGML schema. He earned a Msc in Geography from the Pennsylvania State University, a Msc in Geoinformatics and Bachelor of Surveying (Land) from University of Technology Malaysia. His research interests include semantic interoperability, data modeling, cadastral information system and ontology.

Siow Wei JAW is currently a postdoctoral fellow in Singapore-ETH Centre. She is working on the Digital Underground Project, focusing on the development of use cases to understand the best practices and possibilities and limitations of current available tools and technology used for underground utility mapping. After graduation, she started her first job as the research fellow in Geoscience and Digital Earth Centre (INSTeG), under Research Institute for Sustainable Environment and a senior lecturer in Department of Geoinformation in Faculty of Built Environment and Surveying (FABU), Universiti Teknologi Malaysia. Her niche of expertise encompasses remote sensing and geoinformation for applied and environmental sciences related research and development and innovation, focusing on underground utility mapping.

Gerhard SCHROTTER is CEO of the Geomatics Department of the City of Zurich. He received his Ph.D. from Swiss Federal Institute of Technology (ETH, Switzerland), Master and Bachelor of Engineering degree from Technical University of Graz (Austria), and a MAS in public management from the School of Management and Law in Zurich. He worked as project manager at the Urban Planning Office of the City of Zurich, as international project manager at a private GIS company, as a strategic consultant for an outdoor advertisement company, and as a project leader to develop a digital aerial camera. Currently he is involved in the development and introduction of various strategies for the City of Zurich and introducing research projects to public administration.

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CONTACTS

Jingya YAN ETH Zurich, Singapore-ETH Centre 1 Create Way CREATE Tower, #06-01 Singapore 138602 Phone: + 65 88583573 E-mail: Jingya.yan@arch.ethz.ch Website: https://fcl.ethz.ch/people/Researchers/YanJingYa.html

Kean Huat SOON Singapore Land Authority 55 Newton Rd Singapore 307987 Phone: +65 64783537 E-mail: <u>SOON_Kean_Huat@sla.gov.sg</u> Website: http://www.sla.gov.sg/

Siow Wei JAW ETH Zurich, Singapore-ETH Centre 1 Create Way, CREATE Tower, #06-01 Singapore 138602 Phone: +65 83633023 E-mail: jaw@arch.ethz.ch Website: https://fcl.ethz.ch/people/Researchers/JawSiowWei.html

Gerhard SCHROTTER Geomatik + Vermessung Stadt Zurich Weberstrasse 5 8004 Zürich Phone: +79 1026096 E-mail: <u>Gerhard.Schrotter@zuerich.ch</u> Website: <u>https://www.stadt-zuerich.ch/geoz</u>

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