Development of an LADM-based Conceptual Data Model for 3D Underground Land Administration in Victoria

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Overview

Introduction

Methodology

Requirements

The developed LADM-based data model

Discussion and future works
Introduction: underground space and its value

- Development and utilisation of urban underground space one of the top 10 fronts in engineering development in civil, hydraulic and architecture
- 740,000 km of underground assets in Australia, worth more than $340 billion

- Applications
  - Tunnels
  - Underground parking lots
  - Underground shopping malls
  - Public walkway
  - Subsurface utility networks
  - Underground cities
  - …
Introduction: underground land administration

• 3D digital data plays an underpinning role in managing underground spaces

• Data from land administration perspective:
  ✓ Physical data
  ✓ Legal data

Spatial and semantic information of physical structures
Ownership information and the extent of legal spaces

(Park et al. 2010)
Underground land administration solutions differ among jurisdictions, but they rely on the 2D parcel.
Problems of 2D models - Victoria

- There is ambiguity in the visualization and interpretation of Rights, Restrictions, and Responsibilities (RRRs) of underground assets in 2D models.

Introduction: current practices

- The depths of underground objects are not specified.
- Physical objects (cables, pipelines, tunnels) are not registered.
- The assets are not defined as entities in cadastral maps and it is not possible to query on them.
- For every parcel crossed by a pipeline, a reference is made to the same subject (holder of the pipeline), which makes redundancy.
An LADM-based conceptual 3D data model is developed to integrate physical and legal data of different underground assets based on the requirements in Victoria.
Methodology

Step 1: Foundation
- Literature Review

- Explicate Research Problem:
  Current data models focus on the physical or legal aspects of underground space in Victoria and are mostly based on 2D approaches, leading to ineffective underground land administration in terms of addressing critical data management and communication issues related to legal and physical aspects.

Step 2: Elicit Requirements
- Underground legal objects
- Underground physical objects

- Investigation of current practices
- Literature review
- Participant observation method

Step 3: Design and Develop Artefact
- Develop an LADM-based 3D conceptual data model

LADM conceptual data model
Requirements

- Underground legal objects
  - Primary underground parcels
  - Secondary underground interests
  - Underground legal boundaries

- Underground physical objects
  - Physical objects required to define legal spaces
  - Physical objects which are demands required from an integrated 3D underground data model for different use cases
Requirements - primary underground parcels

- Base-level parcels for forming the continuous cadastral fabric
- There is no overlap and gaps between primary parcels
- Single, part, multipart parcels
- 2D cross-sectional diagrams and upper and lower limits of parcels are used to represent underground lots in 3D
- In 3D, the spatial extent of these parcels should be a closed volume (volumetric legal spaces)
- Underground lot, stage lot, crown, common property, and reserve
Requirements - primary underground parcels

- Some examples
Requirements - secondary underground parcels

- Provide benefits and/or pose restrictions on primary parcels
- These legal interests can overlap any primary parcels or other secondary parcels
- These legal objects have relationships with at least one primary parcel for which the benefits are provided
  (semantic relationships)
- Each secondary underground interest needs to be fixed to a primary parcel (spatial relationships)
- In 3D, the spatial extent of these parcels should be a closed volume (volumetric legal spaces)
- Underground easement, depth limitation, and restriction
Requirements - secondary underground parcels

- Some examples
Requirements - underground legal boundaries

- By investigating the current underground subdivision practices, this research has developed a new taxonomy of legal boundaries defined in underground environments.
Requirements - underground legal boundaries

- Some examples
Requirements - underground physical objects

- Two types of physical information
  - Physical objects required to define legal spaces (e.g. building boundaries)
  - Physical objects which are demands required from an integrated 3D underground data model for different use cases beyond land registration such as planning, design and construction of underground assets, excavation, and utility management
Requirements - use case of a 3D integrated model: West Gate Tunnel – Melbourne

- Issues of current practice: fragmented data, different data sources, several sheets, and no connection between legal and physical assets to have spatial queries (e.g. finding all parcels through which a planned tunnel will pass)

- Benefits of a fully integrated 3D model: close to reality, better interpretation, solving ambiguities of 2D models such as objects’ forms and depths, managing both physical and legal data of all underground objects in an integrated environment via a single model, minimise impacts on third party property and infrastructures, and enabling data query and analysis
### Requirements - underground physical objects

<table>
<thead>
<tr>
<th>Use case</th>
<th>ULA function</th>
<th>Example of underground asset</th>
<th>Physical Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Registration (Cadastre)</td>
<td>Land tenure</td>
<td>All underground assets: Private (lots, storage tanks, etc.) and Crown (tunnels, subways, train stations, etc.)</td>
<td>Physical objects that define the spatial arrangements of legal objects (walls, doors, columns, ceilings and floors)</td>
</tr>
<tr>
<td>Excavation and Utility Management</td>
<td>Land use Land development</td>
<td>Utilities: Water, drainage, sewerage, telecommunications, electricity (generation, transmission and distribution), gas (transmission and distribution), petrochemical (e.g. oil, petrol and LPG), etc.</td>
<td>Utility type, position (x, y and z-coordinate), the accuracy of the position, size (cable tubes, pits, utility strips), radius, length and number of pipes /cables, date of installation (Bitenc, Dahlberg et al. 2008, Zlatanova and Gorte 2017) Protective areas of utilities, a ‘buffer’ around the utility (Döner, Thompson et al. 2010)</td>
</tr>
<tr>
<td>Planning, design and construction of large-scale building projects</td>
<td>Land tenure Land use Land development</td>
<td>Tunnels: Rail, highways, tram, etc. Buildings: Subways, train stations, private buildings, etc.</td>
<td>The outer surface of physical structures Tunnel protection; Buffer zones to keep the force equilibrium (Peng, Qiao et al. 2021)</td>
</tr>
<tr>
<td>Smart Cities, Digital twins</td>
<td>Land tenure Land value Land use Land development</td>
<td>All underground assets</td>
<td>Physical data integration Data quality and consistency The surface of the lands (ground/site level) / topography</td>
</tr>
</tbody>
</table>
The developed LADM-based data model

Step 1
Extending LADM to support underground legal objects in Victoria

Step 2
Developing external classes to support ULA physical objects

Step 3
The relationship between physical and legal objects
The general data model for underground land administration in Victoria
The UML class diagram of LADM

- Legal spaces are defined based on the asset types
Extending LADM to support ULA legal objects in Victoria

"VIC_" is the prefix for the Victoria country profile
- LADM uses external classes defined as `<<blueprint>>` to model physical objects
- There are only two classes for utilities and buildings: `ExtPhysicalUtilityNetwork` and `ExtPhysicalBuildingUnit`.
- They are not adequate to model all underground physical assets
Relationship between legal and physical objects
Discussion and future works

- Relationship between physical and legal objects:
  - Legal spaces are parcel-based
  - Physical objects such as a long tunnel or pipeline are defined as a single object
  - Physical objects can pass through several parcels
  - It is possible to divide a tunnel or pipeline by parcels; however, in reality, it is mostly defined as one object
  - Assigning unique identities (IDs) to physical objects and specifying them as attributes of legal spaces can help link a single physical asset to all its legal spaces.
  - What about a legal space with several physical counterparts such as multi-purpose easements?
  - What about other relationships (n-m)?
Discussions and future works

- Underground vertical boundaries only include distance (vertical distance); challenging when a vertical boundary is not straight (oblique boundary such as underground parking ramp)

- How is the ground surface defined? Some legal boundaries are defined by the ground surface

- Real-world case studies and prototyping of the proposed data model

- Evaluation of the proposed 3D data model by key stakeholders in underground land and asset management and 3D data modelling experts

- Finally, this paper did not investigate survey, administrative and party elements. They can be considered in the data model.
Thank you...

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Question?!
Suggestion?!