A 3D data modeling approach for integrated management of below and above ground utility network features

Xander den Duijn

1\textsuperscript{st} mentor: Sisi Zlatanova
2\textsuperscript{nd} mentor: Wilko Quak
Co-reader: Alexander Wandl

Mentor Gemeente Rotterdam: Edo Roldan Sanchez
Content

1. Title explanation
2. Problem statement and motivation
3. Research question and scope
4. Background
   - Utility networks
   - Existing data models
5. The data modeling approach
   - Data
   - Preprocessing
   - Utility network data modeling
   - Derivation of a relational database
   - Inserting the data
6. Testing and validation
7. Conclusion
8. Future work
A 3D data modeling approach for integrated management of below ground utility network features and related above ground city objects
A 3D data modeling approach for integrated management of below ground utility network features and related above ground city objects

A way of handling/storing three-dimensional data
A 3D data modeling approach for integrated management of below ground utility network features and related above ground city objects.

Management of different data in a (cooperative) system/environment

**Asset management**

[as-et man-ij-muh nt]

noun

1. An integrated framework for the maintenance of the assets, above and below ground, in public space. In order to spend the maintenance budget as wisely as possible and better decision making an optimum balance is needed between costs, performance and risk.
A 3D data modeling approach for integrated management of **below ground utility network features** and related **above ground city objects**

- Any components that are part of the below ground utility network e.g. a pipe or cable.
- City objects that are visible above ground and have a relationship or dependency with the below ground utility network e.g. a streetlight
Problem statement and motivation

Substantial work has already been done in the modelling and representation of above ground features in the context of 3D city modelling

**BUT** the below ground part of the real world, of which utility networks form a big part, is often neglected in 3D city models

At the same time…

Several utility network data models exist.

**BUT** these are commonly tailored to a specific domain

A comprehensive 3D standard data model which provides a common basis for the integration of the different utility networks and 3D city objects in order to facilitate analyses, visualization and management tasks, lacks.
Research question and Scope

How to efficiently model below ground utility networks and related above ground 3D city objects in order to facilitate integrated asset management?

Sub-research questions:

- What dependencies and relations between below and above ground utility network features are of importance for the municipality of Rotterdam in order to facilitate asset management?
- To what extent can the current state of an existing utility network data model such as the CityGML Utility Network ADE fulfil the needs of the municipality of Rotterdam?
- Is the proposed data modeling approach suitable for implementation of existing utility network data and city objects in 3D city models?
- Which mapping methods are required to derive a relational database from the designed data model?
- Can the designed relational database be used to perform essential (spatial) operations?
- How to visualize the modeled data and (spatial) operations on the designed relational database?

Scope:

- Two different types of utility networks and related city objects
- Only actual physical relationship (nothing like proximity)
- Representation in a low LoD
- Other types of data, e.g. financial data, will not be considered
Background: Electricity network

Most above ground city objects relate to the Low-Voltage Grid, e.g. streetlights
Background: Sewer network

In a standard sewer system, water is transported from higher to lower elevation due gravity.

Manholes are mainly used for inspection and put at points of intersection or change of direction/material.
Background: Existing utility network data models

Why the CityGML Utility Network ADE?

The CityGML Utility Network ADE is capable of:

- Relating utility network features as well as utility network features and above ground city objects
- Modeling relationships and dependencies between network features of different types of networks
- Embedding into 3D urban space (since it is part of the matured CityGML standard)
CityGML Utility Network ADE

- Currently consisting of:
  - the Core module
  - 5 additional modules to add more detail
    - Feature Material
    - Functional Characteristics
    - Hollow Space
    - Network Components
    - Network Properties
- This data model is continuously under development!

Figure 4.7: Utility Network ADE topology principle
Conceptual design
What are we working with?

- Lines representing a pipe or cable
  Depending on the use, different types of utility networks are measured differently. For example, the inner bottom of standard sewer pipes is measured. For other types mostly the outer top is measured.

- Points representing the location of a city object, e.g. a streetlight
  Often these are in 2D

Both lines and points are in ESRI Shapefile format!

- A 3D model of the city of Rotterdam
  The 3D model includes buildings, trees, ground level, design and building information. Pipes and cables are modeled as generic city objects.

The 3D model is in CityGML format
Preprocessing

Problem

The connection line to streetlights is not registered
→ it is unknown how the streetlights are connected to the below
ground electricity lines.

Solution

An algorithm that computes a best estimate of what streetlights are
connected to what streetlights and what streetlights are connected
to what electricity line
Utility network data mapping

Electricity network

"the end point of the electricity network"
Utility network data modelling

Electricity network

Topography

Graph

Node
InterFeatureLink
InteriorFeatureLink

Above ground
Below ground

FeatureGraph of TerminalElement
FeatureGraph of Cable
FeatureGraph of Cable
FeatureGraph of Cable
Utility network data modelling

Sewer network

“A manhole is a vertical pipe, usually made of concrete, that connects the below ground sewer network to the surface”

“a manhole is a point of connection”

These are manholes! →
Utility network data modeling

Sewer network

Topography

Graph
Linking below and above ground utility network features

A directional one-to-one relationship!
This is completely done in FME!

- This is a complex translation (over a 100 transformers are used and lots of relationships)
- The workspace is particularly designed for the Rotterdam data in vector file format
- Building the topology is an important step. Its success relies on the type and quality of the input data

→ a .gml file is output

And can be visualized in the FZKViewer or the FME Data Inspector

BUT the support and possibilities are limited
Derivation of the relational database

Why?
- CityGML datasets may become very large and objects may be arbitrarily nested leading to complex data structures
- Efficient storage and management of CityGML data requires carefully optimized database schemas
- To ensure interoperable data access and detailed (network) operations

How?
- Mapping the CityGML Core
- Extend the database by mapping the CityGML Utility Network ADE

All by means of 3DCityDB!

3DCityDB can be used to store, represent, and manage virtual 3D city models in a relational database that implements the CityGML standard.
Derivation of the relational database

Mapping the relevant classes of the CityGML Core \(\rightarrow\) 5 tables

What kind of cityobject
Derivation of the relational database

Mapping the relevant classes of the CityGML Utility Network ADE → 5 more tables!

Generally, most abstract classes are mapped to a single table with an additional field used to specify the object class. Additional tables had to be created for establishing the one-to-many, many-to-one or many-to-many relationships.
Importing the CityGML data

- Importing the data is a task that must be handled with care.
- Parallel importing of all feature types into the tables in a single workspace might cause an error due to referencing to not existing id's.

*Depending on the utility network type, the features differ slightly.
Importing the CityGML data

• The inserting of the CityGML Utility Network ADE data is done in FME (again)

• A command line batch file is created that runs the different workspaces, used to populate the different tables with the CityGML data, after each other

And connecting to a GIS e.g. ArcGIS
Testing and Validation; querying the database

SQL scripts are written in order to conduct (network) analyses on the spatial data in the relational database.

Scenario: What streetlights are affected in case of a utility strike?
1. Knowing the location, what geometries are affected?
2. What FeatureGraphs and corresponding nodes are affected?
3. What nodes can (not) be reached? (PgRouting)
4. What city furniture objects (streetlights) are affected?

<table>
<thead>
<tr>
<th>id</th>
<th>classname</th>
<th>cityobject_id</th>
<th>lod1_other_geom</th>
</tr>
</thead>
<tbody>
<tr>
<td>142</td>
<td>TerminalElement</td>
<td>1560</td>
<td>01020000A040...</td>
</tr>
<tr>
<td>151</td>
<td>TerminalElement</td>
<td>1569</td>
<td>01020000A040...</td>
</tr>
<tr>
<td>159</td>
<td>TerminalElement</td>
<td>1577</td>
<td>01020000A040...</td>
</tr>
<tr>
<td>1037</td>
<td>Cable</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>1038</td>
<td>Cable</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>1039</td>
<td>Cable</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>1235</td>
<td>Cable</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>1291</td>
<td>Cable</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>1326</td>
<td>Cable</td>
<td>null</td>
<td>null</td>
</tr>
</tbody>
</table>

A tabular output is not so sexy.
Affected streetlights in ArcGIS
Conclusion

How to efficiently model below ground utility networks and related above ground 3D city objects in order to facilitate integrated asset management?

This research has shown the suitability of the CityGML Utility Network ADE by the implementation of two types of below ground utility networks (viz. Low-Voltage electricity and standard sewer)
And is successfully examined by implementing relationships between:
   1) the below ground electricity network and above ground streetlights and
   2) between the sewer network and the above ground manhole covers

The object-oriented CityGML model is successfully mapped to a relational database which has proven to be efficient for storing, management and analyses by means of the performed (network) operations.
Future work

- Implementation of more different utility networks and city objects
- Modeling in a higher Level of Detail (LoD)
- Detailing the CityGML Utility Network ADE classes and use
- Better investigating on more types of analyses
- Implementing larger datasets
- Implementing datasets with a different accuracy
- Exporting a CityGML file from the relational database
- Better investigating on visualization of the data
- Investigation on how to model different types of relationships
Stroomstoring Rotterdam-Noord na anderhalf uur voorbij

Door een grote stroomstoring in het gicleerkanaal gemeent in grote delen van Rotterdam-Noord. In onder meer Bergpoort, Blijlaga en het Oude Hoornse Laken 29.463 houders stroomloos voor een uur na stroomstoring. ’

Volop lekkages aan waterleidingen na storm

UPDATE: Volop lekkages aan waterleidingen na storm

Elke dag een nieuwe