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Utilities – Operations and Maintenance conceptual schema

Data Specification

Detailed description of utility data through a class model overview in UML, focused on the domain of operations and maintenance.

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				- Extra type values added for controller, storage, connection, measurement, terminal, other and complex components - 'MaintenanceProperties' reframed - 'ProtectiveShell' and its subclasses reframed - RelatedParty' and its data types reframed - Geometric primitives reframed - Extra type values added for electrical, solid, liquid and gaseous commodities - Class names and attribute names rephrased
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Foreword

This document contains the data specification belonging to the Operations and Maintenance conceptual schema. The conceptual schema covers the utility disciplines of electricity, oil, gas, chemicals, sewage, water, thermal and telecommunication. Aim of this data specification is to provide metadata, as well as a detailed description about the concepts and relations captured in the conceptual schema.

The data specification forms together with two other documents the complete documentation of the Operations and Maintenance conceptual schema. The other documents are:

[1.] Operations and Maintenance – Feature Catalogue version 2.1
  - OM_Feature_Catalogue.pdf

[2.] Operations and Maintenance – Overview of class models in UML version 4.1
  - OM_UML_Overview.pdf

Of the three, this data specification is the main document. However, to fully comprehend and understand the conceptual schema, the data specification should be used alongside the 'Operations and Maintenance – Feature Catalogue'. The feature catalogue clarifies each of the concepts and relations captured in the conceptual schema. If one only requires the sole class models, the 'Operations and Maintenance – Overview of class models in UML' document can be consulted. All documentation can be retrieved from the following online repository:

https://github.com/RamonTerHuurne/UtilityNetwork-OperationsAndMaintenance

The Operations and Maintenance conceptual schema is developed as part of the ReDUCE (Reduction of Damage to Utilities & Careful Excavation) programme, hosted by the University of Twente (Enschede, the Netherlands). In the context of the ReDUCE programme, the Operations and Maintenance conceptual schema not only covers reduction of damages to utilities and careful excavation, but also extends towards the domain of operations and maintenance. The Operations and Maintenance conceptual schema is developed with support of the developers of the internationally recognized CityGML UtilityNetwork ADE. As a result, the schema builds upon the CityGML UtilityNetwork ADE conceptual schema and adds those concepts and relations relevant for the domain of operations and maintenance.

The Operations and Maintenance conceptual schema explained and presented in this data specification is a prototype. The schema has not yet been fully implemented and evaluated within its application domain. Therefore, the conceptual schema is possibly subject to change.

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1 Introduction

A notable shift in the utility sector is the increasing attention to digital lifecycle management. In order to operate and maintain the utilities, organizations, such as utility owners, utility operators and contractors, require a comprehensive set of digital information. The shift to life cycle management ideally assumes that domain knowledge is captured in a uniform and consistent set of modelled concepts and relations. However, in practice this overview is missing whereas organizations, such as the aforementioned, describe utility concepts/objects using different (1) attributes, formats, relationships and (2) semantic terms. This hampers the system interoperability of utility data.

Within this data specification the Operations and Maintenance conceptual schema is presented and clarified. This conceptual schema provides an overview of those concepts and relations relevant for operations and maintenance of utilities. The concepts and relations included in the conceptual schema are, thereby, developed in close collaboration with the end-user of the utility data. End-users are, for example, the aforementioned organizations such as utility owners, utility operators and contractors. Use of the Operations and Maintenance conceptual schema allows consistent processing and exchange of operations and maintenance related utility data, thereby improving system interoperability between users of the schema.

The Operations and Maintenance conceptual schema builds upon CityGML UtilityNetwork ADE. CityGML UtilityNetwork ADE on its turn is an application domain extension (ADE) to the CityGML standard. CityGML is a language for the modelling and exchange of 3D city and landscape models. It defines the "classes and relations for most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical and appearance properties" (CityGML, 2017). As an extension to CityGML, CityGML UtilityNetwork ADE adds features and properties required for modelling of utility networks and accordingly energy simulations and storage of corresponding results. The UtilityNetwork ADE allows network hierarchies of arbitrary depth, nesting of network components and modelling of multi-model networks (CityGML, 2016).

However, the purpose of CityGML UtilityNetwork is not modelling operations and maintenance related domain knowledge of utilities. Consequently, CityGML UtilityNetwork ADE is not capable to capture this domain knowledge in a uniform and consistent set of modelled concepts and relations. Hence, the aforementioned missing overview in practice. Therefore, the Operations and Maintenance conceptual schema is developed. The Operations and Maintenance conceptual schema adds, compared to the UtilityNetwork ADE, those concepts and relations relevant for the domain of operations and maintenance of utilities.

The targeted use of the conceptual schema lies in asset management related applications, covering the domain of operations and maintenance of utilities. The Operations and Maintenance conceptual schema is applicable to the following utility disciplines: (1) electricity, (2) oil, (3) gas, (4) chemicals, (5) sewage, (6) water, (7) thermal and (8) telecommunication. The use of the data specification has no geographic boundary, but is based on utility networks of developed countries.

In addition to this data specification, an overview of UML (Unified Modelling Language) class models and a feature catalogue are provided in two separate documents. The former contains the class models of the modelled domain knowledge in the graphical modelling language UML. The latter contains definitions and descriptions of the terms and names applied to the concepts and relations captured within the UML class models. To this end, the complete documentation of the Operations and Maintenance conceptual schema consists of the following three documents:

[1.] Operations and Maintenance – Data Specification version 4.1
   - OM_Data_Specification.pdf

[2.] Operations and Maintenance – Overview of class models in UML version 4.1
   - OM_UML_Overview.pdf

[3.] Operations and Maintenance – Feature Catalogue version 2.1
   - OM_Feature_Catalogue.pdf

All documentation can be retrieved from the following online repository:

https://github.com/RamonTerHuurne/UtilityNetwork-OperationsAndMaintenance

This document is structured in seven chapters of which this being the first. Chapter 2 describes the scope of which this data specification is of interest to. Chapter 3 provides an overview of the document including an informal description of the data specification. This informal description briefly describes the conceptual schema's expressiveness and purpose. This chapter also includes normative references, a list of terms and definitions, and a list of abbreviations. Chapter 4 provides a brief summary and identification of the data specification in table layout. Chapter 5 explains the data specification by providing the UML class models and a detailed description for each of these class models. The chapter refers to the feature catalogue document for clarification of the applied terms and names in the UML class models. Chapter 6 describes the reference systems to be used with the Operations and Maintenance conceptual schema. The final chapter, chapter 7, includes information about the online repository of the conceptual schema.

2 Scope

Aim of this data specification is to provide users of utility information a description of the structure, content and quality of utility information modelled through the Operations and Maintenance conceptual schema. The use of the schema has no geographic boundary, but is based on utility networks of developed countries.

The data specification builds upon the CityGML UtilityNetwork ADE (CityGML, 2016). The concepts and relations as described in the CityGML UtilityNetwork ADE are inherited within this data specification and extended with the relevant concepts and relations for the domain of operations and maintenance. Therefore, this data specification does show many similarities with the CityGML UtilityNetwork ADE. However, the Operations and Maintenance conceptual schema can be applied as a stand-alone data model.

A list of the main features of Operations and Maintenance conceptual schema are:

- Geospatial data model for operations and maintenance on utilities
- Based on the CityGML UtilityNetwork ADE conceptual schema
- Representation of utilities in both 2D and 3D
- Representation of a subnetwork and superordinate network
- Representation of supply areas
- Representation of detailed utility objects, including:
  - Spatial attributes
  - Material attributes
  - Dimensional attributes
  - Shape attributes
  - Cost attributes
  - Performance attributes
  - Impact attributes
  - Use attributes
  - Surrounding soil attributes
  - Status attributes
- Integration of the utility domain with CityGML models:
  - Buildings (CityGML Building module)
  - City furniture (CityGML CityFurniture module)
  - Land use (CityGML LandUse module)
  - Vegetation (CityGML Vegetation module)
  - Water objects (CityGML WaterBody module)
  - Transportation (CityGML Transportation module)
  - Tunnels (CityGML Tunnel module)
  - Bridges (CityGML Bridge module)

3 Overview

3.1 Name

Utilities – Operations and Maintenance conceptual schema

3.2 Informal description

3.2.1 Definition

Utility network: A collection of network features belonging to a single transported commodity. Includes facilities for electricity, oil, gas, chemicals, sewage, water, thermal and telecommunication.

3.2.2 Utility networks

A utility network is a collection of network features belonging to a single transported commodity. This collection of network features exists of (1) distribution components facilitating transport of commodities such as pipes and cables, (2) protective network components such as ducts and (3) functional components facilitating roles such as measurement and storage.

The Operations and Maintenance data specification presents a conceptual schema for the exchange of information considering various utility disciplines. The utility disciplines covered are: (1) electricity, (2) oil, gas and chemicals, (3) sewage, (4) water, (5) thermal, and (6) telecommunication. The conceptual schema has a specific focus on utility information regarding the domain of operations and maintenance. Aim of the Operations and Maintenance conceptual schema is, therefore, to model the domain knowledge regarding operations and maintenance of utilities in a standard set of concepts and relations. As a standard, the conceptual schema improves system interoperability of utility data when adopted and applied within the utility sector.

The domain of operations and maintenance in the context of the conceptual schema is comparable with distinct phases in infrastructure asset management. To this end, the domain of operations and maintenance refers to the set of activities performed and strategies implemented with the goal to preserve and extend the service life of utilities.

The utility networks modelled within the conceptual schema are all build around connections and connection points, together defining the network as a whole. The main logic within utility networks is described using a topological model based on network and feature graphs. Utility components are represented in a feature graph. Utility networks are represented in a network graph. A network – i.e. network graph – thereby consist of various components – i.e. feature graphs. The topological model is further clarified within the 'Core and geometry' UML class model, section 5.3.1. In addition, the Operations and Maintenance conceptual schema allows for representation of surfaces and solids, and thereby three-dimensional storing of utility component data.

3.2.3 Links with other themes

The Operations and Maintenance conceptual schema might touch upon other themes including:

- Buildings (CityGML Building module)
- City furniture (CityGML CityFurniture module)
- Land use (CityGML LandUse module)

- Vegetation (CityGML Vegetation module)
- Water objects (CityGML WaterBody module)
- Transportation (CityGML Transportation module)
- Tunnels (CityGML Tunnel module)
- Bridges (CityGML Bridge module

These themes have separate modules within CityGML and are connected to the CityGML UtilityNetwork ADE. This relationship is inherited by the Operations and Maintenance conceptual schema.

3.3 Normative references

[1.] City Geography Markup Language (CityGML) UtilityNetwork ADE 0.9.2
[2.] D2.8.III.6 Data Specification on Utility and Government Services – Technical Guidelines
[3.] IMKL – Data specification Utility Networks 1.2
[4.] ISO 1000:1992 SI units and recommendations for the use of their multiples and certain other units
[5.] ISO 19136:2007 Geographic information – Geography Markup Language (GML)
[6.] ISO 19101-1:2014 Geographic information – Reference model
[7.] ISO 19103:2015 Geographic information – Conceptual schema language
[8.] ISO 19107:2003 Geographic information – Spatial schema
[9.] ISO 19109:2015 Geographic information – Rules for application schema
[10.] ISO 19111: 2007 Geographic information – Spatial referencing by coordinates
[11.] ISO 19131:2007 Geographic information – Data product specifications
[12.] ISO 19156:2011 Geographic information – Observations and measurements
[13.] ISO 8601:2000 Data elements and interchange formats
[14.] ISO/IEC 2382:2009 Information technology - Vocabulary
[15.] NEN 3610:2011/A1:2016 Basic Schema for Geo-information
[16.] NEN-EN-ISO 19107:2005 Geographic information – Spatial schema
[17.] OGC City Geography Markup Language (CityGML) Encoding Standard 2.0

3.4 Establishment

This data specification is established by the University of Twente and based on the CityGML UtilityNetwork ADE version 0.9.2.

Title of document	Operations and Maintenance – Data Specification
Reference date	11-01-2019
Author	Ramon ter Huurne
Language	English
Online repository	https://github.com/RamonTerHuurne/UtilityNetwork-OperationsAndMaintenance

3.5 Terms and definitions

Below a list of terms with their definitions used in this data specification is provided:

[1.] Aggregation
Special form of association (4) that specifies a whole-part relationship (28) between the aggregate (whole) and a component (9) part [UML 1]

[2.] Application
Manipulation and processing of data in support of user requirements [ISO 19101-1:2014]

[3.] Application schema
Conceptual schema (12) for data required by one or more applications [ISO 19101-1:2014]

[4.] Association
Semantic relationship (28) that can occur between types instances (21) [UML 2]

[5.] Attribute
Feature (19) within a classifier (8) that describes a range of values that instances (23) of the classifier may hold [UML 1]

[6.] Cardinality
Number of elements in a set [UML 1]

[7.] Class
Description of a set of objects (27) that share the same attributes (5), operations, methods, relationships (28), and semantics [UML 1]

[8.] Classifier
Mechanism that describes behavioral and structure features (19) in any combination [UML 1]

[9.] Component
Representation of a modular part of a system that encapsulates its contents and whose manifestation is replaceable within its environment [UML 2]

[10.] Composition
Aggregation (1) where the composite object (27) (whole) has responsibility for the existence and the storage of the composed objects (parts) [UML 2]

[11.] Conceptual model
Model that defines concepts of a universe of discourse [ISO 19101-1:2014]

[12.] Conceptual schema
Formal description of a conceptual model (11) [ISO 19101-1:2014]

[13.] Coordinate
One in a sequence of n numbers designating the position of a point in n-dimensional space [ISO 19111:2007]

[14.] Coordinate reference system
Coordinate system that is related to an object (27) by a datum [ISO 19111:2007]

[15.] Coordinate system
Set of mathematical rules for specifying how coordinates are to be assigned to points [ISO 19111:2007}

[16.] Data specification
Detailed description of a data set or data set series together with additional information that will enable it to be created, supplied to and used by another party [ISO 19131:2007]

[17.] Data type
Specification of a value domain with operations allowed on values in this domain [ISO 19103:2015]

[18.] Depth
Distance of a point from a chosen reference surface measured downward along a line perpendicular to that surface [ISO 19111:2007]

[19.] Feature
Abstraction of a real world phenomenon [ISO 19101-1:2014] In UML also defined as the property of a classifier [UML 2]

[20.] Feature catalogue
Catalogue containing definitions and descriptions of the feature (19) types, feature attributes, and feature relationships occurring in one or more spatial data sets, together with any feature operations that may be applied [ISO 19101-1:2014]

[21.] Feature type
Class of features (19) having common characteristics [ISO 19156:2011]

[22.] Generalization (inheritance)
Taxonomic relationship (28) between a more general element and a more specific element of the same element type [UML 2]

[23.] Instance
Individual entity having its own value and possibly its own identity [ISO 19103:2015]

[24.] Interoperability
Capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units [ISO/IEC 2382:2009, 212317]

[25.] Model
Abstraction of some aspects of reality [ISO 19109:2015]

[26.] Multiplicity
Specification of the range of allowable cardinalities (6) that a set may assume [ISO 19103:2015]

[27.] Object
Entity with a well-defined boundary and identity that encapsulates state and behavior [UML 1]

[28.] Relationship
Semantic connection among model elements [UML 1]

[29.] Schema
Formal description of a model (25) [ISO 19101-1:2014]

[30.] Spatial object (geo-object, feature type)
Object (27) used for representing a spatial characteristic of a feature (19) [ISO 19107:2003]

[31.] Stereotype
Extension of an existing metaclass that enables the use of platform or domain specific terminology or notation in place of, or in addition to, the ones used for the extended metaclass [UML 2]

[32.] Value domain
Set of accepted values [ISO 19103:2015]

3.6 Abbreviations

Below a list of the abbreviations used in this data specification are provided:

ADE
Application Domain Extension

GIS
Geographic Information System

GML
Geography Markup Language

INSPIRE
Infrastructure for Spatial Information in Europe

ISO
International Organization for Standardization

OGC
Open Geospatial Consortium

UML
Unified Modelling Language

URI
Uniform Resource Identifier

XML
Extensible Markup Language

4 Identification information

This chapter includes information about the identification of the Operations and Maintenance conceptual schema. Table 1 presents descriptive information about the data specification following "ISO 19131:2007 Geographic Information – Data product specifications".

Table 1 – Descriptive information about the Operations and Maintenance conceptual schema

Title	Utilities – Operations and Maintenance conceptual schema
Summary	The Operations and Maintenance conceptual schema describes the topology, vocabulary and semantics of utility networks – with a focus on operations and maintenance activities. The Operations and Maintenance conceptual schema builds upon and extends CityGML UtilityNetwork ADE. CityGML UtilityNetwork ADE allows for identification and modelling of utility networks. The Operations and Maintenance conceptual schema adds concepts and relations relevant for the domain of operations and maintenance. Newly added concepts and classes cover amongst others related party, performance, dimensional, surrounding soil, cost and maintenance properties. The Operations and Maintenance conceptual schema can provide a comprehensive set of utility information required for operations and maintenance related processes activities.
Geographical applicability	Global, but based on utility networks of developed countries
Goal	Goal of this document is to describe the Operations and Maintenance conceptual schema by providing its class models together with a detailed description. The conceptual schema allows for registration of utility data related to the domain of operations and maintenance.

5 Data specification: content and structure

5.1 Introduction

The following paragraphs explain the structure and content of the Operations and Maintenance data specification. The data specification is built around in total eight class models, together forming the complete conceptual schema. Each of these are intertwined with another, but for clarity reasons, it was chosen to present these in a separate manner. The eight class models of the Operations and Maintenance conceptual schema are:

[1.] Core and geometry
[2.] Functional characteristics
[3.] Network properties
[4.] Network components
[5.] Component properties
[6.] Maintenance and operations properties
[7.] Performance properties
[8.] Hollow space

Each of these class models are elaborated in separate sections, starting from section 5.3.1. The UML class models show in a graphical manner what kind of utility information can be modelled by the Operations and Maintenance conceptual schema. The class models present objects, their attributes and the relations between one another. In addition to the UML class model itself, each section provides an accompanying description.

Section 5.4 present an overview of the heritage and stereotype of all classes captured in the conceptual schema (explained section 5.2). However, to fully comprehend and understand the class models and Operations and Maintenance conceptual schema as a whole, the data specification should be used alongside the 'Operations and Maintenance – Feature Catalogue' (OM_Feature_Catatalogue.pdf).

Before the UML class models themselves are shown, the following section explains the applied UML notation and accompanying colour coding.

5.2 Notation and colour coding

5.2.1 UML notation

The Operations and Maintenance conceptual schema is modelled in the Unified Modeling Language (UML) notation. The class model presented in Figure 1 shows the UML notations used in this data specification. The associations between model features in the Operations and Maintenance conceptual schema are bi-directional. This means associations can be navigated in two directions. The direction itself is depicted in the UML class models by the arrowhead. Within an association the context a feature takes is indicated by its role. This role is displayed near the target of the association. In case of a bi-directional association, roles are displayed at both ends of the association.

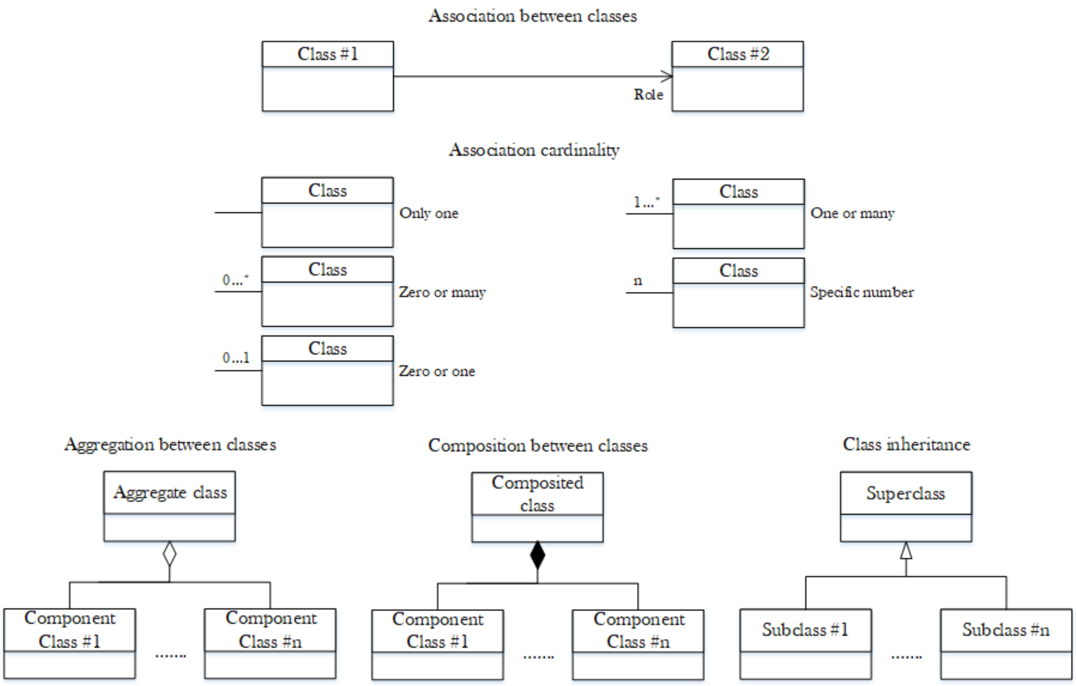


Figure 1 – UML notation (ISO 19103:2015 Geographic information – Conceptual schema language)

In the modelling of the UML class models, the stereotypes as described in Table 2 are used. These stereotypes follow the style used in ISO 19103 and ISO 19109 for models of geographic information.

Table 2 – Stereotypes used in UML class models

Stereotype	Model Element	Explanation
ApplicationSchema	Package	Conceptual schema required by applications.
CodeList	Class	Value domain including a code for each permissible value.
DataType	DataType	Represent a set of properties without identity.
Enumeration	Enumeration	Data type whose numbers are enumeration literals.
FeatureType	Class	Represent a spatial object.

Attributes of the model elements are either described through complex types (i.e. other stereotypes) or through one of the value types as described in Table 3.

Table 3 – Value types used in UML class models

Value type	Explanation
boolean	Used for logical expression, consisting of the predefined values true and false.
date	Describing the date in YYYY-MM-DD.
integer	Integer values.
characterString	Sequence of characters in set to display information.
measure	Declared or measured quantity.
quantityExtent	A range of integer values.
URI	Uniform Resource Identifier used for identification.

5.2.2 Colour coding

In the UML class models of the Operations and Maintenance conceptual schema, the UML class models of CityGML UtilityNetwork ADE are taken as a basis. Giving the domain of operations and maintenance, new UML class models are added or existing UML class models of the CityGML UtilityNetwork ADE are altered. To make this explicit, within the UML class models of the Operations and Maintenance conceptual schema – as presented in the upcoming eight sections – it is highlighted which classes have been copied from, copied with alternations from, and newly added to the CityGML UtilityNetwork ADE with three colours:

- Purple : copied from CityGML UtilityNetwork ADE version 0.9.2
- Orange : copied with alterations from CityGML UtilityNetwork ADE version 0.9.2
- White : newly added to CityGML UtilityNetwork ADE version 0.9.2

Alterations to the CityGML UtilityNetwork ADE classes include changes in the naming of the classes and attributes, the addition of new attributes, and the removal of existing attributes. These alterations were made to better fit the classes to the domain of operations and maintenance of utilities.

The UML class model in Figure 2 demonstrates the colour coding* as used throughout this data specification. As presented in the example the class 'AbstractCommodityClassifier' is copied from CityGML UtilityNetwork ADE. The class 'Network' and 'AbstractCommodity' are copied with alterations. The class 'RelatedParty' is newly added.

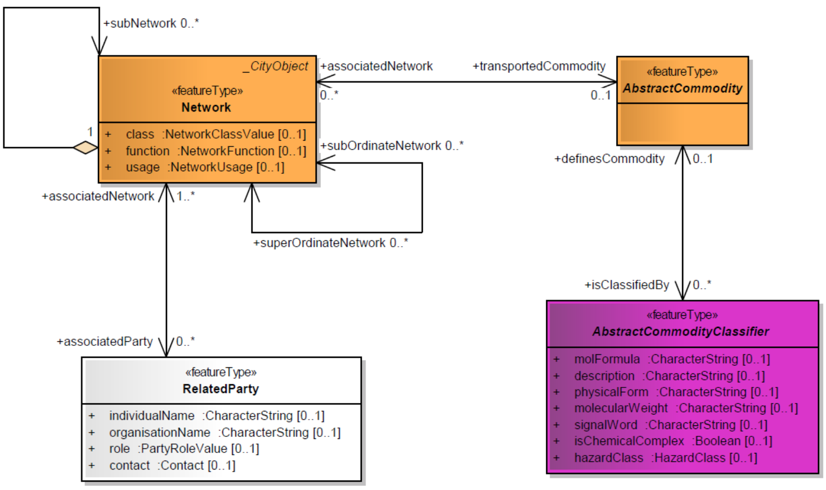


Figure 2 – Use of colour coding in UML class models (adapted from 'Network properties' class model)

* The colours are chosen in such a way that they are still distinguishable when printed in black and white. However, to guarantee the best readability when printed, it is recommended to print the UML diagrams in colour.

5.3 UML class models

5.3.1 Core and geometry

Main characteristics of the 'Core and geometry' class model are:

- Defines the topographic model of the utility network
- Defines the topological and functional model of the utility network

Below additional explanation to the 'Core and geometry' class model is provided. Page 16 presents the accompanying UML class model.

Topographic and topological view

The central concept within the Operations and Maintenance conceptual schema, and the CityGML UtilityNetwork ADE, is 'Network'. A network can be defined as a collection of network features belonging to a single transported commodity. As in the CityGML UtilityNetwork ADE, a network is represented in two ways: topographically as an aggregation of network features, and topologically by the means of a network graph which is composed of feature graphs of the individual network features (Kutzner & Kolbe, 2016).

Shown in the UML class model, a 'Network' consist of zero or many 'AbstractNetworkFeature'. Whereas the feature is the basic unit – an abstraction of the real world – the network is a collection of those features. An 'AbstractNetworkFeature' is an abstract class and can represent any kind of utility class, such as distribution components (pipes and cables) and protective components (e.g. mantle tubes and ducts) (see 'Network components' class model, section 5.3.5). To define the topological model, an 'AbstractNetworkFeature' is represented in a 'FeatureGraph', which can be part of one or many 'NetworkGraph'(s). Vice versa, a 'NetworkGraph' can consist of zero or many 'FeatureGraph'.

To connect the network features – i.e. the 'AbstractNetworkFeature' – with one another various linking features are included. The class 'InteriorFeatureLink' connects the interior and exterior nodes of a network feature. Interior nodes are connection points within a single network feature. Exterior nodes are connection points used to connect network features with one another. The class 'InterFeatureLink' connects the various network features – i.e. 'FeatureGraph'. A group of connected network features together forms the network – i.e. 'NetworkGraph. To this end, Figure 3 presents the topographic and topological view. The topographic view is presented on the left side, the topological view on the right side. Whereas the topographic view represents the arrangement of the natural and artificial physical features in an area, the topological view represents the set of rules applied to manage spatial relationships within and between features.

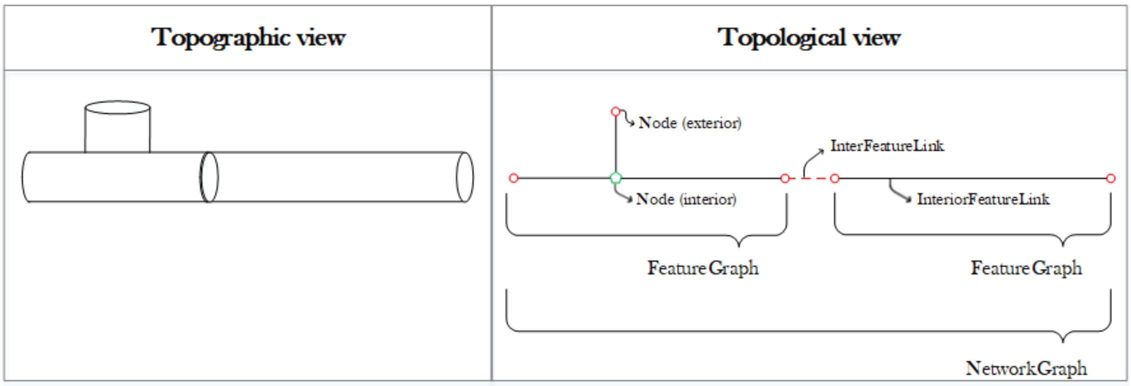


Figure 3 – Topographic (left) and topological (right) view

Not shown in Figure 3 but present in the class model is the link 'NetworkLink'. This link allows modelling of a 'FeatureGraph' that belongs to more than one network. The 'NetworkLink' then connects these networks with each other. An example of such a 'FeatureGraph' may be a water pump, belonging to both a water and an electricity network.

Network hierarchies

The class model is capable of modelling network hierarchies. Networks can be classified as a 'subordinate network' to a 'superordinate network' and vice versa. Drawing on Kutzner and Kolbe (2016), Figure 4 presents a possible network hierarchy of an electricity network.

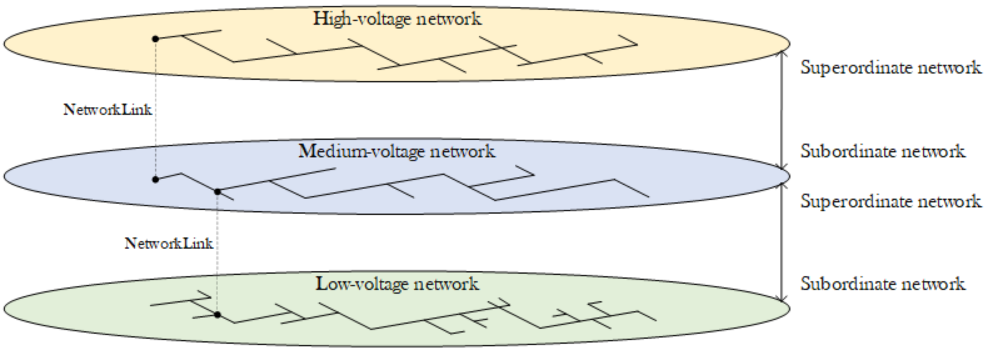


Figure 4 – Example: hierarchical structure of an electricity network

In general, high-voltage networks are applied to transmit and distribute power across large distances. However, for use in local regions, high-voltage is first transformed to medium-voltage and then distributed via medium-voltage networks. Medium-voltage networks in their turn are transformed to low-voltage by means of a distribution substation. These low-voltage networks eventually distribute power to the end-users. As such, the low-voltage network is a subordinate to the superordinate medium-voltage network. The medium-voltage network is a subordinate to the superordinate high-voltage network (Kutzner & Kolbe, 2016). These relations are shown in the UML class model through the associations with the role names 'subOrdinateNetwork' and 'superOrdinateNetwork' for the class 'Network'. These roles can also represent other types of hierarchies, such as a national versus a regional network.

Representing geometry

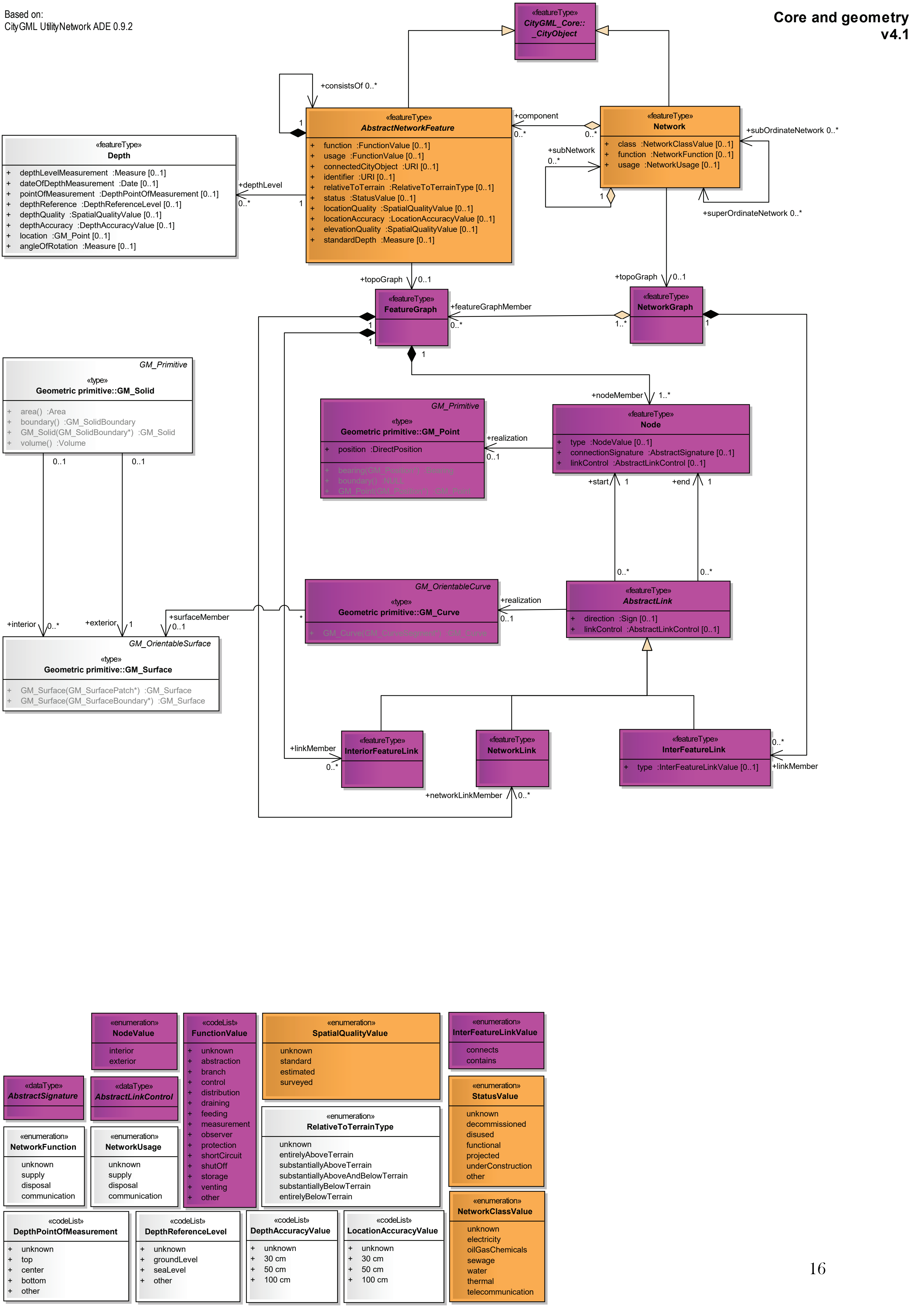
The geometry of utility network components is inherited from CityGML UtilityNetwork ADE. In general the (topological) geometry of an 'AbstractNetworkFeature' consists of a set of nodes ('Node') connected through links ('AbstractLink'). This allows for the generation of point ('GM_Point') and line ('GM_Curve') topological geometry.

In addition to the geometry as presented in CityGML UtilityNetwork ADE the Operations and Maintenance conceptual schema models solids and surfaces. The basis of the modelling of these is inherited from CityGML version 2.0. To model the typology, curves and points allow for the modelling of surfaces, in the class model represented by 'GM_Surface'. Surfaces on their turn allow for modelling of solids, in the class model represented by 'GM_Solid'. Solids are thereby represented through both interior and exterior surfaces, as shown in the corresponding roles names of the associations. It should be acknowledged that the current inclusion of solids and surfaces is yet a proposition and may be altered in future versions of the Operations and Maintenance conceptual schema. All four classes – 'GM_Point', 'GM_Curve', 'GM_Surface', 'GM_Solid' – follow the ISO 19107:2003 Geographic information – Spatial schema.

Depth

Depth is a new addition to CityGML UtilityNetwork ADE. For maintenance and operations purposes it is highly relevant to have valid data regarding the depth of utility network components, not to forget about its necessity for proper 3D modelling. Depth is not by definition the equivalent of the z-coordinate. Whereas the z-coordinate is a measure within a certain geometry reference system, depth can also be measured perpendicular from a specific reference level, such as the ground level. Therefore, the z-coordinate is an absolute measure, whereas depth is a relative measure.

The class ‘Depth’ is associated to ‘AbstractNetworkFeature’ allowing depth registration for every single component in the network. The association between ‘Depth’ and ‘AbstractNetworkFeature’ allows modelling of zero or many depths for a particular network component. In case of a sewage pipe, for example, depth can vary over the length of the pipe due to its angle of rotation. Through the attribute ‘location’ the specific location of the depth measurement is specified. The class ‘Depth’ further includes attributes that describe the point of measurement, the reference level and the accuracy of the measurement. These attributes help in getting a clear image of the depth of the utility network component. In case no depth measurements are available the attribute ‘standardDepth’ of ‘AbstractNetworkFeature’ includes the standard depth of the particular utility discipline and thereby utility component.



Based on:
CityGML UtilityNetwork ADE 0.9.2
Core and geometry
v4.1
«featureType»
CityGML_Core::_CityObject
+consistsOf 0..*
«featureType»
AbstractNetworkFeature
+ function :FunctionValue [0..1]
+ usage :FunctionValue [0..1]
+ connectedCityObject :URI [0..1]
+ identifier :URI [0..1]
+ relativeToTerrain :RelativeToTerrainType [0..1]
+ status :StatusValue [0..1]
+ locationQuality :SpatialQualityValue [0..1]
+ locationAccuracy :LocationAccuracyValue [0..1]
+ elevationQuality :SpatialQualityValue [0..1]
+ standardDepth :Measure [0..1]
+component
0..*
0..*
«featureType»
Network
+ class :NetworkClassValue [0..1]
+ function :NetworkFunction [0..1]
+ usage :NetworkUsage [0..1]
+subOrdinateNetwork 0..*
+superOrdinateNetwork 0..*
+subNetwork
0..*
1
«featureType»
Depth
+ depthLevelMeasurement :Measure [0..1]
+ dateOfDepthMeasurement :Date [0..1]
+ pointOfMeasurement :DepthPointOfMeasurement [0..1]
+ depthReference :DepthReferenceLevel [0..1]
+ depthQuality :SpatialQualityValue [0..1]
+ depthAccuracy :DepthAccuracyValue [0..1]
+ location :GM_Point [0..1]
+ angleOfRotation :Measure [0..1]
+depthLevel
0..*
1
+topoGraph
0..1
«featureType»
FeatureGraph
+featureGraphMember
0..*
1..*
+topoGraph
0..1
«featureType»
NetworkGraph
1
1
1
1
+nodeMember
1..*
GM_Primitive
«type»
Geometric primitive::GM_Solid
+ area() :Area
+ boundary() :GM_SolidBoundary
+ GM_Solid(GM_SolidBoundary*) :GM_Solid
+ volume() :Volume
0..1
0..1
GM_Primitive
«type»
Geometric primitive::GM_Point
+ position :DirectPosition
+ bearing(GM_Position*) :Bearing
+ boundary() :NULL
+ GM_Point(GM_Position*) :GM_Point
+realization
0..1
«featureType»
Node
+ type :NodeValue [0..1]
+ connectionSignature :AbstractSignature [0..1]
+ linkControl :AbstractLinkControl [0..1]
+start
1
+end
1
0..*
0..*
GM_OrientableCurve
«type»
Geometric primitive::GM_Curve
+ GM_Curve(GM_CurveSegment*) :GM_Curve
+realization
0..1
«featureType»
AbstractLink
+ direction :Sign [0..1]
+ linkControl :AbstractLinkControl [0..1]
+interior
0..*
+exterior
1
+surfaceMember
0..1
*
GM_OrientableSurface
«type»
Geometric primitive::GM_Surface
+ GM_Surface(GM_SurfacePatch*) :GM_Surface
+ GM_Surface(GM_SurfaceBoundary*) :GM_Surface
+linkMember
0..*
«featureType»
InteriorFeatureLink
«featureType»
NetworkLink
+networkLinkMember
0..*
«featureType»
InterFeatureLink
+ type :InterFeatureLinkValue [0..1]
0..*
+linkMember
«enumeration»
NodeValue
interior
exterior
«codeList»
FunctionValue
+ unknown
+ abstraction
+ branch
+ control
+ distribution
+ draining
+ feeding
+ measurement
+ observer
+ protection
+ shortCircuit
+ shutOff
+ storage
+ venting
+ other
«enumeration»
SpatialQualityValue
unknown
standard
estimated
surveyed
«enumeration»
InterFeatureLinkValue
connects
contains
«dataType»
AbstractSignature
«dataType»
AbstractLinkControl
«enumeration»
RelativeToTerrainType
unknown
entirelyAboveTerrain
substantiallyAboveTerrain
substantiallyAboveAndBelowTerrain
substantiallyBelowTerrain
entirelyBelowTerrain
«enumeration»
StatusValue
unknown
decommissioned
disused
functional
projected
underConstruction
other
«enumeration»
NetworkFunction
unknown
supply
disposal
communication
«enumeration»
NetworkUsage
unknown
supply
disposal
communication
«codeList»
DepthPointOfMeasurement
+ unknown
+ top
+ center
+ bottom
+ other
«codeList»
DepthReferenceLevel
+ unknown
+ groundLevel
+ seaLevel
+ other
«codeList»
DepthAccuracyValue
+ unknown
+ 30 cm
+ 50 cm
+ 100 cm
«codeList»
LocationAccuracyValue
+ unknown
+ 30 cm
+ 50 cm
+ 100 cm
«enumeration»
NetworkClassValue
unknown
electricity
oilGasChemicals
sewage
water
thermal
telecommunication

5.3.2 Functional characteristics

Main characteristics of the ‘Functional characteristics’ class model are:

- Defines the functional role of objects in the utility network
- Defines the area the commodity is supplied to by the network

Below additional explanation to the ‘Functional characteristics’ class model is provided. Page 18 presents the accompanying UML class model.

Link with city objects

CityGML UtilityNetwork ADE connects with CityGML through the class ‘AbstractCityObject’. City objects are objects used in CityGML to represent all kinds of objects seen in urban environments. Therefore, the ‘AbstractCityObject’ class can refer to various types of objects, of which the following are of particular interest to utility networks:

- VegetationObject (e.g. trees)
- CityFurniture (e.g. streetlamp)
- WaterObject (e.g. fountain)
- TransportationObject (e.g. drainage)

‘AbstractCityObject’ is inherited in the Operations and Maintenance conceptual schema. The ‘AbstractCityObject’ may require supply (for example electricity for a streetlamp) and has a specific role in the network. This role is characterized in the class model by the class ‘RoleInNetwork’, which is in turn connected to ‘Network’. By including city objects, interferences of city objects with utility objects can be modelled and identified.

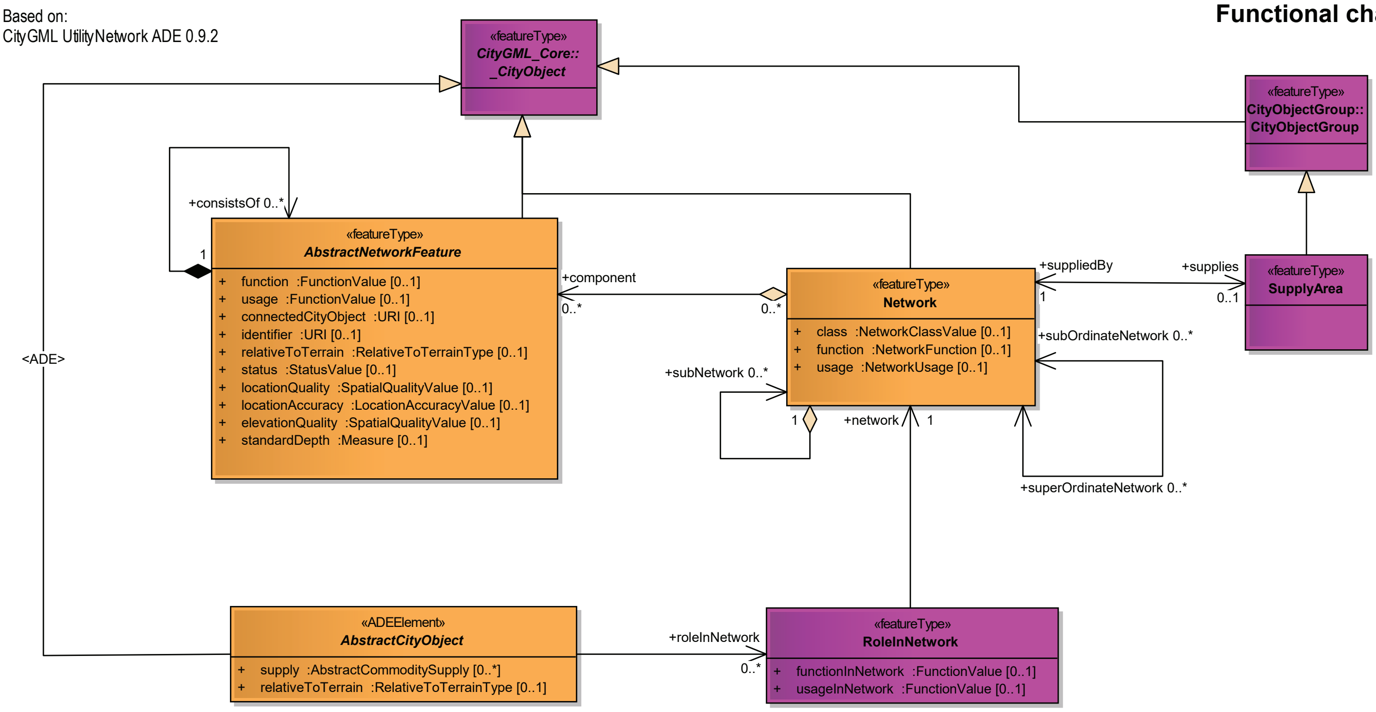
The class ‘AbstractCityObject’ is related to the class ‘AbstractCommoditySupply’ through its attribute ‘supply’ to indicate the commodity supplied to the city object. The class ‘AbstractCommoditySupply’ provides three attributes being ‘potentialSupply’, ‘currentSupply’ (expressing the suppliability and suppliedness of the commodity to the city object) and ‘storage’ (expressing possible available storage of the commodity as a back-up) (Kutzner & Kolbe, 2016). The class ‘AbstractCommoditySupply’ is further specialized in five subclasses to classify the transported commodity. This specialization is in conformation with the class ‘AbstractCommodity’, part of the ‘Network properties’ class model (section 5.3.4). The enumerations used for ‘AbstractCommoditySupply’ are, therefore, reused for ‘AbstractCommodity’.

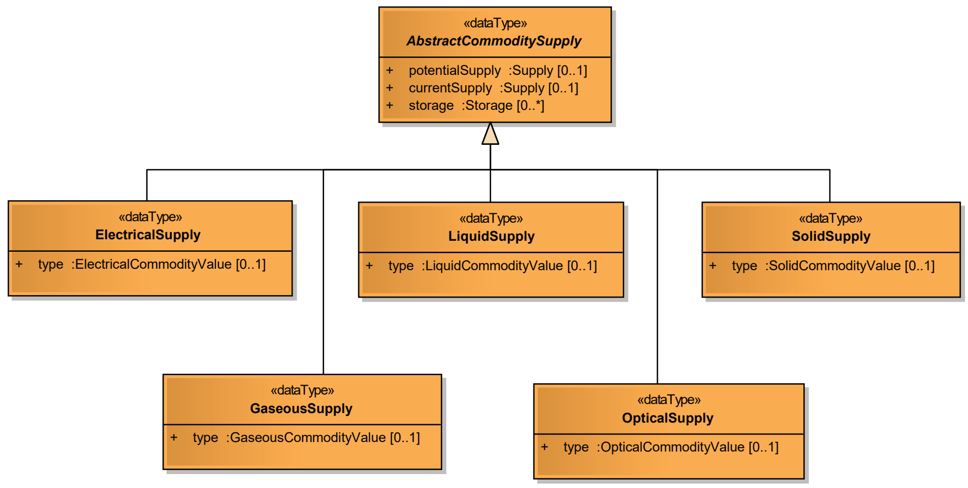
Supply area of network

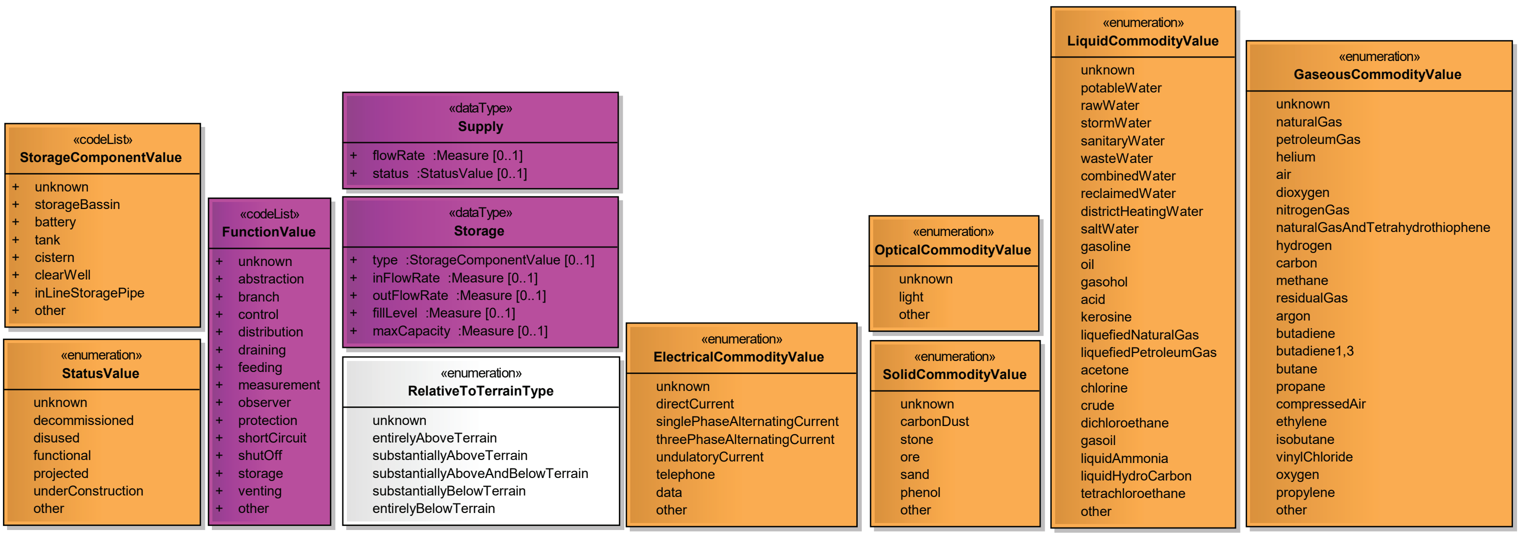
The Operations and Maintenance conceptual schema represents the structure of a network including all discrete network components that the utility network is composed of. As a result one can track the route of a commodity from source to destination. In addition, in case less to no information about a utility network is available, a supply area still allows determination of the area where a specific commodity is supplied to. The supply area is defined as “that geographic region a specific commodity is supplied to by a network” (Kutzner & Kolbe, 2016). The class ‘SupplyArea’ represents the supply area. The object ‘SupplyArea’ is a subclass of ‘CityObjectGroup’, on its turn a subclass of ‘AbstractCityObject’. These relations allow identification of those city objects located within a specific supply area way. The supply area is also strongly related to the utility network. This is characterized by the association between ‘Network’ and ‘SupplyArea’ and the role names ‘suppliedBy’ and ‘supplies’. A supply area is supplied by a network, whereas a network supplies a supply area. Since networks can be subordinate and superordinate, this association also allows modelling of ‘sub’ and ‘super’ supply areas.

Based on:
CityGML UtilityNetwork ADE 0.9.2

Functional characteristics v4.1







5.3.3 Network properties

Main characteristics of the 'Network properties' class model are:

- Defines the transported commodity and its characteristics
- Defines the parties involved within the particular network

Below additional explanation to the 'Network properties' class model is provided. Page 20 presents the accompanying UML class model.

Commodities within utility network

The transported commodity by the utility network is characterized through the abstract utility network class 'AbstractCommodity'. The class 'AbstractCommodity' is specialized in five subclasses each addressing a particular kind of commodity, being either liquid, gaseous, solid, electrical or optical. For each of the subclasses the class model defines multiple characteristics. The attribute 'type' defines the specific type of commodity being transported. The possible commodity type values are enclosed by an enumeration for each subclass of 'AbstractCommodity'. The conceptual schema also allows modelling of pressure levels and ranges, bandwidth, temperature, electric conductivity as well as other characteristics.

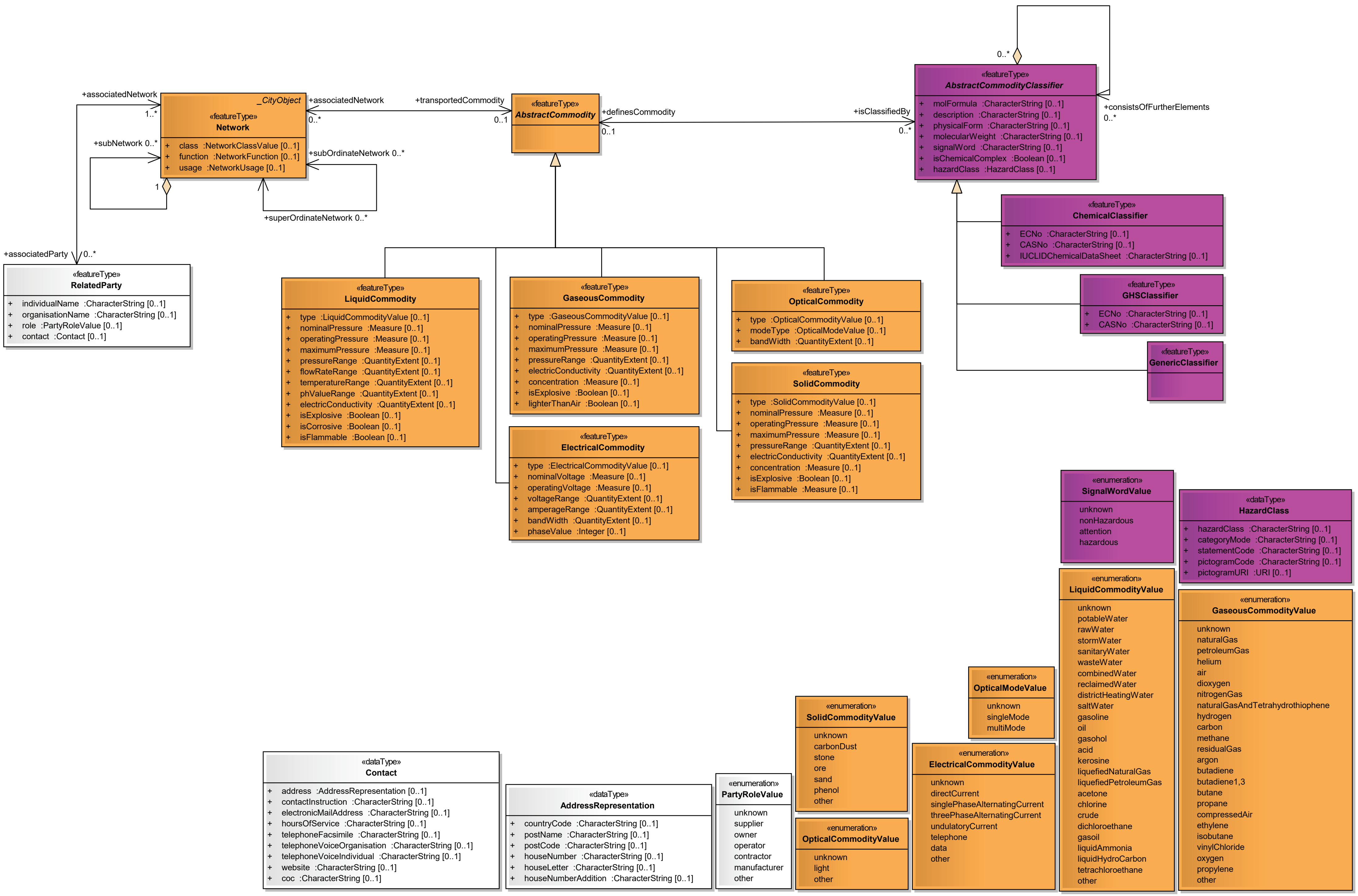
To classify the commodities from a chemical perspective the class 'AbstractCommodityClassifier' is associated with 'AbstractCommodity'. 'AbstractCommodityClassifier' classifies the associated commodity in terms of its chemical characteristics. The class includes attributes such as 'molFormula', 'physicalForm' and 'molecularWeight'. The abstract utility network class 'AbstractCommodityClassifier' also groups three specific classifier classes: (1) 'ChemicalClassifier', (2) 'GHSClassifier' and (3) 'GenericClassifier'. 'ChemicalClassifier' contains three well-defined and standardized chemical classifiers being the Enzyme Commission (EC) number, the Chemical Abstracts Service (CAS) registry number and the International Uniform Chemical Information Database (IUCLID) data sheet. 'GHSClassifier' refers to the Globally Harmonized System of Classification and Labelling of Chemicals. Attributes included for this classifier are the EC number and CAS number. The 'GenericClassifier' is applied as a generic and additional mean to classify the commodity of interest.

Related party

Information about related parties is newly added by the Operations and Maintenance conceptual schema in comparison with CityGML UtilityNetwork ADE, through the class 'RelatedParty'. This class has a bi-directional association with the class 'Network', where a network may be associated with multiple parties. Parties are also associated with network components in specific. Within a single network, network components may have different related parties. Even network components themselves can be related to multiple parties. The association between 'RelatedParty' and 'AbstractNetworkFeature' is therefore present, although not in the 'Network properties' class model. This association is modelled in the 'Component properties' class model (section 5.3.6). The UML class model distinguishes the role of the related party through the enumeration 'PartyRoleValue'. Party roles distinguished are the supplier, owner, operator, contractor and manufacturer. Moreover, for every related party both contact and address information are possible to model through the data types 'Contact' and 'AddressRepresentation'. Modelling of the related parties follows the structure from the INSPIRE D2.8.III.6 Data Specification on Utility and Government Services – Technical guidelines. In addition to the INSPIRE data specification, the attributes 'telephoneVoiceOrganisation', 'telephoneVoiceIndividual', 'website', 'countryCode', 'houseNumber', 'houseLetter' and 'houseNumberAddition' have been added.

Based on:
CityGML UtilityNetwork ADE 0.9.2

Network properties v4.1



5.3.4 Network components

Main characteristics of the 'Network components' class model are:

- Defines the distribution components for transport and distribution of a commodity
- Defines the functional components within the network
- Defines the protective components relevant for the security of the network

Below additional explanation to the 'Network components' class model is provided. Page 23 presents the accompanying UML class model.

Distribution components

Distribution components transport and distribute the commodity through the network. Distribution components are represented in the Operations and Maintenance conceptual schema through the class 'AbstractDistributionComponent'. 'AbstractDistrubtionComponent' is a subclass of 'AbstractNetworkFeature'. For each distribution line its specific characteristics are specified through the attribute 'class' and 'functionOfLine'. The attribute 'class' describes the type of the distribution line, defining whether the line is a main line, a transport line, a supply line or a house service line. The attribute 'functionOfLine' describes the specific function of the line, in addition to its type. The distribution line may function, for example, as a cooling line or a return line.

Means of distributions are either pipes or cables. This is represented in the class model through two abstract subclasses of 'AbstractDistributionComponent', being 'AbstractCable' and 'AbstractPipe'. 'AbstractCable' is further specified into its subclasses 'ElectricityCable' and 'TelecommunicationCable'. 'AbstractPipe' is further specified into its subclasses 'OilGasChemicalsPipe', 'WaterPipe', 'ThermalPipe', and 'SewerPipe'. Through various attributes specific characteristics of both cables and pipes can be modelled within the Operations and Maintenance conceptual schema.

Functional components

Functional components are represented by the class 'AbstractFunctionalComponent'*. 'AbstractFunctionalComponent' is a subclass of 'AbstractNetworkFeature'. The abstract utility network class 'AbstractFunctionalComponent' groups all common functional utility components having any other function than the distributional or protective components. Functional components are separated into simple components ('SimpleFunctionalComponent') and complex components ('ComplexFunctionalComponent'). A component is considered complex when it consists of multiple simple functional components. Examples of complex functional components are a station or power plant. This multiplicity is modelled within the class model with the aggregation between 'ComplexFunctionalComponent' and 'AbstractFunctionalComponent'.

Simple components are either active or passive. In case the component is active it has an active movement to generate, regulate or continue flow of commodities through the network. In case the component is passive it has no active movement. Simple components are specialized into six subclasses. A 'ConnectionComponent' describes those components used to link a utility link or sequence with another. A 'StorageComponent' describes those component used for storage and buffer of commodities for future use. A 'ControllerComponent' describes those components used to control, limit or influence the flow of the transported commodity. Controller components are thereby specialized in being either an actuator or regulator. A 'MeasurementComponent' describes those components used to detect or measure a physical property and consequently record, indicate or respond to it. A 'TerminalComponent' describes those

* Functional components are currently under debate and might be subject to change in future versions of the conceptual schema.

components at the end of the distribution line consuming the transported commodity. The final simple component class is 'OtherComponent', which groups the remaining simple components who cannot be assigned to one of the previous discussed five simple component classes.

For all of the simple component classes the specific type of component can be assigned through the attribute 'type' (in case of 'StorageComponent' indirectly through the attribute 'storage'). The attribute 'type' is also present for 'ComplexFunctionalComponent'. The attribute 'type' refers to a codelist for the particular kind of component. Values within these codelist are based on CityGML UtilityNetwork ADE and the INSPIRE D2.8.III.6 Data Specification on Utility and Government Services – Technical guidelines, but are also empirically grounded. The classes 'ControllerComponent' and 'TerminalComponent' are described through additional attributes concerning the component's preferred mode, actual mode, rotational direction, its number of rotations (in case of rotational movement), and (if applicable) whether the earth and neutral are connected. For the class 'StorageComponent' the attribute 'storage' is included describing the type of storage component, its in- and outflow rate, its current fill level and its maximum capacity.

Protective components

A protective component is applied to protect a certain network component, which can be a distribution component, functional component or protective component itself. Protective components are represented in the class model through the class 'AbstractProtectiveComponent'. 'AbstractProtectiveComponent' groups two subclasses, being 'Bedding' and 'ProtectiveShell'. 'ProtectiveShell' is on its turn specialized in three subclasses, being 'RectangularShell', 'RoundShell' and 'OtherShell'. 'OtherShell' involves those protective shells that aren't either rectangular or rounded. The dimensions of the protective components are described through a separate class described in the 'Component properties' class model (section 5.3.5).

The class 'AbstractProtectiveComponent' is a subclass of 'AbstractNetworkFeature'. Since a protective component protects another component, an 'AbstractNetworkFeature' can contain an 'AbstractNetworkFeature' itself. To model this relation, the class model includes an association between 'AbstractProtectiveComponent' and 'AbstractNetworkFeature' with a zero or many multiplicity. To this end, a protective component may contain more than one distribution component. Therefore, the attributes 'numberOfPipes' and 'numberOfCables' are added to 'AbstractProtectiveComponent' to quantify the number of pipes and cables located within the particular protective component. This allows related parties to assess whether room is left inside the protective component. Figure 5 illustrates possible scenarios how a protective component can include multiple components. In the figure relations between a rectangular shell, round shells and cables are presented.

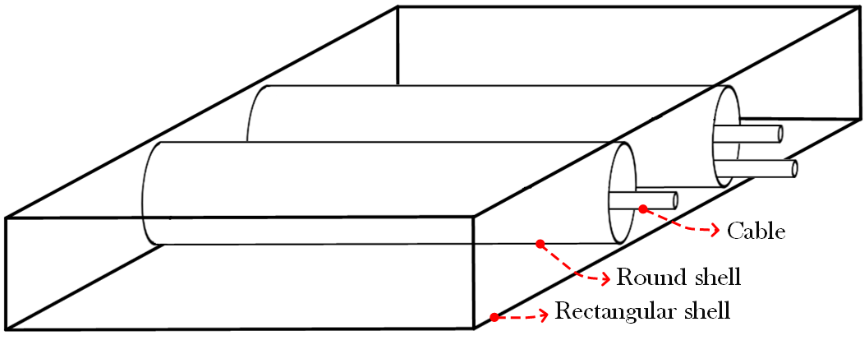
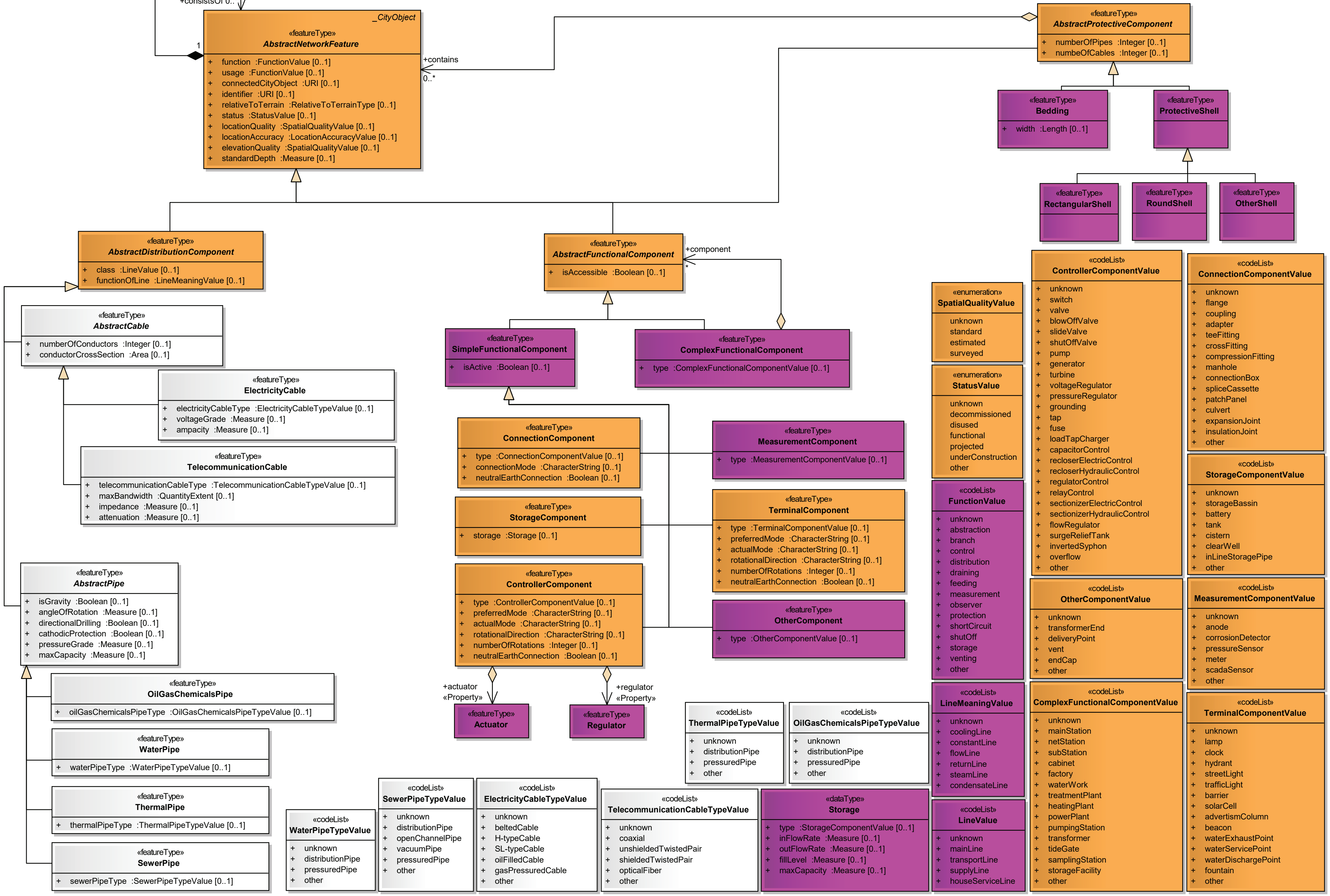


Figure 5 – Possible scenarios illustrating relations between a rectangular shell, round shells and cable

Based on:
CityGML UtilityNetwork ADE 0.9.2

Network components v4.1



5.3.5 Component properties

Main characteristics of the 'Component properties' class model are:

- Defines the dimensional properties of utility network components
- Defines the surrounding soil and groundwater properties of utility network components
- Defines the material properties of utility network components
- Defines the related party of utility network components and the network as a whole
- Provides extra information concerning identification of utility network components

Below additional explanation to the 'Component properties' class model is provided. Page 26 presents the accompanying UML class model.

Dimensional properties

Dimensional properties describe the dimensions of the associated component. Dimensional properties are represented by the abstract utility network class 'AbstractDimensionalProperties' which connects to 'AbstractNetworkFeature' through an association. Dimensions of components are described through both qualitative and quantitative measures. Qualitatively, 'AbstractDimensionalProperties' describes the shape of the components through the attribute 'shape' and associated codelist 'ShapeValue'. Shape refers to the geometric shape of the component, for example, circular or rectangular. Quantitatively, 'AbstractDimensionalProperties' defines the dimensions of the component through both its subclasses 'ExteriorDimensions' and 'InteriorDimensions'. These two classes respectively describe, if applicable, the width, height, length and diameter of a particular component.

Surrounding soil properties

Surrounding soil properties describe both soil and groundwater related properties for the associated component. Surrounding soil properties are represented by the class 'SurroundingSoilProperties' which is connected to 'AbstractNetworkFeature' through an association. The class 'SurroundingSoilProperties' inhabits various attributes describing the type of the soil, reactivity, permeability, strength, density, and moisture content.

The groundwater properties are represented through the data type 'GroundWater'. The class 'SuroundingSoilProperties' has an attribute 'groundWaterProperties' referring to the data type 'GroundWater'. To this end, the groundwater properties can be described through the surrounding soil properties. The 'GroundWater' data type describes the groundwater level, whether the level is real-time or not, and the reference level against which the groundwater level is measured. Possible values for the groundwater reference level are enclosed in the codelist 'GroundWaterReference'.

Material properties

Material properties describe the exterior, interior and filling material of the associated component. Material properties are described through the abstract utility network class 'AbstractMaterialProperties'. This class is connected to 'AbstractNetworkFeature' through an association to establish the relation between material properties and a component.

The class 'AbstractMaterialProperties' is specialized in three subclasses describing the aforementioned filling ('FillingMaterial'), exterior ('ExteriorMaterial') and interior ('InteriorMaterial') material. For each of the three material subclasses, the type of material is included through the attribute 'type' which refers to the codelist 'MaterialValue'. In addition to the material type, the aforementioned material subclasses describe the material's strength, ductility and conductivity through included attributes.

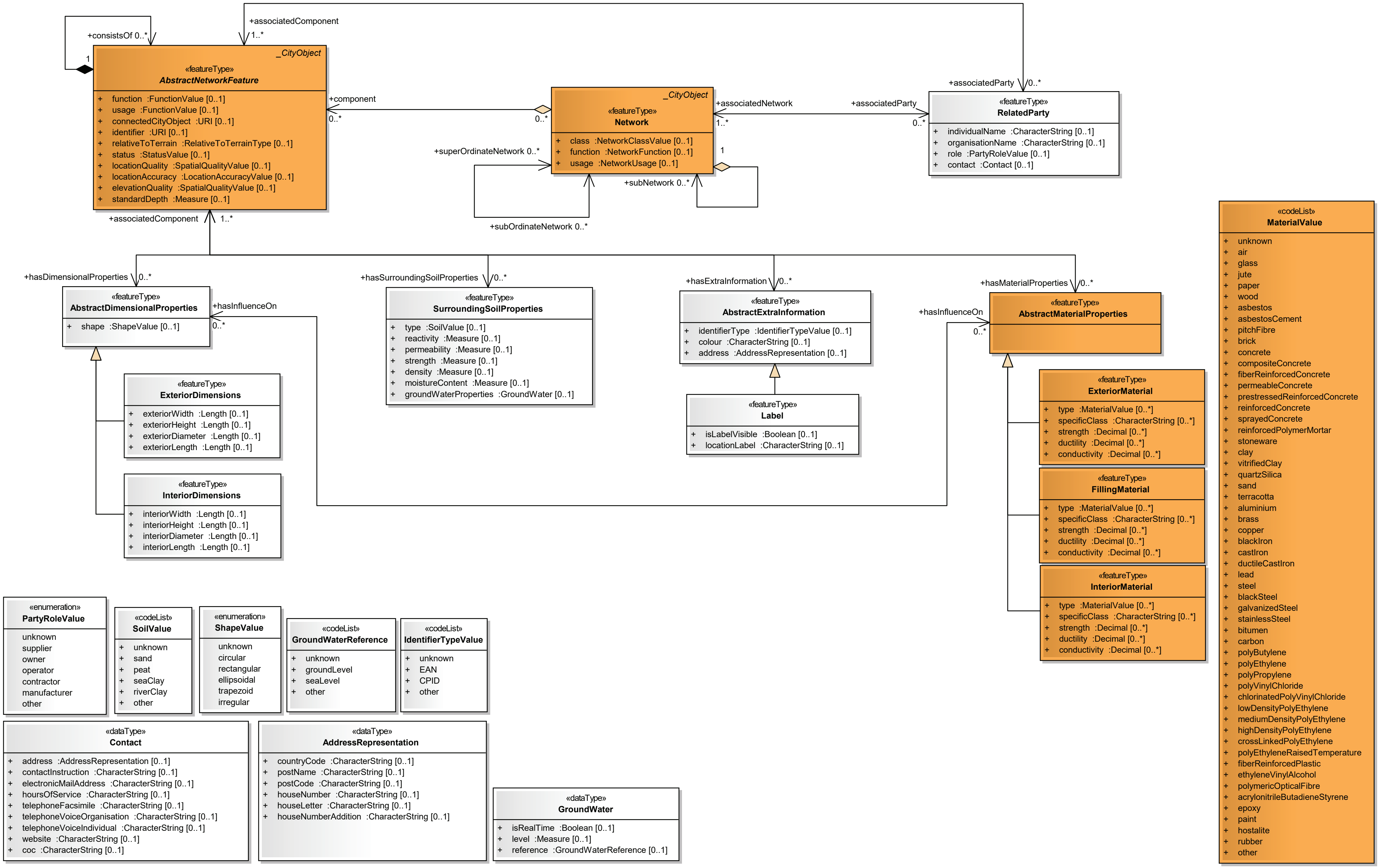
Related party
Related party properties have been discussed before in section 5.3.3. Only addition in the 'Component properties' class model is the association between 'AbstractNetworkFeature' and 'RelatedParty'.

Extra information
Extra information describes extra detail and identifier information. Extra information is represented by the class 'AbstractExtraInformation' which is connected to 'AbstractNetworkFeature' through an association. 'AbstractExtraInformation' allows further detailing and identification of the network component through the attributes 'identifierType' and 'colour'. The identifier allows identification of each individual component within the utility network. The identifier type refers to a specific identification method, such as EAN or CPID. These identifier types are captured in the codelist 'IdentifierTypeValue'. The attribute 'colour' adds visual guidance by defining the (main) colour of the component.

A subclass of 'AbstractExtraInformation' is the class 'Label'. A label concerns a physical piece that may be attached to a network component to give information about that particular component. The class 'Label' includes attributes describing whether this label is visible and where it is located on the network component.

Based on:
CityGML UtilityNetwork ADE 0.9.2

Component properties v4.1



5.3.6 Maintenance and operations properties

Main characteristics of the 'Maintenance and operations properties' class model are:

- Defines the maintenance properties of utility network components
- Defines the costs properties of utility network components
- Defines the date properties of utility network components

Below additional explanation to the 'Maintenance and operations properties' class model is provided. Page 29 presents the accompanying UML class model.

Maintenance and operations properties

Maintenance and operations properties describe properties related to the set of activities performed with the goal to preserve and extend the service life of the utilities. The class model represents these properties through the class 'MaintenanceProperties'. This class associates to the class 'AbstractNetworkFeature' to link the properties to the component maintenance and operations are performed on. In this association, 'MaintenanceProperties' always has a connected utility component, 'AbstractNetworkFeature'. Vice versa, the zero or many multiplicity shows that a component does not necessarily have be to associated with maintenance properties, but can, in case required, also be associated with many.

The class 'MaintenanceProperties' describes (1) the type of maintenance performed, (2) the specific maintenance activity, (3) whether the activity has been the previous maintenance activity, the current one, or a planned one and (4) which parties are related. The attribute 'maintenanceType' describes the type of maintenance performed and refers to the codelist 'MaintenanceType'. Types distinguished are corrective, preventive, predictive and prescriptive maintenance. The attribute 'activityType' describes the type of maintenance activity and refers to the codelist 'MaintenanceActivityType'. Activities distinguished are inspection, surveillance, rehabilitation and replacement. The attribute 'maintenanceTimeline' describes whether the particular maintenance activity is the last maintenance activity, the current maintenance activity or the planned maintenance activity, enclosed as values in the enumeration 'MaintenanceTimelineType'.

For each individual maintenance activity specific related parties can be assigned. In addition to the related parties to the utility network or utility component in general, additional (and new) parties may be involved in the particular maintenance activities. Within the class 'MaintenanceActivities' the related parties are described through the attribute 'relatedParty'. This attribute refers to the class 'RelatedParty' and has been explained before in section 5.3.3.

Cost and date properties

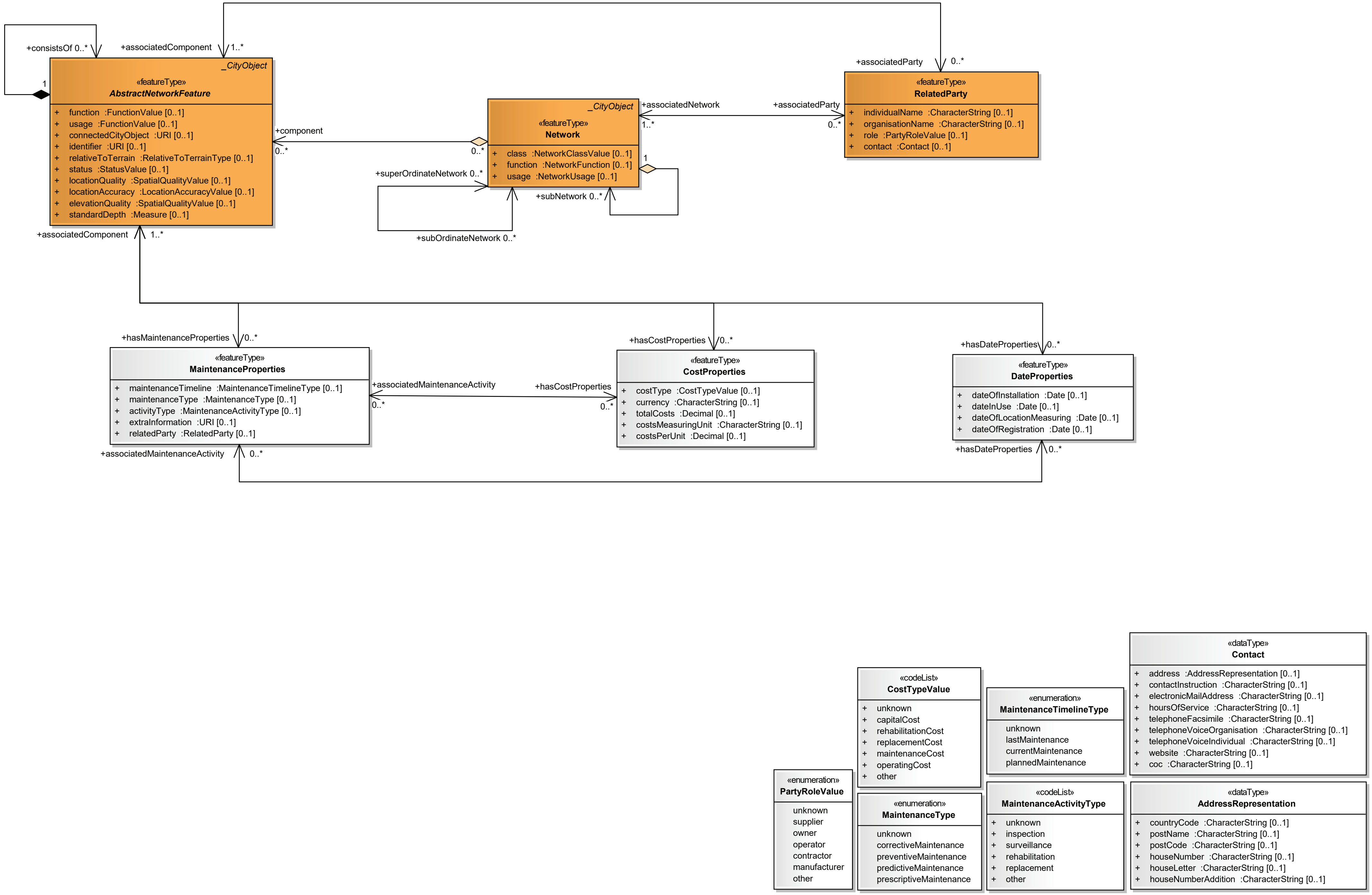
Cost properties define in general terms the type and amount of costs involved in the service life of the utility network and utility components in specific. Cost properties are represented in the class model through 'CostProperties'. Cost properties always connect with a component, i.e. 'AbstractNetworkFeature'. Vice versa, the zero or many multiplicity shows that a component does not necessarily have be to associated with cost properties, but can, in case required, also be associated with many.

The type of costs is described through the attribute 'costType' and refers to the codelist 'CostTypeValue'. Cost types include capital, rehabilitation, replacement, maintenance, and operating costs. Costs also can be modelled per defined measuring unit (for example per unit of length in case of a pipe). The attribute 'totalCosts' defines the costs for the component as a whole, which then might be the sum of the costs per unit. In addition, cost properties have a bi-directional association with maintenance properties. Maintenance and operations of utility components does bring costs into account. For example, rehabilitation of a component does result in rehabilitation costs. Another example is the existence of maintenance costs due to performed inspections and surveillances.

Date properties define the dates of interest to a utility component including the date of (1) installation, of (2) start usage, of (3) location measuring and of (4) registration. The date types are described through four separate attributes. The date properties are represented in the class model through the class 'DateProperties'. Date properties are always connected with a component, i.e. 'AbstractNetworkFeature'. Vice versa, the zero or many multiplicity shows that a component does not necessarily have be to associated with date properties, but can, in case required, also be associated with many. The date properties have an association with maintenance properties. For example, replacement of a component is associated with the date of installation and may consequently also have an influence on other date types.

Based on:
CityGML UtilityNetwork ADE 0.9.2

Maintenance and operations properties v4.1



5.3.7 Performance properties

Main characteristics of the 'Performance properties' class model are:

- Defines the performance properties of utility network components
- Defines the environmental, social and economic impact utility networks and their components

Below additional explanation to the 'Performance properties' class model is provided. Page 32 presents the accompanying UML class model.

Performance properties

Performance properties describe how utility networks and individual components perform. The class 'PerformanceProperties' represents the performance properties in the class model. Performance is described through five performance types being (1) engineering, (2) serviceability, (3) safety, (4) financial and (5) sustainability performance. Briefly, these five types of performance concern:

[1.] Engineering performance: structural soundness of the components.
[2.] Serviceability performance: intended functioning of the components.
[3.] Safety performance: safety of the component towards human beings.
[4.] Financial performance: balance between costs and benefits of the component.
[5.] Sustainability performance: ability of the component to be maintained at a certain serviceable level.

The performance types are included in the codelist 'PerformanceType'. Other attributes described by 'PerformanceProperties' involve the performance requirement, the performance score, whether the performance is sufficient and when the performance was measured. Extra information can be coupled through the attribute 'extraInformation'.

'PerformanceProperties' is both associated with the utility network as a whole and its individual components. Performance properties are thereby always connected with a utility network or an individual component. Vice versa, a network or individual component is not necessarily associated with performance properties.

Impact properties

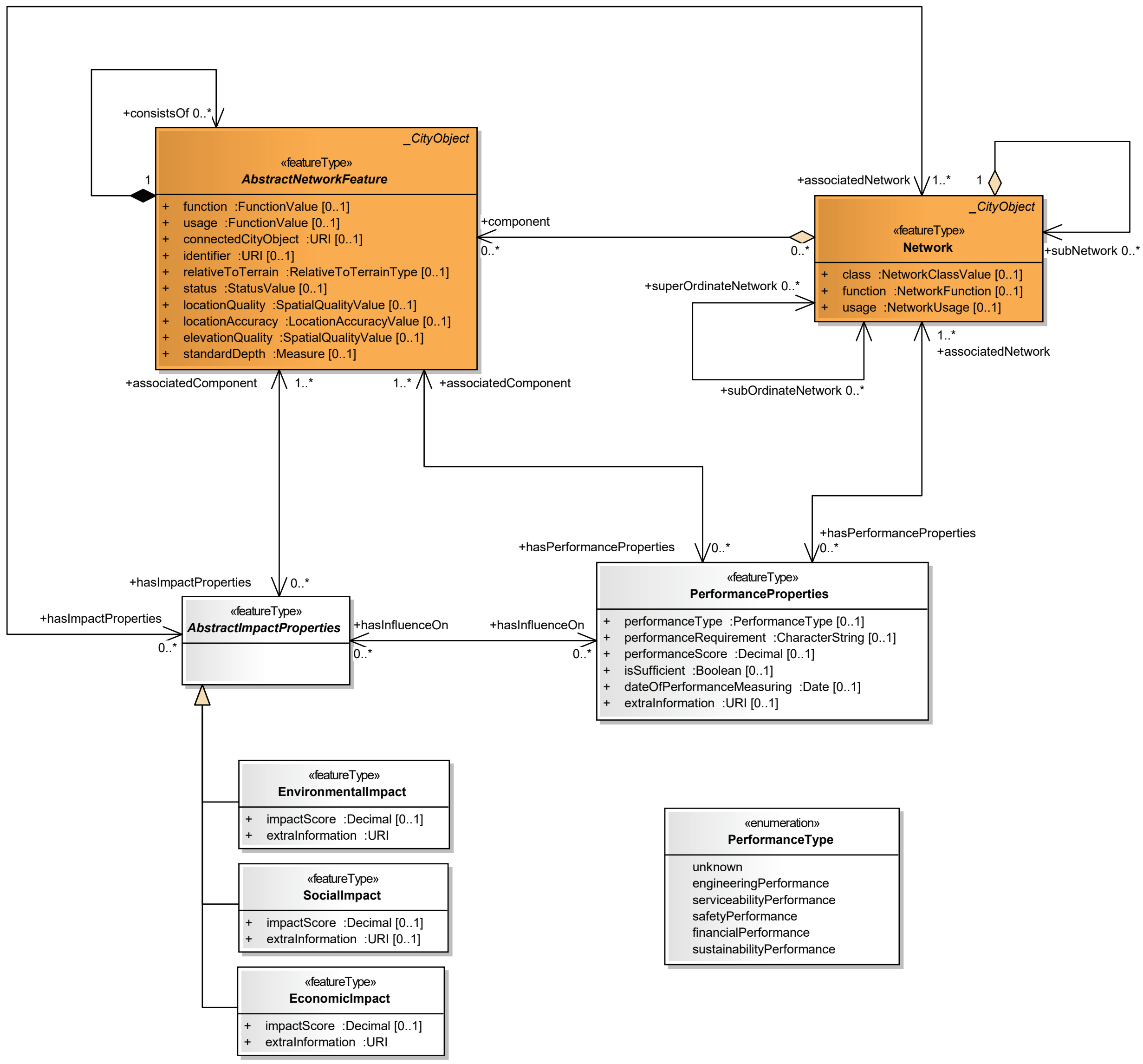
Impact properties describe the environmental, social and economic impact of utility networks and their individual component. The class 'AbstractImpactProperties' represents the impact properties in the class model. 'AbstractImpactProperties' is specialized into three subclasses being 'EnvironmentalImpact', 'SocialImpact' and 'EconomicImpact', describing respectively the environmental, social and economic impact of the component. Briefly, these three types concern:

[1.] Environmental impact: an effect to organisms or their environment as a result of development, industrial or infrastructural projects or activities.
[2.] Social impact: effect on the well-being of the surrounding community.
[3.] Economic impact: a financial effect that a decision, policy, or event has on the institution from a microeconomic perspective.

Each of these three subclasses describes the (relative) numeric impact score and can provide extra information about the impact through the attribute 'extraInformation'. The impact scores together provide a qualitative indication of the economic, social and environmental impact of a utility network and its components.

‘AbstractImpactProperties’ is associated with both the utility network as a whole (‘Network’) and its individual components (‘AbstractNetworkFeature’). Impact properties are thereby always connected with a utility network or an individual component. Vice versa, a network or individual component is not necessarily associated with performance properties.

In addition, the class ‘AbstractImpactProperties’ is bi-directionally associated with the class ‘PerformanceProperties’. Whereas an association is not necessarily present, the performance on safety, for example, may have an influence on the social impact. Another example may be the influence of the sustainability performance on the environmental impact. Through the multiplicity of zero or many of the association, the aforementioned association can be created though is not obligatory if not applicable.


+consistsOf 0..*
1
_CityObject
«featureType»
AbstractNetworkFeature
+ function :FunctionValue [0..1]
+ usage :FunctionValue [0..1]
+ connectedCityObject :URI [0..1]
+ identifier :URI [0..1]
+ relativeToTerrain :RelativeToTerrainType [0..1]
+ status :StatusValue [0..1]
+ locationQuality :SpatialQualityValue [0..1]
+ locationAccuracy :LocationAccuracyValue [0..1]
+ elevationQuality :SpatialQualityValue [0..1]
+ standardDepth :Measure [0..1]
+component
0..*
+associatedNetwork 1..*
1
_CityObject
«featureType»
Network
+ class :NetworkClassValue [0..1]
+ function :NetworkFunction [0..1]
+ usage :NetworkUsage [0..1]
+subNetwork 0..*
0..*
+superOrdinateNetwork 0..*
+subOrdinateNetwork 0..*
1..*
+associatedNetwork
+associatedComponent 1..*
1..* +associatedComponent
+hasPerformanceProperties 0..*
+hasPerformanceProperties 0..*
+hasImpactProperties 0..*
+hasImpactProperties
0..*
«featureType»
AbstractImpactProperties
+hasInfluenceOn
0..*
+hasInfluenceOn
0..*
«featureType»
PerformanceProperties
+ performanceType :PerformanceType [0..1]
+ performanceRequirement :CharacterString [0..1]
+ performanceScore :Decimal [0..1]
+ isSufficient :Boolean [0..1]
+ dateOfPerformanceMeasuring :Date [0..1]
+ extraInformation :URI [0..1]
«featureType»
EnvironmentalImpact
+ impactScore :Decimal [0..1]
+ extraInformation :URI
«featureType»
SocialImpact
+ impactScore :Decimal [0..1]
+ extraInformation :URI [0..1]
«featureType»
EconomicImpact
+ impactScore :Decimal [0..1]
+ extraInformation :URI
«enumeration»
PerformanceType
unknown
engineeringPerformance
serviceabilityPerformance
safetyPerformance
financialPerformance
sustainabilityPerformance

5.3.8 Hollow space

Main characteristics of the ‘Hollow space’ class model are:

- Defines the free and occupied space of distribution and protective components

Below additional explanation to the ‘Hollow space’ class model is provided. Page 34 presents the accompanying UML class model.

Free and occupied space

Hollow space refers to the volume available in either a distribution component* or a protective component. Information about the hollow space is relevant for maintenance and operations related activities. For example, through the hollow space it can become clear how much room there is left for an additional cable.

The hollow space class model is inherited from CityGML UtilityNetwork ADE. The total volume of distribution and protective component is represented in the class model by the class ‘AbstractHollowSpace’. This class is specialized in two subclasses being ‘HollowSpaceFree’ (defining which volume is free) and ‘HollowSpaceOccupied’ (defining which volume is occupied). ‘AbstractDimensionalProperties’ defines within the class model the measurements of the component, and therefore, the volume. This is represented by the association between ‘AbstractDimensionalProperties’ and ‘AbstractHollowSpace’.

In case of a distribution component, the hollow space is bounded by the dimensions of the distribution component and the commodity transported through the distribution components. This is represented in the class model through the association between ‘AbstractCommodity’ and ‘AbstractHollowSpace’. The space occupied by the commodity is represented by ‘HollowSpaceOccupied’. The free volume by ‘HollowSpaceFree’. This is illustrated in Figure 6 with the left schematization illustrating a pipe filled partially with water.

In case of a protective component, such as a round shell, the hollow space is bounded by the dimensions of the protective component and the number of components (likely to be cables and / pipes) it houses. The space occupied by the components inside the protective component are represented by ‘HollowSpaceOccupied’. The free space by ‘HollowSpaceFree’. This is illustrated in Figure 6 with the right schematization illustrating a round shell with two cables inside.

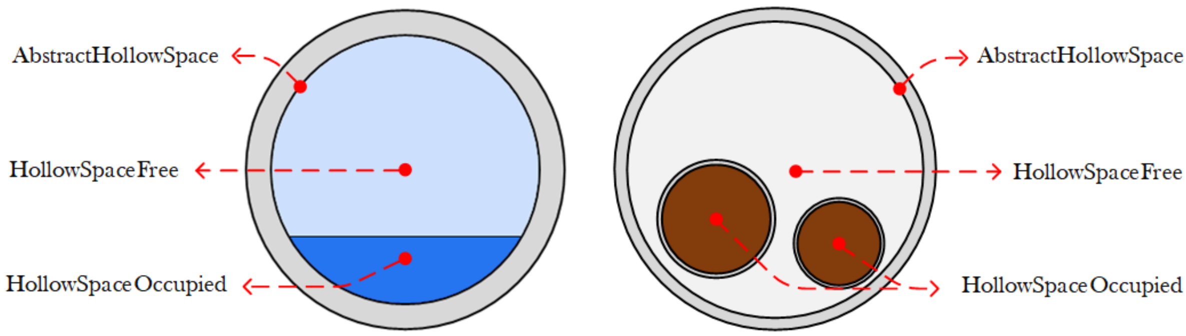
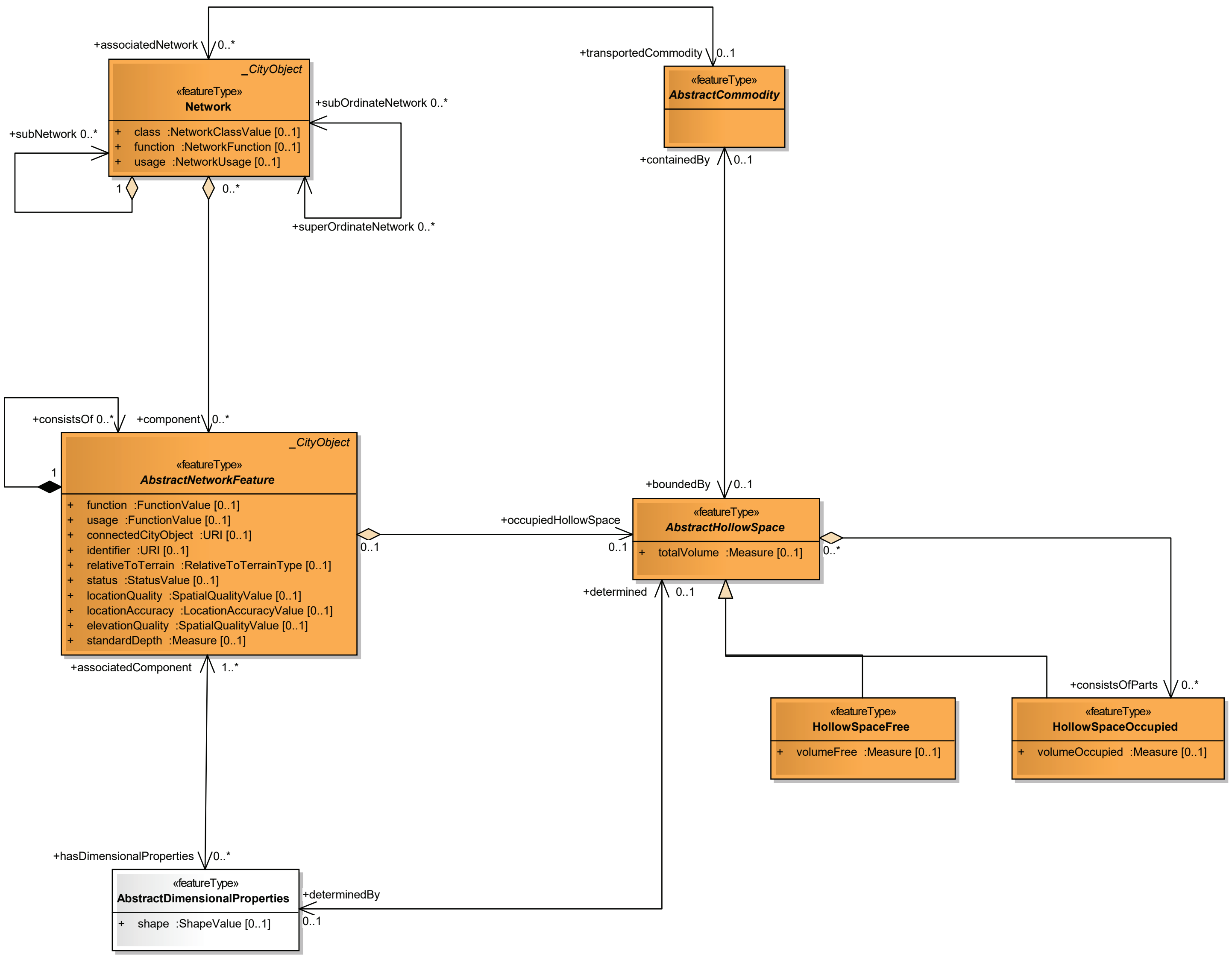


Figure 6 – Schematization of hollow space (distribution component left, protective component right)

* Does not apply to all distribution components under pressure (i.e. a gas pipe).


+associatedNetwork 0..*
_CityObject
«featureType»
Network
+ class :NetworkClassValue [0..1]
+ function :NetworkFunction [0..1]
+ usage :NetworkUsage [0..1]
+subNetwork 0..*
+subOrdinateNetwork 0..*
+superOrdinateNetwork 0..*
1
0..*
+transportedCommodity 0..1
«featureType»
AbstractCommodity
+containedBy 0..1
+consistsOf 0..*
+component 0..*
_CityObject
«featureType»
AbstractNetworkFeature
+ function :FunctionValue [0..1]
+ usage :FunctionValue [0..1]
+ connectedCityObject :URI [0..1]
+ identifier :URI [0..1]
+ relativeToTerrain :RelativeToTerrainType [0..1]
+ status :StatusValue [0..1]
+ locationQuality :SpatialQualityValue [0..1]
+ locationAccuracy :LocationAccuracyValue [0..1]
+ elevationQuality :SpatialQualityValue [0..1]
+ standardDepth :Measure [0..1]
+occupiedHollowSpace
0..1
0..1
+boundedBy 0..1
«featureType»
AbstractHollowSpace
+ totalVolume :Measure [0..1]
0..*
+determined 0..1
+associatedComponent 1..*
+consistsOfParts 0..*
«featureType»
HollowSpaceFree
+ volumeFree :Measure [0..1]
«featureType»
HollowSpaceOccupied
+ volumeOccupied :Measure [0..1]
+hasDimensionalProperties 0..*
«featureType»
AbstractDimensionalProperties
+ shape :ShapeValue [0..1]
+determinedBy
0..1

5.4 Feature catalogue

The feature catalogue is provided in the separate document 'Operations and Maintenance – Feature Catalogue'. Table 4 provides the main document characteristics of the feature catalogue.

Table 4 – Feature catalogue document characteristics

Name	Operations and Maintenance – Feature Catalogue
Document name	OM_Feature_Catalogue.pdf
Scope	Operations and Maintenance conceptual schema
Version	2.1
Date of version	11-01-2019
Origin of definitions	Operations and Maintenance – Data Specification

In addition to the feature catalogue, Table 5 presents the classes defined in the feature catalogue, including their heritage and stereotype. In case features of the CityGML UtilityNetwork ADE were altered in the Operations and Maintenance conceptual schema (orange classes in the UML class models), the heritage is defined as being from the Operations and Maintenance conceptual schema. Only those directly inherited from CityGML UtilityNetwork ADE (purple classes in the UML class models) also get their heritage defined as being CityGML UtilityNetwork ADE.

Table 5 – Classes defined in feature catalogue

Class	Heritage	Stereotype
AbstractCable	Operations and Maintenance	<< FeatureType >>
AbstractCityObject	Operations and Maintenance	<< ADEElement >>
AbstractCommodity	CityGML UtilityNetwork ADE	<< FeatureType >>
AbstractCommodityClassifier	CityGML UtilityNetwork ADE	<< FeatureType >>
AbstractCommoditySupply	Operations and Maintenance	<< DataType >>
AbstractDimensionalProperties	Operations and Maintenance	<< FeatureType >>
AbstractDistributionComponent	Operations and Maintenance	<< FeatureType >>
AbstractExtraInformation	Operations and Maintenance	<< FeatureType >>
AbstractFunctionalComponent	Operations and Maintenance	<< FeatureType >>
AbstractHollowSpace	Operations and Maintenance	<< FeatureType >>
AbstractImpactProperties	Operations and Maintenance	<< FeatureType >>
AbstractLink	CityGML UtilityNetwork ADE	<< FeatureType >>
AbstractLinkControl	CityGML UtilityNetwork ADE	<< DataType >>
AbstractMaterialProperties	Operations and Maintenance	<< FeatureType >>
AbstractNetworkFeature	Operations and Maintenance	<< FeatureType >>
AbstractPipe	Operations and Maintenance	<< FeatureType >>
AbstractProtectiveComponent	Operations and Maintenance	<< FeatureType >>
AbstractSignature	CityGML UtilityNetwork ADE	<< DataType >>
Actuator	CityGML UtilityNetwork ADE	<< FeatureType >>
AddresRepresentation	Operations and Maintenance	<< DataType >>
Bedding	CityGML UtilityNetwork ADE	<< FeatureType >>
ChemicalClassifier	CityGML UtilityNetwork ADE	<< FeatureType >>
CityGML_Core:: AbstractCityObject	CityGML UtilityNetwork ADE	<< FeatureType >>
CityObjectGroup	CityGML UtilityNetwork ADE	<< FeatureType >>
ComplexFunctionalComponent	CityGML UtilityNetwork ADE	<< FeatureType >>

ComplexFunctionalComponentValue	Operations and Maintenance	<< Codelist >>
ConnectionComponent	CityGML UtilityNetwork ADE	<< FeatureType >>
ConnectionComponentValue	Operations and Maintenance	<< Codelist >>
Contact	Operations and Maintenance	<< DataType >>
ControllerComponent	Operations and Maintenance	<< FeatureType >>
ControllerComponentValue	Operations and Maintenance	<< Codelist >>
CostProperties	Operations and Maintenance	<< FeatureType >>
CostTypeValue	Operations and Maintenance	<< Codelist >>
DateProperties	Operations and Maintenance	<< FeatureType >>
Depth	Operations and Maintenance	<< DataType >>
DepthAccuracyLevel	Operations and Maintenance	<< Codelist >>
DepthPointOfMeasurement	Operations and Maintenance	<< Codelist >>
DepthReferenceLevel	Operations and Maintenance	<< Codelist >>
EconomicImpact	Operations and Maintenance	<< FeatureType >>
ElectricalCommodity	Operations and Maintenance	<< FeatureType >>
ElectricalCommodityValue	Operations and Maintenance	<< Enumeration >>
ElectricalSupply	Operations and Maintenance	<< DataType >>
ElectricityCable	Operations and Maintenance	<< FeatureType >>
ElectricityCableTypeValue	Operations and Maintenance	<< Codelist >>
EnvironmentalImpact	Operations and Maintenance	<< FeatureType >>
ExteriorDimensions	Operations and Maintenance	<< FeatureType >>
ExteriorMaterial	Operations and Maintenance	<< FeatureType >>
FeatureGraph	CityGML UtilityNetwork ADE	<< FeatureType >>
FillingMaterial	Operations and Maintenance	<< FeatureType >>
FunctionValue	CityGML UtilityNetwork ADE	<< Codelist >>
GaseousCommodity	Operations and Maintenance	<< FeatureType >>
GaseousCommodityValue	Operations and Maintenance	<< Enumeration >>
GaseousSupply	Operations and Maintenance	<< DataType >>
GenericClassifier	CityGML UtilityNetwork ADE	<< FeatureType >>
Geometric primitive:: GM_Curve	CityGML UtilityNetwork ADE	<< DataType >>
Geometric primitive:: GM_Point	CityGML UtilityNetwork ADE	<< DataType >>
Geometric primitive:: GM_Solid	Operations and Maintenance	<< DataType >>
Geometric primitive:: GM_Surface	Operations and Maintenance	<< DataType >>
GHSClassifier	CityGML UtilityNetwork ADE	<< FeatureType >>
GroundWater	Operations and Maintenance	<< DataType >>
GroundWaterReference	Operations and Maintenance	<< Codelist >>
HazardClass	CityGML UtilityNetwork ADE	<< DataType >>
HollowSpaceFree	Operations and Maintenance	<< FeatureType >>
HollowSpaceOccupied	Operations and Maintenance	<< FeatureType >>
IdentifierTypeValue	Operations and Maintenance	<< Codelist >>
InterFeatureLink	CityGML UtilityNetwork ADE	<< FeatureType >>
InterFeatureLinkValue	CityGML UtilityNetwork ADE	<< Enumeration >>
InteriorDimensions	Operations and Maintenance	<< FeatureType >>
InteriorFeatureLink	CityGML UtilityNetwork ADE	<< FeatureType >>
InteriorMaterial	Operations and Maintenance	<< FeatureType >>
Label	Operations and Maintenance	<< FeatureType >>
LineMeaningValue	CityGML UtilityNetwork ADE	<< Codelist >>

LineValue	CityGML UtilityNetwork ADE	<< Codelist >>
LiquidCommodity	Operations and Maintenance	<< FeatureType >>
LiquidCommodityValue	Operations and Maintenance	<< Enumeration >>
LiquidSupply	Operations and Maintenance	<< DataType >>
LocationAccuracyValue	Operations and Maintenance	<< Codelist >>
MaintenanceActivityType	Operations and Maintenance	<< Codelist >>
MaintenanceProperties	Operations and Maintenance	<< FeatureType >>
MaintenanceTimelineType	Operations and Maintenance	<< Enumeration >>
MaintenanceType	Operations and Maintenance	<< Codelist >>
MaterialValue	CityGML UtilityNetwork ADE	<< Codelist >>
MeasurementComponent	CityGML UtilityNetwork ADE	<< FeatureType >>
MeasurementComponentValue	Operations and Maintenance	<< Codelist >>
Network	Operations and Maintenance	<< FeatureType >>
NetworkClassValue	Operations and Maintenance	<< Enumeration >>
NetworkFunction	Operations and Maintenance	<< Enumeration >>
NetworkGraph	CityGML UtilityNetwork ADE	<< FeatureType >>
NetworkLink	CityGML UtilityNetwork ADE	<< FeatureType >>
NetworkUsage	Operations and Maintenance	<< Enumeration >>
Node	CityGML UtilityNetwork ADE	<< FeatureType >>
NodeValue	CityGML UtilityNetwork ADE	<< Enumeration >>
OilGasChemicalsPipe	Operations and Maintenance	<< FeatureType >>
OilGasChemicalsPipeTypeValue	Operations and Maintenance	<< Codelist >>
OpticalCommodity	Operations and Maintenance	<< FeatureType >>
OpticalCommodityValue	Operations and Maintenance	<< Enumeration >>
OpticalModeValue	Operations and Maintenance	<< Enumeration >>
OpticalSupply	Operations and Maintenance	<< DataType >>
OtherComponent	CityGML UtilityNetwork ADE	<< FeatureType >>
OtherComponentValue	Operations and Maintenance	<< Codelist >>
OtherShell	CityGML UtilityNetwork ADE	<< FeatureType >>
PartyRoleValue	Operations and Maintenance	<< Enumeration >>
PerformanceProperties	Operations and Maintenance	<< FeatureType >>
PerformanceType	Operations and Maintenance	<< Codelist >>
ProtectiveShell	CityGML UtilityNetwork ADE	<< FeatureType >>
RectangularShell	CityGML UtilityNetwork ADE	<< FeatureType >>
Regulator	CityGML UtilityNetwork ADE	<< FeatureType >>
RelatedParty	Operations and Maintenance	<< FeatureType >>
RelativeToTerrainType	Operations and Maintenance	<< Enumeration >>
RoleInNetwork	CityGML UtilityNetwork ADE	<< FeatureType >>
RoundShell	CityGML UtilityNetwork ADE	<< FeatureType >>
SewerPipe	Operations and Maintenance	<< FeatereType >>
SewerPipeTypeValue	Operations and Maintenance	<< Codelist >>
ShapeValue	Operations and Maintenance	<< Codelist >>
SignalWordValue	CityGML UtilityNetwork ADE	<< Enumeration >>
SimpleFunctionalComponent	CityGML UtilityNetwork ADE	<< FeatureType >>
SocialImpact	Operations and Maintenance	<< FeatureType >>
SoiValue	Operations and Maintenance	<< Codelist >>
SolidCommodity	Operations and Maintenance	<< FeatureType >>

SolidCommodityValue	Operations and Maintenance	<< Enumeration >>
SolidSupply	Operations and Maintenance	<< DataType >>
SpatialQualityValue	Operations and Maintenance	<< Enumeration >>
StatusValue	Operations and Maintenance	<< Enumeration >>
Storage	CityGML UtilityNetwork ADE	<< DataType >>
StorageComponent	Operations and Maintenance	<< FeatureType >>
StorageComponentValue	Operations and Maintenance	<< Codelist >>
Supply	CityGML UtilityNetwork ADE	<< DataType >>
SupplyArea	CityGML UtilityNetwork ADE	<< FeatureType >>
SurroundingSoilProperties	Operations and Maintenance	<< FeatureType >>
TelecommunicationCable	Operations and Maintenance	<< FeatureType >>
TelecommunicationCableTypeValue	Operations and Maintenance	<< Codelist >>
TerminalComponent	Operations and Maintenance	<< FeatureType >>
TerminalComponentValue	Operations and Maintenance	<< Codelist >>
ThermalPipe	Operations and Maintenance	<< FeatureType >>
ThermalPipeTypeValue	Operations and Maintenance	<< Codelist >>
WaterPipe	Operations and Maintenance	<< FeatureType >>
WaterPipeTypeValue	Operations and Maintenance	<< Codelist >>

5.4.1 Spatial object types

See Operations and Maintenance – Feature Catalogue.

5.4.2 Codelists and enumerations

See Operations and Maintenance – Feature Catalogue.

6 Reference systems

This section describes (1) the coordinate reference system, (2) the temporal reference system, and (3) the units of measure used within the Operations and Maintenance conceptual schema.

Coordinate reference system

A coordinate reference system is composed of a coordinate system and a datum. A coordinate system is a set of mathematical rules for specifying how coordinates are to be assigned to points. A datum is a parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system. (ISO 19111:2007)

Following ISO 19136:2007, GML does not assume a fixed coordinate reference system. Although based on GML, the Operations and Maintenance conceptual schema does explicitly specify the coordinate reference systems for all contained geometry elements. Reason is that, even though GML does allow a mixed usage of coordinate reference systems within the same dataset, a limited number of coordinate reference systems simplifies the processing of the dataset by software.

Spatial data sets modelled by the Operations and Maintenance conceptual schema are based on both two- and three-dimensional coordinate reference systems. The datum of the coordinate reference system is the European Terrestrial Reference System 1989 (ERTS89). Spatial data sets should adhere to the two- and three-dimensional coordinate reference systems from Table 6. These are in accordance with INSPIRE D2.8.III.6 Data Specification on Utility and Government Services – Technical guidelines.

Table 6 – Coordinate Reference Systems

Coordinate reference system	URL identifier
Three-dimensional Cartesian coordinates based on ERTS89 using parameters of the Geodetic Reference System (GRS80)	http://www.opengis.net/def/crs/EPSG/0/4936
Three-dimensional geodetic coordinates based on ERTS89 using parameters of GRS80	http://www.opengis.net/def/crs/EPSG/0/4937
Two-dimensional geodetic coordinates bases on ERTS89 using parameters of GRS80	http://www.opengis.net/def/crs/EPSG/0/4258
Plane coordinates using ERTS89 Lambert Azimuthal Equal Area	http://www.opengis.net/def/crs/EPSG/0/3035
Plane coordinates using the ERTS89 Lambert Conformal Conic	http://www.opengis.net/def/crs/EPSG/0/3034
Plane coordinates using the ERTS89 Transverse Mercator	http://www.opengis.net/def/crs/EPSG/0/3038

Temporal reference system

The default temporal reference system is the Gregorian calendar with UTC, following ISO 8601:2000. Examples of how the temporal reference system is applied are:

2019 (the year 2019), 2019-05-16 (16th May 2019), 2019-05-16T15:30:50+01:00 (16th May 2019, 15h 30' 50", time zone: UTC+1)

Units of measure

All units of measure are expressed using the SI system of units (ISO 1000:1992). This is in accordance with INSPIRE D2.8.III.6 Data Specification on Utility and Government Services – Technical guidelines and GML (ISO 19136:2007).

7 Online repository

All documentation and data of the Operations and Maintenance conceptual schema are available at an online repository, being:

https://github.com/RamonTerHuurne/UtilityNetwork-OperationsAndMaintenance

Documentation available at the repository includes the 'Operations and Maintenance – Data Specification', 'Operations and Maintenance – Feature Catalogue' and 'Operations and Maintenance – Overview of class models in UML'. In addition, the repository includes the following:

[1.] The **UML model** of the Operations and Maintenance conceptual schema created within Enterprise Architect:
- The .eap file containing the UML model.

[2.] The **XML schema file** of the Operations and Maintenance conceptual schema directly derived from the UML class model using the software ShapeChange:
- The file containing the XML schema file.
- Codelist dictionary in .xml, accessible for alterations.
- FME feature types definition file in .xml.

[3.] The **ShapeChange configuration file** to derive the XML schema file and code lists dictionaries:
- For further use of the software it is referred to http://shapechange.net/.

Bibliography

CityGML. (2016). *CityGML UtilityNetwork ADE.* Retrieved from http://www.citygmlwiki.org/index.php/CityGML_UtilityNetworkADE

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Kutzner, T., & Kolbe, T. H. (2016). Extending Semantic 3D City Models by Supply and Dispossal Networks for Analysing the Urban Supply Situation. *Drëilandertagung der DGPF, der OVG, und der SGPF* (pp. 382-394). Bern, Switzerland: DGPF.

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