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Use Cases and their Requirements on the Semantic Modeling of 3D Supply and Disposal Networks

IHAB HIJAZI[1,2], TATJANA KUTZNER[1] & THOMAS H. KOLBE[1]

Abstract: Different utility network data models were developed by different industries to provide means to represent, exchange and store utility networks. Often, these network data models are developed to meet the needs of specific domains without considering the integrated representation of different network systems. Moreover, mutual relations between networks as well as their embedding into 3D urban space are not always supported. The CityGML extension UtilityNetworkADE aims at meeting the requirements of the complex modern urban utilities.
This paper aims at evaluating the capability of the different network models including the UtilityNetworkADE to meet the needs of network infrastructure. The requirements were extracted from a list of use cases that was defined by a number of experts from different domains. The investigation points out that, in most cases, the UtilityNetworkADE is capable of linking different network systems, providing an integrated view to understand the relation to city entities. Only regarding connectivity rules there is no exact concept to represent them in the UtilityNetworkADE up to now. Many examples are discussed for the limitations and capabilities of different network data models.

1 Introduction

Modern society depends on a stable and a complex array of networks to deliver fuel, water and wastewater, electricity, gas and communication. Utility network infrastructures require an improved model to manage their relation to other network systems and to provide an integrated view to understand the interaction between city entities and utility networks.

In GIS and CAD, distribution systems are typically modeled as networks. Such networks form a directed graph (also called digraph), where each connector, fixture or outlet is viewed as a vertex. Each uninterrupted stretch of wire or pipe is viewed as an edge. Flow networks are represented by a special kind of graph, called a tree, where the nodes are reachable from one starting node and where no cycles exist. When creating a graph for a flow network, questions that deal with the reachability in a digraph G could be answered like this (GOODRICH et al., 2014): Given vertices u and v, determine whether u reaches v (i.e. does a chain between u and v exist?). Find all the vertices of G that are reachable from a given vertex s. Determine the ancestor vertices for a given list of vertices. However, networks in traditional GIS data models do not manage the third and fourth (i.e. temporal) dimensions and also do not consider the representation of network objects together with city entities.

In recent years, the development of semantic 3D city models has allowed for new approaches to town planning and urban management (BILJECKI et al. 2015) such as emergency and catastrophe

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[1] Technische Universität München, Lehrstuhl für Geoinformatik,
  Arcisstraße 21, D-80333 München, E-Mail: [kutzner, ihab.hijazi, thomas.kolbe]@tum.de
[2] An-Najah National University, Department of Urban Planning Engineering, Nablus, Palestine

preparation planning, checking building developments, and utility networks. These 3D city models provide a representation of cities that goes beyond visualization in terms of the application that they can support. One standard for representing semantic 3D city models is the international OGC standard CityGML (GRÖGER et al. 2012) which is currently extended to support applications in the context of urban planning and geo-design. These extensions include: 1) a General Indicator Model which allows for linking indicators to city objects and for evaluating scenarios (ELFOULY et al. 2015); 2) a Dynamizer concept which extends static 3D city models by the ability to support variations of individual feature properties and associations over time (CHATURVEDI & KOLBE 2016); 3) an EnergyADE (KADEN et al. 2015) which aims at storing information for energy simulations and energy system modelling as well as solar energy analysis; the EnergyADE deals with different data qualities, levels of details and urban energy model complexities; and 4) a UtilityNetworkADE (BECKER et al. 2011; BECKER et al. 2012; KUTZNER & KOLBE 2016) that supports the modeling and simulation of supply and disposal networks in 3D city models as well as the fluxes of the commodities such as water, electricity and gas within these networks.

In this paper, utility networks in urban areas are considered. The paper documents use cases defined by a number of expertise from different views and domains such as: planning and simulation of district heating, electricity and freshwater networks, planning and operation of smart energy, supply and disposal networks, vulnerability assessment and disaster management, city system simulation and Smart Cities as well as facility management. The aim is to determine the requirements of these use cases. Different requirements of these situations were defined and a list of requirements was documented complying with their semantics, dimension, visualization, relationships, connection to sensors, and scale level. These are analyzed to evaluate data models that match the requirements in the best way.

The paper is subdivided into five sections. Section 2 presents use cases for utility networks and corresponding requirements. Section 3 introduces different utility network data models. Section 4 reviews these network models with the aim to identify what kind of information modeling is applied and if the methods comply with the identified utility network requirements. Section 5 concludes with a discussion about future research on utility network modeling.

2 Use cases and their requirements

2.1 Utility network use cases

To be able to determine the information need for utility network applications, an inventory of possible applications has been made. The use cases were developed in discussion with experts from different domains, such as storm drainage, water, electricity, energy planning, and facility management. The use cases presented below do not pretend to be complete, but reveal some tendencies. The following cases have been identified.

2.1.1 Storm drainage network

By nature, as cities thrive, urban areas expand. The permeable earth of urban areas that provide the natural drainage or soak the storm water has been replaced by roads, buildings, and other hard surfaces that no longer allow rainwater to soak into the ground. Therefore, now in urban areas,

man – not nature – must control the surface water as well as protect the water supply. So the storm drainage system (cf. figure 1) collects surface water into underground pipes and conveys it to a surface watercourse, streams, rivers and lakes. The storm drainage network system is comprised of pipes, manholes, and catch basins. Catch basins are the buried basins that collect runoff from the streets and other ground surfaces, and are typically located below curb grates seen in the streets. As long as everything functions properly, there is little concern about this
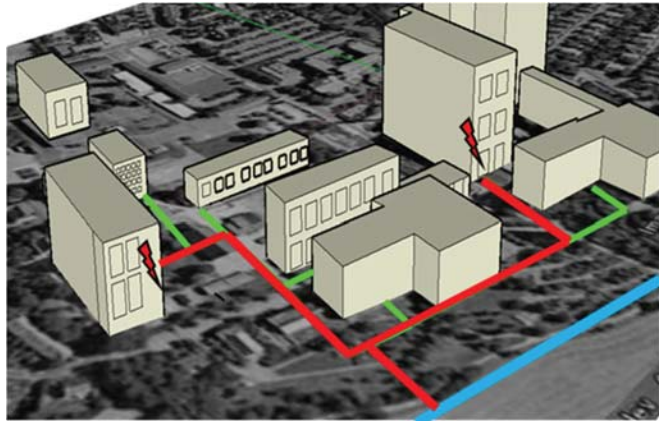

Fig. 1: Building discharge into the storm drainage network

system until a heavy storm occurs and water cannot drain rapidly enough from the streets. The capacity of the drains is determined by the flow that can be discharged by the drainage system and the storage available. When the hydraulic capacity is insufficient in a certain discharge situation, flooding occurs and water discharges to the surface. The occurrence of these events must be minimized, particularly because a lack of drainage systems is related to public health hazards (HIJAZI et al. 2012).

Water authorities have the responsibility to plan and manage the storm drainage network, they need to reduce the overflow in the storm drainage system, and the aim is to decrease the water overflow and to secure the city from flooding. The water authorities have the responsibility to know the building sites (area/volume, private/public), building roofs and sewer systems that are connected to the storm drainage network, the areas of roofs and the land surface type. This will allow the city to estimate the amount of water that will be discharged into the storm drainage system. Therefore, there is a need to calculate the building roof areas, the different built up areas and their covering materials. Moreover, this information is of great importance to the city in order to calculate the fees they need to charge from citizens.

The water authorities do not have yet a tool that allows them to search the network and quickly access the information that enables them to connect to the buildings and get information about its roof properties; also they need to get information about built up areas that are used as parking or as asphalt yards. The water authority needs to be able to get the area of buildings and non-permeable surfaces that are connected to specific parts of the network. Retrieval of the relevant information about the roofs and other surfaces is important in order to take actions to change these surfaces to a permeable one where water can soak in. Also, a textual description that is providing a reference to the locations of the building and their owners would be useful. Information about the area of the roofs, surfaces and building uses is of great importance.

2.1.2 Clean water act

The second use case refers to the inspection of waste water. City authorities perform regular inspections of some buildings in the city (e.g. chemical labs, factories) to ensure that the water discharged from these buildings does meet the safety standards of public water resources. The

inspection team needs to find the location of these elements inside these buildings to test whether they are working properly. The team needs a reliable tool that allows them to select a point in the network. The system should identify the buildings that contain the devices that are connected to the defined point and need inspection, and it should also show the exact location of these devices in the buildings and how they connect to the external network. Therefore, the proposed system should provide a suitable description for the location of these devices inside the building, e.g. the building and the storey they are within. Also, there is a need to establish a linkage to natural water resources such as streams. A method that provides the water authority with the ability to force rules on the network that can be linked to the natural water resource is useful in this use case. Using connectivity rule techniques, the network authority can control how to connect to other systems (HIJAZI et al. 2012)

2.1.3 Vulnerability assessment and disaster management emergency response

This use case refers to disaster management in different stages, i.e. vulnerability assessment and emergency situation. Vulnerability assessment is of great importance, as cities need to know the effects of natural disasters or man-made disasters on utility networks. Important information to know is the area that can be affected and how this can affect specific network systems. The city needs to know the buildings and city facilities that will be out of service based on this natural or man-made disaster, and also the interdependency between a specific network system and other network systems is of great importance. Having the different network systems and the city objects linked in one data model (cf. figure 2) will facilitate vulnerability assessment of the city infrastructure in order to develop mitigation plans.
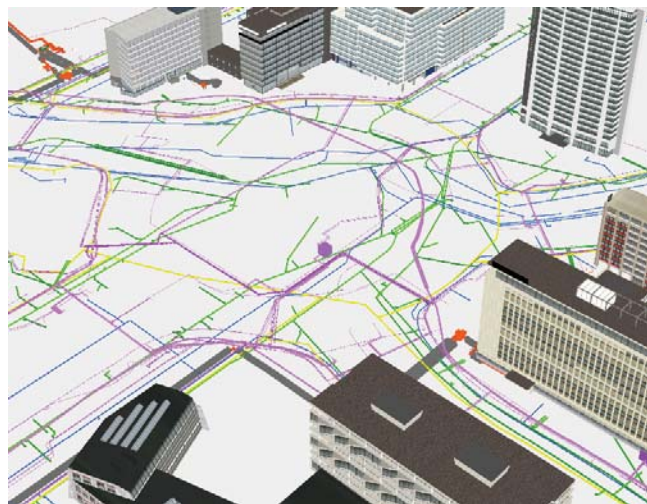

Fig. 2: Integrated representation of city objects and different network systems at the Ernst-Reuter-Platz in Berlin as realized in the SIMKAS 3D project (BECKER et al. 2012)

In emergency situations, when the precise location of a shut-off valve and the response in a timely manner are key issues, e.g. during fire incidents, the crew team should be able to disconnect any part(s) of the service system. The operational workflow starts with a notification of the facility management to help. The facility management needs an information system that can be used to define the location where the accident has occurred. It must identify which device (switch or transformer) should be turned off, so as to disconnect the relevant part(s) of the service system in the building or any city facility; this will also include a shut-off of the flow in other network systems that can be affected. Moreover, the system should also generate a notification report, list all the buildings and facilities that will be affected by the shut-off, and communicate this list to all the occupants of these buildings and facilities users. The list should include detailed information describing the location of the shut-off with reference to the building structure or any other city

objects, and also information on the building itself. Decisions based on unreliable information about the location of a shut-off can result in a delayed response to a critical situation and additional costs will result from the extra damage. In addition, damage in network systems can affect accessibility to the city and can therefore affect city life.

2.1.4 Maintenance operations

This use case focuses on warning residents about a scheduled or unscheduled maintenance. Facility managers need to perform maintenance operations, which can be either caused by a failure in the network or by planned (preventive) operation (due to date of expiration or cleaning). Both cases will cause an outage of service, because replacing of elements is required. Therefore, occupants of private buildings or public facilities need to be warned. The operational workflow starts by announcing the maintenance operation prior to its date after which the location of the shut-off valve must be defined and submitted to the field crew. The process in the field starts by closing the shut-off valve. In some cases, there is more than one option, and the best one to select will be that which affects the least number of occupants and city facilities (although this is not easy to define in the current system). The facility management teams need a tool that allows them to search the network and quickly access the information that enables them to contact the persons in the buildings or part of the buildings that will be affected; or, at best, since retrieval of the relevant information takes a sizable amount of time, and, thus, not all the information can be retrieved in time, the team has to make an assumption and generalize the announcement. The team needs to be able to input the location of the maintenance and have the GIS return an information product that includes a 3D view that describes the location of the shut-off and provides a textual description of the location of the shut-off in a human-oriented form. The view should provide a perspective of the space where the shut-off is, including the structure elements (e.g. manholes, walls or slabs) and the network segments under suspicion, the segments being connected to the structure elements both upstream and downstream, as well as any other structure elements that immediately surround the shut-off location. Finally, the team needs to define the network elements and their contained space, or city objects that would be out of service when there will be a shut-off. Also a textual description is needed providing a reference to the location of the space within the city feature (e.g. building or a long street).

2.1.5 Smart energy planning, simulation and operation

This use case considers issues related to electrical grid, heating and cooling simulations. Electricity planners and energy authorities need to know how a change in land use can affect the energy consumptions and production, therefore they need to relate a supply area to a specific object that provides the commodities to the area – this object can be considered the source for the supply area. Supply areas are in particular useful, when the detailed modeling of the supply lines is not available (KUTZNER & KOLBE 2016). Another important information is related to the ability to perform network analyses of the different utilities considering different scale levels. Moreover, another important issue to consider for simulation purposes is the ability to provide network objects themselves with information about their potential and current supply of commodities to them. In addition, considering the issue of security is of great importance, therefore the availability of supply areas can be important in this matter. This use case also requires that energy planning

authorities can define rules of how to connect network features to city entities and other network types. Furthermore, there is a need of coupling smart grids with buildings to simulate various issues concerning energy production, consumption and distribution.

2.1.6 Facility management

Facility management departments that are responsible for maintaining utility networks need an integrated modeling of the utilities with other city features (cf. figure 2). In addition, an important part of their work is their ability to access utility network objects for maintenance or repair, which can be done by humans or robots. Facility managers need to have a tool that enables them to navigate within networks for utility network analysis and to find easy access points, which allows performing the maintenance operations and minimizing disturbances.
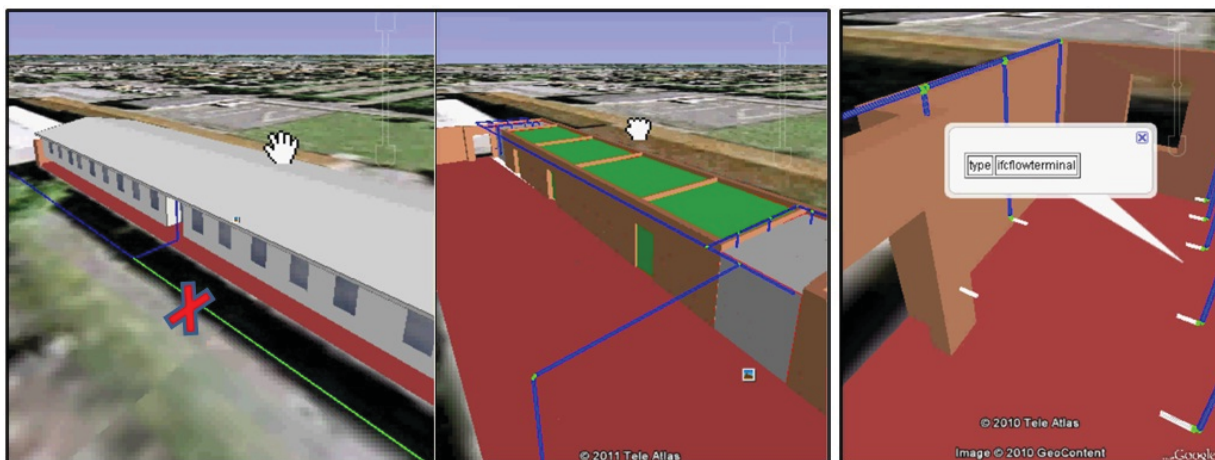

Fig. 3: Outdoor and indoor network integrated with 3D building features (HIJAZI et al. 2012)

2.2 Utility network requirements

On the basis of the use cases presented in the previous section, we define aspects that are relevant to the use cases. These aspects can be considered as modeling criteria or data modeling requirements regardless of the application or the final goal. These aspects will be used for the evaluation of selected network models that will be discussed in the next section. In all, a set of 18 generic and sub generic requirements were identified and subdivided into five groups:

- *Spatial scope*: The use cases provide us with the spatial extent that is required to facilitate the workflow in the use case. Some of the use cases operations need to be modeled on city block level, others on city level or district level. Providing a modeling mechanism to aggregate or disaggregate the models to different scopes and extents is of importance.
- *Visualization*: Topographic representation is one of the most important aspects for 2D and 3D representation of network objects. Realism and interaction are necessary for information to be understood quickly. In this part of the requirements investigation, we consider the following aspects:
  - Resolution and true 2D and 3D representation of network objects and other city objects
  - Representation methods such as iconic, mapped and realistic visualization.
  - Levels of detail as another method used to decrease the complexity of 3D representations.

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- *Spatial relationships*: The investigation of the operation to be performed on the different use cases provides us with the relationships that should be preserved. These spatial relationships are relationships between network objects itself within the same network, between different networks or between network objects and other city features. These relationships can be summarized as follows:
    - There is a need to link in the data level between the network fixtures (e.g. lamps, sinks), and the city features e.g. space, street in order to select the spaces - or part of buildings or city features that would be out of service.
    - There is a need for a link between network elements itself in order to be able to trace the commodities that are moving through the network objects.
    - There is some network-to-network linkage that must be made between the network systems; i.e. the logical relationship between the hot water and the electricity network that needs to be maintained in the network.
    - The relation between the exterior and interior networks needs to be maintained.
    - Finally, there is a need to force constraints on how to establish the different relationships mentioned above.
- *Semantic representation*: Most of the use cases require a semantic categorization of the network objects based on their role in the network. Moreover, other semantic information related to the dimensionalities, materials, volume and geometric properties of network objects are required.
- Connection to *sensors* and time-variant attributes: Some of the decisions related to network management or planning requires up-to-date information about the status of the network elements or the amount of stocks available at a specific time.

3   Related network models

A range of data models for representing, exchanging, analyzing and storing utility network infrastructures exist already. This section provides a short overview of those models which are currently most relevant in the geospatial domain.

- The EU Directive INSPIRE provides the *INSPIRE Utility Networks* model (JRC 2013a) which is based on the INSPIRE Generic Network Model (JRC 2013b). The INSPIRE Utility Networks data model defines a 2D topological relationship between network objects and allows for representing five different types of networks (water, electricity, waste water, district heat and oil/gas/chemicals). However, the semantic categorization of network objects is basic, i.e. the data model defines, for instance, pipes and cables, but does not provide a further domain-specific classification of these network elements.
- The *Industry Foundation Classes* (IFC) is an ISO standard (ISO 16739:2013) which is predominantly used in Building Information Modeling. IFC provides a 2D and 3D representation of network objects. Relationships between network objects are described using a connectivity concept, which comprises both the physical and logical connectivity. Therefore, with the IFC data model it is possible to establish a linkage between different network types. IFC provides a rich semantic categorization of network objects based on their role in the network. However, the IFC data model was developed with the intension to provide a way to

model utilities at the building level. The integration of city scale network on small scale (large areas) is not supported.

- ArcGIS provides two sets of network data models to manage the logical and physical relations in a network. The *ESRI Geometric Network* model (ESRI 2017a) represents the basic structure for any utility network type. The network is composed from nodes and junctions that can be generated automatically by ArcGIS based on the physical connectivity of network objects that are represented as points and lines in the database. *ArcGIS Schematics* (ESRI 2017b) provides a mechanism to represent the logical relation in a network. Using a relationship class that represents relationships between network objects, it is possible to generate a graph that represents the linkage between different network objects. ArcGIS has a set of industrial-specific domain data models for gas, water and electricity that are customized based on the Geometric Network model. However, the model is lacking the topographic representation of network objects in 3D and also managing the logical relation between network objects is a challenge.

- The *CityGML UtilityNetworkADE* proposed by BECKER et al. (2011), BECKER et al. (2012) and KUTZNER & KOLBE (2016) aims, on the one hand, at providing "a common basis for the integration of the diverse models in order to facilitate joint analyses and visualization tasks" (BECKER et al. 2012), but, on the other hand, also intends to overcome shortcomings of existing network models with respect to the following characteristics: The data model should allow for the representation of heterogeneous networks, i.e. not only for specific types of networks, for a dual representation of network topography as well as topology and for a representation of topographic/graphic aspects (including 3D) as well as of functional aspects. Furthermore, the data model is to allow for a hierarchical modelling of networks and subnetworks as well as of components and subcomponents and for modelling interdependencies between network features and city objects.

- Another ISO standard, which allows for representing utility networks, is *SEDRIS* (Synthetic Environment Data Representation and Interchange Specification) (SEDRIS 2006). SEDRIS focuses on the representation and exchange of synthetic environments and allows for modelling networks for electricity, water and wastewater as well as for oil, gas and chemicals. SEDRIS was developed for training simulation and is to date only applied in the military domain. SEDRIS exhibits a similar good support regarding the characteristics mentioned above for the CityGML UtilityNetworkADE; disadvantages, however, are the high representational ambiguity of the format at runtime and the limited software support.

- PipelineML is a GML-based data interchange standard for the exchange of pipeline data focusing on the oil and gas industry which is currently under development by the OGC (OGC 2016). In its current stage of development, the standard focuses on distribution components and 2D geometries only, terminal elements such as pump stations are not considered, neither is a topological representation of networks.

- Data models for networks also are proposed in scientific literature. HALFAWY (2010) for instance, presents data models for water and wastewater networks, taking hereby also into account lifecycle aspects of network components such as maintenance operations or performance assessment.

4 Discussion

In the following, the use cases presented in section 2.1 and the data models introduced in section 3 are analyzed with respect to the requirements that were defined in section 2.2.

4.1 Evaluation of use cases with respect to requirements

The evaluation in this section considers the requirements with respect to the criteria that were defined in section 2. The columns in table 1 indicate which information will be required to analyze the use cases. Some of the use cases require the linkage to other city objects and the linkage to the specific elements within the city object, for example storm drainage network use cases required the connection to the building roofs. In addition, some information important for other use cases that include planning, is the ability to have a hierarchical view of the network in order to be able to do the analysis at different scale levels.

Tab. 1: Requirements relevant to different use cases

		Storm Drainage Network	Clean Water Act	Vulnerability and Emergency	Maintenance Operation	Facility Manage-ment	Smart Energy
Sensors		•	++	+	•	++	++
Semantics		++	++	++	++	++	++
Spatial Relationships	• Network for indoor navigation	–	•	++	+	+	–
	• Indoor to outdoor network	•	+	+	+	++	++
	• Connectivity rules	+	++	+	•	++	++
	• Network to City features	+	++	++	+	+	++
	• Network itself	+	+	+	+	+	+
	• Network to Network	–	+	++	+	+	++
Visualization	• Mapped	+	+	+	++	++	•
	• Iconic	–	+	+	+	•	+
	• LOD	++	++	+	+	+	+
	• 2D utilities	++	++	++	++	+	•
	• 3D utilities	++	•	++	++	++	•
	• 2D city features	++	•	+	+	+	+
	• 3D city features	+	+	++	++	++	•
Spatial Scope	• City	++	++	+	•	–	+
	• Block	+	•	++	+	++	++
	• Building	•	•	++	++	++	+
– = not needed, • = basics, + = needed, ++ = very much needed							

Table 1 clearly shows that the information requirements strongly depend on the application. Emergency response poses the highest requirements in total. To be able to support emergency and disaster management and perform rescue, response and navigation in timely manner, there is a need to have a linkage between different network systems and also to have a connection to city

objects. Therefore, geometrical, topological (connectivity and adjacency) and semantic information shall be available. Information about movable objects such as cars, city furniture, or indoor furniture is critical for transporting equipment for maintenance or emergencies.

Many applications need a time component indicating the status of the network objects, e.g. the availability of commodities, either through the supply line or through storage, at a specific point in time.

All applications need semantic information to be able to address the network operations in the best possible way. Although not of general interest, connectivity rules (how network objects connect to each other or other network types) are critical for planning and simulation of different scenarios. The table shows that several applications need real-time information and connection to sensors.

4.2 Evaluation of data models with respect to requirements

The overview of data models presented in section 3 does not pretend to be complete, but it reveals some tendencies. As mentioned above, most of the data models are based on the graph representation of utility network objects in order to provide the ability to perform reachability analysis. Table 2 provides an estimation of the fitness of the different data models for the requirements under consideration.

Tab. 2: Support of requirements by different data models

		INSPIRE Utility Networks	IFC	ArcGIS Utility Networks	SEDRIS	Pipeline ML	CityGML UtilityNetwork ADE
	Sensors	–	•	–	+	–	•
	Semantics	+	++	•	+	•	++
Spatial Relationships	• Network for indoor navigation	–	•	–	–	–	•
	• Indoor to outdoor network	–	–	–	•	–	+
	• Connectivity rules	–	•	++	–	–	•
	• Network to City features	–	•	–	•	–	++
	• Network itself	+	+	++	++	+	++
	• Network to Network	–	++	–	–	–	++
Visualization	• Mapped	•	++	–	+	•	++
	• Iconic	•	–	++	–	•	•
	• LOD	–	–	–	•	–	++
	• 2D utilities	+	+	++	+	+	+
	• 3D utilities	–	++	–	+	–	++
	• 2D city features	++	–	++	+	–	++
	• 3D city features	–	–	+	+	–	++
Spatial Scope	• City	+	–	++	+	+	++
	• Block	+	–	++	+	+	++
	• Building	–	++	•	•	-	++
– = no support, • = basic support, + = sophisticated support, ++ = comprehensive support							

The IFC data model is a sophisticated generic data model that provides a semantic categorization of network objects based on their role in the network and a mechanism to derive specialized classes from specific network objects. Also, the IFC data model provides a detailed 3D representation of network objects, and in addition, a graph representing logical and physical connectivity relationships can be extracted to generate a directed graph for flow analysis.

The CityGML UtilityNetworkADE integrates characteristics of different models. The UtilityNetworkADE is the only model that manages the interdependencies between network objects and city entities. In addition, the data model allows the analysis of the network systems at different scales i.e. city, block or building and at different levels of detail. In addition, the data model provides the basic classes to differentiate network objects based on their role in the network. The UtilityNetworkADE provide a basic mechanism to control how network objects can connect to each other. However, this mechanism still needs further development to force different rules to control how network objects can connect to each other or other network types.

5 Conclusion

This paper discusses utility network issues and applications that can be found among city settings. Current data models available for planning and management of utility networks in GIS consider 2D, such as 2D maps and 2D analysis functionalities, and model specific network types. Therefore, this paper introduces use cases for utilities in the built environment, which demonstrate the need of 3D, i.e. 3D virtual reality, 3D analysis functionalities and 3D spatial relationships, and which also require the integration of different utility network types.

Several use case scenarios, "maintenance operation", "emergency response", "inspection operation", "storm drainage network" and "energy planning and simulation" were described. The use cases are used to define the requirements in order to evaluate selected network data models. These requirements can be summarized as follows: there is a need for a holistic modeling framework that supports the management of utility networks at different scales e.g. city or building. Also, there is a need to link networks to other network types, to interior networks, and to city entities. Such a model will help us determining the effects of maintenance operations undertaken on specific utilities on other networks types, as well as to work out the cause of waste materials discharged from networks into the natural resources. It will also allow us to investigate both, the result of damage to the city structure and to another utility network, and the effect of different maintenance operations in different locations within a city on utility service systems. Moreover, it will allow planning the network in conjunction with other city entities, as a change in land use can affect the energy demand on specific utility network systems. The model will help us to see the whole picture of the network, use it for planning the future demand and maintenance and for enhancing management.

The CityGML Utility Network ADE represents a suitable data model for modeling heterogeneous networks in the context of 3D city models. The model is matured and considers most of the requirements defined by the uses cases. However, the model still needs further development which includes:

- Connectivity rules: to constrain the type of network features that may be connected to one another and the number of features of any particular type that can be connected to features of another type. Also this will allow managing of how different network types can connect to each other. This will provide utility managers with the ability to selectively validate features in the network and generate reports as to which features in the network are invalid, i.e. are violating one of the connectivity or other rules. Currently, the CityGML UtilityNetworkADE provides basic support of this concept which still needs further development.

- Application-specific extensions: The current UtilityNetworkADE data model defines base feature types and properties which are applicable to all areas of application. Specific use cases such as district heating simulations or electricity grid simulations, however, might require more specific properties which are not part of the general UtilityNetworkADE data model. To fully support these use cases as well, suitable extensions need to be developed for the UtilityNetworkADE.

- Reference network objects: there is a need to couple indoor navigation models with utility network data models. Successful routing in case of utilities is of great importance for facility management – to response in timely manner or to reduce the cost of the associated maintenance operation. External networks, which follow the street network path, can be easily referenced to these one-dimensional objects. However, the built environment, is complicated and needs a method to reference objects to this complex structure. This is important for repair and maintenance operations and emergency response in a timely manner.

- 3D models are a valuable contribution, but it is also apparent that they are not needed for all types of applications. Utility network planning on small scale is easier to undertake and visualize with 2D maps. However, 3D is of importance for complex irregular structures and in cases when vertical information needs to be considered (height), for routing above and below objects, without touching a surface. There is a need to provide a mechanism to aggregate networks to one node in 2D. In addition, an investigation is required to support modeling of networks in different levels of detail.

- Connection to the CityGML EnergyADE and to sensors: The CityGML UtilityNetworkADE needs to be further extended to support sensors and time-variant data. Moreover, a further investigation is required on how to link the UtilityNetworkADE with the EnergyADE.

Acknowledgements

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