TECHNISCHE UNIVERSITÄT BERLIN
DEPARTMENT OF CIVIL SYSTEMS ENGINEERING

MODELING CIVIL ENGINEERED SYSTEMS

ASSIGNMENT 1 REPORT
ONTOLOGICAL MODELING

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1. Introduction & System Overview

1.1 Purpose, Scope, and Intended Use

The purpose of this ontology is to provide an abstract, clear picture and an understandable representation of the concepts and components involved within the sanitary drainage network. It aims to model their interdependent relationships in a functional and logical process. The outcome is a knowledge management system that can be used as a fundamental construction knowledge base for the sanitary drainage network. The scope of this ontology focuses on the physical elements of a sanitary sewage system, from the property-line connection to the input of the treatment facility. It includes the logical connections between components and their important functional characteristics, such as shape and material. The scope does not cover detailed chemical processes within the treatment plant, social aspects, or environmental attributes(6).

This ontology is designed for several intended users, including Asset Managers and Maintenance Personnel who need component information for maintenance scheduling, Civil and Environmental Engineers planning upgrades, and Urban Planners reviewing system capacity. Therefore, its primary intended use is to support better asset management, network retrofitting, and environment-interface management. These uses are demonstrated with specific examples in later section.

1.2 System Overview

The chosen system is a sanitary drainage network, a critical piece of infrastructure designed to collect and dispose the wastewater effectively and efficiently from a public or a private space to treatment plants to maintain public health, pollution control, and assure economic and environmental sustainability (1). This system was broken down based on its physical and functional characteristics(2,3,4,9).

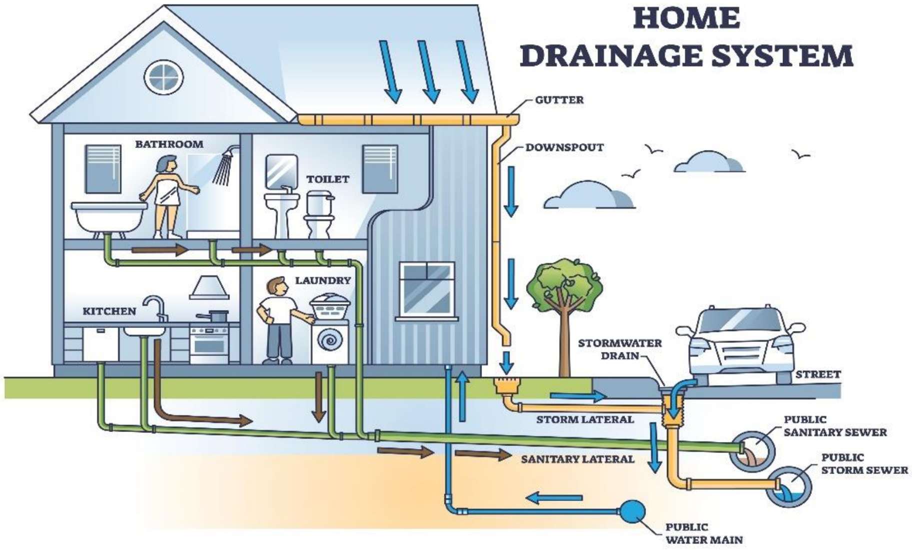


Figure 1: Rough sketch of a home drainage system(8)

1.2.1 Physical Decomposition

The system is a hierarchical network of physical components. It originates with a Building Sewer (or House Connection), which collects wastewater from a building and connects to a Lateral Sewer. These laterals discharge into larger Main Sewers, which are consolidated into Trunk Sewers. Finally, a single Outfall Sewer transports all collected wastewater to the Wastewater Treatment Plant (WWTP). The network is also supported by critical structures called Appurtenances. The most common is the Manhole, which provides essential access for inspection and maintenance. In low-lying areas, a Pumping Station (or Lift Station) is used to lift sewage to a higher elevation through a pressurized Force Main. The network terminates at the WWTP's Inlet Works, which begins the treatment process.

1.2.2 Functional Decomposition

This physical system was then decomposed into its core functions, including Collection (performed by building and lateral sewers), Gravity Conveyance (performed by main and trunk sewers), Lifting (performed by pumping stations), Pressurized Conveyance (performed by force mains), Access and Maintenance (performed by manholes), and Discharge and Preliminary Treatment (performed by the inlet works). This complete decomposition forms the basis for the ontological model developed in Protégé.

2. Ontology Development Methodology

The process began by defining the domain, scope, and intended competence questions. Key classes (like NetworkComponent and NetworkFunction) were then enumerated and organized into a taxonomic hierarchy. Next, object and data properties were defined to capture system relationships and critical metrics. Finally, individuals like the Lowlands_Network were created to parametrize and validate the model's logic. A key principle from this methodology is that an ontology should not contain all possible information about a domain. Therefore, the model was limited to the scope required for the intended engineering applications. For example, while the class NetworkMaterial and its subclasses like PVC are included, the ontology does not model the chemical composition of PVC or the manufacturing process for a PrecastConcrete manhole, as this level of detail is not required by the intended users or use cases(12).

3. Logical Axioms

To formally and logically model the sanitary drainage system, a set of key logical axioms were implemented in Protégé. These axioms define the formal structure of the classes, properties, and relationships within the ontology. This section summarizes the most critical axioms used in the model in Table 1.

Logical Axiom	**Applications in ontology model**
SubClassOf	Used to create the class hierarchy (e.g., MainSewer **SubClassOf** SewerPipe).
Disjoint Classes	Ensured logical separation between concepts (e.g., NetworkComponent **DisjointWith** NetworkFunction).
Inverse Object Properties	Enabled automated reasoning (e.g., hasDownstreamConnection is the **Inverse Of** hasUpstreamConnection).
Object Property Domain	Restricted the *subject* of a property (e.g., hasMaterial **Domain** NetworkComponent).
Object Property Range	Restricted the *object* of a property (e.g., hasMaterial **Range** NetworkMaterial).

Object Property Characteristics (Transitive)	Used to create logical chains for properties (e.g., hasComponent was set to **Transitive**).
Data Property Domain	Restricted which class can have a data property (e.g., manholeDepth **Domain** Manhole).
Data Property Range	Defined the data type for a property (e.g., pipeDiameter **Range** xsd:double).
Existential Restriction (some)	Defined classes by their relationships (e.g., SewerPipe **SubClassOf** performsFunction **some** GravityConveyance).
UnionOf (or)	Used in the Class expression editor to create flexible domains for disjoint classes (e.g., pipeDiameter **Domain** SewerPipe or ForceMain).

Table 1: Summary of Logical Axioms Applied

4. Results, Parametrization, and Engineering Perspectives

This section presents the results of the modeling process. This includes the key aspects of model structure, the parametrization of the ontology with individuals and data, and the successful test of the reasoner.

4.1 Model Structure

The final structure of the ontology is captured in the class hierarchies. Instead of an unreadable graph, the structure is best presented by the "Class hierarchy" view, showing the clear organization of components, functions, and materials.

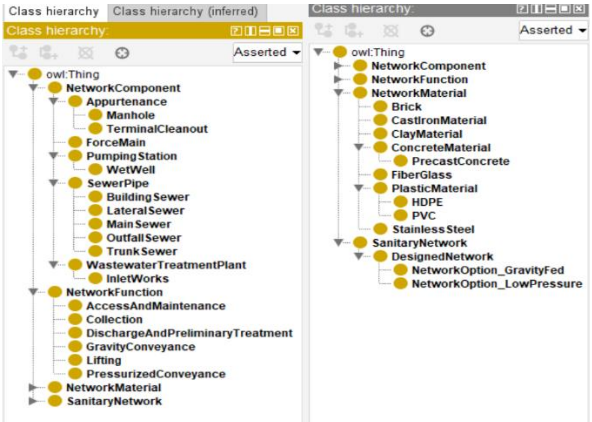
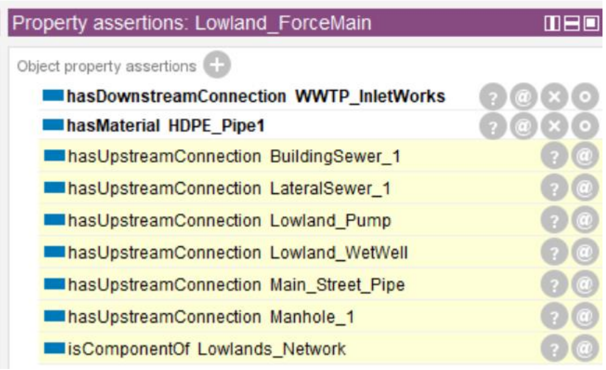


Figure 2: The Final class hierarchy for the sanitary network ontology.

4.2 Model Parametrization and Reasoning Results

A prototype system, Lowlands_Network, was developed as an individual of the NetworkOption_LowPressure class to verify the ontology and satisfy the assignment's parametrization requirement. A full, logical chain of constituent individuals including BuildingSewer_1, Main_Street_Pipe, Lowland_Pump, and WWTP_InletWorks, was then set up in this network. Data attributes, such as pipeDiameter = 0.3 and installationYear = 1988, were used to populate the individuals with actual data values. This parametrization demonstrates that the ontology's structure is sound and prepared for the addition of actual asset data.

The most important result is the successful execution of the reasoner. As shown in Figure 3, the reasoner successfully *inferred* new knowledge (highlighted in yellow) based on the logical axioms, proving the model is consistent and functional.



Property assertions: Lowland_ForceMain

Object property assertions

hasDownstreamConnection WWTP_InletWorks

hasMaterial HDPE_Pipe1

hasUpstreamConnection BuildingSewer_1

hasUpstreamConnection LateralSewer_1

hasUpstreamConnection Lowland_Pump

hasUpstreamConnection Lowland_WetWell

hasUpstreamConnection Main_Street_Pipe

hasUpstreamConnection Manhole_1

isComponentOf Lowlands_Network

Figure 3: Property assertions for the Lowland_ForceMain individual.

4.3 Engineering Examples

This ontology was designed to solve several well-defined engineering challenges. The following scenarios demonstrate the model's intended use.

A common challenge for asset managers is planning maintenance. For instance, if a road containing an old manhole is scheduled for repaving, a manager can query the ontology for that manhole's Installation Year and Condition. Based on its age and poor condition, they can prioritize its rehabilitation *before* the repaving, preventing a more expensive future failure(11).

Engineers must often determine if existing infrastructure can handle new loads. Consider a scenario where a new residential development plans to connect to an existing main sewer pipe. An engineer can use the ontology to understand the existing pipe's key parameters. By querying the model, they can retrieve critical data for certain components. This data can then be fed directly into a hydraulic model to confirm if the pipe is undersized, justifying a network upgrade.

A critical task is preventing cross-contamination between sanitary and storm sewers. If a nearby river shows high bacteria levels, an engineer might suspect a design flaw in the sanitary network. The engineer can use the ontology to trace the system's logical flow. By querying the downstream connection path, they can verify that all components logically terminate at the wastewater treatment plant. This helps rule out a systemic design flaw, allowing the team to focus their investigation on finding a physical pipe leak.

5. Conclusion

A rational and expandable ontology for a sanitary drainage network was successfully created by this project. This ontology operates as an effective knowledge base by modeling the parts, operations, and relationships of the system. The model's logical consistency is validated when the reasoner is successfully used to deduce new facts. By offering a computable tool to address important engineering and asset management problems, the final model directly serves its intended users.

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