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# Data Model Design of Underground Utilities Using General Feature Model in Korea

Ji Hui Ryu,[1] Seon Cheol Yu,[2] and Jong Wook Ahn[2*]

[1]Smart Urban Space Institute, Anyang University,
22, Smadeok-ro 37 beon-gil, Manan-gu, Anayang-si, Gyeonggi-do 14028, Korea
[2]Dept. of Smart City Engineering, Anyang University,
22, Smadeok-ro 37 beon-gil, Manan-gu, Anayang-si, Gyeonggi-do 14028, Korea

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In this study, we present a logical spatial data model according to the International Organization for Standardization (ISO) 19109 targeting nine types of underground utilities (wide-area water, water, sewage, heating, communication, electric power, gas, garbage, and oil) among underground information. To this end, we reviewed the integrated underground utility systems in Korea, the integrated underground spatial maps, and previous studies in South Korea and abroad. Subsequently, the design direction of the underground utility data model is constructed on the basis of the problems derived from the review of previous studies and current status. According to the design direction, the terminologies of underground utilities, classification systems, and topological association between objects are defined. The ISO and Open Geospatial Consortium (OGC) standards established as international standards are referenced to design applicable spatial data models suitable for Korea's underground space environment using Unified Modeling Language (UML) diagrams. The resulting design is expected to provide consistency to the underground utility data and play a role in the interoperability of domestic and foreign underground utility data.

## 1. Introduction

The concentrations of city populations and the movement of capital have been increasing since the Industrial Revolution resulted in urbanization. The use of skyscrapers and accompanying underground space made city planners view cities in 3D.(1) Underground spaces are actively developed in Korea as the country matures around smart cities with increased high-rise buildings and underground concentrations. As the demand for underground space development is increasing, the preparation of safety measures against the expansion and aging of underground utilities is urgent.(2) As a solution, in 2018, the Korean government created an integrated underground spatial map that collects all underground information to strengthen underground safety management. The underground information provided by the map was available through the Utilization Support Center, but was underutilized owing to an insufficient

*Corresponding author: e-mail: ajw0603@anyang.ac.kr
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update system and a low accuracy. In this study, we aim to design an underground utility data model for systematic construction and management according to the need for a data model to enhance the underground utility data location accuracy and information utilization.

## 2. Evaluation of Current Status and Previous Studies

### 2.1 Current status of underground utilities in Korea

Korea is building an integrated underground utility management system and an integrated underground spatial map using an underground utility-data-related system as part of construction projects (Figs. 1 and 2). An integrated underground utility database (DB) is established in the integrated underground utility management system[(3)]* to ensure accuracy with per-type data quality reviews. The integrated underground spatial map construction project builds and operates 3D data for the underground area. The information collected from various institutions is processed and utilized by collectively and nationally revising it to be more in system.[(4)] However, the integrated underground spatial map is underutilized owing to an insufficient update system and a low accuracy.[(5)]

*A system by the Ministry of Land, Infrastructure, and Transport that integrates the information of six road-based underground utilities (water supply, sewage, gas, electric power, communication, and heating), which the managing department searches and handles complaints online (Korea policy briefing, integrated underground utility management system has been established.) https://www.korea.kr/news/cartoonView.do?newsId=148712661#goList

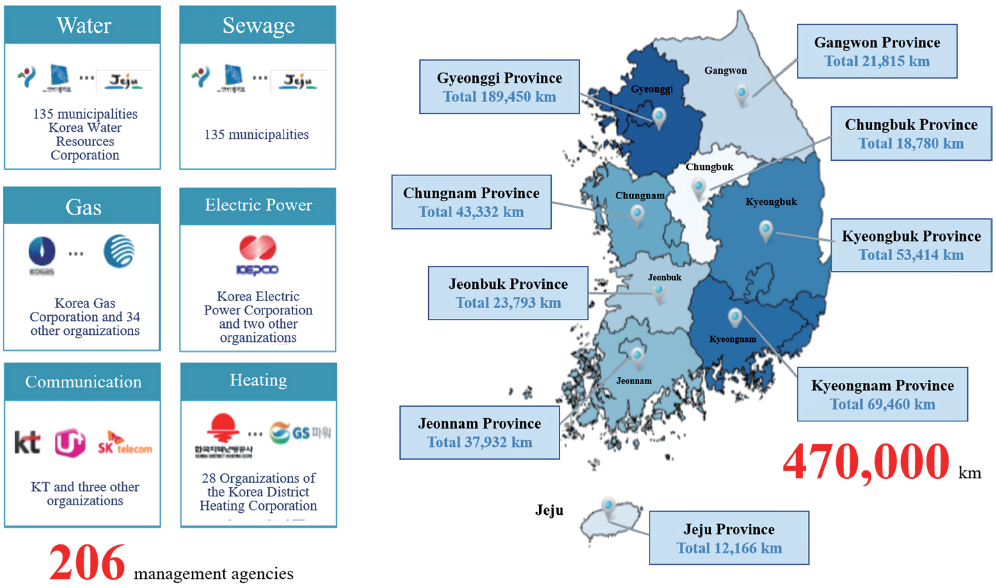


Fig. 1. (Color online) Current status of the integrated underground utility system construction. Source: Ministry of Land, Infrastructure, and Transport, 2019.[(6)]


Fig. 2. (Color online) Concept diagram of the integrated underground spatial map. Source: Ministry of Land, Infrastructure, and Transport, 2019.[7]

### 2.2 Review of previous studies

Previous domestic and international studies regarding underground utility data were reviewed for underground utility data construction consistency. The reviewed details are as follows.

In a domestic study covering an underground utility model, Jeong[8] considered the Korean underground information environment in which 3D pipe-type underground utilities were constructed. Additionally, Jeong designed and validated a 3D data model of pipe-type underground utilities corresponding to the international standard CityGML. However, the proposed model did not fit Korea as it is different from the Korea Standards (KS) and Telecommunications Technology Association (TTA) data model standards.

In an overseas study, Kutzner *et al.*[9] proposed an expanded concept of application domain extension (ADE) development through an extensive analysis of CityGML Utility Network ADE model use cases. A list of requirements was prepared on the basis of the proposal, and current data models were compared and evaluated. The concepts of network node-links, which are network objects connected to city objects, functional characteristic modeling, refined network object modules, and new electrical network packages were also presented.

In another overseas study, Duijn *et al.*[10] proposed a 3D data modeling method for the integrated management of underground utility networks and related on-ground city objects. This method first manipulates the structure of the existing utility data in the commonly used FME ETL software such that the data conforms to the CityGML Utility Network ADE model. CityGML data were then stored in 3DCityDB to manage the utility network data. In this study, we verified that 3DCityDB is suitable for performing graph-based topological tasks through PostgreSQL and pgRouting extensions.

In this study, we also designed a 2D and 3D universal data model of nine types of underground utilities based on GMF, considering Korea's underground information environment. This ensures consistency in constructing domestic and overseas underground utility data and proposes an interoperable data model for different application fields. Table 1 provides a summary of the studies reviewed in this section and this study.

## 3. Materials and Methods

### 3.1 Establishment of direction for underground utility data model design

Korea's underground space was not included as a major consideration in the national space information system because its utilization was relatively lower than on-ground objects.(11) Therefore, in this study, we designed an underground utility data model suitable for the Korean underground space environment through the following procedure to increase the utilization of underground utility data (Fig. 3). First, the properties and classification system for underground utility objects in the underground space were defined and redefined on the basis of the content determined in the construction system. The geometry and topological association between objects were then defined by referring to the blueprint and layout for each underground utility. Finally, a logical underground utility data model (base and per-theme models) was designed using unified modeling language (UML) on the basis of the defined content.

Table 1
Review of previous studies.

| Category | | Key points | Limitation |
|---|---|---|---|
| Domestic | Jeong (2021) | - Designed and validated a 3D data model of pipe-type underground utilities corresponding to the international standard CityGML while considering the Korean underground information environment | - Its difference from the underground utility standard of integrated underground spatial map construction projects in Korea limits the model's application. |
| Overseas | Kutzner *et al.* (2018) | - Proposed an expanded concept of ADE development through an extensive analysis of CityGML Utility Network ADE model use cases<br>- Designed centered around the network objects between objects different from pipe-type underground utilities | - In the network component, the properties related to the underground facilities are insufficient, and the 2D-level expression is provided in relation to the object and the level of detail. |
| | Duijn *et al.* (2018) | - Studied a 3D data modeling method for the integrated management of on-ground city objects related to underground utility networks | - The designed topology for the network between pipe objects remains a 2D-level information display. |
| This study | - Designs a 2D and 3D universal data model of nine types of underground utilities by considering the underground information environment constructed in Korea<br>- Contains academic values in ensuring consistency in the construction of domestic and international underground utility data and proposes an interoperable data model for different application fields | | |

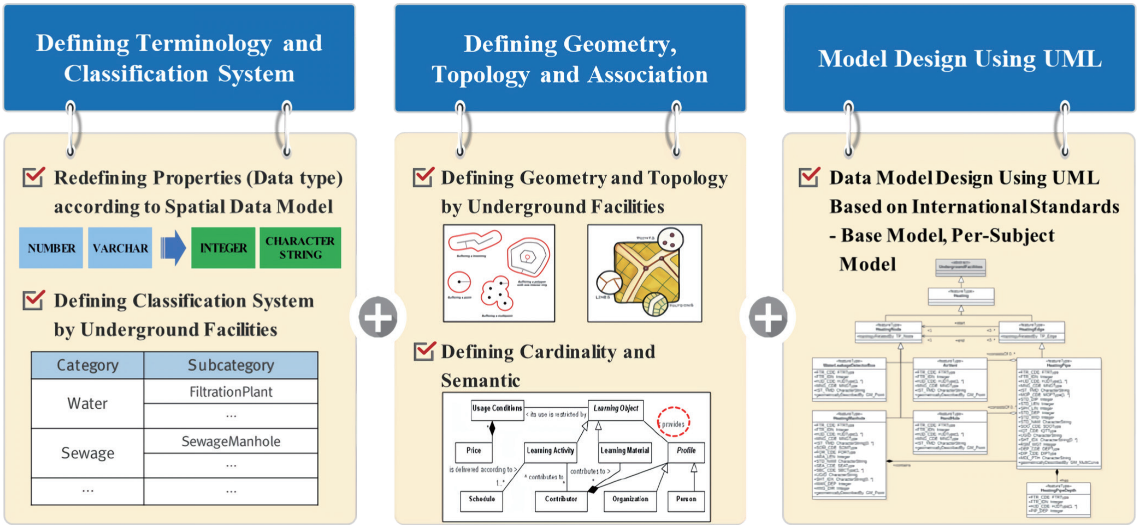


Fig. 3. (Color online) Underground utility data model design direction establishment.

## 3.2 Defining underground utility terminologies and classification system

Underground utilities are designated to abbreviate the names of objects in the table design plan provided during underground utility space information construction for each municipality. For example, water manholes are designated 'WTL_MANH_PS', and water pipes are 'WTL_PIPE_LM'. These abbreviations are unintuitive in providing object information to users. Additionally, the detailed functions of each object are missing in the previously provided table design plan and other documents, making the association between objects difficult to understand. Accordingly, the classification system and object terminologies related to the nine types of underground utilities (wide-area water, water, sewage, heating, communication, electric power, gas, garbage, and oil) are defined in this study (Table 2).

## 3.3 Defining geometry and topology

In this study, we define the meaning and relationship among actual geometry, topology, and object by referring to the blueprint and layout of underground utilities. Figure 4 illustrates and defines the relationships between the objects composing the underground utilities and pipe objects based on the reference and corresponding concept diagrams of the underground electric power utilities. The geometry and topology of each underground utility object are defined and reflected in the data model. The electric power object was divided into point (GM_Point), curve (GM_MultiCurve), surface (GM_Surface), and complex (GM_Complex) structures. Table 3 shows the definitions related to geometry, association, and semantics between classes.

Table 2
Underground utility classification system.

| Category | Subcategory | Category | Subcategory |
|---|---|---|---|
| Water | HeadOfRiver | Gas | LPGPipe |
| | WaterPurificationPlant | | NaturalGasPipe |
| | WaterGain | | GasPipeDepth |
| | Reservoir | | LPGManhole |
| | ServiceWaterReservoir | | NaturalGasManhole |
| | PressurisedPumpingStation | | ConstantPressure |
| | ServiceWaterPipe | | AntipotentialObservationBox |
| | ServiceWaterPipeDepth | | GasValve |
| | SupplyWaterPipe | Heating | HeatingManhole |
| | StandPipe | | WaterLeakageDetectorBox |
| | FireFightingFacility | | HeatingPipe |
| | Flowmeter | | HeatingPipeDepth |
| | ServiceWaterManhole | | AirVent |
| | WaterPressureGauge | | HandHole |
| | LeakLocationRepairHistory | Communication | TelecommunicationPole |
| | HydrantMeter | | TelecommunicationManhole |
| | Valve | | TelecommunicationPipe |
| Sewage | SewerageManhole | | TelecommunicationPipeDepth |
| | InversedSiphon | Garbage | GarbagePipe |
| | StormWaterSoilChamber | | GarbagePipeDepth |
| | WaterSpout | | GarbageManhole |
| | VentilatingOpening | Oil | OilLeakageDetectCable |
| | SewerOutlet | | OilPipe |
| | SewageConnectionPipe | | OilPipeDepth |
| | SideDitch | | PressurizationStation |
| | SewagePipe | | SafeguardFacility |
| | SewagePipeDepth | | ValveStation |
| | DentionBasin | | OilTankStation |
| | SewageTreatmentPlan | | ValveBox |
| | SewagePumpStation | Wide-area water | WideAreaFireHydrant |
| | DrainageDistributionZone | | WideAreaServiceWaterManhole |
| | DisposalDistributionZone | | WideAreaServiceWaterPipe |
| | DrainageArea | | WideAreaServiceWaterPipeDepth |
| | DisposalArea | | WideAreaWaterTower |
| Electric Power | ElectricManhole | | WideAreaServiceWaterTunnel |
| | Switch | | VariableFlowValveFacility |
| | Transformer | | |
| | ElectricPowerPole | | |
| | ElectricPowerRoofVent | | |
| | PowerTransmissionTunnel | | |
| | PowerDistributionTunnel | | |
| | ElectricPowerPipe | | |
| | ElectricPowerPipeDepth | | |

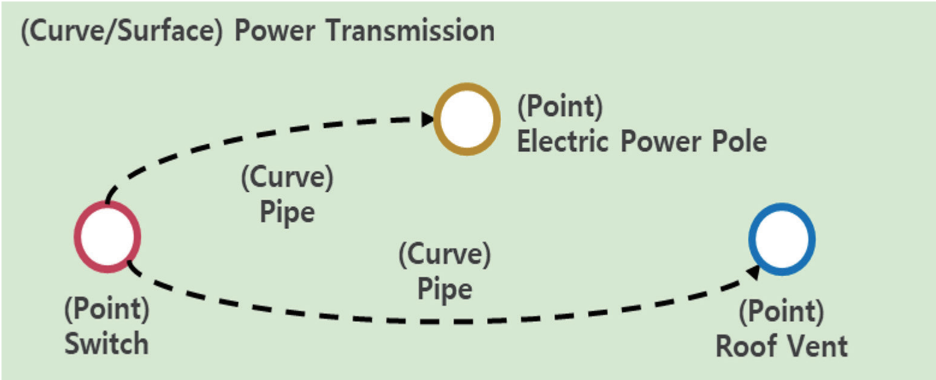


Fig. 4. (Color online) Diagram of (electric power) power transmission/distribution tunnel and pipe object association.

Table 3
Key points of electric power object geometry, association, and semantics.

| Class-/-Geometry | Association | Class-/-Geometry | Semantics |
|---|---|---|---|
| Power Distribution Tunnel-/-Surface, Curve | —— | Electric Power Pipe-/-Curve | - contain |
| | —— | Electric Power Roof Vent-/-Point | - contain |
| | —— | Switch-/-Point | - contain |
| Power Transmission Tunnel-/-Surface, Curve | —— | Electric Power Pipe Depth-/-Curve | - contain |
| | —— | Electric Power Roof Vent-/-Point | - contain |
| | —— | Switch-/-Point | - contain |
| Electric Manhole-/-Point | —— | Electric Power Pipe-/-Curve | - intersected |
| Electric Power Pole-/-Point | —— | Transformer-/-Point | - attached |
| Electric Power Pipe-/-Curve | ◆— | Electric Power Pipe Depth | - has |

## 4. Data Model Design

### 4.1 Base model

For the underground utility data model, the general feature model (GFM) specified in ISO 19109 was applied as a base model for the logical data model. GFM is a conceptual model necessary for classifying perspectives in the real world. Here, the relationship between geographic feature types is expressed as feature association and inheritance. These concepts are represented as metaclasses in GFM, which is a metamodel of such geographic feature types.[12,13] The geographic feature definition method defines an application schema suitable for each field in various application fields, making it an essential reference. Figure 5 shows how models for each subject are instantiated, centering on the base model. Among them, the underground information subcategories («featureType») are expressed by subordinating to the per-subject model package («package»). The concept diagram represents the subcategories of underground utilities. FeatureType indicates a metaclass instantiated as a class representing the geographic feature type.[14–17]

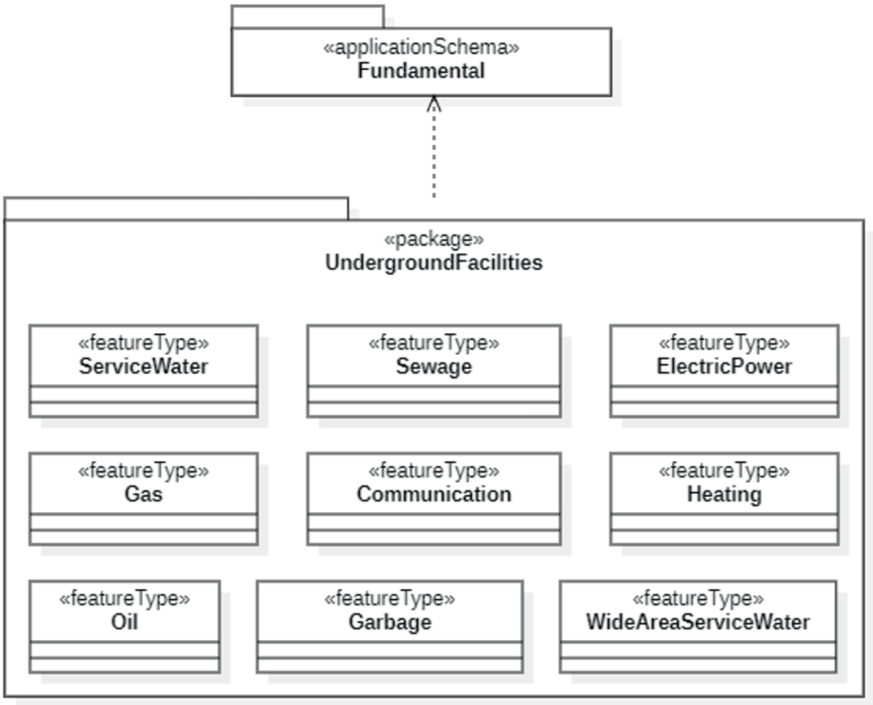


Fig. 5. Underground utility data model categorization layout.

### 4.2 Per-subject data model

A logical data model for underground utilities was designed by stipulating naming standards for all data required for underground utility constructions according to the previously defined underground utility classification system, and standard item names were assigned according to the criteria. The topology objects of underground utilities are expressed as UF_Face, UF_Edge, and UF_Node. These structured objects that group geometric objects are suitable for each topology type. The properties of each object are designed to inherit the abstract class and utilize common properties such as the feature code (FTR_CDE), management number (FTR_IDN), and administrative, town, and village code (HJD_CDE) according to the table definition. Finally, by using Enterprise Architecture (EA), the underground spatial data model for underground utilities is divided into the point (GM_Point), curve (GM_Curve, GM_MultiCurve), surface (GM_Surface), and complex (GM_Complex) structures defined in the diagram and description. The definitions related to geometry, association, and semantic between classes are expressed in the figures (Figs. 6–14).

The water subcategory consists of 21 classes, including a head of a river, a water purification plant, and a service water pipe. The sewage subcategory consists of 21 classes, including a sewage manhole, a sewage connection pipe, and a sewage pipe. The electric power subcategory consists of 12 classes, including an electric manhole, a switch, and a power transmission tunnel. The gas subcategory consists of 11 classes, including an LPG manhole, an LPG pipe, and

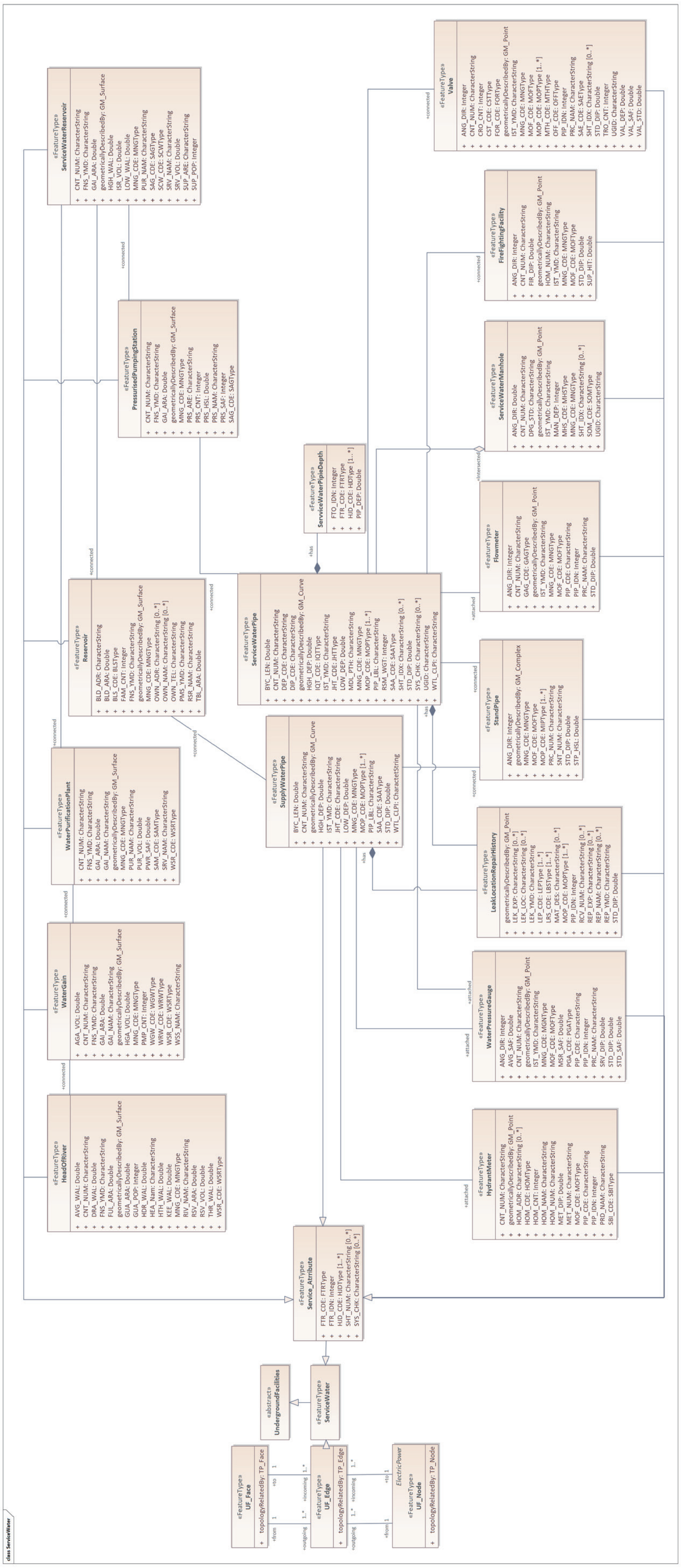

Fig. 6. (Color online) Water data model.

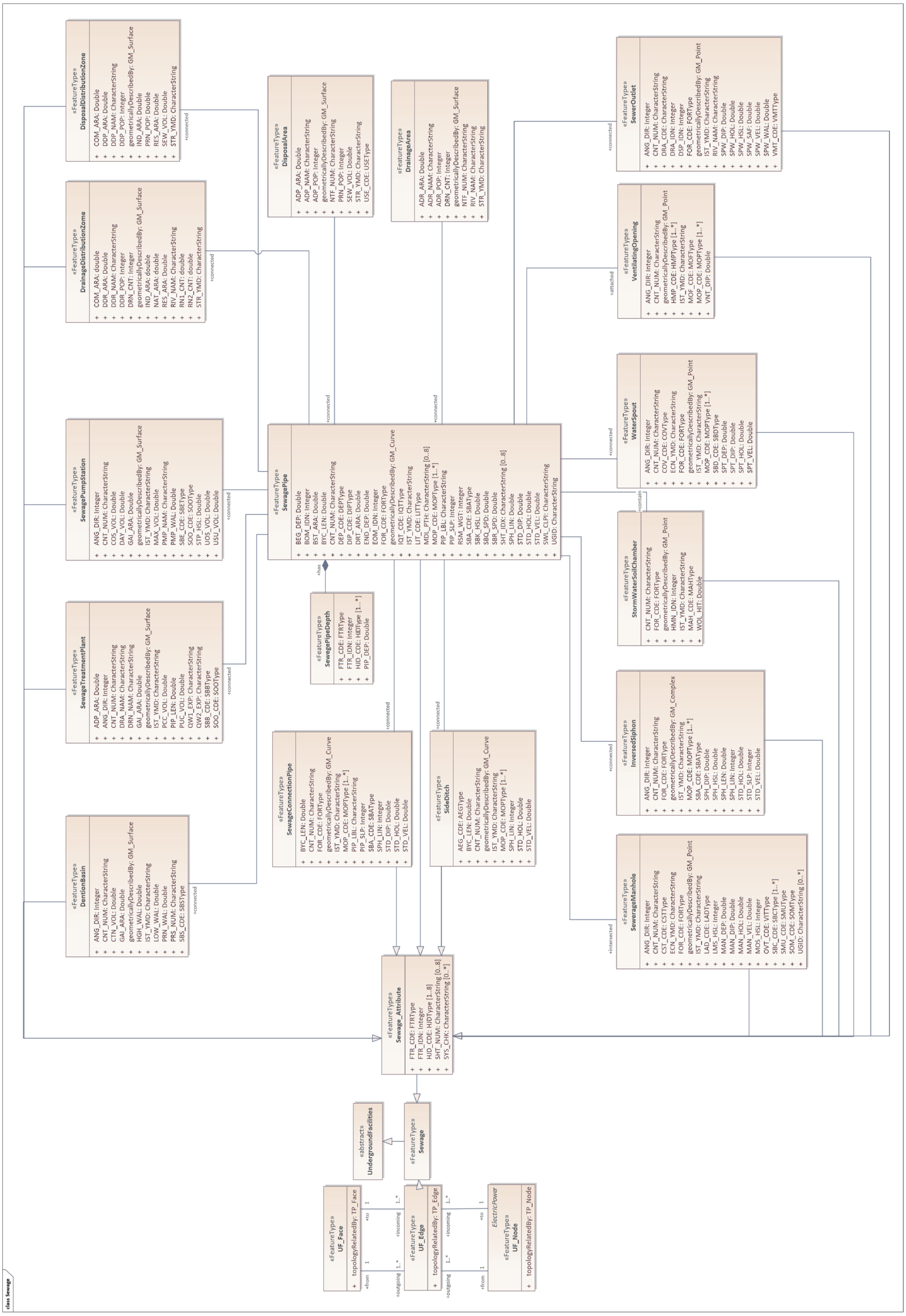


Fig. 7. (Color online) Sewage data model.

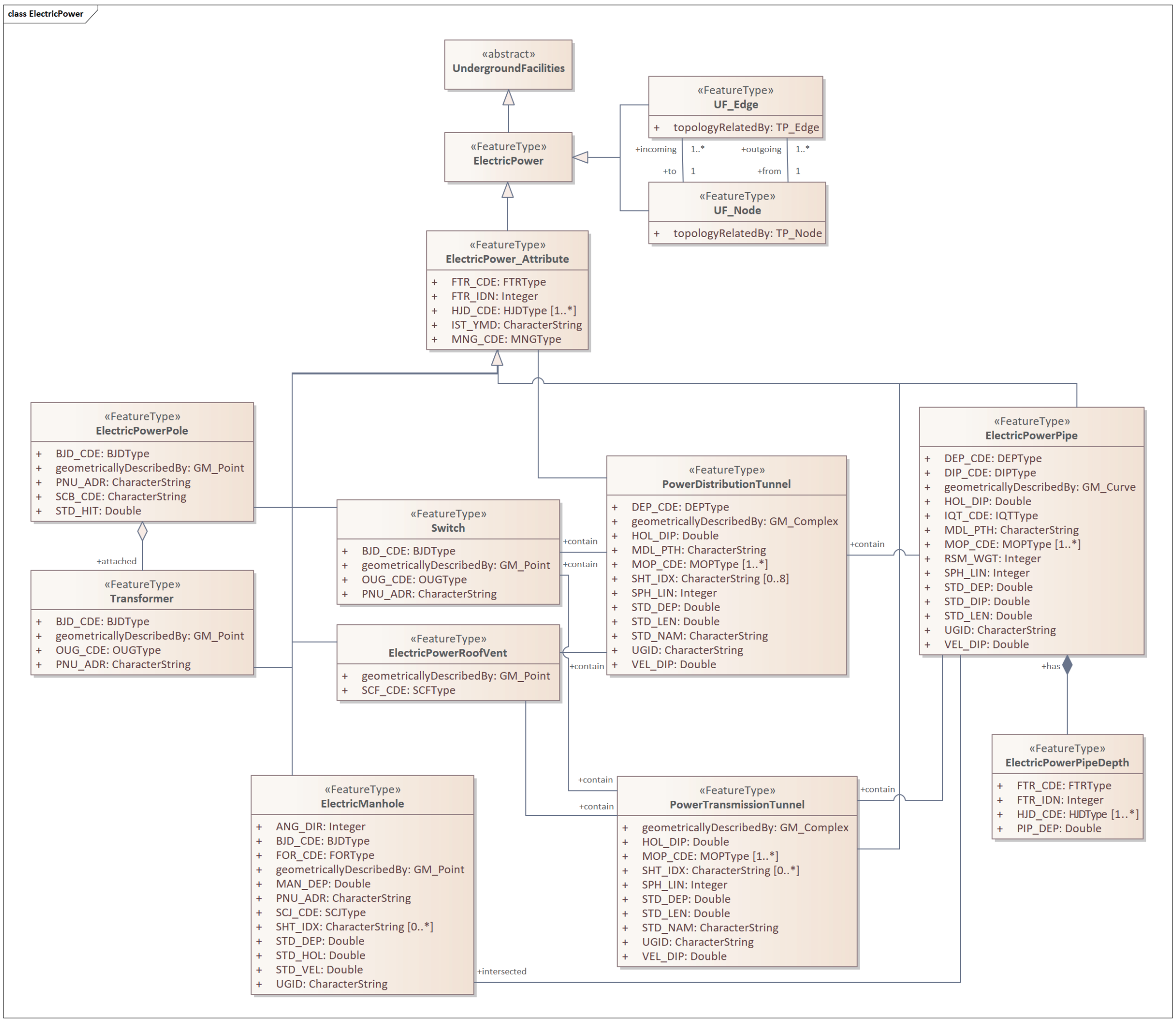


Fig. 8. (Color online) Electric power data model.

constant pressure. The heating subcategory consists of nine classes, including a heating manhole, a water leakage detector box, and a heating pipe. The communication subcategory consists of seven classes, including a communication pole, a communication manhole, and a communication pipe. The garbage subcategory consists of six classes, including a garbage pipe and a garbage manhole. The oil subcategory consists of 12 classes, including an oil pipe, a pressurized station, and an oil tank station. The Wide-Area water subcategory consists of 10 classes, including a service water pipe and a service water manhole.

## 4.3 Implications

In this study, we proposed a logical data model design of Korean underground utilities corresponding to international standards for consistent domestic and international underground utility data construction. The model is expected to yield a unified construction of domestic and

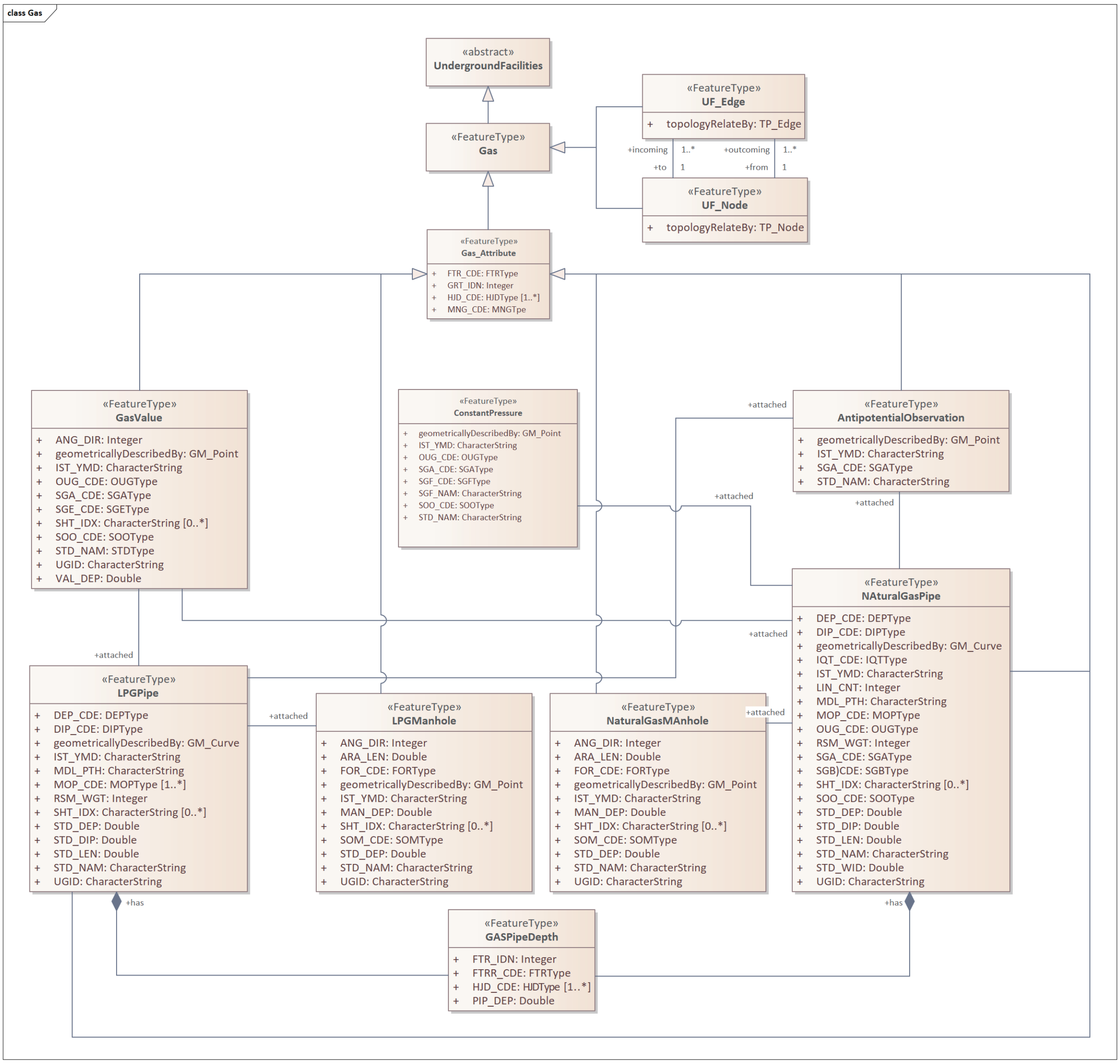


Fig. 9. (Color online) Gas data model.

foreign underground utility data models in Korea. It also has academic significance as a data model that can interoperate with other application fields. It is expected to serve as a standardized space data model that can be utilized for various space analyses based on the data model and using the idea of GIS, the spatial query and spatial analysis technology can be used to process the existing data by securing systemic management and accurate construction data of underground utilities in Korea. The range of the geographic feature was limited to the underground, and the on-ground content could not be reflected in the data model. Expanding to a 3D data model that can cover all physical objects in the future is necessary. Therefore, in the future, it is necessary to develop a physical model based on the design of logical data models in

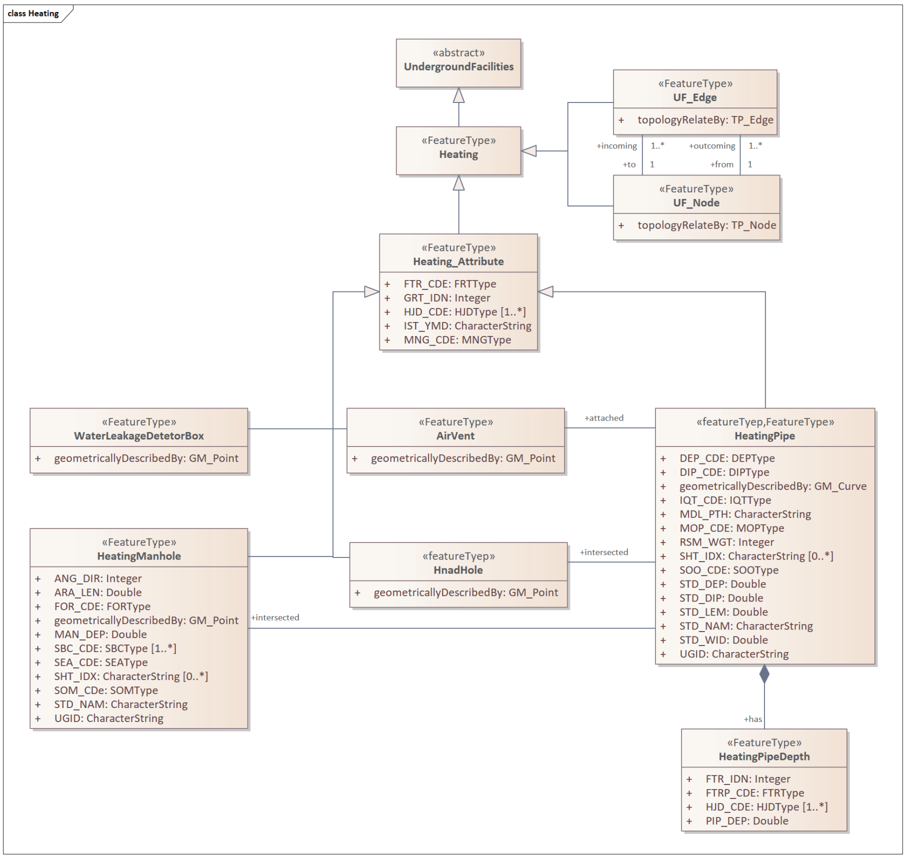


Fig. 10. (Color online) Heating data model.

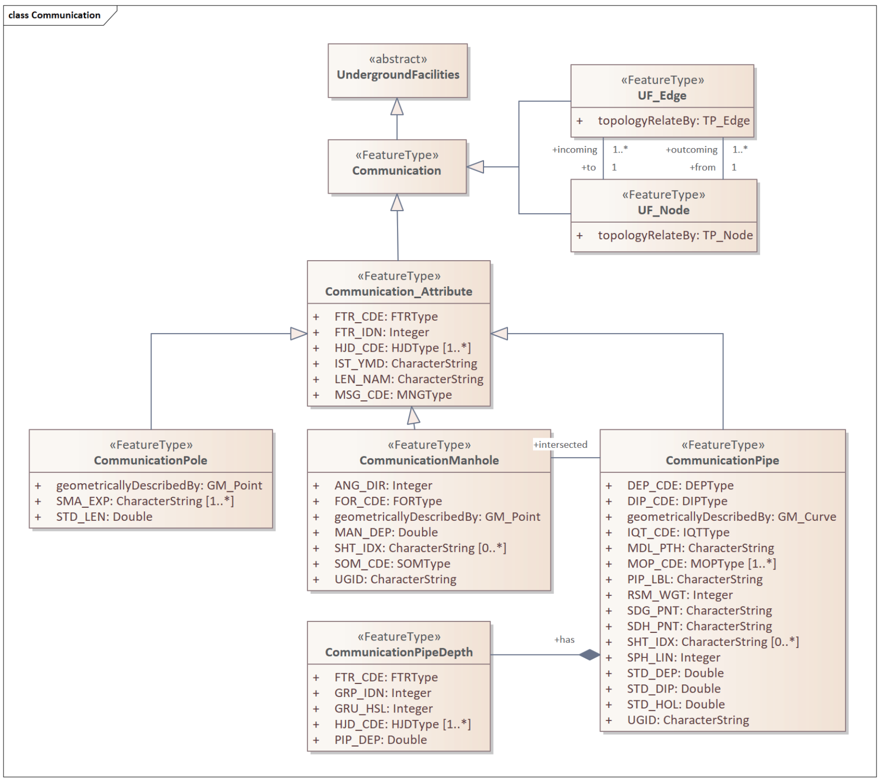


Fig. 11. (Color online) Communication data model.

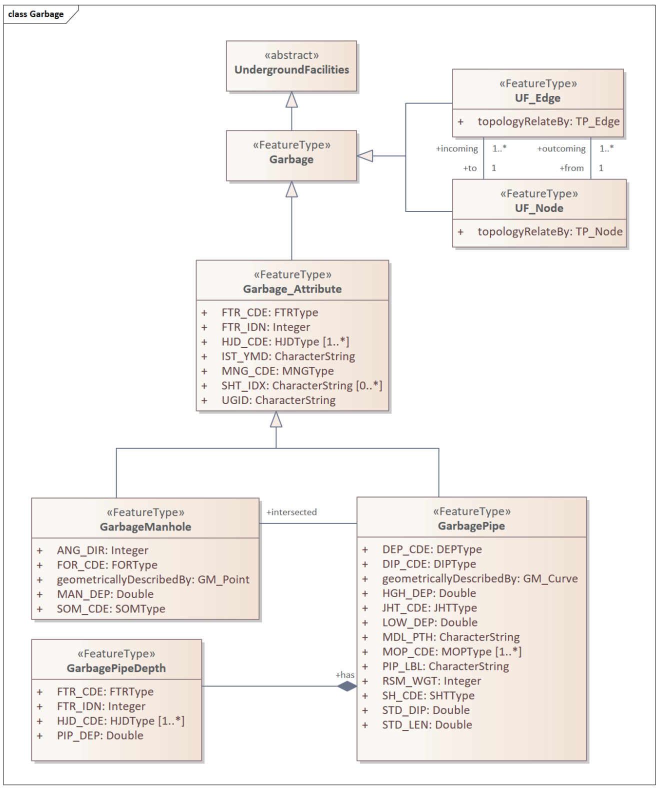


Fig. 12. (Color online) Garbage data model.

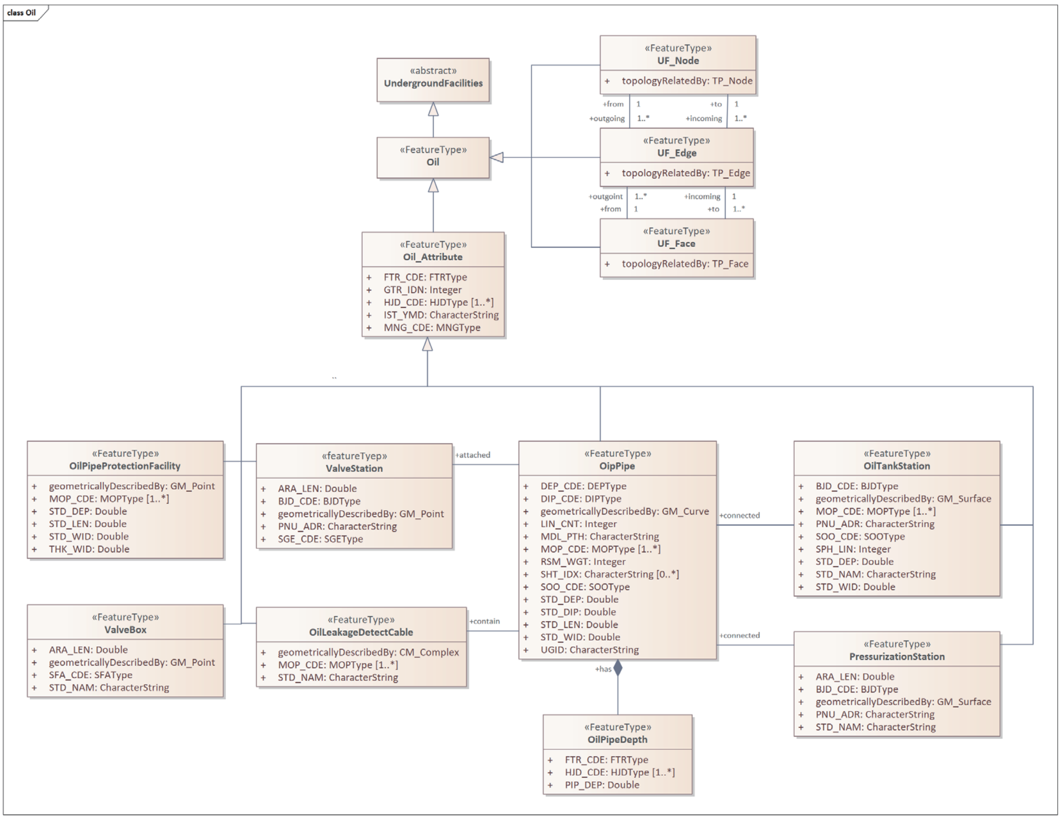


Fig. 13. (Color online) Oil data model.

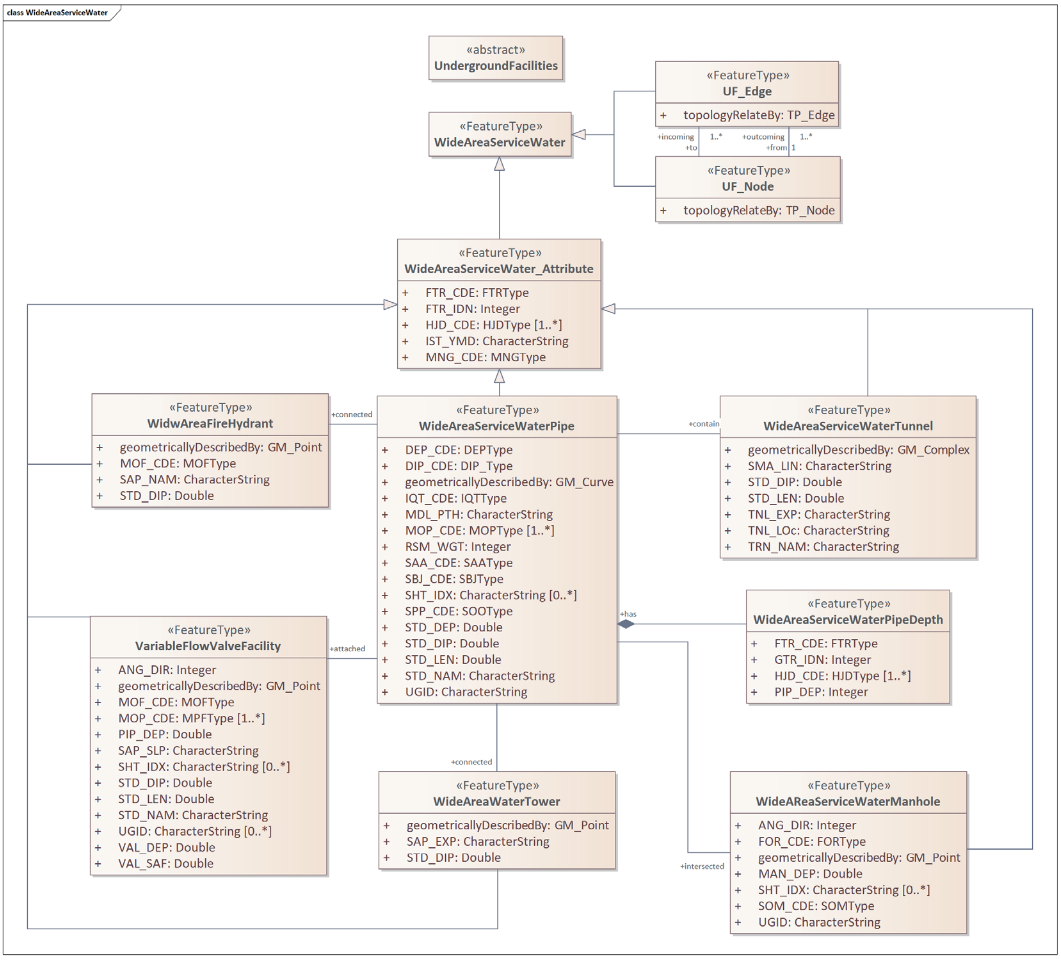


Fig. 14. (Color online) Wide-area water data model.

the future, and to study the data model in terms of ground/underground space connectivity for the interoperability of digital twins by verifying the developed content.

## 5. Conclusion

In the past, various types of underground information were constructed and utilized according to the purpose of each institution. However, a standardized underground spatial data model is needed owing to problems in data accuracy and information underutilization. Therefore, in this study, we aimed to provide a data model standard in Korea that corresponds to international standards by designing a logical data model of the underground spatial data for underground utilities. To this end, the current status of construction systems, such as Korea's integrated underground utility systems and an integrated underground spatial map, was reviewed, as well as previous studies related to domestic and foreign underground utility data models. The underground spatial data model design direction was established accordingly. Subsequently, terminologie and classification systems were defined for the underground utility objects. Each object's geometry and topological association were defined by identifying the relationship between the underground utility objects. Finally, the GFM specified in ISO 19109 was expanded and utilized as a reference model through UML. The logical data model was designed by depicting the underground utility data model based on the above as a UML diagram. Thus, in this study, we proposed a standardized spatial data model for securing systemic underground utility management and accurate and unified data through a logical data model design of underground utilities corresponding to international standards. The physical design based on the proposal is expected to improve data consistency and reliability, which is a problem with the existing system in Korea. Moreover, the proposed data model can serve as a standardized spatial data model that can be used for various space analyses beyond simple inquiry purposes. It is expected that the standardization of this study will expand the applicability of international spatial information standards and contribute to the promotion of international standardization activities such as data model standard development cases that meet national requirements.

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## About the Authors

**Ji Hui Ryu** received her B.S., and M.S. degrees from Anyang University, Korea, in 2014 and 2022, respectively. Since 2022, she has been a research engineer at the Smart Urban Space Institute in Anyang University. Her research interests are in smart city, spatial information, and standards for spatial information. (0613jijui@gmail.com)

**Seon Cheol Yu** received his B.S., M.S., and Ph.D. degrees from Anyang University, Korea, in 2003, 2005, and 2011, respectively. From 2011 to 2014, he was an associate research fellow at the Korea Research Institute for Human Settlement. Since 2021, he has been a professor at Anyang University. His research interests are in urban planning, big data, smart city, and urban regenerations. (scyu@anyang.ac.kr)

**Jong Wook Ahn** received his B.S., M.S., and Ph.D. degrees from Anyang University, Korea, in 2000, 2002, and 2007, respectively. From 2007 to 2011, he was an associate research fellow at the Korea Research Institute for Human Settlement. Since 2011, he has been a professor at Anyang University. His research interests are in urban planning, smart city, big data, and spatial information. (ajw0603@anyang.ac.kr)