TECHNICAL SCIENCES

CONCEPTUAL MODEL OF A GEOGRAPHIC INFORMATION SYSTEM FOR LOCATING LEAKS ON UNDERGROUND TECHNICAL INFRASTRUCTURE – PART SEWERAGE

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Abstract

The management and development of the Water sector in the Republic of Bulgaria are based on two key documents – the "National Strategy for Water Sector Management and Development" and the "Strategy for the Development and Management of Water Supply and Sewerage Systems in the Republic of Bulgaria". These documents identify the main problems related to Sewerage Infrastructure, including insufficient maintenance of Sewerage Systems and facilities. These problems are clearly identified as key issues.

The main objective of this publication is to present the conceptual model of a Geographic Information System for locating leaks in the Sewerage System, with a special focus on the problems related not only to the detection of leaks in the underground technical infrastructure, but also to the structuring of information about the leaks. The conceptual model will be presented through the applicable ISO/TC 211 standards in the field of digital Geographic information and Geomatics, with an emphasis on the application of the principles and approaches of the systems approach.

This model can be a key tool for improving the management of Sewerage Infrastructure as a whole, including reducing losses and increasing efficiency.

Keywords: Sewerage infrastructure, Sewerage system, leaks in underground technical infrastructure, GIS, ISO/TC 211 standards for Geographic information and Geomatics, UML class diagram.

1. Introduction

At the time of this analysis, there are 40 Water Supply and Sewerage operators in the Republic of Bulgaria with different ownership structures (35% are wholly state-owned, 28% are wholly municipal-owned, and 37% are mixed-owned – state and municipal). In certain areas, there are also 28 Water Supply and Sewerage associations, in accordance with the provisions of Article 198b of the Water Act [1].

The lack of regulatory framework governing uniform basic requirements for the creation of a Geographic Information System (GIS) for the needs of Water Supply and Sewerage operators has led to the existence of multiple GIS systems with non-standardized databases, layers, attributes and operations. This hinders the effective management of Sewerage Infrastructure and the development of the sector - [2], sewerage in the country – [3] and [4].

The definition of a Sewerage System is given in § 1, para. 1, item 33 of the transitional provisions of the Water Act [1], namely:: "A set of sewer branches, street sewer networks in urban areas, discharge collectors, and treatment plants or treatment facilities through which wastewater and/or rainwater is drained from consumers properties, their treatment and, where necessary, their disinfection to the required quality and their discharge into the relevant water body."

Based on the analysis of the main documents cited above, it can be concluded that there is a lack of standardized application of: registers of sewerage assets and/or GIS as a technology and approach; registers of treatment plants, sewerage networks, and facilities, including within the meaning of [5] as specialized data and registers; databases/registers for personnel, etc.

One of the main unresolved issues is the collection and use of reliable geographic information about the underground technical infrastructure of the sewerage network, leak detection and their reliable identification in the reference coordinate and elevation system established by national regulations [6]. The purpose of this publication is to present a standardized Metadata level (according to [7]) for locating leaks and damage in the Sewerage network – both visible and hidden in the underground infrastructure.

2. Research methodology

The application of GIS in the field of Sewerage Infrastructure, in this publication, is based on the assumption that: Sewerage is an integral part of the overall technical infrastructure of the country. This should lead to better management/maintenance and reduce the time needed to make adequate management decisions. Structured data according to generally accepted standards [8] will improve the exchange of information between different internal and external users and minimize potential errors.

The data sources used so far by Water Supply and Sewerage operators in the country are diverse, with most of them contained in maps and diagrams on traditional media, as well as in digital files (mainly in AutoCAD DWG and/or ESRI SHP), text documents, etc.

The main problems related to the storage and management of Sewerage Infrastructure data can be summarized as follows:

Much of the information is stored on traditional media (most often paper), which leads to outdated and physically damaged documents;

Different scales of spatial data, which affects the accuracy of location, elevation, and detail. In urban areas, the data is predominantly at a scale of 1:5,000, while in rural areas it is 1:25,000 or 1:100,000;

Lack of information on the sewerage network in some settlements, which hinders response to accidents and investments;

Various digital formats (mainly in AutoCAD DWG, ESRI SHP), but no uniform requirements for the structure and visualization of this data;

Disconnect between asset identifiers and spatial objects (sewer pipes, facilities, etc.), which makes it difficult to keep information up to date;

Lack of standardized procedures for data exchange between departments within water and sewerage operators;

No history of events (leaks, repairs, damage, and interventions) related to sewer system objects and facilities is maintained;

The methodology for data validation is in some cases missing or inadequate.

The creation of a unified GIS for the Sewerage Infrastructure, based on standardized Metadata, would contribute to more efficient management of the latter, as well as faster localization of leaks and accidents.

From what has been said so far, it is clear that the application of GIS as a technology/tool for locating leaks in underground technical infrastructure, with a focus on the Sewerage System, is a complex information system that must take into account all aspects of the technological field.

The conceptual model presented below has been developed in accordance with the approaches and recommendations of ISO/TC 211 of ISO (ISO/TC 211) – Geographic information/Geomatics, [8]. This involves the creation of a reference conceptual model that follows the principles of the systems approach and the application of the principle of synergy.

The methodology presented in this way (implemented through the Meta-meta Data level and the Meta Data level) guarantees reliable results. In addition, it provides opportunities to compare the data obtained with already known results in the subject area under consideration.

Such an approach is essential for the effective management of Sewerage Infrastructure and ensuring data reliability and accuracy.

3. Meta-meta Data Level

The Meta-meta data level of the Sewer System (SS) presented below is in accordance with the guidelines presented in [7] and after the analysis of the studied issues based on the regulatory framework [9] and subjects included in the Water Supply and Sewerage curriculum at the University of Architecture, Civil Engineering and Geodesy (UACEG). The terms and terminology used are in accordance with [10].

In Statistical Classification of Economic Activities in the European Community Rev. 2 (2008): Level 1 Codes – Code E, Water Supply; Sewerage, Waste Management and Remediation Activities, Water Supply is defined as water collection, treatment and supply [11]. These activities cover groundwater, surface water, and rainwater that must be treated, and the supply is delivered to consumers in various sectors—domestic, industrial, or agricultural.

The elements of the SS (in terms of the issues addressed) can be classified into two main categories: Pipe network and Facility. The Pipe network category consists of: Building diversions, Street drains (branches), Collectors, Ducts. The Facility category consists of: Inspection shafts, Rainwater intake shafts (outlets), Waterfall (energy-extinguishing) shafts (belonging to Control and operational subcategory); Rainwater spillways, Holding (regulation) tanks, Sewage pumping stations, Protective channels (belonging to Hydrotechnical and auxiliary subcategory); Wastewater treatment plants, Local treatment facilities, Oil separators, Sludge traps (belonging to Treatment subcategory).

Particular attention should be paid to Sewerage infrastructure, i.e. the perception of Sewerage as an integral part of the overall concept for Spatial Development, including the place, role, significance of [5] and related subordinate legislation (regulations, instructions, and orders), such as [6]. The concept of Sewerage infrastructure is not only a technical one, but also a legal one.

In terms of scope, Sewerage infrastructure refers to pipes and facilities, legal framework, management, planning, investment, maintenance, and everything else related to the modernization of the country's Water Supply and Sewerage Infrastructure.

4. Meta Data Level

The created Meta Data Level (in the form of a UML Class Diagrams) is in accordance with the ISO 19103:2015 Geographic information – Conceptual schema language standard (part of ISO/TC 211 – [8]).

Fig. 1 presents a conceptual model of Sewerage Infrastructure in the context of the current regulatory framework (technical and legal aspects) in the domain of Water Supply and Sewerage and the related domains of Cadastre, Property Register, and Spatial Development.

A UML semantic relationship has been modeled between the classes Sewerage Infrastructure, Cadastre, and Spatial Development, as well as between the classes Cadastre and Property Register, i.e., each class "knows" about the existence of the other (others) and can interact with it (them), with the relationship being bidirectional. The elements of the Cadastre and Spatial Development classes are modeled as UML relationships of the "has a relationship" or "uses" type:

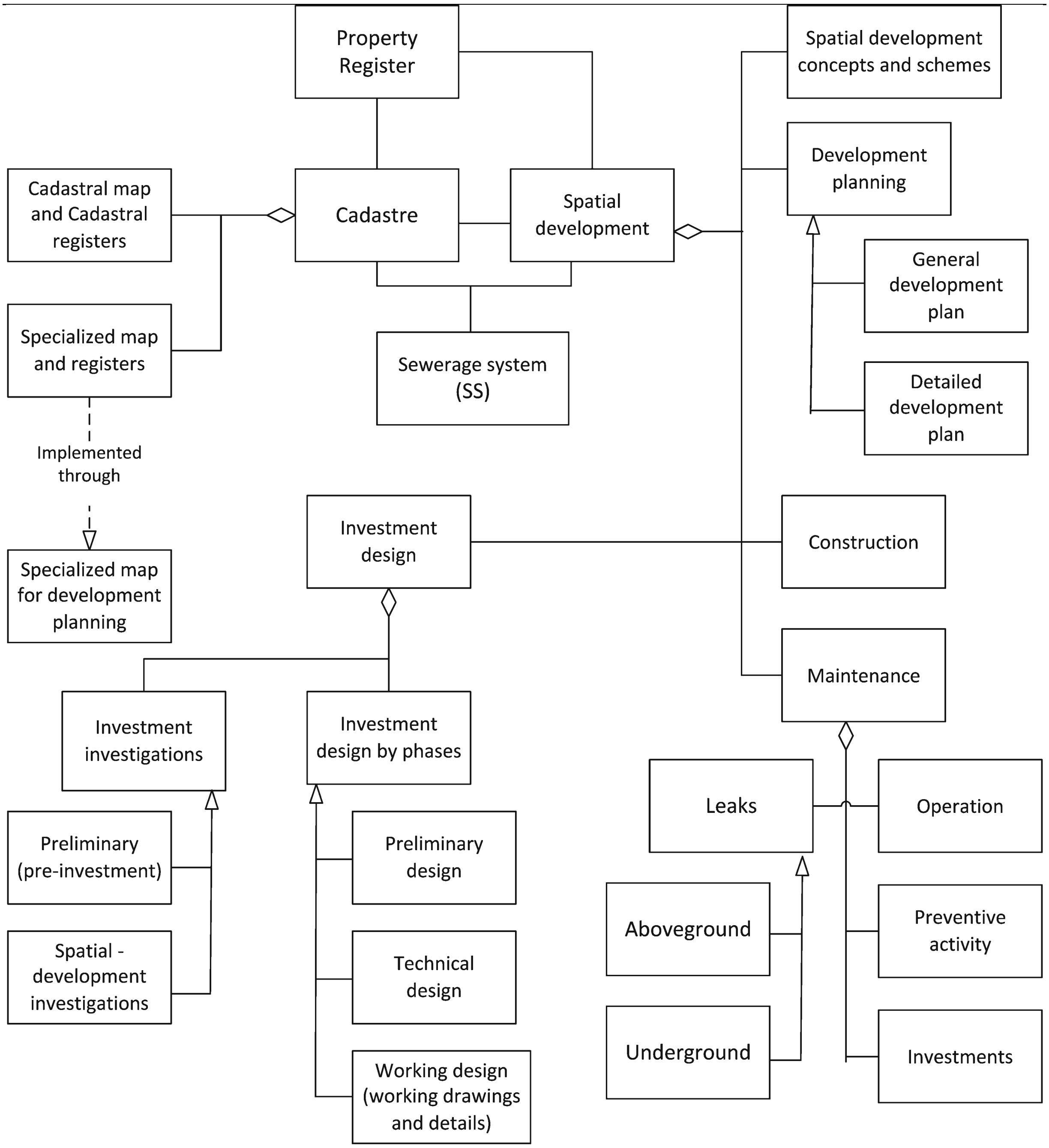

Fig. 1. Conceptual model - Sewerage Infrastructure.

Fig. 2 presents basic categories, subcategory elements, and relations in a sewerage system. UML relationships of the type "has a relationship" or "uses" are modeled:

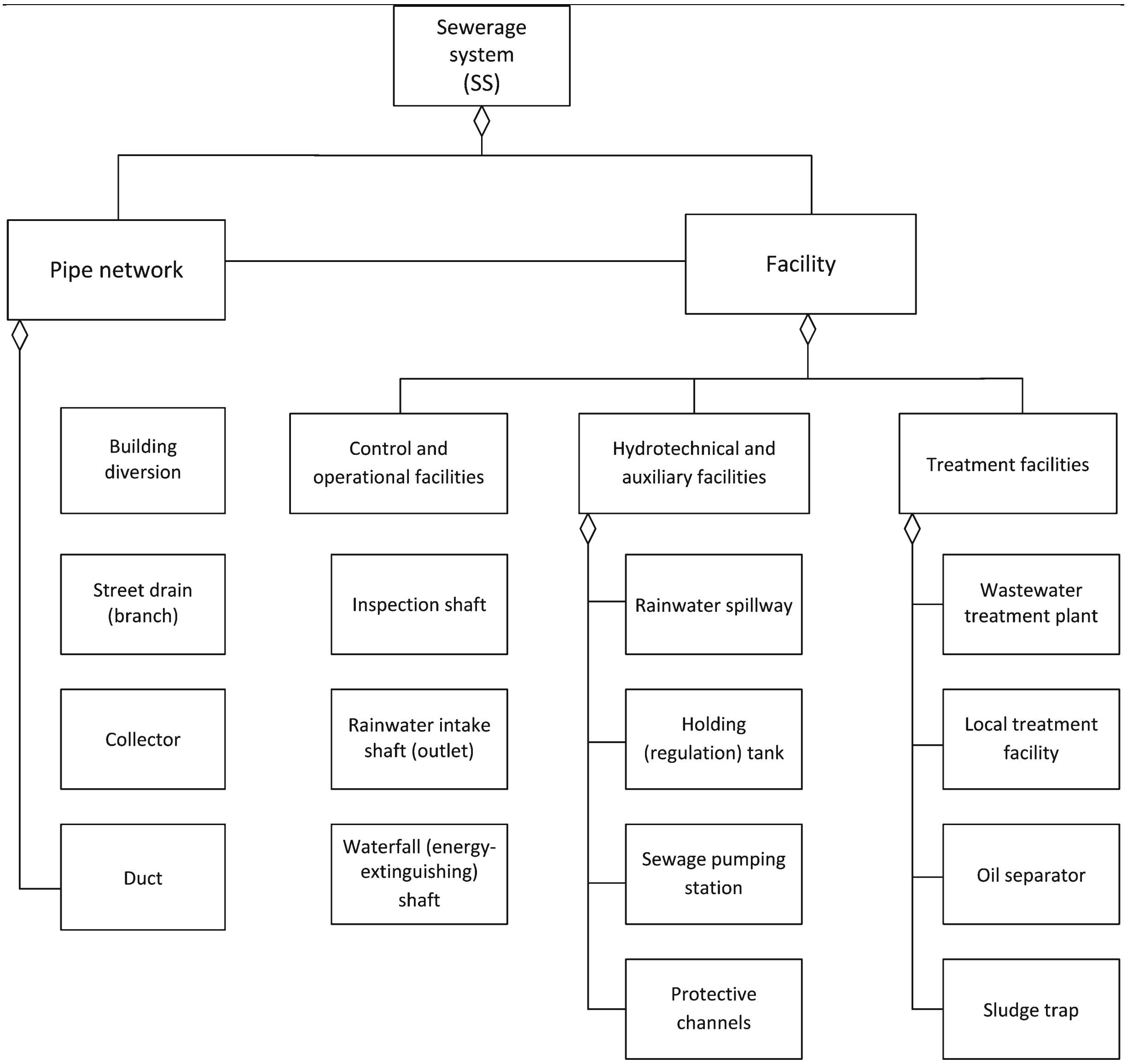

Fig. 2 Basic categories, subcategory elements and relations - Sewerage system (SS).

Fig. 3 presents a high-level diagram of the domain of the sewerage system. The modeling performed reflects the fact that the elements of the SS Metadata Set and SS Dataset classes must be georeferenced in the Reference coordinate/vertical system established in the country – [6]. Leaks in the sewerage system (Leak class) are modeled as a UML relationship of the type "has a relationship" or "uses" with respect to the SS Event class. It is envisaged that the application scheme of the sewerage system will be implemented through the Drawing rule class and applied through the Reference coordinate/vertical system class. To detect and reflect leaks in a Sewerage system, it is planned to apply the currently used approach using SAR images (Synthetic Aperture Radar) – a new, non-invasive and highly effective approach to dealing with leaks and eliminating their adverse effects. For this purpose, a UML relationship of type Specialization has been modeled between the Leak and SAR images classes:

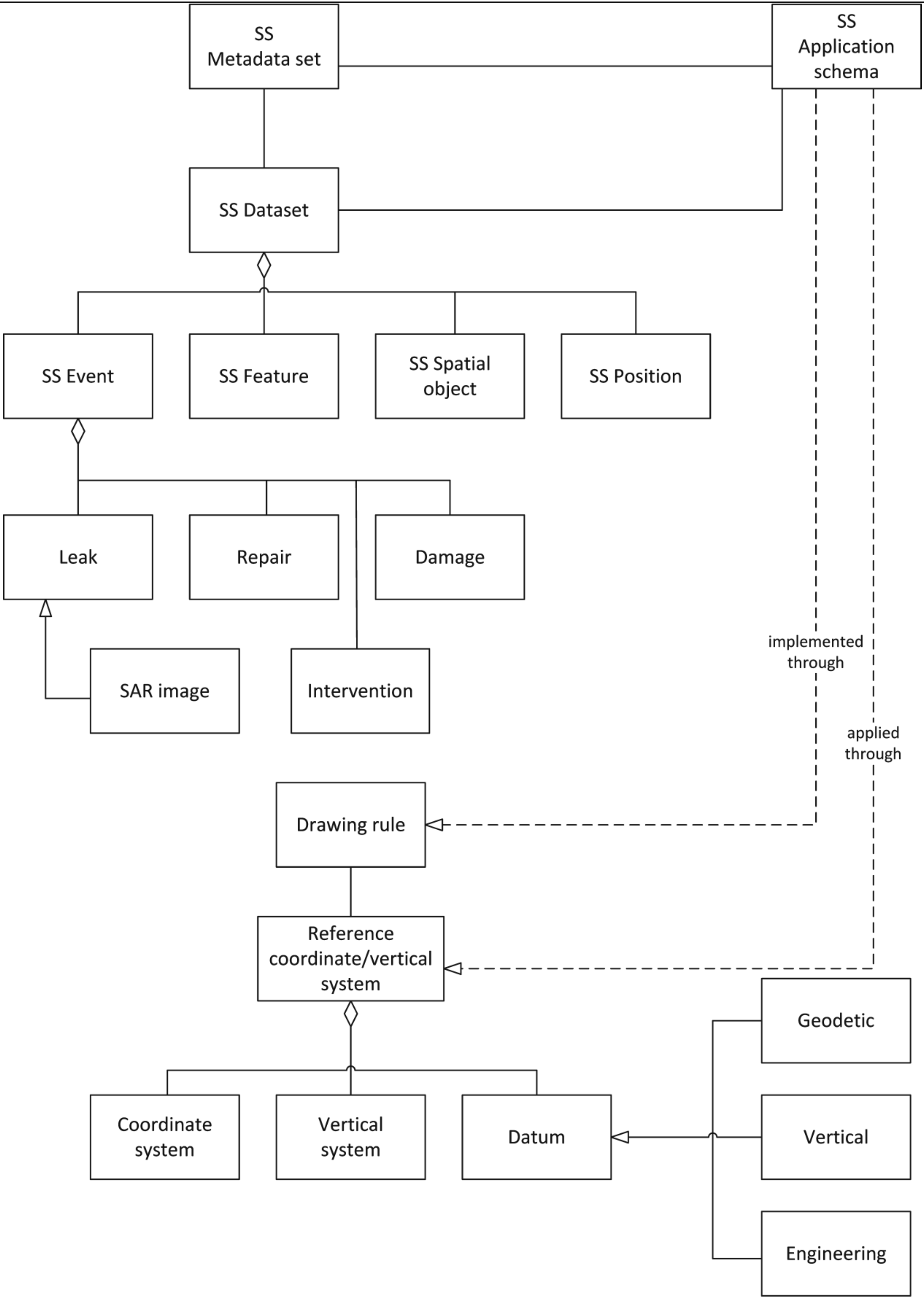

Fig. 3 High level diagram of the domain Sewerage system (SS).

Fig. 4 presents the concept of geometric representation of objects from a Sewerage System through corresponding specializations of the Geometry and Object SS classes. UML semantic relationships between the respective classes are modeled, i.e., each class "knows" about the existence of the other (others) and can interact with it (them), with the relationship being unidirectional (directed):

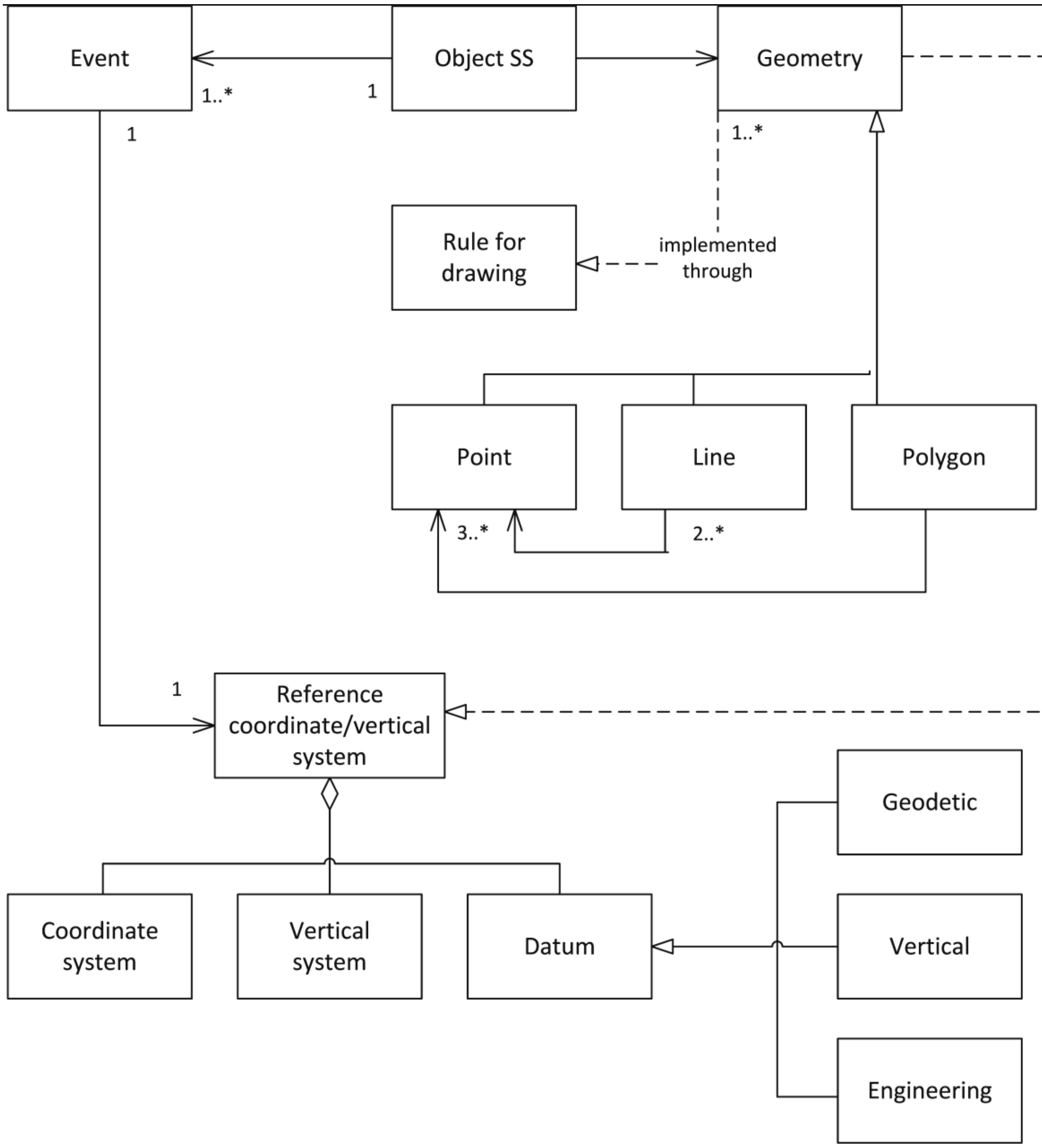

Fig. 4 Geometry representation of objects from a Sewerage system (SS).

5. Conclusion

The presented Meta-meta Data Level and Meta Data Level is in accordance with:

- The principles of the systemic approach that leads to the achievement of synergy and
- The applicable set of generally accepted standards for information on objects or phenomena that are directly or indirectly related to a location relative to the Earth – for this publication these are the standards of ISO/TC 211 Geographic information/Geomatics.

This is a reliable prerequisite for the successful implementation of the next two levels, namely:

- Application schema level (application schemas) - define the types of objects (including attributes and operations), data, and processing;
- Data level - contains the data that is defined by the application schema level.

The inclusion of SAR images in the presented Meta Data Level for detecting and registering leaks in the Sewerage System will expand the functionality of GIS as a technology and reveal the advantages of the approach: non-invasive - does not require excavation or physical access to the network; wide coverage - allows rapid monitoring of large areas (populated areas and/or regional networks); high efficiency – reduced operating costs, complemented by field efficiency – directs resources only to areas with potential problems; detection of leaks that are not visible on the surface; independence from weather conditions.

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