Tallinn Urban Environment and Public Works Department

2019

CREATION OF A PROTOTYPE OF A TECHNOLOGICAL SOLUTION FOR 3D DATA MONITORING OF UNDERGROUND FACILITIES

Final report

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DEFINITIONS AND ABBREVIATIONS

EML	Electromagnetic locator, route locator. A device to detect underground utilities.
Data transition	A process of transferring data from the source format to the database (data import) or from the database to the target format (exporting data).
GPR	A ground-penetrating radar is a high-tech geophysical device to detect underground utilities.
A-scan	A set of samples collected in one point with GPR
B-scan	A sequence of A-scans with GPR, a matrix of electric fields
C-scan	A set of B scans with GPR allowing horizontal view
BIM	Building information modelling
Point of inflection	A point of a linear or plane element in the digital drawing where the direction of the element in the drawing is changed.
Facility-type object	A flat plane element or a closed broken line for the depiction of underground manholes and chambers as a geometric layout.
Pipe-type object	Linear objects the cross section of which is a circle or ellipse (for example, round single pipes, single cables).
Package-type object	Linear objects the cross-section of which is a rectangle (cable and pipe packages, troughs, protective structures, etc.).
Manhole-type object	Manhole-type objects are presented by means of a central point and object measurements.
Characteristic point	Start, end, branching and point of inflection of the piping or cable. All connection points of the pipeline or cable (connectors, diameter transition elements, joints, welds, blind flanges, etc.).
Unknown object detected	An object the presence and height of which have been detected but cannot be classified on the basis of the available data (to determine the utility network, type of installation, etc.).
Route	A reference axis or zone indicating the course of an existing or planned linear object and its designation on the plan.
Coordinate point	A point measured on the axis of the linear object of the utility network and facility during the utility survey or measured in the centre of a point-object and describing the location of an object in a nationally established coordinate system with X, Y and Z coordinates.
2.5D CAD drawing	A drawing in DWG or DGN format, in which the parameters and height data of the elements are attached as attribute data to the coordinate points depicting elements and characteristic points. A drawing in 3D file format, the height of the elements of which is not determined by the geometry of these elements but which is described as mentioned above, is considered a 2.5D drawing.
2D CAD drawing	A two-dimensional drawing in DWG or DGN format.
3D CAD drawing	A drawing in DWG or DGN format the geometry of the elements of which contains their actual height.
3D data set	Elements stored in the database with the attributes for their properties, origin, etc., the geometry of which reflects their location in nature through three dimensions.

DWG	AutoCAD[1] platform file format used to formalise survey results and as-built drawings.
DGN	MicroStation[2] platform file format used to formalise survey results and as-built drawings.
FME	Licensed paid software for checking and processing data from different sources, spatial data, data management tasks and process automation (Feature Manipulation Engine).
GIS	Geographical information system for the management, visualisation and analysis of spatial information. (Geographic Information System)
NIS	Network Information System for the management of network objects and links between them.
GNSS	The Global Navigation Satellite System is a positioning device that simultaneously uses signals from many satellites (GPS, GLONASS, Galileo, etc.).
Total Station (TS)	Geodetic high-tech measuring unit, total station.
Pseudo NMEA	Data specification for the transmission of real-time positioning data from TS devices to third-party software.
NMEA[3]	Data specification for the transmission of real-time positioning data from GNSS devices to third-party software.
VRS	A service that allows land surveyors, civil builders and geography specialists to access real-time kinematic (RTK) GPS & GLONASS (GNSS) corrections without having to use a base station.
RTK[4]	Real-time kinematic method to improve the accuracy of the location of GNSS positioning data.
CCTV	A camera system for determining the condition of pipes
Requirements of the Ministry of Economic Affairs and Communications[5]	Regulation of the Minister of Economic Affairs and Infrastructure No. 34 of 14/04/2016 “Requirements for a topo-geodetic study and utility survey”.
Tartu Geo-archive[6]	Tartu region geodetic survey information system
Tallinn Geoportal[7]	Tallinn geodetic survey information system
TUPA	Tallinn Urban Planning Authority

1 AutoCAD platform https://www.autodesk.com/products/autocad/overview
2 MicroStation platform https://www.bentley.com/en/products/brands/microstation
3 NMEA data specification https://en.wikipedia.org/wiki/NMEA 0183
4 RTK https://en.wikipedia.org/wiki/Real-time kinematic
5 Requirements of the Ministry of Economic Affairs and Communications https://www.riigiteataja.ee/akt/119042016003
6 Tartu Geo-archive https://geoarhiiv.tartu.ee/
7 Tallinn Geoportal https://geoarhiiv.tartu.ee/

1. SUMMARY

The methods of pre-construction surveys and post-construction utility surveys and the equipment and technologies used for measuring the construction and renovation of infrastructures in Tallinn today do not allow the collection, processing or use of a complete data set of underground facilities with the necessary level of detail and precision. This has led to a situation in which work is carried out with insufficient data, which makes work more resource and time intensive and puts the safety of builders and urban residents at risk. In addition, data with unknown quality and reliability are produced.

In Estonia, information on underground utility networks is mainly collected and managed by network owners themselves in the amount and manner necessary for them to carry out their tasks and which requires minimum expenditure. The issue of data to others depends on the rules established by the different utility network owners. A system of coordination is in place for the resolution of tasks that require the data and locations of different utility networks to be taken into account. The main problem is that the utility network owners do not themselves have accurate location information about their networks and are not interested in entrusting their information to foreign hands.

Local authorities need to have an overview and an obligation to process geodetic work and excavation work carried out in their administrative territory. Geodetic work is divided into two categories: pre-design surveys and post-construction utility survey (as-built). Excavation work is necessary for the construction of virtually all infrastructures and buildings. In order to fulfil these obligations, the City of Tallinn must have access to all the location data of the underground utility networks located in its territory and ensure their reliability and availability to all persons with reasonable interest.

In Tallinn, Tartu and some other local governments they have developed their own solutions for handling geodetic work and maintaining data. Tallinn has the geo-measuring information system Tallinn Geoportal, where mainly geodetic layouts and as-built drawings are managed. It is also possible to manage data correcting, engineering geology and cadastral surveying work. All data exchange happens via the web application. Master plan data is stored in the database. Geoportal is used by surveyors and city officials. In Tartu, the web-based work management environment “Tartu Geo-archive” is developed to manage geodetic works. Geo-archive was implemented in the end of 2011. The purpose of the geo-archive is to process the work and obtain a comprehensive master plan of the surveyed objects together with meta-information that can be used to perform various tasks in the city. The established complete picture is used by surveyors as initial data for new measurements.

Modern technologies are available to obtain and manage high-quality and reliable data, the introduction of which ensures the achievement of the objectives of the project. In the framework of the project, many solutions and alternatives were studied as a result of which usable technologies and processes were defined. The complete process of data acquisition and management is divided into stages:

Figure 1: Stages of the process of data acquisition and management

The planning of the process is based on the challenges to be addressed and their priorities:

- to enable reliable 3D base information for planning and engineering work
- to avoid unexpected issues in construction and excavation work and thus ensure their planned progress
- to ensure the integrity of existing utility networks in construction and excavation work
- to ensure that the collected 3D data is up to date
- to ensure the reliability of the collected 3D data
- to reduce the need for repeated surveys of the same underground installations
- to endure machine readability of a utility network data set

The detection and mapping of underground utility networks has been complicated so far, since they are largely lacking both physical and visual access. Although technologies have evolved rapidly in recent years, there is no one perfect technology that can detect, visualise, map and describe all underground utility networks. Detection and mapping of underground utility networks is possible by using a combination of several geophysical and geodetic technologies and a complete process of data acquisition. As a result, it is possible to determine and accurately map most underground utility networks and obtain a complete set of data that can be used in different GIS and CAD software. The three most important technologies in underground utility networks are: ground-penetrating radar (GPR), electromagnetic locator (EML) and RTK GNSS or a TS for geodetic measurements. In studies requiring accurate and perfect data on underground utility networks, the use of all three technologies is mandatory.

There are a number of survey methods to detect and map underground utility networks. Different methods make it possible to obtain data of different quality and reliability. Often, the needs vary regarding the accuracy of the data. For example, when drawing up a specific comprehensive area plan, the quality of data on utility networks is not as important as when drawing up a specific construction project or carrying out excavation work. The cost of the underground utility networks survey and the time it takes to complete it depends on how accurate and reliable data are to be obtained. In order to provide clarity to both the client and the surveyor on the results and the work to be carried out, it is recommended to divide the detection and mapping of underground networks into four types of surveys:

- Survey type 1 - Collection of the existing data
- Survey type 2 - Field observation and surveying ground objects
- Survey type 3 - Survey Data acquisition with geophysical devices
- Survey type 4 - Measurement of underground objects

Depending on the type of work, the local authority can also determine which surveys need to be carried out.

This report proposes the creation of quality classes for location and height data of underground utility networks. A quality class indicates the accuracy and reliability of the location and height data of the underground utility network. A quality class is assigned separately to each underground utility network element in the survey area. One utility network may have different quality classes according to the extent and by which methods it has been surveyed and mapped. The client may order data of different quality classes in one survey. Quality classes may be ordered to all utility networks in a specific area or one specific utility network within the survey area. What quality class can be attributed to the utility network will become clear by the end of the survey. The higher the requirements for quality class, the more expensive and time-consuming the survey will be. The quality classes are based on the classification used in different countries (PAS 128[8], CSA S250[9], ASCE 38-02[10]): Class D, C, B and A. This is important both in the conduct of major procurements and in the harmonisation of regulations and activities internationally. This is also important in the case of cross-border projects (Rail Baltica, TAL-HEL tunnel, etc.).

The project will result in a transition from 2D data to 3D data, which will be managed in a single 3D database. As this is a very big change, this work proposes a solution to maintain 2D visuality and, at the same time, load objects with technical data into 3D geometries in the 3D database by means of automated processes. The advantage of the approach offered is:

- existing processes are not broken
- no conflict with the needs of different parties
- changes to existing regulations can be implemented quickly
- not all data quality classes require depth data
- the elements of the drawing are automatically converted to objects in the 3D database
- the drawings are available on paper
- the data from the drawings are available for BIM projects

[8] Specification for underground utility detection, verification and location, BSI 2014
[9] Mapping of Underground Utility Infrastructure, CSA Group, 2012
[10] Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data, ASCE 2003

In order to be able to apply additional requirements, it is necessary to develop a database of 3D technology networks, a data management environment and processes. Processes must support the active use of data, which can improve the quality and reliability of the data.

In order for all stakeholders to be interested in realising the results of the project and in using the 3D technology networks database in the future, they must benefit from this. The different parties have different interests which must be taken into account in the realisation of the project:

Geodesy company:
- all technical information is available from one place
- reliable data provides an opportunity for better planning of surveys and an understanding of what needs to be explored and what data can be reused
- there is no need for repeated measurements of the same objects

Owner of utility networks:
- the presence of accurate location data reduces the disruption of utility networks
- speeds up planning decisions in building new networks

Designer:
- high quality data = higher quality project

Client:
- high-quality data reduces risks and construction costs
- high-quality data speeds up the completion of construction
- high quality data allows for better construction quality

Builder:
- the risk to the health and life of builders is reduced
- the risk of economic damage is reduced
- the need to carry out redesign is reduced
- the number of outages is reduced
- the costs are reduced

2. INTRODUCTION

2.1 Project requirement

The collection and management of underground networks data need a new modern approach and solution instead of the current daily practice. In the planning of urban space and in the design of buildings (houses and facilities) during the transition to model design, the availability of 3D information and actual data in the quality and detail required is an unavoidable presumption. The data must be processed as three-dimensional and reusable without distortion or loss. In consultation with market participants, it has become clear that there is no product or service offered today as a solution to market needs for the collection and management of 3D data on the location of underground infrastructures.

The individual separate components available today on the world market, such as digital laser scanning, GPRs, various information systems and data processing programs, are each separately increasingly seen in daily use, but a comprehensive solution suitable for Tallinn and one that really functions does not exist in Estonia or anywhere else in the world.

In addition to making stand-alone technical components fit for Estonian conditions and assembling them into a complete workflow, the requirements and regulations that all parties must adopt also play a major role in the complete solution. All this must be done in a holistic and coordinated manner, involving all the parties concerned in the process.

2.2 Project objective

The objective of this project is a solution based on modern technologies for the three-dimensional (3D) acquisition, processing and use of underground utility networks in the planning, development and management of urban space. As a result of the project, the city itself will acquire and request three-dimensional, compliant and actual data on underground utility networks from the companies carrying out construction activities in the urban space.

After creating and deploying a solution and data acquisition, city divisions can use a comprehensive, up-to-date and real-time 3D dataset of underground facilities. Solutions created in the course of the project can be introduced by other municipalities as well as set as a standard for national deployment.

The solution created also encourages the introduction of model design in everyday practice in the construction of underground infrastructures and contributes directly to the increase of added value for the construction activities. As a result, new business opportunities will be created for existing geodesy and design companies, and this will also create conditions for new businesses and business areas.

2.3 Project scope

This project focused on finding, testing and proposing technical solutions for data acquisition and data management. It is also the task of the project to develop processes to ensure the functioning of the whole chain and to enable all stakeholders to participate in the process and achieve their objectives.

While proposals for changes to the work organisation are also being made in the course of the project, proposals for changes to the regulations needed to realise the outcome of the project are not included in the project. All proposals for a change in regulations are ordered separately by the City of Tallinn from the Lextal law firm having the relevant competence.

2.4 Project stages

The duration of the project was two years and was divided into the following stages:

Stage 1 - Preparation

Stage 2 - Survey data acquisition with geophysical tools

Testing of GPR hardware was conducted with the aim of assessing the suitability, capability and reliability of GPRs to conduct underground utilities surveys. In addition, it was assessed what potential added value the GPR would provide for the comprehensive detection and mapping process of underground utilities. The added purpose of the GPR survey was to test different types of GPR to understand the capabilities and disadvantages of different types. For this purpose, as wide a range as possible of GPRs suitable for mapping underground utilities was selected for testing.

Stage 3 - GPR software testing

Data processing software from seven industry leading manufacturers was selected to test GPR software. A comprehensive overview of the possibilities of GPR software today was created. Testing of GPR software was carried out on the basis of the raw data collected by data acquisition in the second stage of the project.

Stage 4 - Data analysis to create 3D models

Additional field surveys were carried out to verify the missing and contradictory data. An analysis of the existing dataset of underground utility networks and its usability to create 3D models and the accuracy and overall level of the 3D models in relation to the set objectives was carried out. Based on the data of the underground utility networks collected, different 3D models and a composite model were created and different visualisation options were analysed.

Stage 5 - Prototype creation

In the fifth stage of the project, the focus was on preparing a complete technological prototype solution - with which technologies and how 3D data acquisition takes place, how the data migrates to the 3D database, how the data is managed and how and to which services they move out of the 3D database. The entire data management process was considered in this stage.

Stage 6 - Preparation of requirements and guidance materials

An analysis of the existing data management situation has been carried out, the main issues that need to be changed have been identified, and specific amendment proposals have been made. Proposals were made for the introduction of quality classes and survey types, and proposals were drawn up for the formulation of underground utility networks' measurement.

Stage 7 - Engaging stakeholders and preparing the final report of the project

The implementation of the results and proposals of the project will have a significant impact on the cooperation of many companies and institutions. In order to present to stakeholders the solutions developed during the project and to gather proposals and opinions, many meetings with the representatives of the stakeholders took place during the project.

Presentations introducing the project

- Summer seminar of the Estonian Geodesists Society, September 14, 2018
- Spring Seminar of the Estonian Geodesists Society, March 8, 2019
- Training of the Estonian Utilities Society, March 26, 2019
- Workshop "Smart City" of the City of Tallinn and TalTech, March 1, 2019
- Digital Construction Cluster workshop, 2 July 2019

Presentations of GPRs

- 14 June 2018. - presentation of the equipment of the Italian company IDS GeoRadar s.r.l in Vesivärava Street
- 12 July 2018. - presentation of the equipment of the Swedish company Guideline Geo AB in Vesivärava Street
- 21 March 2019. - presentation of the equipment of the Swedish company ImpulseRadar AB at Viru Square 3

Project round table meetings

- Representatives of geodesy and design companies attended a meeting held at the Tallinn City Government residence on 27 May 2019. In total, there were 21 attendees at the meeting.
- Representatives of infrastructure construction companies attended a meeting held at the Tallinn City Government residence on 28 May 2019. In total, there were 16 attendees at the meeting.

Meeting with the utility networks owners

A separate meeting was held in Tallinn with the main utility network owners. With some network owners-operators a number of meetings took place. Major network operators who were met:

- Telia Eesti AS
- Elering AS
- Elektrilevi OÜ
- Tallinna Küte AS
- Eesti Gaas AS
- Tallinna Vesi AS
- Estonian Water Works Association

Seminars presenting the final report on the project

- On Tuesday, 6 August 2019, a seminar was held at Öpiku Conference Centre, Technopolis, Tallinn.
- On Thursday, 8 August 2019, a seminar was held in DemoCentre SPARK, Tartu.

3. CURRENT SITUATION

3.1 Problem definition

There are no true, adequate or reliable data on underground utility networks in Tallinn, resulting in:

- a direct threat to the life and health of builders and people in the construction area;
- potential material damage;
- changes in the construction work designs and the increase of work prices;
- untimely completion of construction work;
- it is not possible to create a 3D data model or switch to model design;
- it is not possible to use innovative construction technologies.

The methods of conducting construction surveys in Tallinn, as well as the equipment and technologies used for measuring, do not allow the collection, processing or use of the dataset of the underground utility facilities with the necessary detail and precision.

The dataset resulting from the measurement work does not meet the accuracy requirements and is not complete or reliable. This makes it impossible to get a real 3D urban space model and thus to deploy BIM or use new technologies for surveys.

Although the current available data is largely digital, it is not suitable for practical use because of the number of errors and the lack of integrity it contains, for the following reasons:

- the location dataset to be collected and managed is predominantly plane (2D), with no dimension or depth information (3D) for underground objects
- owners of underground infrastructures generally have information on the location of their infrastructure up to a maximum of 30% to 80% of the total network owned
- there are underground infrastructures the owner of which is either unknown or does not know that the infrastructure exists in the given area at all
- where a digital dataset exists, it often contains essential conflicts, has insufficient accuracy and is not suitable for obtaining an appropriate result
- the existing location information for different types of infrastructure in the same region has totally different categories of accuracy and detail
- the digital infrastructure dataset is available, but it is mostly not true and it is very difficult to verify its correctness

The availability and use of correct and reliable data on underground infrastructures is important at all stages of construction, from planning and design up to completion of the work and daily management. The issue of data on the location of infrastructures has been under discussion for years in order to find an economically reasonable and appropriate solution for the parties through their experience and cooperation. Unfortunately, a viable solution has not yet been created.

3.2 Quality and reliability of general geodetic layouts and as-built drawings

The surveys of underground utility networks are mainly carried out by surveyors who carry out the work in accordance with the regulation of the Minister of Economic Affairs and Communications "Requirements for Topo-geodetic survey and as-built survey" (adopted on 14.04.2016 No. 34, hereinafter referred to as "Regulation"). The requirements of the Regulation are not sufficient to identify, document or create a 3D model of the actual 3D location of the underground utility network. In addition, the requirements of the Regulation on underground utility networks are not met when carrying out the surveys to the extent that they allow the acquisition, processing, management or use of accurate and adequate spatial data on utility networks.

The project examined how topo-geodetic surveys and working measurements were carried out in practice and the quality and accuracy of the available data for underground utility networks, and the random verification of general geodetic layouts and as-built drawings was performed. As a result, significant shortcomings were found both in the norms of the Regulation and in meeting the Regulation during the surveys.

The following are the main observations:

3.2.1 The significance of the surveys is not differentiated

The requirements of the Regulation apply in the same way to all surveys; the same requirements apply to geodetic surveys both for the design of the main street of Tallinn, where there are dozens of underground utility networks, and for building a house in a rural area where there are no underground utility networks. Consequently, in many surveys, the norms of the Regulation are only met formally, which means that no actual control or measurement is carried out and it devalues the Regulation and places in doubt the reliability of all surveys. However, the Regulation has left the possibility of ordering additional surveys with the initial task of the client or excluding the survey of manholes from the composition of the survey, for example.

3.2.2 Origin and accuracy class of spatial data is unknown

According to the Regulation, the geodetic layout must include the spatial data of the underground utility networks from existing plans, drawings and diagrams as well as on the basis of the results of field measurements. It is not possible to distinguish on a drawing from which one or the other line was created in the general layout. The origin and accuracy of the data of the underground utility networks marked in the general geodetic layout cannot in fact be read from the drawings. The only distinction that can be read from a drawing about accuracy is the word “ORIENT”, which means that the line in the drawing is definitely inaccurate. The symbol is also used to indicate that the utility network is not working or is being decommissioned. The general geodetic layout does not reflect the technical characteristics of the manholes and pipes of the existing networks (manhole diameter, material, depth, pipe material, diameter and depth, etc.). Only the number of the manholes is entered in the general layout, and the technical data of the manholes and pipes are inserted into a separate Excel table. The table also contains a column for the origin of the data. It is used to indicate whether the manhole data has been extracted from an earlier survey or whether the manholes have been surveyed in the course of the work. As it is not possible to obtain information about the origin of the lines from the general geodetic layout, the age of the networks included in these drawings is not known. Age would provide information on the method of establishing the network, which would make it possible to assume a situation in the ground.

3.2.3 The general geodetic layout does not reflect the actual location of the utility network

The Regulation sets out the requirements for the reflection of the different underground utility networks and their parts in 2D drawings. According to these requirements, underground utility networks are defined as a diagram of the axis and not according to the actual location. Also, the as-built drawings have significantly more information than the norms of the Regulation require from the geodetical general layout. For example, correctly formulated as-built drawings have information on depth, protective pipes and marker balls, but this information is not included in the general geodetic layout. As a result, important information about underground utility networks is lost. As the Regulation does not directly require it, the general geodetic layouts do not include information on underground protection facilities. The drawings must not contain the protection plates and troughs of the underground networks. It is often simply not known that they exist or they are considered irrelevant or natural. For example, heat pipelines were built in concrete troughs during the time of the Soviet Union. They are not included in the general layout, while this information is often reflected in the as-built drawings. There is also a problem with networks owned by private and legal persons (not network companies), for which there is no knowledge of their existence and, consequently, their location. These networks are not reflected in any as-built drawing or general geodetic layout.

3.2.4 Data acquisition does not use modern technology

The regulation lays down requirements for the positioning of ground objects, but there are no requirements or even recommendations for the determination of the actual three-dimensional location of underground utility networks, with the exception of the open trench utility survey. The locations of the utility networks included in the general geodetic layout must be checked at random in accordance with the Regulation, but it is not specified how or with the help of what technology. A utility locator (EM) has been mentioned once in the Regulation, while a GPR has never been mentioned. Hence, the Regulation does not oblige the executor to determine the actual location of the utility network by using modern technologies in the course of field work.

3.2.5 The data is described, stored and issued in different formats and accuracies

Network owners have different requirements for the documentation of networks, and they also store the data differently. They also issue data differently to a surveyor.

- Telia Eesti AS (hereinafter Telia) and Elektrilevi issue data based on the measurement border:
  - Telia describes data in its GIS system and issues data from the description made. The most recent and latest network description from the GIS system is issued in the format of a drawing suitable for a surveyor. The problem is that exact information from the as-built drawing and less accurate information from the general geodetic layout are all issued together with a 1 m accuracy. According to the rules of Telia’s internal procedures, original as-built drawings may not be issued digitally. If Telia has described a third-party utility networks in its system, that information will also be issued, but it has no indication of accuracy.
  - Elektrilevi uses as-built drawings to load into its GIS system as well, but the data is issued as the same as-built drawings that surveyors have provided them. Data is also issued as network diagrams and digitised images from paper media.
- Gaasivõrgud uses the data of as-built drawings in its GIS systems and issues data as a surveyor’s as-built drawing similar to Elektrilevi.
- Tallinna Küte issues data provided there are as-built drawings made by a surveyor. If the data is old or missing, the PDF diagram is issued from the network owner’s GIS system.
- Tallinna Vesi has created special requirements for acceptable as-built drawings. Receives a surveyor’s as-built drawings, uses them to describe the networks in its GIS systems. Issues data to surveyors only when it has come from a surveyor’s as-built drawings. The full view described in the databases is not issued.
- Smaller network owners do not have a system for network description and management of changes in the network (GIS/NIS) at all, so often incomplete data is issued.

3.2.6 There is often no need for accurate data

When drawing up a general geodetic layout, which is the basis for the construction of a particular object, accurate spatial data for underground utility networks are only needed where they can directly obstruct the construction. It is also necessary to know the exact places of connection points if there is a need to join to these utility networks. At the same time, a general geodetic layout is drawn up for a larger area, and all known underground utility networks that remain in that area are drawn there. As they do not directly cause obstruction, the validity and accuracy of spatial data are not relevant to this work and are not verified. As a result, a geodetic general layout with unverified and potentially inaccurate spatial data is submitted to the geoarchive.

3.2.7 Budget and schedule do not allow for accurate spatial data

Existing spatial data (Tallinn Geoportal, Land Board, etc.) on underground utility networks is neither accurate nor complete. Therefore, drawing up a geodetic general layout with accurate spatial data means a large volume of field work, and the later processing of all data and assembling it into a single geodetic general layout. This job is expensive and time consuming. Today’s prices and deadlines for geodetic work used by surveyors to prepare geodetic general layouts do not allow accurate general layouts to be drawn up.

3.2.8 Lack of skills and experience

The collection of accurate and actual data on underground utility networks requires the use of many methods and technologies. In order to allow sufficient data to be collected during field work, EML, GPR and positioning equipment must be used and manhole surveys must be carried out. Most surveyors today do not have all these skills (the use of an EML or a GPR, for example).

3.2.9 Clients do not require geodetic general layouts with accurate spatial data

Inaccurate geodetic general layouts are accepted as inevitable. Surveyors say that the general layouts presented are the best possible. Clients do not know that by using modern technologies and methods it is possible to draw accurate geodetic general layouts. As the general layouts are generally ordered by a design company that has won the job in the context of an underbid, even knowing about these options, their budget would not allow them to order expensive, high-quality work resulting from the survey volume.

3.2.10 Responsibility in the absence of spatial data

The surveyor is generally responsible for the accuracy of the general geodetic layout and as-built drawing. The accuracy of the location of underground utility networks is the responsibility of the owner of the utility network, who should provide the surveyor with accurate spatial data. Many network companies lack accurate spatial data on their underground utility networks and provide or coordinate inaccurate data or specify data at the expense of the surveyor. This means that in the course of the coordination of the general layout, the service of pointing out the utility location with EM is sold to the surveyor. In addition, underground electrical cables designed to serve some objects but not owned by the network company of the electrical network are often present. These include, for example, customer networks between electrical connection points and final customers, power cables for the water and sewerage pump stations, power cables for the active cabinet of the communications network, etc. There are often no as-built drawings made of them. Even if their land use is not regulated, they are legally owned by the owner of the property (e.g. local government), but the owner of the property has no information about their existence. Even if an accurate as-built drawing has been made of the underground utility network when it was built, the builder may change its location during the reconstruction of the roads, and often those changes are not documented. As a result, the as-built drawing made when the network was built no longer reflects the actual situation, and the corresponding information will not reach the network owner.

3.2.11 Incorrect responsibility in drawing up as-built drawings

When a new object is established or when an existing object is reconstructed and the location is changed, an as-built drawing accurately reflecting the new situation must be prepared. It is almost always the builder who orders as-built drawings from a surveyor. The builder is interested in ensuring that the object is quickly handed over and that there are no major differences between the designed project and the actual construction, etc. The builder is not responsible at any stage for the accuracy of the data in the as-built drawing. Consequently, the as-built drawings do not often reflect the actual situation but are re-drawings of the projects or explanations from the builder who carried out measuring with a closed trench. In order to create interest in issuing an accurate as-built drawing, it must not be ordered by the construction company, but instead by a representative of the client of the construction work who controls the work of the construction company - owner supervision. Owner supervision represents the interests of the network owner or owner of the property and is therefore interested in ensuring that the as-built drawing accurately reflects the actual situation and includes accurate spatial data.

3.2.12 Lack of interest of the owner of the utility network

In today's situation, money is saved at the expense of quality of both general geodetic layouts and as-built drawings. Under the current regulation, the designer and builder will gain financially from the poor work and, finally, the client or the owner of the utility network will also benefit in the form of savings in construction costs. Later, when the spatial data of the constructed networks is needed by other subjects, the owner of the network refers to the lack of data and earns additional revenue from coordination and extra surveys. It is necessary to increase the responsibility of the client for the construction of the utility network regarding documenting the true spatial data of the utility networks. It is necessary to amend the regulations in such a way as to oblige the owner of the utility network to bear all costs related to locating the underground utility network during the planning and design work of the objects (including roads and streets).

3.2.13 Reconstruction of communication networks

The law allows the reconstruction of communication networks without having to draw up a general geodetic layout, a design and an as-built drawing. Nor is it necessary to re-legislate land use. By making use of this law, today, new optical cable networks are being massively built instead of old copper cables. The new cables are not being laid in place of old cables, but within a few metres of their vicinity. This reconstruction will result in new communication networks for which no actual information is available.

3.2.14 Reuse of inaccurate data

The preparation of general geodetic layouts is primarily the re-use of existing data, without knowing the origin, reliability and accuracy of this data. Article 28 of the Regulation of the Ministry of Economic Affairs and Communications lays down the procedure for measuring the underground utility network. According to this, data must be obtained from field measurements of the utility network, manhole surveys, earlier utility surveys and the owner of the utility network.

Due to time and financial pressure and other reasons described above, actual field measurements of underground utility networks or sufficient random checks are not carried out, but data already digitally produced is trusted. This activity is indicated by an extract from Tallinn Geoportal of the general geodetic layout carried out at any location. When comparing Geoportal's drawings in the same area, approximately 80% to 90% of the elements in them (both ground and underground) completely overlap. This, in turn, shows that in reality very little is re-measured and specified of the total scope of work. Often, the drawings submitted to the archives do not contain any measurement data at all.

3.3 Current situation in data management

The world's practice is that there are different ways to manage information on utility networks and to respond to requests for information:

- Information is held by the municipality to the necessary extent
- Information is held by a private company
- Information is mediated by a private company by collecting information from the utility route owners in accordance with the relevant contracts in order to respond to a request for information

The main problem is that utility network owners are not interested in trusting their information to foreign hands, thus allowing for the leak of business secrets. In Estonia, property data is collected and managed by utility owners in the volume and manner necessary for them to perform their tasks and which requires minimal cost. The issue of data depends on the rules established by the different utility owners. A system of coordination is in place for the resolution of tasks that require the data and locations of different networks to be taken into account.

The surveyors must submit a digital geodetic drawing and a survey report to the client, building register and remove local government. Local authorities need to have an overview of and process geodetic work in their administrative territory. Geodetic work is divided into two categories: pre-design surveys and post-construction as-built drawings. The above work is carried out in accordance with the requirements of the Ministry of Economic Affairs and Communications. In particular, surveys and measurements must determine the existence, location and height data of underground utility networks. The primary data of the surveys also contain a number of attribute data that can be specified to a certain extent during the surveys. The highest quality attribute data is obtained by performing as-built drawings of an open trench.

3.3.1 Situation in Tartu

In Tartu, the web-based work management environment "Tartu Geo-archive" has been developed to manage geodetic works. Geo-archive was implemented at the end of 2011. The purpose of the geo-archive is to process the work and to obtain a comprehensive master plan of the surveyed objects together with meta-information that can be used to perform various tasks in the city. The established complete picture is used by surveyors as initial data for new measurements.

In Tartu Geo-archive mainly geodetic layouts and as-built drawings are managed. In addition, it is also possible to manage data correcting, engineering geology and cadastral measuring work. All data exchange is via the web application. Master plan data is stored in the database. The users of Geo-archive are surveyors and city officials. In addition, viewer rights have been granted to third parties such as the Land Board and different utility network owners. Users have different permissions according to the role. User management is through the X-Road. A company is added to Geo-archive, and a person authorised by the company adds the performers via the eesti.ee portal. It is also possible to process restricted areas for the management of sensitive information in the city of Tartu. The locking of jobs to manage overlapping work areas and the elements they contain has also been realised. Two-dimensional (2D) location data is stored in the database of Geo-archive. Technical specifications of utility networks are not managed.

3.3.1.1 Process

The process is initiated by a surveyor who will submit a request for a new survey. The system processes the following types of work:

- As-built measurement
- Geodetic general layout
- Data correcting work
- Construction geology
- Cadastral measurement

The following data is issued from Geo-archive on the basis of the work scope registered by the surveyors:

- As-built drawings
- Geodetic general layouts
- Master plan

The drawings are automatically checked for compliance with the requirements of the Ministry of Economic Affairs and Communications before they are accepted. In the event of errors, the submitter corrects the errors identified by the control system. After correcting errors, the submitter loads the drawing to the intermediate layer of the database. When the drawing is being loaded to the intermediate layer, the data in the drawing and main base layer are automatically compared in the same area. On the web map, you can view the elements that have been loaded onto the intermediate layer, rather than changed and deleted, in different colours. The official can make minor geometry corrections on the intermediate layer. Once the work has been submitted, the employee of the municipality will be able to reject the work. If the results of the check are satisfactory, the work is accepted (registered status) and the elements are loaded from the intermediate layer into the main base. Doing so, all elements of the region that are not in the drawing or are not in the same location as the elements in the drawing are deleted from the main base. New elements are added to the main base, including elements the location of which has changed compared to the current status of the main base. The elements of the drawing the location of which coincides with the location of the elements of the main base will be left unchanged.

The Tartu Geo-archive accepts drawings in the following formats:

- DWG (versions R10 to 2013)
- DGN V8

As an extract from the database, the master plan is issued in the following formats:

- DWG
- DGN V8
- MID/MIF
- SHAPE

In addition to the master plan, the surveyor will be able to download all the original files that remain in the work region. All the objects in the database are associated with a job that allows you to conveniently return from the database object to the original document. The description of the objects in the database meets the requirements of the Ministry of Economic Affairs and Communications. The following main components are used in Tartu Geo-archive:

- Database - PostgseSQL/PostGis (freeware)
- Map server - Geoserver (WMS/WFS) services (freeware)
- FME - Data control, import and export (licensed)

3.3.1.2 Data

The city of Tartu receives utility network data from different network owners. The data is updated at different frequencies, is inconsistent in composition and submitted in different formats.

Network	Company	Extract method	Objects
Electricity	Elektrilevi OÜ	Single extract (network view and location view)	Utility assemblies, routes
Street lighting	Tartu City Government	WMS service	Data incomplete
Water and sewerage	AS Tartu Vesi AS Emajõe Veevärk	Yearly	Utility network, piping
Gas	Gaasivõrgud AS Tarbegaas OÜ Varmata AS Adven Eesti AS etc.	Different	Utility network, piping
District heating	AS Fortum	Yearly	Utility network, piping
Communication (WMS)	Land Board	Restrictions map	Utility network

Table 1. Data from the utility network owners

3.3.2 Situation in Tallinn

In Tallinn, the web-based work processing environment “Geoportal – Tallinn’s geo measurements information system” is used to manage geodetic works. The system in use was created in 2004 by Tarkvarastuudio OÜ. The system is planned to be replaced in the near future with a new, more modern system. At the moment, the new system is in the development stage. To gain an overview of all utility networks, the city of Tallinn uses the master plan of the city’s utility networks, reflecting the location data of all buildings, facilities and utility networks to a scale of 1:500. The master plan is updated/modified in the course of the survey processing. The master plan is stored and managed as 1:2000 map sheets in MicroStation DGNV8 format. All elements of the master plan are linked to the work of Geoportal using Tag elements. This allows you to conveniently open the job from which the element is transferred to the master plan.

3.3.2.1 Process

The functionality of the Tallinn geo-measuring system is essentially focused on processing the work and checking the compliance of the requirements of the Ministry of Economic Affairs and Communications. The process is initiated by a surveyor who will submit a request for a new survey via web application. When filling in the form, it is important to add a location to the map. When saving the form, a new request is created. In the case of a geodetic survey, the request is reviewed by the official who will issue the measuring permit. In the case of as-built drawings, the measuring permit will be issued automatically. After issuing the measurement permit, the submitter can download an earlier geodetic survey and as-built measurement files related to the work region.

The Tallinn geo-measurements information system has an automatic verification system in use to check that the drawings are formulated in compliance with the requirements of the Ministry of Economic Affairs and Communications. When jobs are submitted, automatic checks are performed and error reports are saved to the submitted job. An official of the Tallinn Urban Planning Department will review the job, compare it with the master plan and register the job. It is also possible to reject the registered job if deficiencies are detected in the compilation of the master plan. A job in a “rejected” status must be corrected and resubmitted by the person performing the job. The geo-measurements information system of Tallinn accepts drawings in the following formats:

- DWG (versions R10 to 2013)
- DGN V8

In special cases the master plan is issued in DGN V8 format.

3.3.2.2 Data

The city of Tallinn receives utility network data from different network owners. The data is updated at different frequencies, is inconsistent in composition and submitted in different formats.

Network	Company	Extract method	Objects
Electricity	Elektrilevi OÜ	As a single extract	Utility assemblies, routes
Elekter KP	Elering AS	As a single extract	Utility assemblies, routes
Street lighting	Urban Environment and Public Works Department	Monthly	Poles, substations, routes
Water and sewerage	AS Tallinna Vesi	Quarterly	Utility network, piping
Gas	Eesti Gaas AS	Quarterly	Utility network, piping
Heating	AS Tallinna Küte	Quarterly	Utility network, piping
District heating	Adven Eesti AS	As a single extract	Utility network, piping
Communication (WMS)	AS Telia Eesti	current	

Table 2. Data from the utility network owners

3.3.3 Summary of the current situation in Tallinn and Tartu

Both in Tallinn and Tartu, the accuracy of the data decreases over time, as the information collected with the help of as-built drawings is replaced by information provided on general geodetic layouts. The biggest technological difference between Tartu and Tallinn lies in managing the master plan. In Tartu, data is stored as objects in the database and in Tallinn as DGN files 1:2000 map pages in the map grid. Managing master plans is focused on creating a “complete picture” rather than managing objects. In both systems, the data management process replaces the information in the work regions with the new general geodetic layout information. The new information will overwrite the old information. In addition, the methodology used causes the slicing of utility networks (each new job slices objects).

Tallinn and Tartu cooperate with the utility network owners. The data obtained from network owners is of a very different level of detail and quality. One problem is that the utility network owners do not consider it essential to locate the networks with geodetic accuracy. Rather, a schematic network view is used for daily activity in GIS/NIS systems.

Tallinn and Tartu city governments need a dataset of utility networks primarily to perform urban planning tasks. The accurate location of utility networks is essential to address the following tasks:

- determination of the spatial scope of the elements to prevent breakage
- assessment and planning of the installation possibilities for new utility networks
- issuing initial data for surveys and design purposes

4. DATA ACQUISITION AND DATA MANAGEMENT

The process of data acquisition and management is divided into stages:

Figure 2: Stages of the process of data acquisition and management

The planning of the process is based on the challenges to be addressed and their priorities:

- to enable reliable 3D base information for planning and engineering work
- to avoid unexpected issues in construction and excavation work and thus ensure their planned progress
- to ensure the integrity of existing utility networks in construction and excavation work
- to ensure that the collected 3D data is up to date
- to ensure the reliability of the collected 3D data
- to reduce the need for repeated surveys of the same underground installations
- to endure machine readability of a utility network data set

4.1 Data acquisition technologies and methods

The detection and mapping of underground utility networks is complicated because they are largely lacking both physical and visual access. Although technologies have evolved rapidly in recent years, there is no one-perfect technology that can detect, visualise, map and describe all underground utility networks.

Detection and mapping of underground utility networks is possible by using a combination of several geophysical and geodetic technologies and a complete process of data acquisition. As a result, a complete set of data is obtained from underground utility networks that can be used in different GIS and CAD software.

In an urban environment where there are many parallel, intersecting and overlapping underground utility networks, it is not enough to collect methodological data with geophysical devices in order to obtain a complete picture. It is necessary to know the topology and building principles of the various underground utility networks and to use the data available in the databases.

Modern technologies and methods make it possible to identify the vast majority of underground utility networks in the urban environment. Due to technological limits, it is not possible to detect absolutely everything in the urban environment. As a general rule, all main utility networks can be detected and mapped. Many building inputs may remain invisible to geophysical devices. For example, it is difficult to identify plastic water pipes with a small diameter and below the freezing limit of the ground. Also, thin wires, fibre optic cables directly dug into the earth (without a protective pipe) and without detection wire are not visible to the equipment.

The three most important technologies in underground utility networks are: ground-penetrating radar (GPR), an electromagnetic locator (EML), and GNSS or a TS for geodetic measurements. In surveys requiring accurate data on underground utility networks and recording the survey result, the use of all three technologies is mandatory.

As the detection of and mapping of underground utility networks is mainly carried out by geophysical equipment, there are a number of obstacles and limitations that must be taken into account when carrying out the surveys. For example, the results of the survey are influenced by soil type, soil humidity, strongly distinguished layers in the soil, the depth and size of the object being searched for, closely located metal objects, external electromagnetic waves, high seawater level, poor access to the ground (snow, high hay, etc.), etc.

With the overall data acquisition process and the main geophysical technologies, reliable survey results can generally be obtained up to a depth of 3 metres. Although it is also possible to identify objects significantly deeper with suitable soil and proper equipment, it is possible to introduce additional technologies such as CCTV, magnetometer, gyroscope, metal searchers, acoustic devices, etc. for deeper and more specific surveys (assessment of the condition of a utility network, searching for leakage, etc.).

4.1.1 Ground-penetrating radar (GPR)

4.1.1.1 Technology

To map underground utility networks, it is mandatory to use ground-penetrating radar technology. In many cases it is not possible to detect utility networks or accurately determine their location and depth without using a GPR. A GPR is able to locate the underground utility network regardless of the material from which it is made (metal, plastic, ceramic, wood, etc.), provided that the material differs from the composition of the surrounding soil.

A GPR is made up of three main components – a control unit, an antenna and a battery.

The control unit generates and controls the pulses of electromagnetic waves. The control unit generally includes an integrated computer which receives the reflected pulses, records them and performs initial processing. Most control units are provided with a display for adjusting the settings of the GPR and real-time monitoring of survey data.

The transmitter antenna of the GPR transmits electromagnetic pulses into the ground. This energy penetrates deep into the ground. However, some of this energy is reflected back from the objects which differ from the soil. The reflected energy is captured by the receiver's antenna and the strength and time it took to penetrate the soil are measured.

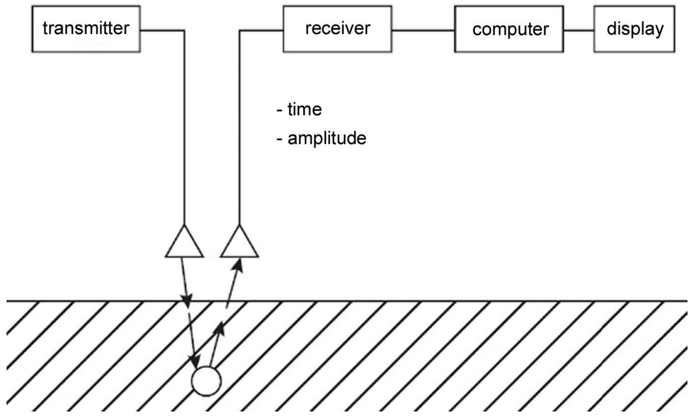


Figure 3: Working principle of a GPR

In order to obtain information about objects at different depths, a GPR collects several hundreds of successive readings of reflections (samples) of an electromagnetic wave from one point. Depending on the oscilloscope technology used in the GPR, a new pulse is emitted to receive each sample (Equivalent-Time Sampling) or all samples can be collected by a single emitted pulse (Real-Time Sampling). The maximum speed at which the GPR can collect data depends on this technology.

A set of scans, called an A-scan, is composed from all samples collected from the same point. The A-scan is used to determine the parameters of the reflected wave at this specific point (x, y). This will provide important information when the parameters of adjacent measurement points are compared. It also shows the strength and polarity of the amplitude at all heights (z). Depending on the mapping task, samples are generally collected and A-scans are generated from them every 1-5 cm. All GPRs are provided with an option to choose whether pulses are emitted automatically into the ground at a certain distance or time or if this is done manually.

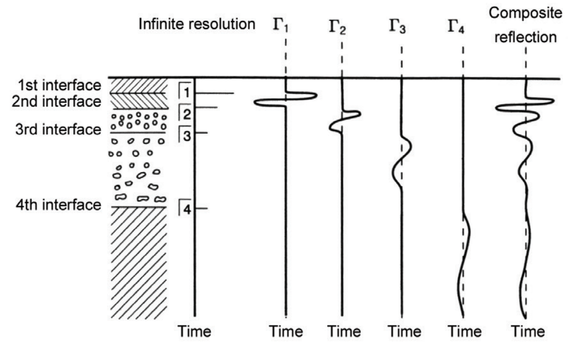


Figure 4: A-scan (D. J. Daniels, 2004)[11]

When a GPR is moved over the ground and A-scans are set next to each other, an electric field matrix, called a B-scan or radargram, is obtained. The B-scan enables accurate detection and positioning of targets. This is the basic method for accurate location of underground utilities (x, y, z). Depending on the direction of a linear target (pipe, cable, etc.) compared with the scanning line, the target on the B-scan is displayed either as a hyperbole, a partial hyperbole or a distinctive line.

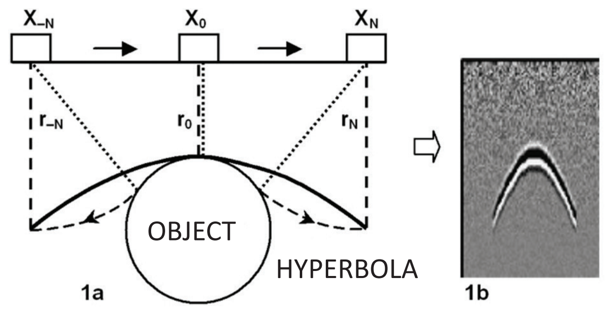


Figure 5: B-scan (Ristic, 2009)

By setting all collected B-scans side by side, they form a 3D matrix or a C-scan.

The C-scan allows slices to be made both horizontally (a time slice) and vertically in the longitudinal and transverse directions of the mapping area. This gives a complete picture of the location of the target. To determine the exact location of the target, different slices from the same area are generally used.

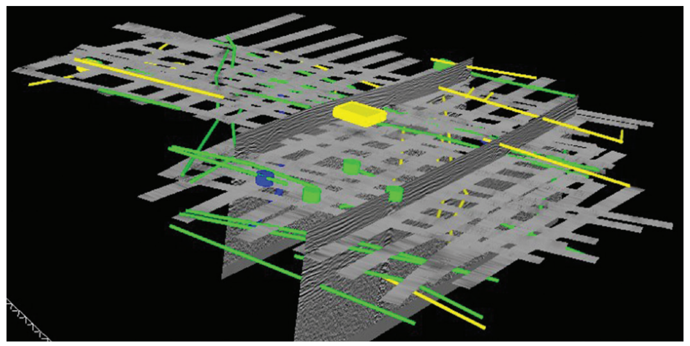


Figure 6: A C-scan 3D view of an intersection of Vesivärava Street and Faehlmanni Street

[11] Ground Penetrating Radar, David J. Daniels 2004

There are several types of devices that can be used for mapping underground utility networks. The most widely used are single-channel 2D GPR units, which are easy to transport and use. At the same time, it takes significant time to map large areas with these units, and in places where there are underground networks running in many directions, the quality of the result is not necessarily good.

Recently, multi-channel GPR units have been increasingly used, in which case antennas are arranged in the housing in such a way that, depending on the device, the channel spacing is between 4 and 8 cm. These 3D GPR units with an antenna array make it possible to obtain high-resolution 3D data from underground utility networks.

Picture 1: 8-channel push-cart 3D GPR

Picture 2: Single-channel 2D GPR

Picture 3: 18-channel 3D GPR

A GPR is a geophysical device, and thus its performance depends directly on soil properties:

- magnetic sensitivity
- electrical conductivity
- dielectric permittivity

Magnetic sensitivity affects the ability of the electromagnetic wave to propagate, but as it is rare in our natural soil, it does not usually affect the operation of a GPR.

The electrical conductivity of the soil directly affects the propagation of the electromagnetic wave and thereby the performance of the GPR because it causes energy loss. Given the electrical conductivity of the soil, the energy emitted from the GPR dissipates in different directions and the remaining quantity is not sufficient to penetrate more deeply into the soil. As a result, the GPR cannot "see" deep enough. For example, saline water is characterised by excellent electrical conductivity and, as a result, a GPR cannot collect data where seawater has penetrated the soil. Also, a GPR cannot "see" through a dense metal grid or a metal plate.

The relative dielectric permittivity of the soil is a characteristic of the soil on which the work of a GPR relies to a large extent. This affects the speed at which the electromagnetic wave passes through the soil with internal resistance of the soil and reflection. Relative dielectric permittivity shows how fast an electromagnetic wave can move in a given type of soil. Different materials have different dielectric values and thus the electromagnetic wave propagates in them at different speeds:

Material	Dielectric value	Max wave velocity (m/ns)	Min wave velocity (m/ns)
air	1	0.30	0.30
freshwater ice	3 to 4	0.15	0.17
seawater ice	4 to 8	0.11	0.15
snow	8 to 12	0.09	0.11
dry sand	3 to 5	0.12	0.17
wet sand	20 to 30	0.05	0.09
gravel	4 to 7	0.15	0.11
slate	4 to 8	0.11	0.15
granite	5 to 7	0.13	0.11
asphalt	4 to 8	0.15	0.11
clayey sand	7 to 10	0.11	0.09
concrete	7 to 10	0.11	0.09
gravel road	8 to 14	0.11	0.08
silt	16 to 30	0.08	0.06
clay	25 to 40	0.06	0.05
peat	40	0.05	0.05
water	80	0.03	0.03

Table 3. Dielectric value of materials and the speed of electromagnetic wave movement (Davis and Annan 1989[12]; Daniels 1996[13]; Teede Tehnokeskus 2014[14])

The GPR measures the amount of time it takes for the pulse to reach the target from the transmitter antenna and from there to reflect back to the receiver antenna.

Knowing the relative dielectric permeability of the soil and how much time it took for the pulse to reach the target and reflect back, the distance (depth) of the target from the GPR can be calculated.

A GPR can be used to map the location and depth of the underground utility network, but it cannot be used to accurately detect what kind of a utility network is involved. Depending on the type of a GPR, software and interpreter skills, it is possible to distinguish cables from pipes and to distinguish between metal and non-metal infrastructure, but it is not possible to tell, for example, whether it is a low voltage or medium voltage cable. It is also not possible to precisely identify with the GPR the size and diameter of the underground utility network.

In order to identify underground utility networks, the GPR needs direct contact with the ground. This is why a GPR cannot be used on a surface covered with thick snow or high hay. A GPR gets the best results on dry and sandy soil and is not as effective on wet and clayey soil. A GPR can "see" through concrete as well. However, if the metal reinforcement grid in concrete is denser than the wavelength of a GPR, the GPR cannot "see" through it.

The ability of a GPR to detect underground utility networks depends on the antenna frequency used.

In general, the frequency of GPRs used for the detection and mapping of utility networks is between 100 MHz and 1000 MHz.

[12] Ground Penetrating Radar for High Resolution Mapping of Soil and Rock Stratigraphy, Davis, J.L. and Annan, A.P. 1989
[13] Surface-Penetrating Radar, David J. Daniels 1996
[14] Asfaltkatteid mittepurustava vastuvõtusüsteemi väljatöötamine, AS Teede Tehnokeskus 2014 (Development of a reception system non-destructive for asphalt coverings)

Lower frequency can penetrate deeper. For example, a GPR with a frequency antenna of 100 MHz can see to a depth of 5 metres or more, whereas with a frequency of 1000 MHz to a depth of less than 1 metre.

As the wavelength is longer at a lower frequency, the resolution is lower and only larger objects can be detected. Thin cables or small diameter pipes cannot be seen with low frequency antennas. At a higher frequency, the wavelength is shorter and the resolution is better, which also allows detection of smaller objects, thinner cables and pipes.

However, it is generally not possible to detect conventional utility networks at a depth of more than three metres with a GPR.

In addition to the frequency, the wavelength and resolution depend on the dielectric permeability of the surface. The higher the dielectric value of the soil, the shorter the wavelength and the better the resolution.

Antenna frequency MHz	Maximum depth in metres		Air	Concrete	Dry soil	Compacted soil	Wet soil
		Dielectric value	1	7	9	14	25
		Wave velocity (m/ns)	0.3	0.12	0.1	0.08	0.06
100	5	Wave-length / resolution (m)	3.00/0.75	1.20/0.30	1.00/0.25	0.80/0.20	0.60/0.15
200	4		1.50/0.38	0.60/0.15	0.50/0.13	0.40/0.10	0.30/0.08
400	3		0.75/0.19	0.30/0.08	0.25/0.06	0.20/0.05	0.15/0.04
1000	1		0.30/0.08	0.12/0.03	0.10/0.03	0.08/0.02	0.06/0.02
1500	0.5		0.20/0.05	0.08/0.02	0.07/0.02	0.05/0.01	0.04/0.01

Table 4. Wavelength and resolution (TSA, 2018)[15]

A GPR is able to determine the location of the underground utility network accurately because the reflection can only come from the exact target on the reception antenna of the GPR. The accuracy with which the network is actually mapped depends on the accuracy of the positioning device and the skill of the GPR data processor.

The depth of an underground utility network can be determined by the GPR with an overall accuracy of ± 10%, depending on how homogeneous the soil is in the survey area and how well the dielectric value of the soil can be determined. At the Vesivärava Street test site, the depth accuracy of the majority of the tested GPRs was ± 5%. It's important to remember that a GPR measures top of the target.

4.1.1.2 Methods of data acquisition with a GPR

4.1.1.2.1 On-site real-time target detection including marking out

This method is used when real-time detection and marking out underground utility networks is required in the survey area. For example, if it is necessary to confirm the location of the underground utility network detected by an electromagnetic locator (EML), start excavation work or construct a new utility network using a closed method (drilling, moling, ploughing), etc.

[15] The essential guide to utility surveys, The Survey Association UK, 2018

This method relies on the skills and experience of a GPR operator. A GPR is set up and calibrated according to the survey area in such a way that data acquisition and signal processing are carried out simultaneously. In this way anomalies detected in the soil that the operator must identify as cables, pipes and other objects are displayed on the GPR.

Using this method, the entire survey area should be systematically scanned according to the type of the GPR and the purpose of the survey. The target found must be marked with sufficient frequency to allow accurate mapping of the location of the utility network. The depth of the target must be indicated for each marking. If possible it must be identified from additional data, a field survey, etc., what kind of utility network is involved, and different utility networks must be identified with different colours.

If necessary, all locations and depths of the identified and marked utility networks can be stored with a positioning device (GNSS or TS) and can be used in GIS/CAD software in the future.

Many modern GPRs also have a recording feature and some also have the ability to connect an external positioning device. Thus, in addition to real-time detection and marking out, raw data can be stored with location data and used later, if necessary.

On-site real-time target detection and marking out have a number of advantages over other methods. It is relatively cheaper because it can be carried out with simpler and cheaper equipment, and the costly process of post-processing GPR data can be avoided. For this method, the on-site environment and context will assist in the detection of utility networks. For example, if a detected utility network exits an electric cabinet, it is most probably an electrical cable. Using this method, a GPR operator is motivated to continuously monitor that the data acquisition is performed properly and that the data is of high quality.

At the same time, this method has several shortcomings. For example, with this method, some utility networks may not be detected in places where there are many infrastructures underground. It is also often not possible to distinguish or it is possible to get confused with different networks where there are many in the same place. This method also makes it difficult to ensure quality control, as the result depends almost exclusively on the skills and experience of a GPR operator. In addition, if in the case of this method only detection and marking out utility networks without recording data is carried out, digital data will not be retained from this survey.

4.1.1.2.2 Data acquisition with recording and post-processing

Data acquisition with recording and subsequent post-processing is used when data from the survey area is needed to be used, for example, for planning, topo-geodetic layouts, building projects, etc.

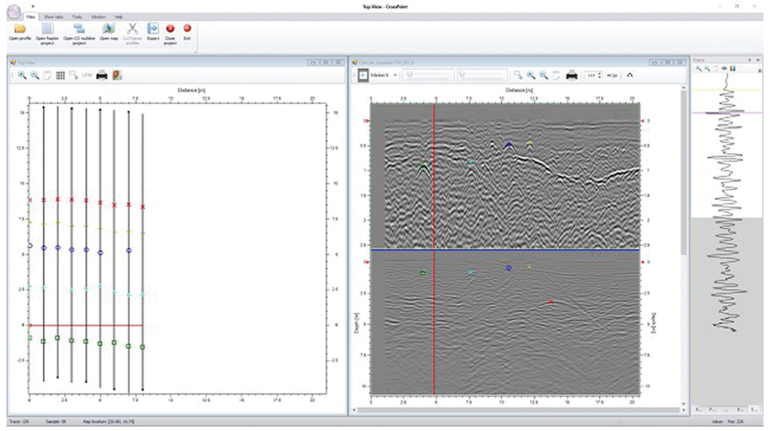
In the case of this method, only data acquisition is performed with a GPR in the survey area. On-site underground utility networks will not be detected or marked out. Using this method, the entire survey area is systematically scanned with a GPR according to the selected device and instructions.

If a GPR is used without an external positioning device, the coordinates for the beginning and end of each profile are recorded separately with a higher accuracy class positioning device (GNSS, TS) so that they can later be placed in the correct position. On GPRs connected to an external positioning device of a higher precision class, the coordinate point (x, y, z) are immediately recorded at each measurement point of a GPR.

This method makes it very important to monitor that the entire survey area is systemically scanned and that no areas remain unscanned. It is also important that the settings of a GPR are performed according to the purpose of the survey, the conditions of the survey area and the instructions of the device manu-facturer. The quality of the data collected in the process of data acquisition depends on how well it is possible to identify and map underground utility networks when processing data.

The data collected during the data acquisition must be taken to the office where they are processed and analysed.

This includes signal processing and interpretation of data by both 2D (vertical scans) and, if possible, 3D (horizontal slices). When post-processing the data, all possible linear objects are detected, which may be utility networks searched for, as well as other underground objects. The resulting data can then be exported to GIS/CAD software, where they will be identified as specific cables, pipes, etc. using other external sources of information.



Picture 4: Post-processing with CrossPoint software

Data acquisition with recording possibilities and subsequent post-processing will ensure better data quality and a bigger opportunity to detect and map the majority of underground utility networks in the survey area. This method also detects other underground objects that may be relevant to the survey.

If data acquisition has been carried out in accordance with the instructions, this method also makes it possible to detect and distinguish underground utility networks in an area where there are a number of similar, intersecting or overlapping networks. It is also possible to distinguish them according to a specific utility network. As the interpretation of data is done through a computer in the office, a variety of additional data can also be used that makes it easier to detect utility networks.

In an urban environment where the underground utility networks are close together, this is the only method that provides a high-quality survey result.

In addition, this method allows the use of a different level of labour for different tasks. For example, a person responsible for data acquisition does not need to be able to do signal processing or post-processing programs, and a person dealing with data post-processing does not need to have geodetic skills.

With this method it is possible to store all survey data and the data can be used for control, even in the future.

A shortcoming of this method is the time and cost of the survey. This method requires the post-processing of GPR data by a professional employee, and post-processing generally takes more time than capturing. Thus, the cost of the survey can be several times more expensive compared to the on-site detection and marking out the target in real time. The survey conducted using this method will last longer, as in addition to data capturing in the study area, post-processing data in the office will also take time.

4.1.1.2.3 Collecting data with one-way direction

The most primitive survey method for detecting and mapping an underground utility network with a GPR is cross-directional scanning of the expected location of the target.

This method can be used if the probable location and the direction of the network to be searched for are known. A single channel GPR is used for the survey carried out by using this method.

A scanning area is determined at the probable location of the utility network. A start and end point of scanning is marked in it every 0.5 m. The points are marked so that the GPR scanning line is perpendicular to the expected path of the utility network.

When crossing the utility network with a GPR, a utility network can be detected by the image of a hyperbole drawn on the radar.

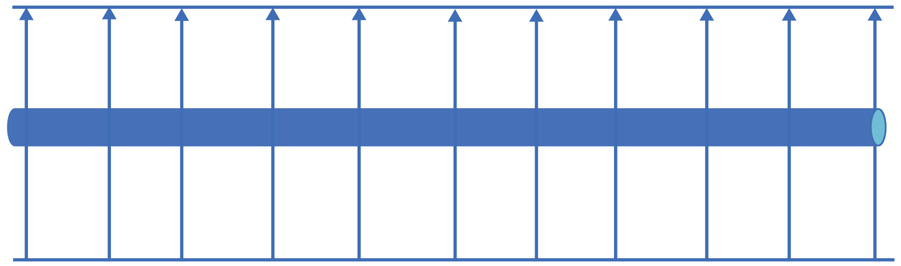
In the case of on-site real-time target detection and marking out, the location of the utility network, including the depth, is indicated on the ground on each profile. To do this, a GPR is driven slightly over the profile, to draw out a complete hyperbole. The GPR is then pulled back exactly to the centre of the hyperbole and a mark is made on the ground.

If capturing is carried out with recording and post-processing, GPR data must also be provided with the location and depth of the targets.

If an external positioning device (GNSS, TS) cannot be connected to the GPR, scanning should be monitored to start precisely from the start point and end precisely at the end point or a reference line must be used. The difference between the start point and end point is measured by a GPR with an internal odometer. The start and end point coordinates of each profile must be recorded with a separate positioning device and all profiles are linked to the exact coordinates during post-processing. If a reference line is used instead of a start and end point, it must be precisely measured.

If an external positioning device can be connected to the GPR, the location data will be recorded immediately with the GPR software. With some GPRs, it is also possible to record the coordinate of the positioning device z as an absolute height. In this case, the height of the positioning device from the ground must be specified in the GPR software settings.

When collecting data using a one-way direction method, it should be kept in mind that metal utility networks running in the same direction as the scanning line may remain invisible to the GPR.



Picture 5: One-way scanning

4.1.1.2.4 Data collection with the survey grid

The main survey method using a single-channel GPR is data collection with the survey grid. Data collection with the survey grid enables the detection and mapping of underground utility networks regardless of their direction.

For this purpose, a survey grid is marked on the entire survey area in two directions, the scanning lines perpendicular to each other (exactly 90°). The scanning lines are marked every 0.5 m and the exact start and end points of the scan are also marked.

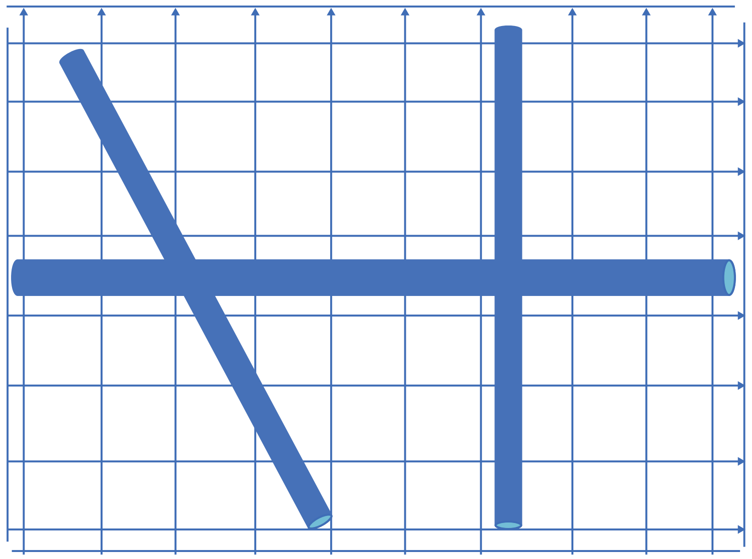
Scanning with a GPR is performed the same way as data collecting by transverse scanning, but the entire area is scanned according to the survey grid marked out.

In the case of on-site real-time target detection and marking out, the location of the utility network, including the depth, is indicated on the ground at a distance of 0.5 m on each scanning line. Dedicated utility networks must be marked in different colours.

If capturing is carried out with recording and post-processing without the positioning device connected to the GPR, all detected targets must also be marked on the ground.

All start and end points of the scanning lines are saved. All targets of different directions are saved in different files in the positioning device.

Using a GPR to which an external positioning device is connected, the area is scanned exactly according to the marked out survey grid and x and y coordinates are also saved with the GPR software.



Picture 6: Data collection with the survey grid

4.1.1.2.5 Data collection as swath

Data collection as swath is used with multichannel GPRs with an antenna array.

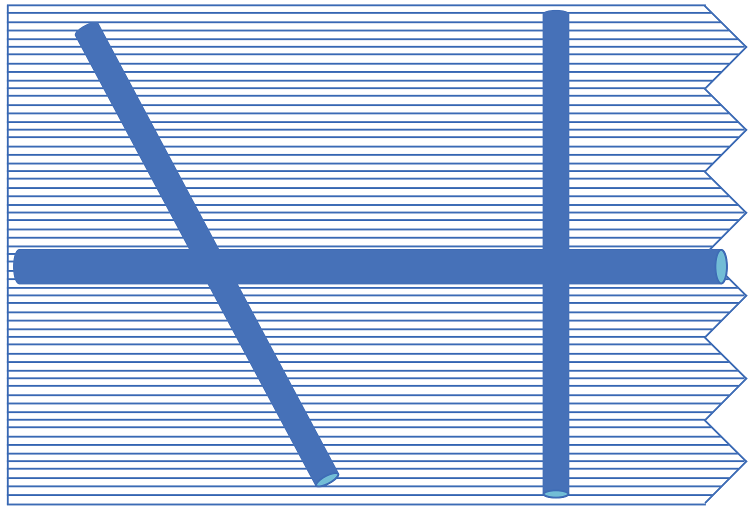
A 3D GPR with an antenna array has a distance between the antennas, depending on the GPR, between 5 and 10 cm. This means that a multichannel GPR with an antenna array scans the ground nearly 10 times more densely than is intended with a single-channel GPR.

It is not necessary to collect data with the survey grid when scanning the ground with this density.

A 3D GPR with an antenna array can detect underground utility networks in all directions only by scanning the survey area in one direction.

It is possible to connect an external positioning device to all 3D GPRs with an antenna array, and the recording of coordinates is done with the recording of GPR data.

A 3D GPR with an antenna array consists of many transmitter and receiver antennas. According to the antenna settings, antenna pairs perform their own profile during scanning, and all antennas together form a scanning swath. When collecting data as swath, be careful so that no unscanned areas remain between the survey lines. As the area is scanned in only one direction, a utility network running in the same direction may remain in an unscanned area. It is also necessary to avoid scanning with too much overlay, as this hinders the post-processing of the data in the later phase.



Picture 7: Data collection as swath

4.1.2 Electromagnetic cable locator (EML)

4.1.2.1 Technology

The cable and utility locator (electromagnetic cable locator – EML) is an important and mandatory technology for underground utility networks. An EML is a widely used technology for the search and identification of metal underground utility networks.

Using EML technology is much easier than using a GPR, and the devices are much cheaper. For capturing and mapping underground utility networks, a positioning device (GNSS, TS) must be used in conjunction with the EML.

EML technology uses electromagnetic field measurement to detect underground utility networks. The magnetic field is generated around the underground utility network detected by the signal generator which conducts electricity (wires, cables, metal pipes). In passive mode, the EML can also detect existing magnetic fields in live electrical cables, communication cables and sometimes metal pipes, for example.

EML consists of two parts: the transmitter (signal generator) and the receiver.

Picture 8: Electromagnetic locator RD8100 with a generator

The transmitter sends out electromagnetic waves. These waves are directed to a specific underground utility network, the location of which is to be identified.

Electromagnetic waves sent outside are always of a specific frequency and can be distinguished. This makes it possible to trace the waves sent out to a particular underground utility network and not to confuse it with another adjacent utility network.

The frequency at which the EML sends out can be controlled in most devices. The frequency of the wave depends on how far the wave spreads, how intense it is, how well or poorly it transmits to adjacent utility networks, etc.

The EML uses different frequencies:
- low frequency 512 Hz
- average frequencies of 8 kHz and 33 kHz
- high frequencies of 100 kHz and above

The low frequency, 512 Hz, is typically used for very long distances, as a wave with such frequency spreads far. A low-frequency wave doesn't jump so easily on adjacent utility networks. However, this frequency cannot be used for induction (clamp) and there are many electrical frequency disturbances in this frequency band that interfere with the correct signal reception.

The 8 kHz frequency is high enough to be used for induction, and there is no electrical frequency interference at this frequency. However, it is not yet so high that it would simply be transferred to the adjacent utility networks. The 8 kHz frequency is not yet high enough to be used to detect small diameter networks.

The 33 kHz frequency is high enough to be free of interference and also available for induction. A signal with this frequency can also be detected on small-diameter utility networks. At the same time, the 33 kHz signal does not spread as far as lower frequencies, and it jumps more easily to adjacent metal utility networks.

Very high frequencies of 100 kHz and more are very rarely used, for example, to search for a cable with a very small diameter. It can only be used in dry soil and in very short distances. The high frequency signal moves only slightly to adjacent utility networks and dissipates quickly.

Sending a signal

Depending on the purpose of the underground utility network survey, the scope of the survey and the type of EML, there are several ways to direct electromagnetic waves from the EML transmitter to the underground utility network that requires detection. Each option has its own advantages and disadvantages.

The most accurate result is achieved by a direct connection where the transmitter is connected directly to the underground utility network (directly to the cable core or, for example, to the tap in the case of a metal pipe).

If it is not possible to connect directly to the cable core (for example, in the case of a working electrical cable), a cable clamp can be placed around the cable. A special clamp connected to the transmitter induces the signal into the cable through insulation.

In the case of underground utility networks which do not conduct electricity but into which a special wire or fibre can be pushed, the detection wire or probe method can be used. For this purpose, the detection wire or probe must be pushed into the pipe to be detected and the signal must be sent to the utility network via them.

In the absence of full access to the underground utility network, it is possible to induce electromagnetic waves through the ground.

Receiving a signal

The EML transmitter generates a magnetic field with variable frequency around the underground utility network to be detected according to the selected connection type. The EML receiver is set so that it can detect a variable magnetic field with the same frequency. By moving the receiver along the utility network, a utility network can be identified by measuring the strength of the magnetic field.

Often, the conditions are not ideal and the signal cannot be directed so accurately that it only remains on the utility network to be identified. The signal may be transmitted to other utility networks, for example, through common connection points or through common grounding. The signal may also be transmitted to another nearby utility network through the ground.

In order to direct the signal more precisely, it is necessary to:
- find a suitable place to connect the transmitter to the network
- find a suitable place for grounding
- set the appropriate frequency for the survey in both the transmitter and receiver
- set the appropriate current in the transmitter

The EML only detects the location of the underground utility network and, by an active method, the depth from the ground. The EML does not record the results of the survey. For the underground utility network survey, the utility network detected by EML must be marked out.

The locations and depths of the utility network marked out are recorded with the positioning device (GNSS, TS). Some EML devices can communicate directly with the positioning device over a Wi-Fi network, thereby saving the utility network data directly to the positioning device.

4.1.2.2 Data acquistion methods with EML

4.1.2.2.1 Active method

Active methods are all these where a controlled and specific frequency signal from an EML transmitter is routed to the underground utility network to be detected and the EML receiver detects the location of that signal on the ground.

In the case of active methods it is possible to check both the frequency of the wave and the strength of the current manhole as the connection point and the grounding point. This enables active methods to produce high-quality survey results.

Direct connection

When using a direct connection method, the transmitter is connected to the cable core or pipe to be detected through the wire. The transmitter is then grounded to another metal item partially buried in the soil. In order for the electrical circuit to close, the signal attempts to move along the utility network to be detected toward the grounded object. This creates a magnetic field around the utility network to be detected and it can be detected on the ground using an EML receiver.

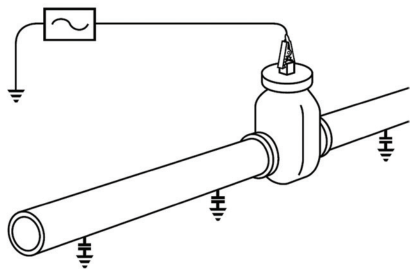
If a direct connection to the cable core is not possible. For example, in the case of a working electrical cable, a special clamp can be used. The clamp is placed around the tracked cable and connected to the transmitter. The clamp allows the transmitter to induce the signal into the cable through its isolation.

The EML receiver is set to the same frequency as the transmitter. When an underground network is found with the EML receiver, it must be tracked in the survey area and its exact location and depth must be marked on the ground. All different utility networks must be marked on the ground with a different colour so that they can be distinguished afterwards.

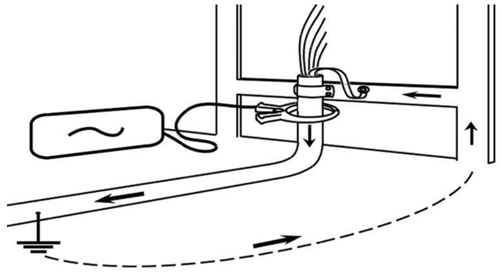
With direct connection, the target can be detected up to a depth of 10 metres with an accuracy of ± 5% depending on frequency and signal strength.

The depth of the underground utility network identified by direct connection is the depth of its centre from the ground. For example, if the electrical cable is in 100 mm protective tube, the EML does not show the upper part of the protective tube (like a GPR) but exactly the position of the cable core.

A direct connection methodology is the primary methodology in each underground utility network survey, as it allows the most efficient search and differentiation of different utility networks.



Picture 9: Direct connection (Radiodetection 2008)[16]



Picture 10. Clamp (Radiodetection 2008)

Detection wire

A detection wire methodology can be used for pipes to which a detection wire can be pushed in and which do not conduct electricity themselves. The detection wire methodology cannot be used for metal pipes. Searching for a route with a detection wire methodology is executed in the same way as in the case of direct connection. Instead of connecting the network to be detected directly to the transmitter, a detection wire is connected to the transmitter.

Before connecting the detection wire to the transmitter, it is pushed into the tracked pipe at the desired distance. The detection wire is then connected to the transmitter and the transmitter is switched on. As a result, a magnetic field is created around the detection wire and the tracked pipe becomes visible to the EML receiver, and the position of the pipe can be determined as in the case of a direct connection.

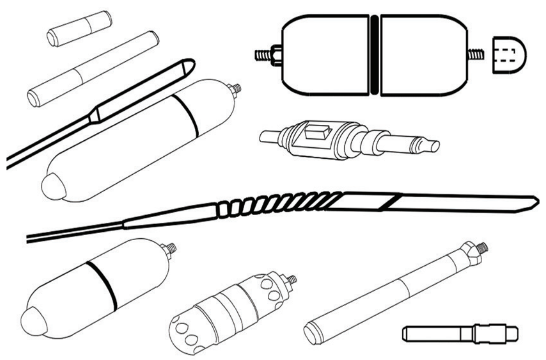
Sonde

As with the detection wire, the sonde methodology can only be used for pipes where the sonde at the end of the fibre can be pushed into the pipe.

The sonde is a miniature EML transmitter attached to the end of the fibre and then pushed into the pipe to be detected. The sonde is gradually moved forward in the pipe and the position and depth of the sonde is detected with the EML receiver and marked out on the ground.

Using the sonde methodology, the depth of the sonde, rather than of the utility network to be detected, is detected from the ground. The sonde may be located in the bottom of an underground utility network to be detected, in the upper part of it, or somewhere in between, according to whether the pipe is empty and clean, has water in it or has other objects in it. Determining the location of the sonde in the network to be detected is particularly important for large collector pipes where the spacing may be tens of centimetres.

Sondes are available in several sizes and for different pipes. The sondes are mainly used in searching for deeper drainage-like pipes, as some sondes can operate at depths of up to 15 metres.



Picture 11: Various sondes (Radiodetection 2008)[17]

[16] abc&xyz of locating buried pipes and cables, Radiodetection 2008

[17] abc&xyz of locating buried pipes and cables, Radiodetection 2008

Induction through ground

Induction is used when no direct connection, detection wire connection or probe can be used. As the name of this method states, induction is used.

The transmitter is placed in a strategic position in the survey area and the transmitter signal is sent directly into the ground. The signal moves forward along the closest wave-transmitting objects, which are usually either metal pipes or cables. The receiver is then used to find the signal and, through it, underground utility networks.

The transmitter and receiver must not be too close to each other to avoid feedback via air. The transmitter can be placed directly on top of the network you are looking for, and by gradually moving it forward, the network can be detected at long distances.

The induction method can detect underground utility networks at a maximum depth of 3 metres.

The induction method should be used as the last of the active methods. Then the utility networks that have already been detected and marked can be excluded from the search.

If possible, the exact location and depth of the underground utility network found by the induction method should be further determined by another active method.

Picture 12: A survey using induction through ground (TSA, 2018)[18]

4.1.2.2.2 Passive method

A passive method is used after the active method. This helps to identify underground utility networks that could not be found by using the active method. This is usually the last method used with the EML in search of underground utility networks.

When utility networks have been detected and marked out using active methods, a passive method can be used to study the entire survey area to determine whether there were any metal utility networks that were not identified by the active method.

The passive method has two modes: “Power” and “Radio”.

In “Power” mode, the receiver can detect the presence of live electrical cables by detecting the electromagnetic field surrounding them. The entire survey area will be studied according to the survey network, and signs of utility networks that have not yet been identified are searched for. When finding such a utility network, the receiver is moved along this utility network and its location is marked on the ground.

[18] The essential guide to utility surveys, The Survey Association UK, 2018

Since the signal does not stay on a particular cable only and it can, for example, be transmitted to an adjacent water pipe, attention should be paid when searching for utility networks using this method.

The best way to avoid such errors is to detect and mark all water pipes and the like in advance by using active methods so that they can be excluded from the search.

It should also be taken into account that the passive method always shows the biggest transmitter of electromagnetic waves, which may not be the cable with the highest voltage. For example, a manhole-shielded high-voltage cable generates only a small electromagnetic field, while older bundles of low-voltage cables can generate a significantly larger electromagnetic field. Also, electrical cables that end with a sleeve are often not detectable in “Power” mode.

The “Radio” mode allows the receiver to find very low frequency radio signals that “reflect” back from underground pipes or cables. The effectiveness of this method depends on the intensity of very low frequency radio waves (VLF) in the atmosphere. It can change with days and even hours. The more intense it becomes, the more effective the use of the “Radio” mode is.

Using the “Radio” mode, the survey area will be studied in the same way as in the “Power” mode and underground utility networks will be marked out. In order for the “Radio” mode to detect a utility network, it must be at least 10 metres long.

Passive methods are capable of detecting the presence of an underground network from a maximum depth of 3 metres. It is not possible to determine their exact depth.

The passive method is very important in finding these conductive underground utility networks that cannot be found by active methods. This is particularly important if, for some reason, it is not possible to scan the entire survey area with the GPR.

4.1.3 Positioning

4.1.3.1 RTK GNSS

The most mobile measurement option is RTK GNSS. In order to achieve the necessary accuracy, it is essential to use multi-frequency and multi-satellite-based positioning systems such as GPS, GLONASS and GNSS receivers that support Galileo.

When measuring with GNSS equipment, it should be borne in mind that, in order to achieve the required accuracy, the horizon must be as free as possible. In the vicinity of higher buildings and high vegetation, GNSS measurements are not reliable and do not provide the desired accuracy of the measured results. In such cases, other accurate measurement technologies must be used.

4.1.3.1.1 Methods

Measurements may be carried out either by the use of corrections from permanent stations or by using a reference station installed by itself. RTK technology enables the receipt of real-time coordinates and heights with the accuracy of a few centimetres.

To bind GPR and RTK measurements, measurement data from the GNSS device in the form of NMEA protocol are used. The measurement data are connected to each other in the GPR device.

4.1.3.2 Tachymetry - measurement station

A Total Station (TS) must be used in areas where it is not possible to carry out accurate measurements with GNSS equipment due to high-rise buildings or high vegetation. The tachymetric measurement sets different limits. The measurement must be carried out with direct visibility between the GPR survey device used for measuring and the Total Station. In order for the result to be accurate, it is also necessary to link the measurement to the points of the geodetic network. Tachymetric measurement is certainly more time-intensive, but in the densely populated areas the most accurate way to geodetic binding of the entire survey.

4.1.3.2.1 Methods

Any Total Station may be used for tachymetric binding. The best option, however, is a robotic TS that is able to transmit measurement results in real time via the pseudo-NMEA protocol directly to the GPR device. This solution provides the best input data for post-processing data.

4.1.4 Accuracy of location data and depth data

The accuracy of the location data and depth data of the underground utility network are never absolute and they depend on many circumstances. Using the correct methodologies and technologies and conducting the survey according to the intended process, the accuracy of the location and depth of the network detected by the survey remains within ± 10 cm.

The data acquisition of geophysical devices must take into account the specificities of these devices.

The EML always provides the depth to the centre of the underground utility network, detection wire or probe.

If the diameter of the network or the location of the detection wire and probe in the network are not known, it is also not possible to determine precisely the depth of the upper part of the network from the ground.

The GPR always shows the depth of the upper part of the underground utility network from the ground.

If the underground utility network is located in a concrete barrier or if bricks are laid for protection on a utility network, the GPR shows the depth of the upper part of these protection facilities and the depth of the utility network itself is not known. In some cases, however, a GPR can also detect a utility network through a protective layer of concrete or stones.

The location of the detected underground objects is determined by an external positioning device, and the actual accuracy of the object’s position depends on the quality of the positioning device used, the method of measurement and the professionalism of the surveyor.

Amongst others, the accuracy of the location and depth data of the underground utility network is influenced by the following:

- the purpose of the survey and the survey methodology
- accuracy of general layouts
- positioning accuracy in the survey area
- accuracy of marking out and recording the survey network
- accuracy of the methodology of the EML survey and the device
- accuracy of the GPR survey, methodology, resolution, calibration and device
- accuracy of the post-processing of GPR data
- the professionalism of the surveyors

4.1.5 Other survey methods for underground utility networks

There are a number of other techniques that can be used in the surveys of underground utility networks. The efficiency of these techniques varies and their use depends on the specific situation. In general, the following technologies are very rarely used in utility network surveys and in very exceptional cases: gyroscopes, CCTV, magnetometers, earth conductivity, metal detectors, IR, seismic, optical, acoustic, odour sensors, etc.

4.2 Data acquisition process

Data acquisition of underground utility networks requires a systemic approach and the use of suitable equipment and the right methods. Although each survey project is different, the overall data acquisition process must be followed to obtain accurate and perfect data:

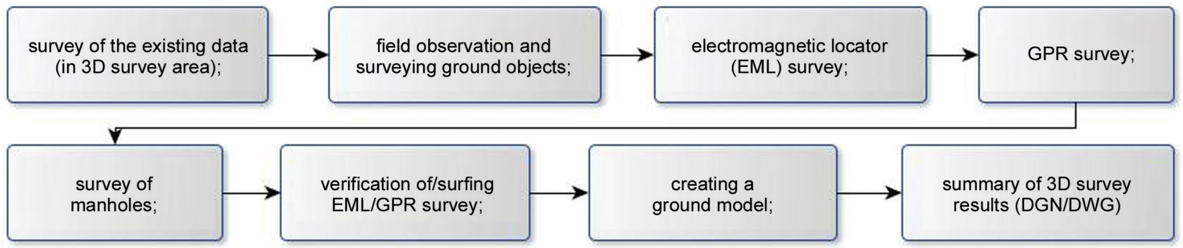


Figure 7: 3D data acquisition process

4.2.1 Survey of the existing data

- The master plan for data on underground utility networks is taken from the geo-measuring information system of Tallinn. It is used mainly as a schematic basis for obtaining an overall picture of the survey area and for the planning and conducting field surveys.
- The as-built drawings are taken from the geo-measuring information system of Tallinn. The information available from the as-built drawings is of the highest accuracy class and the level of detail of the description of the properties of the objects is the most accurate since the work has been carried out immediately after construction. Despite the fact that the as-built drawings are of very different quality and contain errors, the use of this data set is essential for preparing 3D surveys.
- Preparing an initial scheme identifying potential utility networks and their owners in the survey area.
- The information on the utility networks is obtained from the utility network owners. This data can be in different formats, accuracy classes and completeness.
- The existing data will be used to prepare a general scheme. It is used in a further survey and is the basis for preparing 3D survey results.

4.2.2 Field observation and surveying ground objects

- Identification and taking photos of the ground parts of underground utility networks (electrical and communication boxes, electrical and street lighting poles, manhole covers, fire hydrants, gas taps, etc.) in the 3D survey area.
- Detection and taking photos of other findings referring to underground utility networks (excavation traces of routes, house inputs, etc.).
- Measuring the ground parts of underground utility networks with a positioning device.
- Drawing up a description of the survey area for EML and GPR surveys.

4.2.3 EML survey

- Detection of underground utility networks with passive methods and marking out location data.
- Detection of underground utility networks with active methods and marking out location data and depth.
- Recording location data and heights of underground utility networks marked with a positioning device.

4.2.4 GPR survey

With a one-channel GPR

On-site real-time target detection including marking out in the frame of the survey

- Marking out a survey grid
- Device setup and calibration
- Data acquisition by following the survey grid and marking out the depth
- Recording location data and depths of findings marked out with a positioning device, if necessary

Data acquisition including recording and post-processing in the frame of the survey

- Marking out a survey grid
- Device setup and calibration
- Data acquisition by following the survey grid , if possible with positioning
- If necessary, recording start and end points of the survey network with a positioning device
- Data post-processing

With a GPR provided with an antenna array

- Marking out of the start point of the survey area
- Setting up the GPR
- Setting up a positioning device
- Data capturing as panes including positioning
- Data post-processing (visualisation and interpretation)
- Export of points, lines, and panes of detected objects

4.2.5 Survey of manholes

- Measuring the inner dimensions of the manhole
- Description of pipes and cables entering and exiting the manhole (material, quantity, placement, etc.)
- Measuring the internal dimensions of the pipes
- Measuring the external dimensions of packages
- Measuring the depth of pipes and cables from the ground
- Photos of the interior of the manhole and the buried cables and pipes contained therein
- Creation of a manhole scheme

4.2.6 Verification of/surfing EML/GPR survey

- Excavating up to the utility network with a shovel or vacuum pump without damaging it
- Detection and description of the utility network
- Measuring the external dimensions of a utility network
- Measuring and recording the location and depth of a utility network with a positioning device
- Recovery of the excavation site

4.2.7 Creating a ground model

- Geodetic binding
- Measuring characteristic points
- Defining breaklines
- Creating 3D model surfaces

4.2.8 Preparing the results of a 3D survey

- Preparing the results of a 3D survey starts with processing the data from the existing as-built drawings. If the as-built drawings also contain height information, 2.5D objects must be prepared from the objects of 2D as-built drawings by adding attribute data (height, diameter, material, etc.) of the objects. 2.5D objects are created using the CAD (AutoCad or Microstation) software.
- As a result of measuring utility networks on the ground, the first comparison with the data of the existing as-built drawings becomes available. If differences are detected in the location data compared to the measured data, it is clear that the location accuracy of the as-built drawing does not correspond to reality and that the non-conforming parts should be replaced by measured results.
- A 3D ground model is prepared. The ground model is used to calculate the heights of points, lines and surfaces that characterise utility networks from the depths determined by EML and GPR technology.
- According to EML and GPR surveys, and in some cases data from surfing, the planned location of the objects is changed, if necessary, and missing or specified height data is determined.

- The technical properties of objects (diameter, material, etc.) must be checked at random for compliance with the objects for which this is possible. Attribute data can only be partially verified. This can be done in these places where visual inspection can be carried out. Such places are manholes and boxes. If the random check results in a non-compliance of the technical data, all visually inspected objects must be re-checked. If the results of the random check are positive, there is no need to re-check the objects. However, when you re-check objects, you need to trust the data in the as-built drawing in certain parts. For example, if it is not possible to identify pipe material, it will be transferred from the most accurate existing work (TJ).

Objects for which no prior information is available and which cannot be identified are transferred to the 3D survey results file as detected unknown objects.

4.3 Data management technologies and methods

The level of detail of the attribute data to be collected depends on the initial task provided by the client who ordered the survey. It is not practical to collect and manage all the data required by the client in the 3D technology network database of the city of Tallinn that is being created.

In the case of managing attribute data, the main question is for solving of which tasks they are collected. It also determines the volume of data to be collected. It is also important to take into account the possibilities for collecting and transmitting data. It is important to ensure that the collection and management of data will minimise the need for double work in the future.

The data must be provided in an unambiguous and machine-readable format.

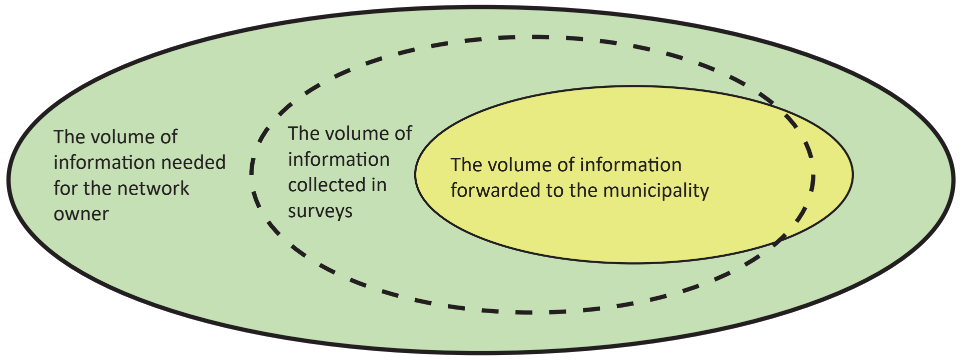


Figure 8: Different information needs.

Two most common CAD platforms in Estonia, AutoCAD and MicroStation, are used to formulate the results of the survey. Today, the above-mentioned platforms are used to formalise jobs by following the MKM requirements. Following the requirements allows the network and type information to be automatically read out about the elements formulated in the drawings. The addition of other attribute data to elements in a drawing is not common and is usually forwarded as separate tables or files, rather than in machine-readable format. There are also several clients in Estonia who require CAD drawings with attribute data to automatically transfer data to databases.

4.3.1 Ways to manage attribute data in CAD files

Attribute data are collected during surveys and utility surveys. Therefore, the software used to create the measurement and survey files must allow adding, modifying and deleting attribute data to objects by using an existing or created user interface. If these options are not initially available in the user interface, it must be possible to create the corresponding user interface. It must also be possible to read the data from the drawing files in order to transfer these to the database, and it must be possible to create the corresponding structures when exporting data from the database to the relevant format.

4.3.1.1 MicroStation DGN

MicroStation DGN V8 format allows you to add non-graphical data in different ways. Some of them are still available to support earlier versions, while others are designed related to the implementation of newer versions and provide a flexible way to add and save data.

Non-graphical data can be linked to graphical elements.

Name	Location
EC Schema Data	Xattribute application provided with official XML Schema definition
Item Types	User friendly EC Schema application in MicroStation CONNECT
Application Element	Non-graphical DgnStore of DGN file
UserData	user data linkage element
XData	user data linkage element
XML_Fragments	Non-graphic DgnStore
XAttributes	Linked with elements, recorded separately in DGN model
Tag elements	An element linked with an independent or graphical element in DGN model

Table 5. Non-graphical data of DGN file (http://www.la-solutions.co.uk/content/Databases/Databases.htm)

Unlike other types of non-graphical data, the MicroStation V8i user interface has the tools for creating, modifying and deleting tags. In addition Tag-e can also be read and written by FME. Starting from MicroStation Connect, it is recommended that ItemTypes elements be used instead of Tags. Unfortunately, FME does not support reading and writing ItemTypes elements.

Comparison of non-graphical data

The comparison table for the use of different non-graphical data shows the existence of a user interface in the main application and the possibilities for using different development tools.

	User interface	VBA	.NET	MDL (C)	MS API (C++)
EC Schema Data	+	+	+	-	+
Item Types	+(Connect)				
Application Element	-	+	+	+	-
UserData	-	+	-	+	+
XData	-	+	+	+	-
XML_Fragments	-	-	-	+	-
XAttributes	-	-	-	-	+
Tag elements	+	+	+	+	+

Table 6. Comparison of non-graphic data

4.3.1.2 AutoCAD DWG

AutoCAD DWG format allows you to add and manage attribute data:

Autocad Map Object Data (OD)

Object data allows you to define and link tables to elements. The drawback is that to use the functionality of this data type it is necessary to use a significantly more expensive AutoCad Map product that is not widely used in Estonia.

Extended Entity Data (EED)

Each element in an AutoCad file may be associated with attributes using Extended Entity Data (EED) data type options. This option is typically used by additional AutoCad applications to store attribute information. In AutoCad the amount of data added is limited to 16K bytes per element. In FME, AutoCad writing functionality is limited to 8K bytes per element. This amount is sufficient to describe the data needed in the scope of the project. In Estonia, there is the experience and skill to develop additional applications for AutoCad.

XRecord Data

In the AutoCAD file, each element can have additional records (XRecords). These records are typically used to store attribute information and are similar to data of the Extended Entity Data type. FME allows for reading and writing XRecords data. The use of (xRecords) records should be considered when Extended Entity Data restrictions hamper the exchange of information.

4.3.2 Using attribute data

At the request of some clients, Tag elements are used to add data, and there is experience in creating corresponding user interfaces to the MicroStation V8i software. The drawback is that there is a relatively simple possibility of accidentally deleting Tags. You can create additional tools in both mdl and VisualBasic programming languages to manage the Tags. These additional tools enable you to manage entries and avoid errors. In the future, you may need to use ItemTypes type elements instead of Tags. The deployment of ItemTypes is limited by the lack of support for third-party software (FME). The AutoCAD platform has user interfaces to add attribute data based on the use of Extended Entity Data structures. Extended Entity Data structures are readable and writable by the FME.

4.3.3 Additional tools to manage attribute data

Because neither Microstation nor AutoCad have convenient tools to allow the user to work with attribute data, it is useful to create the necessary additional tools to manage the attribute data.

The additional tools must allow the following:

- adding, editing and deleting attribute data
- pre-checking added data
    - existence of mandatory data
    - logical set-up of data
- using common classifiers

Tools created for **Microstation** must use Tag elements to describe the attribute data.

Tools created for **AutoCAD** must use Extended Entity Data structures to describe the property data.

The data management CAD tools to be created must be available to all parties and be used both in the conduct of the surveys and in subsequent management. Additional tools must be centrally managed.

4.3.4 Data set to be added as attribute data

4.3.4.1 Object dataset

General data on objects is collected to ensure that the integrity of existing routes is maintained during construction and excavation work and that is a reliable base material for planning and design work.

The data characterising 3D object must, in particular, permit the determination of the spatial size of the elements. It is important to gather information on data collection methods for objects, which can later be used to assess reliability. These data will be issued as initial data for the execution, planning and designing 2.5D/3D surveys. The composition of the data that characterises the object depends on the type of the object.

The composition of the data characterising the survey must be the same for all objects. Objects resulting from 2.5D/3D surveys or utility surveys are stored in the database. Each object is linked to the work in the result of which it was generated or changed. There are data that is the same for all objects within the work.

4.3.4.1.1 Manhole-type objects

Manhole-type objects are presented by means of a central point and object measures.

- A round manhole or the cross-section of a riser pipe is a circle, and dimensions are given by diameter and depth, visualised as a cylinder.
- Manhole-type objects may be associated with facility-type flat objects depicted as a geometric layout.

Property	Example	Obligatory survey	Obligatory as-built	Notes
Marking	K-3		X	
Cover height	44.25	X	X	In metres
Bottom height	42.85	X	X	In metres
Diameter	400	X	X	Internal diameter (mm)
Wall thickness	30		X	In millimetres
Manhole material	PL	X	X	Classifier
Cover material	CAST IRON	X	X	Classifier

Table 7. Manhole-type object

4.3.4.1.2 Parameters of characteristic points

A characteristic point is an object or part of the object described by the coordinate point. In the case of pipeline, the coordinate point determines the height of the pipeline at the point of inflection. The start and end height of the pipeline are described as attributes. A characteristic point may also be the connection point of the piping or cable.

There must be a coordinate point at the points of inflection of all measured pipelines. The coordinates must not overlap with each other. All coordinates must be numbered. If the assembly has a previously assigned code, it will be used.

Property	Example	Obligatory survey	Obligatory as-built	Notes
Marking/no.	11		X	
Type	KP	X	X	Coordinate point, sleeve, branch, diameter transition, etc.
Height	30.55		X	In metres
Height type			X	on/axis/flow bottom
Diameter 1	110			Diameter of the largest pipe in millimetres
Diameter 2				Diameter in millimetres
Diameter type	External			Internal/external

Table 8. Parameters of characteristic points

The height and diameter(s) of attributes are important for determining the spatial size.

4.3.4.1.3 Pole data

Poles are elements which are partially situated underground and partly on the ground. In the context of this task, it is important to specify the dimensions and location of the underground part.

Property	Example	Obligatory survey	Obligatory as-built	Notes
Network type	TV	X	X	Street lighting, utilities, electricity
Marking	P1			
Pole height	8		X	In metres
Foundation type*	RBJ-4B		X	Classifier
Height on the foundation*	22.20	X	X	In metres
Foundation vertical measure**	1.6		X	In metres
Pole diameter	100	X	X	In millimetres
Pole material	MET	X	X	Classifier

Table 9. Post data

* - Mandatory if a foundation exists.
* * - The vertical dimension of the foundation or the length of the underground part of the pole.

The spatial size of the post is indicated by a cylinder determined by the height of the underground part of the pole and diameter at its location. If the cross-section of the foundation of the pole is not a circle, the part of the foundation must be depicted as a facility-type element. The support pole must be depicted as a pipe-type object by measuring the height of both ends of the support pole.

4.3.4.1.4 Pipe-type objects

All pipe-type objects are depicted through their own axis, which determines how they are located. The cross-section of pipe-type objects is a circle. These elements include all round single pipes, single cables or support poles.

Property	Example	Obligatory survey	Obligatory as-built	Notes
Marking				
Internal diameter	160	x*	X	In millimetres
External diameter	200		X	In millimetres
Insulation diameter	240		X	In millimetres
Height type	On	X	X	Flow bottom/on
Start assembly	K-1		X	
Height at the start assembly	30.45		X	In metres
End assembly	K-2		X	
Height at the end assembly	30.40		X	In metres
Material	PE		X	Classifier
Brand	GNHLDV 24,G652.D		X	Filled in case of cables

Table 10. Data of pipe-type objects

* - Inner diameter is mandatory for self-flowing pipes. The pipe element (including cable) may be related to the package-type element.

4.3.4.1.5 Package-type objects

Package-type objects differ from pipe-type objects in their cross-section. The cross-section of package-type objects is a rectangle. Such elements include cable packages, troughs, protection facilities, etc. A cable trench is a virtual package. Depending on the level of detail, in addition to the package, individual pipes or cables may be depicted. A trench in which cables or pipes may be located may also be depicted as a package. If it is sufficient to represent an object as a package, it is not necessary to add individual cables or pipes.

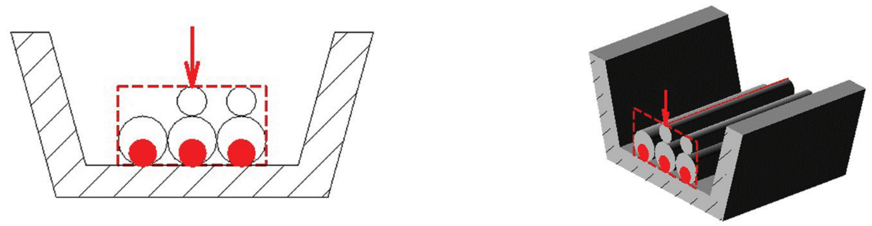


Figure 9: Description of a package (2 x 3) with pipes and filling rate

Property	Example	Obligatory survey	Obligatory as-built	Notes
Marking				
Width	500	X	X	In millimetres
Height	300	X	X	In millimetres
Height type	On	X	X	Flow bottom/on
Wall thickness				In millimetres
Material				Classifier
Package type	2x3			3 pipes in 2 layers
Fill rate of the package	x00.111			0 empty pipe 1 full pipe x no pipe
Package description	x;100;100, 160;160;160			pipe diameter in the package (mm)
Start assembly	K-1	X	X	
Height at the start assembly	30.45	X	X	In metres
End assembly	K-2	X	X	
Height at the end assembly	30.40	X	X	In metres

Table 11. Data of package-type objects

When determining the spatial size, the relevant attributes are the cross-section dimensions (width and height) of the line element and the axis of the object.

4.3.4.1.6 Facility-type objects

Facility-type objects include chambers, special-shaped manholes, foundations and protective structures. The cross-section of the facilities is a rectangle or of a special, flat geometric shape on a single plane. The facility must be drawn as a geometric layout. The facility may not necessarily reach the ground. In the case of a facility, the use of round manholes as riser pipes, which are described as manhole-type objects, may be added.

Property	Example	Obligatory survey	Obligatory execution	Notes
Marking	K-1			
Measure type	External	X	X	Internal/external
Ceiling height	4.22	X	X	In metres
Bottom height	3.12		X	In metres
Wall thickness	100		X	In millimetres
Material	BET		X	Classifier

Table 12. Data of facility-type objects

The height of the bottom and the thickness of the wall may not be detectable for all objects during the surveys.

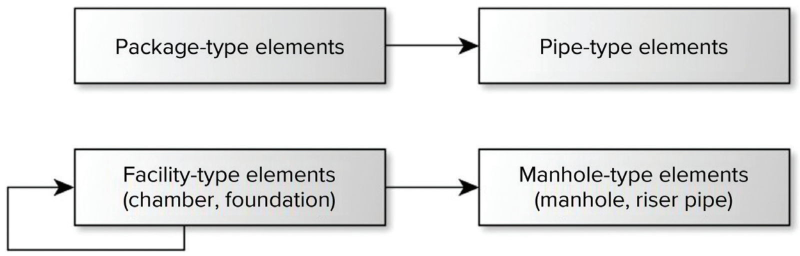
4.3.4.1.7 Data of detected unknown objects

Objects the position of which has been detected during 3D surveys but for which no information is available are transferred to the file of survey results as detected unknown objects. The geometry of detected unknown objects can be a plane or line. These may include concrete tiles, abandoned underground facilities, pipes, cables, etc. In the case of some facilities, vertical dimensions of the object can also be detected, but not always. It is useful to introduce a new "ERINOUE_TTO" layer for the detected unknown objects in the survey files. Generic data for objects is added to detected unknown objects (Table 13). General object data).

4.3.4.1.8 Relationships between objects

In order to facilitate voluminous depiction of various objects, it is useful to describe their sub-objects as different objects, whereas the following relationships may be present:

1. the cable is related to the package in which it is located;
2. the pipe is related to the trough in which it is situated;
3. the riser pipes are related to their special-shaped manhole or chamber (facility);
4. the special-shaped leading-out of the chamber is related to the chamber.



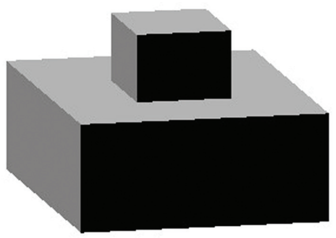


Figure 10: An object consisting of two facilities

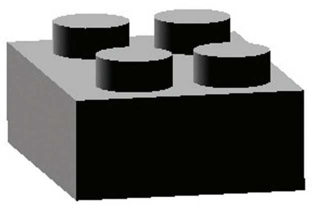


Figure 11. Facility with riser pipes

Relationships are created, if necessary, in the 3D database of utility networks.

4.3.4.1.9 General object data

General data are stored for all objects regardless of their type.

Data	Data type	Mandatory to be added	Notes
ID	Integer		The identifier of the database of the element. Missing for the element inserted for the first time or for the element created due to interruption
WORK ID	Integer		Connects the object to work (Survey or as-built drawing)
Status	String	X	In use, Disused, Eliminated (Optional value)
Owner	String		Utility network owner
Notes	String		
MKM symbol	String	X	Comes from a drawing with an element, used to issue data in DWG/DGN format. Describes a network object
MKM layer	String	X	Comes from a drawing with an element, used to issue data in DWG/DGN format. Describes a network object
Kontroll_kp	String		Inspection date
Quality class	String	X	A, B1, B2, C, D
Survey type	String	X	Type 1, Type 2, Type 3, Type 4

Table 13. General object data

4.3.4.2 Dataset related to the survey

The dataset related to the survey is inserted when the work is registered and is adjusted in Geoportal when the work is submitted. When inserting the work the survey type is determined – either a 2.5D as-built survey or a 2.5D survey.

Data	Description
Status	Registered
Procurement no.	
Client	Trassiehituse AS
Client's contact data	
Client's role	Builder/Designer/Owner
Surveyor	
Surveying company	Geodeesia OÜ
Survey name	As-built drawing of the water and sewerage networks in Asula street
Survey number	G34-16055
Survey type	2.5D utility survey/2.5D survey
Survey standard	MKM-2,5D/EH2000
Geometry of the survey area	2D geometry
Depth of the survey area in metres	3.0
Start date of the work	02/01/2019
End date of the work	27/02/2019
Date of submitting to 3D database	10/03/2019

Table 14. Work data related to the survey or utility survey

4.3.5 Data transition

During data transition the data collected during data acquisition is stored in the database. The data stored in the database can be used for different purposes and, if necessary, exported from it. Because it is useful to use applications built on the same software to import and export data, they are described together here.

The licensed and paid data integration software FME, which runs on Windows, Linux and macOS operating systems, has been selected as a data transition platform. The software is developed in Canada and is owned by Safe Software Inc. The software is in active development and is ideal for checking and processing special format spatial data, solving data management tasks and process automation. FME supports over 400 different formats[19] and allows you to create different data transition services. In addition to CAD and GIS formats, FME also supports BIM formats, different databases and standards of web services. For CAD formats, FME has the capability to read and write Tags and Extended Entity Data. Support for upgrades to existing formats and new file formats is very important.

4.3.5.1 Importing data

The results of the 2.5D survey formulated in DGN or DWG format are transmitted to Geo-archive as work. Data related to the work are saved in Geo-archive. The files to be transmitted must comply with the current requirements for 2.5D.

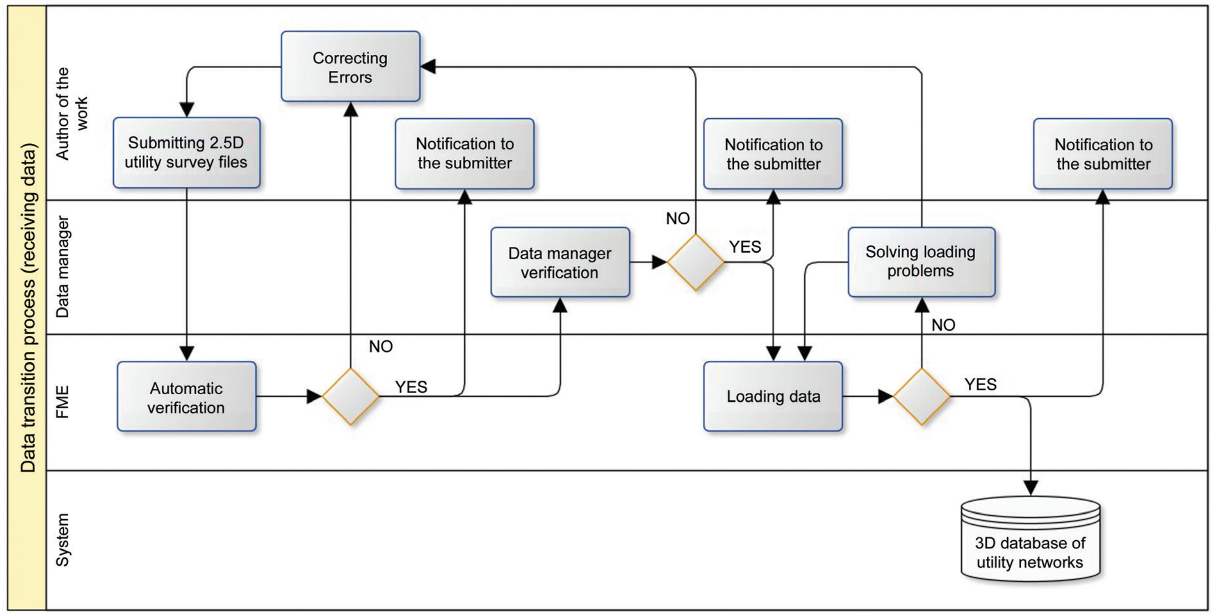


Figure 12: Process of receiving data

Automatic verification – during verification compliance of the submitted file with the requirements is verified:

- verification of the existence of the boundary of the survey area
- verification of geometries
- verification of layers
- verification of symbols
- verification of mandatory attributes
- verification of logical presentation of attributes
- verification of logical presentation of heights
- verification of classifiers

[19] Formats supported by FME https://www.safe.com/integrate/

The results of the automatic verification are transmitted to the performer. Errors must be corrected and the work must be resubmitted. If there are no errors, verification by the data manager is followed.

During verification by the data manager the following is performed:

- verification of logical presentation
- verification and management of added classifiers

If errors are detected, the error report must be transmitted to the surveyor. If the verification results are positive, the data manager will initiate the loading of the data into the database. In the case of errors during loading, the data manager resolves the loading problems and returns the file to the surveyor, if necessary. It is the responsibility of the data manager to monitor whether a utility network object has been given simultaneously to several operators and, if necessary, to resolve conflicts between different versions. The possible challenges and inconsistencies that need to be resolved, caused by loading processes carried out meanwhile can be the following:

- new objects
- changes in attribute data
- changes in geometry

The system to be set up must allow the inconsistencies to be resolved.

4.3.5.2 Exporting data

Data will be issued to 2.5D/3D surveyors, planners, designers and other related parties. Data can be issued in different formats. The main formats are DWG and DGN. If necessary, it must be possible to add in the system a possibility to issue data in other formats.

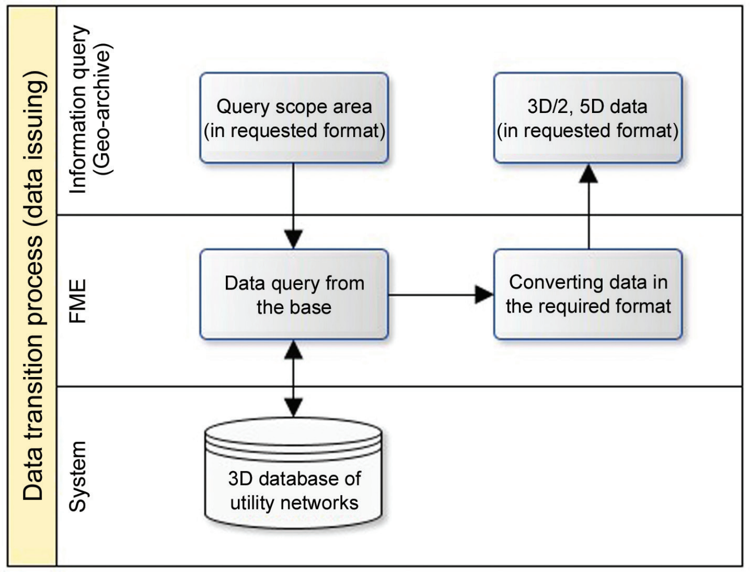


Figure 13: Data issuing process

An input for data issuing query can be a 2.5D/3D survey work scope or, if necessary, a freely defined area. In addition, a requested file format must be chosen. After this the inputs are transferred to the data transition export service. Based on the area, 3D objects are requested from the database with the necessary attributes according to the capabilities of the chosen format. For CAD formats, objects are written into drawing elements based on MKM KIHT and MKM SÜMBOL attributes. For possible GIS output formats, MKM KIHT and MKM SYMBOL are provided as attributes. The depth limit is not applied when selecting 2.5D/3D objects to be issued. In the framework of the ongoing work, it must be possible to request changes in the work scope area since the last extract was requested. This capability is needed for long-term work, in which case the status of the database may change over time between when the extract is issued and it is loaded back.

4.3.6 3D database of utility networks

When selecting a database, account must be taken of the availability of ready-made functionalities necessary to handle the different 3D data. It is also important to take into account the costs of obtaining, managing and administering data bases.

Here basic characteristics are compared which are needed to store, process and manage 3D data. Three of the most common databases supporting spatial data have been compared.

Functionality	**PostgreSQL-PostGis**	**ORACLE Spatial**	**ESRI GDB**
3D geometry support	✓	✓	✓
Availability of 3D features	✓	✓	✓
Data transfer (FME) support	✓	✓	✓
GIS platform support	QGIS, ESRI	QGIS, ESRI	ESRI
Possibility of managing versions	Needs additional development	✓	✓
Free (freeware)	✓	Paid	Paid

Oracle or ESRI databases can be selected from the licensed database platforms.

A highly competitive PostgreSQL/PostGis database can be considered as the only free database platform. With its 3D capabilities, PostgreSQL/PostGis sometimes offers greater opportunities than licensed, paid databases a significantly cheaper administrative costs.

4.3.6.1 Database structure

The following is recorded in the database:

- work data with work scope
- 3D objects with data
- history of changes of 3D objects
- files, documents, or links related to objects and work
- classifiers

The tables and relationships in the database, without tables on the history of changes in objects, are shown in the drawing: files, documents or links to work. It is a good idea to extend the structure of the tables so that files, documents and links can also be associated directly with objects.

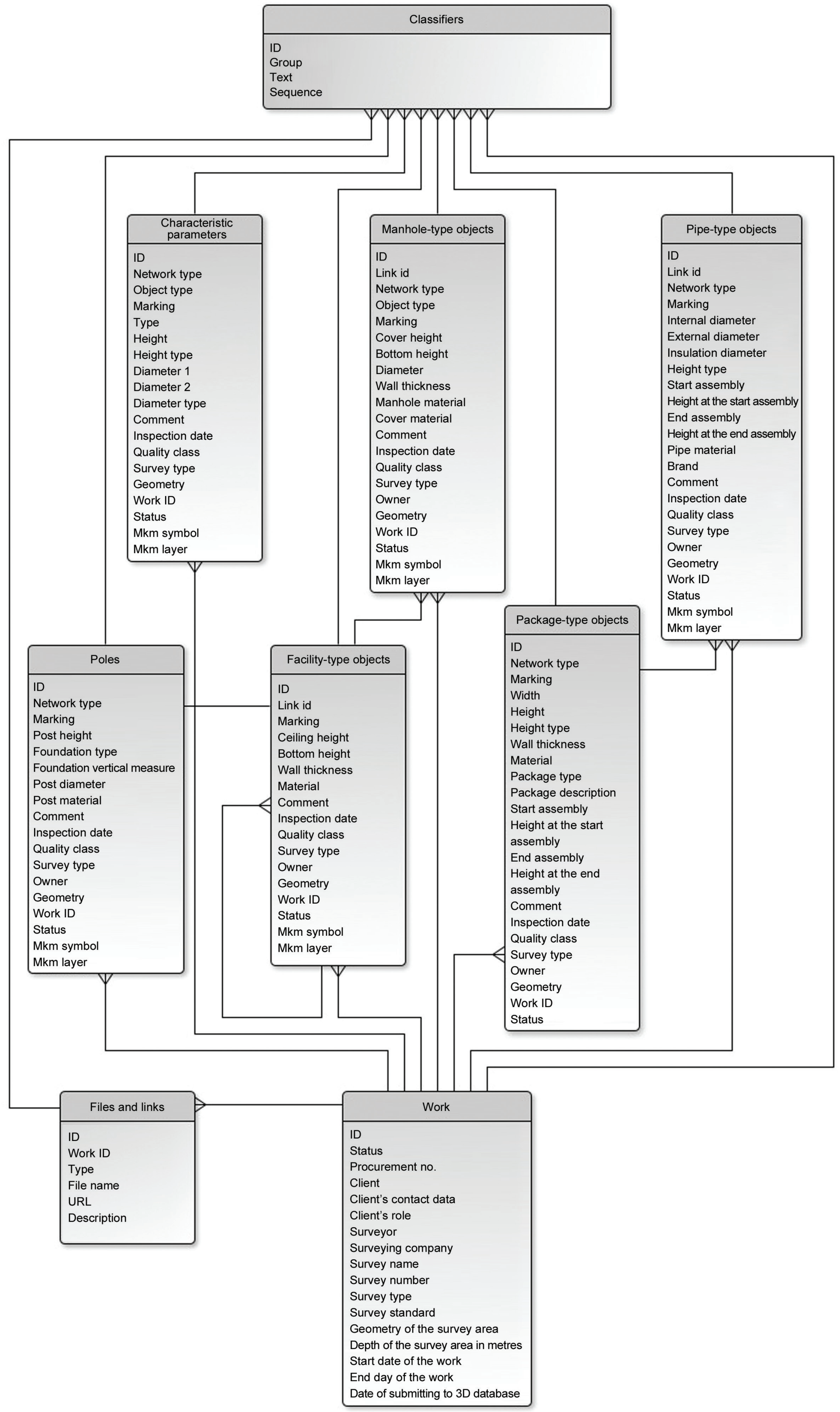


Figure 14: Database tables and links

4.3.6.2 Classifiers

A common system of classifiers (optional values) must be introduced. The purpose of the table of classifiers is to minimise the likelihood of errors occurring when entering essential properties. Classifiers must also be made available to users of the CAD environments and used when adding attributes. Depending on the final structure of the system, classifiers can be kept in one table or as property domains. The principles of the CoClass[20] classification system in force in Estonia must be taken into account when establishing the system of classifiers.

ID	Group	Name	Sequence
1	PIPE MATERIAL	PVC	100
2	PIPE MATERIAL	PE	101
3	PIPE MATERIAL	PP	102
4	STATUS	In use	100
5	STATUS	Not working	101
6	STATUS	Removed	102

Table 15. Example of the table of classifiers

4.3.6.3 General principles of processing objects (2.5D)

Objects are issued in DGN or DWG format to perform the survey. It is possible to modify the received objects during the surveys. In order to reflect the changes made to the database, the principles of processing 2.5D objects must be followed:

- 2.5D objects are issued as complete objects based on work scope (elements are not divided in the work scope)
- 2.5D objects are delivered with attributes, including database ID
- An object issued from the database may not be deleted from file.
- An element issued from a database not found in nature in the course of the survey must not be deleted but must be marked as decommissioned or dismantled.
- A new object measured in the course of the survey is added to the database.
- An object modified (shape or attributes) during the survey is updated based on database ID.
- Detected unknown objects are written to the database as either pipe-type or facility-type elements.
- Cutting linear objects is allowed. As a result of cutting, attribute data must be preserved.
- Slices of linear objects may be connected if necessary.
- Changes may only be made within the scope of the measuring area.

4.3.7 GIS tools for data management

In addition to the previously discussed data management CAD tools used during the data acquisition phase, the data management phase requires the use of GIS tools that allow data to be viewed as spatial objects and the carrying out of data analysis. GIS tools enable direct connection to databases and web services. In addition, it will be possible to integrate objects underground and on the ground into one complete view in the future. Use of GIS tools should be considered when developing the data manager desktop.

4.3.7.1 ArcGIS

ArcGIS is a licensed geographic information system with tools for visualising, editing, managing and analysing 2D and 3D data. The functionality of ArcGIS can be expanded with the help of different programming languages.

[20] https://coclass.byggtjanst.se/about#about-coclass

4.3.7.2 QGIS

QGIS is a free geographic information system. The functionality of QGIS can be expanded using Python applications. The very good additional Qgis2threejs application has been created to visualise 3D objects. QGIS allows the attributes of 3D objects to be managed and 3D geometries to be modified. As this is a free system with open source, its functionality can be developed further.

4.3.8 Data management system components

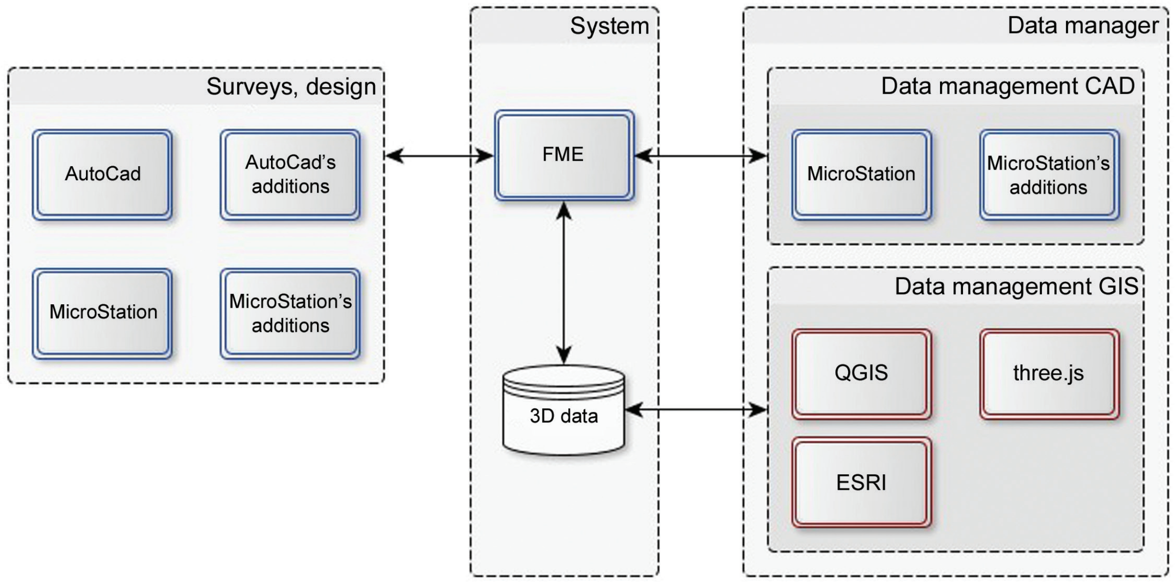


Figure 15: Data management components

4.3.9 Services in need of development

4.3.9.1 Automatic inspection of files

The purpose of automatic inspection of files is to verify that the formulation of test results and logics comply with the requirements of 2.5D. As a result of this inspection, the workload will be reduced and the quality of data is improved.

4.3.9.2 Importing data

The purpose of the data import service is to load data from 2.5D CAD files into the 3D database. During the import process, new elements of the database are loaded, changes to the existing objects are detected, and they are transmitted to the database.

4.3.9.3 Exporting data

The purpose of the data exporting service is to write data from 3D database into 2.5D CAD files or 3D files in an agreed format. The choice of output formats can be expanded to suit your wishes and needs.

4.3.9.4 Converter (DGN < - > DWG)

In the construction process, the parties involved often use different CAD software. There is a need, therefore, for conversion between formats. The purpose of the DGN < - > DWG converter is to convert 2.5D geometries with attribute data from AutoCad to MicroStation and vice versa.

4.3.9.5 Visualisation of 3D data

The purpose of the service is to issue data flow in real time for augmented reality (AR), virtual reality (VR) applications or 3D web maps (such as the Estonian 3D digital twin).

4.3.9.6 Slice

The purpose of the service is to speed up decisions in the planning tasks. The user can draw a cutting line on the map at a point of interest, resulting in the creation of a cross-section of intersecting utility networks with heights and other essential technical characteristics.

4.3.9.7 WMS/WFS

Standard WMS/WFS services to transmit the location and properties of objects to external systems.

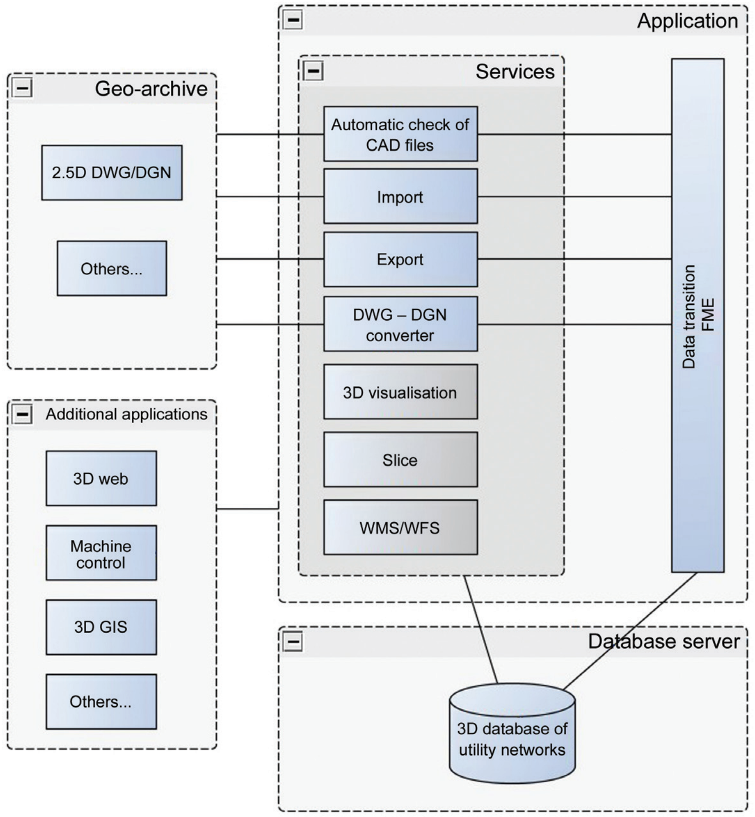


Figure 16: Services and components

In order for the process to work, the following services must surely be developed from the services shown in the drawing:

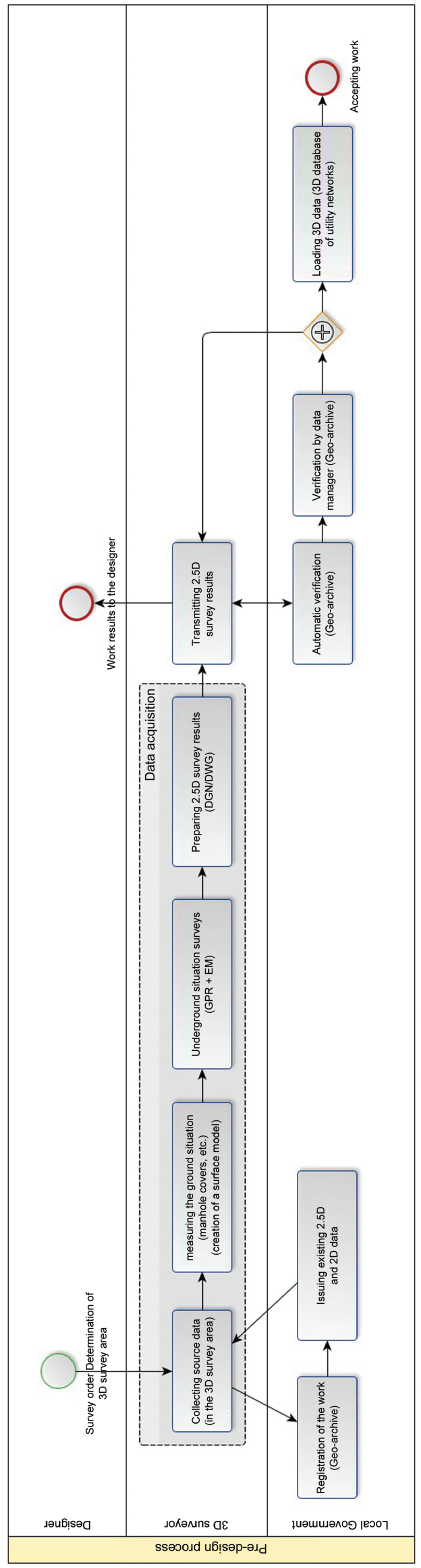
- automatic verification of 2.5D files
- importing 2.5D data
- exporting 2.5D data
- DGN <-> DWG converter

4.4 General data management process

The data management process is divided into a pre-design and post-construction process. From the data management point of view, the processes are similar. The main differences concern data acquisition. The data transition is planned through Tallinn Geoportal. In this work, it is assumed that all surveys and as-built drawings will be submitted to Geoportal in Tallinn.

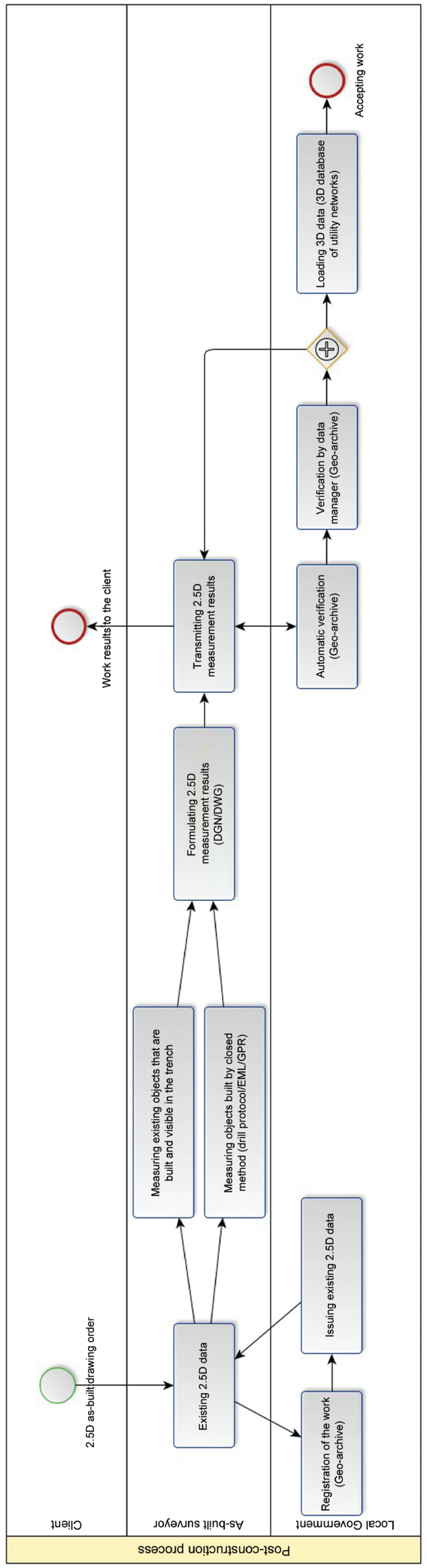
4.4.1 General description of the pre-design process:

- Registration of the work in Geo-archive
- Issuing existing 2D and 2.5D data
- Measuring the situation on the ground (manhole covers, characteristic points of the ground, breaklines, etc.)
- Underground situation survey (manholes survey, GPR, EML)
- Preparing 2.5D survey results (DGN, DWG)
- Transmitting 2.5D survey results to Geo-archive
- Transmitting verified results to the client
- Loading 2.5D objects as 3D objects in the 3D utility networks database



4.4.2 General description of the as-built process:

- Registration of the work in Geo-archive
- Issuing existing 3D data
- Measuring
- Measuring existing objects that are built and visible in the trench
- Measuring objects built by closed method (drill protocol/GPR/EML)
- Formulating the measurement results
- Transmitting 2.5D as-built drawing to Geo-archive
- Transmitting verified results to the client
- Loading 2.5D objects as 3D objects in the 3D utility networks database



5. CARRYING OUT SURVEY IN VESIVÄRAVA STREET

5.1 Purpose of the survey

GPR survey was conducted with the objective of assessing the suitability, capability and reliability of GPR technology to conduct underground utilities surveys. In addition, it was assessed what potential added value the GPR would provide for the comprehensive detection and mapping process of underground utilities. An additional purpose of the GPR survey was to test different types of GPRs to understand the capabilities and disadvantages of different types. For this purpose, as wide a range as possible of GPRs suitable for mapping underground utilities was selected for testing. At the same time, the purpose of the survey was not to compare the selected GPRs with each other, but to assess the capability and suitability of each particular GPR.

5.2 Location of the survey

Vesivärava Street in Tallinn was chosen as a location of the survey. Vesivärava Street has recently been renovated and there are some documents available necessary to compare with the data collected during the survey. The water, sewerage and rainfall pipelines have been fully renovated and as-built drawings have been prepared for these. In addition, power and communication cables are located in the street, for which information is available from the general geodetic layouts.

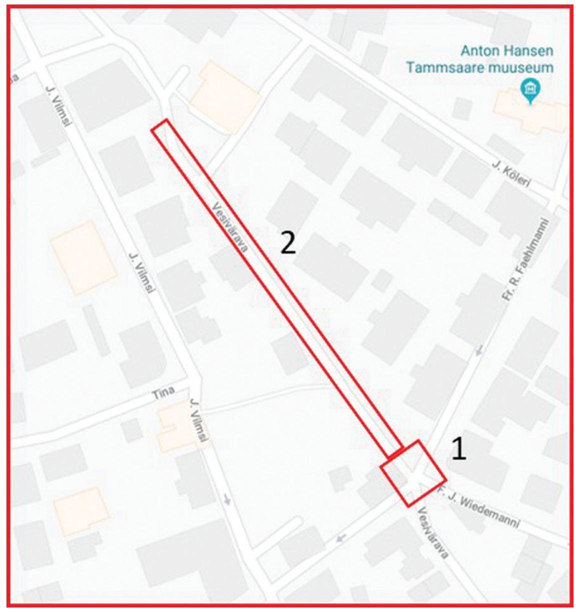
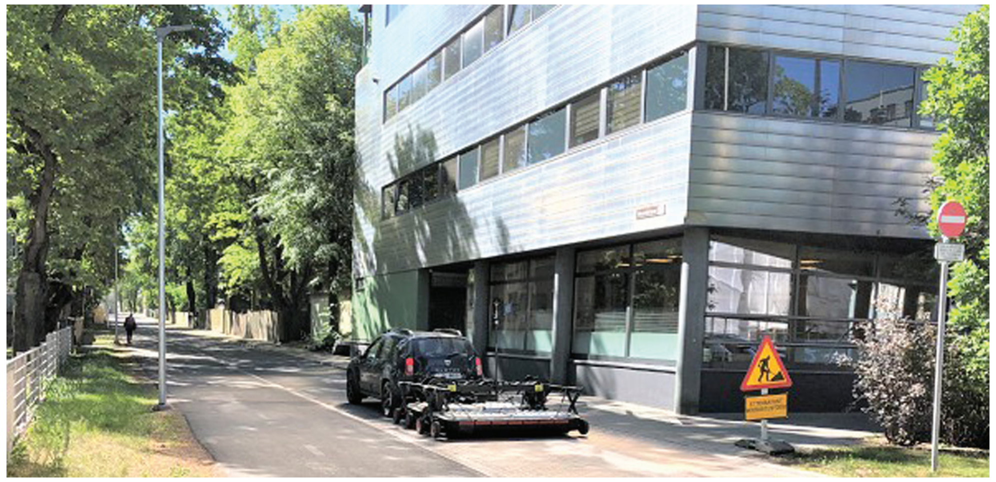


Figure 17: 1 - crossing of Vesivärava, F. R. Faehlmanni and Wiedemanni streets
2 - in the section of Vesivärava Street between Raua Street and F. R. Faehlmanni Street

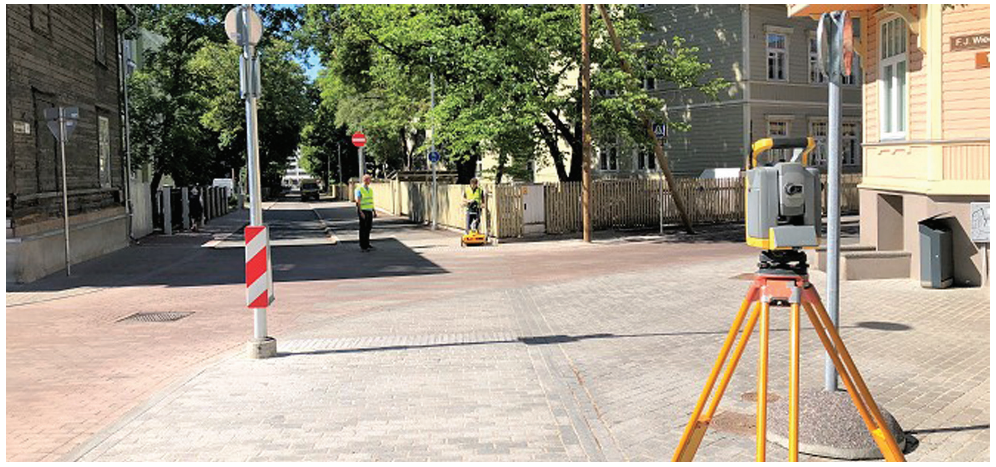
Tests of large GPRs were carried out in the section of Vesivärava Street between Raua Street and F. R. Faehlmanni Street as traffic density in the given street section is low and there are no car parking spaces that could have prevented GPR surveys. The length of the street section is approximately 220 metres and the width including the sidewalk on both sides is approximately 9 metres.

In the section of Vesivärava Street between Raua Street and F. R. Faehlmanni Street there are high trees on south side, and given this it was not possible to use a GNSS device for positioning. Instead, a Total Station was used. This restricted partially the freedom of movement during testing.



Picture 13: View of Vesivärava Street from Raua Street with IDS Stream EM GPR

In addition, tests were carried out with single channel GPRs at the crossing of Vesivärava, F. R. Faehlmanni and Wiedemanni streets, as there are many intersecting underground utilities at the site. At this crossing an area of a size of approx. 300 m2 was measured.



Picture 14: The crossing of Vesivärava, F. R. Faehlmanni and Wiedemanni streets with Total Station and IDS Opera Duo GPR

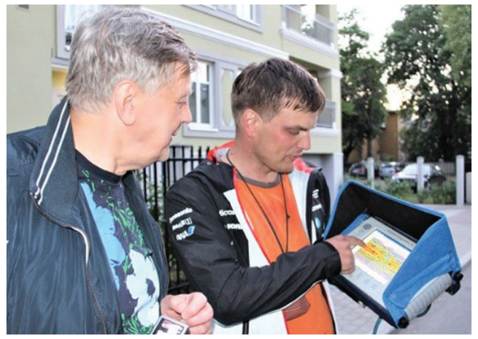
5.3 Devices used in the survey

The purpose of testing the devices was to obtain as good an overview as possible of the capabilities of GPR devices. For this purpose, GPRs with as different functionalities and capabilities as possible were selected for testing. According to the information gathered and the survey carried out, it was decided to carry out the survey with the GPRs from four producers: IDs GeoRadar (Italy), ImpulseRadar (Sweden), Mala Geoscience (Sweden) and 3D-Radar (Norway).

During the preparation of the survey, preliminary measurements were carried out with a GSSI (US) radar SIR 3000 and 270 MHz antenna. The purpose of the pre-measurement was to obtain an overview of the soil type and other factors affecting the testing.

The data collected by GSSI radar were mainly examined on-site.

Picture 15: GPR GSSI SIR 3000 and 270 MHz antenna



Picture 16. Priit Willbach (PhD), Hannes Tõnisson (PhD) and SIR 3000

5.3.1 IDS GeoRadar

The Italian company IDS GeoRadar has developed GPRs specifically for the detection and mapping of underground utilities. Tests with IDS GPRs were carried out between 12/06/2018 and 14/06/2018. It didn’t rain during the testing. Three radars of different size and functionality were selected for the testing:

Opera Duo - The smallest and simplest GPR of a single scan line. Opera Duo has two antennas and it allows the device to use two center frequencies: 250 and 700 MHz. A lower frequency allows detection of deeper objects, but only larger objects with a low resolution. With a higher frequency it is possible to detect smaller objects with a better resolution but closer to the ground’s surface. The Opera Duo is a very compact device and is easy to transport, for example, in a car. The implementation of the device is fast and does not require any special preparation. It is also easy to handle. The Opera Duo has an internal GNSS, but for accurate positioning it can be connected to all external positioning devices capable of generating data flow in NMEA or PseudoNMEA format. The results of the survey with the Opera Duo can be exported from post-processing software to CAD, GIS, etc. software.

Picture 17: Olav Harjo participating in testing IDS Opera Duo in Vesivärava street

RIS MF Hi-Mod - This is a GPR in which case several antennas are placed side by side on the frame, allowing multiple profiles at once to be scanned in one go. It is a modular device where up to four antenna blocks (up to 8 channels) can be placed and thus an area up to 2 metres wide at a time can be mapped. The distance between the RIS MF Hi-Mod channels is 40 cm. The device can use two center -frequency antennas, either 200 and 600 MHz or 400 and 900 MHz. A device with two antenna blocks (4 channels) with center frequency of 200 and 600 MHz was used for testing. The RIS MF Hi-Mod has an internal GNSS, but for accurate positioning it can be connected to all external positioning devices capable to issue data flow in NMEA or PseudoNMEA format. To post-process the collected data, the software Gred HD 3D is used, from which the results can be exported to CAD, GIS and similar software.

Picture 18: Olav Harjo participating in testing the IDS RIS MF Hi-Mod - in Vesivärava Street

Stream EM - This is the largest GPR used in testing, with 40 antennas connected to one complete antenna array. It is a GPR with a high-resolution antenna array the channel spacing of which is approximately 6 cm, so it collects data several times more densely than with the RIS MF Hi-Mod or the Opera Duo. The device used for testing had thirty-two 200 MHz antennas with vertical polarity, four 200 MHz antennas with horizontal polarity and four 600 MHz antennas with horizontal polarity. The Stream EM is a large device transported on a car trailer with a width of 2.5 meters, wider than a conventional car, and to transport it a special wide car trailer is required. This GPR allows the mapping of large areas with little time, but because more space is needed for manoeuvring, it cannot be taken everywhere. The device was too large for this testing area.

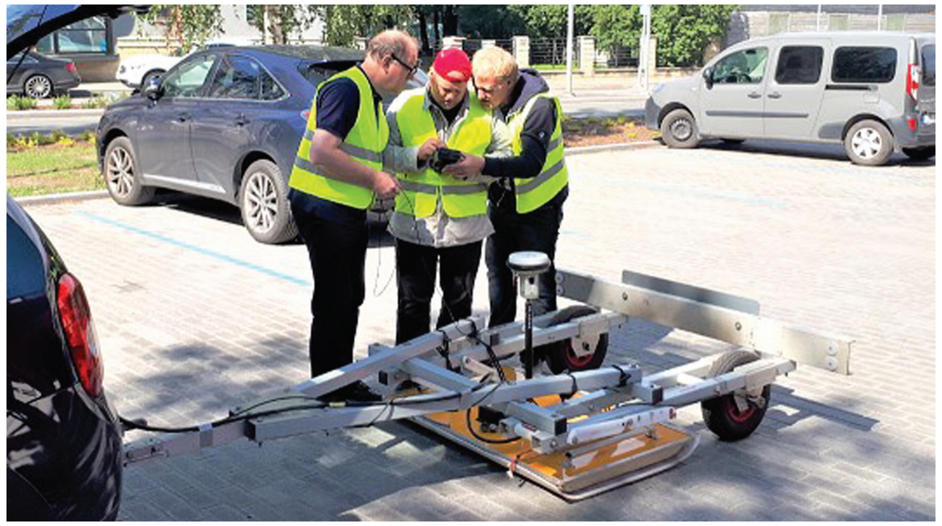
Picture 19: Testing the IDS Stream EM in Vesivärava Street

5.3.2 3D-Radar

The Norwegian company 3D-Radar specialises in the production of step frequency GPRs. Their products are widely used in both military and civil engineering (surveys of road structures, bridges and runways). Increasingly, their equipment is also used to map underground utilities. Tests were carried out with 3D-Radar's GPR between 03/07/2018 and 05/07/2018. It did not rain during the testing.

GeoScope and DXG Antenna Array - GeoScope is a GPR controller to which high-resolution antenna arrays of different sizes and functionalities can be connected. The underground utilities are mapped using antenna arrays in contact with the ground surface: DXG with a width of 0.9; 1.2 or 1.8 metres. A 1.2-meter wide DXG antenna array was used for testing. The antenna has 12 channels and the channel spacing is 7.5 cm. Thus, it allows the collection of data in one go frequently and thereby the ability to obtain a high-resolution three-dimensional dataset. What makes the device special is that it was the only device in the testing using step frequency technology. This means that each electromagnetic wave sent to the soil has a different frequency between 100 MHz and 3000 MHz. In addition, the data acquisition with this device is carried out with a frequency domain, which is later calculated by the software to the time domain . It allows

the use of more information in post-processing than with traditional pulse radars. The GeoScope has its own internal GNSS, but for accurate positioning it can be connected to all external GNSS devices capable of generating data flow in NMEA format. Unlike other GPRs, this does not support PseudoNMEA data flow, i.e. by using a Total Station, positioning data must be stored separately and can be used during post-processing. Thus, there is no real-time information about whether the location data is usable with the radargrams or not. The device used for testing was towed on a car trailer, which allows mapping of large areas with little time. As the device needs more space for manoeuvring, it cannot be used everywhere. At the same time, it is also possible to place the device on a trolley pushed by a person.



Picture 20: Emmanuel Thibaut, Andres Kärk and Raul Rokk participating in testing 3D-Radar GeoScope in Vesivärava street

5.3.3 MALÅ

The Swedish company Guideline Geo AB (MALÅ) produces GPRs with different purposes and capabilities. To identify and map underground utilities, they have simple single scan line Easy Locator series radars and more advanced ProEx controller-based radars. Tests with the MALÅ GPRs were conducted between 10/07/2018 and 12/07/2018. It did not rain during the testing. The latest single scan line GPR Easy Locator Pro WideRange HDR and ProEx controller-based GPR MIRA were selected for testing.

Easy Locator Pro WideRange HDR - This device is similar to the IDS Opera Duo that was also tested. Their main difference lies in signal processing, which is significantly faster and more accurate on the Easy Locator Pro WideRange HDR. Similar to the Opera Duo, the Easy Locator Pro WideRange HDR has two antennas and it allows the device to use two center frequencies: 160 and 650 MHz. Consequently, the actual frequency range should be between 80 and 950 MHz. A lower frequency allows identification of deeper objects, but only larger objects with a lower resolution. With a higher frequency it is possible to identify smaller objects with a better resolution but closer to the ground's surface. The Easy Locator Pro WideRange HDR is a very compact device and is easy to transport in a car. The implementation of this device is fast and does not require any special preparation. It is also easy to handle. The Easy Locator Pro WideRange HDR has an internal GNSS, but for accurate positioning it can be connected to an external positioning device that can deliver NMEA data flow. It is not possible to connect the Wide Range to TS. The processing of data collected with the Easy Locator Pro WideRange HDR is generally performed with the MALÅ Object Mapper program by B-scan, a two-dimensional radargram. The final survey results are three-dimensional and can be exported from post-processing software to CAD, GIS and similar software.

Picture 21: Mike Langton, Elin Johansson and the MALA Easy Locator Pro WideRange HDR in Vesivärava Street

MIRA - This is a GPR with a high-resolution antenna array with an antenna spacing of approximately 5 cm, so data is collected several times more densely than with a one scan line radar. The device used for testing was a smaller version of the MIRA, which has 8 channels and a medium antenna frequency of 400 MHz. This cart-type device is approximately 1 metre wide and, as it has better manoeuvrability than a car with a trailer, scanning at the test site was faster than with larger devices. The MIRA has an internal GNSS, but for accurate positioning it can be connected to all external positioning devices capable of generating data flow in NMEA or PseudoNMEA format. The results of the survey with the MIRA can be exported from the post-processing software rSlicer to CAD, GIS, etc. software.

Picture 22: Mike Langton, Elin Johansson, Vallo Padari and the MALA Mira in Vesivärava Street

5.3.4 ImpulseRadar

Swedish company ImpulseRadar produces a new generation of GPRs based on the latest Real-Time Sampling (RTS) technology. Their GPRs are divided between three product families:

- PintPointR - a simple one-channel and dual-frequency device specially designed to detect underground utility networks
- CrossOver - a one-channel and dual-frequency device with many capabilities and configurations that is suitable for performing very different surveys
- Raptor - 3D GPR with an antenna array with many capabilities and configurations

Tests with radars by ImpulseRadar were conducted between 19/03/2019 and 21/03/2019. The weather was humid and partially rainy during the testing. The ground was partially melted, but largely still frozen. A one scan-line GPR CrossOver and GPR Raptor with an antenna array were selected for testing.

CrossOver - This GPR is similar by its main features and functions to the MALA EL WR and IDS Opera Duo involved in testing. The CrossOver uses the new Real-Time Sampling (RTS) technology, which allows very good bandwidth and dynamic range, meaning better resolution and greater survey depth. In addition, thanks to RTS technology, there is virtually no limit to the speed of data collection, allowing data to be collected at speeds of up to 130 km/h. Similar to the MALA EL WR and the Opera Duo, the CrossOver has two center frequencies: 400 and 800 MHz. A lower frequency allows identification of deeper objects, but only larger objects at a lower resolution. With a higher frequency it is possible to identify smaller objects with a better resolution but closer to the ground's surface. The CrossOver is a very compact device and is easy to transport in a car. The implementation of this device is fast and does not require any special preparation. It is also easy to handle. The CrossOver has an internal GNSS, but for accurate positioning it can be connected to an external positioning device that can deliver NMEA data flow. It is not possible to connect the CrossOver to TS. The processing of data collected with the CrossOver is generally carried out with the CrossPoint program by B-scan, a two-dimensional radargram. The final survey results are three-dimensional and can be exported from post-processing software to CAD, GIS and similar software.

Picture 23: Mikael Burman and the ImpulseRadar CrossOver in Vesivärava Street

Raptor - This is a 3D GPR with a high-resolution antenna array and with an antenna spacing of approximately 4-8 cm depending on the frequency used, so data is collected several times more densely than with a one scan line radar. The device used for testing was a smaller version of the Raptor, which has 8 channels and a center antenna frequency of 450 MHz. This push cart-type device is approximately 90 cm wide and, as it has better manoeuvrability than an equipment attached to a car, scanning at the test site was faster than with larger devices.

The Raptor has an internal GNSS, but for accurate positioning it can be connected to all external positioning devices capable of generating data flow in NMEA or PseudoNMEA format. The results of the survey with Raptor can be exported from post-processing software GPR Slice to CAD, GIS, etc. software.

Picture 24: Christer Gustafsson, Vallo Padari, TS and the ImpulseRadar Raptor in Vesivärava Street

5.3.5 Leica and Trimble

For testing GPRs the following Leica and Trimble positioning devices were used:

- Trimble R6 GNSS device
- Leica Viva GNSS GS15 device
- TRIM TRIMBLE S6 DR PLuS™ robot tachymeter (TS)
- Leica Viva TS12 Robotic - robot tachymeter (TS)

5.4 Testing methodologies

The tests were carried out with eight different GPRs, and a RTK-GNSS device as manhole as a Total Station (TS) were used to link radar profiles to location data, leading to the use of different methodologies during testing. Prior to conducting the tests, the existing documentation of the underground utilities of the selected region was examined: as-built drawings, geobases and maps. An inspection of the location of the test area was carried out to get an idea of the surrounding situation, moving possibilities and the objects that would be mapped with the GPRs. In the course of the inspection of the location, an assessment was made of the possibility of using different GPRs, and it became clear that to a large extent it was not possible to use GNSS on the test object because of the high trees. The use of GNSS in urban conditions is generally difficult due to high buildings and trees, the signal of satellites is interrupted and consequently the quality of the measurement is uneven between 2 cm and 2 m. For best results, a combined method of GNSS + TS must be used.

5.4.1 Preparing GPRs for testing

All GPRs were set up and calibrated before testing to ensure that the quality of the data received was good enough for further processing. The GPRs used for testing had different set-up options, but the basic set-up was performed on all devices:

Odometer calibration - Since all radars used the distance mode during scanning, the radar sent electromagnetic waves to the ground according to the odometer. An accurate and operational odometer is needed to ensure that the scanning is always performed at a given frequency and at a constant density. The use of the odometer is certainly necessary also in surveys carried out using a survey grid and without an external positioning device. In order to calibrate an odometer, a 10-metre path was marked out during the test. The GPR was driven exactly 10 metres and the length of the distance was entered into the GPR settings.

Determination of the dielectric value of the soil - this is necessary to define the depth of the objects on site in the survey area. If it is not important to accurately determine the depth of an object immediately on site, these parameters can be set up later in the post-processing software. The exact dielectric value of the soil was not detected during the tests but the mean values were used.

Setting maximum depth/time window - It was possible to set the maximum depth on GPRs for where to collect data from. During testing, the maximum time during which the reflective signal is recorded was set as 100 ns.

Setting up background filters - Using background filters eliminates horizontal “interferences” from the survey, which may result from, for example, reflections of the GPR wave from terrestrial objects. A background filter was used with all single channel GPRs during the tests.

Adjusting gain - depending on the soil type, weather conditions, etc., it may be necessary to amplify the reflected pulse amplitude in order to more clearly identify the objects you are looking for. In the course of the tests, an automatic gain adjusting mode was mainly used, which should ensure the best ratio of reflections and noise. The gain can also be adjusted later in the post-processing stage of the data.

5.4.2 Positioning methods

All GPR devices have an internal GNSS (Global Navigation Satellite System) device which, although not sufficiently precise for positioning, has the primary function of recording time as accurately as possible. All data in the GPR profile is recorded with the exact scanning time. Also, time is recorded on external high-precision GNSS devices. The external GNSS device transmits the exact time and location coordinates in NMEA data format to the GPR. The same logic also works for the electronic tachymeter Total Station (TS). If TS supports the PseodoNMEA format, the location data and time are recorded similarly to the above description.

The easiest way to determine location is to use the RTK-GNSS method, where location corrections are obtained from the VRS network (network of reference stations consisting of GNSS stationary stations). When using this method, it should be taken into account that the following requirements are met in the survey area:

- at minimum, dual-frequency (L1/L2) devices must be used for measuring
- measurements may be carried out at a distance of not over 30 km from the base station, within the RTK network range
- not over 40 km from the nearest two base stations
- the number of common satellites at the base station and at the point of measurement must be at least 5
- PDOP may not be over 2.5 at the time of measurement

In an urban environment where high houses or trees obscure the visibility of satellites in the survey area, the Total Station - TS method should be used. For this, a Pseudo NMEA format data flow must be used, if possible, which is sent to a GPR, or TS and GPR data should be recorded separately. As location data and GPR data are bound using time, it is extremely important that the time of measurement is recorded in TS output with a minimum accuracy of 1 second. If the GPR device does not support cross-coordinate systems, the data must be converted to WGS84 coordinates. At least 3 points must be measured to the same location at the beginning and at the end of each measurement. Example of a 3D-Radar location data file: Time, B (WGS84), L (WGS84), Height (EH2000) 090617.40, 5926.287798842794, 2446.525987602970, 4.028,. If no GNSS or TS is used for GPR data acquisition, the measuring may be performed using a GPR odometer method. For this purpose, the GPR data must be collected with specific start and end points and later it must be possible to link the data obtained with the L-Est coordinate system with the help of reference points.

5.4.3 Testing single channel GPRs

Tests were carried out with small GPRs at the crossing of Vesivärava, F. R. Faehlmanni and Wiedemanni streets. For high-quality data, the entire crossing was scanned with radars in longitudinal and perpendicular directions. Scanning in both directions is necessary when small devices are used so that, incidentally, communication lines running in the exact same direction as the scanning is performed are not missed between the two scan lines. Since all the small GPRs used in the test had antennas with horizontal polarity, GPRs may not notice the metal utility networks with good conductivity running in the same direction directly under the radar.

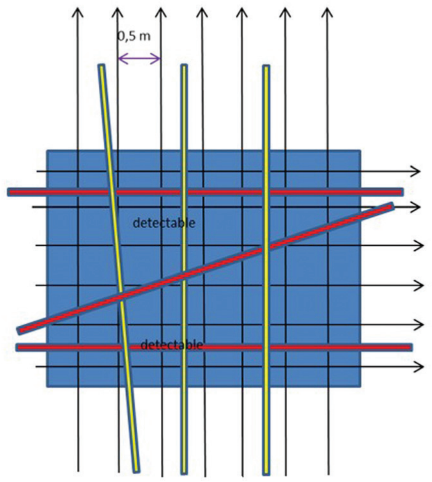


Figure 18: Data collection as matrix (IDS 2018)[21]

The Mala Wide Range and ImpulseRadar CrossOver was used to scan with an interval of 0.5 metres. This was done by marking the start and end points of the scan every 0.5 m. Such a method meant there could have been a "dark area" close to the ground surface between the scan lines, which the radar did not see. At the same time, at the depths where the main utility networks were located, there was no gap.

The data acquisition software of the **Opera Duo and RIS MF Hi-Mod** IDS radars enabled real-time monitoring of GPR movement and displayed the scan line on the screen. Therefore, there was no need to mark out the scan lines on the road in advance, but it was necessary to make sure that the scan lines on the screen were slightly overlapping while driving.

5.4.4 Testing GPRs with an antenna array

With GPRs equipped with antenna arrays - IDS Stream EM, 3D-Radar, MALA Mira and ImpulseRadar Raptor, data collection was performed one-way survey lines and with a slight overlap. Perpendicular scanning is not required with these GPRs, as their channel spacing is small (4-8 cm). In addition, they all have antennas with vertical polarity, which provides excellent possibility to detect the communication routes that run specifically in the direction of the radar swath.

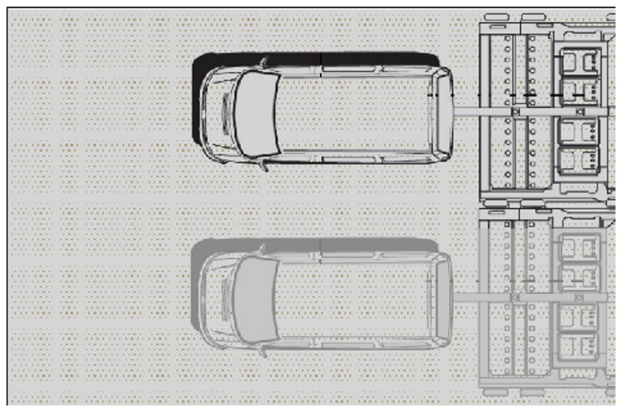


Figure 19: Data collection as swath (IDS 2018)[22]

[21] Utility mapping with IDSGeoRadar system, IDS 2018
[22] Utility mapping with IDSGeoRadar system, IDS 2018

Cart-type versions of MALA Mira and ImpulseRadar Raptor GPRs were used during testing. Scanning with them was performed at normal pedestrian speed.

Stream EM and 3D Radar are GPRs that are towed by a vehicle as car trailers. Theoretically, scanning could have been performed with them at twenty kilometres per hour, but the actual driving speed was 5 - 10 km/h. This is because, in tight conditions, it was not possible to drive faster in order to monitor the driving path accurately and to avoid traffic signs and the like.

5.5 Further specification of data at the test site

During the period June-July 2018 and March 2019, data acquisition was carried out at the project test site in Vesivärava Street with several types of GPRs. The collected data was processed with special software, and a GPR image of underground utility networks in the test area was obtained. In addition, data on the utility networks at the test area was collected from various as-built drawings, general geodetic layouts and datasets. The GPR surveys carried out and the available data from the datasets on the utility networks were at times different and also not sufficient to create a 3D model of the utility networks in the test area. Therefore, it was decided to carry out further surveys at the test site. The purpose of the additional field surveys was to check the differences in the data and to obtain the missing data for the 3D model. The following work was carried out to this end:

- Verification of deviations of utility networks detected based on data from GPR surveys by using alternative methods
- Detection of the location and depth of street lighting and low voltage cables in the part partially excluded from GPR profiles
- Inspection of communication facilities reconstructed during road reconstruction work, as there was no as-built drawing for communication networks
- Surface model measuring

Additional field work was carried out in Vesivärava Street during 20/11 - 12/12/2018.

5.5.1 Devices used

- GNSS devices - Leica GNSS GS15 and Topcon Hyper+
- Total Station - Leica TS12 3"
- Levelling instrument - Leica Runner 24
- Utility locator (EML) - Leica DigiCat550i and Radiodetection RD8100

5.5.2 Linking to a coordinate network

Linking to the coordinate network in the LEST97 system was done by GNSS RTK measuring using the corrections received from the network of HADNET permanent stations. The measurement points were coordinated both before and after tachymetric measurements. With this the points were coordinated with different initialisations as manhole as with different satellite positions. The GNSS receiver used in the measurement supported GPS and GLONASS satellite signals. The corrections used to assign points were obtained in real time, which was calculated using Topnet+ software in the central server.

5.5.3 Linking by height

As the height accuracy of the GNSS RTK measurement in urban conditions is not sufficient in our latitude, linking by height was done with the level trip. Levelling was carried out as a back-and-forth trip from one of the initial flagpoles. Initial flagpole no. 131 H = 6.029 m is 100 m from the survey area.

5.5.4 Tachymetric measurement

Tachymetric measurement was performed from the starting points by orienting the instrument as a free-hold station. A wooden tripod, a Leica 360 prism and aluminium bar were used for the measurement.

5.5.5 Detecting street lighting cables with EML locator and signal generator 33 kHz

A representative of the administrator of street lighting networks Elektrilevi was asked to detect the street lighting cables with the EML. All street lighting controls located in field cabinets are under electronic surveillance and unauthorized opening of the cabinet is not permitted. Access to cables was necessary to identify the location and depth of the cables. An EML locator, generator and clamps were used to locate the cables. The Clamps are contactless and can be connected around the cable without interfering with the operation of the cable. A 33 kHz signal is induced into a cable via clamps without connecting directly to the phase of the cable. Detection of this signal allowed the depth of the detected cable to be determined. The location and depth were marked on the ground and later the marked points were measured tachymetrically. The specified depth was entered in the code of the measured point, which was later used to create the 3D axis of the cable.

Picture 25: Detecting street lighting cables with EML in Vesivärava Street

5.5.6 Measuring stormwater sewerage with a sonde

In cooperation with Lokaator OÜ, the location of the stormwater sewerage pipes was determined during random transit survey. To perform the work, piping manholes were opened at both ends of the test section. A sonde attached to the end of the fibre was used to determine the location of the pipe. The location and depth of the sonde were fixed on the ground using the Radiodetection RD8100 locator. The location and depth were marked on the ground and later the marked points were measured tachymetrically. The specified depth was entered into the code of the measured point, which was later used to create the 3D axis of the cable.

Picture 26: Measuring stormwater sewerage with a sonde in Vesivärava Street

5.5.7 Inspection of telecom manhole and detection of telecom cables manholes with EML.

A representative of Telia Eesti AS, the owner of the telecom network, was invited to examine the manholes and cables of the telecom. As opening the telecommanholes requires special keys and the manholes may be under electronic surveillance, opening them without permission is prohibited. Access to cables was necessary to identify the location and depth of the cables. A cable locator, generator and clamps were used to locate the cables. During the survey of manholes, the height of the pipes exiting in all directions and the dimensions of the manhole body were measured. The location and depth of the localisation result of 33kHz induced signal were marked on the ground and later the marked points were measured tachymetrically. The specified depth was entered into the code of the measured point, which was later used to create the 3D axis of the pipes and a pipe package.

Picture 27: Inspection of telecom manhole in Vesivärava Street

5.5.8 Inspection and measurement of sewerage manholes

Sewerage manholes were inspected due to the fact that in the course of the GPR survey a sewerage manhole together with pipes missing from the as-built drawing and master plan were detected. In addition to the missing sewerage manhole, other sewerage manholes within the survey area were also inspected. Each manhole was measured during the inspection

- lid height and material
- diameter and material
- bottom height
- heights of the flow bottom of the pipes
- inner diameters of the pipes

During inspection of the manholes, differences in the diameters of pipes compared to the as-built drawing were revealed. No inconsistencies were detected in the height data of the flow bottom of the pipes.

Picture 28: Inspection of the sewerage manholes in Vesivärava Street

5.5.9 Coordinates of the manhole covers

For the purpose of carrying out an extra inspection, the central coordinates of all the manhole covers visible in the test area were taken with the TS device.

5.5.10 Measuring and creating the surface model

When comparing the model created by using as-built drawing VGT091 "Utility survey of the covers of Vesivärava Street" with the actual situation, it was found that the drawing did not contain a number of points characterising the micro-relief. This, in turn, did not allow sufficiently precise height linking of the profiles measured with the GPR. In order to gather all GPR data into the most accurate and uniform model possible, it was decided to re-measure the surface model. All the points specific to the break-lines and relief, approximately 600 in the area of the survey, were measured.

Relief breaklines (kerbs, asphalt edges) were drawn using the measured points. 3D dots were generated in the drawing program into all measured dots. Using 3D points and 3D breaklines, a triangle model was created. The use of breaklines allowed the creation of a triangle model for manhole-defined surfaces. For example, the surface of the road between the kerbs. All data from GPR surveys were recalculated according to the uniform surface model. This resulted in the best possible absolute height for the detected objects in the national EH2000 altitude system.

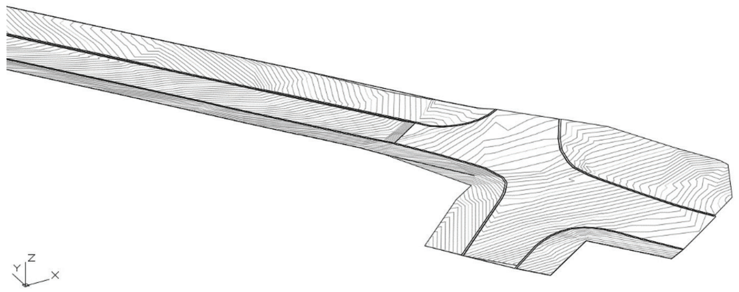


Figure 20: Surface model created from measured points at the crossing of Vesivärava, Faehlmanni and Wiedemanni streets

5.6 Processing the raw data of the survey and software testing

In the course of the survey, a large amount of raw data was collected with all the GPRs used in the survey, which had to be processed so that the result could be used in GIS, CAD, etc. software.

The purpose of post-processing GPR data is to identify, position and visualise the underground utilities that are the target of the survey from the raw data collected.

Data acquisition with GPR results in raw data, from which the target objects of the survey are identified during processing with special software. As data acquisition can be carried out using different methodologies and with different devices, data processing is also different in different projects.

In general, GPR data processing can be divided into four stages: data preparation and correction; signal processing and visualisation; object interpretation and drawing; export of the results.

In order to get an overview of different GPR post-processing software and their capabilities, testing of software was carried out. Seven products were selected for testing GPR software:

They provide a comprehensive overview of the possibilities of modern GPR software, as they are provided by industry leaders. Most of the software used in the world can process GPR data with only one channel. Data processing with GPR with a multi-channel antenna array can only be performed by some software.

The comparison table of software can be found at the end of this chapter. GPRs of these four companies: MALA, ImpulseRadar, IDS and 3D-Radar participated in a test of GPR hardware held in Vesivärava Street in Tallinn.

5.6.1 Object Mapper

Object Mapper is a licensed and paid for GPR data processing software owned by Swedish company Guideline Geo AB (MALA).

The software is Windows-based and provides basic functionality required to perform the work. The 2.0 latest version of the software was introduced on the market in 2018.

Object Mapper is a simple and effective solution for processing raw data of MALA GPRs and interpreting processed data. It can be used to process data collected with single scan line MALA Easy Locator series GPRs Pro, GX, CX, XV or WR produced by MALA. The software enables processing of data whether or not the data acquisition has been performed using the exact RTK GNSS, using the baseline methodology.

Preparing data in the Object Mapper data processing software depends on the type of GPR and how the data acquisition has been performed. According to GPR setup during data acquisition, all collected profiles may be in separate files or an OBM project has already been created during data acquisition, which can be opened directly with the software. All required subdirectories and formats are automatically created by the software, and the user does not need or is not able to set them up.

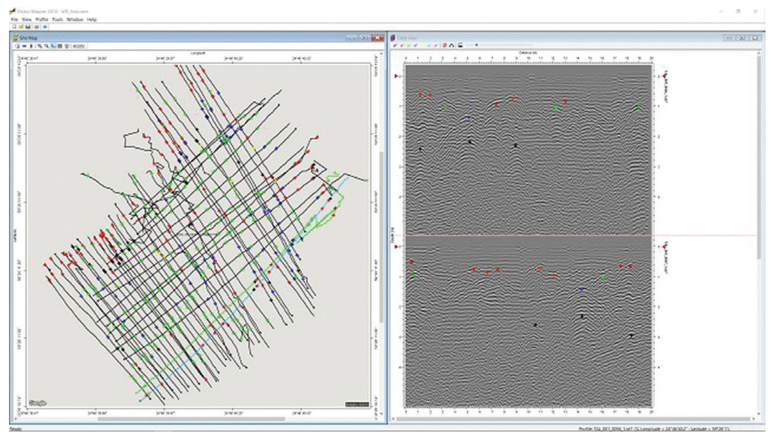
Using the baseline methodology in data acquisition, it is possible to set precise measurement parameters for data processing during data preparation. If an OBM project has already been created during data acquisition, the positioning parameters can no longer be changed or corrected during data processing.

Signal processing is done in the Object Mapper data processing software simply through the menu of the filters.

You can choose between different filters and set parameters for the filters according to raw data, the purpose of the survey or the interpreter's preferences.

Data interpretation is performed based on a B scan. For each profile, the detected target hyperbole is marked with a pre-set marking. All marks of the same target form a line of points, each of which has an x, y and z coordinate. Points with coordinates for all detected and marked targets can be exported to DXF, ASCII or GPS Mapper formats. Results can be further processed in CAD or GIS software.

To present the results, Object Mapper allows you to save and print screen images.



Picture 29: OBM interpreting view

Object Mapper is simple software with few functions that enables the identification and interpretation of underground utilities on simpler sites. In more complex situations where there is a need to identify many underground utilities in the same area, work with Object Mapper is more complicated because it does not allow a horizontal view or different slices for more accurate identification of targets. Also, the software does not allow zooming in the B scan view. The software does not need many computer resources, works quickly and the result is good on simpler sites.

5.6.2 rSlicer

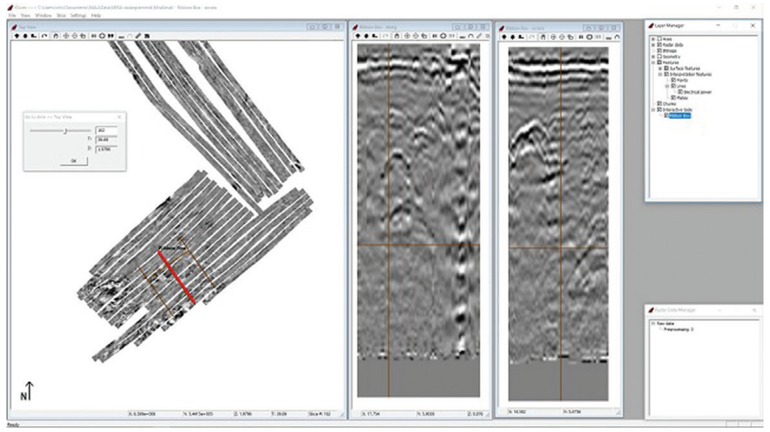
rSlicer is a licensed and paid for GPR data processing software created in 2007 under the order of Swedish company Guideline Geo AB (MALA) by Russian company DECO Geophysical Co.

rSlicer is an effective and reliable solution for processing raw data and interpreting processed data from MALA antenna array GPRs. It can be used to process data collected with the GPRs of the MALA 3D Imaging Radar Array (MIRA) multiple scan line series produced by MALA. The rSlicer software allows data to be processed regardless of whether the data acquisition has been performed using accurate RTK GNSS or a Total Station.

The software allows modification and specification of the positioning data by measurement point if the data acquisition has resulted in inaccuracies or deficiencies in the positioning data.

Signal processing is performed in rSlicer data processing software in a two-step way through the Radar Data Manager menu.

rSlicer software provides views and slices for the entire site examined, both horizontally and vertically. Interactive tools can be used to view the survey area from top to bottom at different heights and to make slices in x, y and z directions. Vertically, it is also possible to perform asymmetrical slices, for example, along the target to be examined, in order to detect its depth at each point.



Picture 30. rSlicer horizontal and vertical slices

Vertical slices can be used to indicate the exact position of the target and the exact position of the target by hyperbole or line.

Horizontal slices can also be used to identify the location of the target, where the signal has been processed with both Migration and Hilbert functions providing a good visual overview of the target.

The rSlicer data processing software allows you to identify and interpret point objects, linear objects and plane objects.

All detected, marked and drawn targets with coordinates can be exported to the DXF format. Results can be further processed in CAD or GIS software. To present the results, rSlicer allows you to take GeoTIFF images and .avi video. You can also save and print screenshots.

rSlicer is a simple and sufficiently functional software that enables the processing of raw data collected with a multiple scan line antenna array GPR to identify and interpret underground utilities even in more complex situations.

The software allows the creation of different signal-processing versions from the same survey area to help identify more complex targets. rSlicer also allows for making slices of different directions from the survey area, which makes interpreting targets more accurate and effective.

Software does not need a lot of computer resources, works quickly and gives a quality result in the hands of an experienced user.

5.6.3 Examiner

Examiner is a licensed and paid for GPR data processing software owned by the Norwegian company 3D-Radar AS.

Examiner data processing software has been specifically developed for the processing of DX & DXG antenna array GeoScope™ step frequency GPR data. GeoScope records the data in a frequency domain during data acquisition and consists of a set of data that characterises the amplitude and phase of the reflected wave. To visualise the data collected with GeoScope, the Examiner software first converts the data to a time domain and makes common numbers from the data set.

Examiner is an effective and reliable solution for processing raw data and interpreting processed data from GeoScope. The Examiner software allows data to be processed regardless of whether the data collection has been performed using accurate RTK GNSS or Total Station .

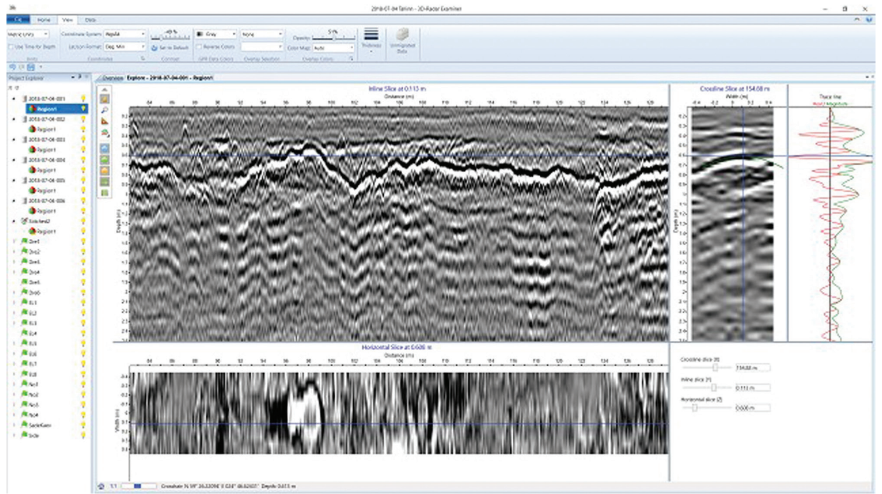
In order to be able to process data for large areas, the use of a resource is optimized in the Examiner data processing software. To do this, the data processing is divided into two stages: signal processing, which is stored in the computer, and all subsequent activities for which the image is changed only on the screen.

When you start a project, the software automatically creates all necessary subdirectories and formats, and the user does not need or is not able to set them up.

If positioning data has been collected with RTK GNSS during the data acquisition and stored together with GPR data, they are automatically linked to each other when the project is started. If the positioning has been performed with Total Station and its data is stored separately from the GPR data, they must be manually gathered in the software during the data preparation process.

The software allows, regardless of the positioning type, modification and refinement of the positioning data by measurement point if the data acquisition has resulted in inaccuracies or deficiencies in the positioning data.

The Examiner software displays on screen different views and slices for the entire site examined, both horizontally and vertically. Vertically, slices are displayed in both the longitudinal and perpendicular directions of the target of the linear object. Horizontally, sections can be made according to pre-set settings. You can also easily zoom in on all views.



Picture 31: Examiner interpreting A and B scans

A combination of methods can be used to interpret data and different slices can be used for this.

The Examiner data processing software allows you to identify and interpret both point objects and linear objects. In addition, different soil layers can be identified with a relevant algorithm in the software to automatically identify them.

All detected, marked and drawn targets with coordinates can be exported to the DXF or DWG format. Results can be further processed in CAD or GIS software.

To present the results, Examiner allows you to export all data to a valid Google Earth format KMZ, make a video and also save and print screenshots.

Examiner is efficient, simple and sufficiently functional software that enables the processing of raw data collected with a multiple scan line variable frequency GPR to identify and interpret underground utilities also in more complex situations.

The software works quickly and logically, it does not need a lot of computer resources and it gives a quality result in the hands of an experienced user.

5.6.4 Gred-HD

GRED-HD is a licensed and paid for GPR data processing software designed specifically for interpreting underground utilities and creating 3D objects.

The owner of the GRED-HD is Italian company IDS GeoRadar s.r.l.

It can be used to process data collected by IDS by the single scan line GPR Opera Duo, multiple scan line GPR RIS MF Hi-Mod and antenna array series Stream (C, EM, X) GPRs.

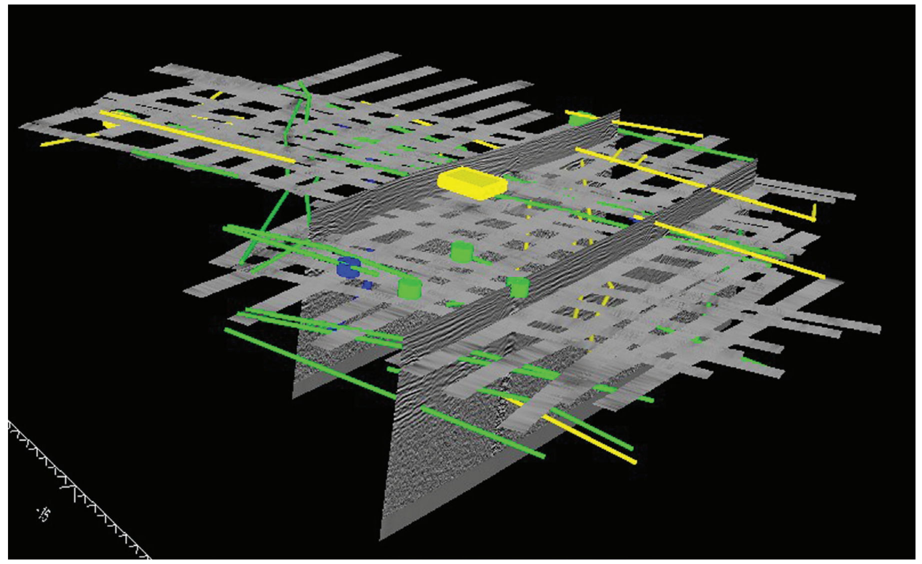
GRED-HD software allows the processing of data no matter which positioning solution was used for data capturing. The software allows, regardless of the positioning type, modification and specification of the positioning data by measurement point if the data acquisition has resulted in inaccuracies or deficiencies in the positioning data.

GRED-HD is powerful GPR data processing software that, in addition to standard features, can create three-dimensional objects.

Preparing data in the GRED-HD data processing software depends on the type of GPR and how the data acquisition has been performed. According to GPR setup during data acquisition, all collected profiles may be in separate files or a GRED-HD project has already been created during data acquisition, which can be opened directly with the software. All required subdirectories and formats are automatically created by the software, but the user is able to set them up themselves.

Data interpretation is performed in the OpenGL module in the GRED-HD data processing software. OpenGL module displays on screen different views and slices for the entire site examined, horizontally, vertically and spatially. Vertically, slices are displayed in both the longitudinal and perpendicular directions of the linear object. Horizontally, slices can be made according to pre-set settings. You can also zoom in on all views. It is possible to move and rotate objects spatially.

If the data acquisition has been performed from a larger area, it must be divided into parts for the data interpretation stage; otherwise the software will not be able to handle it. A combination of methods can be used to interpret data, and different slices can be used for this. The detected targets can be assigned a type immediately, and a three-dimensional image of the target will be created through this for visualisation. All detected and drawn targets with coordinates can be exported in DXF or SHP format and can be further processed in CAD or GIS software.



Picture 32: GRED-HD 3D view

GRED-HD is a complex GPR data processing software with an abundance of capabilities. The software needs a lot of computer resources and is therefore slow. The software is also difficult for a standard user and requires long-term experience to use it effectively.

5.6.5 Radan

RADAN is a licensed and paid for GPR data processing software owned by U.S. company Geophysical Survey Systems, Inc (GSSI).

It can be used to process data collected with the UtilityScan, StructureScan, RoadScan, PaveScan, BridgeScan and SIR® series radars produced by GSSI.

It is primarily intended for use with a single scan line GPR, which is the main product of GSSI, but can also handle data collected with multiple scan lines GPR.

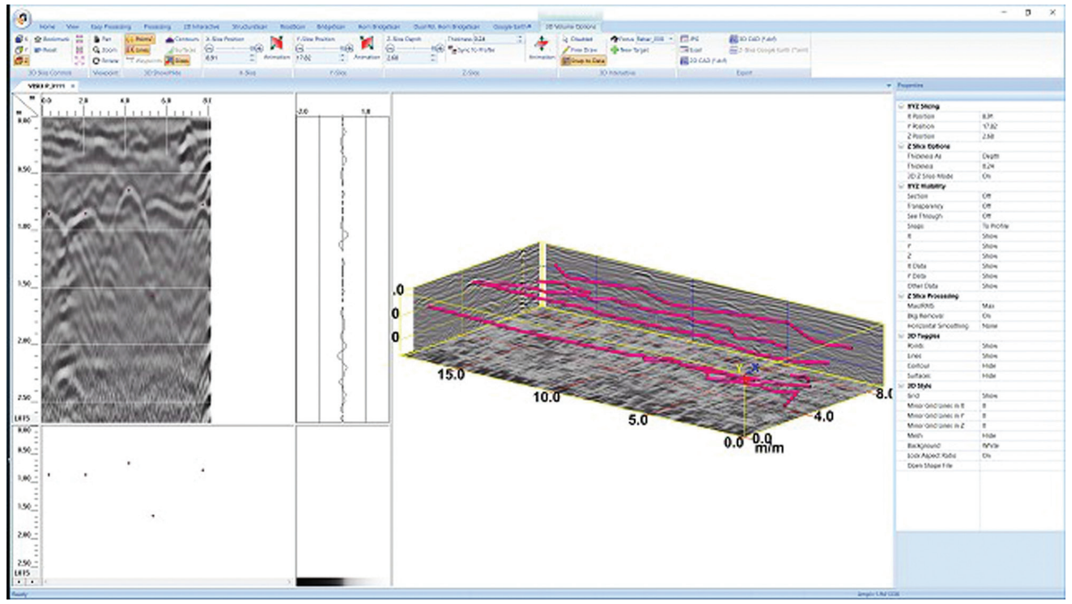
Preparing data in the RADAN data processing software depends on the type of GPR and how the data acquisition has been performed and how the data interpretation is to be performed. According to GPR setup during data acquisition, all collected profiles may be in separate files or a RADAN project has already been created during data acquisition, which can be opened directly with the software.

Using the survey grid in data acquisition, it is possible to set precise measurement parameters for data processing during data preparation.

RADAN software allows the procession of data no matter which positioning solution was used for data capturing. The software allows, regardless of the positioning type, the modification and specification of the positioning data by measurement point if the data acquisition has resulted in inaccuracies or deficiencies in the positioning data.

Signal processing is done via RADAN Easy Processing or the Processing menu. Easy Processing enables the main signal processing stages that are needed in most cases. The Processing menu allows performance of advanced signal processing.

Data interpretation is performed based on 2D data or a B scan. For each profile, the detected target hyperbole is marked with a pre-set marking. All marks of the same target form a line of points, each of which has an x, y and z coordinate. The user can connect a sequence of points to a line and create by this linear objects. All marked points and created objects can be viewed in 3D view.



Picture 33: Radan B and A scans and horizontal and vertical slices

Points and linear objects created for all detected and marked targets can be exported with coordinates to the DXF format. Results can be further processed in CAD or GIS software.

RADAN has an abundance of capabilities, but at the same time is a simply handled GPR data processing software. It is the most advanced data processing software; it allows the processing of raw data collected primarily by a single scan line GPR to identify and interpret underground utilities even in more difficult situations. RADAN does not need a lot of computer resources and works quickly and gives a quality result in hands of an experienced user.

5.6.6 CrossPoint

CrossPoint is a licensed and paid for GPR data processing software owned by Swedish company ImpulseRadar AB. The Crosspoint software is very similar to the MALA Object Mapper data processing software, but slightly more user-friendly. CrossPoint is a simple and effective solution for processing raw data of ImpulseRadar GPRs and interpreting processed data. It can be used to process data collected with one scan line GPRs CrossOver or PinPointR.

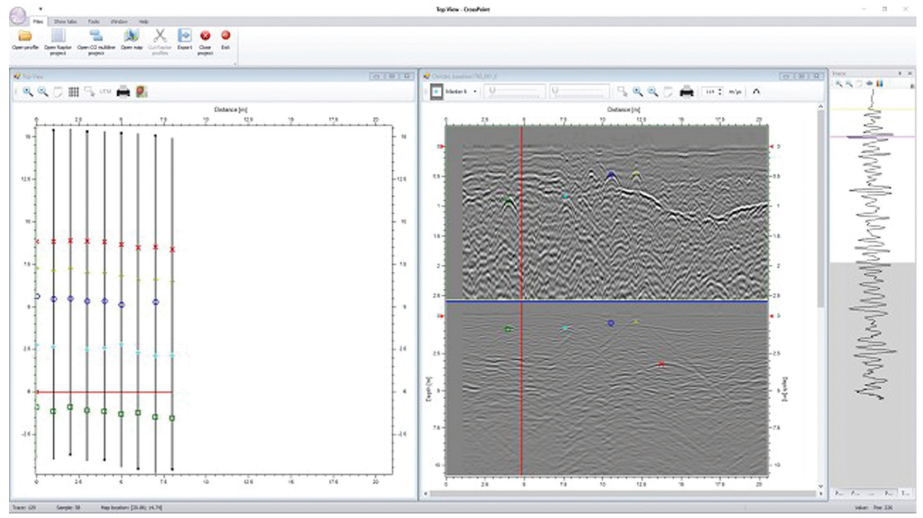
CrossPoint software allows the processing of data no matter which positioning solution was used for data capturing. The software allows, regardless of the positioning type, modification and specification the positioning data by measurement point if the data acquisition has resulted in inaccuracies or deficiencies in the positioning data.

Preparing data in the data processing software depends on the type of GPR and how the data acquisition has been performed. According to GPR setup during data acquisition, all collected profiles may be in separate files or a CrossPoint project has already been created during data acquisition, which can be opened directly with the software.

Using the reference line methodology in data acquisition, it is possible to set precise measurement parameters for data processing during data preparation.

Signal processing is done in the CrossPoint data processing software through the menu of the filters.

Data interpretation is performed based on a B scan. For each profile, the detected target hyperbole is marked with a pre-set marking. All marks of the same target form a line of points, each of which has an x, y and z coordinate.



Picture 34: CrossPoint interpreting using A and B scans

Points with coordinates for all detected and marked targets can be exported to DXF, ASCII or KML formats. Results can be further processed in CAD or GIS software. To present the results, Crosspoint allows screen images to be saved and printed.

Crosspoint is simple software with a few functions that enables the identification and interpretation of underground utilities on simpler sites. In more complex situations where there is a need to identify many underground utilities in the same area, work with Crosspoint is more complicated because it does not allow a horizontal view or different slices for more accurate identification of targets. The software does not need a lot of computer resources, works quickly and gives a quality result on simpler sites.

5.6.7 GPR Slice

GPR Slice is a licensed and paid for GPR data processing software designed by the geophysics doctor Dean Goodman and owned by Geophysical Archaeometry Laboratory, a US company owned by him. The GPR software has many modules and can perform both GPR data processing and data simulations.

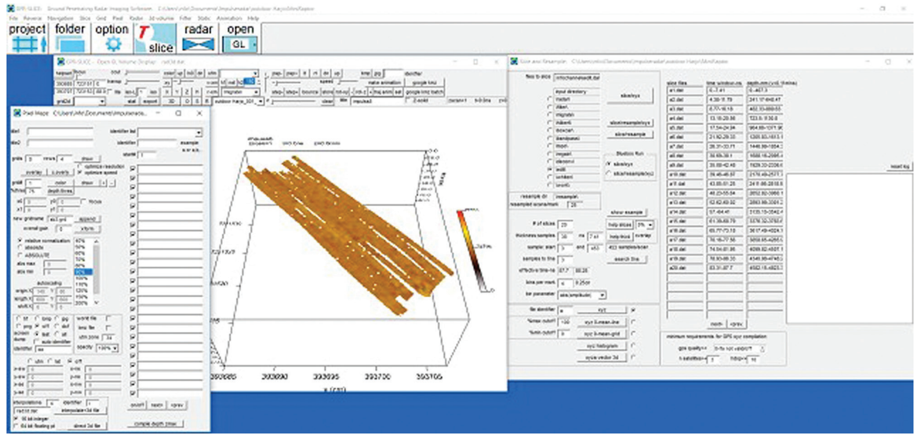
GPR Slice can be used to process data collected with a single scan line GPR or multiple scan line GPR (multichannel). GPR Slice is suitable for processing data from GPRs from the following companies: ImpulseRadar, Geophysical Survey Systems Inc, Mala Geoscience, Sensors and Software, IDS, US Radar, Ditch Witch, ERA Technology, 3D Radar of Norway, UTSI Electronics, Geoscanners, Leica, Proceq, Zond Radar, Koden Radar, GeoTech, Transient Technologies, Loza, SEGY and SEG 2.

Preparing data in the GPR Slice data processing software depends on the type of GPR and how the data acquisition has been performed. Because the software supports many devices, procedures have been created according to the device. During data preparation, they are converted to the GPR Slice format to allow further processing.

The GPR Slice software allows the processing of data no matter which positioning solution was used for data capturing. The software allows, regardless of the positioning type, the modification and specification of the positioning data by measurement point if the data acquisition has resulted in inaccuracies or deficiencies in the positioning data.

Signal processing is done in the GPR Slice data processing software through the module of the filters module.

In the GPR Slice Multichannel data processing software, data interpretation is performed mainly in the OpenGL module. The OpenGL module displays on screen different views and slices for the entire site surveyed, both horizontally and vertically. Vertically, slices are displayed in both the longitudinal and perpendicular directions of the linear object. Horizontally, slices can be made according to pre-set settings. You can also zoom in on all views. A combination of methods can be used to interpret data and different slices can be used for this. The detected targets can be assigned a type immediately, and a three-dimensional object from the target will be created through this.



Picture 35: Identifying GPR Slice targets

All detected, marked, and drawn targets with coordinates can be exported to the DXF format. Results can be further processed in CAD or GIS software. To present the results, GPR Slice allows all data to be exported to a valid Google Earth format KMZ, video to be taken and screenshots to be saved and printed.

GPR Slice is professional GPR data processing software. It has the greatest number of options and can be used to process data collected with many GPRs. Signal processing can be performed in a very specific way, also allowing a result to be obtained from data collected in more difficult conditions. The vast majority of GPR Slice capabilities are not needed to identify and interpret underground utilities, and the software is quite complex for a standard user. The GPR Slice software needs sufficient computer resources.

5.6.8 Software comparison table

		Object Mapper	CrossPoint	Radan	rSlicer	Examiner	GRED-HD	GPR Slice
Type	Single manufacturer GPR	X	X	X	X	X	X	
	Multi manufacturer GPR							X
	Single GPR device				X	X		
	Multi GPR device	X	X	X			X	X

		Object Mapper	CrossPoint	Radan	rSlicer	Examiner	GRED-HD	GPR Slice
GPR Equipment	Single frequency				X			
	Multi frequency	X	X	X		X	X	X
	Single channel	X	X	X				
	Multi-channel				X	X		
	Single and multi-channel						X	X
	Time domain	X	X	X	X		X	X
	Frequency domain					X		X
Positioning & placing	Base line	X		X		X	X	X
	Reference line		X					X
	Grid			X			X	X
	GNSS, TS	X	X	X	X	X	X	X
	Position adjustment	X	X	X	X	X	X	X
	Horizontal Scaling			X				X
	Distance Normalization			X				X
	Surface Normalization			X			X	X
	Static Correction			X			X	X
	Time-zero adjustment	X	X	X	X	X	X	X
	Autoscale					X		
	Automatic ground alignment					X		
Signal Processing	DC Adjustment	X	X		X			
	Threshold	X	X					
	Muting				X			
	Amplitude correction				X			
	Interference Amplitudes					X		
	Antenna Ringdown Removal				X			
	IFFT					X		
	EDGE filter					X		
	FIR	X		X	X		X	X
	HFIR	X						
	ISDFT					X		
	Triangular FIR	X		X				
	Boxcar Filter		X	X				X
	Vertical High Pass Filter		X	X	X	X	X	X
	Vertical Low Pass Filter		X	X	X	X	X	X
	Background Removal	X	X	X	X	X	X	X
	Stacking Filter			X				
	Smoothing filter					X		

		Object Mapper	CrossPoint	Radan	rSlicer	Examiner	GRED-HD	GPR Slice
	Moving Average	X	X					
	Moving Median	X						
	Interference suppression					X		
	Dewow						X	X
	Predictive deconvolution				X			X
	Deconvolution			X			X	
	Peaks Extraction			X				
	Visualisation					X		
	AGC	X	X	X	X	X	X	X
	Time Gain	X	X					
	Range Gain					X		
	Custom Gain	X	X	X		X	X	X
	Linear gain			X			X	X
	Exponential gain			X				X
	Smoothed gain						X	
	Interpolation				X		X	X
	Migration	X	X	X	X	X	X	X
	Hilbert transform			X	X		X	X
	Math/macros			X			X	X
Data interpretation	A scan view		X	X		X	X	X
	B scan view	X	X	X	X	X	X	X
	C scan view			X	X	X	X	X
	3D view			X			X	X
	Target List	X	X	X	X	X	X	X
	Time slice			X	X	X	X	X
	X slice	X	X	X	X	X	X	X
	Y slice			X	X	X	X	X
	Zoom in slice	X		X	X	X	X	X
	Advanced zoom in slice		X	X	X	X	X	X
	Point targets	X	X	X	X	X	X	X
	Line targets			X	X	X	X	X
	Plate targets				X		X	X
	3D targets						X	X
	Target smoothing							X

		Object Mapper	CrossPoint	Radan	rSlicer	Examiner	GRED-HD	GPR Slice
Export	Points	X	X	X	X	X	X	X
	Lines			X	X	X	X	X
	Plates			X			X	X
	DXF	X	X	X	X	X	X	X
	DWG					X		X
	SHP						X	
	ASCII	X	X					
	TXT			X		X		
	KML		X					
	KMZ					X		X
	GeoTIFF				X			
	GPS Mapper	X						
	AVI				X	X	X	X

5.7 Survey results

Vesivärava survey area was divided into two parts:

1. Vesivärava Street slice between Raua and Faehlmanni streets
2. Crossing of Vesivärava and Faehlmanni streets

The following GPR measuring results were compared:

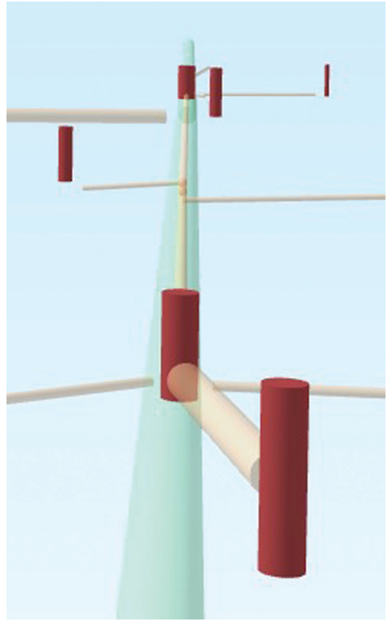
- 3D Radar (Vesivärava Street)
- IDS Stream (Vesivärava Street)
- Mira (Vesivärava Street and crossing)
- IDS Opera Duo (crossing)
- Wide Range (crossing)

As ImpulseRadar GPRs were tested later, after comparing data of other GPRs, the ImpulseRadar results are not included in this comparison.

In comparison, the following was assessed:

- which objects GPRs were able to detect
- which planned accuracy the location of the objects was determined with
- which accuracy the height of the objects was determined with

In the Vesivärava Street slice the detected stormwater system was compared with the results of the utility survey according to both plan and height. For other utility networks, the identification of the objects and the maximum differences were assessed.



Picture 36: Piping and manholes in Vesivärava Street

Utility networks can remain undetected if the scanned areas are not overlapping and there are gaps between the areas. If some utility networks are missing from the final results, this does not automatically mean that the GPR was not able to detect a particular network slice, but it may also be due to a gap in the scan areas.

5.7.1 3D radar results

5.7.1.1 Exportable formats

3D radar results can be exported to the following formats:

1. Data exported in DWG format is very difficult to process because all elements are organized into groups (BLOCK REFERENCE) in a way that the group fixing point is located in the coordinate point (0.0.0). As the derivation of points in this format is troublesome and time-consuming, we will use the exported text file to process the data.
2. KMZ - To show results in Google Earth software
3. Text file

5.7.1.2 Processing the results

Data was exported to a text file to process the results. Linear objects were grouped together in one csv file and point objects into another file. GPR software produced results in the WGS 84 coordinate system and profile heights were measured in the EH2000 system. In order to verify the compliance of heights with the existing ground surface model and base data in the BK77 system, the results obtained were transferred to the BK77 height system. This was done by establishing a correction between the EH2000 and BK77 height systems in this area. The transition model calculator of the Land Board http://www.maaamet.ee/rr/ymudel/ was used to find the correction. At the site 3 reference points were selected for the correction. As the length of the site was relatively short (approx. 240 meters), the correction did not change within this range. The height correction was introduced using the following formula H(BK77)= H(EH2000) - 0.235 m.

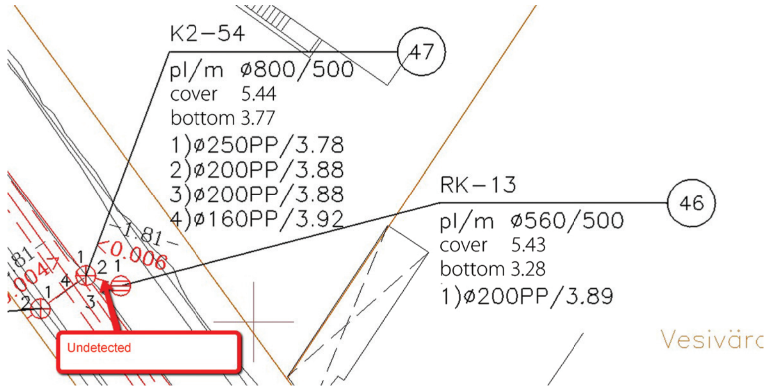
The GPR software delivers the depths of the marked objects from the ground (for example, the depth of the profile point of inflection from the ground to the detected object of -1.310 meters). To obtain the height of the specified object, one must know the height of the ground surface at the corresponding point. For this, a ground surface model was created from the points of the measured profile. The heights of the objects were calculated as the difference between ground height and depth.

5.7.1.3 Data comparison 2D

3D radar was able to identify most of the utility networks reported in the as-built drawings and master plan, which were electricity, communication (decommissioned), stormwater sewerage.

3D radar failed to detect:

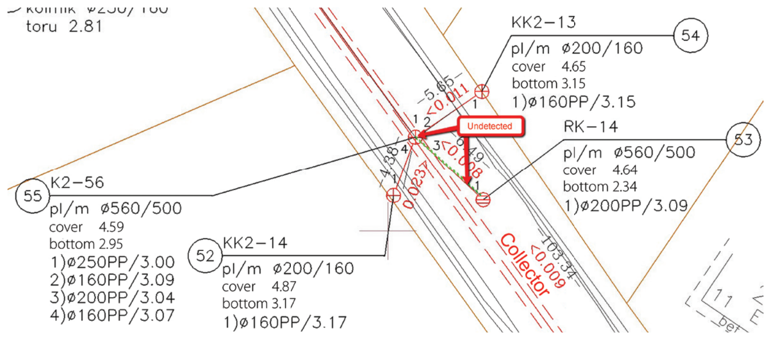
1. A 1000 PP stormwater sewerage route located deeper even in locations where a 250 PP pipeline was not located above the 1000 PP pipeline; the height of the flow bottom of the collector's (1000 PP) was approx. 2.9-3.1 m from the ground surface;
2. 200 PP pipe exiting from the manhole RK-13 (flow bottom approx. 1.54 m from the ground surface)



Picture 37: 200PP pipe exiting from the manhole RK-13

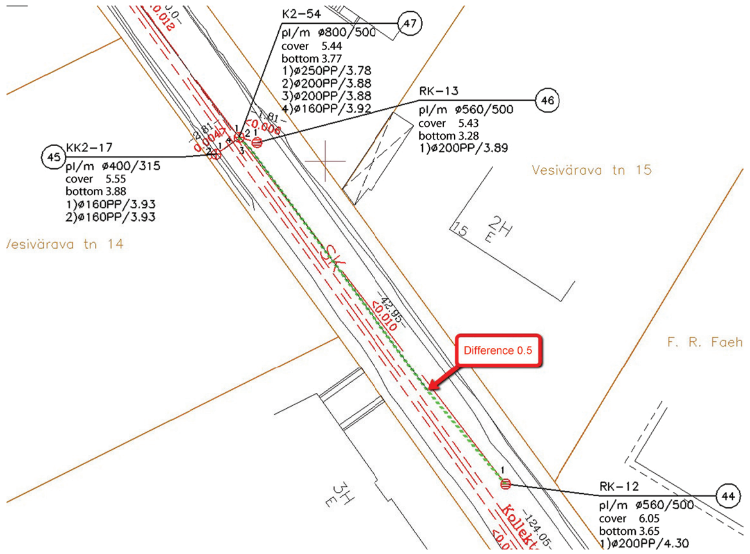
3D radar detected partially:

1. 200 PP pipe exiting from the manhole RK14 (flow bottom approx. 1.55 m from the ground surface)



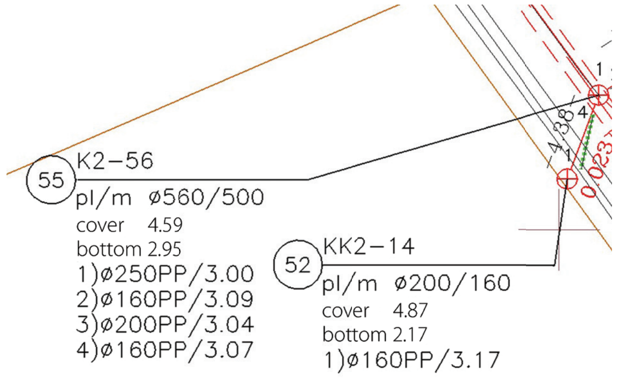
Picture 38: 200PP pipe exiting from the manhole RK-14

200 PP pipe exiting from the manhole RK12 (flow bottom approx. 1.75 m from the ground surface). Although no pipe exiting from the RK12 manhole was visible in the beginning, the pipe becomes visible approx. 12 m from the manhole, and it can be seen there that the pipe does not run straight between the manholes RK12 and K2-54, as shown in the as-built drawing, maximum distance of approx. 0.5 m.



Picture 39: 200PP pipe exiting from the manhole RK-12

In the slice between the manholes K2-56 and KK2-14, the planned difference is approx. 0.46 m compared with the as-built drawing.



Picture 40: Section between the manholes K2-56 and KK2-14

5.7.2 IDS Stream Radar results

5.7.2.1 Exportable formats

IDS Stream results can be exported to the following formats:

1. DXF format - Lines and dots created with IDS software "GRED_HD" can be exported to the DXF format. Line elements are exported to the DXF format as two-dimensional (2D) and an attribute "autocad_elevation" is added

DXF export	Actually determined coordinates
0: 544008.3597, 6589166.9498	0: 544008.3597, 6589166.9498, -1.388404
1: 544015.1699, 6589157.3915	1: 544015.1699, 6589157.3915, -1.30007
2: 544023.9929, 6589144.754	2: 544023.9929000001, 6589144.754, -1.255932
3: 544033.865, 6589131.2737	3: 544033.865, 6589131.2737, -1.282438
4: 544046.5739, 6589114.205	4: 544046.5739, 6589114.205, -1.308944
5: 544049.1936, 6589110.4743	5: 544049.1936, 6589110.4743, -1.273622
6: 544056.9636, 6589099.4474	6: 544056.9636, 6589099.4474, -1.088196
7: 544064.3052, 6589089.0706	7: 544064.3052000001, 6589089.0706, -1.088196
autocad elevation: -1.088196	

Such an export converts all the points of inflection of the line to a depth of -1.088196 according to the last point of inflection, which is incorrect. The DXF export of this application must not be used for further processing of 3D data.

2. SHP format. The geometries are exported as 3D lines/points with the attributes added during the data processing.

	Colour	Diameter	Name
1	00ff00	0.200 [m]	Other62
2	00ff00	0.200 [m]	Other62
3	ff0000	0.200 [m]	Electric7
4	0000ff	0.400 [m]	Water8

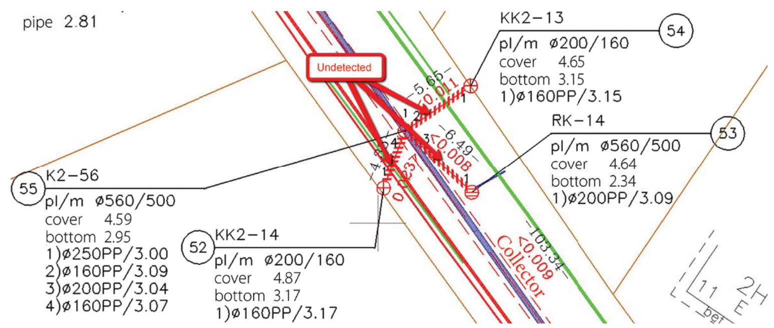
In the course of export, the depths of the marked lines and points from the ground or heights can be issued. In cases where the depths from the ground surface are to be exported, it must be considered that the ground surface is 0.00 m at each measuring point and the real tilts of the objects will not correspond to the reality in case of such exports. The data exported in SHP format, the heights of which were given in the BK77 height system, were used for further comparison.

5.7.2.2 Data comparison 2D

IDS Stream was able to identify the utility networks reported in the as-built drawings and master plan, which were electricity, communication (decommissioned), stormwater sewerage.

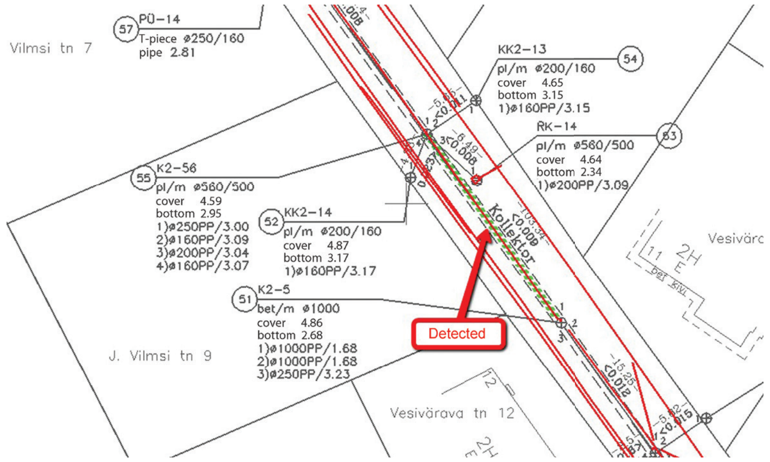
Stream EM radar failed to detect:

1. a 1000 PP stormwater sewer pipe at a deeper depth even in locations where a 250 PP pipeline was not located above the 1000 PP pipeline, the flow bottom height of the 1000 PP collector was approx. 2.9-3.1 m from the ground;
2. most of the collection pipes connected to the main stormwater piping.



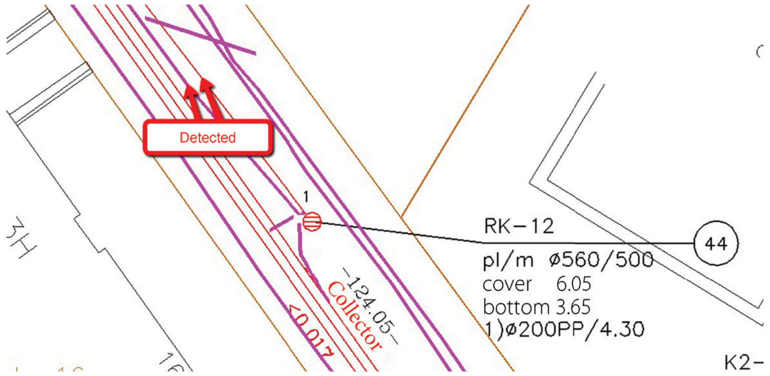
Picture 41: Undetected pipes

Between manholes K2-56 and K2-5, a pipe was detected at a depth of approx. 1.2 m, which is not included in the as-built drawing (height of the pipe 3.53 and 3.66 in the BK77 coordinate system). In this slice, the collector is located at a depth of 2.2 m on the pipe.



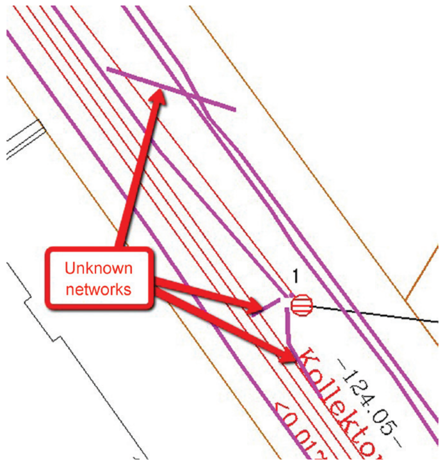
Picture 42: A utility network was detected between the manholes K2-56 and K2-5

Stream EM was able to detect a discrepancy in the as-built drawing data where the pipe exiting from the manhole RK12 does not run straight between the manholes RK12 and K2-54 as shown in the as-built drawing, maximum planned difference of approx. 0.9 m from the as-built drawing.



Picture 43: Utility network between RK12 and K2-54

Unknown utility networks were detected in many locations:



Picture 44: Unknown utility networks

Stream EM was able to detect structures, power cables and an abandoned communication cable. The accuracy of the cables mentioned above is difficult to assess as there is no information on the actual location and origin of the data.

5.7.3 Mira radar results

5.7.3.1 Exportable formats

Mira radar results can be exported to the following formats:

DXF format: In this format, the exported lines and point elements are expressed as a depth relative to the ground surface.

5.7.3.2 Processing the results

Because the Mira rSlicer software produces the data of the objects with depths, the height of the objects in the height system BK77 had to be calculated from the depths. To transfer the depths, a ground surface model was generated from profile positioning files of GPR.

.pos file structure

UNITS:m

1	544006.22	6589176.59	4.250
10	544006.62	6589176.02	4.260

The created ground surface model was compared with the as-built drawing of the existing road (ViaGeo Vesivärava Street pavement as-built drawing no. VGT091). A difference was detected between the as-built drawing and the specified profiles - all profile points were located 0.38 m higher than in the as-built drawing of the pavement of Vesivärava Street. This systematic error also occurred when comparing the existing and Mira 3D data. The error was caused from using the wrong prism height.

- Prism inserted into the measuring station (TS) 1.5 m
- Correct prism height 1.88 m

Calculation of heights for detected lines in BK77 system

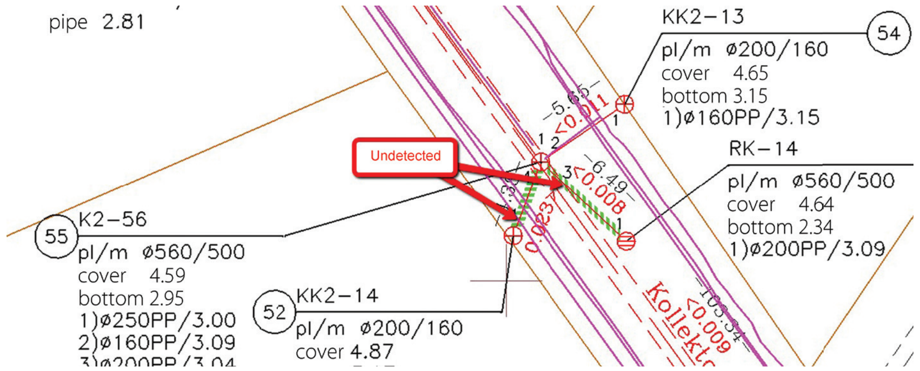
1. A ground surface model was generated from the data of the profiles (contour difference 0.01 m)
2. The detected objects were placed into the ground surface model using the VERTEX (FME Desktop) method, where the element was delivered with the same number of peaks. Each point of inflection of an element was assigned a height as the difference between the height of the ground surface and depth.

5.7.3.3 Data comparison 2D

Mira radar was able to identify most of the utility networks reported in the as-built drawings and master plan, which were electricity, communication (decommissioned) and stormwater sewerage. Most of the collection pipes connected to the main stormwater piping were detected.

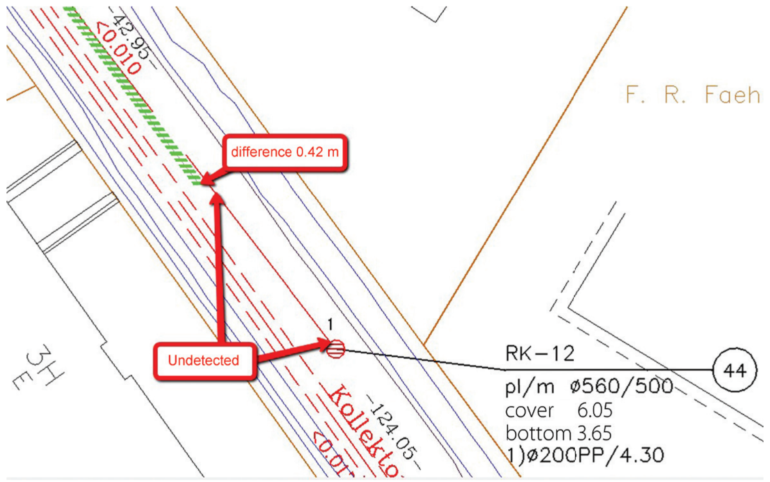
Mira radar failed to detect:

1. a 1000 PP stormwater sewer pipe at a deeper depth even in locations where a 250 PP pipeline was not located above the 1000 PP pipeline, the flow bottom height of the 1000 PP collector was approx. 2.9-3.1 m from the ground
2. Mira failed to detect the connection pipe between the manholes RK-14 and K2-56 and KK2-14 and K2-56



Picture 45: To detect the connection pipe between the manholes RK-14 and K2-56 and KK2-14 and K2-56

200 PP pipe exiting from the manhole RK12 (flow bottom approx. 1.75 m from the ground surface). Although no pipe exiting from the RK12 manhole was visible in the beginning, the pipe becomes visible approx. 11.5 m from the manhole, and it can be seen there that the pipe does not run straight between the manholes RK12 and K2-54, as shown in the as-built drawing, maximum distance of approx. 0.42 m).



Picture 46: Pipe exiting from the manhole RK12

5.7.3.4 2D comparison 3D radar, Stream EM and Mira

To compare the planned location of the utility routes, Vesivärava Street stormwater sewerage pipes were selected. The pipes were built in 2017 and there is a proper as-built drawing on them.

Differences on XY level				
Diameter mm	**Length M**	**3D radar M**	**Stream EM M**	**Mira M**
250	13.8	0.04	0.18	0.09
		0.01		0.05
250	66	0.00	0.11	0.03
		0.13	0.17	0.11
		0.05	0.09	0.03
		0.05	0.06	0.12
			0.15	0.20
			0.07	
250	14.2	0.08	0.17	0.11
		0.01	0.31	0.07
250	29	0.03	0.03	0.08

Differences on XY level				
Diameter mm	**Length M**	**3D radar M**	**Stream EM M**	**Mira M**
		0.11	0.20	0.13
				0.11
				0.11
				0.05
				0.10
				0.05
200	0.7		0.05	0.06
200	42	0.18	0.22	0.17
		0.37	0.86	0.04
		0.48	0.32	0.01
				0.26
				0.34
				0.42
				0.42
200	5.5	0.06		
		0.13		
200	0.5	0.78		0.06
		0.23		
160	5.4	0.13	0.09	0.01
		0.13	0.03	0.05
		0.01	0.17	
160	2.8	0.05	0.13	0.04
		0.06	0.03	0.12
160	5.6	0.00		0.15
		0.02		0.35
		0.04		
160	4.7	0.06		0.22
		0.03		0.06
160	3.4	0.08		
		0.45		
160	4.8	0.04		0.42
		0.05		
		0.09		
160	1.5	0.06		
		0.04		
160	1.8	0.04	0.30	0.02
		0.02		
		0.03		
Average difference		0.11	0.18	0.13
Mean-square error		0.16	0.18	0.12

5.7.4 3D comparison 3D radar, Stream EM and Mira

To compare the heights of the utility routes, Vesivärava Street stormwater sewerage pipes were selected. The pipes were built in 2017 and there is a proper as-built drawing on them. Based on the data obtained from the as-built drawing, the heights were calculated on top of the pipes.

Diameter	Length	TJ	3D radar	TJ-GPR	TJ	Stream EM	TJ-GPR	TJ	Mira	TJ-GPR
250	13.8	2.47	2.56	-0.09	2.55	2.44	0.11	2.55	2.99	-0.44
		2.63	2.64	-0.01				2.63	3.05	-0.42
250	66.0	2.65	2.70	-0.05	2.69	2.56	0.13	2.65	3.03	-0.38
		2.86	3.00	-0.14	2.84	2.76	0.08	2.85	3.3	-0.45
		2.88	2.98	-0.10	3.01	2.90	0.11	2.89	3.35	-0.46
		3.24	3.42	-0.18	3.05	3.03	0.02	3.05	3.52	-0.47
					3.18	3.10	0.08	3.25	3.75	-0.5
					3.22	3.18	0.04			
250	14.2	3.49	3.60	-0.11	3.49	3.30	0.19	3.52	3.98	-0.46
		3.65	3.75	-0.10	3.64	3.52	0.12	4.59	4.1	0.49
250	29.0	3.67	3.80	-0.13	3.77	4.23	-0.46	3.67	4.2	-0.53
		4.02	4.20	-0.18	3.87	4.40	-0.53	3.74	4.16	-0.42
								3.82	4.24	-0.42
								3.86	4.28	-0.42
								3.92	4.35	-0.43
								3.96	4.39	-0.43
								4.02	4.52	-0.5
200	0.7		T*		4.09	4.04	0.05	4.08	4.54	-0.46
200	42.0	4.09	4.08	0.01	4.12	4.64	-0.52	4.09	4.48	-0.39
		4.32	4.40	-0.08	4.41	5.12	-0.71	4.15	4.57	-0.42
		4.39	4.49	-0.10	4.50	4.82	-0.32	4.18	4.6	-0.42
								4.26	4.72	-0.46
								4.31	4.8	-0.49
								4.35	4.85	-0.5
								4.39	4.96	-0.57
200	5.5	3.28	3.42	-0.14		T*			T*	
		3.29	3.41	-0.12						
200	0.5	2.65	2.66	-0.01		T*		2.69	2.91	-0.22
		2.71	2.64	0.07						
160	5.4	2.65	2.69	-0.04	2.61	3.05	-0.44	2.61	3.09	-0.48
		2.63	2.68	-0.05	2.61	2.67	-0.06	2.64	3.14	-0.5
		2.61	2.57	0.04	2.64	2.68	-0.04			
160	2.8	2.98	3.25	-0.27	3.05	3.03	0.02	2.97	3.52	-0.55
		3.09	3.34	-0.25	3.03	3.03	0.00	3.22	3.77	-0.55
160	5.6	3.00	3.21	-0.21		T*		3	3.52	-0.52
		3.11	3.22	-0.11				3.14	3.59	-0.45
		3.22	3.26	-0.04						

Diameter	Length	TJ	3D radar	TJ-GPR	TJ	Stream EM	TJ-GPR	TJ	Mira	TJ-GPR
160	4.7	3.25	3.39	-0.14		T*		3.3	3.81	-0.51
		3.29	3.39	-0.10				3.25	3.75	-0.5
160	3.4	3.24	3.38	-0.14		T*			T*	
		3.32	3.65	-0.33						
160	4.8	3.68	3.67	0.01		T*		3.73	4.18	-0.45
		3.70	3.71	-0.01						
		3.73	3.74	-0.01						
160	1.5	3.69	3.78	-0.09		T*			T*	
		3.67	3.72	-0.05						
160	1.8	4.09	4.27	-0.18	4.09	4.05		4.08	4.57	-0.49
		4.09	4.24	-0.15						
		4.08	4.21	-0.13						
Average difference				-0,10**			-0.11			-0.43*
Average difference after the systematic error has been removed				-0.03			-0.11			-0.05
Mean-square error				0.09			0.28			0.17

* - profiled heights compared with actual road 38 cm higher
** - profiled heights compared with actual road 7 cm higher
T * - undetected
3D radar - The smallest mean-square error and the least undetected utility networks (1)
Mira - The most measured points, undetected utility networks (3)
IDS radar - The most undetected objects (7) and the biggest mean-square error.

5.7.5 Mira radar results at the crossing

In addition to Vesivärava Street, the crossing of the Vesivärava and Faehlmanni streets was also scanned.

5.7.5.1 Data comparison 2D

Mira was able to identify the following utility networks: power, stormwater sewerage, gas, water, sewerage.

There was a conflict when comparing GPR data and sewerage. The as-built drawing "EG-31_17-VK VESIVÄRAVA.dwg" does not contain a sewerage manhole and the layout of the pipes is not true. The missing manhole is present in the as-built drawing of the Vesivärava Street pavement "mkmVGT09117_teeteostus.dgn" and in the transit survey of manholes carried out during the work "Kaevude kontrollmõõtmine130618.dwg".

5.7.5.2 Data comparison 3D

The as-built drawings provided height data only for gas piping and stormwater sewerage. As the Mira GPR did not detect any stormwater sewerage, the heights of the gas pipe and GPR were compared.

Comparison results are shown in the table below:

TJ	Mira	Mira-TJ
5.82	6.18	0.36
5.79	6.09	0.30
5.78	6.16	0.38
5.76	6.13	0.37
5.75	6.21	0.46
5.74	6.13	0.39
5.72	6.09	0.37
5.69	6.11	0.42
5.67	6.06	0.39
5.66	6.09	0.43
5.64	6.11	0.47
5.61	6.08	0.47
5.57	6.05	0.48
5.55	6.02	0.47
5.54	6	0.46
5.53	5.99	0.46
5.52	5.98	0.46
Average difference*		0.41
Average difference after the systematic error has been removed		0.03
Mean-square error		0.054

* - profiled heights compared with actual road 38 cm higher

5.7.6 WideRange radar results at the crossing

5.7.6.1 Exportable formats

From the WideRange device, the measurement results can be exported to a text file. The text file to be exported contains the following information:

Field value	Example	Notes
Profile	TAL 001 0043 2.rd7	Name of the scan line file of the device
Type	One	Freely filled in field
Trace	176	Path number
Sample	107	Reading number
Longitude	24.777782	East longitude (in WGS84 coordinate system)
Latitude	59.436452	North latitude (in WGS84 coordinate system)
Depth [m]	0.867	Depth of the detected object from the ground
GPS height [m]	23.798	GPS height from ellipsoid

In the case of a WideRange device, only a GNSS device can be used for positioning. The output data does not have the necessary parameters to assess accuracy:

- horizontal accuracy
- vertical accuracy
- mean-square error (RMS)
- PDOP
- number of satellites

It is not possible to detect and exclude inaccurate measurements during post-processing.

5.7.6.2 Processing the results

3D points were created based on the parameters Longitude, Latitude and Depth [m]. The coordinates were converted from the WGS84 coordinate system (EPSG:4626) to the LEST97 coordinate system (EPSG:3301).

5.7.6.3 Data comparison 2D

Detected utility networks power, water, gas. Object Mapper software failed to interpret stormwater sewerage and sewerage piping.

5.7.6.4 Data comparison 3D

The as-built drawings provided height data only for gas piping and stormwater sewerage. As the WideRange GPR did not detect any stormwater sewerage, the heights of the gas pipe and GPR were compared. Comparison results are shown in the table below:

TJ (gas)	WideRange	WideRange-TJ
5.70	5.90	0.20
5.68	5.86	0.18
5.68	5.93	0.25
5.66	5.83	0.17
5.65	5.87	0.22
5.63	5.80	0.17
5.62	5.80	0.18
5.60	5.86	0.26
5.59	5.67	0.08
5.58	5.88	0.30
5.56	5.78	0.22
5.54	5.93	0.39
5.53	5.91	0.38
Average difference*		0.23
Average difference after the systematic error has been removed		-0.15
Mean-square error		0.08

* - profiled heights compared with actual road 38 cm higher

5.7.7 OperaDuo radar results at the crossing

5.7.7.1 Exportable formats

IDs Opera Duo results can be exported similarly to IDS Stream radar to the following formats:

1. DXF format - Lines and dots created with IDS software “GRED_HD” can be exported to the DXF format. Line elements are exported to the DXF format as two-dimensional (2D) and an attribute “autocad_elevation” is added.

Such an export takes all the points of inflection of the line to the same depth according to the last point of inflection, which is incorrect. This application's DXF export must not be used for processing of 3D data.

2. SHP format. The geometries are exported as 3D lines/points with the attributes added during the data processing.

	Colour	Diameter	Name
1	00ff00	0.200 [m]	Other62
2	00ff00	0.200 [m]	Other62
3	ff0000	0.200 [m]	Electric7
4	0000ff	0.400 [m]	Water8

In the course of export, the depths of the marked lines and points from the ground or heights can be issued. In cases where the depths from the ground surface are to be exported, it must be considered that the ground surface is 0.00 m at each measuring point and the real tilts of the objects will not correspond to the reality in case of such exports.

The data exported in SHP format, the heights of which were given in the BK77 height system, were used for further comparison.

5.7.7.2 Data comparison 2D

Detected utility networks power, water, gas, communications, sewerage, stormwater sewerage. In addition, a large number of parts of abandoned utility networks were detected for which no information is available.

5.7.7.3 Data comparison 3D

The as-built drawings provided height data for gas piping and stormwater sewerage. Comparison results are shown in the tables below:

Gas		
TJ	Opera Duo	Opera-TJ
5.67	5.57	-0.10
5.60	5.48	-0.12
5.56	5.55	-0.01
5.52	5.74	0.22
5.56	5.35	-0.21
Average difference		-0.04
Mean-square error		0.16

Stormwater sewerage		
TJ	Opera Duo	Opera-TJ
4.83	4.87	0.04
4.78	4.81	0.03
4.73	4.74	0.01
Average difference		0.03

5.7.8 Error assessment

1. GPR measurement error 5-10% - during depth determination
2. Height measuring error ± 3 cm in the as-built drawing when measuring the ground surface
3. Pipe height measuring error ± 3 cm in the as-built drawing
4. Error in height calculation on a pipe ± 3 cm

	Depth value (m)	Error (5%)	Error (10%)
GPR measurement error	1.445	±0.072	±0.145
Ground surface height error		±0.03	±0.03
Total error in finding pipe height (on a pipe)		**±0.10**	**±0.18**
Pipe height range in case of a surface height 5.04		3.49-3.70	3.42-3.78
Height of the flow bottom of the pipe in the stormwater sewerage as-built drawing	3.42	±0.03	
Height of the pipe on a pipe in the stormwater sewerage as-built drawing (total error)	3.67	±0.06	
Pipe height range p.A		3.61-3.73	

5.7.9 Comparison material used

For data comparison the following materials were used:

Drawing	Measurement time	Work title	Work number	Data dimension
EG-31_17-1-SK VESIVÄRAVA.dwg	September 2017	Utility survey of stormwater pipings		2D
EG-31_17-VK VESIVÄRAVA.dwg	September 2017	Utility survey of water and sewerage pipings		2D
Vesivarava tn gaasitrass A kat.dwg	October 2017	A-cat. as-built drawing of a gas pipe		2D
Vesivarava_128a.dgn		Extract from TLPA master plan		2D
mkmVGT09117_teeteostus.dgn	2017	As-built drawing of Vesivärava street pavement	VGT091	3D
teos2119_side.dgn	1998	As-built drawing of telecom networks	VGT119	2D
Kaevude kontrollmõõtmine130618.dwg	2018	Transit survey of manhole covers		3D

All the materials used are in the Estonian national coordinate system LEST97 and the height data contained therein are in the BK77 height system.

5.7.9.1 Data from existing files

The following data were obtained based on the existing data:

Utility networks	Objects	Availability of height	Technical data	Depth range (on a pipe m)
Stormwater	Pipes Manholes	+ +	+ +	1.3-2.1
Gas	Pipes Manholes	+ Not available in the region	+ -	0.9-1.2
Sewerage	Pipes Manholes	Partial Partial	+ +	1.5-1.7
Water	Pipes Manholes	Partial -	+ -	1.6-1.7
Telecommunications	Pipes Manholes	Partial -	+ +	0.6-0.8
Electricity	Cables	-	-	

5.7.9.2 Preparation of the existing data for comparison

In order to assess the height data, the necessary objects had to be taken from the existing 2D drawings to 3D form. When creating 3D objects, it must be taken into account that according to the valid requirements of the Ministry of Economic Affairs and Communications, the height information for different types of piping is presented differently:

1. Piping without pressure - height of the flow bottom
2. Pressure piping - height on a pipe
3. Heat piping - height of a pipe axis

3D objects were created using the data of the manholes or profiles in the as-built drawings. When creating 3D objects, the pipe axis must be calculated to calculate the height of the piping so that a 3D pipe with the correct dimensions can be created later, considering the diameter. As the heights of the GPR objects are obtained on the object, the heights of the existing pipes were also calculated on the pipe for comparison.

5.7.9.3 Creating 3D ground surface model

The ground surface model is required to calculate the height of the object in the BK77 system based on the depths of the objects specified by the GPR equipment. The ground surface model can be created from the results of various GPR measurements. This method introduces a positioning height error. The heights of the ground models were compared with the as-built drawing no. VGT091 of ViaGeo Vesivärava Street pavements. The lowest point of the ground surface model is 3.78 m, highest point 6.76 m. The difference in the height of the ground surface points measured by the 3D radar from the height of the as-built drawing was +6 - +8 cm on average. The difference between the height of the ground surface points measured with Mira radar and the height of the as-built drawing was on average +38 cm due to the use of the wrong prism height for GPR measurements. In order to increase height accuracy, it is necessary to separately measure the heights of the survey area and to create a ground surface model that takes into account the breaklines. FME Desktop software was used to create the model and compare the data.

5.7.9.4 Software used to compare data

FME

FME is a licensed and paid data integration software platform that runs on Windows, Linux and macOS operating systems. The software is developed in Canada and is owned by Safe Software Inc. The software is in very active development and is ideal for processing special format spatial data, solving data management tasks, and process automation. FME platform consists of two products: FME Desktop - to create data processing processes and FME Server - to automate data processing processes. FME supports more than 400 formats. The formats can be divided into the following categories: 3D, Big Data, BIM, Business, CAD, Data Warehouse, Database, GIS & Mapping, Imagery & Raster, LiDAR & Point Clouds, NoSQL, Web. For a detailed description of the formats, see the producer's website https://www.safe.com/integrate/. FME contains over 400 procedures that can be divided into the following categories: 3D, Attributes, Calculated values, Cartography and reports, Coordinates, Data Quality, Filters and Joins, Format Specific, Geometries, Integrations, Point Clouds, Rasters, Spatial Analysis, Strings, Web, Workflows. For a detailed description of the procedures, see the producer's website https://www.safe.Com/transformers/#/

Microstation Powerdraft

Microstation PowerDraft is a licensed and paid for CAD software platform that runs on a Windows operating system. Microstation PowerDraft enables both 2D and 3D objects to be drawn and modified, measured and analysed. PowerDraft allows data presented in different formats to be used together. In this work, PowerDrive was used to obtain 3D objects from 2D drawings, to compare situations in different files and to measure distances between objects.

5.7.10 Creating 3D models

5.7.10.1 Software used

- PostgreSQL/ PostGIS
- FME Desktop 2018.1.0.3
- MicroStation PowerDraft V8i (Select Series 3)
- MicroStation PowerDraft Connect Edition
- MicroStation V8i
- Autocad Civil 3D
- QGIS 3.4.1/ Qgis2threejs

5.7.10.2 Model based on existing data

Based on as-built drawings, a 3D model was created for stormwater sewerage, gas lines, water and sewerage networks and street lighting. There were no as-built drawings for the telecom network and low voltage cables, and an extract from the TLPA master plan was used. All used drawings were 2 dimensional. The height data was obtained in accordance with the table below.

Network type	Source	Heights and diameters
Stormwater sewerage	EG-31_17-1-SK (2) VESIVÄRAVA.dwg	Heights BK77 and diameters in given manhole data
Gas piping	Vesivarava str. gas line A kat.dwg	Heights BK77 and diameters in given profile diagrams
Sewerage	EG-31_17-VK (1) VESIVÄRAVA.dwg	Heights BK77 and diameters in given manhole data
Water (1)	EG-31_17-VK (1) VESIVÄRAVA.dwg	Heights BK77 and diameters in given manhole data
Water (2)	Tallinna Vesi data from Tallinn	Heights EH2000
Street lighting	mkmVGT09117_VESIVÄRAVA TV (2).dgn	Missing
Telecom network	128a.dgn	Missing
Low voltage cable	128a.dgn	Missing

For the model to be obtained from the as-built drawing, objects from different as-built drawings were moved to the tables in the PostgreSQL/PostGIS database using procedures created in the FME software.

In the case of stormwater sewerage piping, it was necessary to determine whether the internal or external diameter was used in the drawing. According to the requirements of the Ministry of Economic Affairs and Communications, the internal diameter of the pipes and, in the case of gravity flow sewerage, the height of the flow bottom must be reflected in the technical specifications of the as-built drawings. Thus, the axis height was calculated to obtain the model using the following formula: haxis=hflow bottom +0.5xDinternal

As the drawing used had the pipe drawn up to the intersection with the symbol of the manhole, when the model was created, there was a gap between the end of the pipe and the wall of the manhole, as the symbol does not take into account the actual diameter of the manhole. The stormwater sewerage manholes were taken as point elements to the height of the cover in the EH2000 system. Diameter and depth data were added for visualization.

In the case of sewerage piping, this section refers to gravity flow sewerage, the treatment of which is similar to that of stormwater sewerage. When comparing the results of the measurement (Part III of the report), it appeared that there was a lack of one sewerage manhole in the earlier as-built drawing and that the pipe described in the model is incorrect accordingly.

In the case of a gas pipeline, the diameter and height information are given in the profile diagrams. The profile includes sections with different diameters, even if they are only 10-12 cm long. The heights are given on a pipe and at the points where the diameter of the pipes changes, the heights of the pipes with different diameters are the same, so the axes of the pipes are not in one straight line. So when you look from the side, the piping looks like this:

Picture 47: Gas piping profile

The heights of the pipe axes included in the model are calculated using the following formula: htelg=htoru_peale -0.5xD.

As the drawing shows the height of the route on a pipe, when the pipe is moved to the axes, there is an interruption of the axis coherence.

The gas networks objects in this drawing were gas covers for which information was provided in the profile from where the ground surface height and height on a pipe can be read. The linear objects of the gas pipe shown in the drawing were located outside the work area.

In the case of water piping, the height information in the as-built drawing used is given only for one slice. The location and height information of the other slice is obtained from shp files provided by Tallinna Vesi. The dataset of water objects in the source materials was incomplete and contradictory.

Street lighting. Poles and cables were included in the model. Poles and cables are at a height of 0 due to lack of height information and 6 m was added as post height for visualisation. The cables are presented as single cables. A diameter of 50 mm was added for visualisation. Since it was not possible to uniquely identify the location of the objects from the data of the protective pipes shown in the as-built drawing, these objects were not included in the model.

Communication objects. As the height information was missing, objects were left at zero height. A diameter of 50 mm was added for visualisation.

Low voltage cables. As the height information was missing, objects were left at zero height. A diameter of 50 mm was added for visualisation.

Observations on the existing data set

Network type	Observation
Stormwater sewerage (pipe)	Cannot be identified whether it is inner or outer diameter.
Stormwater sewerage (manhole)	If the manhole cover is located outside the centre, the location of the walls of the manhole are wrong. In the case of a chamber, there is no height for the bottom of the manhole which does not allow the depth of the manhole to be depicted.
Gas piping	The heights of the pipes with different diameters are given on pipes. The element axis should be specified to create 3D elements. Moving to the axis will result in an interruption of coherence.
Gas object	Only gas valve caps were presented as objects in this as-built drawing. Other information (about welds, transitions, etc.) is presented literally in profiles and is not presented as objects.
Sewerage	Height data was provided for a new network section only. The location and heights of the existing pipe were obtained from the Tallinna Vesi dataset.
Water (pipe)	Cannot be identified whether it is the inner or outer diameter. Height data was provided for a new network section only. The location and heights of the existing pipe were obtained from the Tallinna Vesi dataset.
Street lighting	The cable is presented as a single line as well as a protective tube. However, in the case of a protective tube, it can be seen from the text description that the number of pipes is bigger. 2xØ110 mm 750N l=9 m, There is no information about their location. There is no information about the height or depth of the cables.

5.7.10.3 Model based on the results of additional field surveys

Based on the results of additional surveys, a 3D model was created in the part where

- For a master model the information was not with the required level of detail
- A conflict between the existing utility networks and GPR was detected
- Unknown objects were detected by GPR measurement

The following was added to the model:

- Low and medium voltage cables
- Street lighting cables and poles
- Communication manholes and communication channel
- Non-conforming to as-built drawing
  - o Stormwater sewer pipe
  - o Sewage pipes and manhole
- Gas route pipe missing from the as-built drawing
- Unknown Objects Detected

5.7.10.4 Attribute data contained in the models

In order to store the data, PostgreSQL/PostG database tables were created that contain the following data according to the types of elements.

Data of pipe-type elements

Field	Explanation
gid	ID
cross section type	Circle/rectangle
width	In case of a round manhole diameter, in millimetres
height	Height measures in millimetres
diameter type	Di, De
type	Utility network type
material	Pipe material
brand	Cable pipe brand
number of pipe cables	Number of pipes/cables per route
status	In use, decommissioned
measuring time	Measurement date
height from the system	EH2000/BK77
height type	Flow bottom/axis/on
survey method	TJA, TJS (drill protocol), EM, GPR
accuracy class	1 - open trench, 2 - EM/GPR, 3 – approximate
source	Source reference
symbol	As-built drawing line name
geom	geometry (LineStringZ,3301)

Data of manhole-type elements

Field	Explanation
gid	ID
marking	Object marking
ground surface height	Ground surface height
cover material	Cover material
cover height	Cover height
bottom height	Bottom height of the manhole
type	Utility network type
obj type	Object type
obj height	Object height
diameter	Internal diameter (mm)
material	Manhole, object material
post found type	Post foundation type
post type	Number of pipes/cables per route
post height	Post height
foundation depth	Post foundation depth
status	In use, decommissioned
measuring time	Measurement date
height from the system	EH2000/BK77
survey method	TJA, TJS (drill protocol), EM, GPR
accuracy class	1 - open trench, 2 - EM/GPR, 3 - approximate
source	Reference to the source
symbol	As-built drawing line name
geom	geometry (PointZ,3301)

Data of facility-type elements

Field	Explanation
gid	ID
marking	Facility symbol
ground surface height	Ground surface height in metres
ceiling height	Ceiling height in metres
bottom height	Bottom height in metres
width	Facility width in millimetres
length	Facility length in millimetres
wall thickness	Wall thickness in millimetres
type	Utility network type
material	Pipe material
brand	Cable pipe brand
number of pipe cables	Number of pipes/cables per route
status	In use, decommissioned
measuring time	Measurement date
height from the system	EH2000/BK77
survey method	TJA, TJS (drill protocol), EM, GPR
accuracy class	1 - open trench, 2 - EM/GPR, 3 - approximate
source	Reference to the source
symbol	As-built drawing line name
geom	geometry (PolygonZ,3301)

5.7.10.5 Joining objects in the models and objects contained in the models

As a result of the comparison of data, it was decided to include the following data in the final model:

Data from the as-built drawings corresponding to the results of the surveys:

- Manholes and pipes of stormwater sewerage besides one pipe, the course of which did not correspond to the reality
- Gas piping
- Sewer piping partially
- New element of the water piping

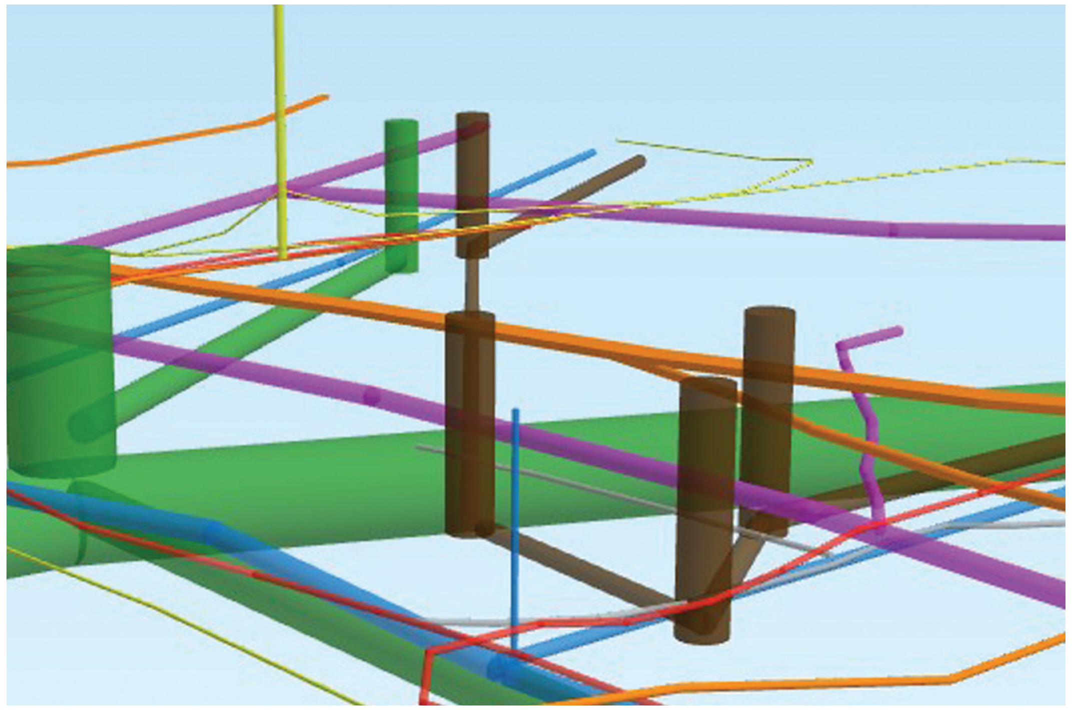
Data obtained from Tallinna Vesi:

- Water piping

Data added or specified as a result of the surveys:

- Low and medium voltage cables
- Street lighting cables and poles
- Communication manholes and communication channel
- Stormwater sewer pipe not conforming to the as-built drawing
- Sewerage pipes and manhole not included in the as-built drawing
- Gas pipe missing from the as-built drawing
- Unknown Objects Detected

For data fusion the master model tables were created in the database where all added or adjusted data resulting from the surveys and all data from the as-built drawings that corresponded to the results of the surveys were copied. Free QGIS 3.4.1 software was used to correct the data.



Picture 48: 3D master model of utility networks at the crossing of Vesivärava and F. R. Faehlmanni streets

6. PROJECT OF REQUIREMENTS FOR THE SURVEY OF UNDERGROUND UTILITY NETWORKS AND RESULTS

6.1 Survey types

There are a number of methods for identifying and mapping underground utility networks. Different methods make it possible to obtain data of different quality and reliability. Often, the needs vary regarding the accuracy of the data. For example when drawing up a specific comprehensive area plan, the quality of data on utility networks is not as important as when drawing up a specific construction project or carrying out excavation work. The cost of the underground utility networks survey and the time it takes to complete it depends on how accurate and reliable data are to be obtained.

In order to provide clarity to both the client and the surveyor on the results and the work to be carried out, it is recommended to divide the identification and mapping of underground networks into four types of surveys:

- Survey type 1 - Study of the existing data
- Survey type 2 - Field observation and measuring ground objects
- Survey type 3 - Data acquisition with geophysical devices
- Survey type 4 - Measuring underground objects

Survey types are set hierarchically: each following type of survey provides better data quality and reliability, but also requires more resources. Survey type 1 - study of the existing data - is mandatory in all surveys and must be carried out before Type 2, Type 3 and Type 4 surveys. All other types of surveys are independent and do not require a previous level survey to be performed. For example, for the Type 3 survey it’s not necessary to perform a Type 2 survey. The order in which the surveys are performed is not specified and may be selected by the surveyor. For example, both the measurement of ground objects in Type 2 and the inspection of the manholes or the surveys with the open trench in Type 4 may be carried out simultaneously.

6.1.1 Type 1 - Study of the existing data

The study of the existing data is mandatory for the identification and mapping of all underground utility networks. This survey may be an independent survey and may also be a preliminary survey for the surveys of the next levels. The purpose of the survey is to obtain an overview of the situation in the survey area, the accuracy and reliability of the available data and to plan the surveys of the next level accordingly. By the study of the existing data a quality class can be achieved for the underground utility network data according to the quality, reliability and quality class of the available data. If the utility network data are not provided with a quality class and/or the data is unreliable, only quality class D can be achieved.

6.1.1.1 Survey methods

The study of the existing data must be based on the use and an analysis of all existing data available to the surveyor and from where information on the survey site and on the utility networks located on the site can be obtained.

The study of the existing data does not create new measurement data or attribute data, and the validity of existing data is not checked.

In order to obtain an overall picture of the survey area and to determine the expected location of the utility network routes, a master plan of the underground utility networks available from the Tallinn geo-measurement information system must be used.

If possible, the as-built drawings from the geo-measurement information system must be used. Information available from the as-built drawings is generally of better quality and the level of detail of the description of the properties of the objects is the most accurate since the work has been carried out immediately after construction.

Data from the Tallinn geo-measurement information system must be compiled into a preliminary diagram, from where potential utility networks and their owners in the survey area can be identified.

Additional information on these networks in the survey area will be collected from owners of utility networks. The data obtained can be in different formats, accuracy classes and levels of completeness.

From all available data collected, the general diagram and the survey report will be prepared in suitable formats in accordance with the purpose of the survey.

6.1.2 Type 2 - Field observation and measuring ground objects

The purpose of the field observation and the measurement of ground objects is to verify the accuracy of the existing data through the ground parts of the utility network and to collect accurate location information on the ground objects.

The results of the survey can also be used to plan surveys of the next levels.

With the survey of field observation and measurement of ground objects a quality class C can be achieved for the utility network data if field observation confirms the available data or D if field observation shows the inaccuracy and/or unreliability of the existing data.

If the utility network data in the survey area belongs to class A or B and the field survey does not question it, the existing quality class will remain.

6.1.2.1 Survey methods

Within this survey the reliability of the existing data is examined by visual observation in the survey area and accurate additional data by measuring the ground parts of utility networks are created.

During field work in the survey area, visual identification and photographing of the ground network elements of underground utility networks (power and telecom boxes, power and street lighting post, manhole cover, fire hydrants, water and gas taps, etc.) is carried out.

Other findings referring to underground utility networks (trenching signs of routes, house connections, etc.) are also identified and photographed.

All ground network elements of underground utility networks are measured with the positioning device in such a way that the maximum permissible error in their plane position is 8 cm in relation to the nearest points of the measuring grid and the maximum permissible height error in relation to the nearest points of the measuring grid is 3 cm.

As a result of the survey, the location and height information of the network elements measured will be specified in the existing data and in the general diagram. The survey report will assess the reliability of the existing data.

6.1.3 Type 3 - Data acquisition with geophysical devices

Geophysical devices: a GPR and electromagnetic locator (EML) must be used to obtain location and height information on underground utility networks without opening the surface. Other technical equipment may also be used, but these are not covered in this report.

GPR and EML surveys are preceded by a study of the existing data showing potential utility networks and their indicative locations in the survey area.

The aim of the GPR and EML survey is to obtain accurate location and height information on underground utility networks. It is not possible to obtain or specify the attribute data of utility networks in this survey.

By using only one geophysical method, it is generally not possible to detect all underground objects. In the case of some soil types or some utility networks, one geophysical device (either GPR or EML) cannot detect an object. In order to detect and map most objects, both a GPR and EML should be used in the survey.

In addition to the utility networks, the GPR survey also provides location information for other underground objects in the survey area. All detected and mapped but unknown objects must be reported as unknown objects detected in the survey report.

- In GPR and EML surveys, the following quality classes of the utility network data can be achieved
- D - the utility network is on a master plan but no utility network was detected with any geophysical device
- B1 - the utility network was detected and mapped with one geophysical device
- B2 - the utility network was detected and mapped with two geophysical devices

Different methods and geophysical devices may be used in one survey area according to the situation and the required quality class of the utility network data.

6.1.3.1 Survey methods with GPR

A GPR is a high-tech device that requires special skills to work with. Consequently, the GPR survey may only be carried out by a specialist who has received special training.

The survey area, situation, soil types and objects surveyed are different. In order to perform an effective GPR survey and obtain a high quality result, the appropriate device and appropriate frequency antenna(s) must always be chosen.

GPRs are different, and there are also different setup needs and options for conducting the survey. Consequently, the GPR survey must be carried out in accordance with the instructions, limitations and requirements of the device producer.

When using an external positioning device, it must be observed that it produces data in a suitable format for the GPR, with the necessary accuracy and frequency. The result of the survey depends on the accuracy and quality of positioning.

A GPR is a device that is influenced by the geophysical properties of the ground and these properties may change over time in the survey area depending on the weather. It is recommended to carry out a GPR survey in weather conditions that allow for the highest quality results. It is not permitted to carry out a GPR survey in the same survey area in different weather conditions (for example, half of the survey area is inspected in dry weather and the other half with wet ground immediately after rain).

When conducting a GPR survey with a single-channel GPR, the appropriate method of data acquisition should be chosen according to the size of the survey area, the purpose of the survey and the density of utility networks:

- collection of data perpendicular to the utility network
- collection of data by the survey grid

Data collection perpendicular to the utility network may only be used for tracing a single utility network or in a survey area with only one-way utility networks.

The collection of data perpendicular to the utility network for mapping purposes must be carried out in such a way as to ensure the accuracy of the location and height data of the utility network according to the required quality class. The straight slice may not have a gap of over 100 cm between the scan lines and over 50 cm at points of inflection.

When collecting data with the survey grid, the gap between the scan lines may not be over 50 cm.

In accordance with the purpose and strategy of the survey, it is necessary to choose whether on-site real-time target detection with marking out or data acquisition with recording and post-processing is carried out. Post-processing data generally results in better data quality.

In the survey area, where there are a number of utility networks with different directions, post-processing is mandatory.

When conducting a GPR survey with a GPR with an antenna array, the distance between the antenna channels may be no more than 10 cm and the data collection density must be equal to or less than the distance between the antenna channels.

When collecting data with a GPR with an antenna array, the entire survey area must be scanned in such a way that the gap between the survey lines is not greater than the distance between the antenna channels.

In the survey areas not accessible to a large towable GPR with an antenna array, the data collection must be performed either by a manual cart-type GPR with an antenna array or by a single channel GPR using the survey grid method.

The results of the survey must be presented in a format that enables their further processing with CAD/GIS software.

6.1.3.2 Survey methods with EML

An electromagnetic locator (EML) is a geophysical device that requires special skills to work with. Consequently, the EML survey may only be carried out by a specialist who has received special training.

The survey area, situation, soil types and objects surveyed are different. In order to perform an effective EML survey and obtain a high quality result, the appropriate device, frequency and method must always be chosen.

Whenever an active EML method can be used, it must be used. Active methods in order of priority: direct connection, detection wire, clamp, probe and induction through the ground. The collection of the utility network data for mapping purposes with an active method must be carried out in such a way as to ensure the accuracy of the location and height data of the utility network according to the required quality class.

When tracing a utility network on a straight slice, the route must be marked out in such a way that the distance between the measuring points does not exceed 200 cm and that the location and/or height deviation of the route does not exceed the permitted limit.

At the point of inflection, the distance between the coordinate points is selected considering that the difference between the straight line and the actual position of the utility network resulting from the connection of the coordinate points does not exceed the maximum permissible plane position error of 8 cm in relation to the nearest points of the measuring grid.

A passive method is used to track the underground utility network only if it is not possible to use an active method.

In the survey on geophysical equipment of underground utility networks in which GPR is not used, in addition to mapping utility networks using an active method, a passive method should be used to locate undetected utility networks in the entire survey area in such a way that the distance between the survey lines is not over 100 cm.

If an EML survey is carried out using a passive method only and without a GPR survey, the maximum quality class of the underground utility network data is C.

All underground utility network coordinates detected by the EML must be accurately marked out on the ground for recording with a positioning device.

The type of utility network and the location and depth of the coordinate point from the ground must be indicated on the ground. A different colour or code must be used for each utility network in the survey area, where there are several utility networks.

The markings must be made on the ground with an aerosol paint marker that is biodegradable.

In places where aerosol paint cannot be used, thin wood rods may be used. The use of metal pickets is not permitted as they may damage utility networks close to the ground surface.

There should remain minimum time, but not over 48 hours between marking the utility route and recording it with the positioning device.

The results of the survey must be presented in a format that enables their further processing with CAD/GIS software.

6.1.4 Type 4 - Measurement of underground objects

The purpose of the measurement survey of underground objects is to obtain accurate location and height data as well as attribute data for the utility network. Also, accurately measured height data can be obtained to calibrate geophysical devices.

Physical and visual access to the underground utility network as a whole or to its coordinate points is necessary for the measurement of the underground utility network.

The measurement of underground objects includes the following types of measurement:

- utility surveys with an open trench
- utility surveys of a utility network installed with closed method
- survey of manholes
- surfing

With a utility survey of underground objects the quality class A of the utility network data can be achieved.

6.1.4.1 Utility surveys with an open trench

The location of the underground utility network is measured and its attribute data is described before the trench is closed.

A utility survey with an open trench is carried out in accordance with the provisions of Chapter 7 of the Regulation of the Ministry of Economic Affairs and Communications, entitled “Additional requirements for the utility survey of the utility network arising from the type of construction”, and with the accuracy requirements of the quality class A.

If the quality class A requirements for the accuracy of the data conflict with the Regulation of the Ministry of Economic Affairs and Communications, the requirements that provide more accurate and reliable data must be taken into account.

6.1.4.2 Utility surveys of the utility network installed using a closed method

During a utility survey of the utility network installed using a closed method, an appropriate protocol, such as a drill log, enabling the location and height of the utility network to be mapped, must be used.

The location and height of the utility network installed using a closed method must be detected by at least one geophysical device.

All measuring points must be marked out accurately on the ground to be recorded with the positioning device.

In order to confirm the location of the utility network installed using a closed method, its actual location and height must be verified, if possible, from an open trench or manhole by means of control measurements or, if necessary, surfing must be performed.

In case it is not possible to confirm the location and height data of the closed method from the trench, manhole or by surfing, the quality class of the given utility network data is B1 or B2.

6.1.4.3 Survey of a manhole

A survey of a manhole may cause unintended consequences or it can be fatal. Consequently, a manhole survey may only be carried out by a specialist who has received special training. In order to carry out a survey of a manhole, a permit from the owner of the utility network is required. If the manhole cover is damaged or cannot be opened, the owner of the utility network must be notified.

The survey of a manhole must be carried out on all utility networks within the survey area for which the A quality class is required.

If the manhole of the utility network remains outside the survey area, the manhole must also be inspected outside the survey area if necessary.

The survey of a manhole includes the following work:

- measuring the inner dimensions of the manhole
- description of pipes and cables installed in the ground entering and exiting the manhole (material, quantity, placement, etc.)
- measuring the internal dimensions of the pipes
- measuring the external dimensions of packages
- measuring the depth of the pipes and cables from the ground
- photos of the interior of the manhole and buried cables and pipes contained therein
- creation of a manhole scheme

6.1.4.4 Surfing

Surfing may be used to detect and map one particular or several underground utility networks in a small area.

The purpose of surfing is to get visual and physical access to the underground utility network.

The prerequisite for surfing is the prior detection of the location of the underground utility network with at least one geophysical device.

Surfing must be done manually by digging with a shovel or by a vacuum method using compressed air and/or water. When surfing at a site covered with a hard cover (asphalt, stone parquet, etc.) which does not allow shovelling or vacuum excavation, the hard cover must be removed to the necessary extent.

In the course of surfing, an underground utility network must be exposed to the extent that allows its location, height, type, material and external dimensions to be mapped.

The underground utility network exposed as a result of surfing is measured with the positioning device in such a way that the maximum permissible error in its plane position is 8 cm in relation to the nearest points of the measuring grid and the maximum permissible height error in relation to the nearest points of the measuring grid is 3 cm.

After measuring the underground utility network and collecting the attribute data, the surfing area must be restored in accordance with the requirements.

SURVEY TYPE	SURVEY NAME	SURVEY METHOD	USE OF THE SURVEY
Type 1	Study of the existing data	Available data from the urban geo-measurement information system, as-built drawings and network owners	Obtaining general information about the region, drawing up general planning, planning of further surveys
Type 2	Field observation and measurement of ground objects	The study of the existing data and identification of, photographing and measuring the ground parts of the network	Drawing up general planning, planning of further studies, designing ground buildings
Type 3	Data acquisition with geophysical devices	Study of the existing data; data acquisition with an EML active or passive method; data acquisition with GPR different methods and post-processing	Planning and designing ground and underground buildings using a "standard method"
Type 4	Measurement of underground objects	Study of the existing data; survey of a manhole; surfing; measurements with an open trench; utility surveys of a utility network installed using a closed method	Preparing as-built documentation, a 3D source model, a 3D design model, a 3D as-built model

Table 16. Survey types of underground utility networks

6.2 Quality classes of location and height data of underground utility networks

This design proposes the creation of quality classes for location and height data of underground utility networks.

A quality class indicates the accuracy and reliability of the location and height data of the underground utility network.

A quality class is assigned separately to each underground utility network element in the survey area.

One network may have different quality classes according to the extent and by which methods it has been surveyed and mapped.

The client may order data of different quality classes in one survey. Quality classes may be ordered for all utility networks in a specific area or one specific technical network within the survey area. What quality class can be attributed to the utility network will become clear by the end of the survey.

The higher the requirements for a quality class, the more expensive and time-consuming the survey will be.

A quality class is assigned separately to each underground technical network element during the survey.

The quality class is determined based on the following:

- quality class of the existing data (obtained before the survey)
- the type of the survey carried out
- detection and mapping method
- positioning method

The quality classes are based on the classification used in several countries (PAS 128[23], CSA S250[24], ASCE 38-02[25]): Class D, C, B and A.

This is important both in the conduct of major procurements and in the harmonisation of regulations and activities internationally. This is also important for cross-border projects (Rail Baltica, TAL-HEL tunnel, etc.).

The quality class of B1 or B2 is generally sufficient for planning and design.

Quality class A indicates not only the accuracy of the location and height data of the utility network, but also the accuracy and reliability of the attribute data.

Quality class A data is generally required for preparing as-built documentation and the creation of a 3D model (source model, design model, as-built model).

6.2.1 Quality class D

Only a study of the existing data obtained from the Tallinn geo-measuring information system and network owners has been carried out.

The quality and reliability of the data is fully based on the existing data.

According to the requirements of the Ministry of Economic Affairs and Communications, the maximum permissible error in the plane position of the underground utility network is 1 metre relative to the nearest points of the measuring grid. If one-meter accuracy is not guaranteed due to incomplete source data, the network facility is marked with the text "ORIENT".

[23] Specification for underground utility detection, verification and location, BSI 2014
[24] Mapping of Underground Utility Infrastructure, CSA Group, 2012
[25] Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data, ASCE 2003

Quality class D generally does not include the accuracy of the height position of the underground parts of the utility network.

The reliability of the available data on the location and height of the utility network is low.

The properties of the utility network (diameter, material, etc.) are taken from a survey of the existing data and have not been verified or specified.

6.2.2 Quality class C

A study of the existing data has been carried out. The data has been obtained from the Tallinn geo-measuring information system and network owners.

In addition, a field survey and a survey of the ground parts of the utility network have been carried out, confirming or clarifying the existing data.

The ground parts have been measured in accordance with the requirements of the Ministry of Economic Affairs and Communications and the maximum permissible error in their plane position is 8 cm relative to the nearest points in the measuring grid and the maximum permissible error is 3 cm relative to the nearest points in the measuring grid.

The indicative location and height information of the underground parts is taken from the survey of the available data and has not been specified in the survey.

The properties of the utility network (diameter, material, etc.) are taken from a survey of the existing data and have not been verified or specified.

6.2.3 Quality class B1

A study of the existing data and field observation and the measurement of ground objects have been carried out. In addition, the underground parts of the utility network have been identified and mapped by a GPR survey or EML active method survey, and the data resulting from this survey have been used to specify the existing data.

The maximum permissible error in the plane position of the underground utility network with specified data is 10 cm in relation to the nearest points of the measuring network.

The maximum permissible height error in relation to the nearest points of the measuring grid is 20% of the depth of the utility network from the ground.

The properties of the utility network (diameter, material, etc.) are taken from a survey of the existing data and have not been verified or specified.

6.2.4 Quality class B2

A study of the existing data and field observation and the measurement of ground objects have been carried out.

In addition, the underground parts of the utility network have been identified and mapped by GPR or EML active method surveys, and the data resulting from them have been used to specify the existing data.

The maximum permissible error in the plane position of the underground utility network is 8 cm in relation to the nearest points of the measuring network.

The maximum permissible height error in relation to the nearest points of the measuring grid is 10% of the depth of the utility network from the ground.

The properties of the utility network (diameter, material, etc.) are taken from a survey of the existing data and have not been verified or specified.

6.2.5 Quality class A

In the case of a utility survey, the actual location and height of the utility network has been measured with an open trench in accordance with the requirements of the Ministry of Economic Affairs and Communications.

In the case of a topo-geodetic survey, an inspection of the existing data and field observation and the measurement of ground objects have been carried out.

In addition, the utility network has been identified and mapped by a GPR and EML survey.

To verify data, physical access to the utility network has been obtained in several coordinate points (manhole, surfing) and the measurement was carried out.

Surveys of the manholes have been carried out.

The maximum permissible error in the plane position is 8 cm in relation to the nearest points in the measuring grid and the maximum permissible error in relation to the nearest points in the measuring grid is 3 cm + 1% of the depth of the utility network from the ground.

All properties of the utility network (diameter, material, etc.) have been checked and, where appropriate, specified.

QUALITY CLASS	QUALITY AND RELIABILITY OF DATA					EXECUTED SURVEYS
	Parts on the ground		parts installed in the ground		Attribute data	
	Location	Height	Location	Height		
D	not known	not known	not known	not known	not known	Survey of the existing data
C	the maximum permissible error is 8 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 3 centimetres relative to the nearest points in the measuring grid	not known	not known	not known	An inspection of the existing data and field observation and measuring the parts on the Ground
B1	the maximum permissible error is 8 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 3 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 10 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 20% of the depth of the utility network from the ground	not known, except in the as-built drawings	An inspection of the existing data, field observation and measuring the parts on the ground and GPR or EML survey
B2	the maximum permissible error is 8 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 3 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 8 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 10% of the depth of the utility network from the ground	not known, except in the as-built drawings	Study of the existing data, field observation and measuring the parts on the ground and GPR or EML survey
A	the maximum permissible error is 8 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 3 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 8 centimetres relative to the nearest points in the measuring grid	the maximum permissible error is 3 centimetres + 1% of the depth of the utility network from the ground	Verified and specified	Study of the existing data, field observation and measurement of ground parts, GPR and EML survey and verification of data

Table 17. Quality classes of location and height data of underground utility networks

6.3 Additions to the formalisation of the survey of underground utility networks

At the moment, the entire operational process is built on the visual depiction of 2D and contains generalisations corresponding to the needs and approaches of the utility network owners and, at times, a certain degree of schematics. Consequently, it is necessary to make changes to the requirements. The scope and nature of the changes are different when switching to 2.5D or 3D drawings.

The switch to 2.5D leaves the possibility of submitting the same file to the client, the Register of Buildings and the municipality. In this case, there is no need to make changes to the use of texts, line measures or dimensions.

Nor is it necessary to make significant changes to the coherence approach. As the objective is to store elements in the drawing as 3D elements in the database, it is necessary to provide requirements for handling the height data of the elements.

During the transition to 3D, the object heights are contained in their geometry. Problems can be caused by taking into account specific requirements of the clients (network owners) as they have been developed in accordance with the limitations of 2D files. The transition will lead to the need to change the requirements for dealing with texts, line styles and coherence.

In both cases, the need to use the attribute data is added, but the data composition is different.

It is necessary to create requirements for data delivered from the 3D base as initial data according to the type of the survey.

Elements with attribute data are entered in the 3D data base.

6.3.1 Additions to the formulation of topo-geodetic surveys of underground utility networks

When submitting a 2.5D file

- There is no need to re-check reliable data;
- undetected underground objects which can be plane or linear objects are inserted in "ERINOUE_TTO" layer using the line style "CONTOUR".
- the explanatory note must include a list of identified unknown objects together with explanatory notes;
- if necessary, attribute data must be added to the utility network objects;
- the utility network objects must be provided with a quality class and the type of the survey;
- in the surveys a coordinate point is used as the height information carrier at the point of inflection of the utility network; the start and end height of the network is entered in the form of the object together with its properties.
- Using coordinate points
  - o Coordinate points are obtained by measuring;
  - o Coordinate points are obtained from the existing as-built drawings;
- Where the utility network is described by coordinate points belonging to different quality classes, the utility network element is provided with the lowest quality class of the coordinate point;
- For surveys of type 3 and 4, the client must provide the depth of the survey. Where the depth of the survey is not specified in the initial task, the survey will be carried out up to a depth of 3 m;
- On the specific request of the client the survey may be presented as a 3D file.

When submitting a 3D file

- the distribution of the layers specified in the requirements of the Ministry of Economic Affairs and Communications must be used;
- the line styles specified in the requirements of the Ministry of Economic Affairs and Communications must be used for both surfaces and lines;
- the symbols specified in the requirements of the Ministry of Economic Affairs and Communications must be used:
- uniform colours for the visualisation of utility networks must be used;
  - o possible colour codes for a 3D file

Utility network	**Colour**
Water	#1780d5
Stormwater sewerage	#007f3f
Drainage	#00cc00
Sewerage	#4c1300
Electricity, low voltage, medium voltage and street lighting	#00ffff
Communications	#cd2bdf
Gas	#ff7f00
District heating	#cc0033

- The coherence requirements described in the applicable requirements of the Ministry of Economic Affairs and Utilities are not used in the 3D drawing;
- The texts used in the 3D drawing are represented at zero height;
- In the case of 3D drawings, the coordinate points are provided with a description only at the connection points of the utility network, i.e. fittings, diameter transitions, joints, welds, blind flanges, etc.

6.3.2 Additions to the formalisation of the utility survey of underground utility networks

An as-built drawing must be presented as a 2.5D file, which allows the transfer of the objects that have been subject to a utility survey to the 3D database as objects with 3D geometry.

- The underground parts (foundations) of poles, supports and other network elements must be described in such a way that they can be depicted as 3D elements.
- During a utility survey of district heating piping the pipes must be measured. The axis of the route is depicted in the drawing on the specific request of the client.
- The data set of district heating pipes is added to the pipe.
- The thermal troughs of district heating are depicted by means of an axis. The dimensions of the through are added as attributes to the axis. The axis is measured on top of the trough.
- The height of the pressure pipes of all networks is measured on the pipe (including district heating pipes).
- Regarding gravity flow pipes, the height of flow bottom of the pipe is measured.
- Schematic representation of utility networks is only allowed on the specific demand of the client on ERINOUE _ * layer.
- Schematic representation of utility network objects on other layers is not allowed.
- The details of round manholes are added to the manhole sign. If the diameter of the manhole is less than 1.5 m, the riser pipes are not described separately.
- In the case of rectangular or special-shaped manholes, the manhole body is dimensionally depicted as a contour of the facility, accompanied by the data of the facility-type object.
- In the case of underground chambers with riser pipes, the data of the chamber are added to the facility contour and the data of the riser pipes are added to the manhole (cover) sign. In the case of such objects, the manhole number is added to the chamber as wellas to the manhole (cover) signs.

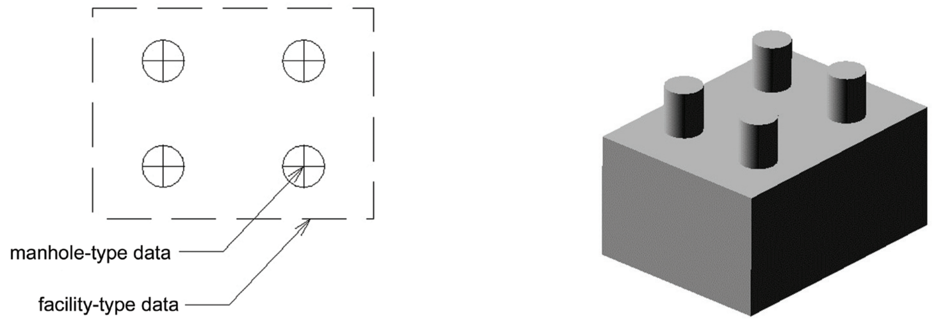


Figure 21: Depiction of chambers

- A single cable is handled as a pipe object.
- If the cables are more than 20 cm apart, they must be drawn separately.
- If the cables are located closer than 20 cm, they are represented by an axis of the route. The axis of the route must be interrupted at the branching points and the dimensions and cross section of the package must be added to each route section.
- The axis of the route is used to depict the following:
    - o heat piping trough
    - o route of electric cables (trench axis)
    - o route of power cable trenches (trench axis)
    - o route of communication cables (trench axis)
    - o route of communication trenches (trench axis)
- The axis of the route is measured on top of the package and attribute data containing the dimensions and cross-section of the package are added. The contents of the package elements is reflected in such a way that, if necessary, the contents of the package can be depicted in three dimensions.

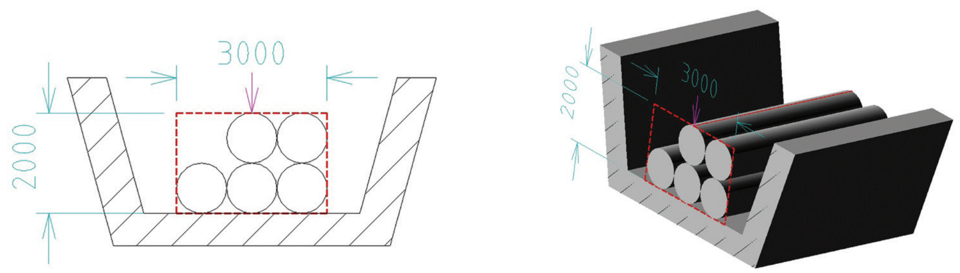


Figure 22: Depiction of 2 x 3 package

- The protective and the reserve pipes are depicted in the same way as cables as pipe-type or package-type objects. In the case of reserve pipes in several layers, the axis of the route is measured and the dimensions and cross-section of the package is determined.
- Schemes of assemblies and photographs of assemblies must also be presented as separate files in the *. jpg file format. The files are named according to the coordinate point number in the as-built drawing. For example: Additional files belonging to coordinate point no. 102 are referred to as "102_foto.jpg" and "102_skeem.jpg".
- The schemes and photographs provided for the assemblies must be oriented north. The resolution of the attached photos must be 1920 x 1080 (FHD) or bigger and the file size may be up to 500 KB.
- Coordinate points.
    - o In the case of an as-built drawing, the coordination points must be included in all the characteristic points of the utility networks.
    - o The coordinate points are used to communicate the height of the access point of the utility network at this point. The coordinate points are used to communicate the height and dimensions of the type of utility network object at this point.
    - o In a coordinate point the parts/assemblies of a utility network are described:
    - o Data transmission device
        - Branch
        - Hydraulic lock
        - Sleeve
        - Connection point without a manhole
        - Cathode protection converter
        - Welded joint
        - Point of inflection
        - Expansion bellows
        - Diameter transition element
        - Ground valve
        - Collar
        - End plug
        - Knee
        - Saddle branch
        - Shut-off device
        - Service assembly
        - W-condensate collector
        - Exit area
        - Single earthing (electrode)
- Intersecting objects are measured similarly to the new objects
- Attribute data and coordinate points with height are added to intersecting objects.
- All utility networks are provided with a quality class and survey type.

6.3.3 Element types used in the drawings

The following element types are allowed to be used in drawings:

No.	Element	AutoCAD	MicroStation
1	Straight slice	Line	Line (Type 3)
2	Breakline	Polyline, Lwpolyline	Linestring (Type 4)/Complex Chain (Type 12)
3	Symbol element	Insert	Cell Header (Type 2)
4	Text	Text	Text(Type 17)
5	Ellipse	Ellipse, Circle	Ellipse (Type 15)
6	Plane[26]	Lwpolyline (closed)	Shape (6), complex shape (14)
7	Arc	Arc	Arc (Type 16)

Table 18. Permitted element types

[26] Plane element is a closed breakline.

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