Thesis proposal for MSc Geomatics

Spatial and semantic enrichment of utility networks data

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CHAPTER 1 INTRODUCTION

The complexity and size of utility networks have significantly increased in recent years due to the fast urbanization and growth of cities along with the development of new technologies. Urban environments rely on these networks, which include those for water supply, power, gas, and telecommunications to support inhabitants', businesses', and institutions' daily operations. It is essential for urban planning, infrastructure development, emergency response, and general sustainable city management that these utility networks are accurately represented and managed.

Traditional utility network maps are frequently displayed in two dimensions (2D), giving the network layout in a more streamlined manner. However, this constrained depiction is unable to adequately convey the complex spatial linkages and vertical information inherent in an urban setting. As a result, the planning, maintenance, and decision-making processes related to utility networks are often challenging and prone to errors, which may lead to damages during excavation work, or other issue due to a lack of accurate data.

The field of Geomatics offers an effective solution to this problem: upgrading the current 2D representations into three dimensions and providing a convenient representation of spatial and non-spatial data in a coherent way. It is possible to construct a thorough and accurate model of utility networks by expanding their representation into the third dimension, which would facilitate better analysis, visualization, and decision-making procedures.

The main problem this thesis aims to address is the lack of comprehensive 3D models for utility networks in urban environments along with with the incoherent representation of data in different formats. All cities work with a different approach and many issues arise due to a lack of a coherent modeling approach in processes, such as geo-referencing. While utility network maps exist in 2D formats, the absence of accurate and up-to-date 3D representations hampers effective planning, management, and maintenance of these networks.

The traditional 2D maps often lack critical information, such as the vertical alignment of utility components, spatial interconnections, and the accurate depiction of underground or overhead infrastructure. This lack of information leads to challenges in visualizing the network's true spatial configuration, understanding its interactions with the surrounding environment, and conducting reliable analysis for efficient urban planning.

By collecting 2D utility network maps and upgrading them to 3D models, this thesis seeks to bridge the gap between the existing 2D representations and the true complexity of utility networks. The project aims to develop a systematic approach for transforming 2D maps into accurate and comprehensive 3D models, which will entail dealing with the semantic and non-semantic issues that come from working with data sets with little to no interoperability.

By accomplishing this, the thesis will provide a process for integrating data in a way that it can be conveniently visualised in three dimensions. The 3D models generated through this research will hopefully help to enhance understanding of the spatial dynamics of utility networks, facilitating improved planning, efficient resource allocation, and more effective emergency response strategies.

In conclusion, this thesis focuses on the relevance of 3D modeling of utility networks in urban environments. By addressing the lack of comprehensive and accurate 3D representations, this research aims to overcome the limitations of traditional 2D depictions of utility networks and provide a valuable resource for enhancing urban planning and management processes.

CHAPTER 2 RELATED WORK

The related work section of this thesis explores relevant studies and developments related to the research topic. This section provides an overview of the existing literature and technological advancements in the field of Geomatics, focusing on the acquisition, integration, and management of underground utility data.

The studies discussed in this section cover various aspects, including advanced technologies for 3D data acquisition, the integration of heterogeneous data sources, and the development of data models for utility network representation. the revision of these works will help gain insights into current techniques and approaches used in the field.

2.1 Kabel- en Leiding Informatie Portaal

The Kabel- en Leiding Informatie Portaal (KLIC), is a system that plays a significant role in the acquisition and management of underground utility data. KLIC is a centralized platform implemented in the Netherlands to facilitate the exchange of information between utility network operators, contractors, and other stakeholders involved in excavation and construction projects. (Hansen *et al.*, 2021) This section explores the relevance and impact of KLIC in the context of underground utility data acquisition and management.

KLIC serves as a crucial source of information for obtaining utility network data before conducting any excavation activities. By submitting a request through the KLIC system, contractors can access detailed information about the location and characteristics of underground utilities in the proposed work area. (Döner *et al.*, 2010) The data provided by KLIC includes the presence of cables, pipes, and other utility assets, along with associated documentation, such as maps, drawings, and technical specifications.

The utilization of KLIC offers several benefits. Firstly, it promotes safety by providing contractors with essential information to identify and avoid damaging underground utilities during excavation. This helps prevent accidents, service disruptions, and associated costs. Secondly, KLIC enhances efficiency by streamlining the process of acquiring utility data. Contractors can access the necessary information from multiple utility providers through a single platform, eliminating the need to contact each operator individually. However, the KLIC does not provide semantic or non-semantic 3D data and if contractors choose not to utilize the KLIC data then the 2D maps and semantic data can differ vastly.

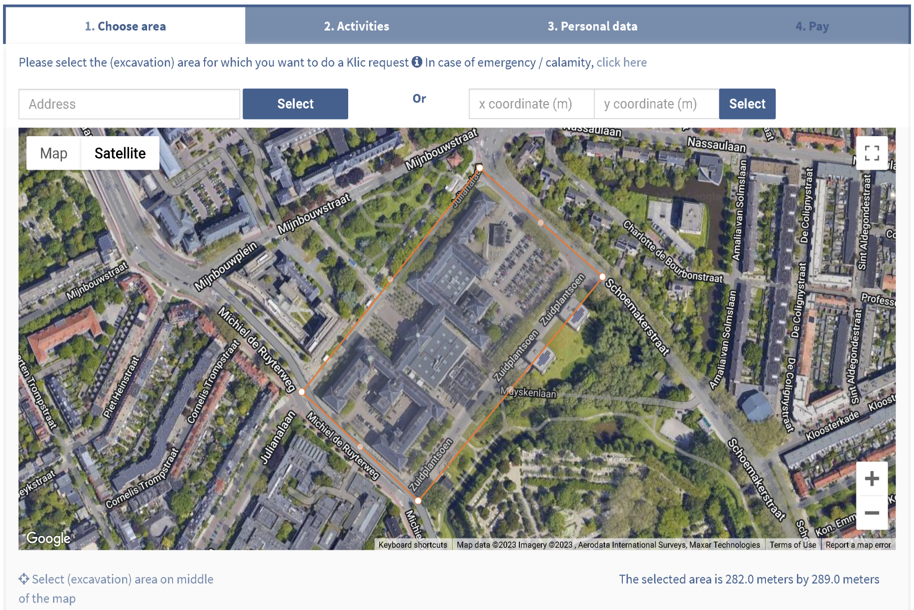

Figure 2.1: KLIC request of TU Delft architecture faculty (2022)

2.2 Data integration

The article ”Addressing the Elephant in the Underground: An Argument for the Integration of Heterogeneous Data Sources for Reconciliation of Subsurface Utility Data” (Hansen *et al.*, 2021) discusses the challenges associated with subsurface utility data management and argues for the integration of diverse data sources to address these challenges effectively.

Hansen *et al.* highlight the complexity of subsurface utility data, which often comes from various sources, such as as-built drawings, GIS databases, and field surveys, each with its own level of accuracy and reliability. These heterogeneous data sources contribute to inconsistencies and discrepancies in the information, leading to errors and uncertainties in utility mapping and management.

To address these issues, the article proposes the integration of different data sources to reconcile and harmonize subsurface utility data. Hansen *et al.* emphasize the importance of data reconciliation techniques that aim to resolve conflicts, improve data accuracy, and create a unified and reliable representation of underground utilities.

The article presents various approaches and technologies that can be utilized for data integration and reconciliation. These include spatial data infrastructure, data interoperability standards, semantic modeling, and advanced data fusion techniques. The authors argue that by combining these tools and methodologies, it is possible to create a comprehensive and consistent subsurface utility data model.

Furthermore, the article discusses the potential benefits of integrating heterogeneous data sources for subsurface utility management. These benefits include improved accuracy and reliability of utility mapping, enhanced asset management and maintenance, better risk assessment, and cost savings through optimized planning and decision-making.

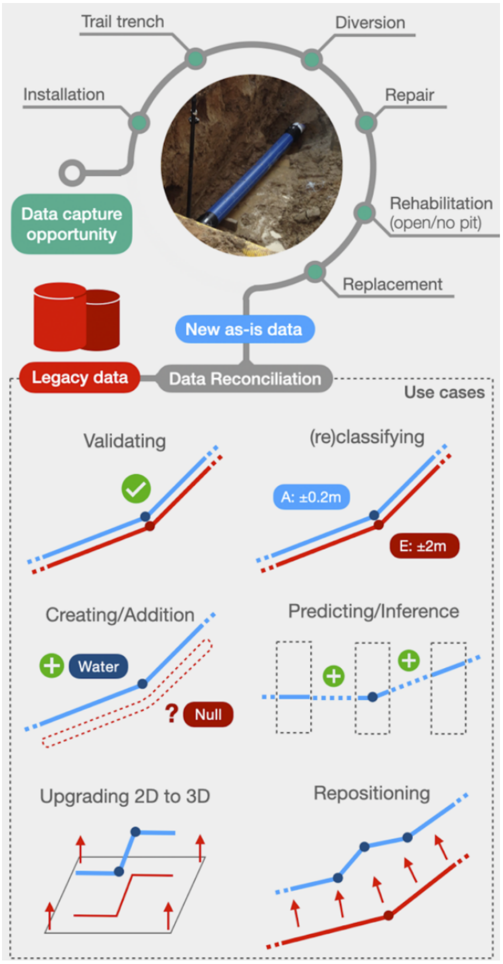

Figure 2.2: Data collection opportunities and data reconciliation use cases (Hansen *et al.*, 2021)

2.3 Related articles

The related articles section explores several studies that are relevant to the research topic of semantic enrichment of utility networks. These studies contribute to the understanding of various aspects related to geodata, data modeling, and the integration of utility networks into 3D city models. The following articles have been reviewed:

- Widl *et al.* (2021) focus on linking semantic 3D city models with domain-specific simulation tools for planning and validating energy applications at the district level. This study demonstrates the integration of energy-related simulations within the context of 3D city models, providing valuable insights into the planning and evaluation of energy systems.
- Fossatti *et al.* (2020) examine data modeling for the operation and maintenance of utility networks. The study investigates the implementation and testing of data models specifically designed for utility network management, contributing to the development of efficient operation and maintenance practices.
- Kavisha *et al.* (2019) conduct a survey on the adoption of GIS data and standards in urban application domains. This study explores the use of GIS data and standards in various urban domains, shedding light on the challenges and opportunities in integrating geospatial information in urban planning and management.
- Den Duijn *et al.* (2018) discuss the modeling of below- and above-ground utility network features using the CityGML Utility Network ADE. The study presents experiences from Rotterdam and showcases the use of the CityGML Utility Network ADE for representing utility networks in 3D city models.
- Boates *et al.* (2018) investigate the maturity of the Utility Network ADE for CityGML by testing it with a water network case study. The study assesses the capabilities of the Utility Network ADE for representing complex water networks in 3D city models.

These articles collectively contribute to the understanding of data modeling, integration, and visualization of utility networks in 3D city models. They provide valuable insights into the challenges, methodologies, and potential applications in the field of geomatics and utility network management.

CHAPTER 3

RESEARCH QUESTIONS

3.1 The Problem

To re-iterate, a few issues the thesis will address:

- The lack of a coherent model for utility networks.
- Some of the data is not geo-referenced.
- The data is currently only in 2D and it is prefered to have it in 3D for a more accurate representation.
- The only 3D information is provided in utility trench cross-sections.
- The datasets are different per city and per provider.

3.2 Objectives

The main research question for this thesis is:

- *Is it possible to upgrade an existing 2D model of utility networks to 3D using trial pits?*

The aim of this research will be to explore and develop a method that will combine trail pit elevation data with 2D utility network maps in order to produce an accurate estimate of the elevation of individual pipes and cables. More specifically, the operation should ideally be automated in such a way that the process can be applied to data sets provided by different contractors. The final product of this research will be a 3D model of the utility networks of the three cities from which both utility network and trial trench (proefsleuf) data has been provided. These cities are Amsterdam, Rotterdam and Enschede. Sub-questions that could be derived from this topic are:

- *If possible, then to what extent can this information be integrated?*
- *To what extent can a common strategy be derived from the 3 different cities?*
- *How far can the adoption of standards reduce the current issues?*
- *Which strategies can be developed to automate the data harmonization and integration process of the existing data?*

3.3 Scope of research

In this research, the primary objective is to enrich 2D utility networks with both semantic and non-semantic data in order to facilitate the process of developping a comprehensive 3D model/map of utility networks in specific sections of Amsterdam, Rotterdam, and Enschede. The process of creating this model will be thoroughly documented, ensuring the possible reproducibility of the results.

Additional significance of this research lies in addressing the limitations and challenges associated with the current standards for utility network representation. By exploring the existing standards and their applicability to the selected study areas, this research aims to identify gaps and propose improvements for more accurate and reliable 3D modeling of utility networks.

The methodology employed in this research will involve a combination of data collection, integration, and visualization techniques. The first step will involve gathering 2D utility network maps and relevant data from various sources. These data sources will provide the foundation for the enrichment and construction of the 3D model.

To achieve the 3D representation, the collected 2D maps will be incorporated with elevation data and accurate spatial positioning, along with other necessary data in order to prepare them for the transfer to three dimensions. The main method of elevation data retrieval will come from an analysis of 'trial trenches' conducted within the areas of study. Additionally, software tools and technologies, will be explored to enhance the analysis and visualization capabilities required in the research.

As was stated, limitations and challenges associated with the current standards for utility network representation will be thoroughly examined and discussed. This includes addressing issues such as data inconsistencies, accuracy discrepancies, and the lack of standardized data models. By identifying these limitations, this research aims to propose enhancements and recommendations to improve the utility network modeling process.

Overall, in this research we would like to:

- Enrich the utility networks of different municipalities.
  - Obtain GIS data from different datasets/providers.
  - Normalize the data.
  - Extract Z values from utility trench .dwg files.
  - Integrate Z values with 2D GIS data.
  - Try to reconstruct 3D pipes/cables between successive trenches.
  - Understand challenges and problems in data availability and quality.
- Define and implement methodology that allows to solve the problem (semi-) automatically based on data from Enschede, Rotterdam, Amsterdam.

CHAPTER 4

METHODOLOGY

The desired outcome of this thesis is a set of 3D models constructed from the data provided of Amsterdam, Rotterdam and Enschede. In order to do so, the data sets in question will be analysed in Chapter 6, *Tools and data sets*.

1. **Data retrieval and analysis:** Before making any major decisions on how the data should be extracted and processed, the data must be thoroughly inspected in order to make informed decisions in subsequent steps. This analysis will be both qualitative and quantitative in order have a proper understanding of the contents both semantic (attributes) and physical (e.g. shapefile, dwg, etc.). If any topological errors or incomplete information is provided in the data then it will be corrected in the following steps.

2. **Software selection and data cleaning:** Following the analysis of the data one can decide upon the software to be used. It will be decide which software(s) will be used to view, extract, process and model the data. Additionally, given that there are topological errors in the data, it must be decided what will be used to correct those errors.

3. **Extract the data:** Using the selected software, the data will be extracted. In the case of this project, the data to be extracted will be the 2D utility network map and the semantic data from the trial trenches. This data will be stored in a Geo-manageable file-type (e.g. GeoJSON, GeoPackage, etc.). Ideally, all the desired information will first be stored in a database but, for the sake of time the modelling process will be prioritized before potentially creating such a database.

4. **Data preparation:** In this step the goal is to get the data in a format that is easily transferable to the final software. This step may also include some additional cleaning of the data.

5. **Model Development:** This entails both having the elevation data added to the 2D map and then transferring the output to a visualisation software.

6. **Data storage and capturing standards:** This will be a discussion section of the thesis where the data from each city will be compared and analysed. The goal of this section will be to come up with a conclusion in terms of which standards will aid this specific project best.

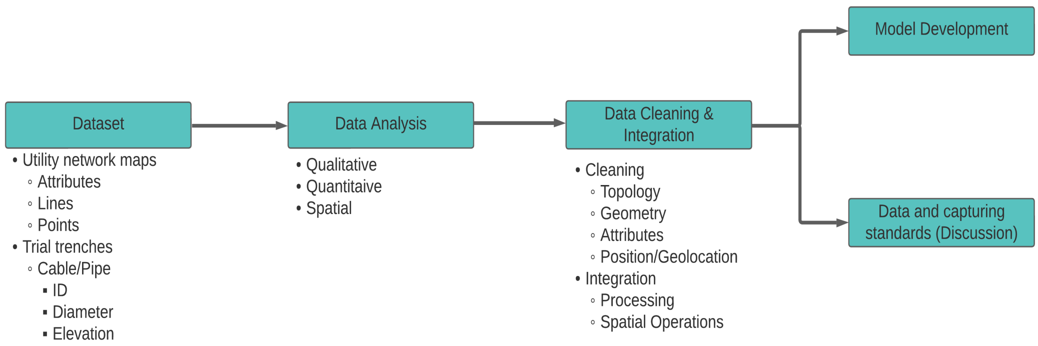

Figure 4.1: Methodology workflow

CHAPTER 5

TIME PLANNING

A Gantt chart was created in order to be properly organized. The chart depicts the dates and months at which certain steps of the thesis will be worked on. (Note: not all dates are planned/fixed and could be subject to change)

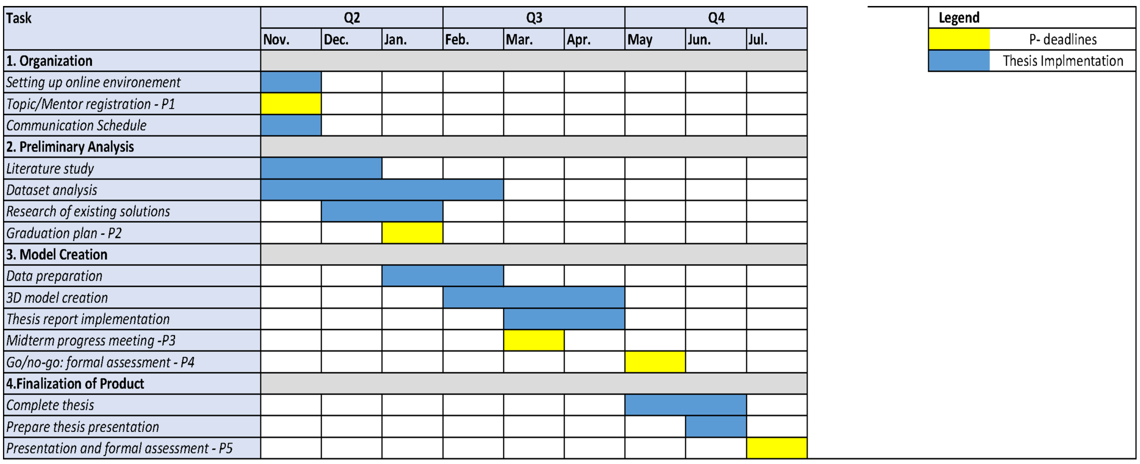

Figure 5.1: Gantt chart

5.1 Communication schedule

Over the course of this thesis the meetings with the primary supervisor, Dr. Giorgio Agugiaro, will occur either weekly or bi-weekly depending on the progress made in a certain week. Secondary supervisor, Dr. Jantien Stoter will be present at meetings of greater import. External supervisor, Dr. Léon olde Scholtenhuis, will also be present at significant meetings and will be in contact when questions arise about data set contents and processing and is in contact with Enschede and Rotterdam.

CHAPTER 6

DATA SETS AND TOOLS

6.1 Data sets

The data acquired for this thesis comes from three different cities and sources/contractors. These data sets all depict a utility network containing, water supply, power, gas, and telecommunications. In addition, the data sets are accompanied by utility trench cross section depictions and their locations on the network. Each city, Amsterdam, Enschede and Rotterdam, has their utility network and utility trench data depicted in a unique manner. On of the challenges to overcome during the implementation of the thesis will be finding a (preferably) automatic solution to extracting the data to a uniform output.

Given that all this data comes from within the Netherlands, it is understood that the data, will be referenced in the Dutch coordinate system, Amersfoort / RD New Netherlands.

Prior to the development of a model, the data must be studied in order to understand what it contains and how it can be used. This will be done both qualitatively and quantitatively. In terms of a qualitative analysis, one must observe the characteristics that provide a description of their contents, the metadata, and the completeness of the data. This is to say, if the data is erroneous, it must be either corrected or cleaned of incorrect or irrelevant information. (Jones, 2007) It is assumed that the majority of the work will be qualitative however, one can expect that a quantitative analysis can be of use when finding patterns and relationships between variables in the data. Watson (2015) This being said, each data set is slightly unique and will, as a result, require a slightly different process in terms of data analysis, cleaning and extraction. The following sections will discuss each city individually and will analyse what steps may need to be taken to continue forwards.

6.1.1 Enschede

The data received from Enschede is a combination of the KLIC utility network map and a set of utility trenches conducted by the Siers Groep. Two sections of the city were acquired and their contents are displayed in Figure 6.1.

Along with the contents listed in Figure 6.1, several PDF files are included in the contents. The majority of these are simply prints of the individual utility trenches, however some of them display examples of anomalies in the data in relation to real world positions. The Ground Penetrating Radar (GPR) files will most likely not be used in the actual creation of the model, however, they may be discussed in a future research section in the final thesis.

	Trial trenches	GPR	CAD/.dwg	Photos
Brammelerdwarsstraat	10	3	1	23
Deurningerstraat	25	3	1	58

Figure 6.1: Enschede data received

CAD file

As mentioned above, the CAD/.dwg files received are composed of KLIC utility network map and the utility trench additions added on by the contractor. It can been seen in Figure 6.2 that utility trenches (proefsleuf) are overlaid onto the KLIC map. The utility trenches conveniently contain the coordinates of the opposite corners of their bounding boxes and, each cable is labeled. For each utility trench that contained anomalies, the CAD file also has red text to point out and explain the issue. For example, there is a sewage pipe in utility trench 05 that was not represented in the KLIC. These issues are important to take note of as they will help to better imitate the real world in our digital model.

To reiterate, all the files provided are from the Netherlands and accordingly should be referenced in the Amersfoort / RD New Netherlands with the following attributes:

- **Geodetic CRS:** Amersfoort
- **Datum:** Amersfoort
- **Ellipsoid:** Bessel 1841
- **EPSG code:** 28992

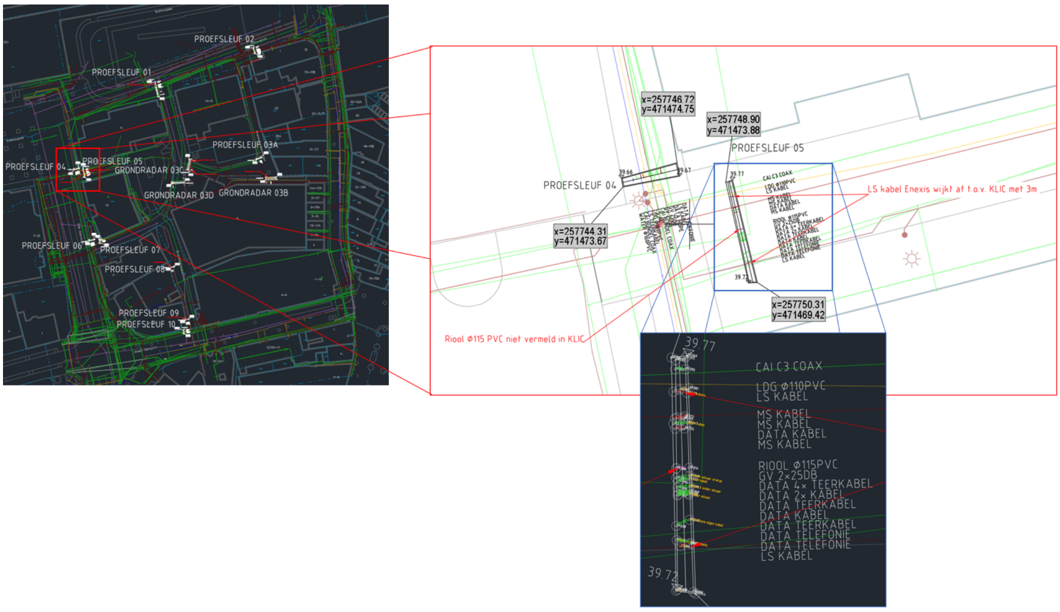

Figure 6.2: Brammelerdwarsstraat CAD/.dwg file zoomed to three levels

The Enschede CAD files are the only files provided that are accurately geo-referenced. This will help when testing how to implement the CAD files quickly into a mapping software. This process will be discussed in a later section.

Utility Trench data

For every utility trench depicted on the map, there is a cross-section provided along with it. These cross-section contain the elevation data required in order to upgrade the 2D maps. Along with this, they provide the positional data of the cables in relation to the side of the utility trench. Each cable is individually labeled with it's use and diameter.

The main issue observed with the cross-sections is that they are all drawn together in the same .dwg file as the utility map. It would be difficult to extract data from a CAD file with many utility trenches let alone the whole map, if one were to conduct this process automatically, as is desired in this thesis. The immediate solution, for the sake of time, will be to separate the map and the utility trenches into different work spaces. However, finding a solution that will possible extract this data properly and automatically for Enschede and the other cities would be ideal.

CAD to QGIS

As one of the steps in this thesis will inevitably be converting the utility map to a mapping software. To be able too do so, it is important that the data received from the municipalities are properly geo-referenced. This happens to be the case for Enschede, which will allow for a much easier, and automated, extraction.

To extract the data from the .dwg files python was used alongside the ezdxf library. The ezdxf library allows us to find the start and end coordinates (including Z) of the center line, or cross-section, of each utility trench. Now with the coordinates and the length of the cross-section, each point along that line can be placed along the line and their new Z value can be calculated. Figure 6.7 displays a table of the point in utility trench 1.

The points were then visualized by importing the .csv file into QGIS as a delimited text layer. The points are then classifed according to their description (cable type) as seen it Figure 6.4.

Proefsleuf	width	depth	descriptioi	E	N	Z
1	0.07	1.45	WATER %9	257787.9	471520.9	38.7292
1	0.69	1.4	HDG %%c1	257788.1	471520.3	38.79868
1	1.74	1.11	WATER %9	257788.3	471519.3	39.12168
1	1.78	0.43	CAI 40HDF	257788.3	471519.2	39.80294
1	2.01	0.9	LDG %%c1	257788.4	471519	39.34016
1	2.11	0.73	LS KABEL	257788.4	471518.9	39.51331
1	2.15	0.67	LS KABEL	257788.4	471518.9	39.57456
1	2.22	0.72	LS KABEL	257788.4	471518.8	39.52676
1	2.37	0.68	DATA TEEF	257788.5	471518.6	39.57148
1	2.4	0.61	LS KABEL	257788.5	471518.6	39.64242
1	2.85	0.38	DATA 40HI	257788.6	471518.2	39.88656
1	3.23	0.49	LS KABEL /	257788.7	471517.8	39.7885
1	5.41	0.53	LS KABEL	257789.2	471515.7	39.81701
1	6.07	0.27	LS KABEL	257789.4	471515.1	40.09775
1	7.44	0.38	CAI KABEL	257789.7	471513.7	40.0308

Figure 6.3: Data extracted from utility trench 1

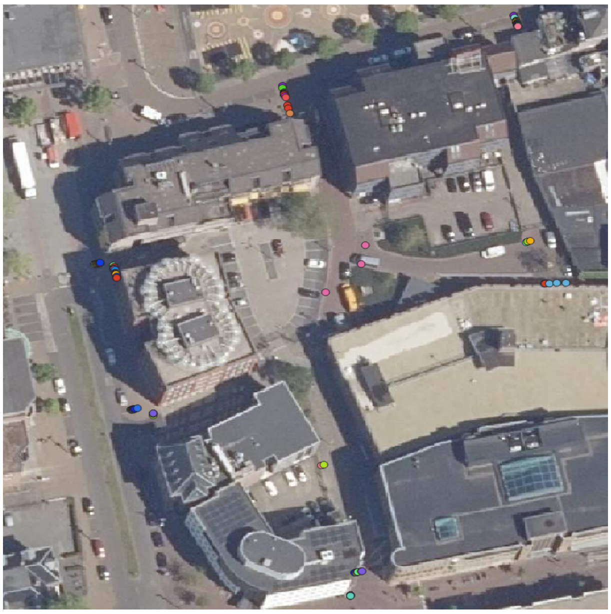

Figure 6.4: Utility cable points per utility trench

6.1.2 Rotterdam

The Rotterdam data is much like that of Enschede's, however, there are a couple of key differences that will need to be taken into account for when developing the data extraction process. In terms of the contents received from Rotterdam, the files include:

- 1 overview .dwg
- 1 utility trench positions .dwg
- 3 utility trench cross-section .dwg's, each containing 30-40 utility trench depictions

CAD file

The cables on the utility map itself are quite similar but, there are many more labels in the actual drawing file of the Rotterdam data, this is both a benefit and a disadvantage as it improves clarity but will also need to be removed and cleaned before creating a final model. Another difference is that, in the Rotterdam data, there is no coordinate description of where the utility pits are located on the map, they are roughly displayed but not quite as exact as those of Enschede. This also relates to one of the greater issue presented in this data, which is, incorrect geo-referencing (Figure 6.5). Notice that the football field in the CAD/.dwg file does not line up correctly with the base-map.

Utility Trench data

The utility trench data of Rotterdam improves upon that of Enschede as the utility trench cross-sections are depicted together but in a separate file than the utility map. This makes the utility trench data more easily processable. An example of the Rotterdam depiction of the utility trenches can be seen in Figure **??**.

Figure 6.5: Incorrectly geo-referenced Rotterdam data

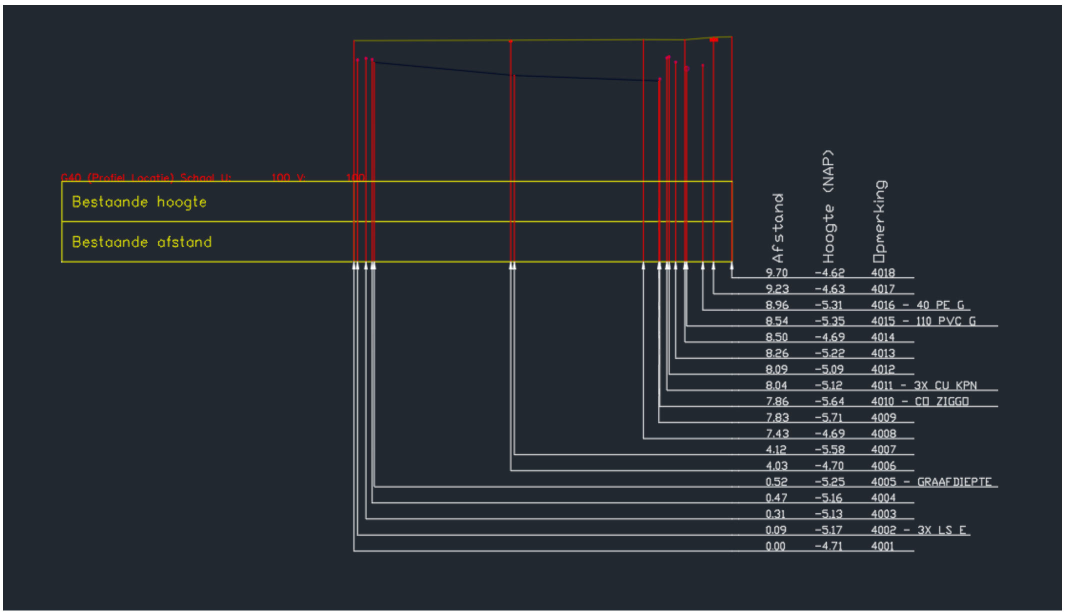

Figure 6.6: Rotterdam utility trench example

6.1.3 Amsterdam

Of the three cities being observed the Amsterdam data is the most dissimilar to the rest in both scale and organization. The data from Amsterdam is more disorganised than the other two cases and much of it is not attainable in certain formats. For example, the utility trench cross sections provided by Amsterdam were only provided in PDF format. It has been decided that the Amsterdam data will not be utilized due to a lack of information, including empty utility trenches and un-geo-referenced data.

Preliminary suggestions

The current plan of action will be to work on the most manageable data set first in order to quickly create an ideal format in which all the enriched data will be presented in and the process towards doing so. This is already mostly complete, as seen in the Enschede example, the difficulty now will lie in connecting the points from each utility trench to each other, this includes: drawing lines around corners and ordering the points correctly so that line is drawn correctly. Connecting lines has been tested but only with utility trenches that are along the same street and not around a corner (Figure 6.6).

Figure 6.7: Connections between utility trench 1 & 2

6.2 Tools

The tools section of this paper outlines the software tools that will be utilized in the research process. The following tools have been identified as integral components:

1. QGIS (QGIS, Accessed 2023): QGIS (Quantum GIS) is an open-source geographic information system that will be used for data management, analysis, and visualization. QGIS provides a wide range of functionality, including spatial data processing, geo-processing, and 3D visualization capabilities. It will be employed for tasks such as data integration, geo-referencing, and creating basic visualizations of the utility network data.

2. AutoCAD (Autodesk Inc., Accessed 2023): AutoCAD is a widely used computer-aided design (CAD) software that is particularly well-suited for creating 2D and 3D models. It will be utilized for working with the original 2D utility network maps, extracting relevant data, and providing a foundation for the 3D modeling process. AutoCAD's powerful drawing and editing tools will be instrumental in accurately representing the utility network features.

3. Python (Python Software Foundation, Accessed 2023): Python is a powerful, general-purpose programming language widely employed for various applications, including data science, scripting, and automation. Its readability, versatility, and extensive library support make it an excellent choice for developers. In this thesis, Python will be utilized for scripting and automating tasks, providing a robust foundation for efficient data processing and analysis.

4. ezdxf Library (ezdxf Development Team, Accessed 2023): The ezdxf library is a Python library designed for working with DXF files, a widely used format for CAD data. ezdxf simplifies the creation, modification, and analysis of DXF files, offering a straightforward interface for handling geometric entities, layers, and attributes. In this thesis, ezdxf will be employed for reading and extracting DXF information.

In addition to these core tools, there is a possibility of incorporating other software or technologies based on the specific requirements of the research. These additional tools might include:

1. 3D Modeling Software: Depending on the complexity of the utility network modeling and visualization requirements, additional 3D modeling software may be employed. These software tools could include popular options such as Autodesk InfraWorks or ESRI CityEngine. These tools offer advanced capabilities for 3D modeling, simulation, and visualization of urban infrastructure.

2. GIS Extensions/Plugins: Various extensions or plugins available for QGIS or AutoCAD might be utilized to enhance functionality or streamline specific tasks. For example, plugins for QGIS such as the CityGML extension or the Network Analysis Library (pgRouting) can provide additional capabilities for modeling utility networks or performing network analysis.

3. Database Management Systems: Depending on the scale and complexity of the project, a database management system (DBMS) such as PostgreSQL with the

PostGIS extension might be utilized for efficient storage, retrieval, and querying of geospatial data.

The final selection and implementation of tools will be based on the specific research requirements, availability, and compatibility of the tools with the desired workflows.

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Colophon

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