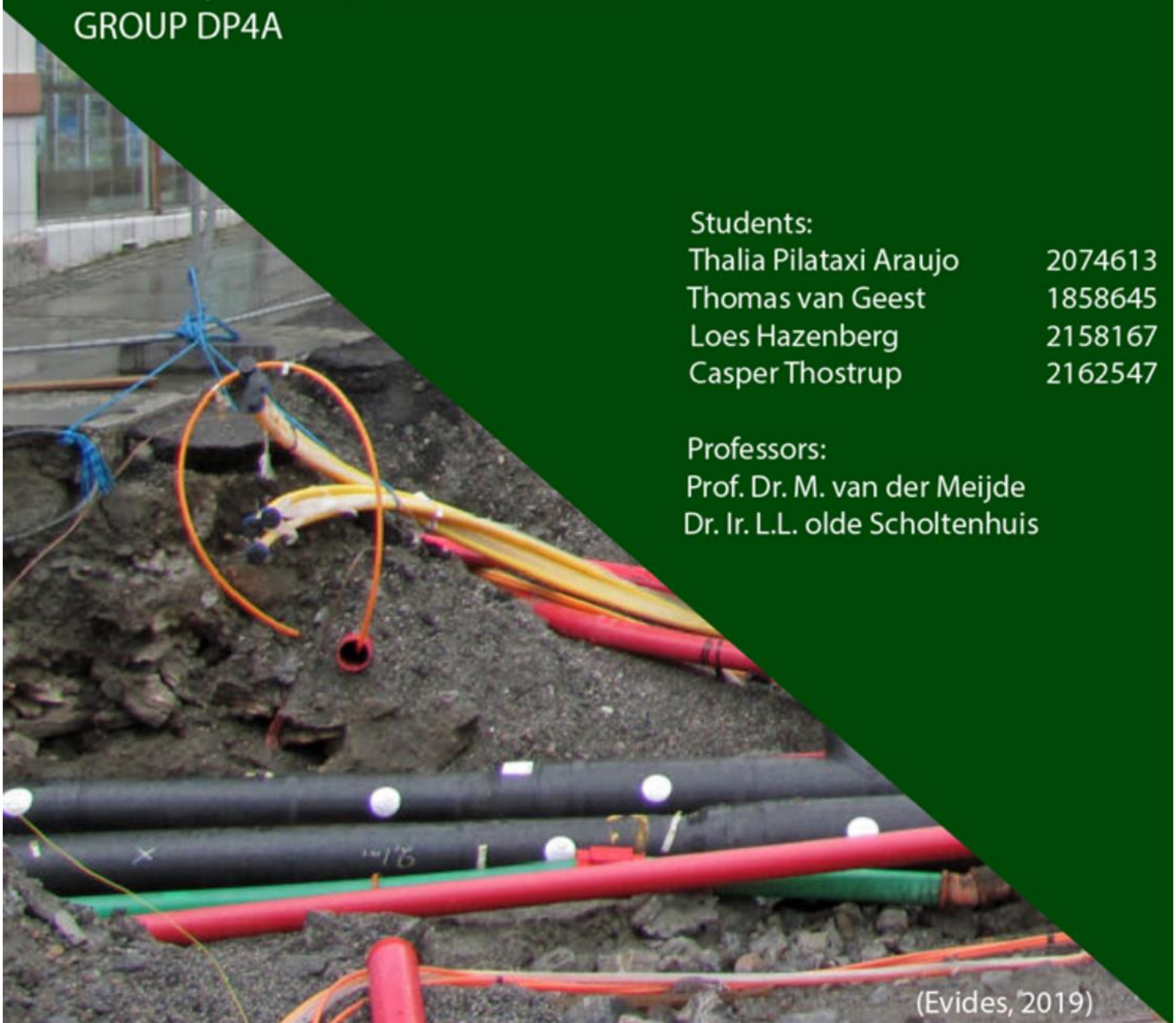
DURA VERMEER

UNIVERSITY OF TWENTE.

SMART INFRASTRUCTURE EXPLORATION

Smart ways to make smart cities smarter

GROUP DP4A



(Evides, 2019)

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Executive Summary:

From a study once conducted it was found that from the 187 incidents where utilities were struck 52% were not recorded in the utility companies plans (Dou, 2020). In this report a method of 3D visualization of utilities in the underground in described for the Elferinksweg, where the client, Dura Vermeer is currently involved in a project. The method describes the choosing of trial trench locations, 3D visualization of underground utilities and the uncertainties related to those utilities.

Trail trench locations were found to be important as these are the input for the methodology. Due to this a clear method and suggested improvements with Ground Penetration Radar technology was described.

Before 3D visualizations could be created a 2D visualization of the data was made. For this method vectors and Gaussian distributions were used. The Gaussian distributions allowed for the visualization of uncertainty where 2 Standard deviations distance from the mean location were taken as a 95% certainty that a utility is located at that place.

The 3D visualization uses the Gaussian distributions created in the 2D visualization but adds additional methods for creating a “Fussy shape”. In this data from the municipality (KLIC data) and the previously found data was used. This allows for the creating of a fussy shape around the probable locations of utilities. These fussy shapes are created by taking the given data, attaching a certain weight based on the accuracy of measurement and then creating the shape around the mean location. Such a shape represents with a given certainty how much chance there is that a utility is located at that place.

After the creation of the methodology an example was made between trench 2 and 3 from the data provided by Dura Vermeer. In the example the KPN cable located between the trenches was visualized successfully.

After showing a draft report to the client it was found that more priority should be placed on the reduction of trial trenches whilst increasing the data density gathered from these trenches. This had not been clearly communicated to the team and would have the be improved upon in a further edition.

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1. Introduction

Dura Vermeer is currently working at a project in the Elferinksweg, this project is about re-developing this street in order to prevent flooding (Municipality Enschede, 2020). In the Elferinksweg, many utilities are located which has made the endeavor of avoiding the wrong pipes and finding the right cables difficult. It is important to avoid these utilities, since damaging one of them can have big impacts on residents, environment, etc.

To do this, our consultancy group has been tasked with developing a methodology to determine the location of utilities with the use of 3D modelling and trench trials. This methodology will make it possible to extract data from trial trenches into a 2D model and translate that 2D model into a 3D model. While taking uncertainties into account. These methods will then be used on incomplete maps provided to us by Dura Vermeer (the client in this project). With incomplete is meant, only the data of the trial trenches or the data from KLIC (Kabels en Leidingen Informatie Centrum (in English: Cables and Pipes Information Centre)) (since this is not accurate enough).

The methodology created in this report is aimed to help Dura Vermeer with the construction of the Elferinkgsweg, but in the future the methodology can also be used for other projects.

Within this report, first the method of the project will be explained. After this requirements are set based on the information received from the client as well as information gathered through stakeholder analysis. After that the functions of the methodology are explained. In the design synthesis segment both trial trench methodology and the conversion of the data gathered from these trenches to 3D visual information are explained. To conclude the impact on society and relation to smart city engineering is discussed after which a verification and validation is performed.

1.1 Goals and research question

The main goal of this project is to make a 3D model of (underground) utilities incorporating uncertainty of the exact location of utilities. This main goal can be divided into multiple research questions, namely:

- How to make a 3D model from trial trench information?
- How to incorporate uncertainty in the 3D model?
- How to determine the trail trench location?

2. Method of project

Within this assignment the V-shaped system engineering method was used. Within this the team was only required to deliver a Low-Level Design. This means that the consultancy delivered the methods which could be implemented but were not responsible for the implementation. Within this low-level design, the stages given in Figure 1 are followed. In this report all the different outcomes of the different steps are explained.

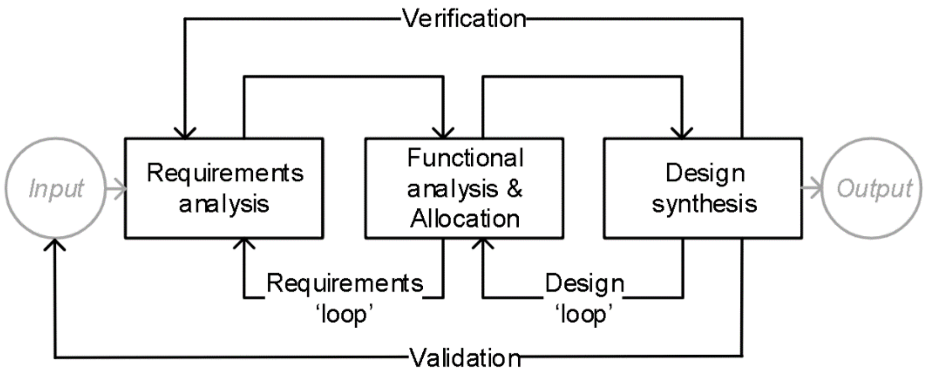

Figure 1 Representation design method (Graaf)

Below a clear description of each stage can be found with their purpose, end result and importance described.

2.1 Input- Stakeholder analysis

The first step that was conducted, was determining the input. As it says, the input gives the starting point of the project. It shows why a project needs to be conducted. In this case this is done by doing a stakeholder analysis.

The first part of the analysis consists of an overview of the different stakeholders that have a stake in the project. This overview also contains an overview of their wishes/objectives in order to have insight in the different opinions, this is useful for the requirement analysis.

Besides this overview, also a power-interest grid can be found in the Section 3.1.2 Power-interest grid. This power interest grid is a visual representation of how much power and interest the stakeholder has in the project. On the y-axis of this grid, the power is given and on the x-axis the interest. The higher on the grid, the more power a stakeholder has and the more to the right, the more interest the stakeholder has in the project. Based on their positions, the stakeholders can be divided into 4 different groups, namely the context setters (many power, not a lot of interest), key players (many power and interest), crowd (little power and interest) and subject (much interest, a little power). This categorization can help to determine which extent the wishes of stakeholders, should be taken into account. For example, an objective from the crowd is less relevant than the wish of a key player.

2.2 Requirement analysis

The second step was translating these objectives and wishes from stakeholders into requirements. The requirements are criteria which the design should meet. The requirements are therefore a useful element to evaluate whether the outcome of the design corresponds to what it should be. To make it even easier to see whether the requirements are met, the requirements are made SMART (Specific, Measurable, Achievable, Realistic and Timely).

To have an indication when the requirements are met, criteria are set up for each requirement. If the criteria is met with the set performance standard, the requirement is fulfilled. The requirements, criteria and performances are put together in a table. In this table, also the priority and the source are given. The priority indicates whether the requirement is a demand or a wish. A demand means that the performance of a requirement must be met, a wish indicates that the outcome of the design would be better if it is met (it is not demanded). The source indicates on which stakeholders' wish the requirement is based.

The Table in which all the above-mentioned things are stated can also be called the Design brief.

2.3 Functional analysis

With the requirements, functions (and objects) were made. A function describes a certain action that is needed to be done to fulfil the goal to which the function is related. To this function, an object is connected. The object indicates what (object) should be part of the design to fulfil the function it relates to. These functions and objects are put in a function-object tree.

2.4 Design synthesis

The last step of the system engineering method is doing the design synthesis. The design synthesis is about combining all the different objects that are given in the function-object tree (gotten from the function analysis) into one design. The outcome of this step is therefore the (final) design, depending on whether an iteration is needed.

2.5 'Evaluation'

As can be seen in Figure 1, there are multiple 'evaluation' loops (requirement and function loop, verification and validation). With evaluation is in this case meant, checking whether the outcome of the different stages correspond with the outcome of other stages. This is done to make sure that the outcome of the design synthesis corresponds with the goal of the project.

3. Quantification of goals

In this section the goals, which are stated in Section 1.1 Goals and research question are specified. This is done by doing the first 3 steps of the system engineering methodology, which are respectively input/stakeholder analysis, requirement analysis and function analysis.

3.1 Input - Stakeholders analysis

As mentioned before in Section 2.1 Input- Stakeholder analysis, the first step that was conducted for the system engineering method, was a stakeholder analysis. In this section, the different stakeholders, their formal positions, and their objectives are discussed. Also, their power and interest levels is given in a power-interest grid.

3.1.1 The stakeholders, their formal position, and their objectives

- The Municipality of Enschede

The main project Elferinksweg, from which this project is part of, has been spearheaded by the municipality. They wish for the Elferinksweg to be re-developed to prevent flooding (Municipality Enschede, 2020). Besides this broad wish for the main project, they are also interested in this part of the project. Since they want to have a good 3D model of the utilities in order to make sure that the utilities do not get damaged during construction/maintenance. Also, they want to minimize the inconvenience for citizens during the detection of the utilities and they want that the detection is done in the most efficient way.

- Dura Vermeer

Dura Vermeer is the contractor for this project, also all the data used in this project was supplied by Dura Vermeer. They wish to have a more efficient method for determining the location of utilities. Not only for this project, but they also want this method to work in future projects.

- Residents Enschede (Pathmos and Stadsveld)

The residents of Enschede may be bothered when trial trenches are made at the Elferinksweg, since it will cause some disturbance in their daily life. Also if a utility would be damaged during maintenance or construction it could have (big) impacts on, especially residents living in the area, but also on residents living further away. The wish of the residents living in Pathmos and Stadsveld, and the other residents of Enschede, is to have a minimum disturbance from the trial trenches. Also the citizens wish to have no damage to the utilities (or at least no damages that will have effects on them).

- Utility companies

Utility companies are the owners of the utilities that play a big role in the project. They wish to have no damage to their utilities, since damage will cost them money.

3.1.2 Power-interest grid

As mentioned before in Section 2.1 Input- Stakeholder analysis, the power-interest grid gives an overview of the positions of stakeholders when looking at their power compared to their interest.

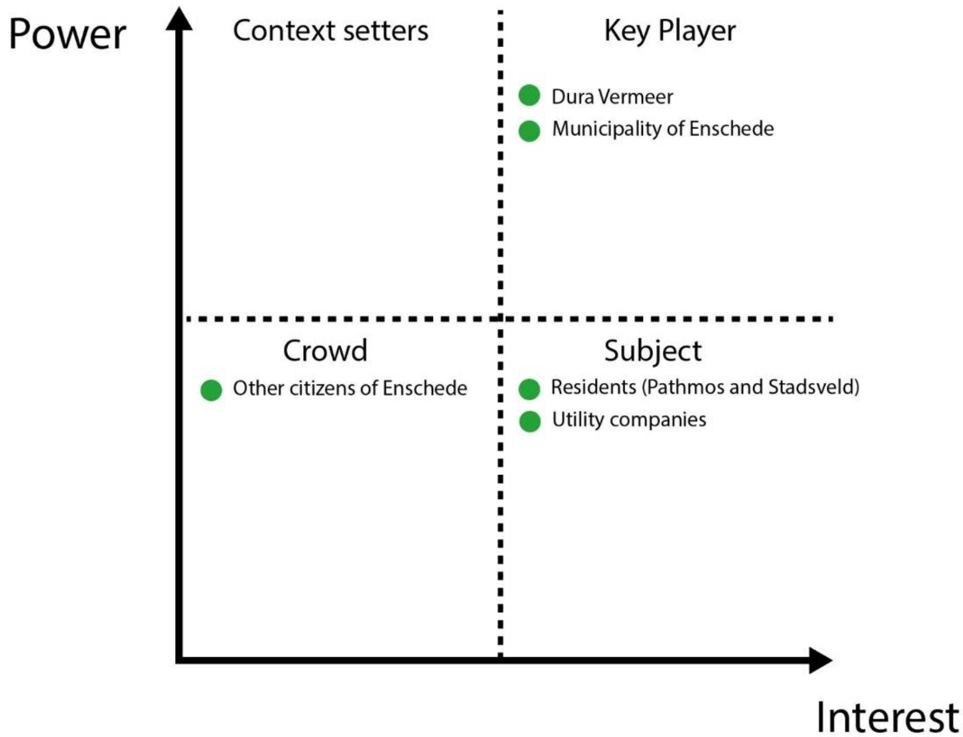

Figure 2 Stakeholder power-interest grid

As was mentioned before in Section 2.1 Input- Stakeholder analysis, the power-interest grid is used for the determination of how stakeholders wishes should be taken into account in the project. In this case the wishes of the stakeholders are fairly in line with each other, so all wishes can be taken into account. But when wishes of stakeholders change, or something else comes up, it is good to have the power-interest grid because this can give some insight.

3.2 Requirements analysis

After the stakeholder analysis was done, the requirements were made based on the objectives of the stakeholders and information provided by them. These requirements are put in a table to create a clear overview, this table is also called the Design Brief. In Table 1, this 'Design Brief' can be found.

Table 1 Requirements

ID	Description	Criterion	Performance	Priority	Source
1.1	Create a 3D model methodology of (underground) utilities	95% accuracy	- 5%	Demand	Client, Utility Companies, Residents Enschede and Municipality of Enschede
1.2	Map the uncertainty of the location of the utilities	95% accuracy	- 5%	Demand	Client, Utility Companies, Residents Enschede and Municipality of Enschede
1.3	Determine trial trench locations	Are the trial trench locations effective for locating utilities?	Yes	Demand	Client

3.2.1 Elaboration requirements:

Here the reasoning for each requirement is given.

1.1 Create a 3D model methodology of (underground) utilities.

This was the main task of the assignment. As per given by the project description.

"The main question for them is how local, verified, 3D information of the trial trench can be used to generate a model of remaining underground of the project." (Scholtenhuis, 2020)

1.2 Map the uncertainty of the location of the utilities.

Within this same project brief importance was placed on visualizing uncertainty. This was also important for the team as the effectiveness of the method is related to how little damage is caused to utilities. Creating a visualization of uncertainty will prevent a false sense of security.

1.3 Determine trial trench locations.

The information input for the 3D methodology is the trial trench data. Due the importance of this data for the quality of visualization additionally this requirement was added.

3.3 Functions analysis of the system

With the use of the requirements, functions and objects were determined. These functions are given in the Function-Object tree in figure 3), as explained in Section 2.3 Functional analysis.

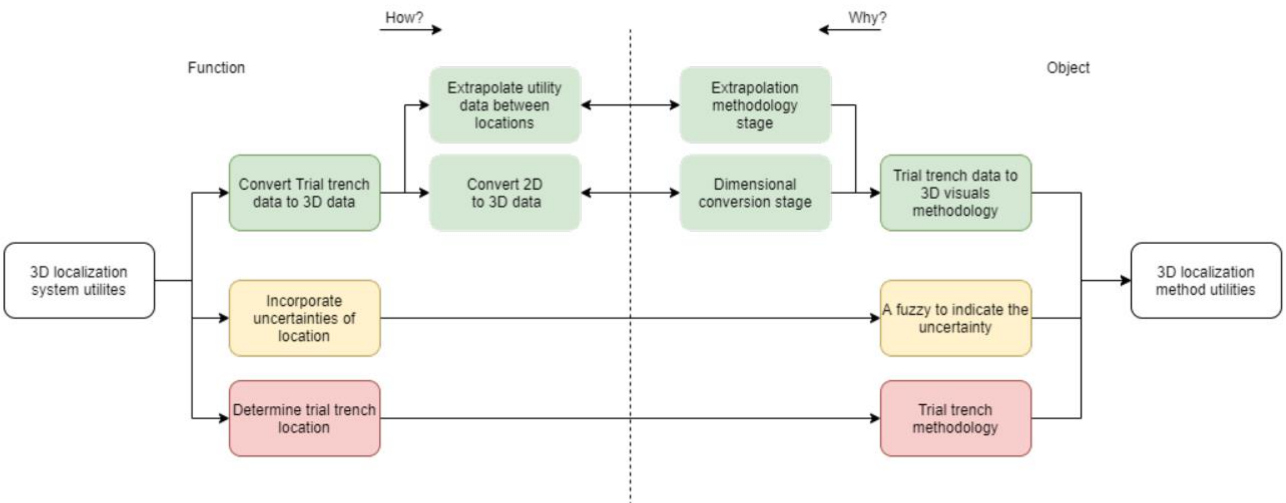

Figure 3 Function-Object tree

This tree can be read from the left to the right (and the other way around). On the left side the task is given, this is the main/final 'function' of the project. This task is divided into multiple functions. And these functions can be divided into sub-functions again. These sub-functions are connected to objects. These objects can be combined to bigger objects, which eventually leads to the object that is wanted as the outcome. When you read the tree from left to right (so from task -> function -> sub-function), the question "how?" will be answered, the other way around (so from the right to the left) the question "why?" will be answered.

3.4 Constraints

The current methodology was created for a very specific situation with specific geophysical properties. Enschede is situated very differently to places like The Hague or Limburg. This means that the assumptions and methods may not hold if the situation changes. For now, the constraints of this methodology is limited to the project in the Elferinksweg.

3.5 Requirements loop

System engineering is an iterative process. So, after several stages, it is determined whether the outcome of the stage still corresponds with the stage before. When this is not the case, adaptions will be made until it corresponds again. The first iterative step that was done is the requirement loop. This loop checks whether the function analysis corresponds with the requirement analysis. In this project, this was also done. The results presented before are the 'final' results (this is the result after the iterations).

4. Design Synthesis

After the function analysis was done, the design synthesis was conducted. The goal of this project was to find a method to make a 3D utility model. To do this, the method was divided into three different stages, namely the stage for trial trench determination, extrapolation of utility data between locations and the 2D data to 3D conversion. The three stages are truly part of one method, although the three stages can be used separately. If the utilities location underground has not been extrapolated or determined yet the whole methodology must be used. If this data is already available, however, one can start in the second phase of the methodology.

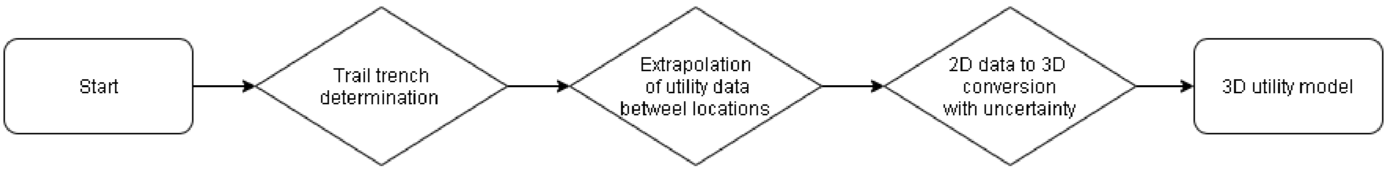

Figure 4: A schematic overview of the methodologies

This will allow users to easily jump in the method at the stage which their data has been organized.

This section is divided in four parts. In the first part, called model description, the three different stages are explained. After this the function loop is discussed. In the third part an example of the method is given with the use of data from the Elferinksweg project. The last part of this section is about the reflection on implications for society.

4.0.1 Uncertainties related to method

The method described below has uncertainties directly built into it. Some of the reasons for this can be found below. It is important that if the method is used no false sense of security is created.

- Not all utilities are present on the maps

Often when cables and pipes are not being used anymore, they get erased from maps without removing them from the underground. This can cause major problems with excavations but also with radar utility detection.

Another uncertainty that could occur is the fact that maps of utilities are made when the utilities were already there. In the past, utilities were not mapped accurately. At a certain point they started to map the utilities, and thus also the utilities that were already at the location. But since the locations of these utilities are not stored at all, or not stored accurately, it is harder to make a map out of them. Which causes a bigger uncertainty.

- GPR and GRPS sensors will give some small errors.

When performing underground utility detection (the GPR radar) different soil layers due to the dielectric constant changing can give smaller fluctuations in measurements. The weakening of the signal can also cause problems with detection of the exact location. GPS trackers will also inherently always have uncertainties built in.

- When GPR is used: Sensor will also detect other objects (such as stones)

When performing the underground utility detection (with the use of the GPR radar), it is possible that the sensors will also measure other objects (that are not categorized as utilities). This could cause problems with the 2D mapping of the system/determining the accuracy of the 2D map(s).

4.1 Model Description

4.1.1 Determining trial trench locations

Before 3D visualizations of the utilities can be determined these utilities must first be located, otherwise there is no starting point for the visualisation. Although the digging and locating of trial trenches falls outside of the project scope it was found to be important, since this directly contributes to the accuracy of the final 3D maps. If the input data is inaccurate the output will also be inaccurate. Creating Trial trenches allows for the confirmation of utility location from which further extrapolation can be performed. Within this segment of the report the process of determining where trial trenches should be dug is explained. This method was based on information received from Dura Vermeer, the client. If more information is desired about trench locating projects groups from the 4th topic, Smarter Infrastructure Network localization, can be contacted.

Assumptions:

- Historical maps of utilities are only accurate to +/- 1 meter in all directions.
- Utilities travel mostly parallel to the measured direction at a trail trench location.
- Under manhole covers, utilities such as sewage piping flows
- If ground penetrating survey is used and detects a shift in frequency return it could be a utility.
- Locations where streets meet utilities the direction of said utilities can change.

Possible information used:

- Information from Municipalities of utility registrations (KLIC data)
- Manhole cover locations
- Ground penetrating survey data (This is not used by Dura Vermeer within the project)
- Change in soil properties such as colour indicated a place where excavation has taken place (Sahlstrom, 2018)

Steps:

1. Set boundaries of the area that is wished to be surveyed. This also sets the boundaries for the 3D visualization
2. Based on historical known information and manhole cover locations firstly ground penetrating surveys could be performed at the locations where the first trench might be dug.
3. If GPR detects a signal a trial trench can be dug, if no GPR is used trial trenches should be dug based on the historical data
4. The type, location and direction of the utilities is measured and catalogued

5. The direction of utilities is followed until a change in situation occurs, these could be the following
    - A street connecting to the current street where utilities are being detected
    - A Geophysical change such as a river or steep elevation change
    - A turn in the street where measurements are being taken
    - At crossings
6. Again, historical maps and potentially GPR methods are used to firstly estimate the location of utilities.
7. Then a new trail trench is dug to confirm the type, location and direction of utilities.

This process is continued until all directions of utilities within the set boundaries has been followed. This should result in most utilities having been detected.

Guidelines for number of Trial Trenches:
Although more trial trenches will always give clearer information on utility locations it is not an optimal solution as digging trial trenches costs money. Due to this it is best to only dig trenches in the cases described in step 5. A specific amount of trial trenches per meter cannot be given as the need for a trial trench is mostly due to a change in situation. An example of this is that less trial trenches have to be created in case of no change in road layout such as in farming areas where roads often don’t change for kilometer long stretches. In cities this is often very different.

4.1.2 Extrapolation of data from trial trenches to 3D information
In this segment the data gathered at trial trench locations, from municipal databases and various other sources is used to create a 3D visualization of the utilities underground. Firstly the assumptions are explained, then a 2D visualization is described which lays the foundation for the 3D visualization of the underground utilities.

Assumptions:

Before the method can be described the assumptions must first be explained.

- The directions of utilities can never be accurately measured. Therefore, distributions will be used. This is done to not give a false sense of security when digging around utility locations.
- All depth and location distributions follow a Gaussian curve. This is because it is believed that the location is always approximately normally distributed.
- Utilities travel in a straight line between trial trench locations with variation determined through a distribution. This is because it would be the fastest path between the two locations and therefore efficient for laying down in this manner.
- Only utilities are considered meaning that other complex joints, curves, and so on, will not be considered within the scope of this project.
- The utilities have a perfect cylinder shape, and the outer radius will stay the same between the trail trenches.

Stage 1: 2D extrapolation of trial trenches information

Goal:

Within this segment the data collected of utilities from the trial trench locations will be extrapolated with the direction it travels in the underground. Within this stage no 3D uncertainty is considered, merely the direction of the utilities is estimated with a given certainty. The distributions that are calculated for utilities within this stage of the method lay the foundation for the 3D visualization as these distributions are used there further.

Method:

The steps taken in this stage are a simplified version of the method created by Qingxu Dou. This method uses the combination of both trial trench observations as well as subsurface surveys to create a probabilistic determination where utilities are located. (Dou, 2020)

The steps:

After the trial trench surveys have been conducted the data related to the utilities location and direction is used. Each utilities direction is recorded as a vector in both the x and y plane. A vector describes the movement from one point to another in a horizontal and vertical component, combining these two gives the direction of the utility. Within (Dou, 2020) this is referred to as pan and tilt. These recordings are considered to be probabilistic as it is difficult to make a reliable measurement, this is in large part due to inaccurately saved information, uncertainties in measurements and uncertainties in the direction of utilities. These probabilities are based on the gaussian distribution.

The Gaussian distribution is determined through the mean and standard deviation of the measured direction of utiltities. A distribution is created for both the x and y direction of each utility. The peak of the curve represents the mean, and the slope is determined through the standard deviation. This distribution gives the probability that a utility is located within a certain location.

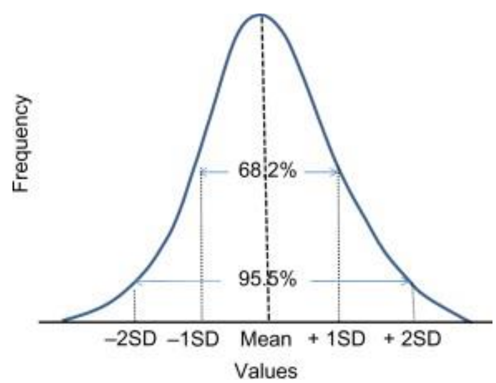

Figure 5 A Gaussian distribution showing percentage of values within a certain standard deviation from the mean. (Quesda, 2020)

There are two ways of finding the mean and standard deviation, these are highly related to the situation that one finds themselves in with regards to the provided data. These two situations are as followed.

2.A The mean and standard deviation should be found by recording the x and y direction of each utility for a minimum of 3 distinct data sets. Since there are three types of data that can play a role: trench surveys, municipal records, and expert opinions. By taking these 3 sets, the mean and standard deviation of the utilities direction can be found.

2.B if three distinct data sets are not available, which in this project is the case, a different method must be used. The paper by Duo mentions a probability of ‘correctness’ is given; however it is not indicated how to obtain this probability. In the paper by Tanoli, an error range of +/- 100 mm is taken to prevent damage. This value was found through trial testing (Tanoli, 2019).

Due to the limited amount of data the error range from 2B will be used as the 2 times the standard deviation value, this means that with +/- 100 mm, excavators can be 95.5% sure that it lays within that area. To make sure that this error range is also applicable to this method/project, the value should be verified. In this case this is done by Dura Vermeer. Dura Vermeer uses equipment from Leica. Per equipment it differs how much error there is. For the equipment that is used at this project, a devilation of 5-15 mm was given for GPS measurements of the direction. For other projects a deviation of 30-50 mm was given. Since the 100 mm is more than that, it is assumed that this is a correct value. For other projects, this value should be verified again.

After the 2 times the standard deviation has been determined a 2D visualisation can be created using the two direction vectors that were determined. This can be visualised as follows. Important to note is that trial trenches are always connected by a straight line. This may not directly link with reality and many flexible utility cables may have small bends and kinks in them.

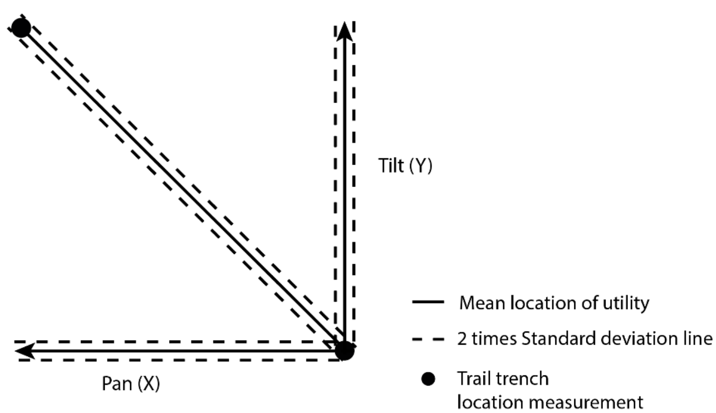

Figure 6: Pan and tilt methodology

In this diagram both the x and y vectors can be seen as the vertical and horizontal line. The combination of these two vectors represents de direction of the utility. This combination is the angled line in between the pan and tilt vectors. The middle solid line represents the mean of the measurements where the dotted line are the standard deviation calculated times two. This means that if a person digs outside the dotted and solid lines, they can be 95% sure that they do not hit the utility.

Stage 2: 2D conversion to 3D

Goal:

The precise mapping of buried infrastructure is of great importance in order to manage the underground infrastructure together with the prevention of utility damage. Nevertheless, it is uncommon to obtain a full overview of buried infrastructure (olde Scholtenhuis, Smart city development - lecture 2, 2020). Models in three-dimensional (3D) aim to provide a better visualization of buried infrastructure which can be sometimes ambiguous. 3D uncertainty representation will help to avoid inexactness in the use of utility data which can lead to better time managements and cost reduction. As in the case of Enschede which can improve a lot in the precise mapping. To this day the utility mapping only indicates a 2D model without uncertainties representation (Municipality of Enschede, 2020).

The steps:

One reason for the creation of few 3D models, is the uncertainty related to the utility's exact geospatial location. In general, utility data can be collected with certain precision. Practitioners use four different ways to express uncertainty in the location of utilities. They can be guided by standards, estimate or rule of thumb, surveyed (for instance GPS measurements) and unknown (data stored in a database without the indication if was obtained from standards, estimated or surveyed) (olde Scholtenhuis, Representing geographical uncertainties of utility location data in 3D, 2018).

The different registration practices, ground conditions and measurement instruments have created the situation where different databases exist. In this case, two datasets are considered, one from KLIC that is a public register from the government which is based on different sources. The other dataset is originated from the trial trenches. Both datasets can be used to represent uncertainties. The idea will be to implement a fuzzy shape around the possible location of a cable or utility, as shown in Figure 7. In the figure two red cables can be observed, which come from different datasets but refer to the same utility. The red circle around the cables represent the uncertainty, meaning that in reality the cable may be encountered anywhere within the red area(fuzzy shape).

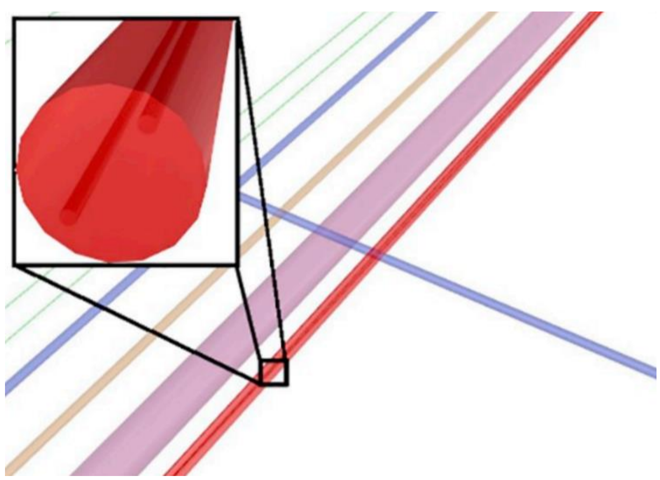

Figure 7 Visualization of uncertainty in 3D utilities (olde Scholtenhuis, Representing geographical uncertainties of utility location data in 3D, 2018)

In practice one dataset will be more reliable than the other. Data from trial trenches will have more importance than data from KLIC, since trial holes were made onsite. For that reason, weight factors are introduced. Weight factors, called weights, are used to give more importance to datasets which have more reliable values. These weights have a value between 0 and 1 and a higher value means that the dataset is more reliable. In the end, this means that trail trench data will receive a higher weight (w_{trial}) and KLIC data will receive a lower weight(w_{KLIC}). The easiest way to determine the values of the weight factor is by common sense.

With the use of the information collected from these datasets and the corresponding weight factors, the middle point of the fuzzy shape and the centering line can be determined. The formula of the middle point of the fuzzy shape can be calculated with:

$$x_{fuzzy} = \frac{w_{KLIC}\, x_{KLIC} + w_{trial}\, x_{trial}}{w_{KLIC} + w_{trial}} \qquad \textit{Equation 1}$$

$$y_{fuzzy} = \frac{w_{KLIC}\, y_{KLIC} + w_{trial}\, y_{trial}}{w_{KLIC} + w_{trial}} \qquad \textit{Equation 2}$$

$$z_{fuzzy} = \frac{w_{KLIC}\, z_{KLIC} + w_{trial}\, z_{trial}}{w_{KLIC} + w_{trial}} \qquad \textit{Equation 3}$$

This procedure is the same as shown in Figure 8**Error! Reference source not found.**, in which the centre of the fuzzy shape is represented in black.

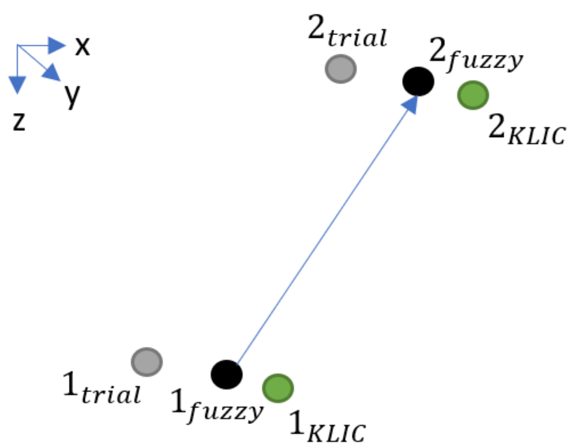

Figure 8 Visualisation of datasets in utility surveying

Another way to determine the fuzzy's coordinates is by using the 2D visualization, the Gaussian distribution, worked out in 3D. With this method, the weight factor can be determined mathematically. For each dataset (trial trenches and KLIC) a separate Gaussian distribution will be made with the Gaussian formula.

$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad \textit{Equation 4}$$

μ=Mean
σ = standard Deviation

In this case, μ is the measured value and σ is based on the uncertainty of the dataset. Note, that the trial trenches and KLIC Gaussian distribution are based on one dataset instead of at least three.

If two or more Gaussian distribution are multiplied with each other a new Gaussian distribution is made. Multiplying the trial trenches and KLIC gaussian distribution will give a Gaussian distribution for the Fuzzy shape. The mean value will be taken (the peak of the Gaussian distribution) for the middle point of the fuzzy shape.
For the Fuzzy Gaussian distribution are already two dataset used. In the end, a third dataset is advised.

After determining the fuzzy's center coordinates, it is possible to calculate the radius which will have the fuzzy shape. In order to determine formula 3 is used:

$$r_{fuzzy} = r + \max|l_{KLIC}, l_{trial}| \qquad \textit{Equation 5}$$

In this formula it is necessary to know two distances, from the centre of the fuzzy shape to the centre of the trial trench utility and from the centre of the fuzzy shape to the KLIC utility. From that, the largest distance is taken and added to the radius of the studied utility, that give as a result the radius of the fuzzy shape. Which is represented in Figure 9.

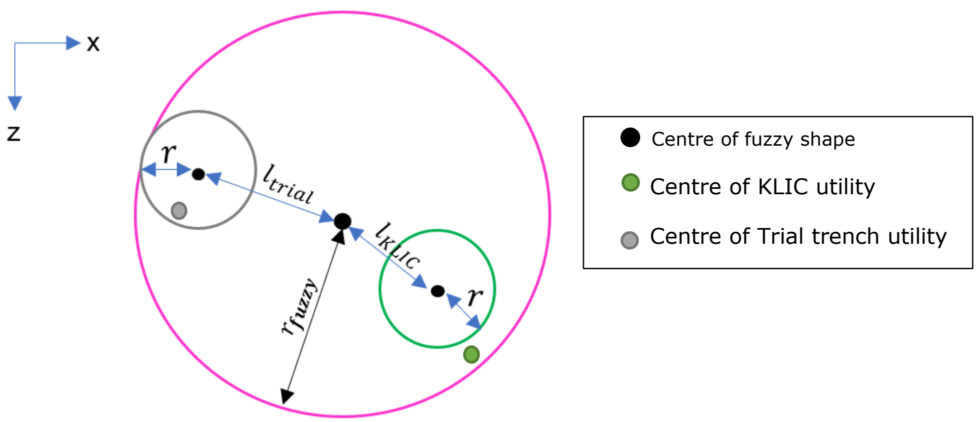

Figure 9 Fuzzy shape visualization

4.2 Design loop

As mentioned at Section 3.5 Requirements , system engineering is an iterative process. So, after several stages, it is determined whether the outcome of the stage still corresponds with the stage before. When this is not the case, adaptions will be made until it corresponds again. The second iterative step that is done is the design loop. This loop checks whether the design synthesis corresponds with the function analysis.the linking of functions and their objects can be found.

Table 2 Function object linking

The function	**The linked object (Can be clicked on)**
Estimating digging location	4.1.1 Determining trial trench locations
Trench digging optimization	Guidelines for number of Trial Trenches:
Extrapolate utility data between locations	Stage 1: 2D extrapolation of trial trenches information
Convert 2D to 3D data	Stage 2: 2D conversion to 3D

4.3 Example of use

In this Section, an example of the method described in the Section above (4.1 Model Description) is given. This example will be made with the use of data provided by Dura Vermeer from the project Elferinksweg.

4.3.1 Choosing trial trench location.

Within this project scope, trial trench locations had already been chosen and excavated. This information has been provided by Dura Vermeer. Due to this the process of selecting trial trench locations cannot be performed in hindsight as it would bring in biases.

Due to this, two trial trenches were chosen to act as our methodology test location. The chosen two trench locations were trial trench 2 and 3. There were a few reasons for this.

1. Between the two trenches different diameter pipes run, this makes working with the different uncertainty diameters interesting.

2. The depth relative to the surface changes for the utilities between the two locations

3. There are a very limited number of utilities travelling between the two locations. This makes creating the example for end users clearer.

Below the two trial trenches can be seen.

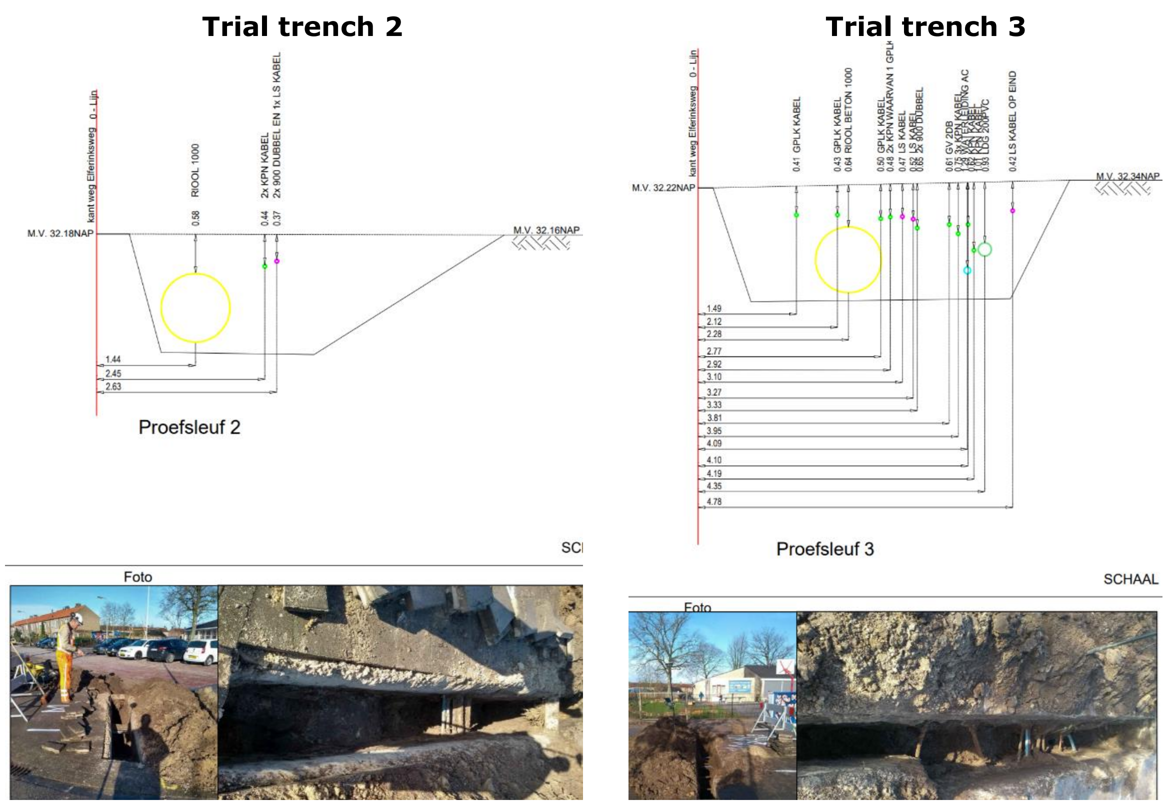

Figure 10 Trial trenches used in example

4.3.2 The method at work

Stage 1: The 2D visualization

The current visualization of the trial trenches looks as follows. As can be seen no connections have been made between the trenches. It is important to note that within the 2D visualization stage no KLIC data will be used, however, this will be used for the 3D visualization. The KPN cable was used for the example. The first step in the process will be to calculate the vectors to get the direction right.

Figure 11 Trial trench 2D data before extrapolation

Firstly, the angle of the utility relative to the horizontal axis has to be calculated. This is done with the data provided from the models. Using simple trig functions, the angle can be found of the utility.

Table 3 Trial trench angle calculation

	Length X	Length Y	Angle
Trial trench 2 KPN cable	0.2752	0.123	24.08
Trial trench 3 KPN cable	0.293	0.1028	19.33

As can be seen the angle of the utility is different for both Trial trenches, though not very large. As it is assumed that the utility travels in a relatively straight line the average of both angles will be taken. This leaves us with an angle 21.7 degrees to the horizontal. This angle is then used to connect the two KPN trial trench holes.

The final extrapolation can be seen of Figure 11 where the trial trench locations of the KPN cable have been connected with the white line.

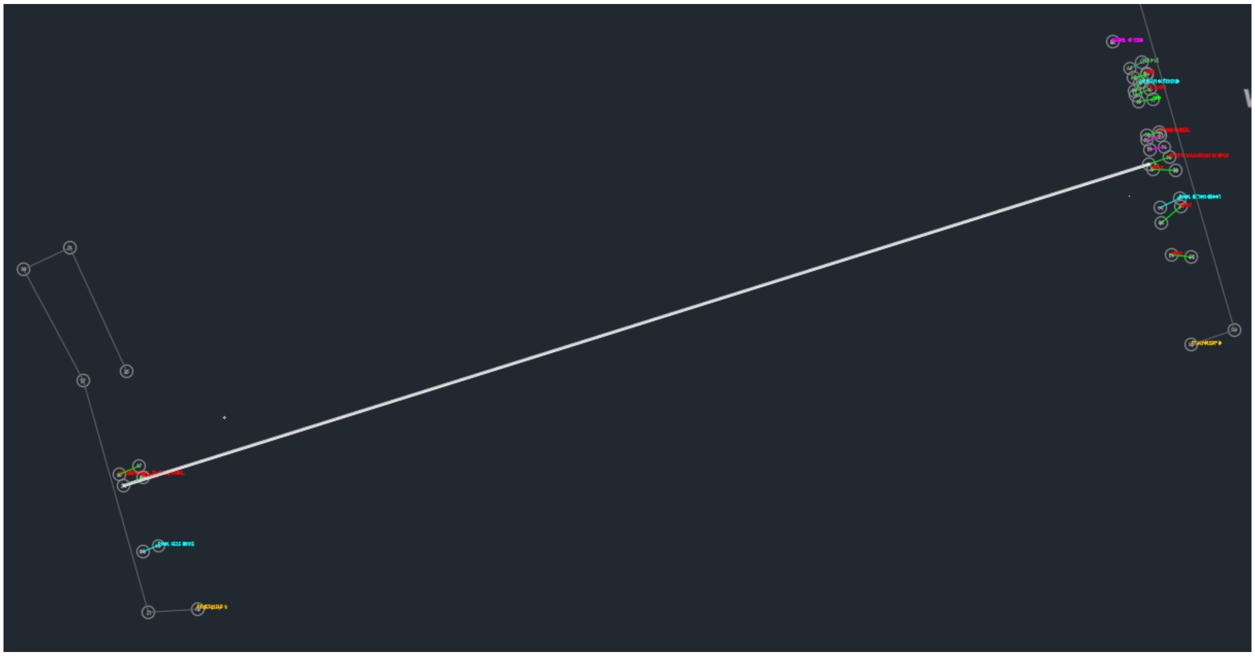

Figure 12 Trial trench 2D data before extrapolation

As only one data set was used the safety buffer that was given was 100mm based on the literature and information provided by Dura Vermeer. This buffer can be seen in Figure 13 with the centre line representing the mean utility location and the two lines either side being the 100 mm buffer.

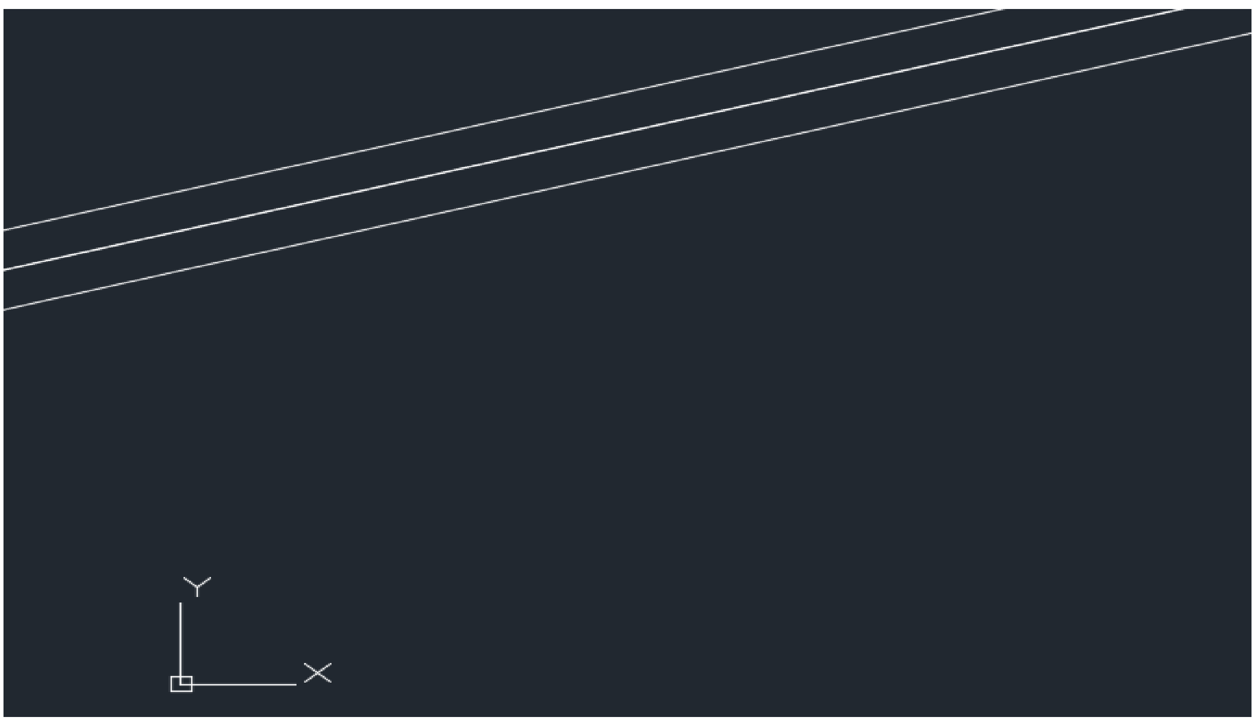

Figure 13 2D visualization of uncertainty in the model

Stage 2: The 2D-3D visualization with uncertainties

After the 2D utility was made, the utilities were converted to 3D, which was done in the same location (between trial trench 2 and 3). With the aid of the SWEEP function this was possible.

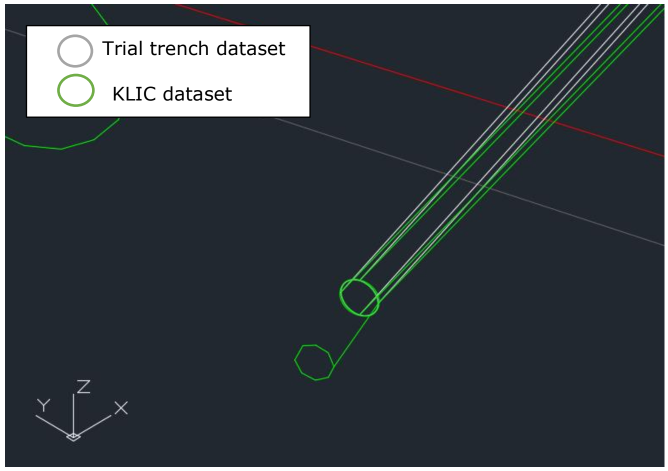

Figure 14: KPN cable at trial trench 2

As mentioned before, uncertainties were also taken into account. To do that, first it was important to collect the coordinates from both datasets, trial trenches and KLIC. Table 4 shows the coordinates of a KPN cable in trial trenches 2 and 3.

Table 4 Coordinates from Trench data KPN cable

	Coordinate X	Coordinate Y	Coordinate Z
Trial trench 2 KPN cable	256042.702	470598.47	31.724
Trial trench 3 KPN cable	256057.687	470603.142	31.813

The coordinates from the KLIC dataset were also considered and are shown in the following table:

Table 5 Coordinates from KLIC data KPN cable

	Coordinate X	Coordinate Y	Coordinate Z
KLIC data near trial trench 2	256042.929	470598.525	31.473
KLIC data near trial trench 3	256057.811	470602.788	31.56

With this data the coordinates of the center of the fuzzy shape can be determined, which is based on formula 2. By using MATLAB[1], the Gaussian distribution of the KLIC and trial trenches was done.

[1] The MATLAB script can be found in the supplied files

First, trial trench 2 was considered. As it can be visualized in Figure 15, three graphs are located at the top, each one represents a coordinate. In the first graph two Gaussian distributions are shown representing the x coordinate, each distribution corresponds to a dataset. By multiplying both Gaussian distributions a new Gaussian distribution is given below. The peak of this new distribution was used as the x coordinate for the fuzzy shape. Since this value has the highest probability in which the fuzzy shape will be located. This procedure was repeated for the remaining y and z coordinates.

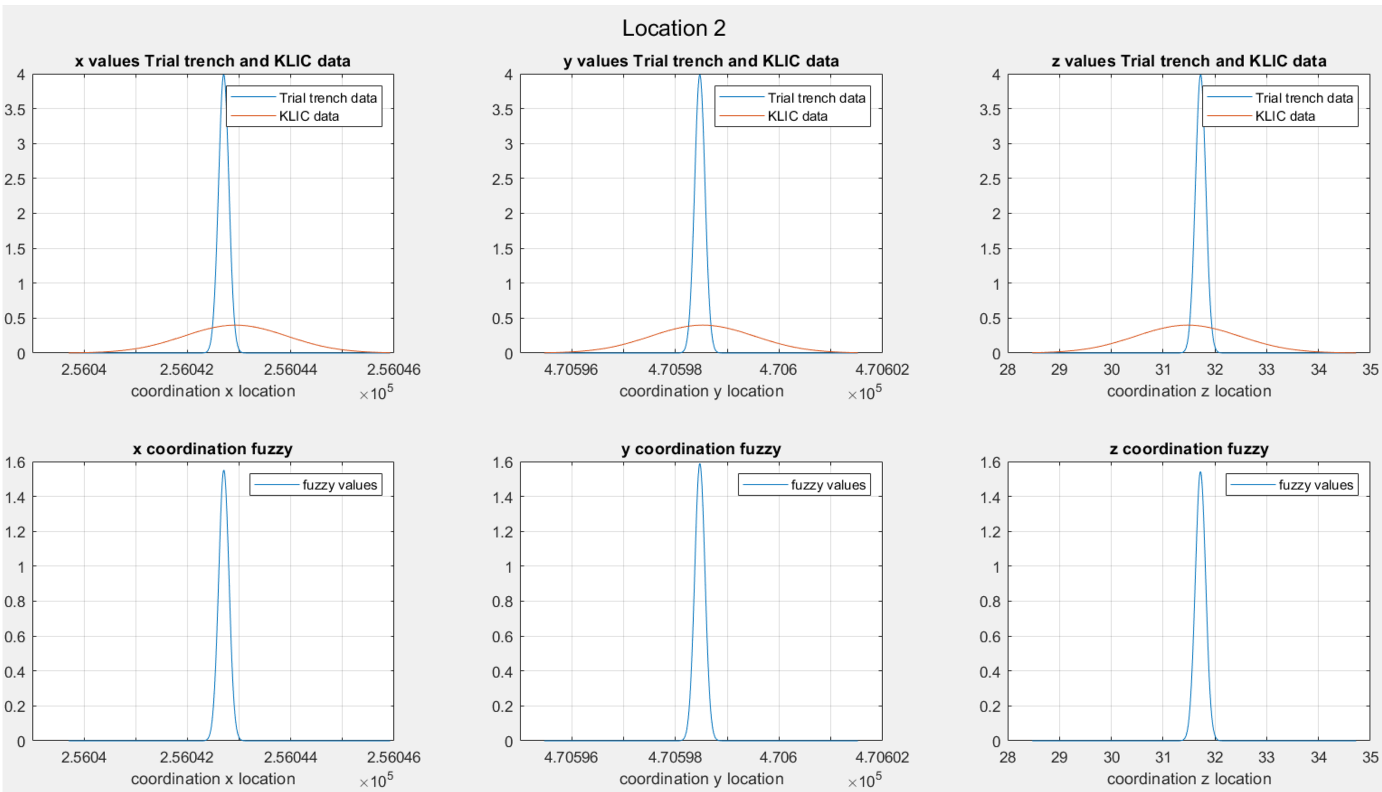

Figure 15:The Gaussian distribution of the datasets in Proefsleuf 2

After the coordinates from trial trench 2 were calculated, it was also necessary to calculate the coordinates from trial trench 3. The same procedure from trial trench 2 was followed, the results can be visualized in Figure 16.

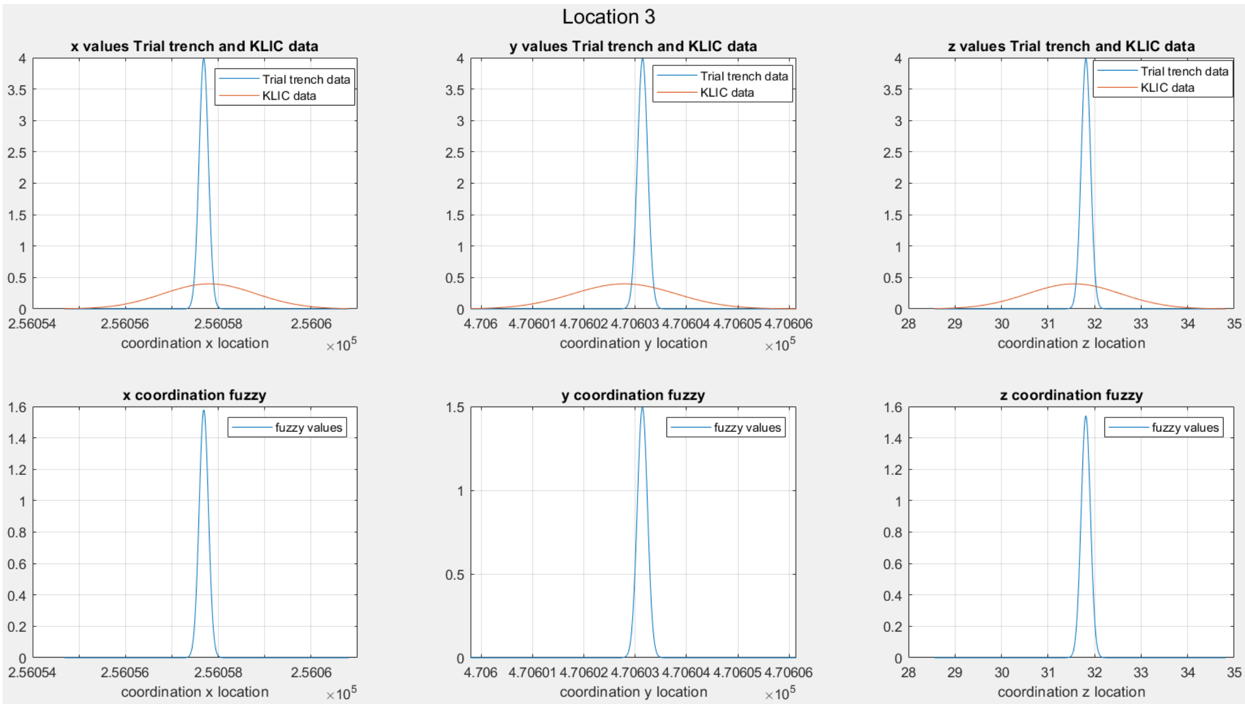

Figure 16: The Gaussian distribution of the datasets in Proefsleuf 3

The peak of the fuzzy's distribution is used for the center coordinates of the fuzzy shape, which have the following values:

Table 6: Coordinates of the fuzzy shape of KPN cable

	Coordinate X	**Coordinate Y**	**Coordinate Z**
Fuzzy shape trial trench 2 KPN cable	256042.702	470598.470	31.723
Fuzzy shape trial trench 3 KPN cable	256057.687	470603.138	31.810

The radius of the shape will be determined with formula 3. Therefore, it is necessary to know two values, the radius of the KPN cable and the largest distance measured from the center of the fuzzy shape to the center of the KPN cable in both datasets. Since the radius of the considered pipe is 5 mm. It was only necessary to look up for largest distance, as it is shown in Figure 16. The distance from the centre of the Fuzzy shape to the trial trench point is smaller, the measured value was 0.104. While, the distance from the center point of Fuzzy shape to the KLIC dataset was 0.378.

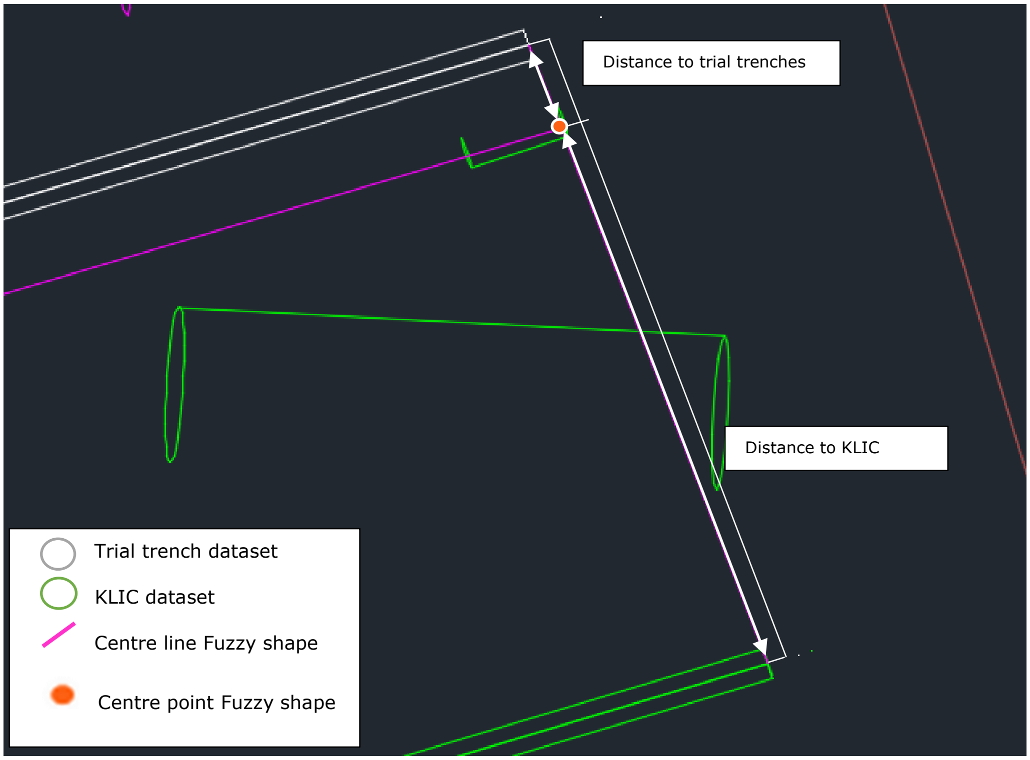

Figure 17:Top view of trial trench three

According to the formula the maximum distance should be taken. Therefore, 0.378 was added to 0.05 giving a value of 0.383 for the radius of the Fuzzy shape. Giving as a result the shape showed in Figure 18.

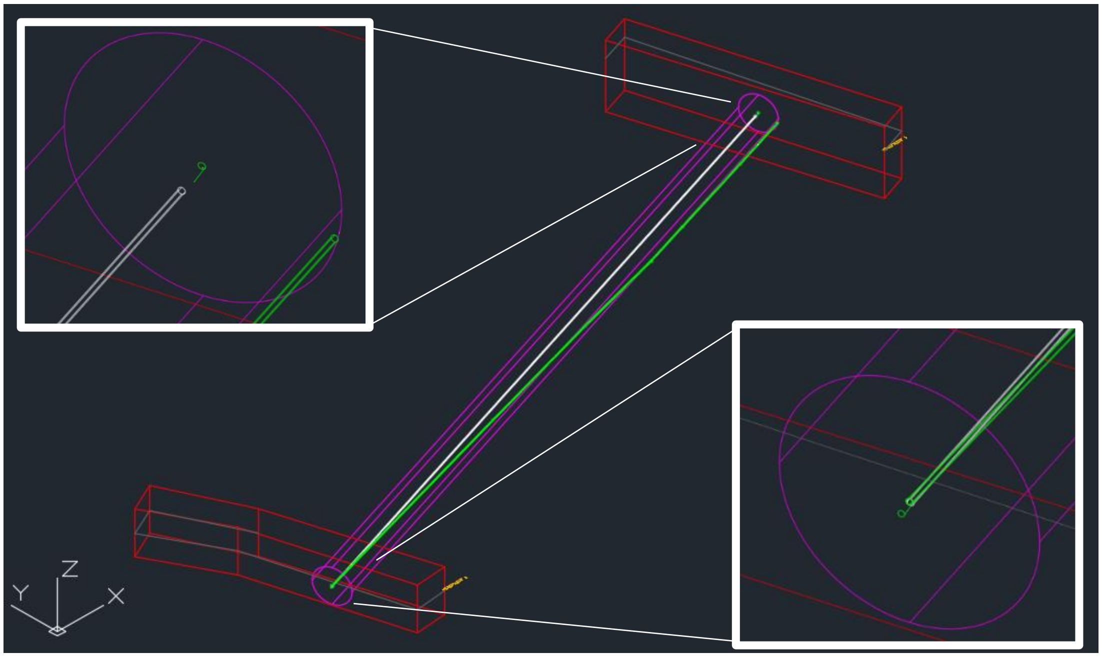

Figure 18:Uncertainty around KPN cable

4.4 Reflection on implications for society

Utilities are as important as they are dangerous to our society. A great example of the dangers is the 2018 gas explosion in Sun Prairie which left 1 fireman dead and several wounded (nbcnews, 2018). Having a 3D model which visualises the locations of utilities improves overall awareness of the utilities in the underground. More importantly, when regarding safety, is the use of probabilities. This has a direct psychological effect on a person (Robinson, 2020). The uncertainty creates a form of anxiety as contractors will be unsure of the exact locations of pipes and therefore by their nature will be more careful. Such a change will make the lives of people safer in the long term.

Another major benefit that this could bring is the preparation for infrastructure changes related to climate change. With the European Green deal in action the Netherlands has large aims of becoming climate neutral in the year 2050 (European union, 2019). These drastic changes mean that some utilities will become obsolete and could be converted for use with another medium. Having clear ideas where pipes lines are located will help with these utility changes. This will safe society money overall and make the process of switching to a greener way of living much simpler.

Related to both these benefits is the current change in the industry with Augmented reality which is currently being experimented with at BAM and other companies in the field (bHome, 2020). Having prepared 3D models will make these new innovations even easier to implement increasing efficiency and perhaps saving taxpayers money in the end.

4.5 Verification and Validation

As mentioned before, besides the requirement and design loop also a verification and validation were conducted in order to make sure that the result of the Design synthesis is what is desired. Verification refers to the checking of results to the set requirements in section 2.2. Validation is the act of showing results to the Client.

4.5.1 Verification

With the verification it is checked whether the requirements are met. In total, 4 requirements were set up, see Table 7. These requirements are translated into a method, in the Table 7 it is stated which part of the method connects with which requirement.

Table 7: Connection between methods and requirements

ID	Description	Criterion	Performance	Related method
1.1	Create a 3D model methodology of (underground) utilities	95% accuracy	- 5%	Extrapolation of utility data between locations + 2D to 3D conversion with uncertainty
1.2	Map the uncertainty of the location of the utilities	95% accuracy	- 5%	2D to 3D conversion with uncertainty
1.3	Determine trial trench locations	Are the trial trench locations effective for locating utilities?	Yes	Trial trench determination

In Section 3.2 Requirements analysis, the requirements and their performance criteria are given (see also Table 7). These performance criteria are used to determine whether the requirement is met. The verification is about checking whether these performance criteria are met. In this case it was not possible to check this, because there was no data available for this. It is therefore recommended to get some extra data to perform the verification. An example to create extra data is making extra trial trenches in which it is tested whether the location of the utilities corresponds with what is given in the 3D model.

4.5.2 Validation

The validation is about determining whether the result of the design corresponds with the wishes of the client (and the stakeholders). After sending the draft report to the client, Dura Vermeer, the following points were interpreted from their feedback.

Uncertainty related to measurements was found to be very interesting. The +/- 100 mm buffer found in the 2D visualization was realistic for practical use as it would certainly be enough for avoiding utility damage.

According to the client, however, this was not their main priority when creating this methodology. The clients main wish was for the amount of trial trenches to be reduced whilst the information gathered from them could be increased.

Although the method created may assist in this process the focus was not put upon this wish as this had not been directly communicated to our team. This is one of the items that could be worked upon in the future.

5. Relation to introduction to smart city engineering Concepts

Smart city engineering is a concept that does not have one definition. In fact, there are many different definitions based on the opinion of different researchers. This makes that also all Smart Cities are different. Contributing to this differences, is the fact that Smart Cities self-proclaimed to be smart. Hollands did a research regarding the aspects of self-proclaimed Smart City characteristics. (Hollands, 2008) The outcome was that there are 4 different characteristic that often occur in cities that self-proclaim to be a smart city. Namely (olde Scholtenhuis, Smart city development - lecture 2, 2020):

1. “Utilization of networked infrastructures to improve economic and political efficiency and enable social, cultural and urban development
2. Being economically attractive for entrepreneurs, businesses, large corporations -> business-led urban developments
3. Communities need to become smart to drive a smart economy. This requires social learning education and social capital.
4. Social inclusion and environmental sustainability”

When comparing these different characteristics to the project that is described in this report (Creating a method to make a 3D model of (underground) utilities), it can be found that there is relation between them. Namely the method that is designed in this paper, can be categorized as the characteristics 1 and 4 (utilization of networked infrastructures and environmental sustainable)

The method is a technological innovation regarding the localization of (underground) infrastructures. With the new method the efficiency in economic view is increased. Since the use of the method decreases the amount of trial trenches which is economic beneficial as extrapolation allows for less trenches to be dug. Besides this the 3D models that are created by this method can give opportunities to further improve the economic and political efficiency and enable social, cultural and urban development by using it for other purposes. For example if maintenance should be done, the 3D models can be used to make this smart maintenance.

Also this method will increase/ensure the (environmental) sustainability. Since less trial trenches will result in less construction, which results in less emissions. But also because of the better localization of utilities, the chance that a utility get damaged will decrease. Which can also have positive effects on the climate (because if for example a gas pipe is damaged it can have big consequences for the environment).

6. Conclusion

Overall, the consultancy has managed to create a methodology by which it is possible to obtain a 3D visualization of the utilities and also consider the uncertainties. For a better understanding, the methodology was applied to a real example within trial trench 2 and 3. This helped the group to prove that the methodology worked as intended and two visualize the results that can be obtained if its applied in reality. Therefore, the method fulfills the goal which was proposed at the start of the project. Furthermore, it can be applied to more utilities and will help the construction companies to have a better estimation of the locations of utilities in 3D also considering the uncertainties.

7. Recommendations

With the methodology completed there are some recommendations that the client could do further research into for increasing the efficiency of 3D visualization.

Firstly, it is recommended that the method is tried within the projects scope. This is as the team has not had a possibility to test if the methodology is accurate within the boundaries set by the requirements. After the confirmation that the method works sufficiently, the next step would be to trial the approach in locations outside the project area, especially in locations with different geophysical attributes. This will give insight, in large part, to the assumptions set within the current method and if the steps could be used on a nationwide scale.

Secondly the introduction of Ground Penetration Radar within the method should be explored. Within the 2D visualization hints of its use have already been placed. Introducing this into the methodology adds and additional data point for the 3D visualization and could make trial trench digging more efficient.

Third, both stages require as many possible measurements as possible to get accurate results. As seen in the example used within this report very little data was available. Only survey data and KLIC data, which is very unreliable, could be used. This made using the 2D and 3D visualization very difficult, especially for determining the 2 standard deviations in the 2D visualisation. It is recommended that when wishing to create 3D visualizations more measurements of the same type should be performed as well as different methods of measuring. This will allow for even more accurate maps to be created.

Fourth, from the validation stage it became clear that the clients wish had not fully been fulfilled. For the next edition it is recommended that more focus is set on the efficient use of trial trenches and preferrable reducing the amount of trenches that have to be dug.

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