Spatial and semantic enrichment of utility networks data

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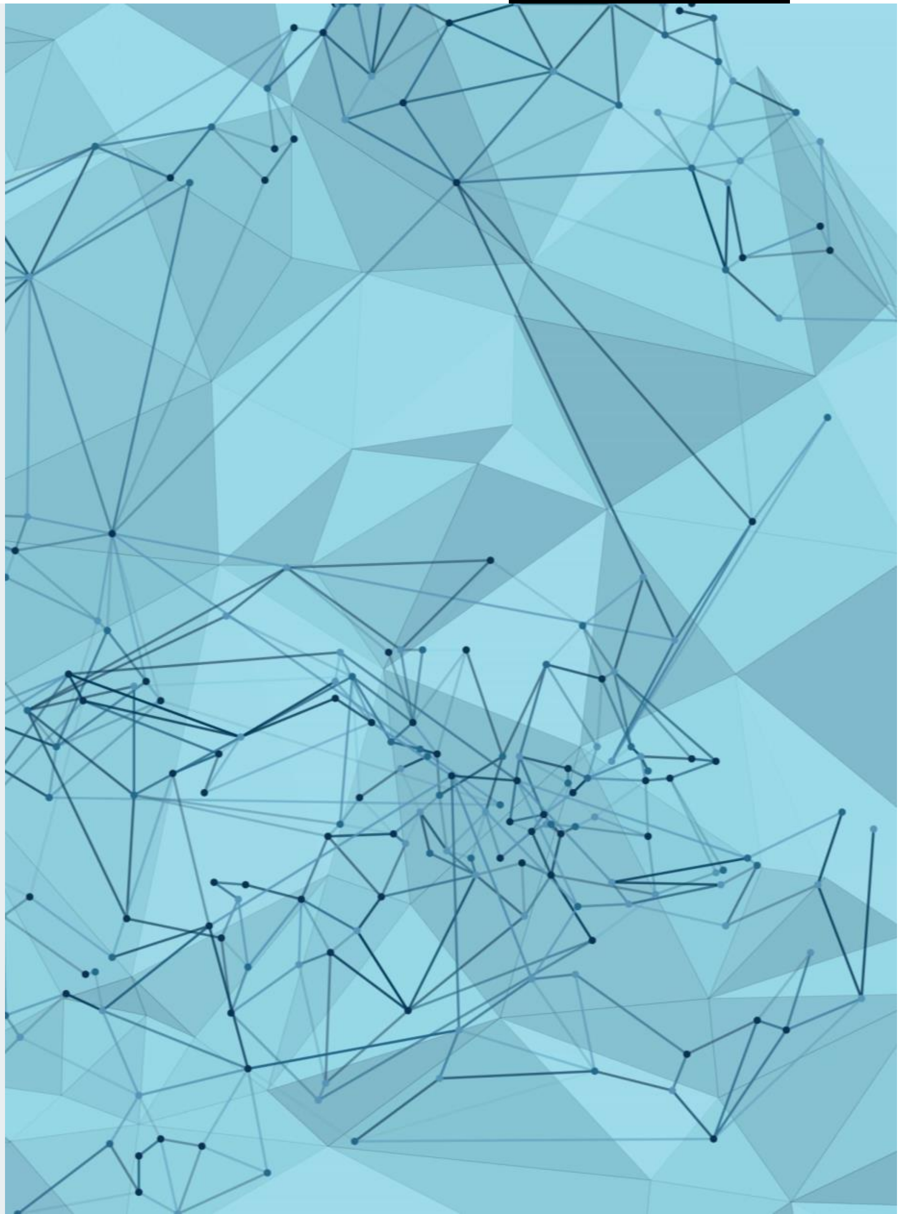


Utility Network Maps

- Purpose:
  - Representations of infrastructure systems
  - Illustrates the physical layout, connections and relationships
- Current state:
  - Traditionally represented in 2D
- Objective:
  - Enhance the maps by enriching the information spatially and semantically

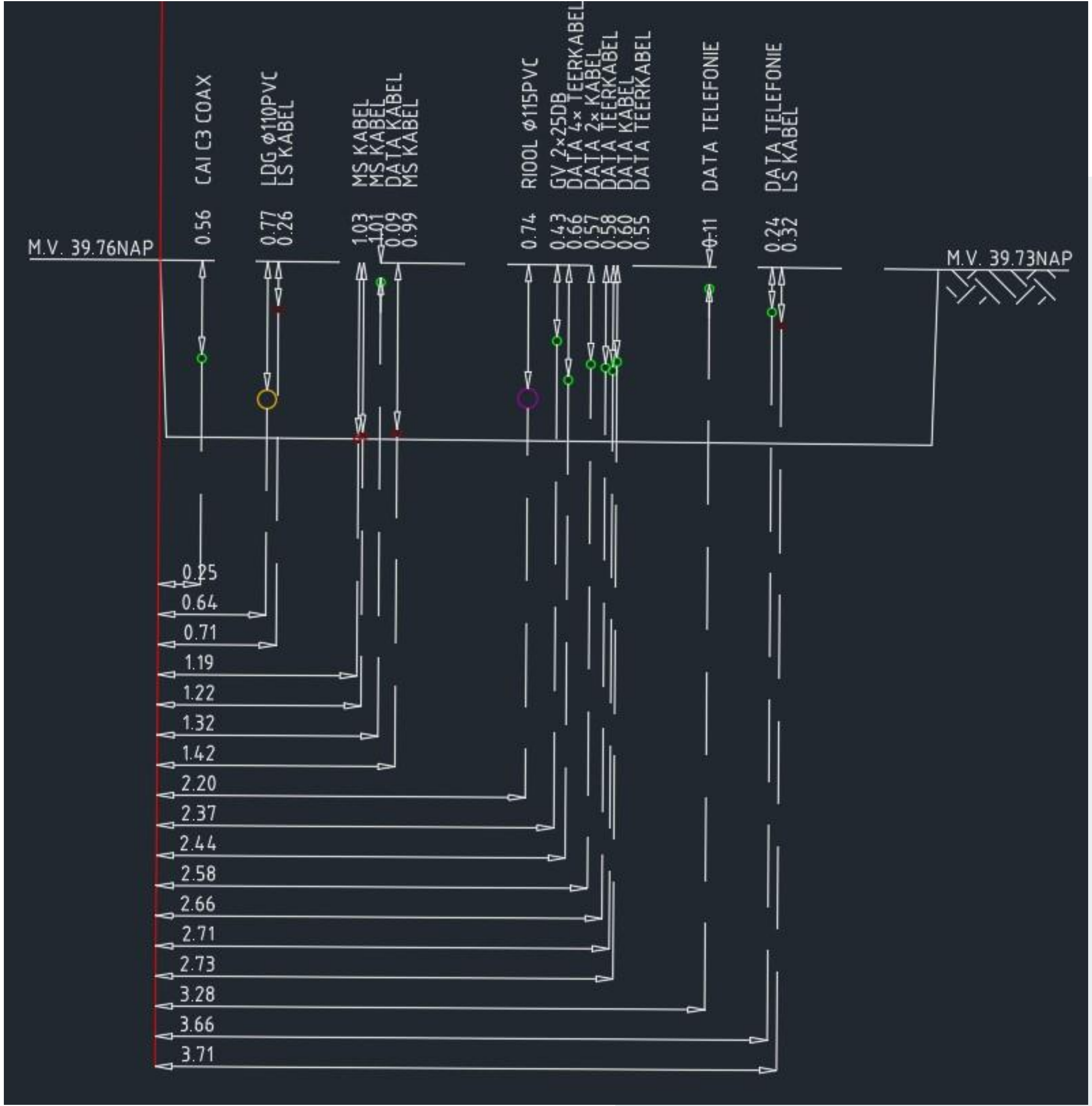
Source: Yan, Jingya et al. "THREE-DIMENSIONAL DATA MODELLING FOR UNDERGROUND UTILITY NETWORK MAPPING."

Why?

- Increased complexity and size of utility networks due to:
  - Urbanization and growth of cities
  - New technologies
- Infrastructure planning and development
- Preventing damages
- Efficient maintenance
- Emergency response

Source: https://www.centriforce.com/news/utility-damage-prevention-preventing-utility-strikes/

Utility Trenches (Proefsleuven)



Provided by the municipality of Enschede

What is the goal?

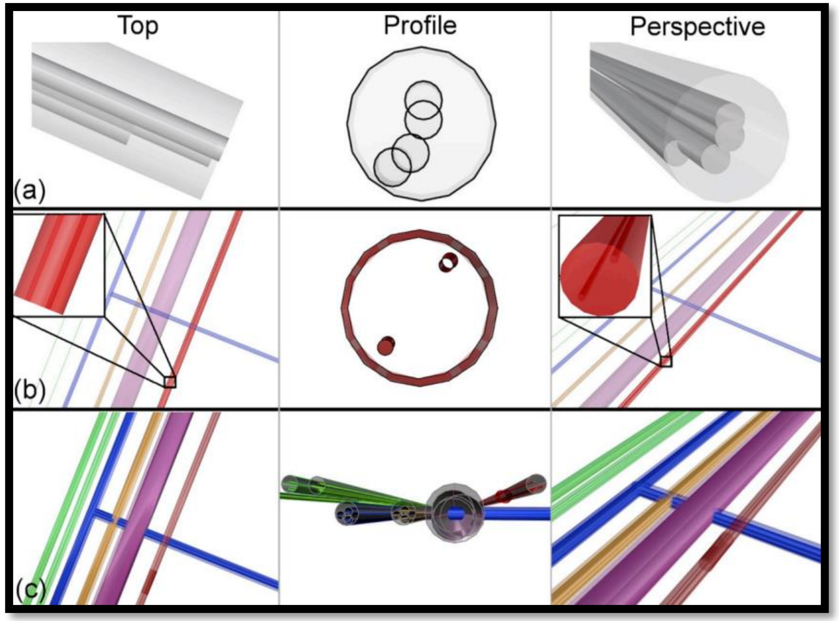
- Enrich the utility networks of different municipalities
  - Using data obtained from utility trench surveys
- Define/implement methodology that allows to solve the problem (semi-automatically)

Provided by Gemeente Rotterdam

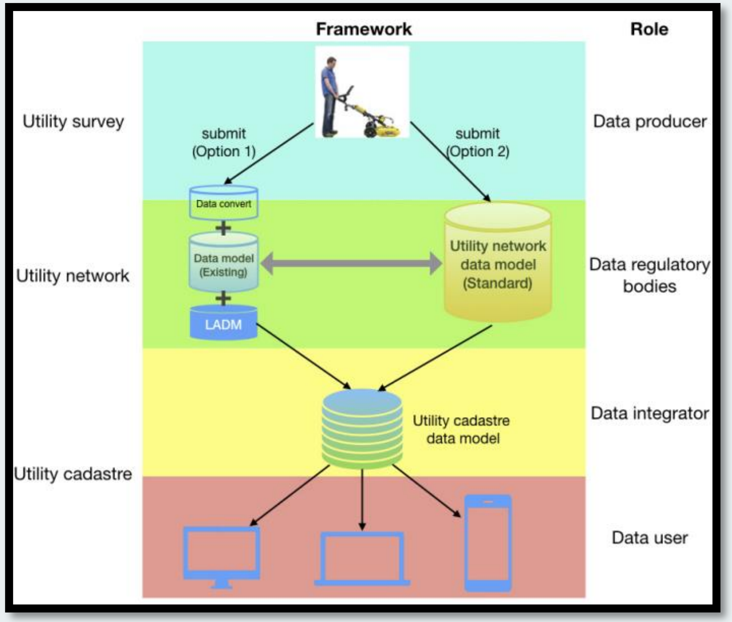
Research Question

- To what extent can existing 2D utility network models in the Netherlands be enriched using surveyed utility trench data?
  - To what extent can the information be integrated either semantically and/or geometrically?
  - To what extent can a common methodology be implemented for the 3 different cities?
  - Which strategies can be developed to automate the data extraction and integration process?
  - How far can current standards help reduce issues relating to data integration?

Related work

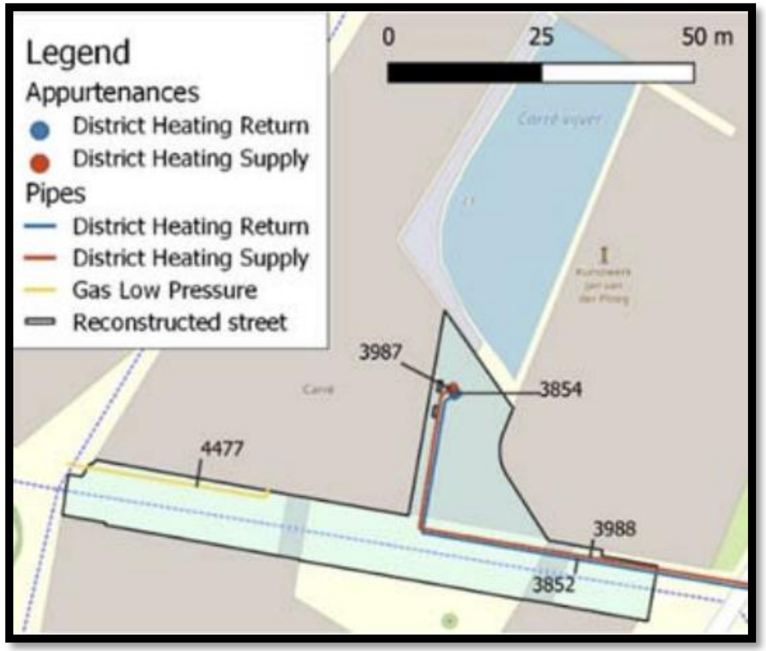


L.L olde Scholtenhuis et al. (2018) – Representing geographical uncertainties of utility location data in 3D

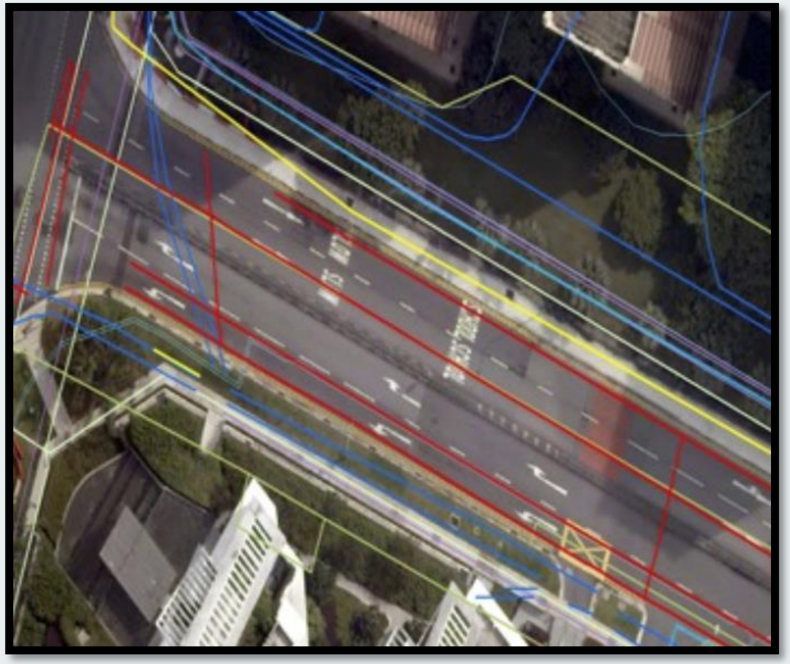


Jingya Yan et al. (2018) – Three-dimensional data modelling for underground utility network mapping

Related Work



F. Fossatti et al. (2020) – Data modelling for operation and maintenance of utility networks: implementation and testing



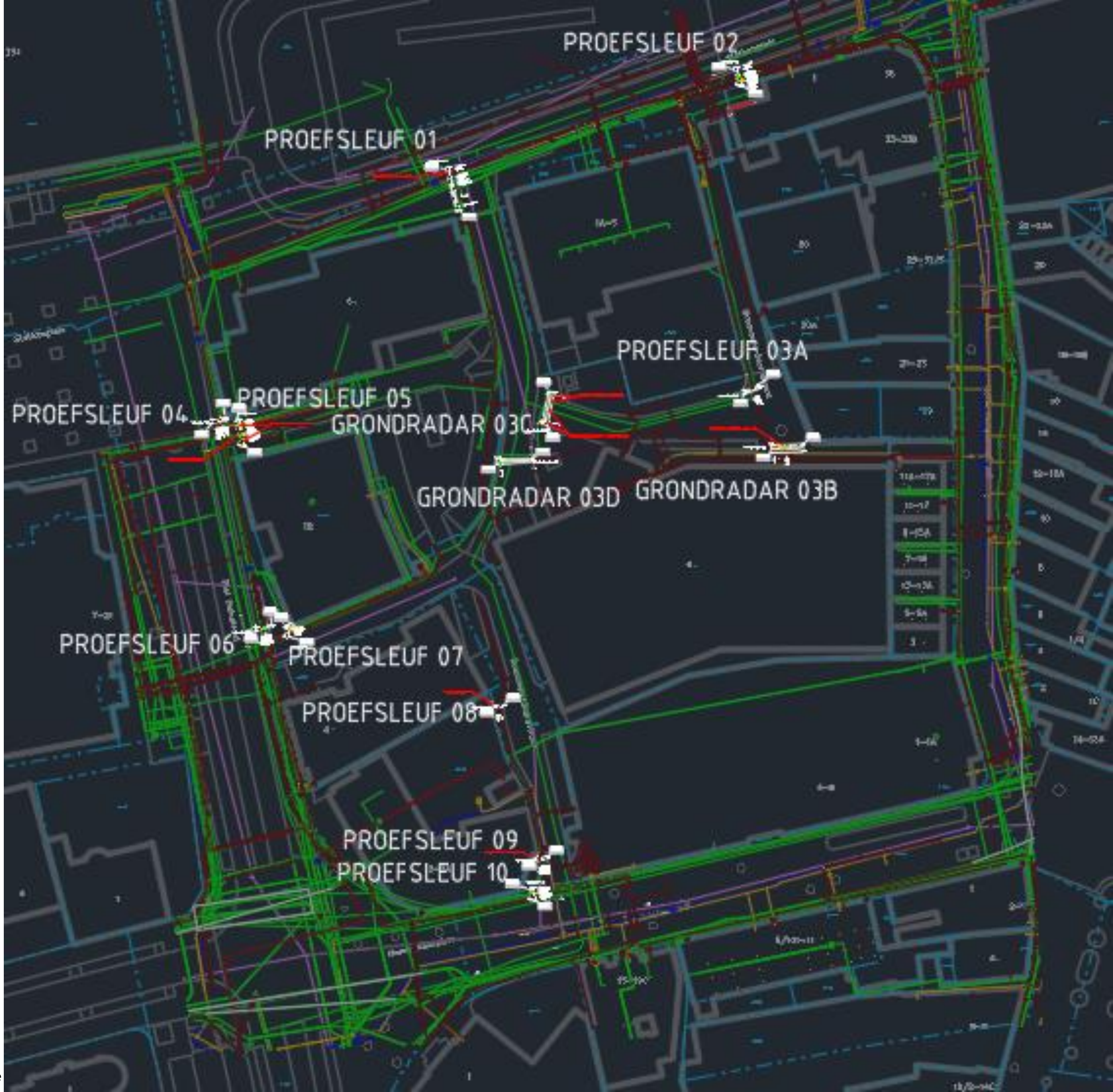
L. H. Hansen et al. (2021) – Addressing the elephant in the underground: an argument for the integration of heterogenous data sources for reconciliation of subsurface utility data

Methodology workflow

- Data acquisition
- Extraction & preparation
  - Geometrical processing
  - Label processing
- Integration
- Result analysis

Case studies

- Enschede (Brammelerdwarstraat & Deurningerstraat)
  - Utility trench survey data (.dwg)
  - KLIC network map with trench positions (.dwg)
- Rotterdam
  - Utility trench survey data (.dwg)
  - LVZK network map with trench positions (.dwg)
- Amsterdam
  - Utility trench survey data (.pdf)
  - Utility network map (.dwg)



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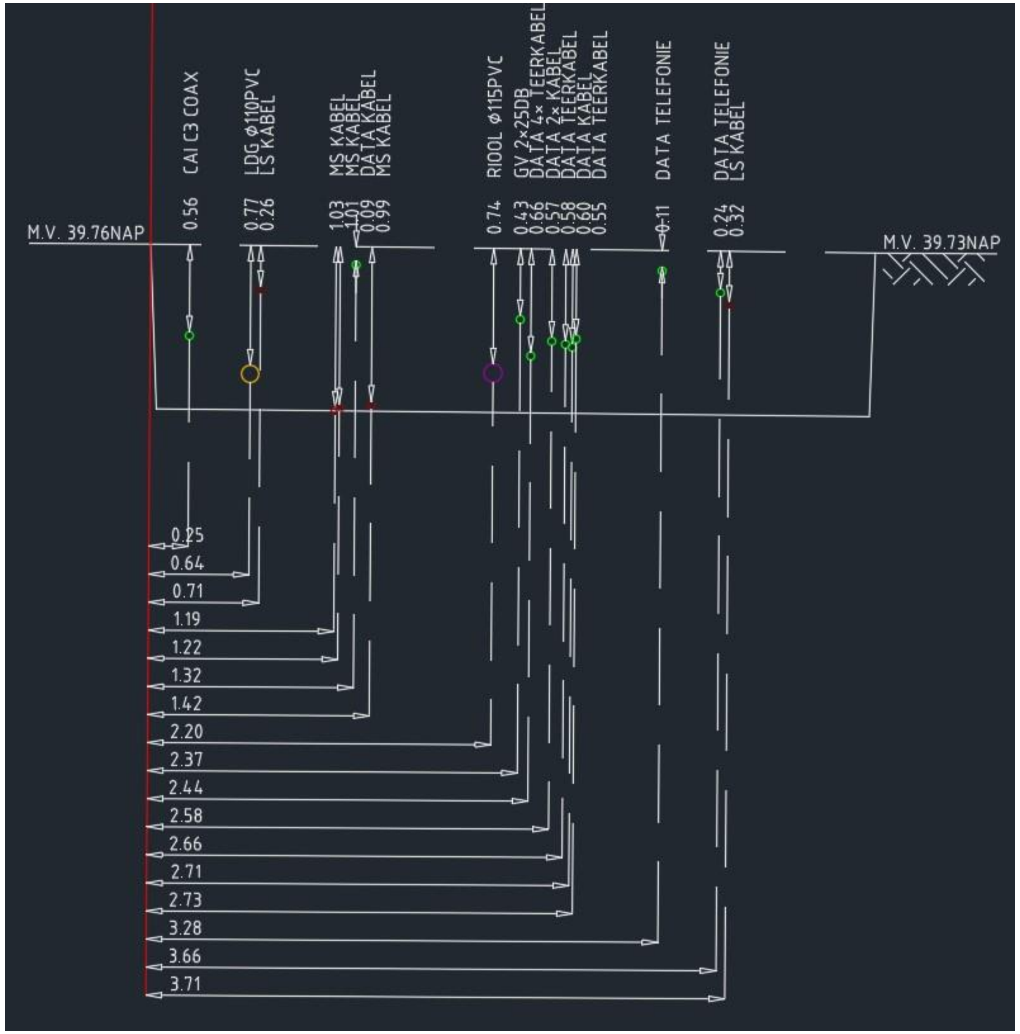
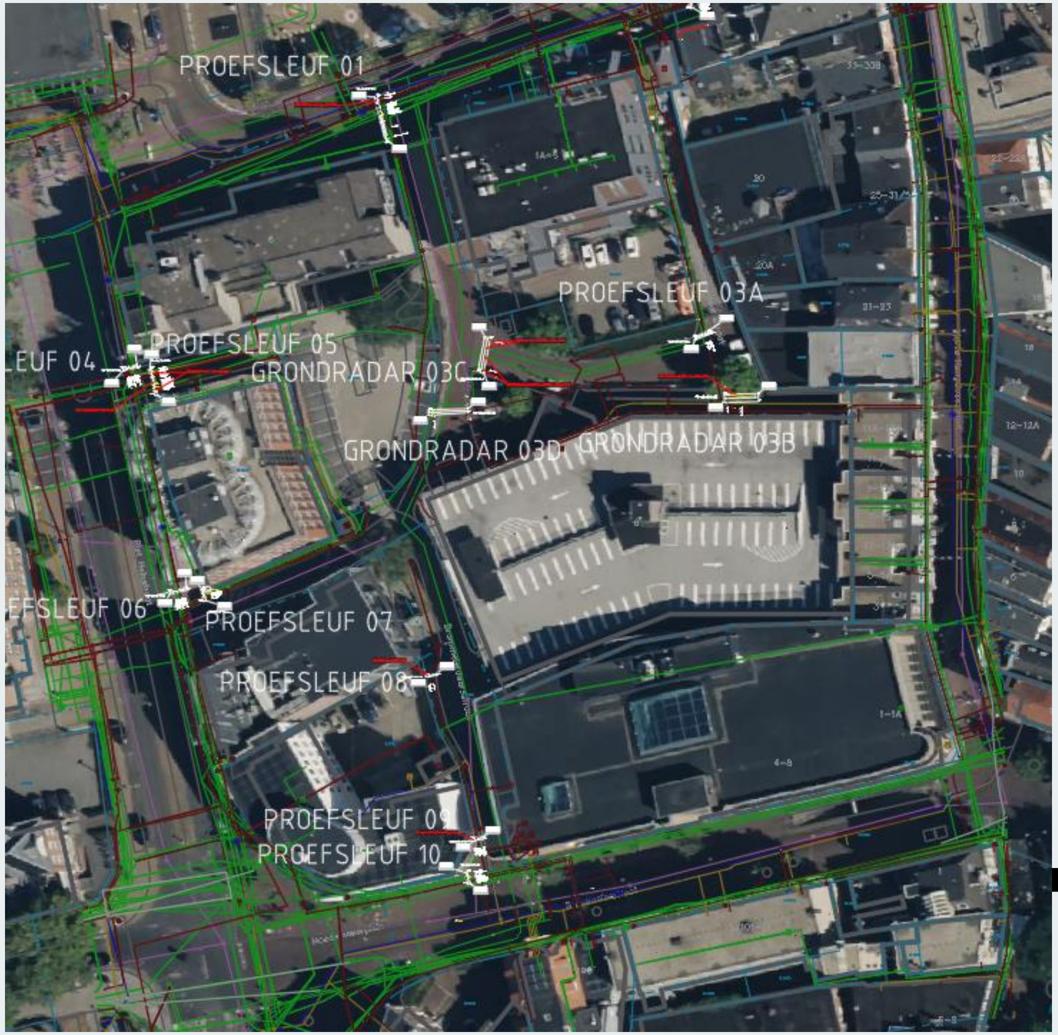
Enschede Data





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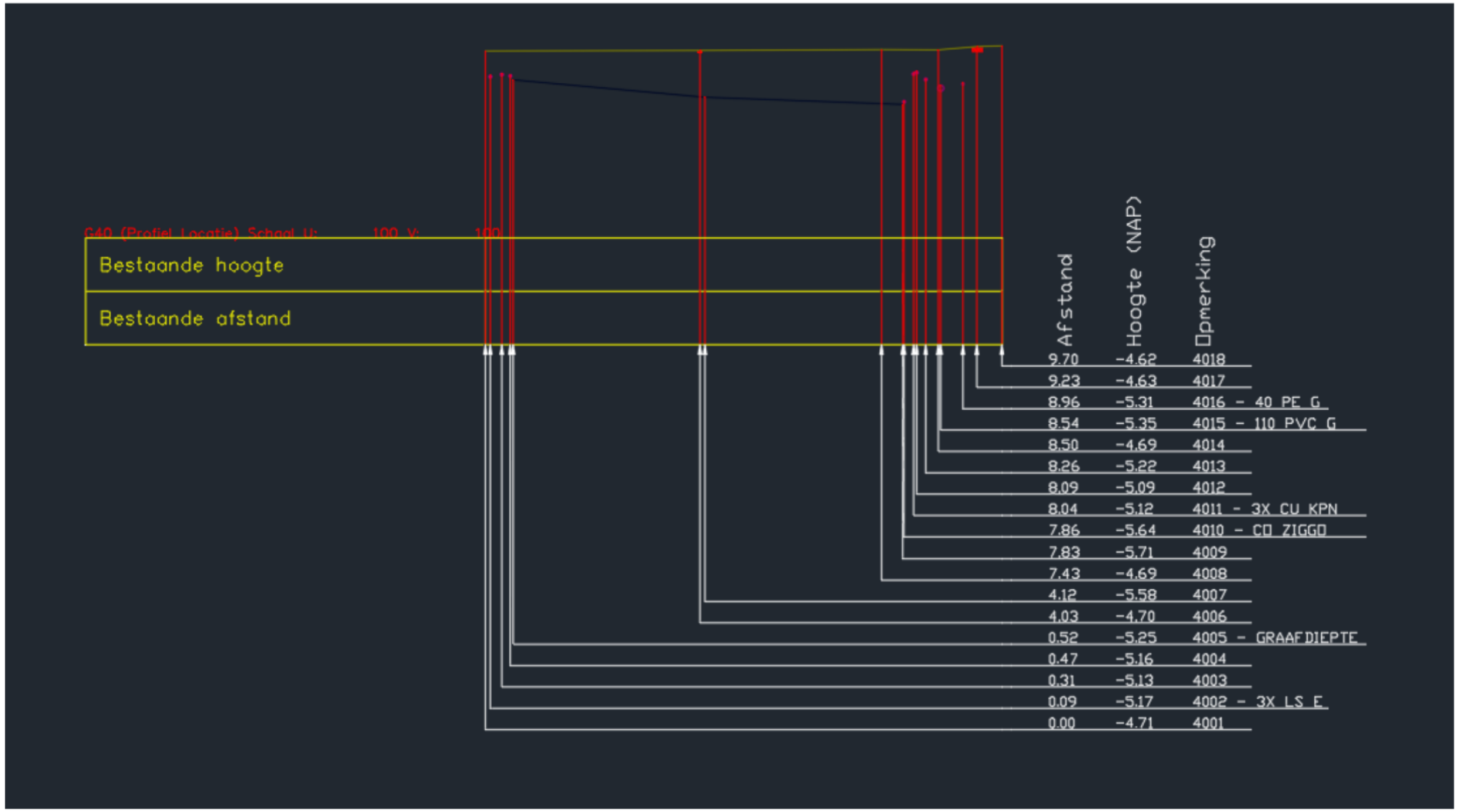
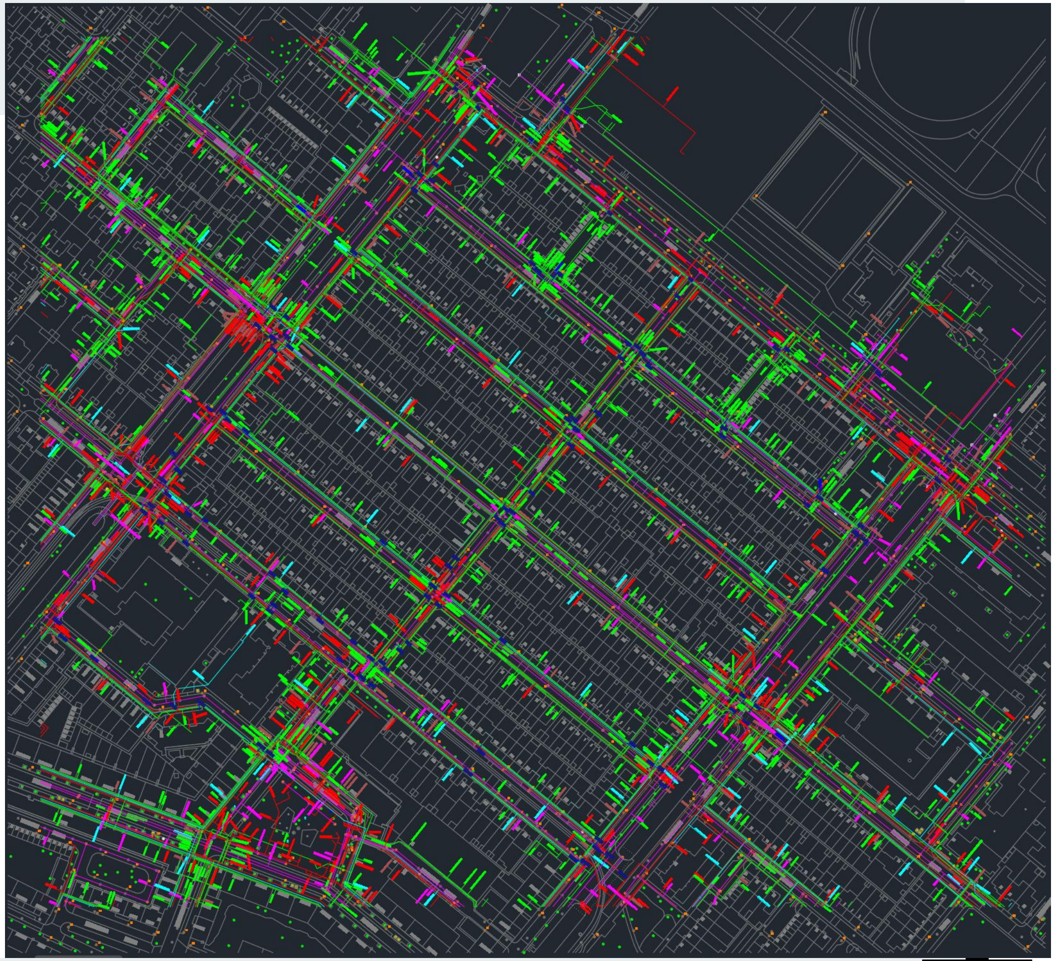
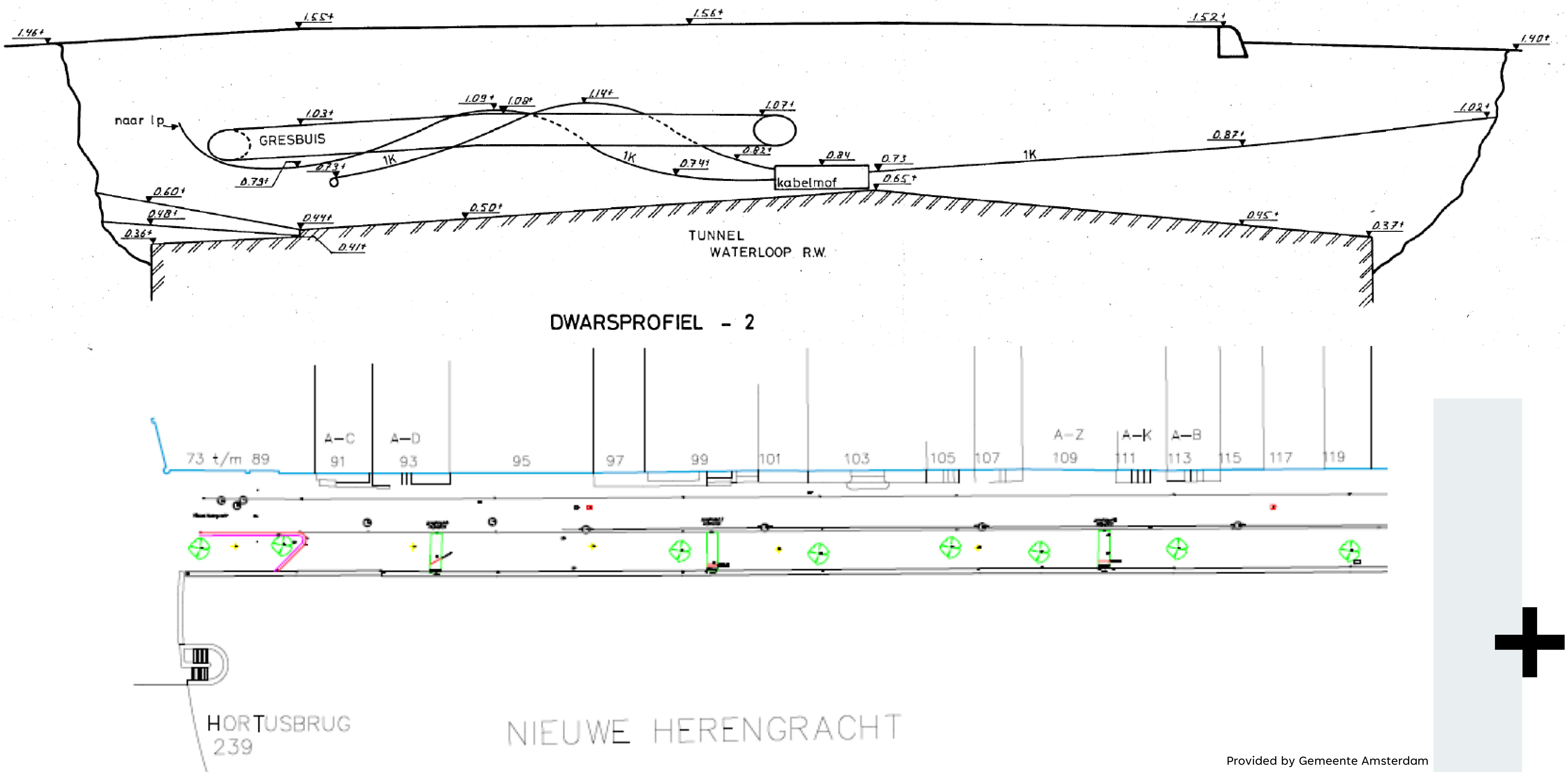
Rotterdam Data





Provided by Gemeente Rotterdam

Amsterdam data



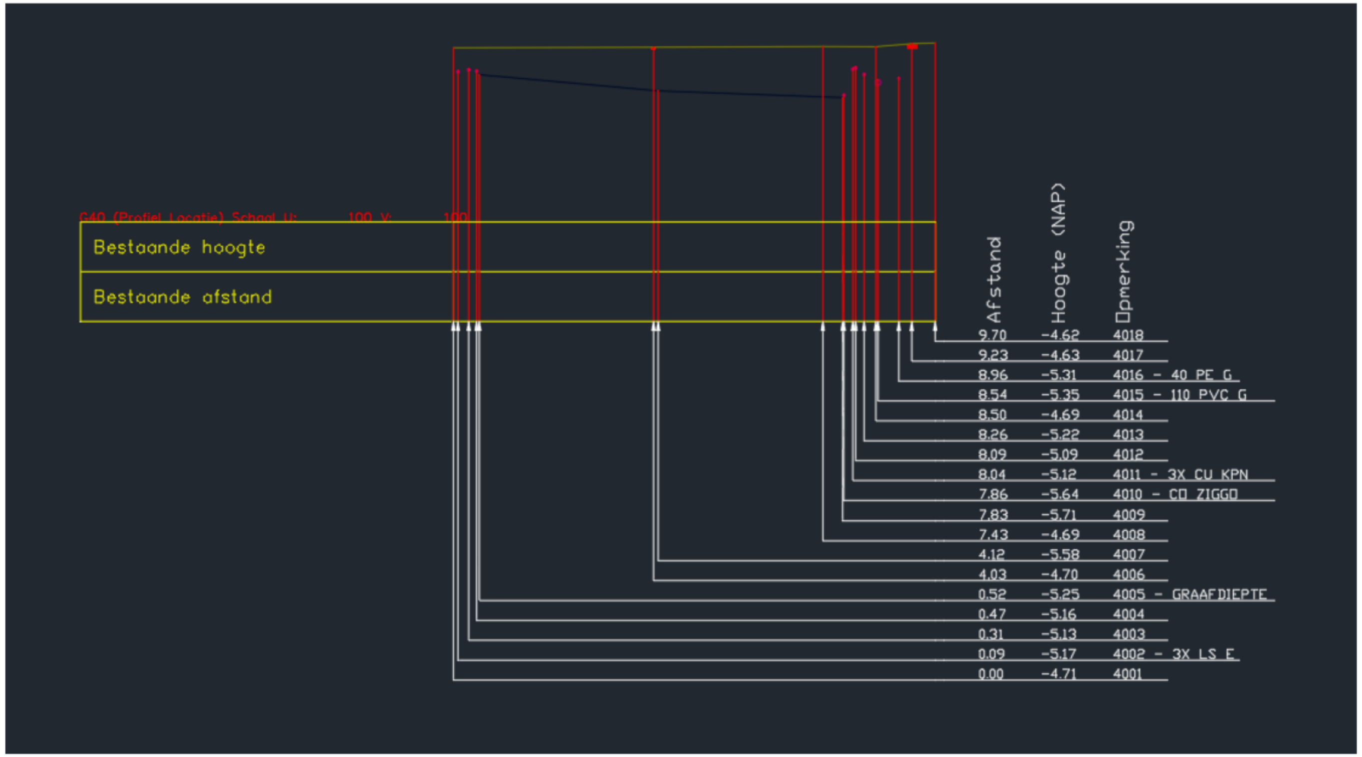
Provided by Gemeente Amsterdam

Methodology workflow

- Data acquisition
- Extraction & preparation
  - Geometrical processing
  - Label processing
- Integration
- Result analysis

Geometrical Processing

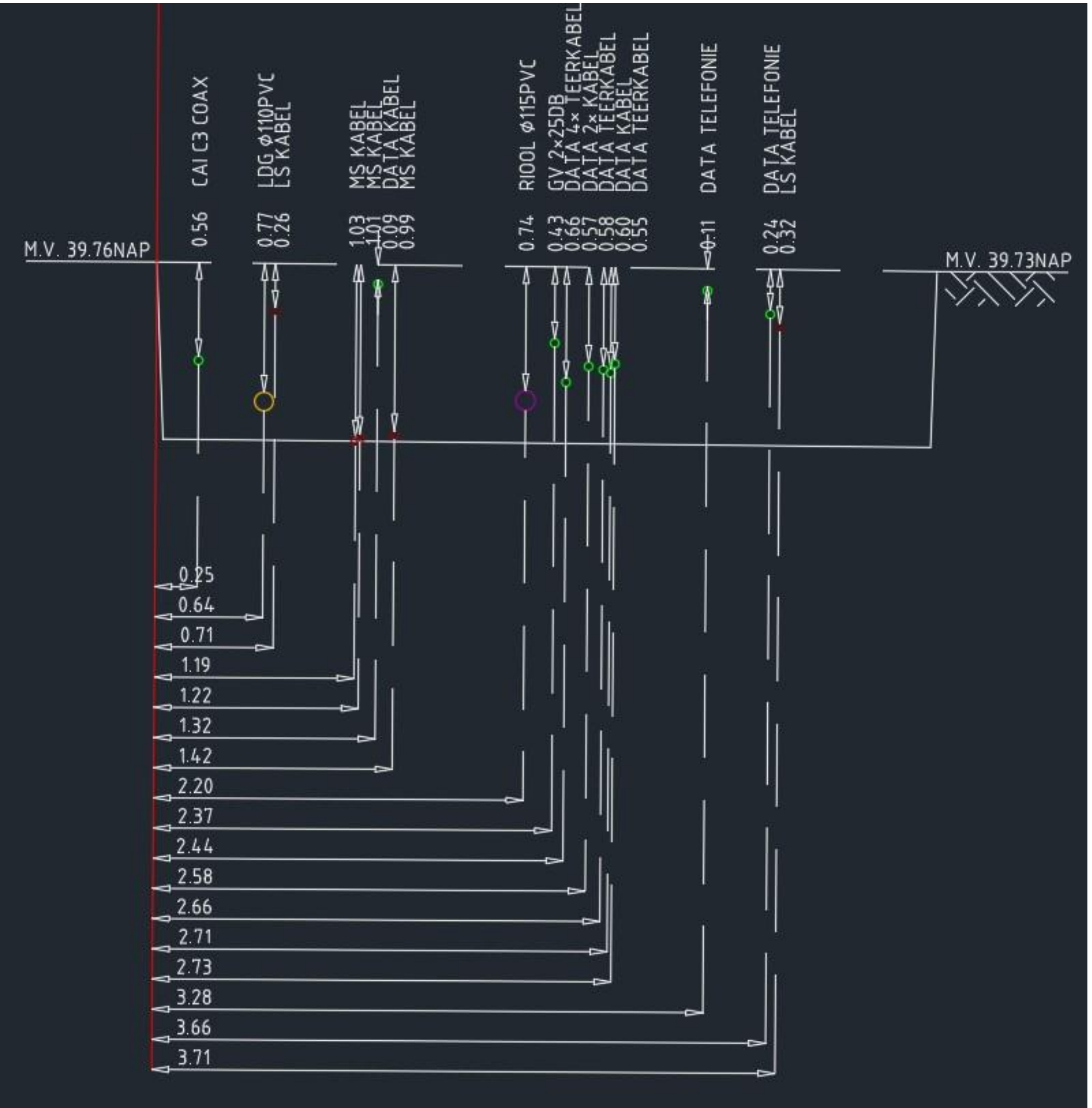
- Extract surveyed trench data
- Extract trench positional data
- Calculate individual cable positions
  - E, N, Z (for Enschede)



Tools used

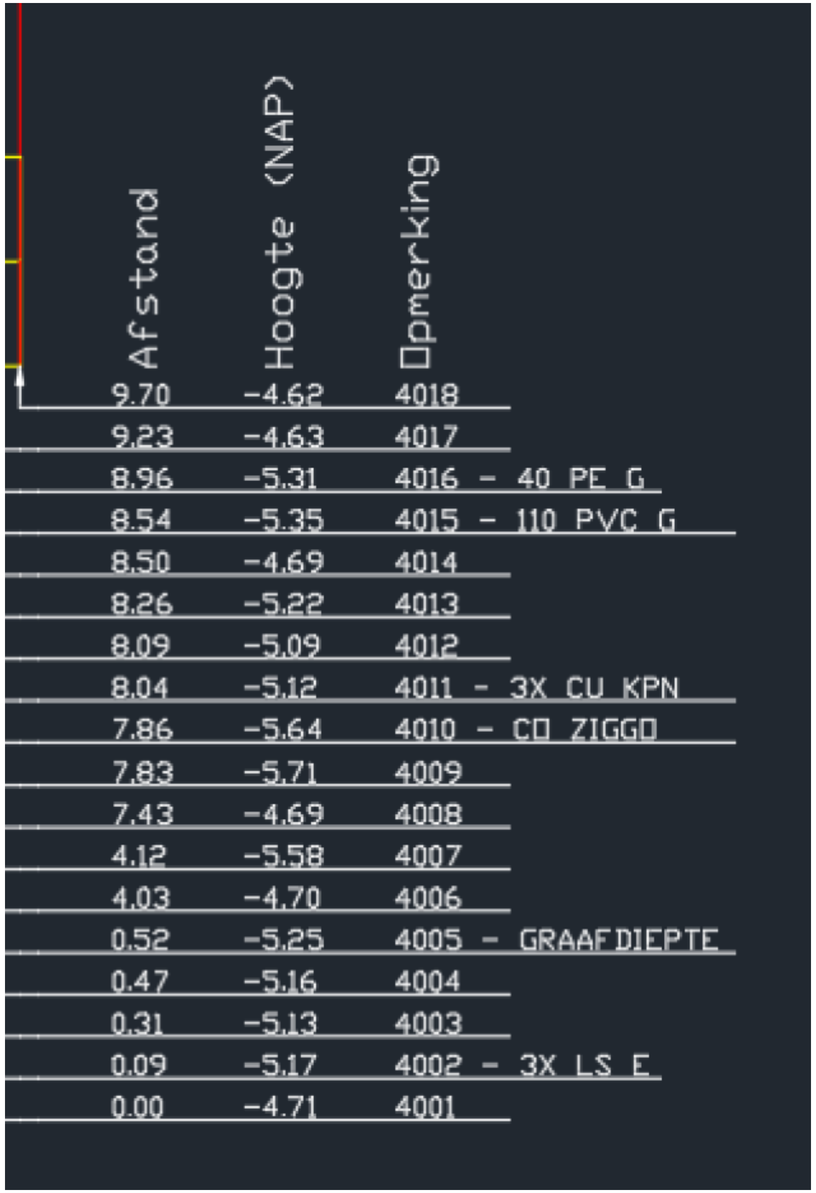
- Python 3.9.7
  - ezdxf
  - NumPy
  - Openpyxl
  - qgis.core
- AutoCAD 2024
- QGIS 3.34.6

Extracted surveyed data: Enschede



Width	Depth (m)	Description	Diameter (mm)
0.25	0.56	CAI C3 COAX	
0.64	0.77	LDG /PVC	110
0.71	0.26	LS KABEL	
1.19	1.03	MS KABEL	
1.22	1.01	MS KABEL	
1.32	0.09	DATA KABEL	
1.42	0.99	MS KABEL	
2.2	0.74	RIOOL /PVC	115
2.37	0.43	GV 2*DB	25
2.44	0.66	DATA 4* TEERKABEL	
2.58	0.57	DATA 2* KABEL	
2.66	0.58	DATA TEERKABEL	
2.71	0.6	DATA KABEL	
2.73	0.55	DATA TEERKABEL	
3.28	0.11	DATA TELEFONIE	
3.66	0.24	DATA TELEFONIE	
3.71	0.32	LS KABEL	

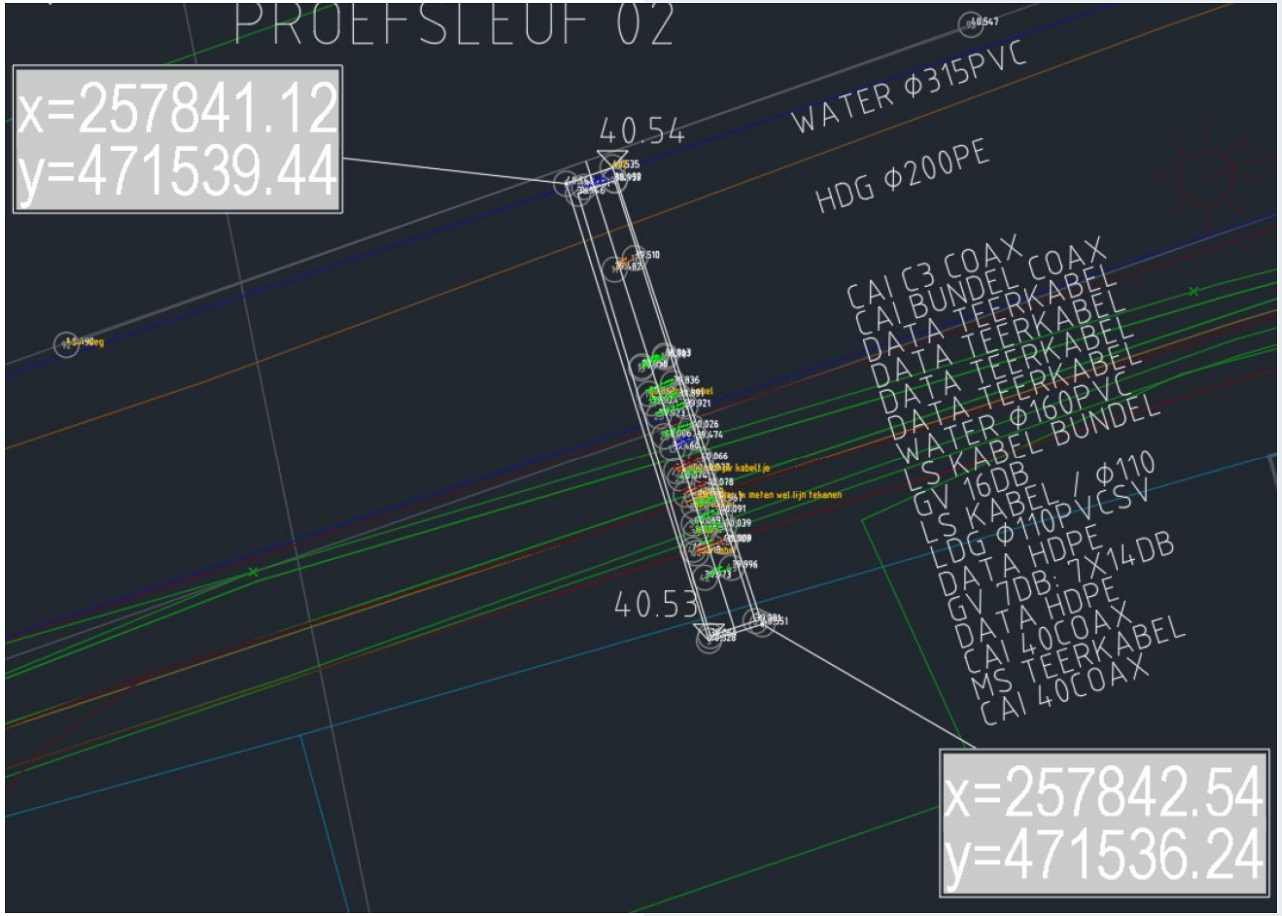
Extracted surveyed data: Rotterdam



Afstand	Hoogte (NAP)	Opmerking
9.70	-4.62	4018
9.23	-4.63	4017
8.96	-5.31	4016 - 40 PE G
8.54	-5.35	4015 - 110 PVC G
8.50	-4.69	4014
8.26	-5.22	4013
8.09	-5.09	4012
8.04	-5.12	4011 - 3X CU KPN
7.86	-5.64	4010 - CO ZIGGO
7.83	-5.71	4009
7.43	-4.69	4008
4.12	-5.58	4007
4.03	-4.70	4006
0.52	-5.25	4005 - GRAAFDIEPTE
0.47	-5.16	4004
0.31	-5.13	4003
0.09	-5.17	4002 - 3X LS E
0.00	-4.71	4001

Width	Depth (NAP)	Description	Diameter (mm)
9.7	-4.62	4018	
9.23	-4.63	4017	
8.96	-5.31	PE G	40
8.54	-5.35	PVC G	110
8.5	-4.69	4014	
8.26	-5.22	4013	
8.09	-5.09	4012	
8.04	-5.12	3X CU KPN	
7.86	-5.64	CO ZIGGO	
7.83	-5.71	4009	
7.43	-4.69	4008	
4.12	-5.58	4007	
4.03	-4.7	4006	
0.47	-5.16	4004	
0.31	-5.13	4003	
0.09	-5.17	3X LS E	
0	-4.71	4001	

Trench positional data



Start X	Start Y	End X	End Y	Length	Start Z	End Z
257841.26	471539.61	257842.34	471536.18	3.591145	40.523	40.54

Linear interpolation for cable positions

Start X	Start Y	End X	End Y	Length	Start Z	End Z
257841.26	471539.61	257842.34	471536.18	3.591145	40.523	40.54

Easting Calculation:

$$E_x = X_1 + \left(\frac{d_x}{l}\right) \times (X_2 - X_1)$$

Northing Calculation

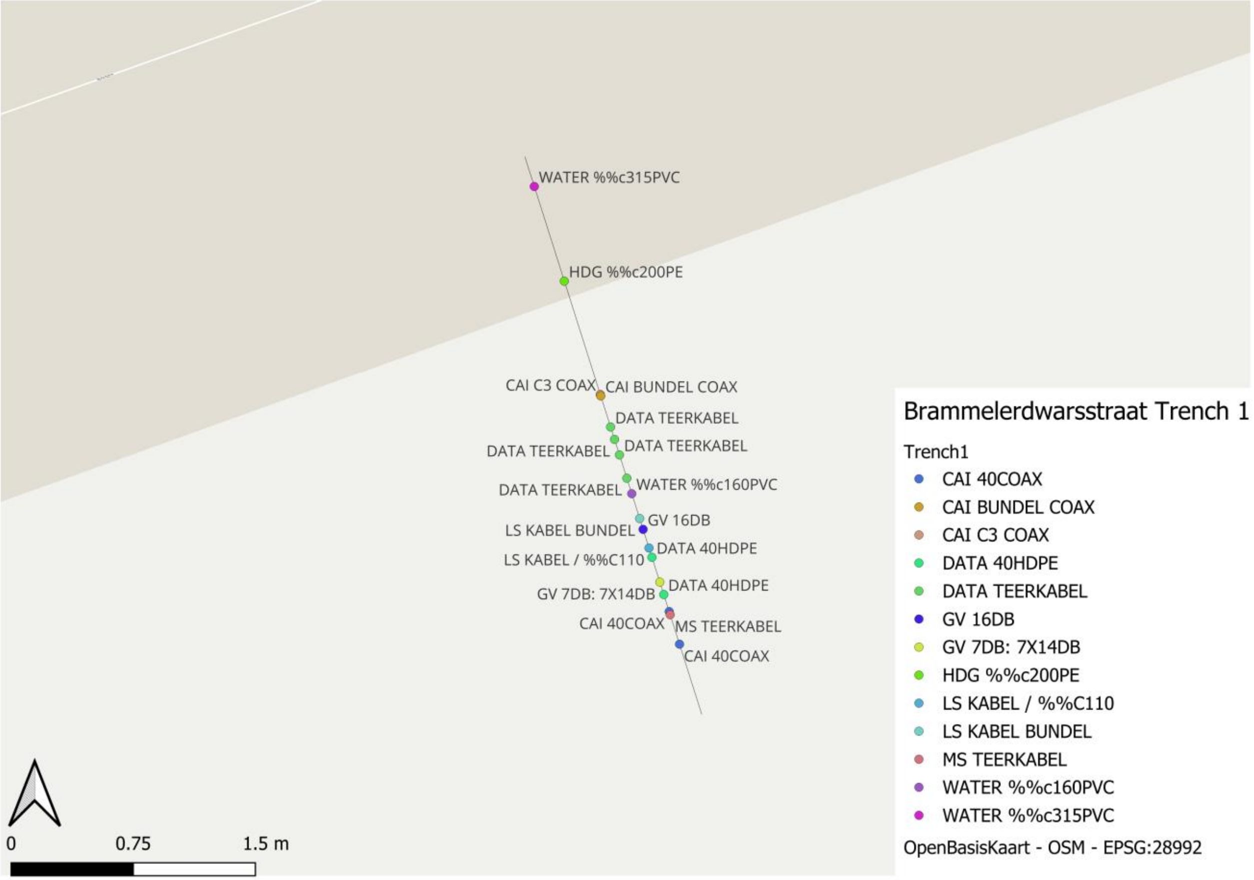
$$N_x = Y_1 + \left(\frac{d_x}{l}\right) \times (Y_2 - Y_1)$$

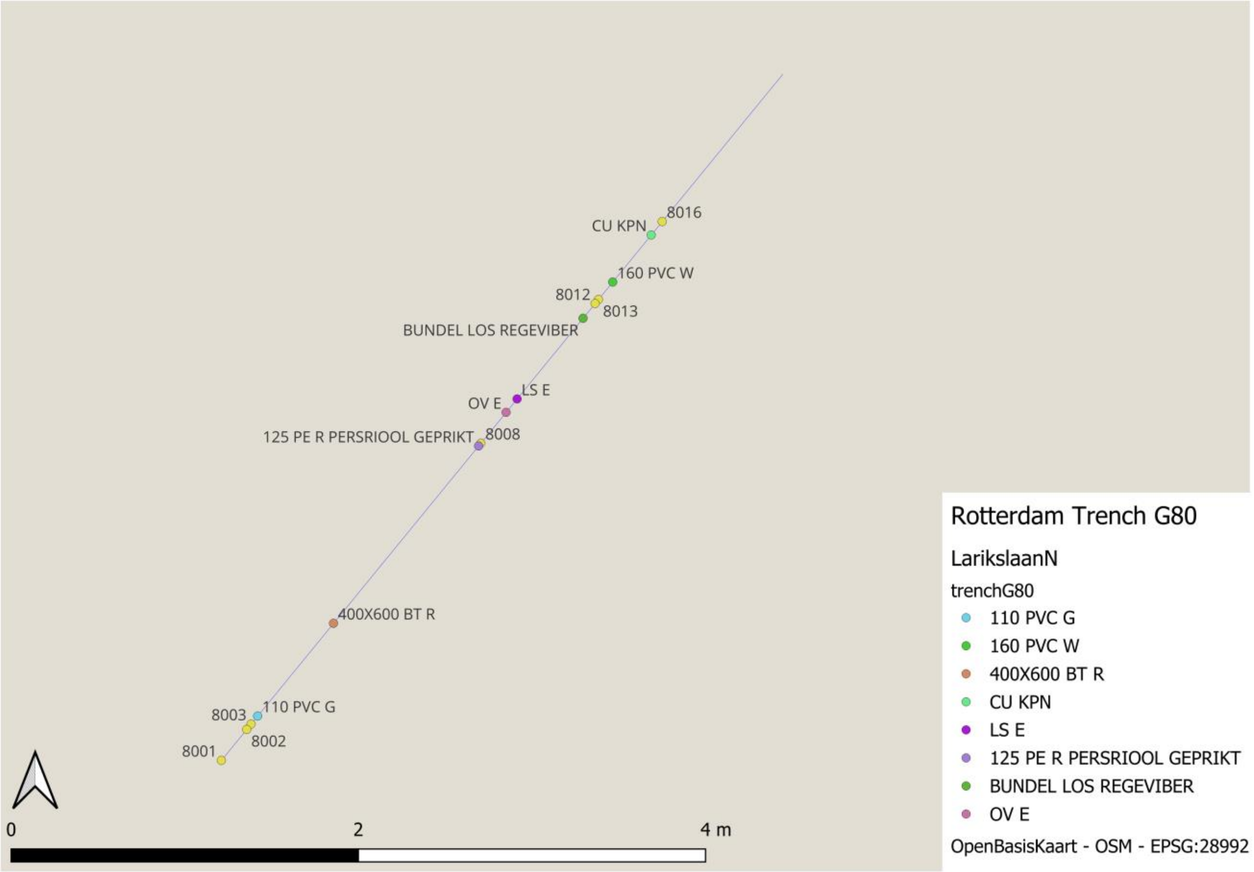
Elevation Calculation

$$NAP_x = Z_1 + \left(\frac{d_x}{l}\right) \times (Z_2 - Z_1) - h_x$$

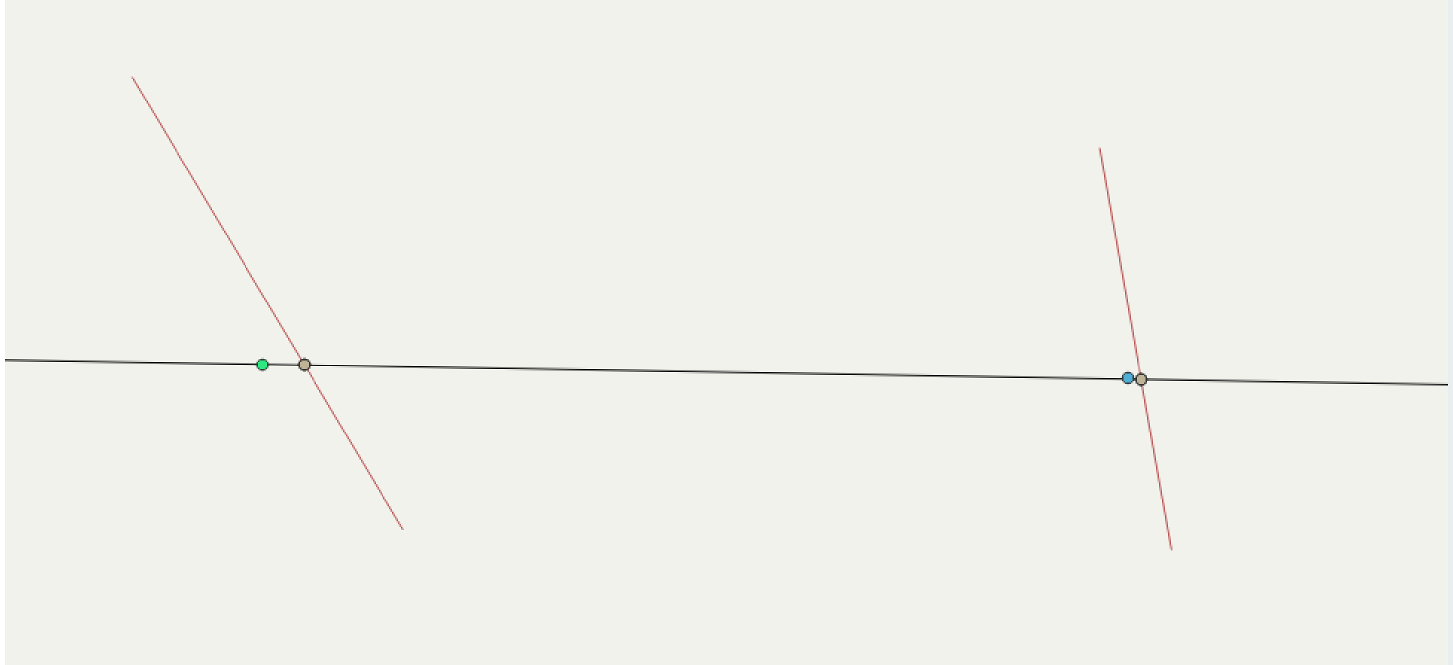
Trench	description	Diameter	E	N	Z
1	WATER /PVC	315	257787.9	471513	38.7292
1	HDG /PE	160	257788.1	471513.1	38.79868
1	WATER /PVC	160	257788.3	471513.3	39.12168
1	CAI 40HDPE		257788.3	471513.3	39.80294
1	LDG /PVCSV	110	257788.4	471513.3	39.34016
1	LS KABEL		257788.4	471513.3	39.51331
1	LS KABEL		257788.4	471513.3	39.57456
1	LS KABEL		257788.4	471513.3	39.52676
1	DATA TEERKABEL		257788.5	471513.3	39.57148
1	LS KABEL		257788.5	471513.3	39.64242
1	DATA 40HDPE		257788.6	471513.4	39.88656
1	LS KABEL / /PVC	125	257788.7	471513.4	39.7885
1	LS KABEL		257789.2	471513.7	39.81701
1	LS KABEL		257789.4	471513.8	40.09775
1	CAI KABEL / PVC	75	257789.7	471514	40.0308

Enriched trench data results





Data Validation



Description	Distance to surveyed points(meters)
WATER PVC	0.0095
HDG PE	0.0039
CAI C3 COAX	0.0028
CAI BUNDEL COAX	0.0037
DATA TEERKABEL	0.0012
DATA TEERKABEL	0.001
DATA TEERKABEL	0.0008
DATA TEERKABEL	0.0022
WATER PVC	0.0034
LS KABEL BUNDEL	0.0059
GV 16DB	0.0033
LS KABEL	0.0039

Average distance Enschede	**0.0065 m**

Label Processing

- Select usable trenches
- Clean/correct labeling of cables
- Collect statistics regarding cable connections between trenches

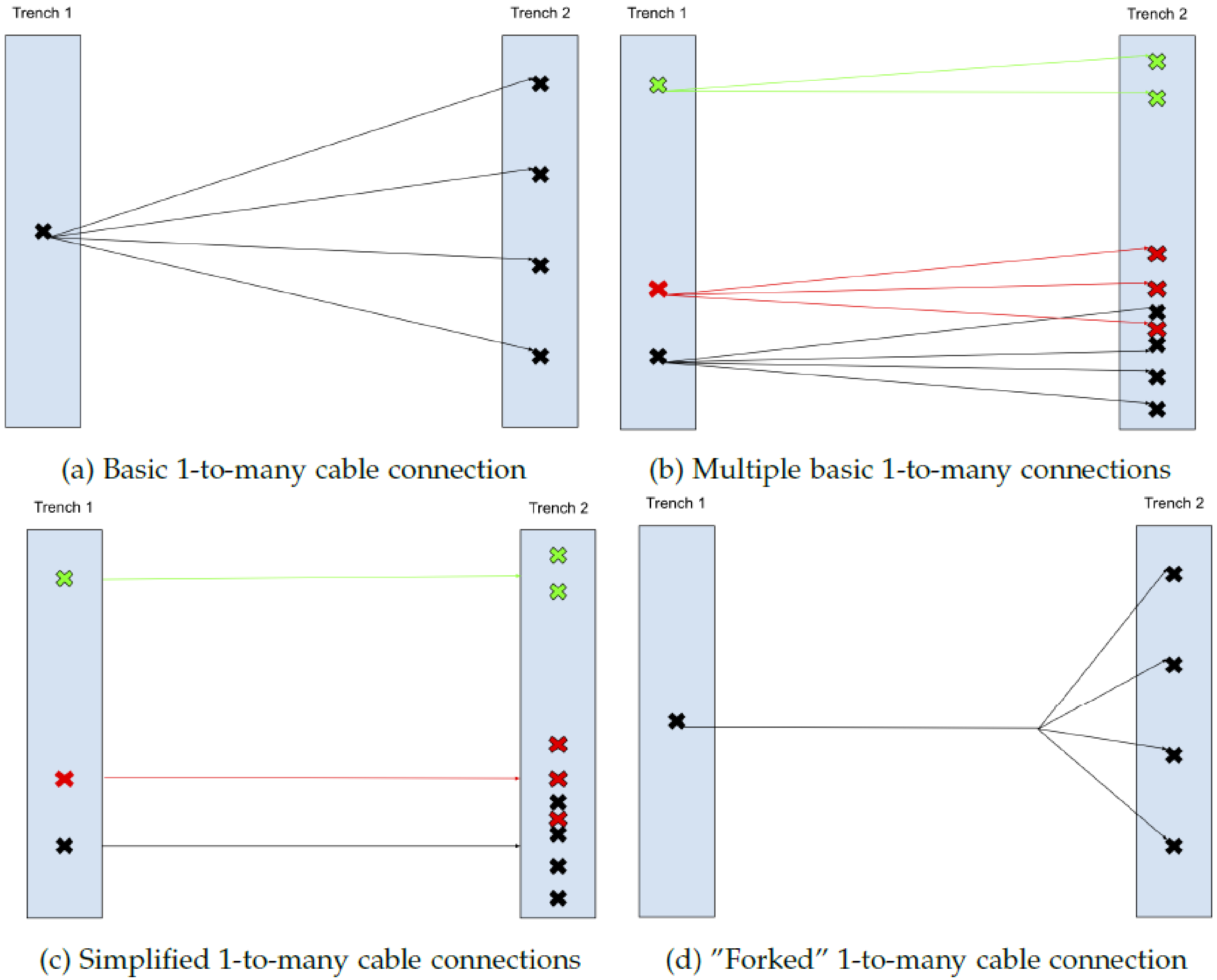
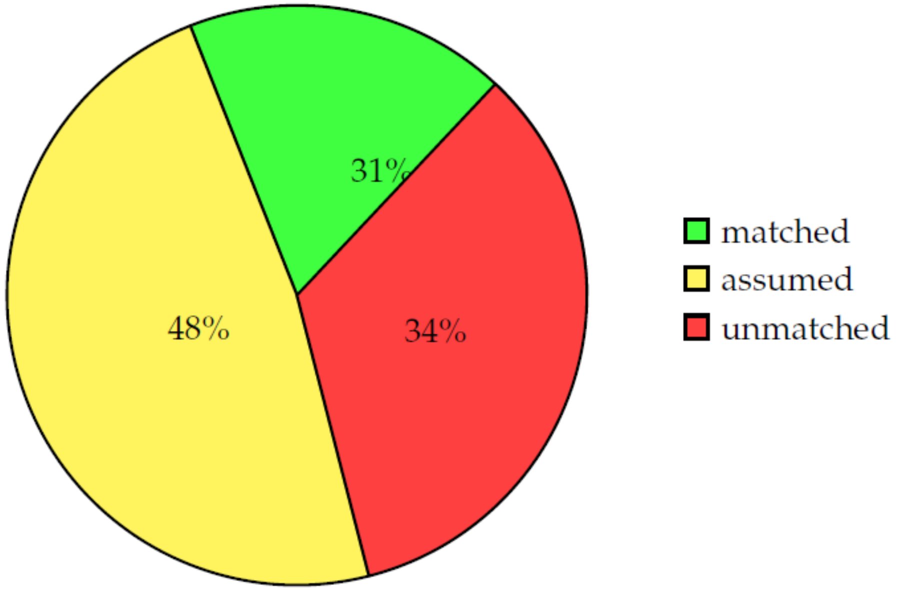


Figure 3.18.: Four examples of how cable connections can be stylized.



Trench 1	Trench 2
WATER /315PVC	WATER /315PVC
HDG /200PE	HDG /160PE
CAI C3 COAX	WATER /160PVC
CAI BUNDEL COAX	CAI 40HDPE
DATA TEERKABEL	LDG /110PVCSV
DATA TEERKABEL	LS KABEL
DATA TEERKABEL	LS KABEL
DATA TEERKABEL	LS KABEL
WATER /160PVC	DATA TEERKABEL
LS KABEL BUNDEL	LS KABEL
GV 16DB	DATA 40HDPE
LS KABEL /110	LS KABEL /125 PVC
DATA HDPE	LS KABEL
GV 7DB: 7X14DB	LS KABEL
DATA HDPE	CAI KABEL /75 PVC
CAI 40COAX	
MS TEERKABEL	
CAI 40COAX	

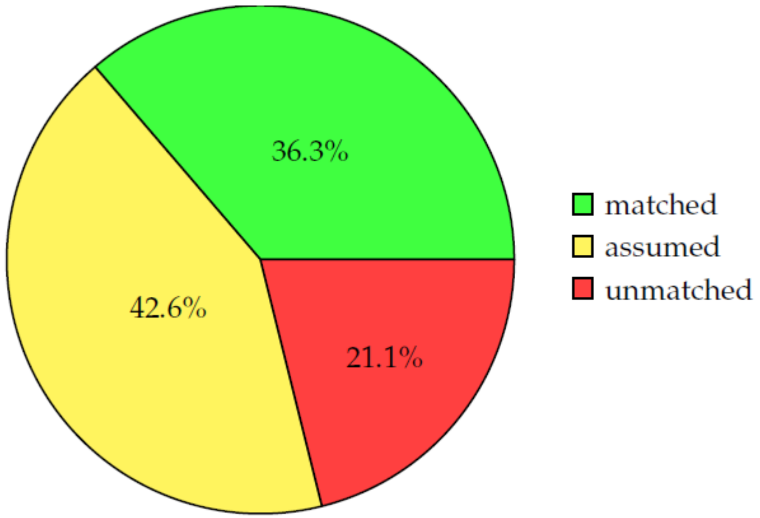


Figure 5.16.: Deurningerstraat: Total Distribution of cable status

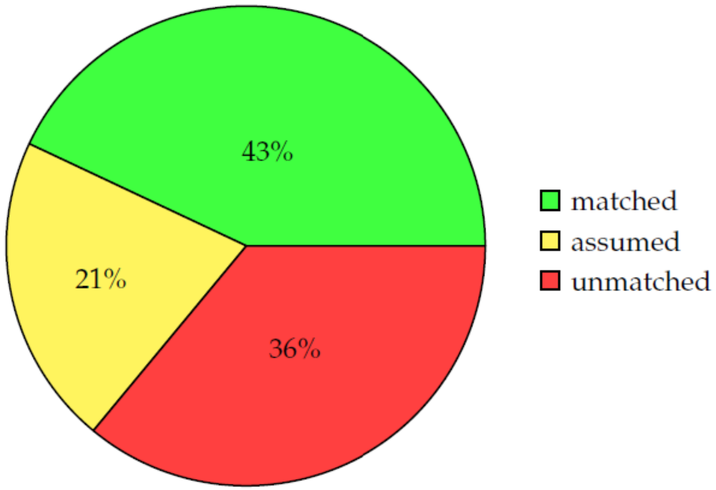


Figure 5.4.: Brammelerdwarsstraat: Total Distribution of cable status

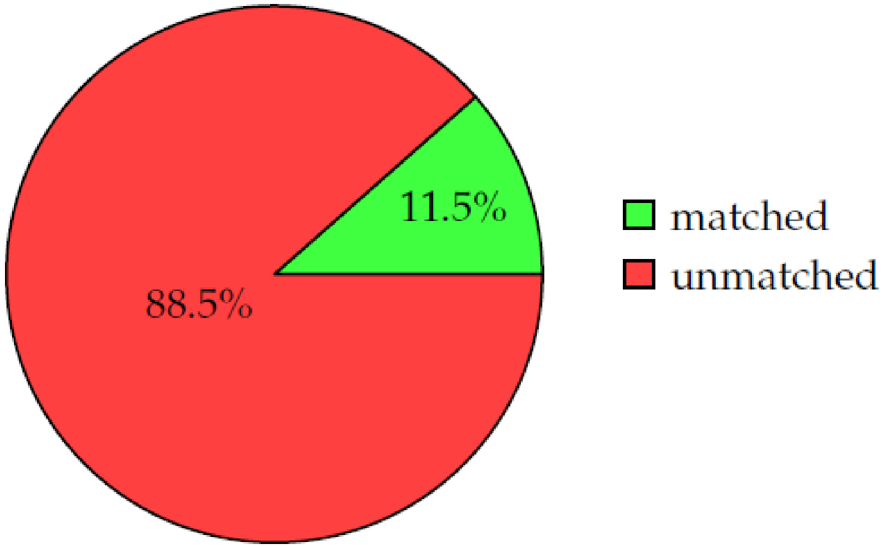


Figure 5.28.: Rotterdam: Total Distribution of **labelled & unlabelled** cable status

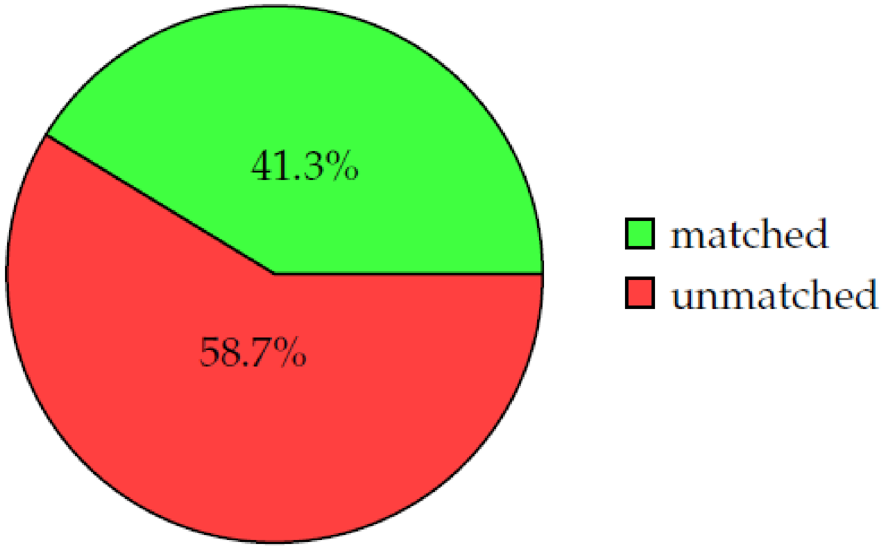
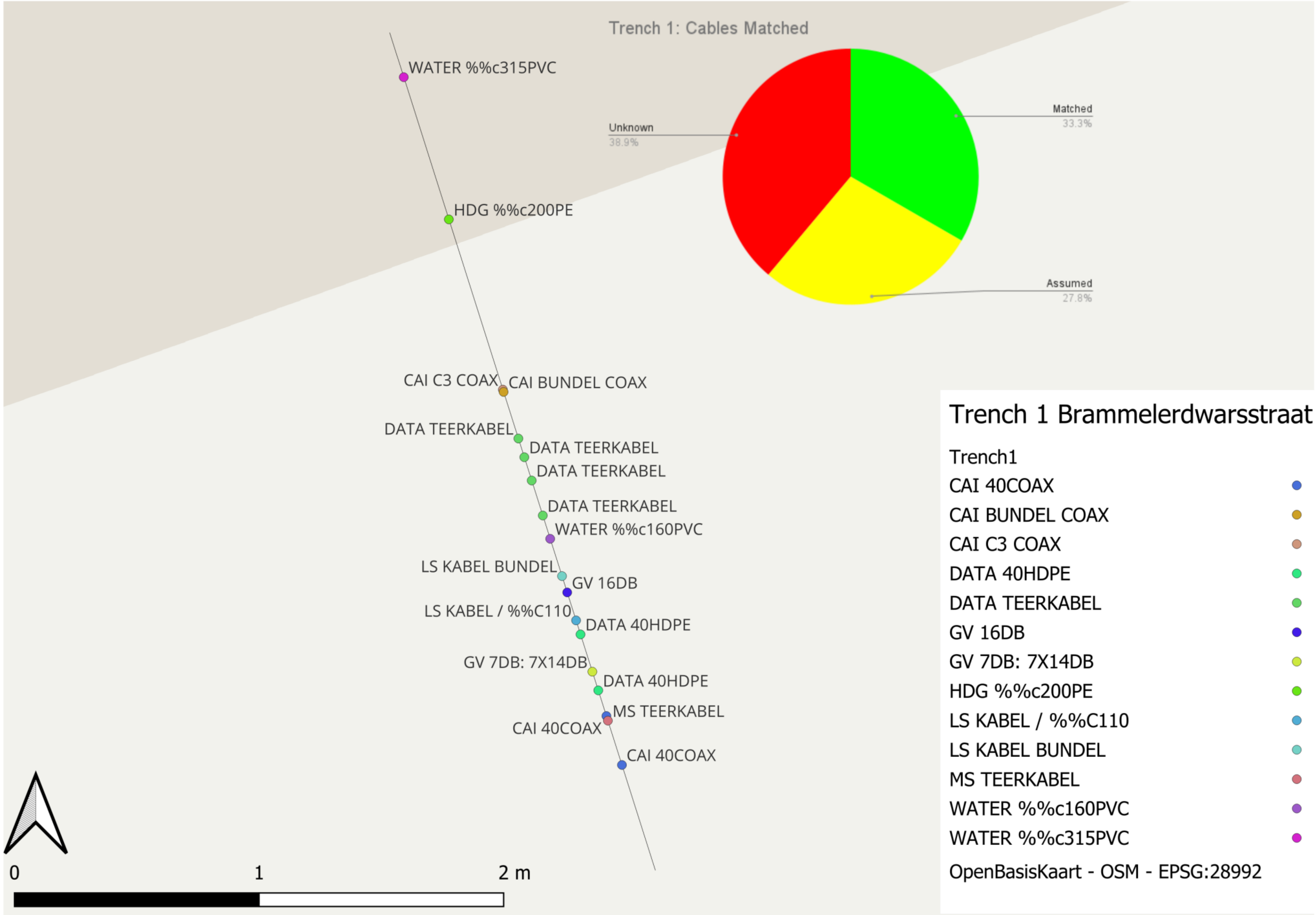


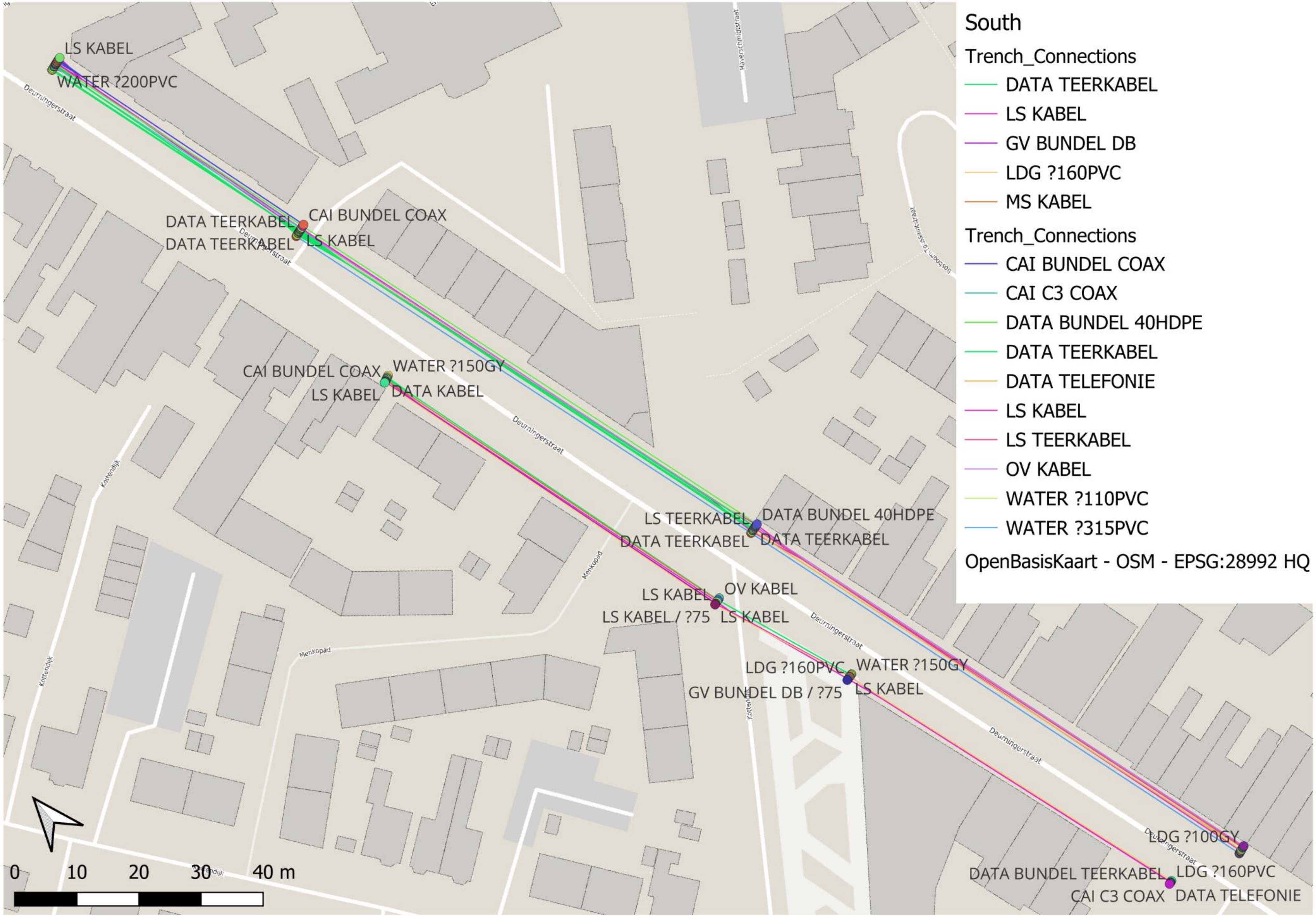
Figure 5.29.: Rotterdam: Total Distribution of **labelled** cable status


Trench 1: Cables Matched
Unknown
38.9%
Matched
33.3%
Assumed
27.8%
WATER %%c315PVC
HDG %%c200PE
CAI C3 COAX
CAI BUNDEL COAX
DATA TEERKABEL
DATA TEERKABEL
DATA TEERKABEL
DATA TEERKABEL
WATER %%c160PVC
LS KABEL BUNDEL
GV 16DB
LS KABEL / %%C110
DATA 40HDPE
GV 7DB: 7X14DB
DATA 40HDPE
MS TEERKABEL
CAI 40COAX
CAI 40COAX
0
1
2 m
Trench 1 Brammelerdwarsstraat
Trench1
CAI 40COAX
CAI BUNDEL COAX
CAI C3 COAX
DATA 40HDPE
DATA TEERKABEL
GV 16DB
GV 7DB: 7X14DB
HDG %%c200PE
LS KABEL / %%C110
LS KABEL BUNDEL
MS TEERKABEL
WATER %%c160PVC
WATER %%c315PVC
OpenBasisKaart - OSM - EPSG:28992

Methodology workflow

- Data acquisition
- Extraction & preparation
  - Geometrical processing
  - Label processing
- Integration
- Result analysis

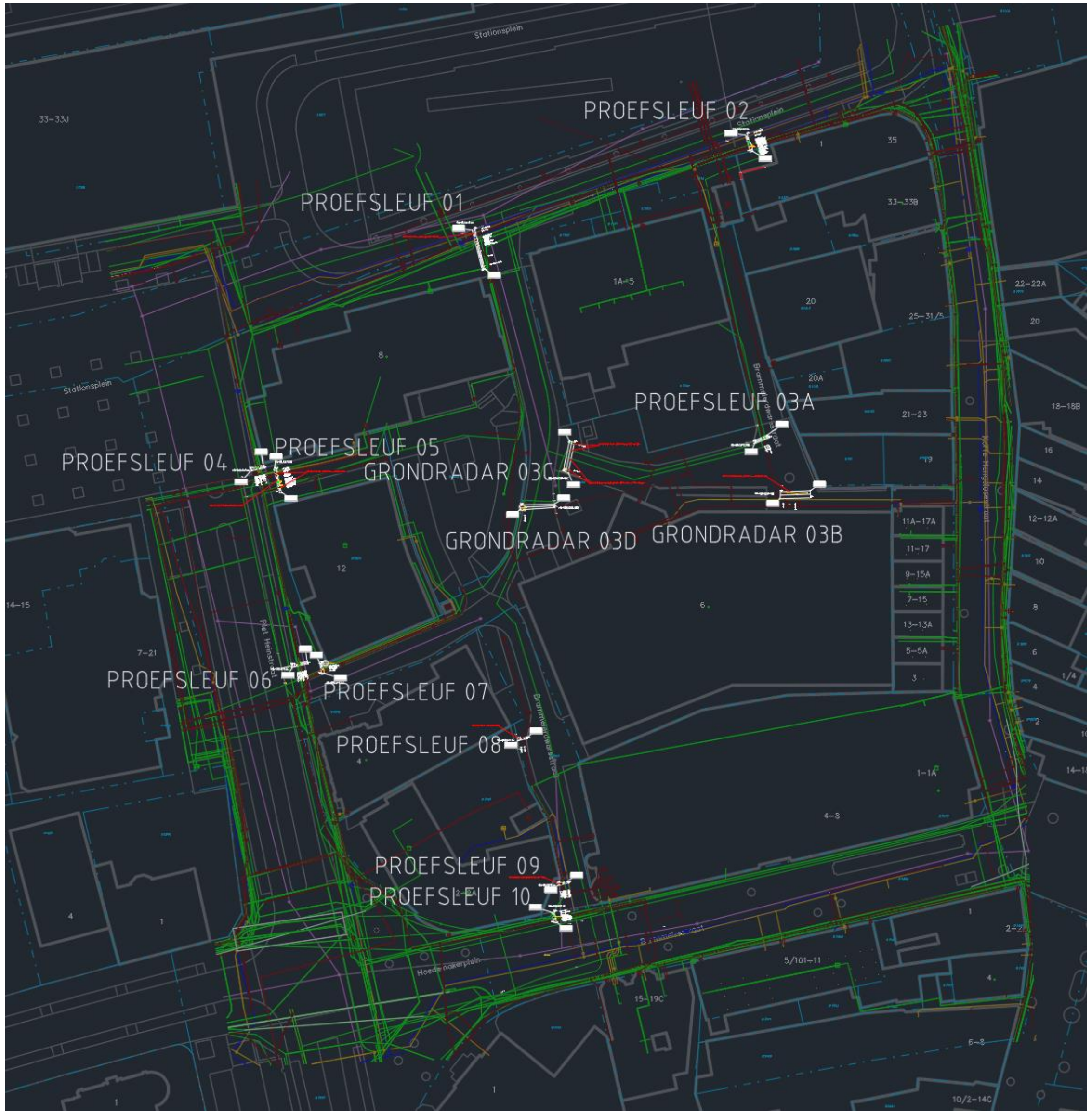
Data Integration


South
Trench_Connections
DATA TEERKABEL
LS KABEL
GV BUNDEL DB
LDG ?160PVC
MS KABEL
Trench_Connections
CAI BUNDEL COAX
CAI C3 COAX
DATA BUNDEL 40HDPE
DATA TEERKABEL
DATA TELEFONIE
LS KABEL
LS TEERKABEL
OV KABEL
WATER ?110PVC
WATER ?315PVC
OpenBasisKaart - OSM - EPSG:28992 HQ
LS KABEL
WATER ?200PVC
DATA TEERKABEL
CAI BUNDEL COAX
DATA TEERKABEL
LS KABEL
CAI BUNDEL COAX
WATER ?150GY
LS KABEL
DATA KABEL
LS TEERKABEL
DATA BUNDEL 40HDPE
DATA TEERKABEL
DATA TEERKABEL
LS KABEL
OV KABEL
LS KABEL / ?75
LS KABEL
LDG ?160PVC
WATER ?150GY
GV BUNDEL DB / ?75
LS KABEL
LDG ?100GY
DATA BUNDEL TEERKABEL
LDG ?160PVC
CAI C3 COAX
DATA TELEFONIE
Deurningerstraat
0
10
20
30
40 m

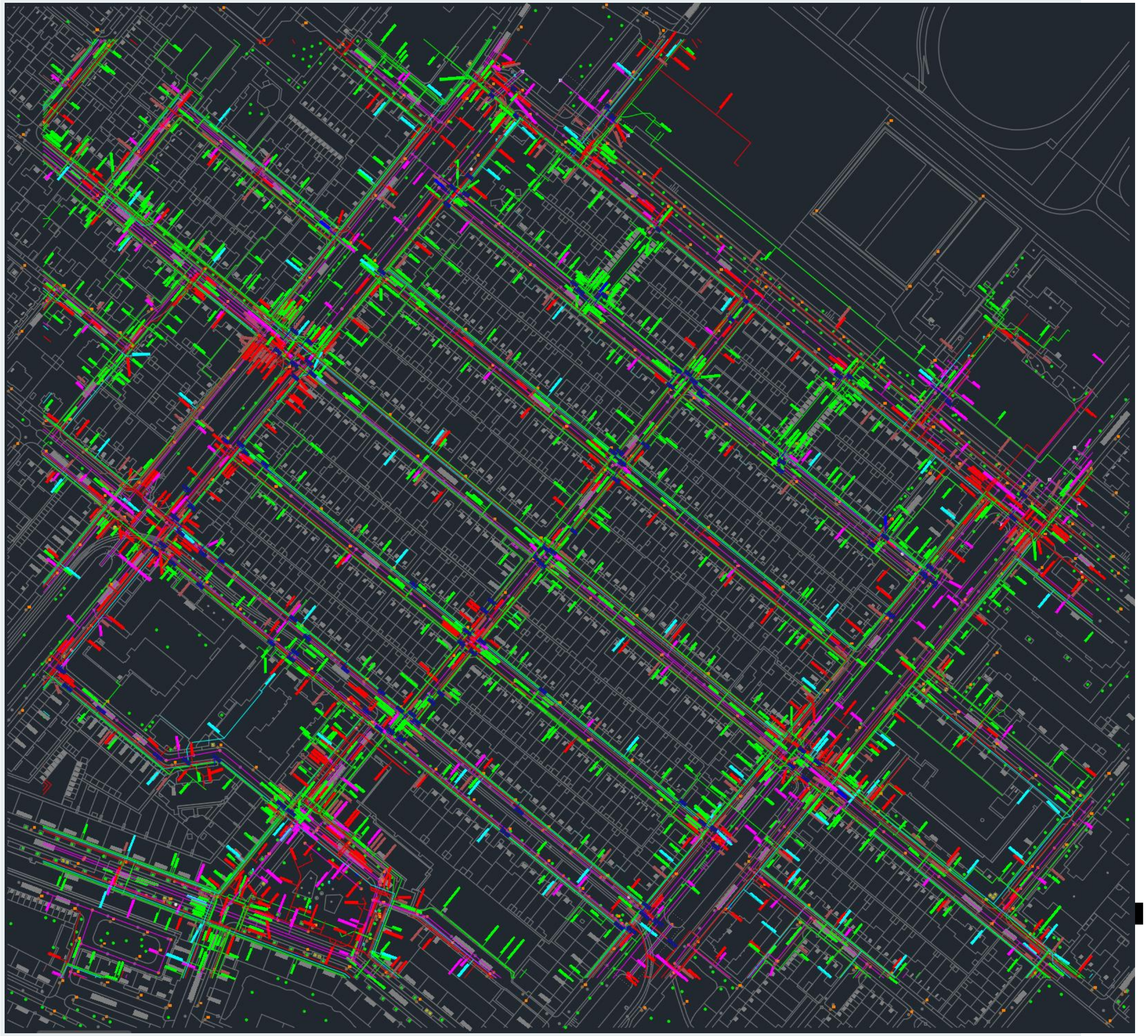
Methodology workflow

- Data acquisition
- Extraction & preparation
  - Geometrical processing
  - Label processing
- Integration
- Result analysis

Cable & pipelines maps



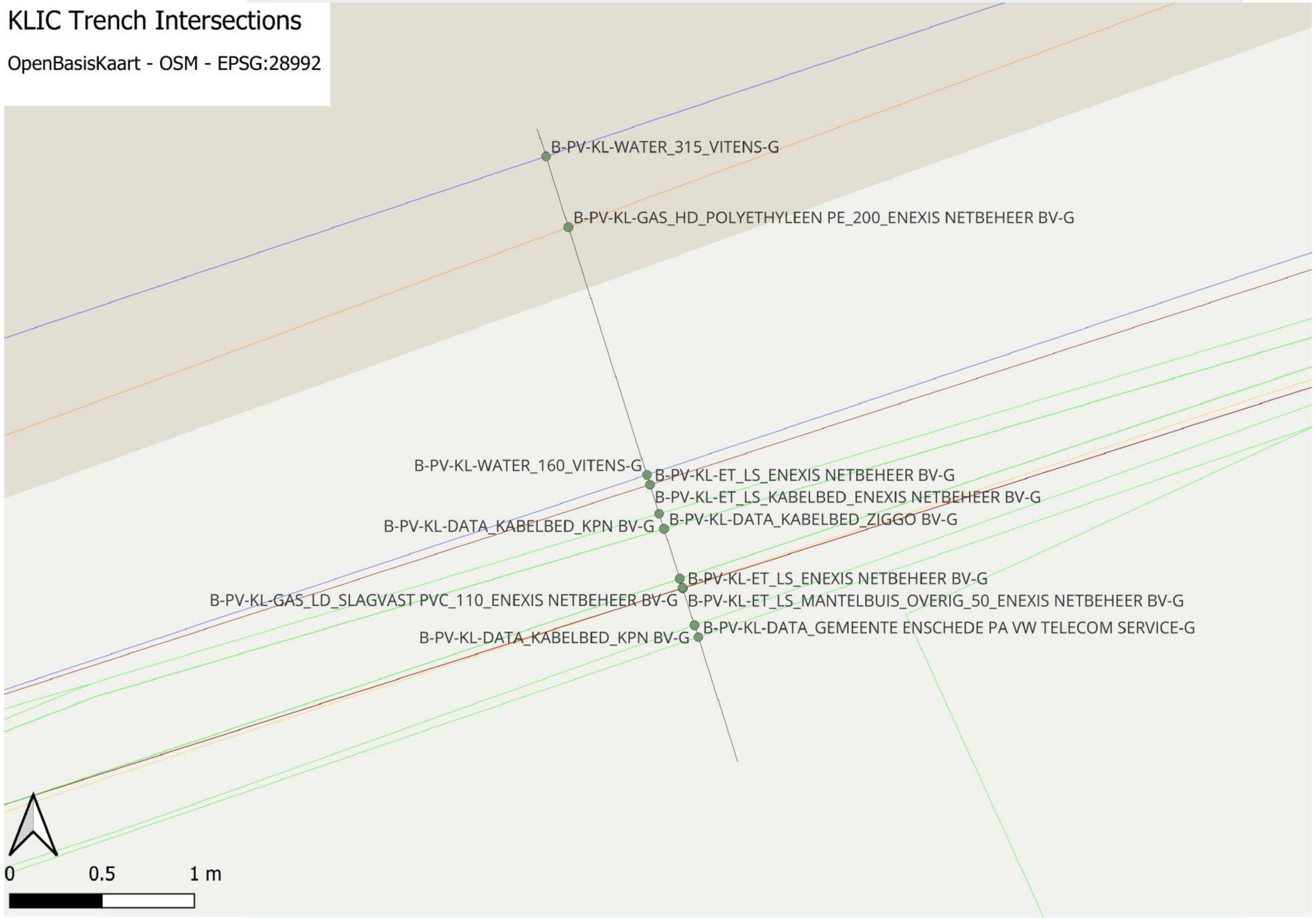
Enschede: KLIC data



Rotterdam: LVZK data

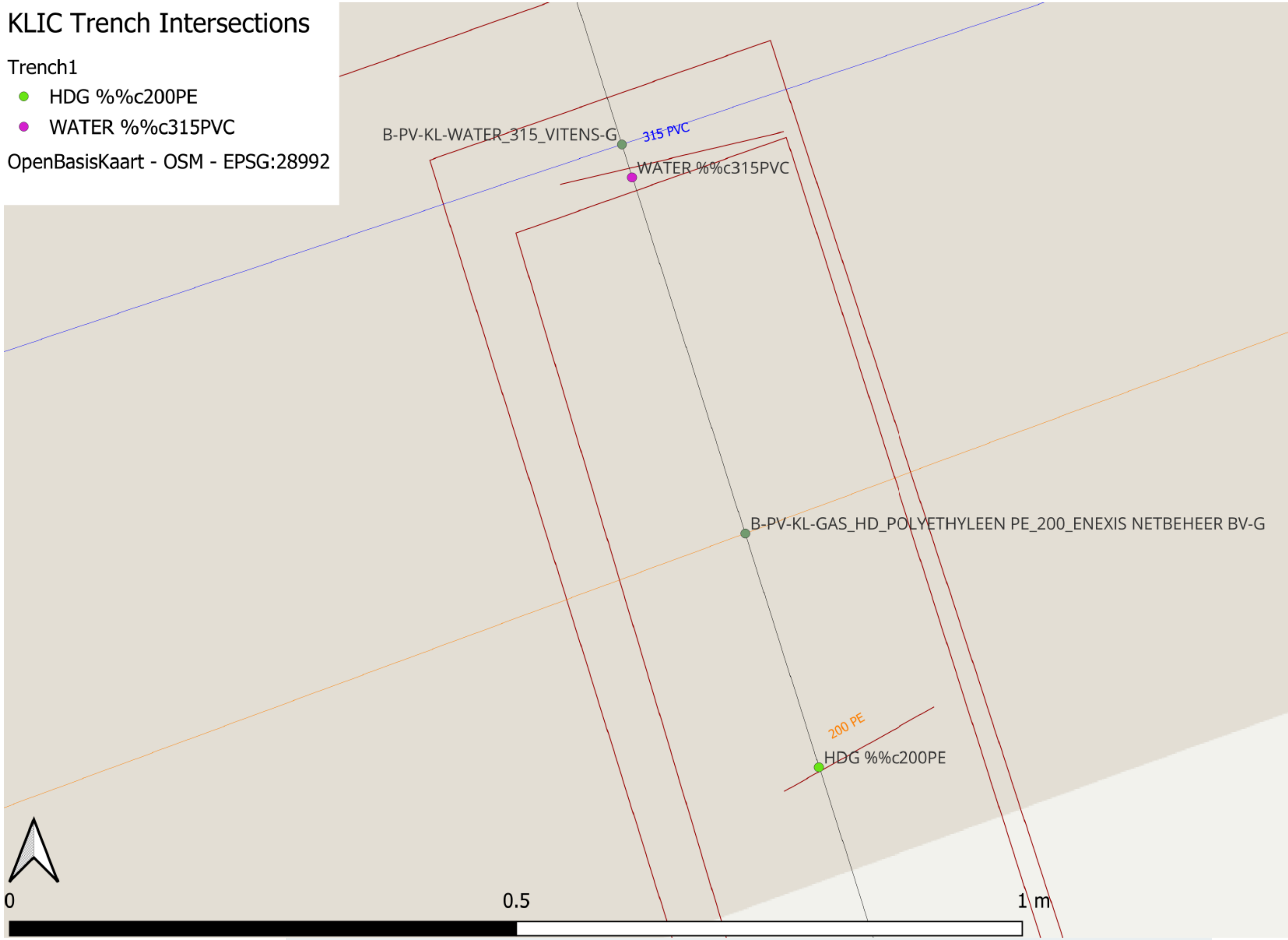
Data Analysis

- Compare surveyed positions to KLIC/LVZK cable positions
- KLIC/LVZK points are found at the intersection of the trench lines
- Analysis is performed along the trench line for greatest accuracy

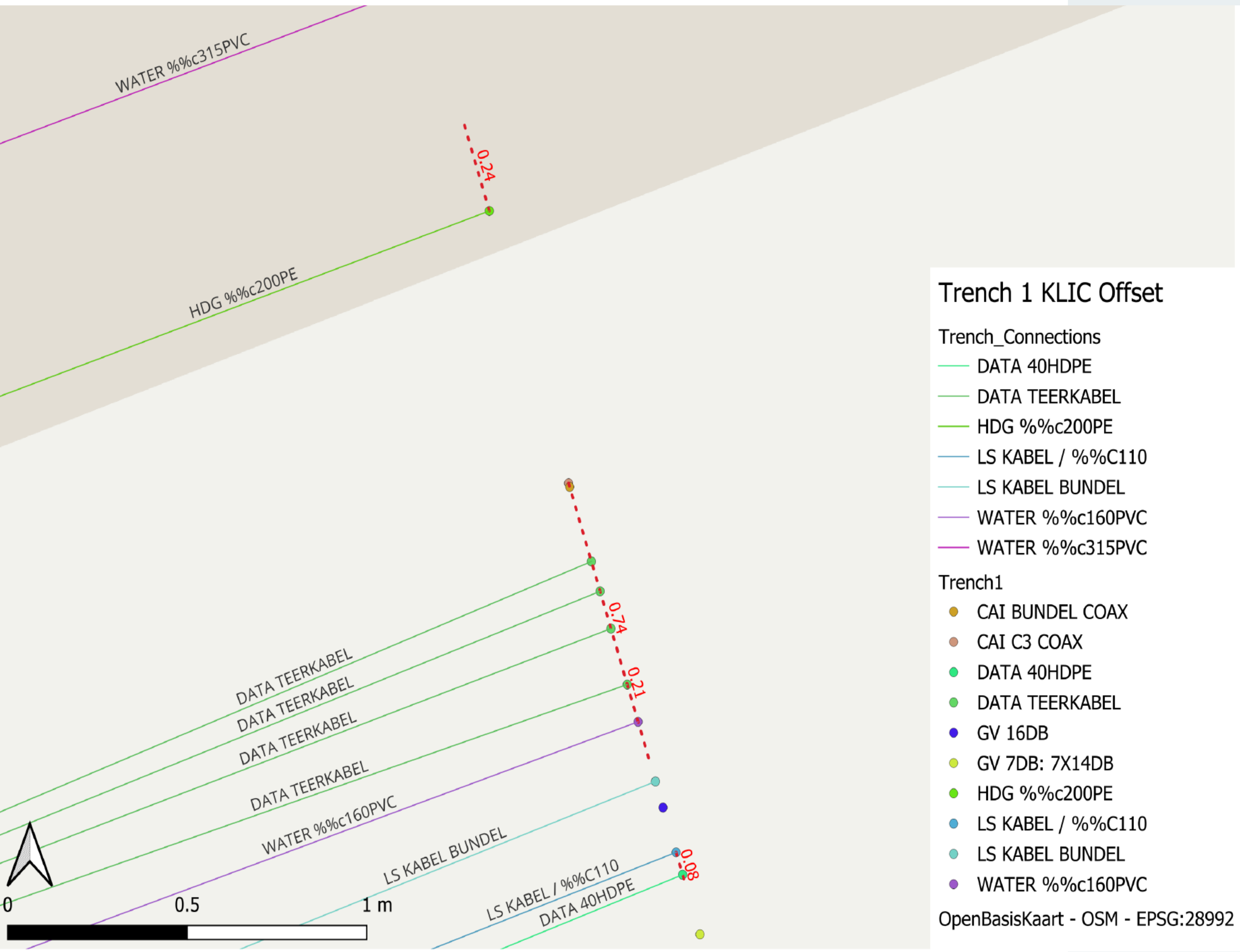


Data Analysis

- Utility trench points are more accurate than KLIC/LVZK points
- Surveyed points can be used to measure inconstancies in KLIC/LVZK



Data Analysis: Results



Trench	Description	Distance (m)	Points used
Trench 1	WATER 315PVC	0.03	27.8%
	LS KABEL / 110	0.08	
	WATER 160PVC	0.21	
	HDG 200PE	0.24	
	CAI C3 COAX	0.74	
Trench 2	WATER 315PVC	0.02	42.9%
	HDG 200PE	0.05	
	WATER 160PVC	0.07	
	LDG 110PVCSV	0.10	
	DATA 40HDPE	0.13	
	DATA TEERKABEL	0.14	
	CAI KABEL / 75 PVC	0.45	
Trench 4	GV 25DB	0.002	61.5%
	GV 25DB	0.01	
	GV 25DB	0.06	
	GV 25DB	0.07	
	LDG /160PVC	0.11	
	WATER /160PVC	0.36	
	CAI BUNDEL COAX	0.42	
	CAI BUNDEL COAX	0.98	
Trench 6	DATA HDPE	0.01	58.3%
	LDG /160PVCSV	0.01	
	DATA HDPE	0.01	
	CAI 40COAX	0.03	
	DATA HDPE	0.18	
	DATA HDPE	0.18	
	RIOOL /200PVC	0.20	
Trench 8	CAI 40COAX	0.74	50.0%
Trench 9	CAI C3 COAX	0.07	42.9%
	CAI 40COAX	0.11	
	WATER /54CU	0.12	
Average		0.30	47.2%

Trench	Description	Distance (m)	Points used
15	WATER 50PE	0.001	66.7%
	LDG 160PVC	0.10	
	CAI BUNDEL COAX	0.12	
	WATER 315PVC	0.19	
	LDG 100GY	0.31	
20	DATA TEERKABEL	0.03	40.9%
	LDG 110PVC	0.04	
	DATA TEERKABEL	0.05	
	WATER 315PVC	0.10	
	WATER 110PVC	0.10	
	DATA TEERKABEL	0.12	
	DATA TEERKABEL	0.13	
	LS TEERKABEL	0.23	
	DATA TEERKABEL	0.49	
22	LS 4X150	0.01	75.0%
	CAI BUNDEL COAX	0.03	
	GV BUNDEL DB	0.07	
	LS 2x TEERKABEL	0.07	
	WATER 315PVC	0.10	
	LDG 160PVC	0.36	
25	WATER 200PVC	0.01	83.3%
	DATA 40HDPE	0.01	
	DATA 40HDPE	0.02	
	DATA TEERKABEL	0.02	
	DATA 40HDPE	0.06	
	LS KABEL	0.08	
	DATA 40HDPE	0.08	
	DATA BUNDEL TEERKABEL	0.09	
	DATA TEERKABEL	0.10	
	CAI BUNDEL COAX	0.13	
	LS KABEL	0.14	
	LDG 200PVC	0.17	
	LS KABEL	0.17	
	DATA 40HDPE	0.21	
	LS KABEL	0.25	
	DATA 40HDPE	0.27	
	CAI BUNDEL COAX	0.28	
	DATA 40HDPE	0.28	
	LS KABEL	0.29	
	CAI BUNDEL COAX	0.30	
	LS KABEL	0.30	
	CAI BUNDEL COAX	0.31	
	DATA 40HDPE	0.35	
	LS KABEL	0.43	
	CAI BUNDEL COAX	0.58	
	CAI BUNDEL COAX	0.59	
	CAI BUNDEL COAX	0.61	
	LS KABEL	0.71	
	DATA TEERKABEL	0.73	
	CAI BUNDEL COAX	0.76	
	LS KABEL	0.80	

Trench	Description	Distance (m)	Points used
17	GV BUNDEL DB	0.004	40%
	LDG 160PVC	0.01	
	LS KABEL	0.10	
	LS KABEL	0.15	
18	GV BUNDEL DB / 75	0.08	71.4%
	GV BUNDEL DB / 75	0.08	
	LDG 32PVC	0.1692	
	GV BUNDEL DB / 75	0.18	
	GV BUNDEL DB / 75	0.18	
	DATA TEERKABEL	0.20	
	LS KABEL	0.23	
	WATER 150GY	0.26	
	LS KABEL	0.27	
	DATA TEERKABEL	0.35	
19	LS KABEL	0.05	50.0%
	LDG 160PVC	0.08	
	LS KABEL	0.10	
	LS KABEL	0.39	
	MS KABEL	0.59	
21	DATA TEERKABEL	0.003	84.6%
	CAI BUNDEL COAX	0.02	
	LS KABEL	0.03	
	LDG 160PVC	0.04	
	LS KABEL	0.06	
	CAI BUNDEL COAX	0.08	
	WATER 150GY	0.09	
	LS KABEL BUNDEL	0.14	
	DATA TEERKABEL	0.15	
	DATA TEERKABEL	0.26	
	LS KABEL	0.45	
	MS KABEL	0.54	
Average		0.33	64.0%

Trench	Description	Distance (m)	Points used
G76	110 PVC G	0.16	23.5%
	CU KPN	0.53	
	400X600 BT R	0.81	
	160 PVC W	0.85	
G80	110 PVC G	0.47	33.3%
	400X600 BT R	0.60	
	LS E	0.74	
	160 PVC W	0.74	
	CU KPN	0.91	
G88	110 PVC G	0.28	28.6%
	400X600 BT R	0.28	
	160 PVC W	0.54	
	CU KPN	0.64	
G93	160 PVC W	0.04	31.3%
	110 PE G	0.08	
	LS E	0.09	
	110 PVC ZIGGO	0.14	
	400X600 BT R	0.16	
	CU KPN	0.43	
G99	400X600 BT R	1.33	42.9%
	160 PVC G	1.34	
	160 PVC W	1.41	
	KUNSTOF MAT ZIGGO	1.48	
	1 LS E	1.53	
	1 CU KPN	1.64	
G101	110 PVC O	0.07	44.4%
	110 PVC E	0.60	
	1 OV E	1.08	
	160 PVC G	1.09	
Average		0.69	34.0%

Trench	Description	Distance (m)	Points Used
52	3X LS E	1.40	11.50%
	CU KPN	1.47	
	118 GY W	4.84	
53	110 PVC ZIGGO	0.62	27.80%
	200 PVC KPN	0.65	
	2X LS E	1.30	
	2X CU KPN	1.56	
	160 PVC W	1.96	
54	250 PE W	0.003	27.30%
	CU KPN NTV	0.58	
	110 PVC REGEFIBER	0.75	
55	250 PVC W	0.15	25.00%
	110 PVC REGEFIBER	0.25	
	2X CU KPN	0.85	
56	LS E	0.31	20.00%
	2X LS E	1.30	
	250 PVC W	4.48	
	2X CU KPN	4.89	
57	250 PVC W	0.26	21.10%
	CU KPN	1.20	
	4X LS E	1.34	
	CU KPN	2.96	
58	LS E	1.58	19.00%
	CU KPN	1.76	
	250 PVC W	2.40	
	400 BT R	3.15	
59	110 PVC REGEFIBER	0.95	21.70%
	110 PE RET	1.09	
	110 PVC REGEFIBER	1.15	
	2X 160 PVC STEDIN	1.23	
	110 PVC REGEFIBER	1.35	
Average		1.54	21.7%

Conclusions

- 2D utility network data were minimally enriched
  - Elevation, diameter and descriptions are added for individual cables
  - However, a high percentage of missing data limits the usability of this data
- Results can be used to show inconsistency in traditional utility network data
  - Brammelerdwarsstraat: 0.30 m avg. offset, 47.2% avg. of matched cables
  - Deurningerstraat: 0.33 m avg. offset & 64.0% avg. of matched cables
  - Rotterdam: 0.69 m avg. offset & 27.8% avg. of matched cables
- However, methodology can not be fully exploited at the moment due to poor data

[redacted]

	Proefsleuf	depth	description	E	N	Z	distance	diameter
1	2	1.1	WATER PVC	257841.3145	471539.4259	39.42389943	0.19	315
2	2	1.04	HDG PE	257841.4989	471538.8445	39.48678709	0.8	200
3	2	0.58	CAI C3 COAX	257841.7197	471538.1486	39.95024281	1.53	NULL
4	2	0.56	CAI BUNDEL C...	257841.7227	471538.1391	39.97029015	1.54	NULL
5	2	0.69	DATA TEERKABEL	257841.7832	471537.9485	39.84123693	1.74	NULL
6	2	0.63	DATA TEERKABEL	257841.8074	471537.8722	39.90161564	1.82	NULL
7	2	0.62	DATA TEERKABEL	257841.8376	471537.7769	39.91208902	1.92	NULL
8	2	0.52	DATA TEERKABEL	257841.883	471537.6339	40.0127991	2.07	NULL
9	2	1.07	WATER PVC	257841.9132	471537.5386	39.46327249	2.17	160
10	2	0.48	LS KABEL BUN...	257841.9616	471537.3861	40.05402991	2.33	NULL
11	2	0.46	GV 16DB	257841.9828	471537.3194	40.07436128	2.4	NULL
12	2	0.49	LS KABEL	257842.0191	471537.205	40.04492934	2.52	110
13	2	0.57	DATA 40HDPE	257842.0372	471537.1478	39.96521337	2.58	NULL
14	2	0.46	GV 7DB: 7X14DB	257842.0856	471536.9953	40.07597079	2.74	NULL
15	2	0.49	DATA 40HDPE	257842.1098	471536.919	40.0463495	2.82	NULL
16	2	0.5	CAI 40COAX	257842.1431	471536.8142	40.03687023	2.93	NULL
17	2	0.63	MS TEERKABEL	257842.1491	471536.7951	39.9069649	2.95	NULL
18	2	0.55	CAI 40COAX	257842.2066	471536.614	39.98786434	3.14	NULL

Limitations

- Process can not be applied to cities without properly stored surveyed trench data
- Inconsistencies in data collection and naming strategies
  - Ex. Depth vs. Elevation
  - Introduces human error (in data collection & analysis)
- Assumptions in methodology
  - Assumption in matching similar cable labels
  - Surface between start and end of trench is flat
- Limited automatability
  - Different cities require separate extraction techniques
  - Matching of cables requires manual input
  - Only linearly successive trenches were used
  - No possibility of one continuous automatic process

Future Recommendations

- Provide surveyed data with all relevant information
  - Following the conventions set by the current utility network
  - Use standardized labelling conventions
- Using a relevant CRS when surveying trenches
- Developing algorithms that can identify and sort cables provided from various sources
- Broaden case study area to get more accurate values