Delft University of Technology

MSc. Geomatics

Integrated modeling of utility networks in the urban environment

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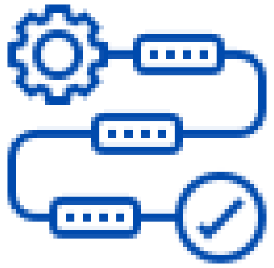
Co-reader: **Bastiaan van Loenen**
External supervisor: **Jan van der Voorst**

Agenda


Introduction/ Motivation


Problem statement


Literature review


Methodology

Results


Conclusions

Introduction/Motivation

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- The ever-increasing need for the existence of the dual representation of the geographical information for the underground utility networks
- Improvement and development of the data-driven models
- The need for evaluation of the existing information related to the underground utility networks condition

Source: https://www.city-journal.org/untangling-nyc-underground-utility-infrastructure

Problem statement

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The limited availability of a detailed and accurate geo-referenced map for the underground utility networks

- Bad data quality
- Incomplete and/or unreliable datasets
- Information mostly in 2D
- Lack of metadata
- Not up-to-date

There is a need for a reliable and well-maintained network

Research objective

Research question:

How is it possible to model underground utility networks in 3D, integrated with the above-ground objects, such that they can be suitable for multiple uses?

Sub-questions:

- *How to represent a direct connection with the above-ground condition?*
- *Is it possible to achieve that connection?*
- *Is the 3D information useful?*
- *Is it possible a limited 3D information to be extended to a larger network?*

Literature review

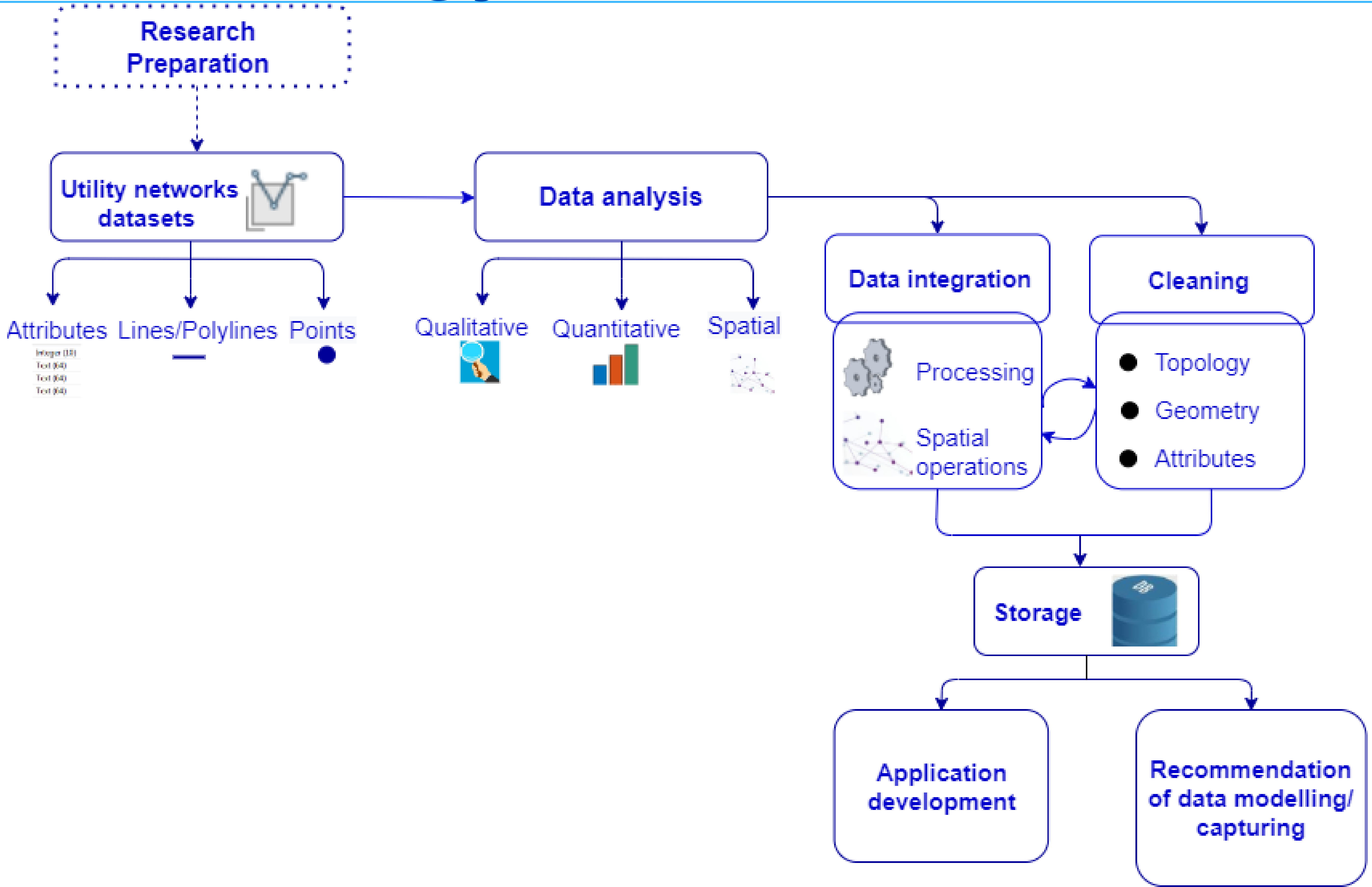
Developed models supporting utility networks mapping

- *INSPIRE Network*
- *CityGML Utility Network ADE*
- *Industrial Foundation Classes -IFC*
- *ESRI Geometric Network*
- *Model for Underground Data Definition and Integration-MUDDI*

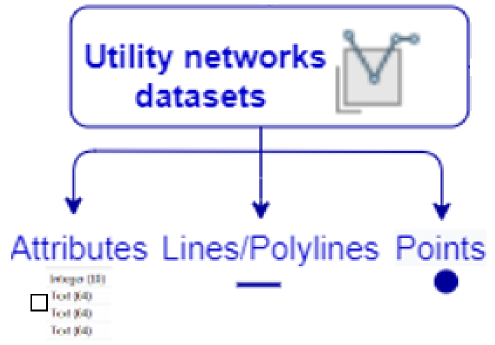
Related work:

- **den Duijn et al., 2018:** *Modelling below and above-ground utility network features with the CityGML Utility Network ADE: Experiences from Rotterdam*
- **Yan et al., 2018:** *Three-Dimensional Data Modelling for Underground Utility Network Mapping*
- **Fossatti et al., 2020:** *Data modeling for operation and maintenance of utility networks: implementation and testing*
- **Boates et al., 2018:** *Network modeling and semantic 3D city models: Testing the maturity of the Utility Network ADE for CityGML with a water network test case*

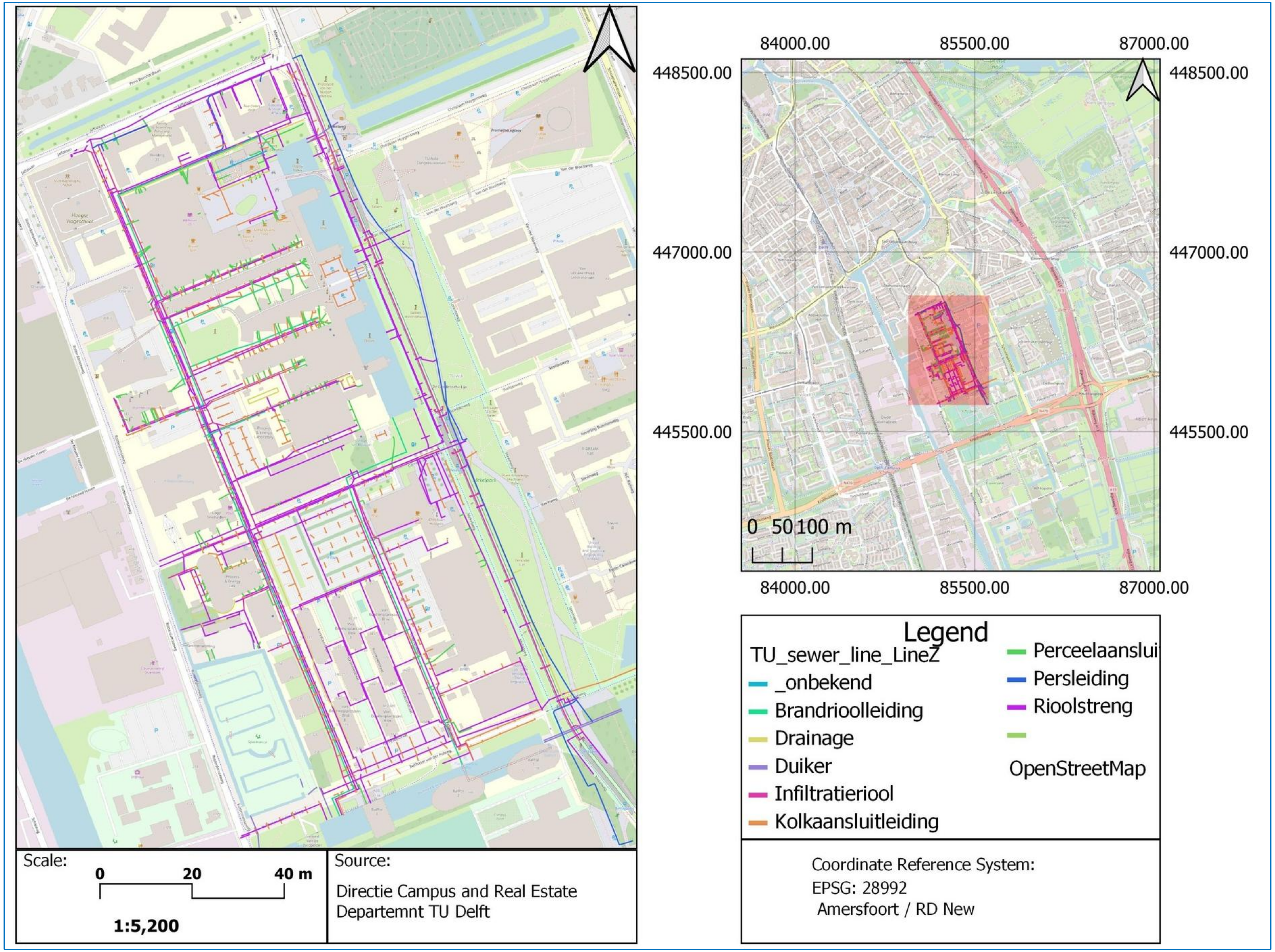
Methodology

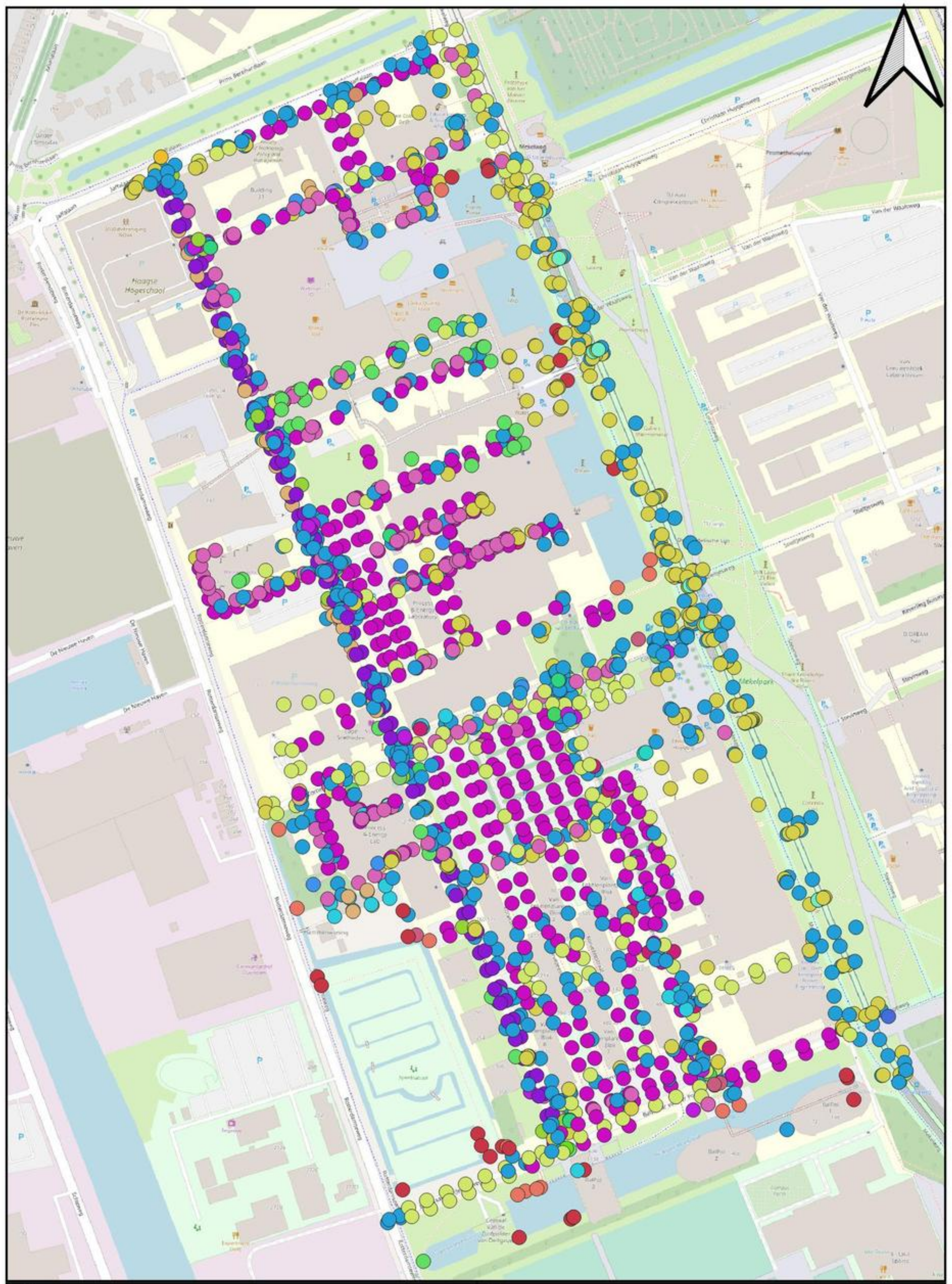


Data collection



Vector data			Raster data
Attributes	**Geometry**	**Topology**	**Elevation**
Data features that describes their nature (e.g. network type, usage, semnatic information)	Information related to data shape, legnth and type of geometry (e.g. geometry: line, point)	Information about the connectivity between the stored entities and the between them relationships	Height information related to the surface of the study area, extracted from the corresponding Digital Terrain Model


84000.00
85500.00
87000.00
448500.00
447000.00
445500.00
0 50100 m
Legend
TU_sewer_line_LineZ
_onbekend
Brandrioolleiding
Drainage
Duiker
Infiltratieriool
Kolkaansluitleiding
Perceelaanslui
Persleiding
Rioolstreng
OpenStreetMap
Scale:
0 20 40 m
1:5,200
Source:
Directie Campus and Real Estate
Departemnt TU Delft
Coordinate Reference System:
EPSG: 28992
Amersfoort / RD New



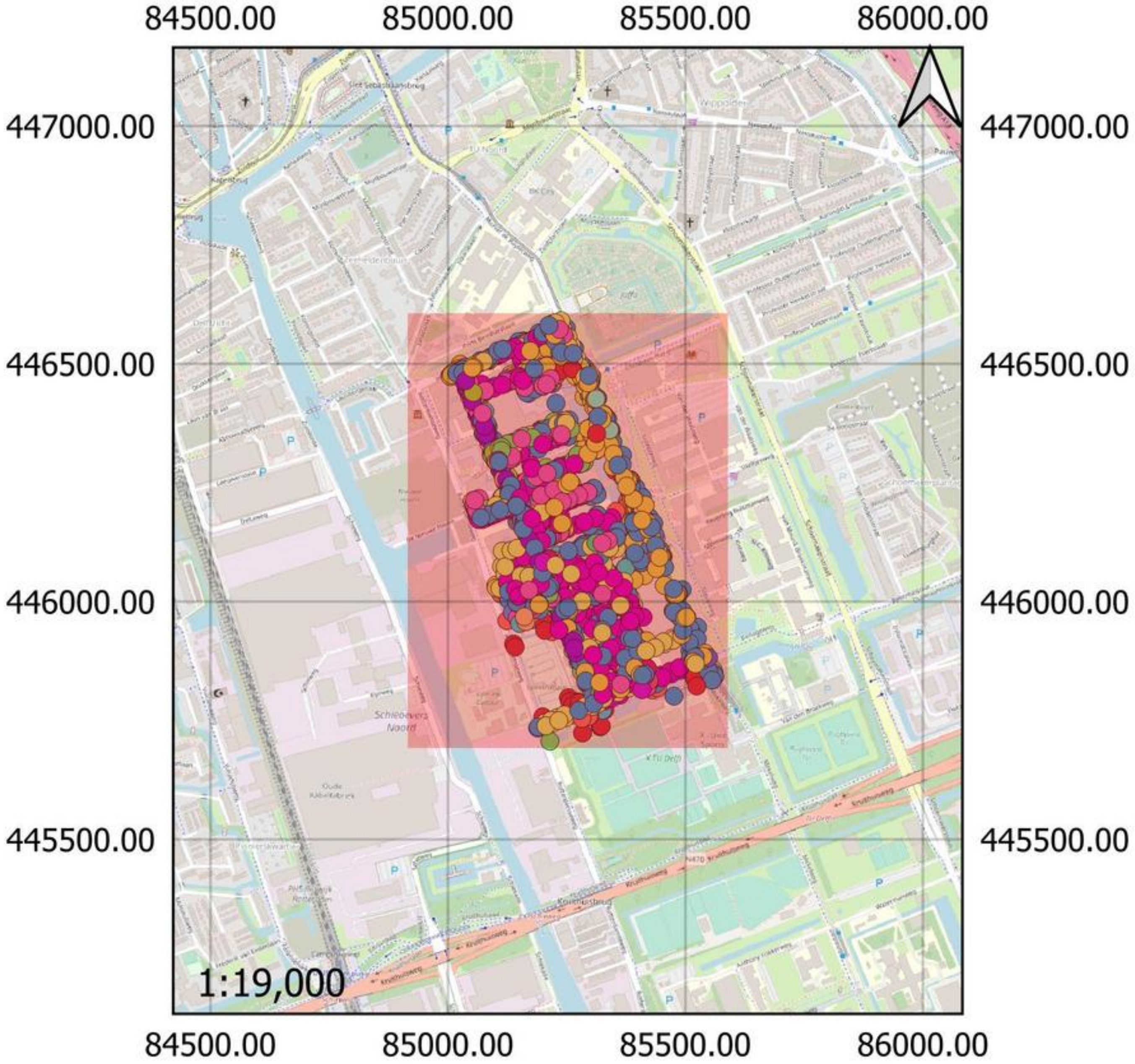
Scale:

0 20 40 m

1:5,200

Source:

Directie Campus and Real Estate Departement TU Delft



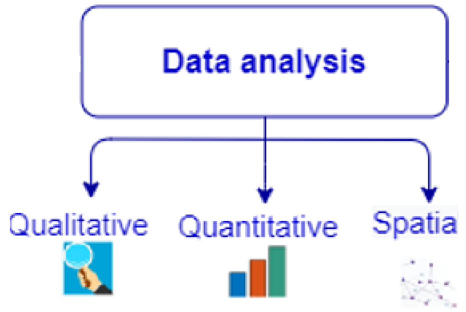
Legend

TU Sewer network elements

OpenStreetMap

Coordinate Reference System:
EPSG: 28992
Amersfoort / RD New

Data analysis

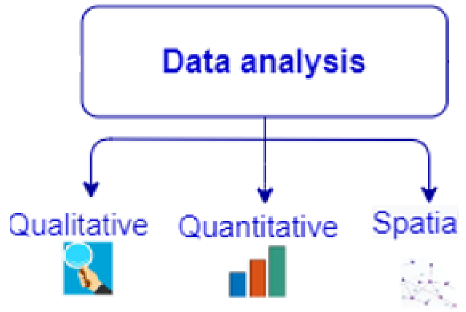


✓ **Quantitative:** Refer to numerical analysis; finding patterns, cause-effect relationships

✓ **Qualitative:** Refer to the elements characterize the data
- Transcription
- Content analysis

✓ **Spatial:** Refer to the study of the entities using their topological, geometric, and geographic properties.

Data analysis



Qualitative
Quantitative
Spatial

Attributes: Analyze the stored records that characterize the network and network elements (e.g. available 3D information)

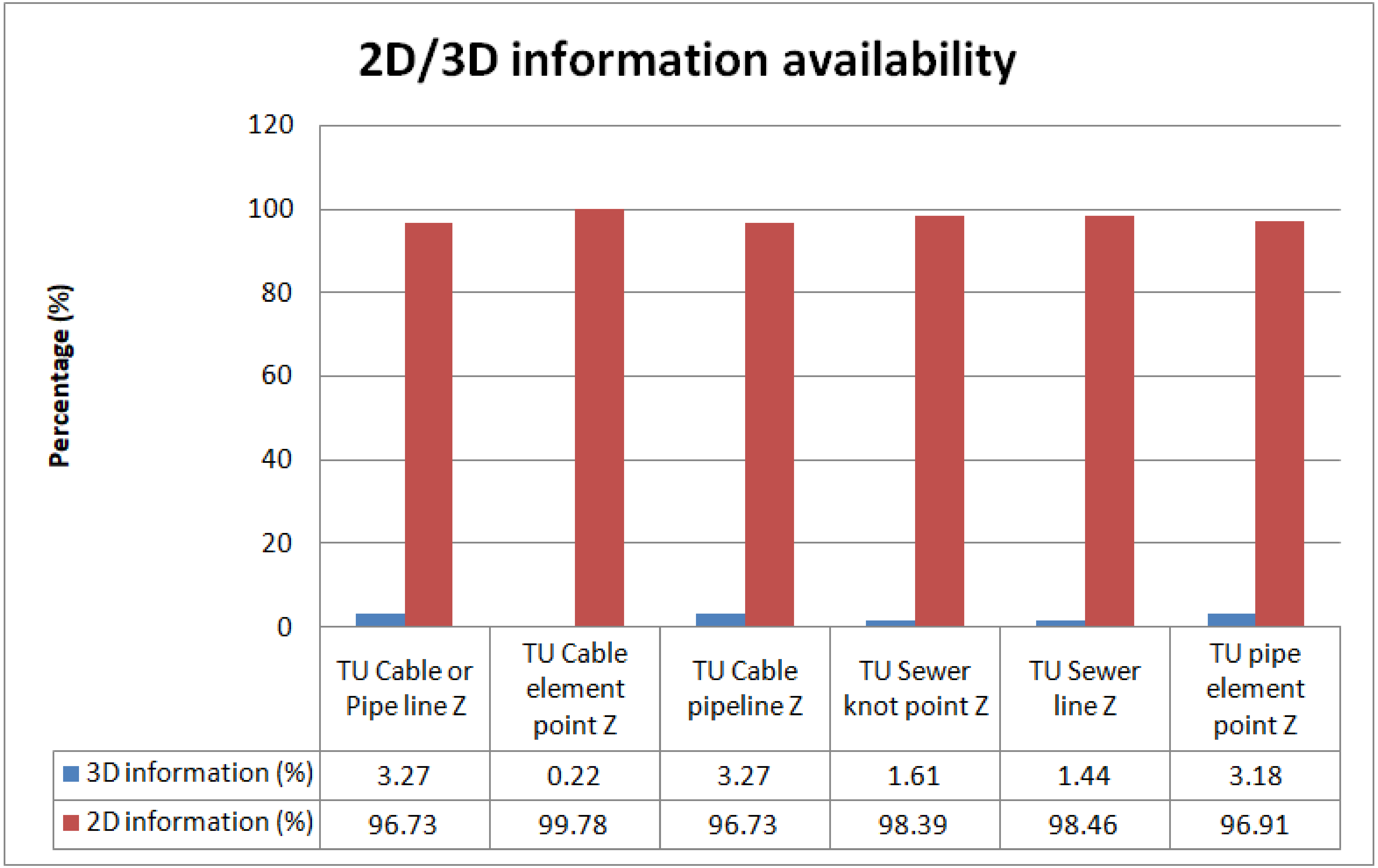
Geometry: Clarification of the shapes and lengths of the available features

Topology: Examine connectivity between the features stored in the vector data as well as the existing relationships

Dataset/ completeness	Total number of rows	Rows with complete information	Rows with incomplete information
TU Cable or Pipe line Z	1407	-	1407
TU Cable element point Z	912	34	878
TU Cable pipeline Z	1407	-	1407
TU Sewer knot point Z	1986	-	1986
TU Sewer line Z	2080	19	2061
TU pipe element point Z	1038	-	1038

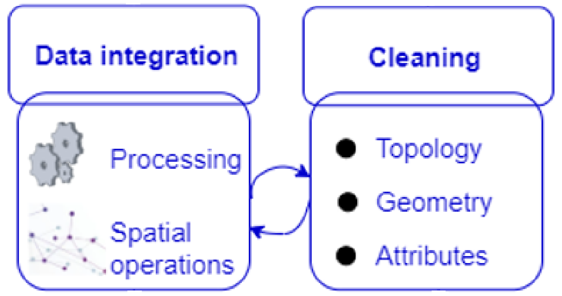
3.7%

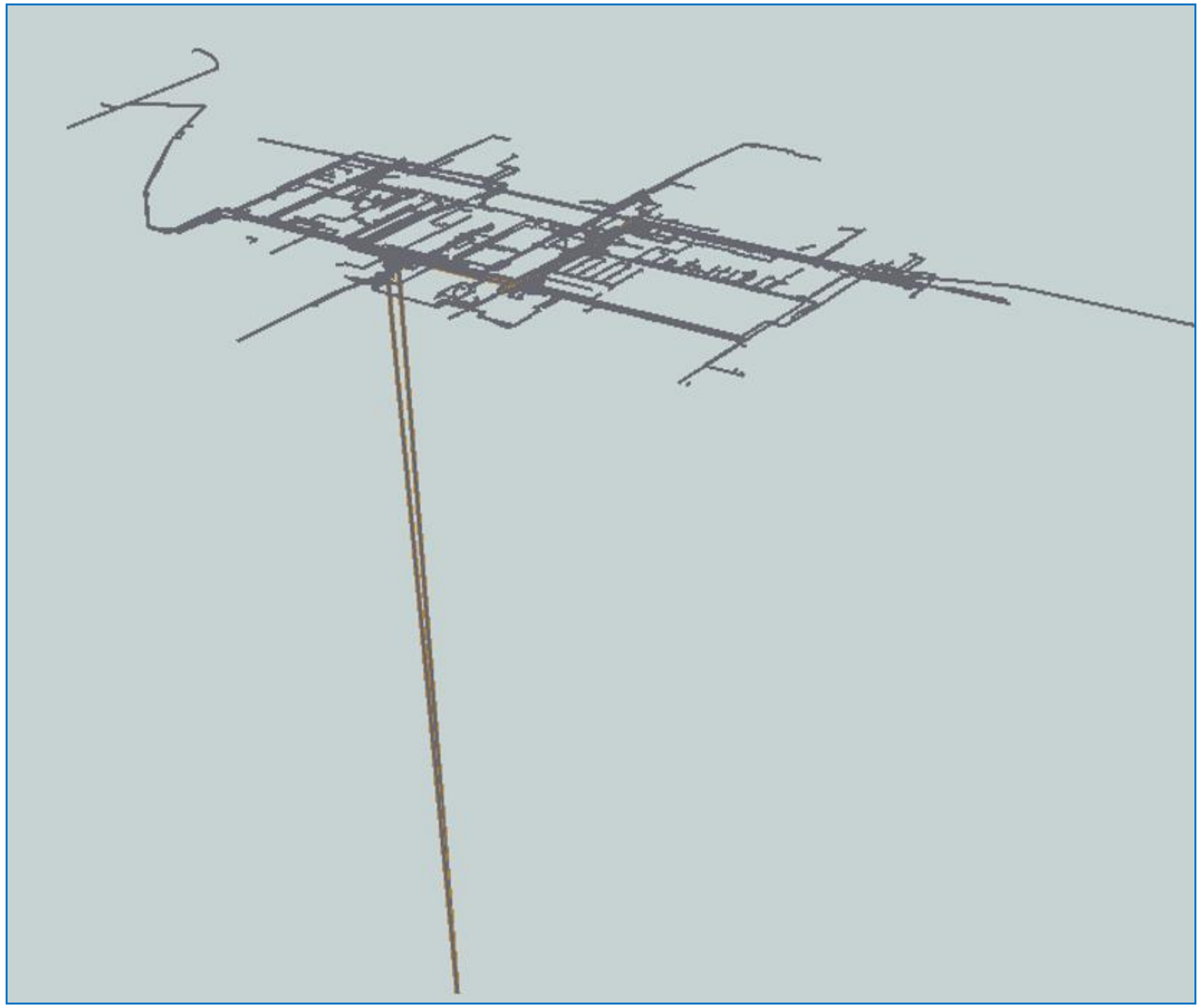
0.9%

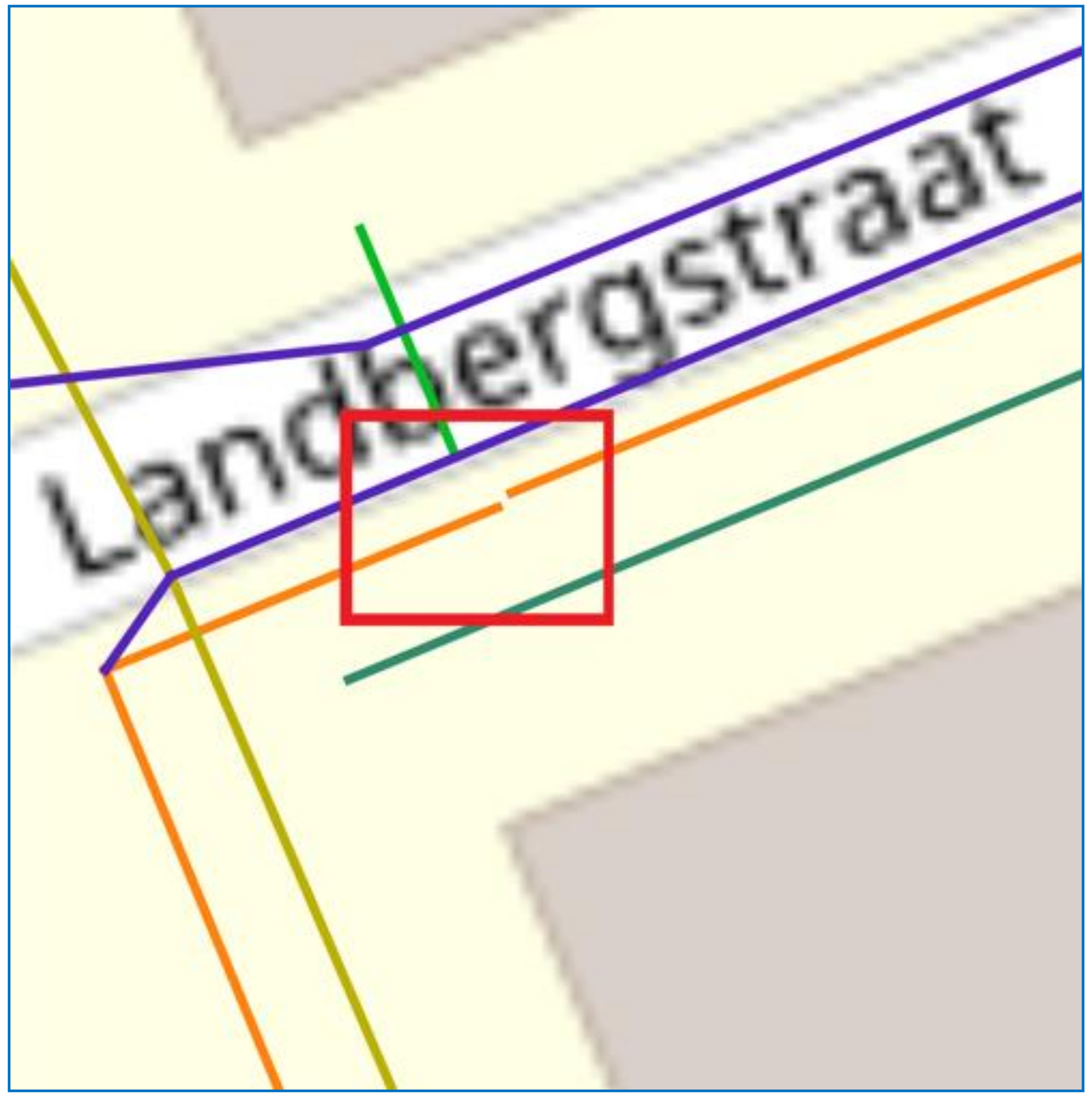


	TU Cable or Pipe line Z	TU Cable element point Z	TU Cable pipeline Z	TU Sewer knot point Z	TU Sewer line Z	TU pipe element point Z
3D information (%)	3.27	0.22	3.27	1.61	1.44	3.18
2D information (%)	96.73	99.78	96.73	98.39	98.46	96.91

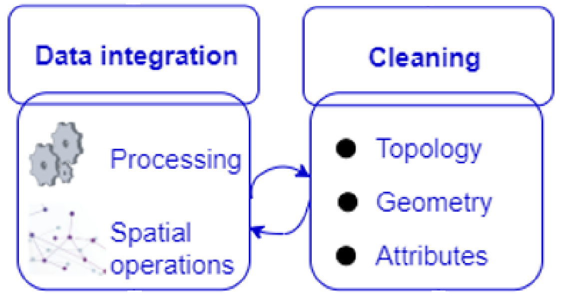
Data processing/ cleaning



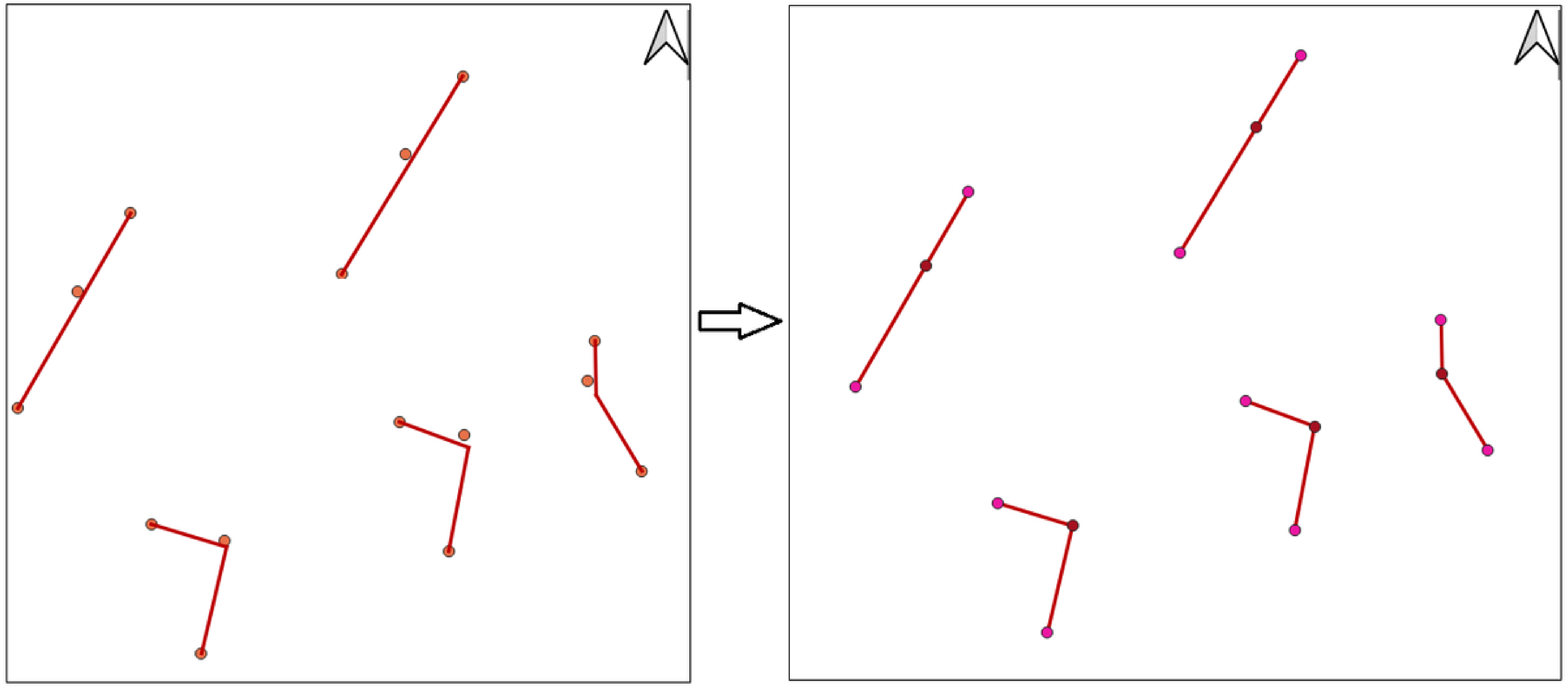


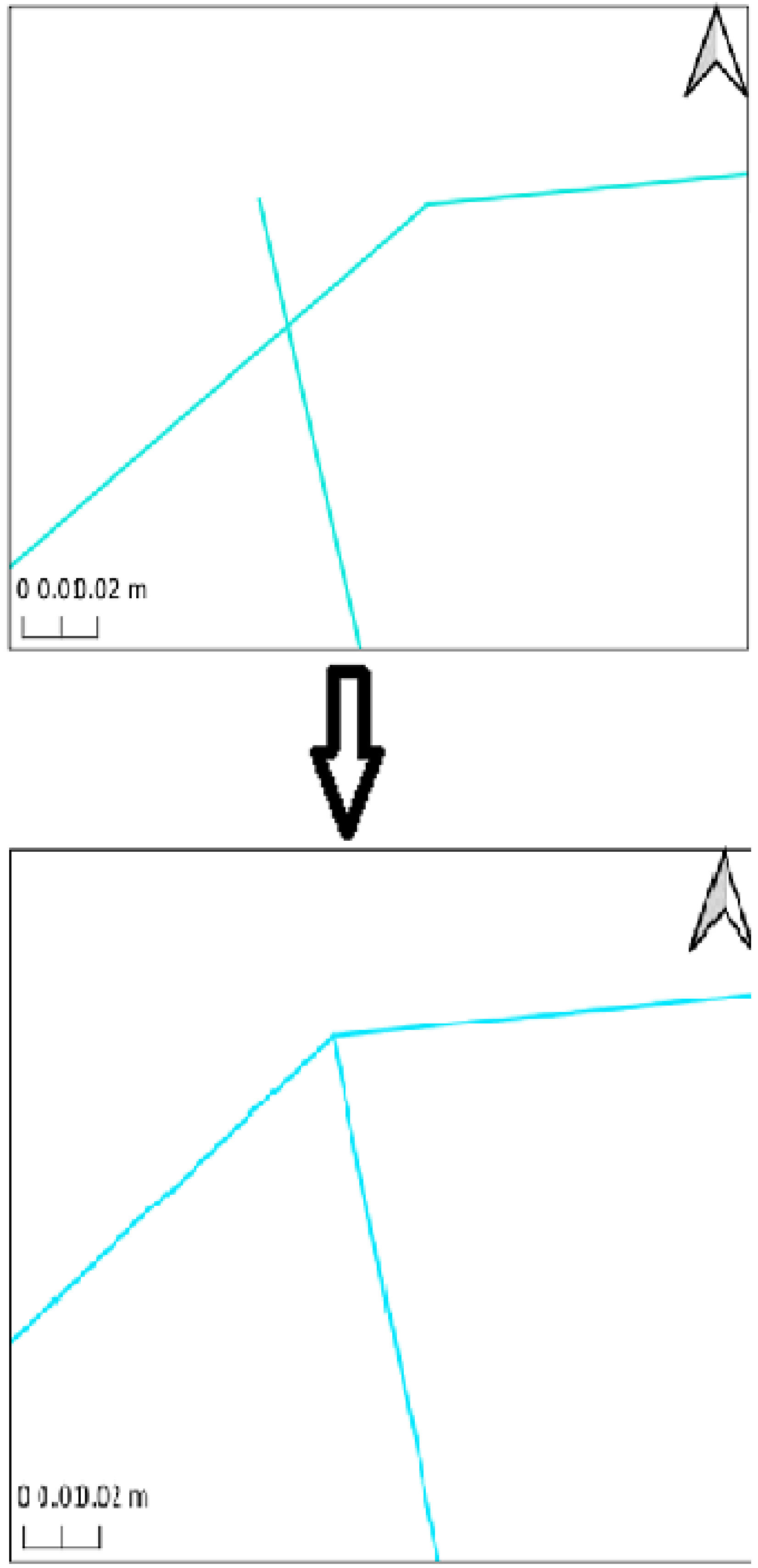


Data processing/ cleaning



- **Data cleaning process**: manual modifications

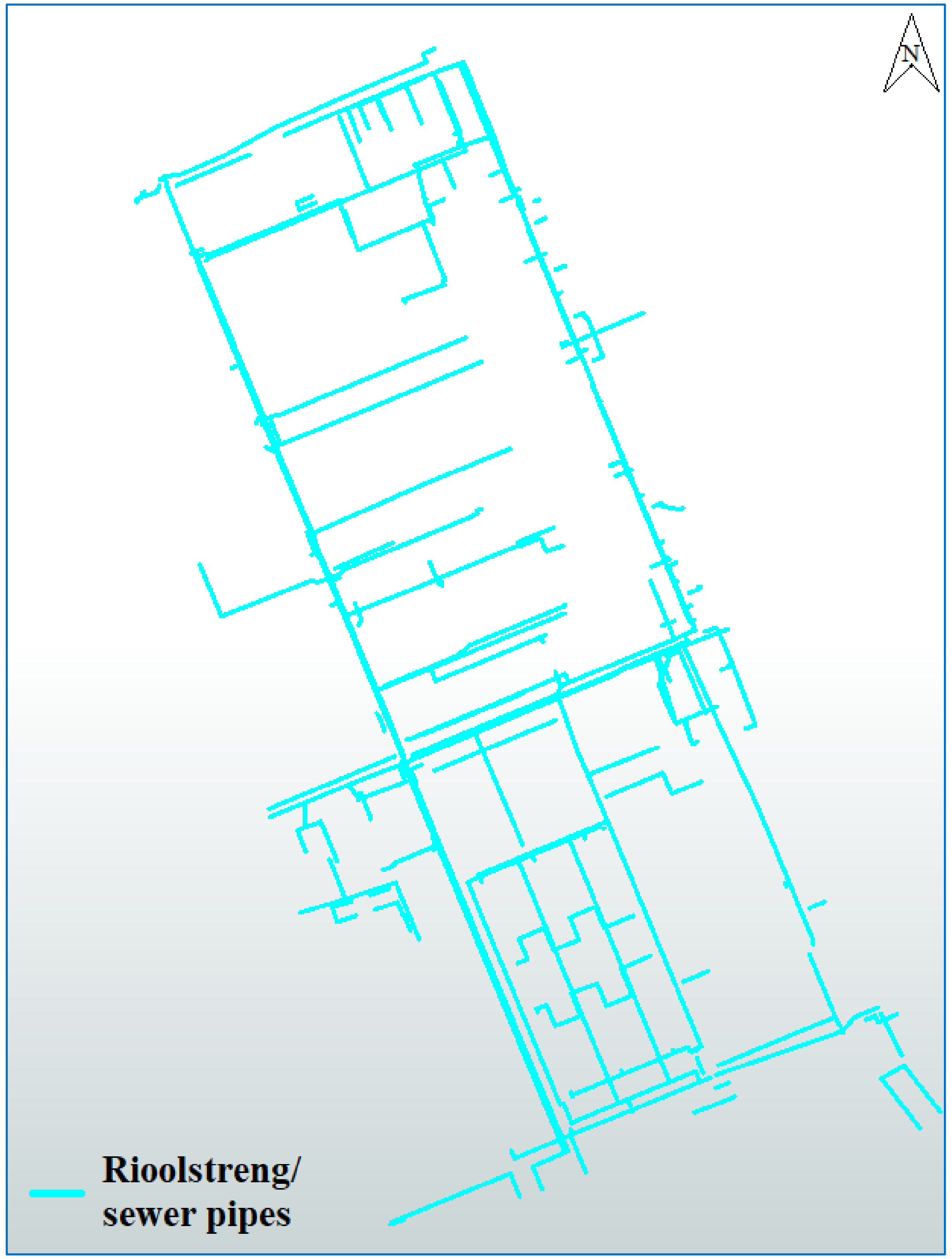


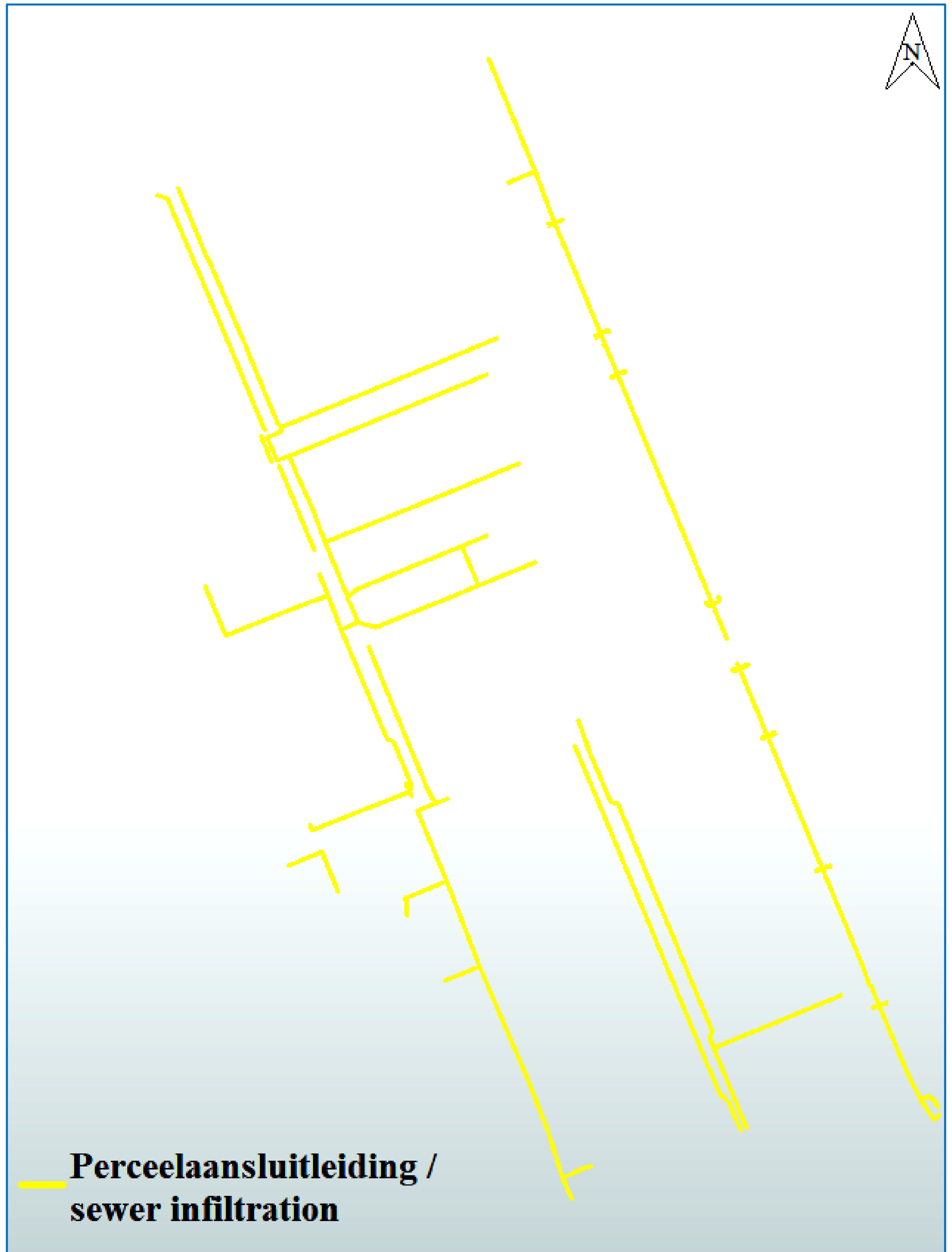


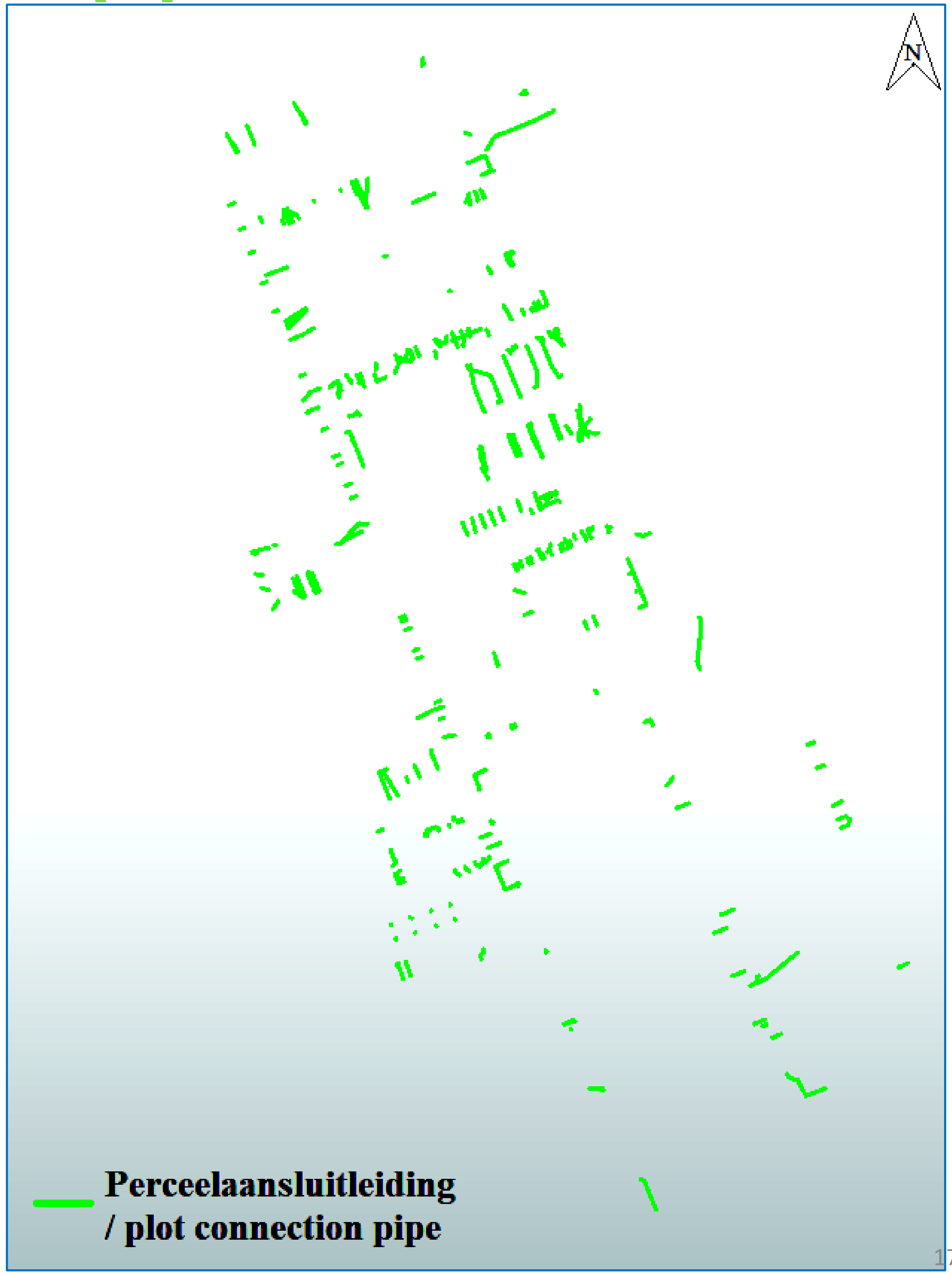
Sewage network

Infiltration network

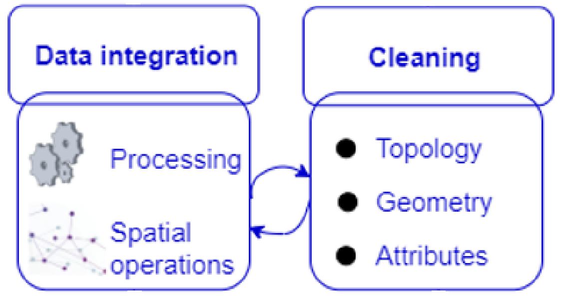
Plot connection pipes



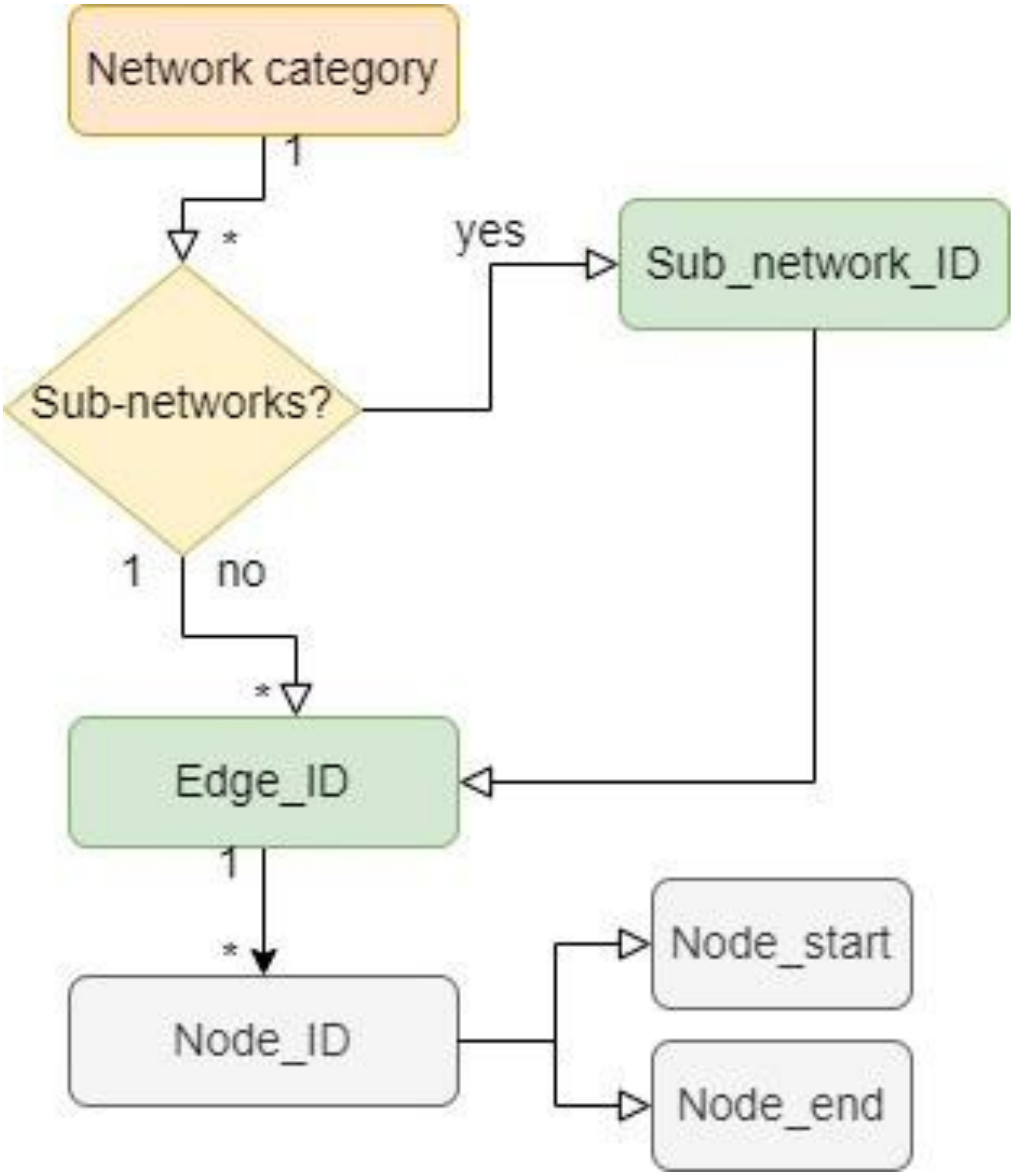




Data processing/ cleaning

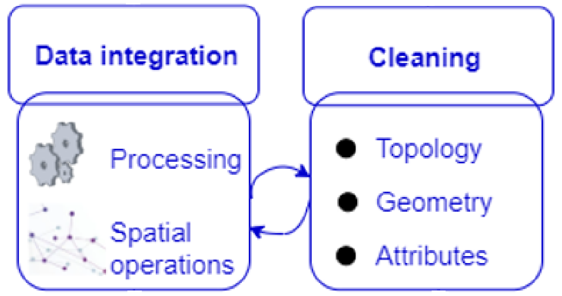


2. **Data processing and integration:** addition of fields to create interdependencies between the datasets and their components

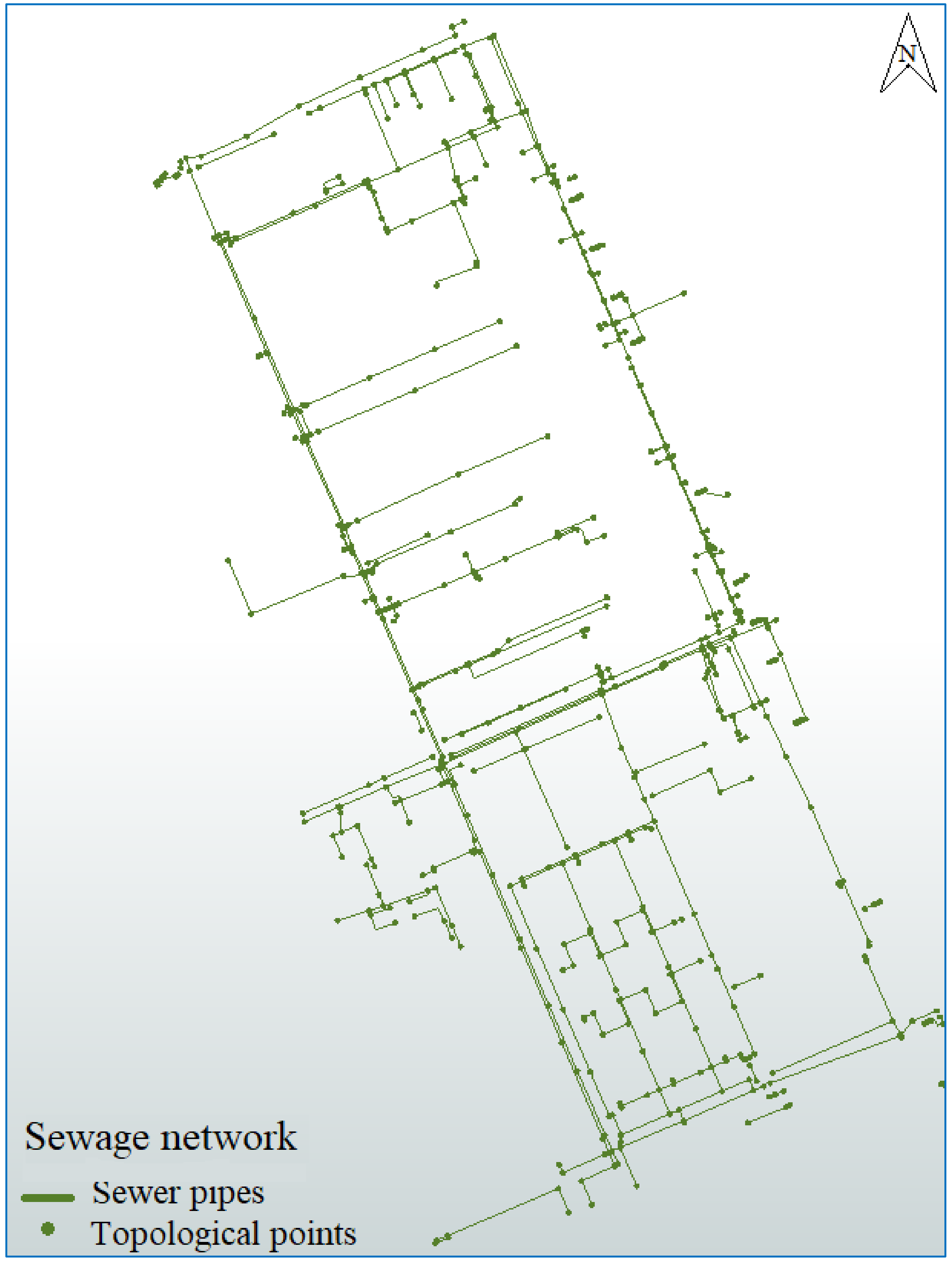


Network_id	Edge_id	Subnetwork_id	Node_start	Node_end
2	2	130	157	55
2	1	174	73	56
2	2	167	173	57

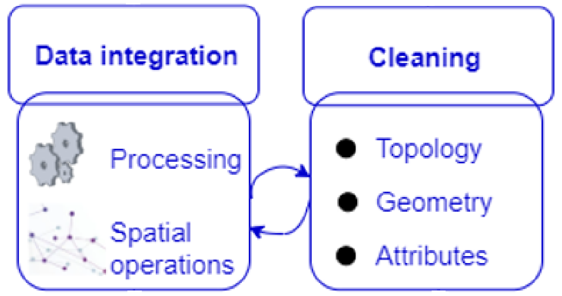
Data processing/ cleaning



3. **Topology reconstruction:**
Extract the significant nodes of the networks
+
associate them with the point datasets information



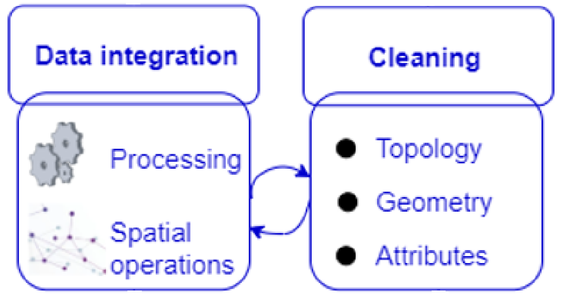
Data processing/ cleaning



Maintenance of the attributes of the initial point dataset- ***spatial overlay***

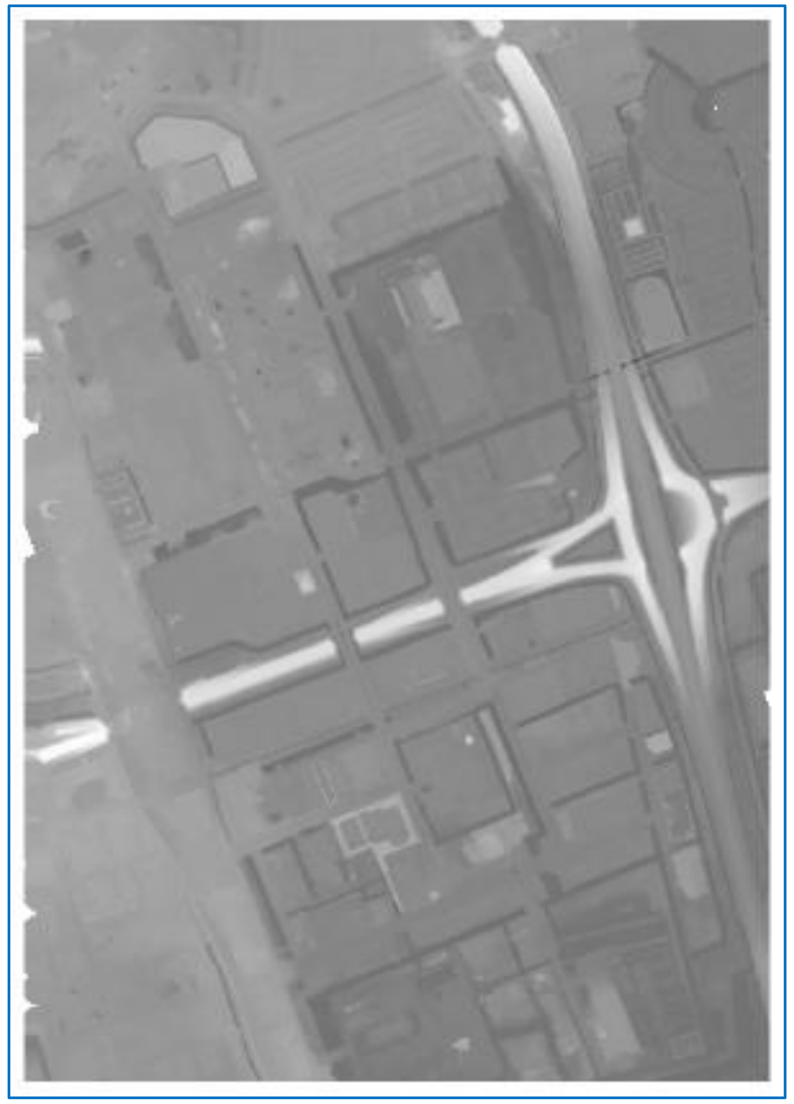
Node_id	Network_id	Sub_network	OBJECTID
1	2	1	2563
3	2	1	3347
4	2	1	4272
5	2	2	3808
6	2	2	4492
. . . . .			

Data processing/ cleaning

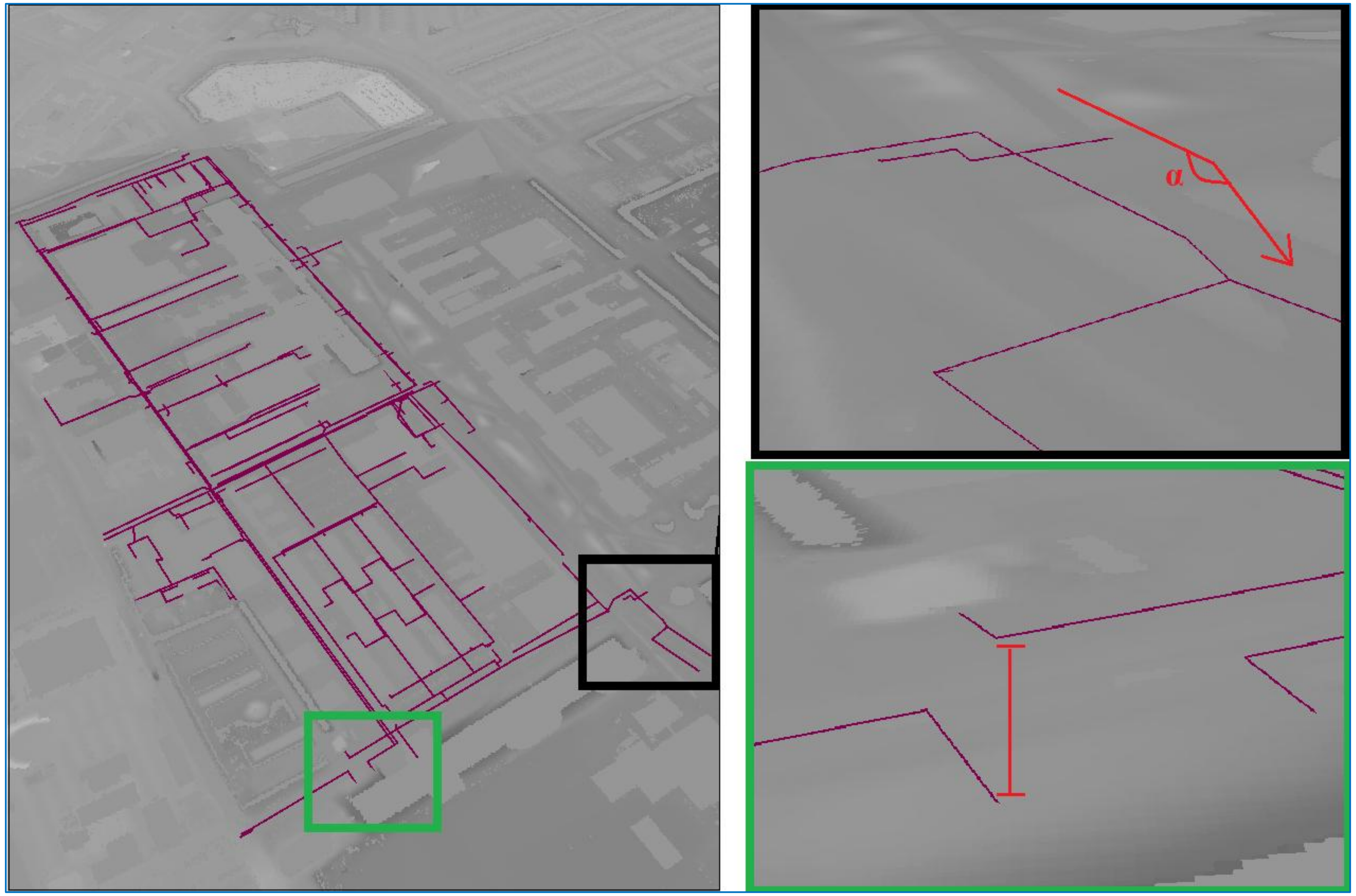


4. Data integration - 3D model of underground utility networks

DTM: null values

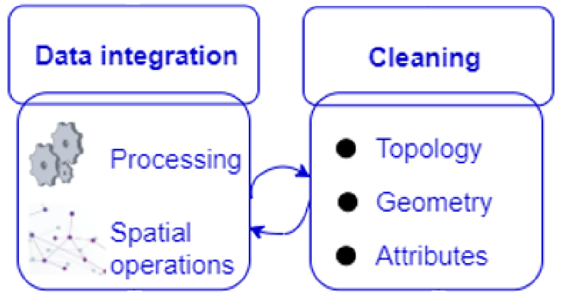


DTM: filled values

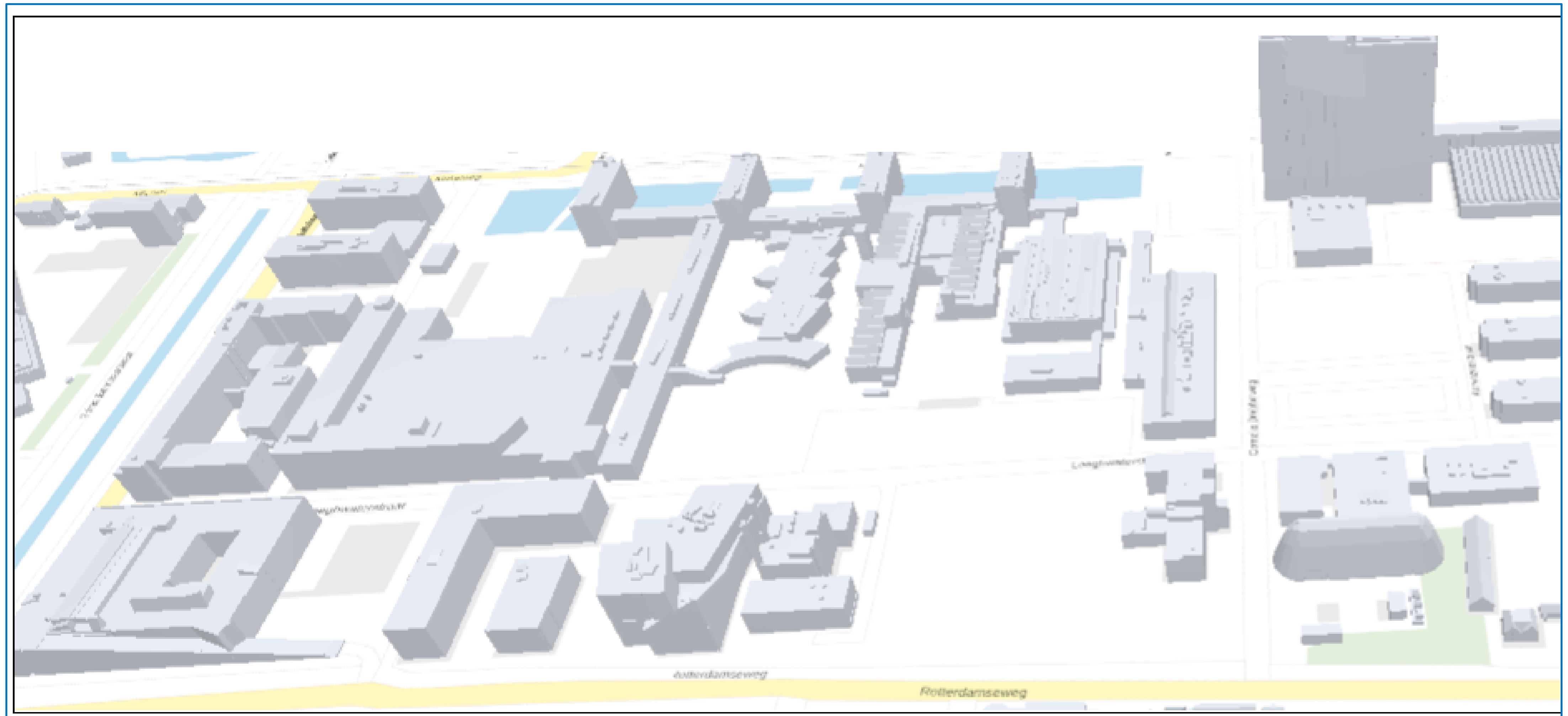


Draped features

Data integration



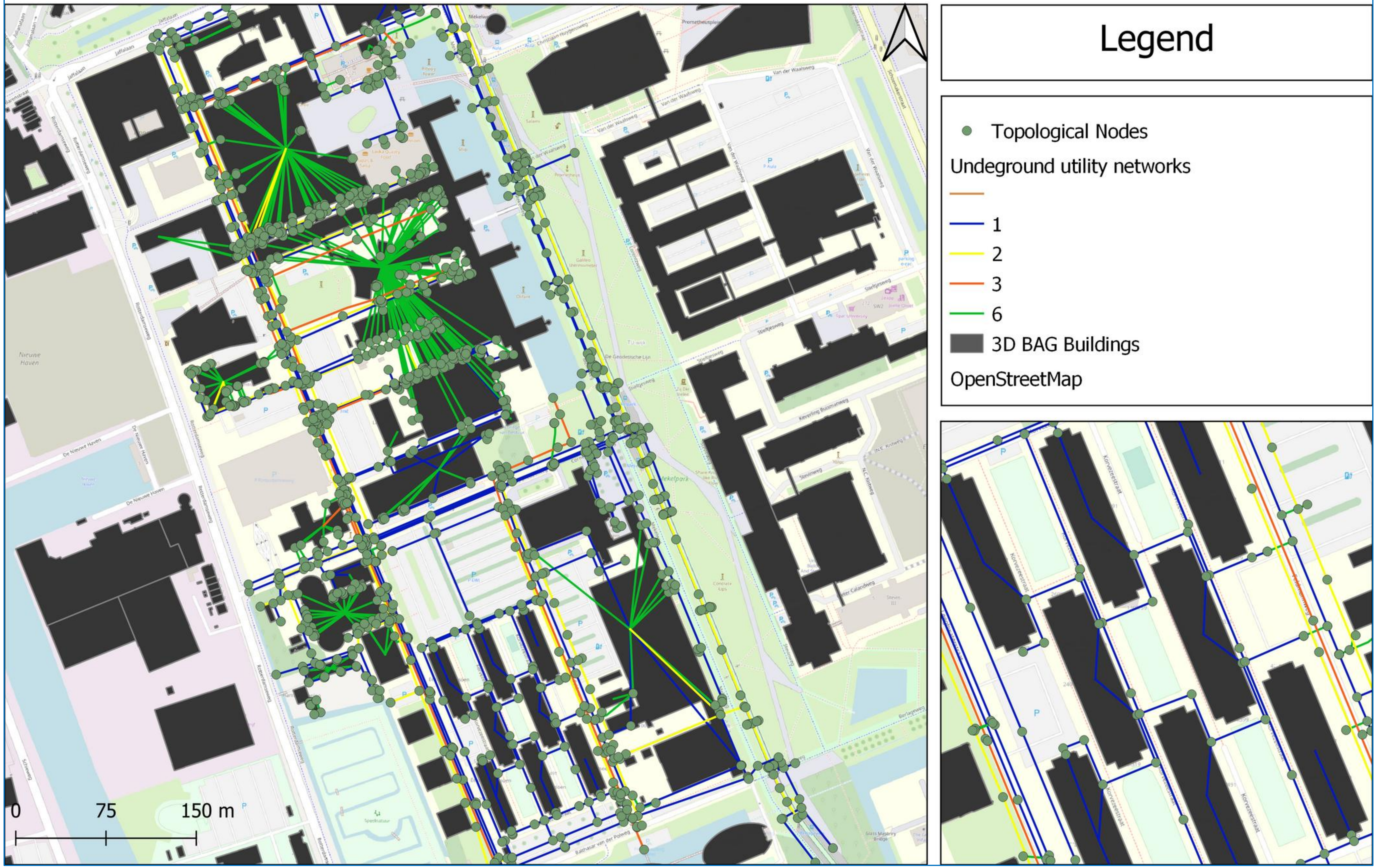
5.1 Utility network model integration with city objects (Buildings)



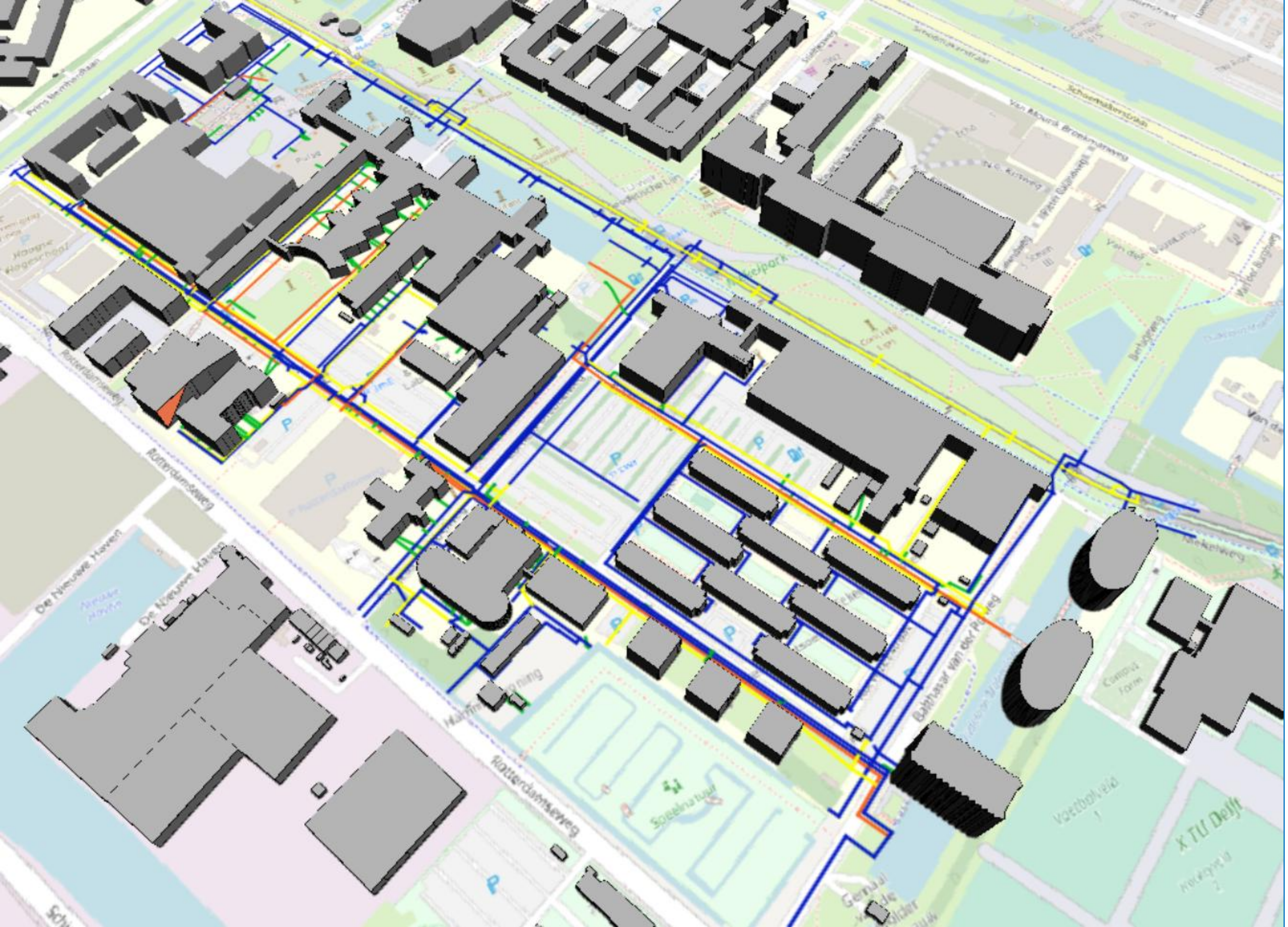
3D BAG

Base layer: BRT Achtergrondkaart
LoD: 2.2

Integrated undeground utility networks



- Virtual edges connected with buildings' centroid
- Connection between topological nodes and city object



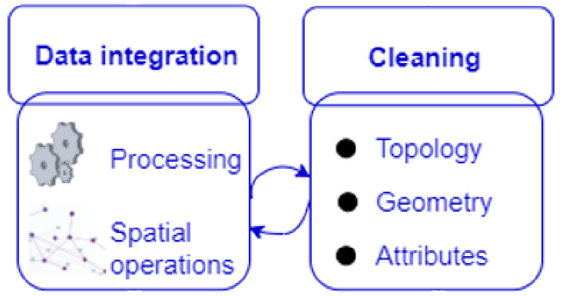
Sewage network

Infiltration network

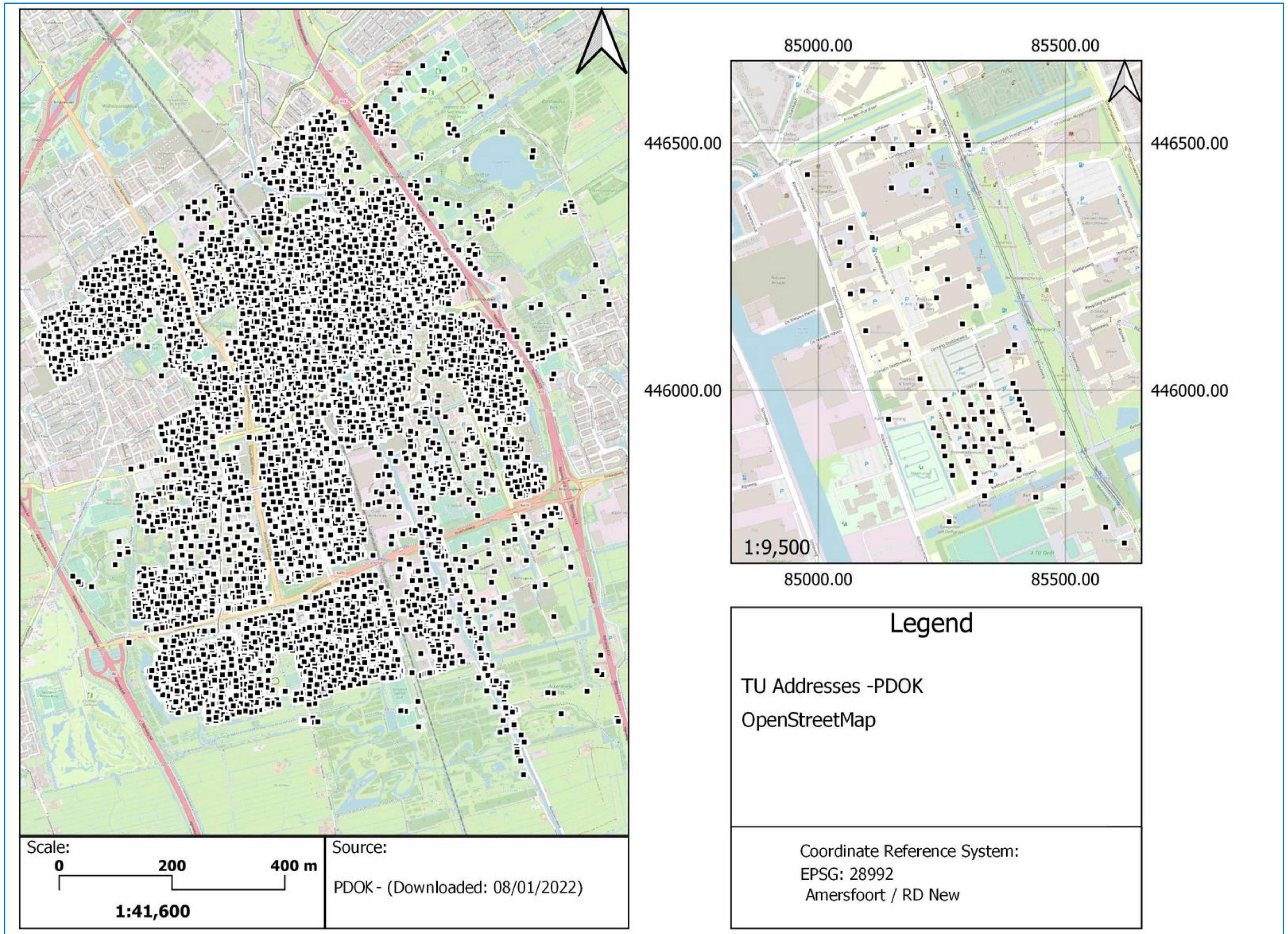
Fire pipes network

Plot connection pipes

Data processing/ cleaning

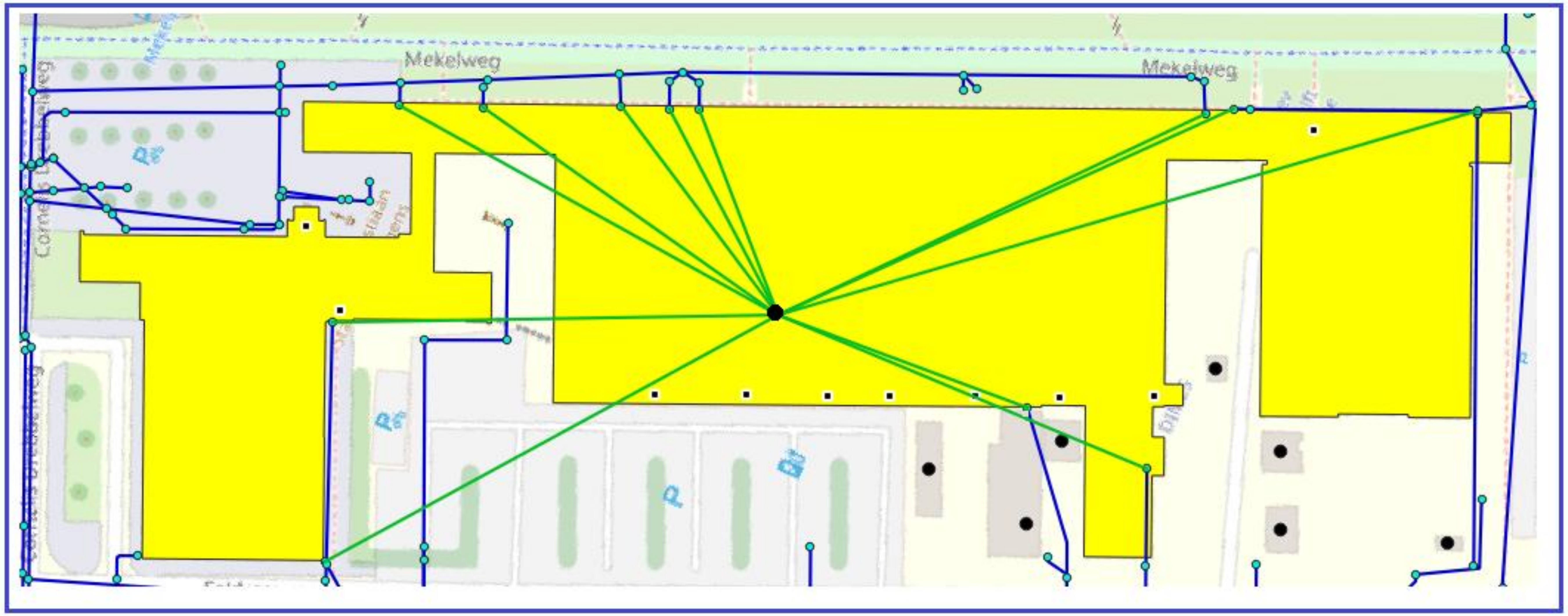


5.2 **Utility network model integration with city objects (Addresses)**

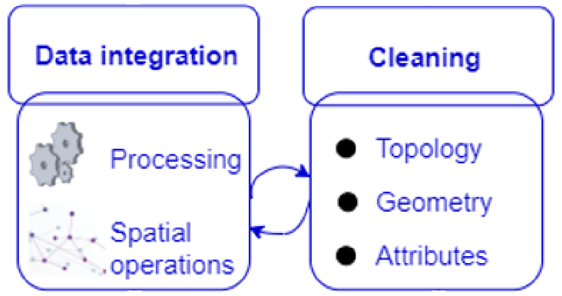


Addresses point approach

Building-centroid approach



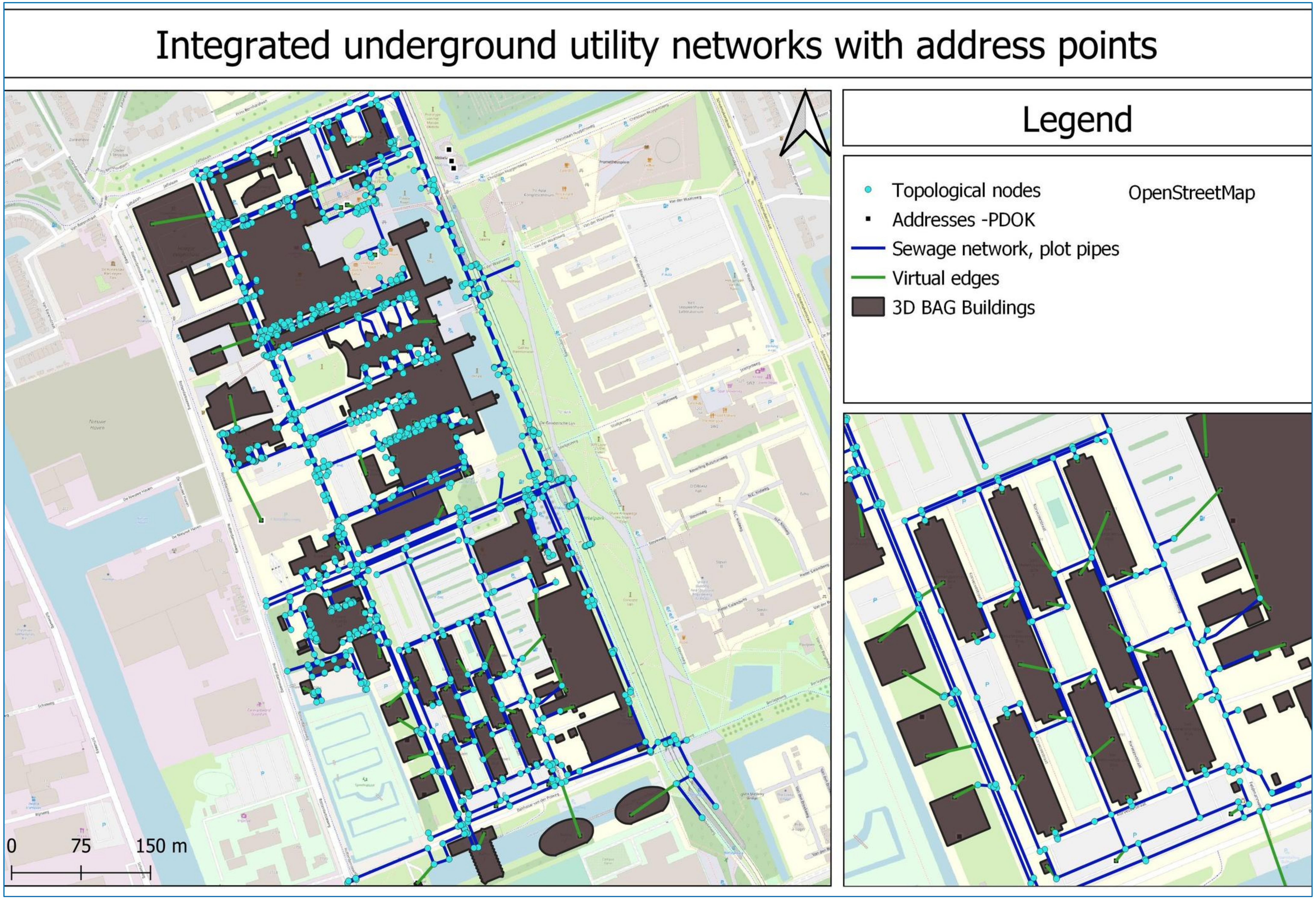
Data processing/ cleaning



Attributes

- House number id
- Postcode
- Building entity id
- Municipality

	openbareru	isnumm	uislette	isnumm	postcode	oonplaa	emeenten	rovincie	verblijfso	ppervlal	verblijf_1	peadres	adresseerb	pandid	andstatu	ndbouw	nummeraand
1	Rotterdamseweg	139	B	11	2628AL	Delft	Delft	Zuid-H...	woonfu...	33	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
2	Rotterdamseweg	139	B	46	2628AL	Delft	Delft	Zuid-H...	woonfu...	30	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
3	Rotterdamseweg	139	B	51	2628AL	Delft	Delft	Zuid-H...	woonfu...	30	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
4	Rotterdamseweg	139	B	53	2628AL	Delft	Delft	Zuid-H...	woonfu...	30	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
5	Rotterdamseweg	139	B	14	2628AL	Delft	Delft	Zuid-H...	woonfu...	29	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
6	Rotterdamseweg	139	B	47	2628AL	Delft	Delft	Zuid-H...	woonfu...	31	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
7	Rotterdamseweg	139	B	17	2628AL	Delft	Delft	Zuid-H...	woonfu...	31	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
8	Rotterdamseweg	139	B	28	2628AL	Delft	Delft	Zuid-H...	woonfu...	29	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
9	Rotterdamseweg	139	B	5	2628AL	Delft	Delft	Zuid-H...	woonfu...	29	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...
10	Rotterdamseweg	139	B	44	2628AL	Delft	Delft	Zuid-H...	woonfu...	30	Verblijfsob...	VBO	NL.IMBAG.Verbl...	NL.IMBAG.Pand....	Pan...	2010	NL.IMBAG.Nummer...



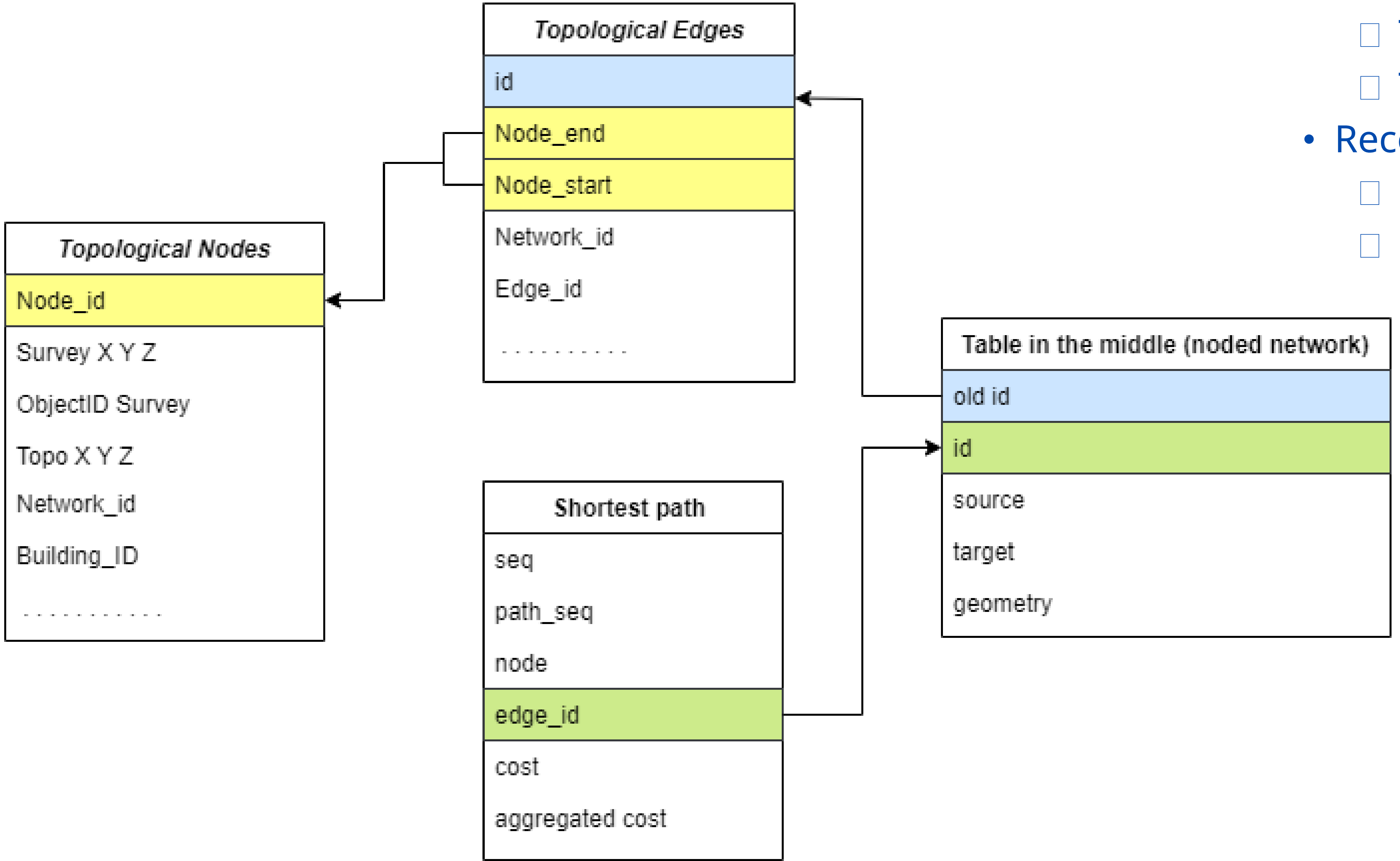
Sewage network

Plot connection pipes

Storage

Storage

6. **Relational database -** using *PostGIS/PgRouting* extensions

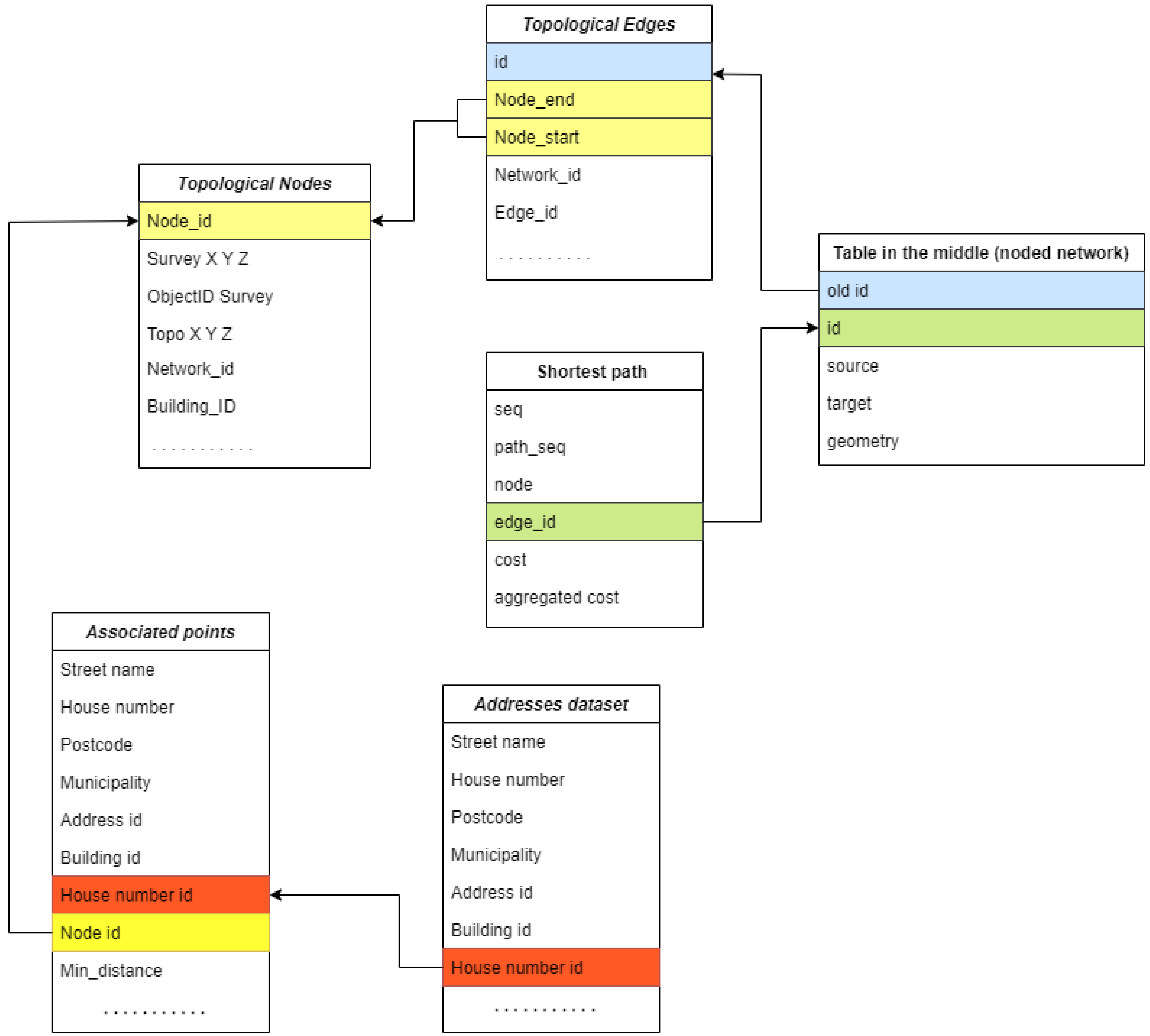


- Initial tables:
  - Topological nodes
  - Topological edges
- Reconstructed tables:
  - Noded_network (table in the middle)
  - Routing tables (shortest path)

Storage

Storage

6. **Relational database -** using *PostGIS/PgRouting* extensions



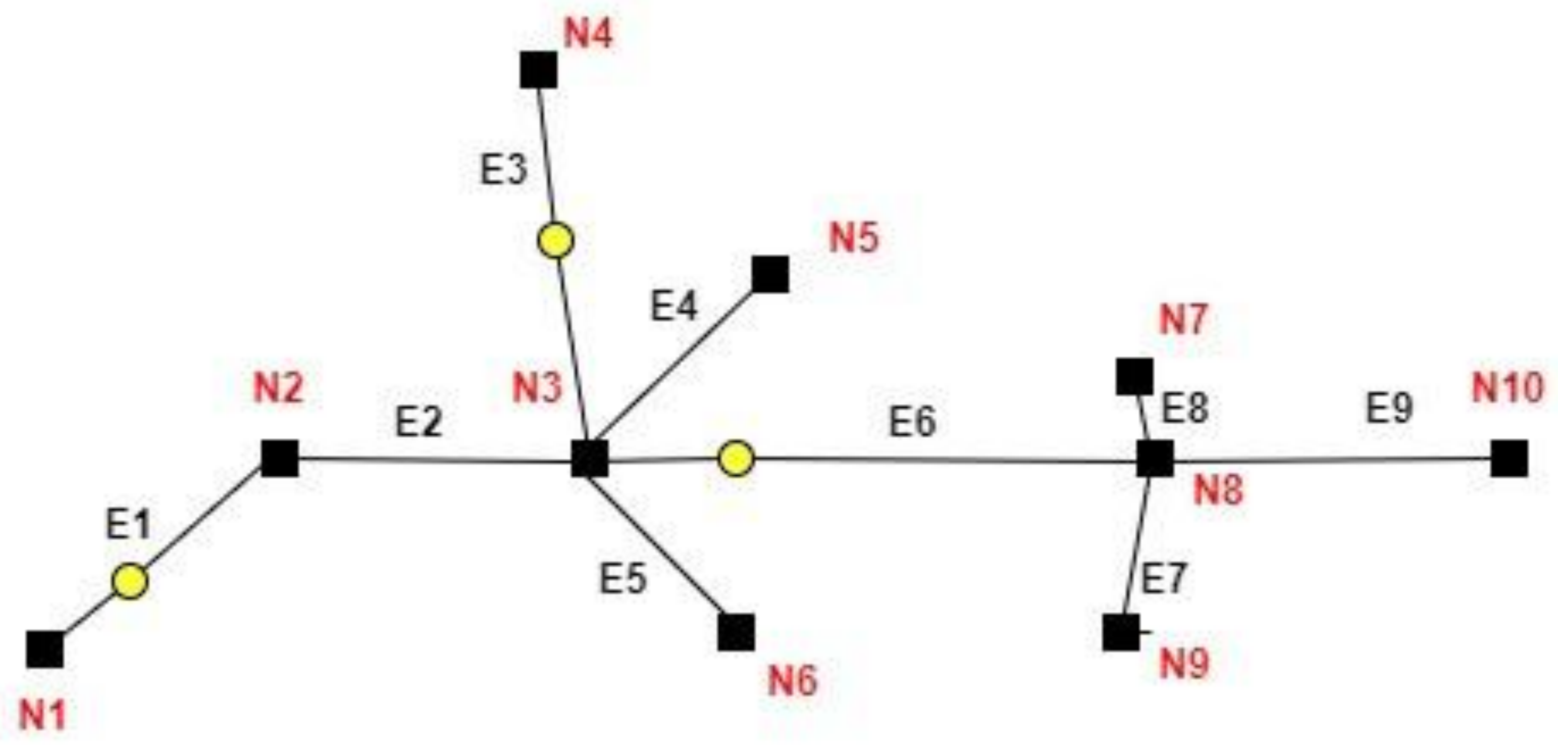
- Initial tables:
  - ☐ Topological nodes -addresses
  - ☐ Topological edges
  - ☐ Overlapping points
- Reconstructed tables:
  - ☐ Noded_network (table in the middle)
  - ☐ Routing tables (shortest path)

Case study: results

Application development

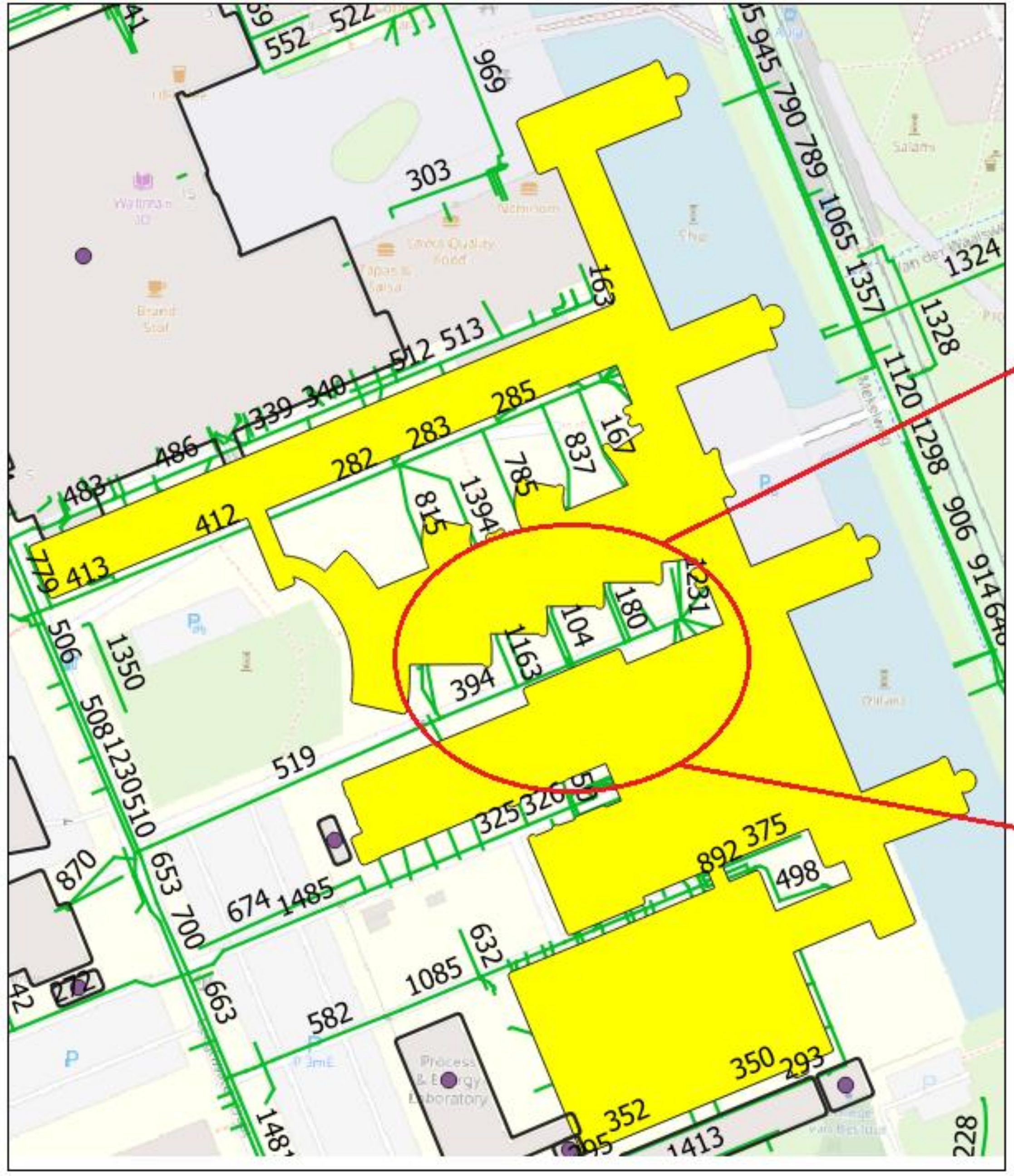
7. Case 1: *Disaster management- shortest path algorithm for building service*

Case 2: *Cost-effective route detection*



Edge ID	Node From	Node To	Length (m)
1	1	2	15.3
2	2	3	14.5
3	3	4	17
4	3	5	12.3
5	3	6	11.9
6	3	8	19.4
7	8	7	8.5
8	8	9	5.5
9	8	10	17.6

■ Node
○ Vertex
E: Edge


303
513
412
413
282
283
285
837
815
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167
163
394
1163
104
180
1231
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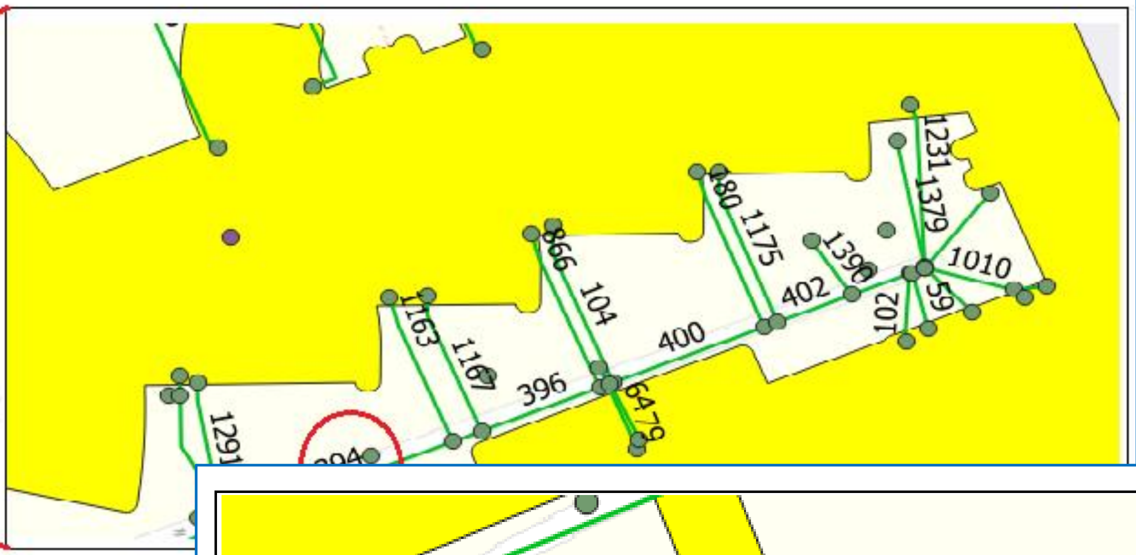
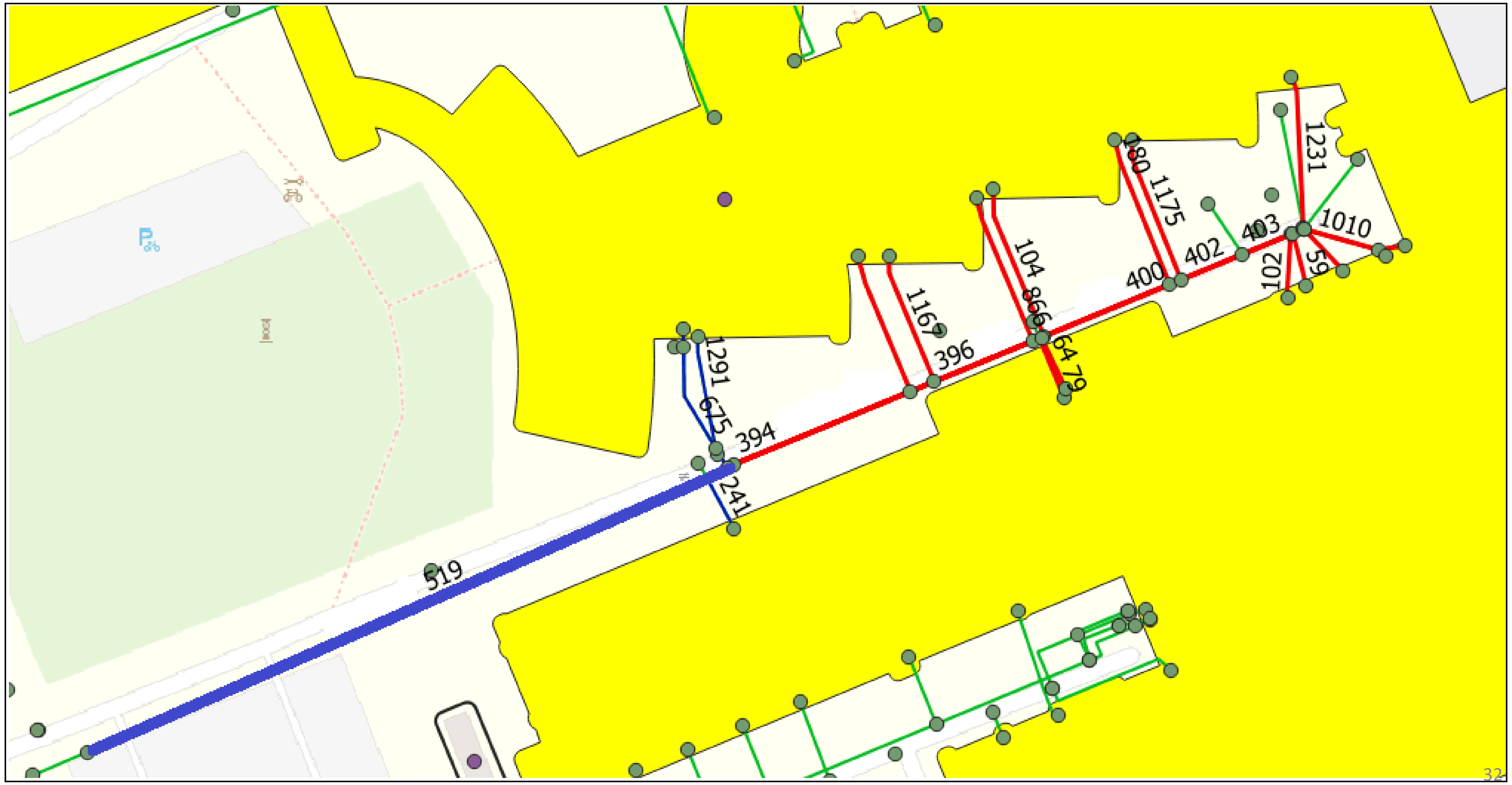
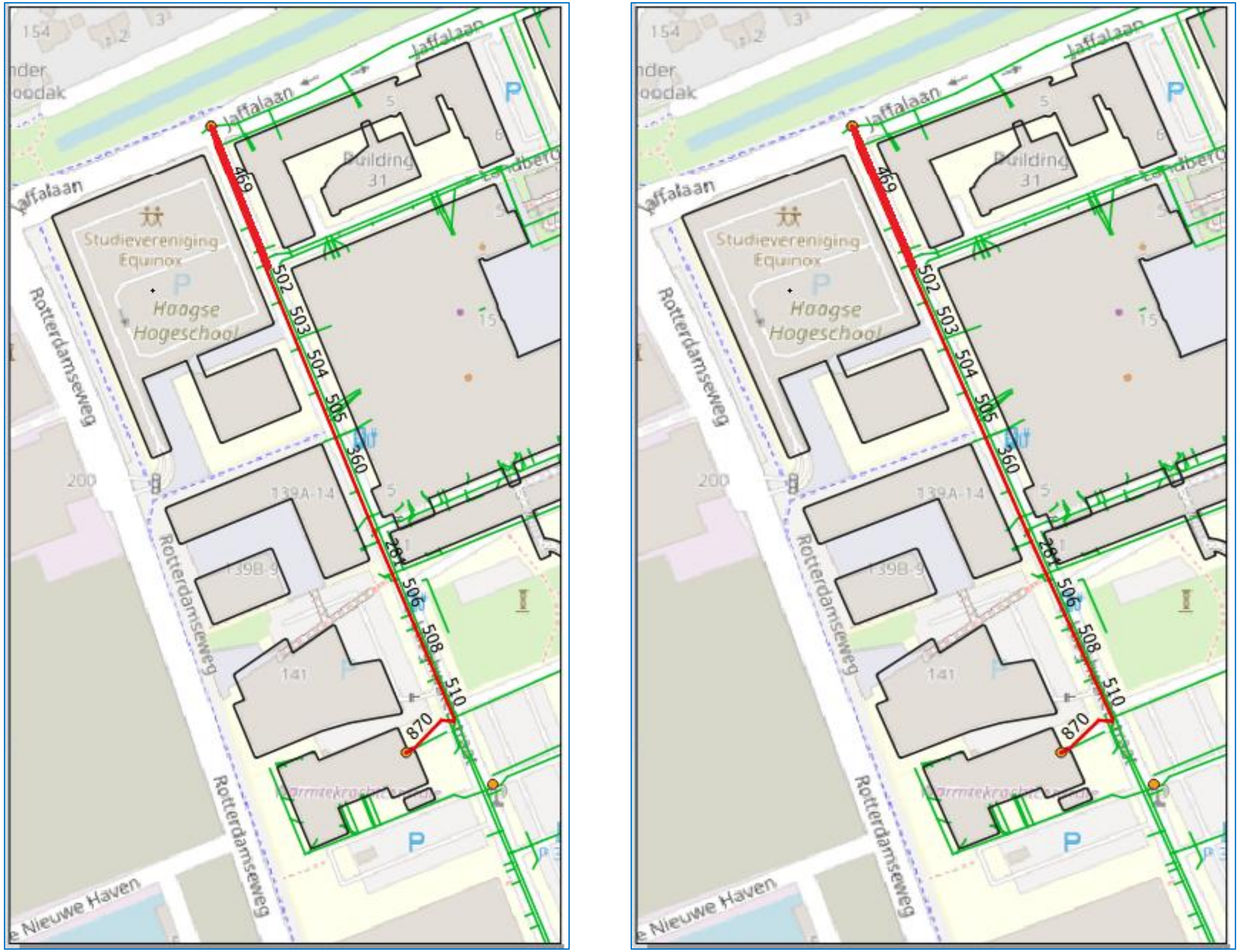
1324
1328
1298
906


1231
1379
180
1175
1396
402
1010
102
59
866
104
400
1163
1167
396
64 79
1291


1231
180
1175
1010
403
402
400
102
59
104
866
64
79
1167
396
1291
675
394
241
519

Case 1

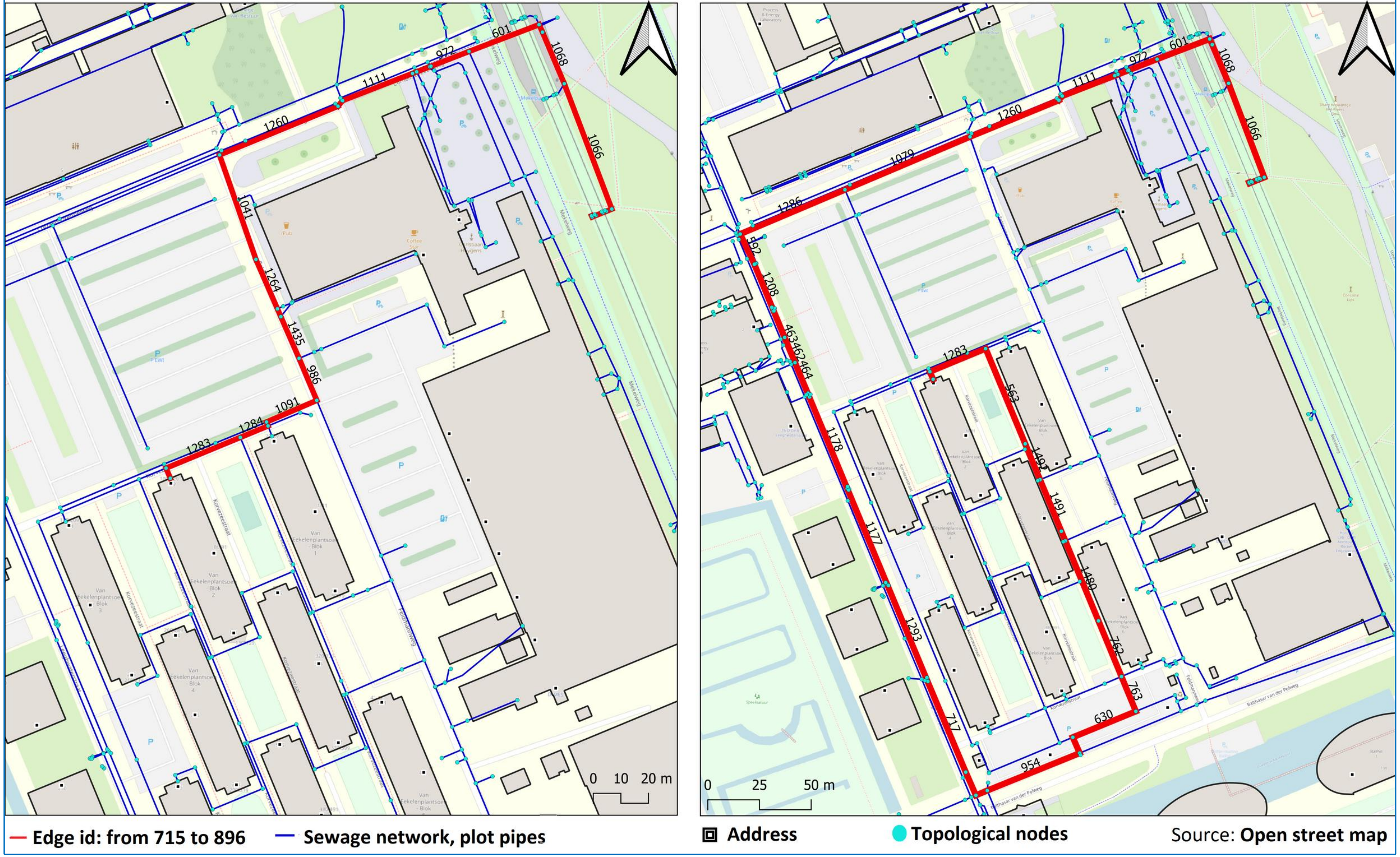
Cost optimum path for building service



Case 2

Modification of the length from selected edges, to calculate the most optimum route based on the 'cost'

Cost optimum path for address(-es) service



Objectives & Challenges

√ 3D model of underground utility networks

- √ Topology reconstruction
- √ "DTM - 3D information"

√ Integration with the above-ground objects

- √ Integration with the buildings of the study area
- √ Integration with the addreses of the study area

√ Simulation of real-world scenarios applications

- Many assumptions required due to poor data quality.
- Both approaches are based on assumptions. The connectivity must be confirmed by an expert.
- For connectivity applications topology is important (reconstruction)
- Gravity dependent applications 3D information is important (e.g. sewage network)

Comparison of the two approaches

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Building- centroid	Addresses
• Connectivity at the building level	• More realistic model
• Simplified integration	• Spatially refined connectivity

- Methods are based on assumptions regarding the connectivity
- the validity of the connections must be confirmed by an expert

Conclusions

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Delft University of Technology

Research question:

How is it possible to model underground utility networks in 3D, integrated with the above-ground objects, such that they can be suitable for multiple uses?

Sub-questions:

- *How to represent a direct connection with the above-ground condition?*
- *Is it possible to achieve that connection?*
- *Is the 3D information useful?*
- *Is it possible a limited 3D information to be extended to a larger network?*

Conclusions

Strengths	Weaknesses	Opportunities

• The proposed methodology works for the transformation of the geographical information into the topological representation
 	
• The assumptions made were operational and allowed for the utilization of the final model
 	
• List of recommendations for improving data quality
	• The integration was achieved using the topological nodes, not the survey points
	
	• The current condition of the data does not allow for their compliance with one of the available standards
	
	• Data quality cannot be improved by Geomatics experts only
		• Time must be invested in the detection of the existing inconsistencies in the available data
		  ◦ Validity should be ensured
		  ◦ Spatial processing/cleaning
		  ◦ Harmonization/ integration with available models
		
		• The data should be enriched by adding the missing information (e.g. depths) networks' depth - fieldwork

Thank you for your attention!