Modelling different levels of detail of roads and intersections in 3D city models

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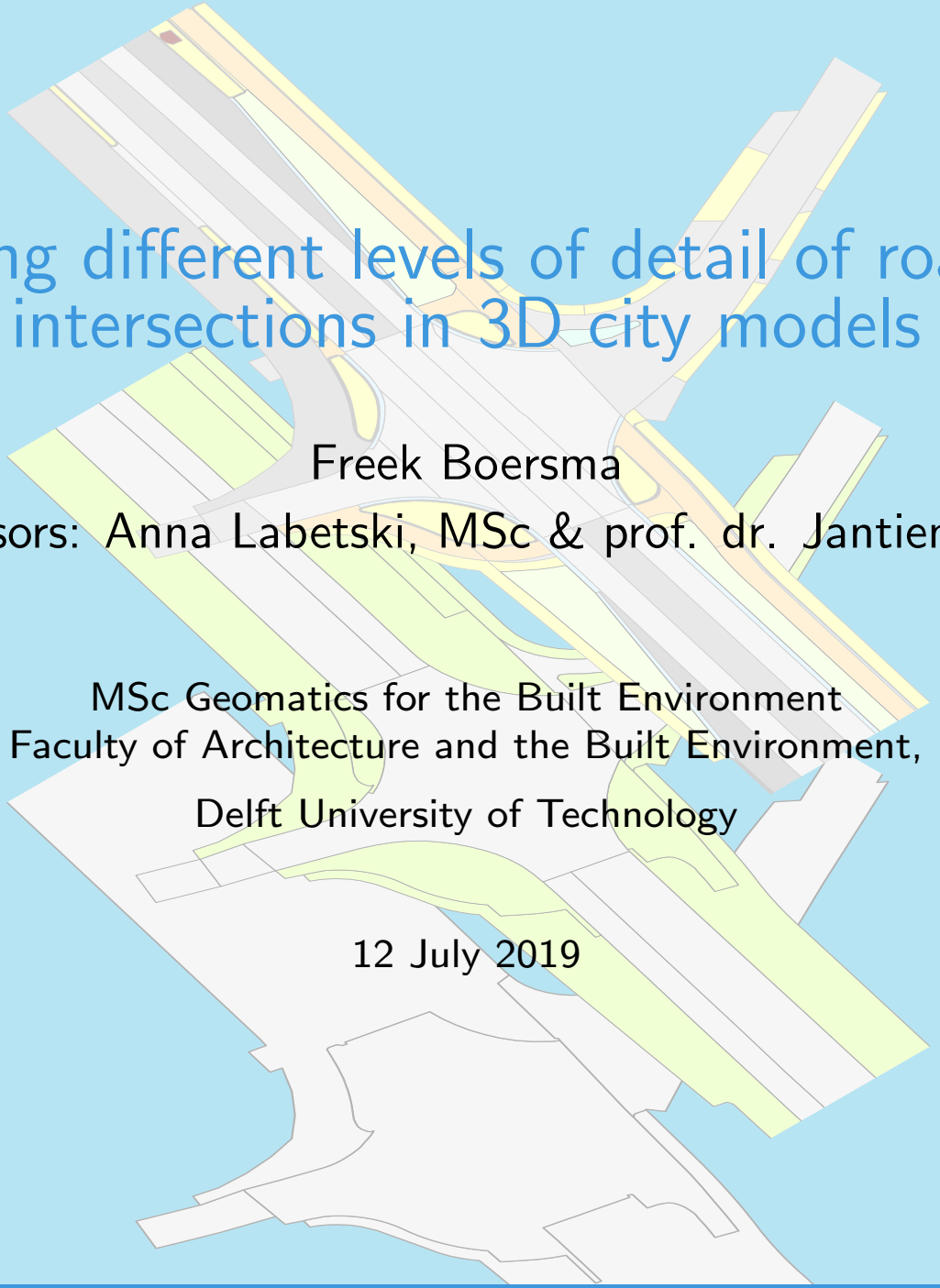
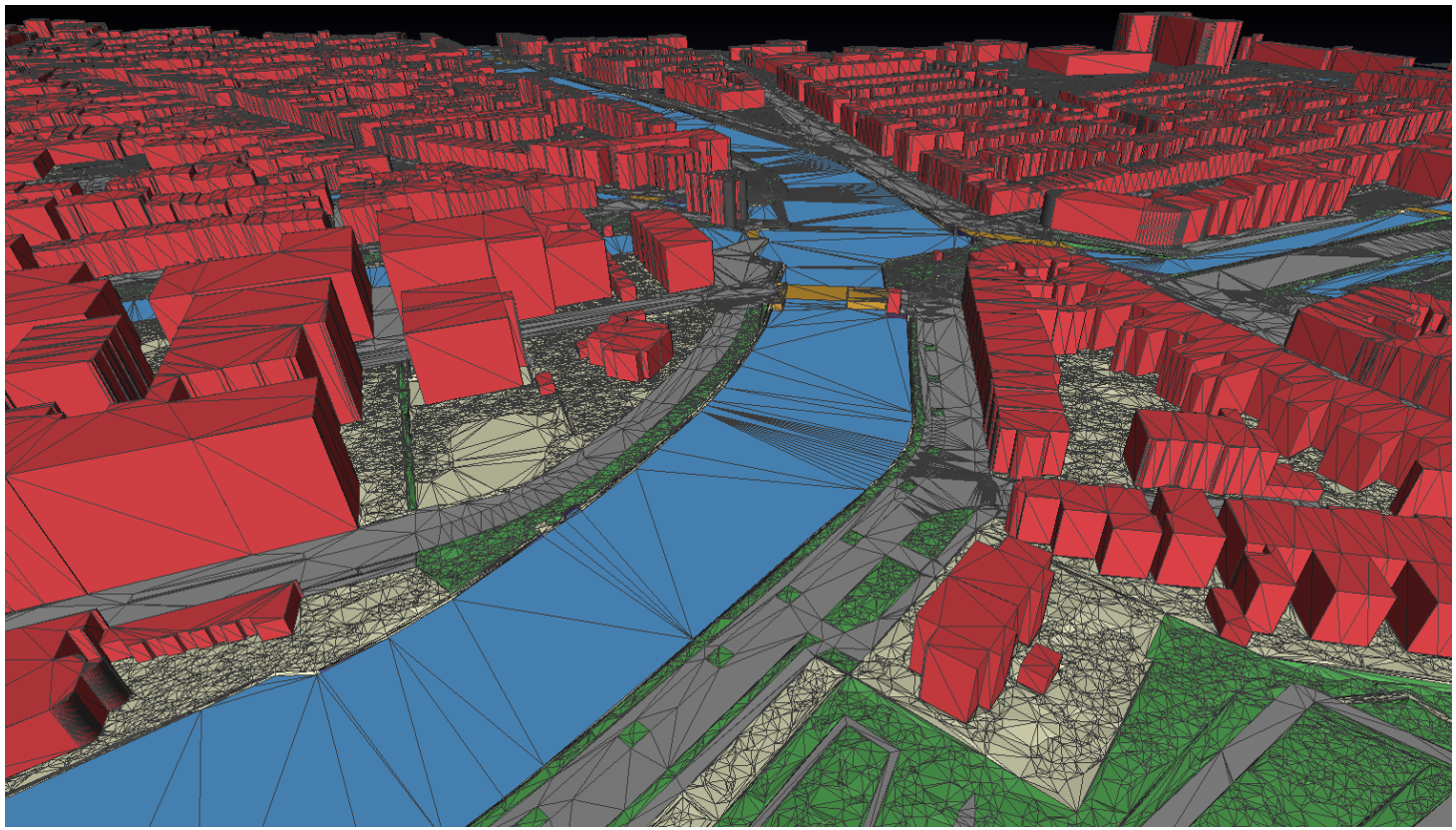


2D to 3D geo-information

- Increase in creation and use of 3D geo-information
- 3D data can be stored in 3D city models



Level of Detail (LoD)

Computer graphics

- Geometric complexity of modelled object

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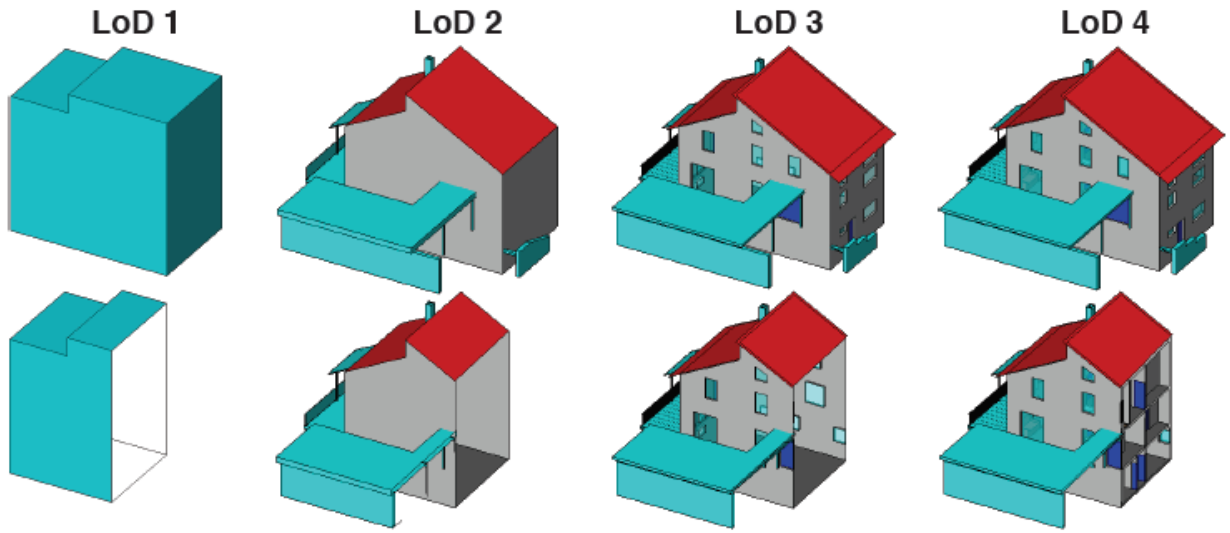
3D city models

- Model's usability
- Level of approximation to real world features
- Quality measure for 3D city model
- Each level suited for a group of applications

CityGML

- Data model *and* XML encoding
- Thematic modules: buildings, transportation, vegetation, etc.
- Five LoDs: LoD0 – LoD4. Focus on buildings.
- Spatio-semantic coherence

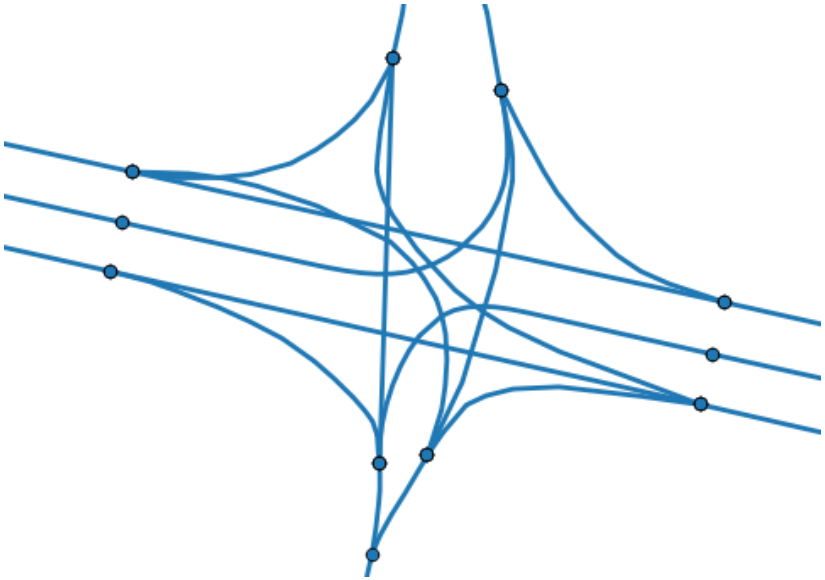


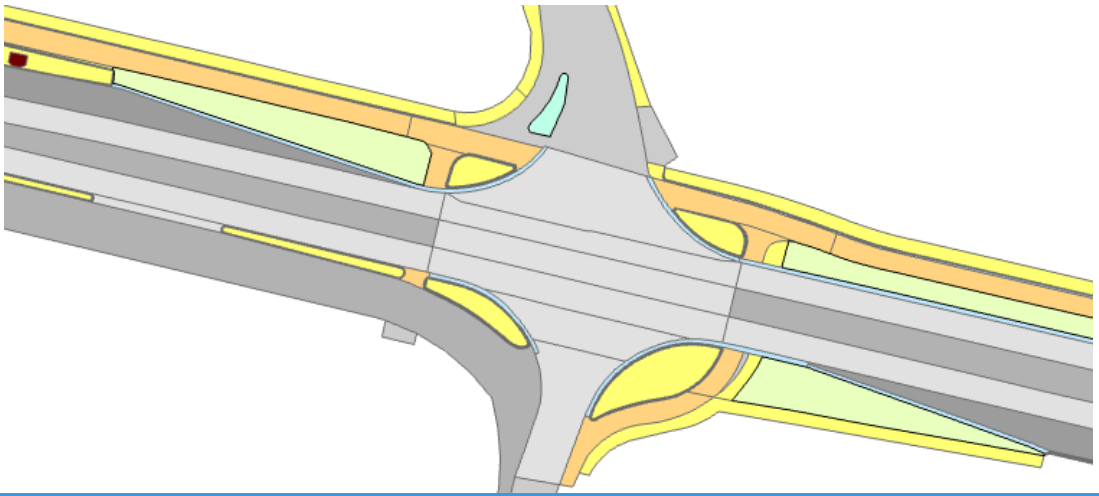
[1]

[1] Open Geospatial Consortium (2012). *OGC City Geography Markup Language (CityGML) Encoding Standard*.

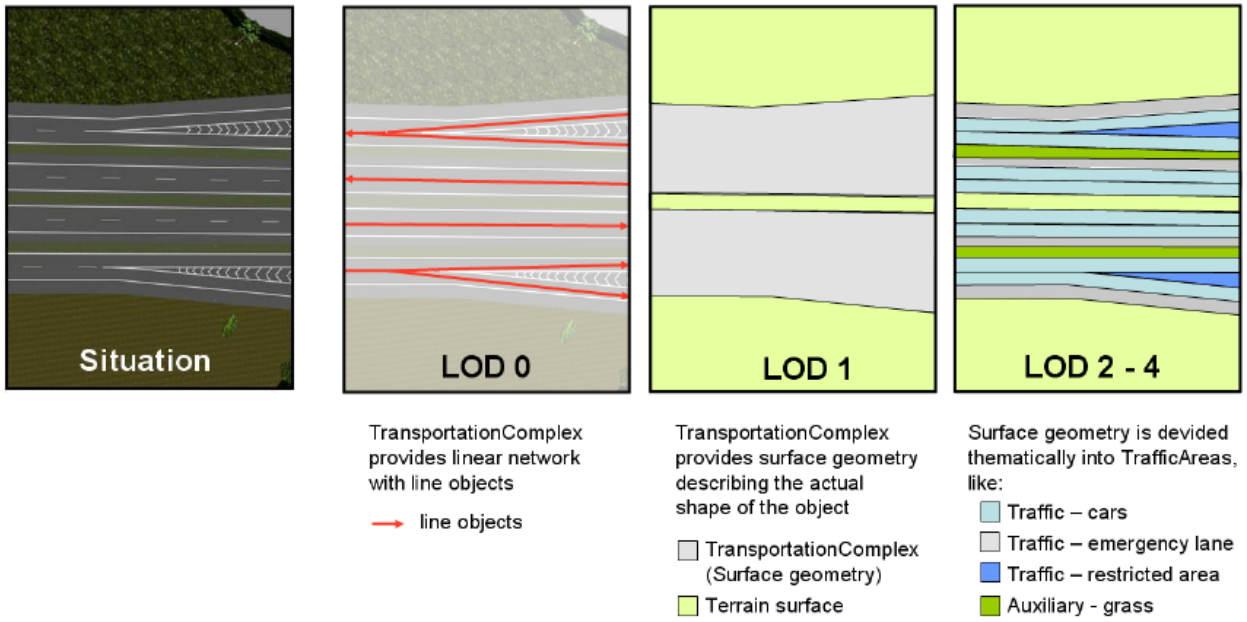
Road modelling

Roads are often modelled as either lines or surfaces.





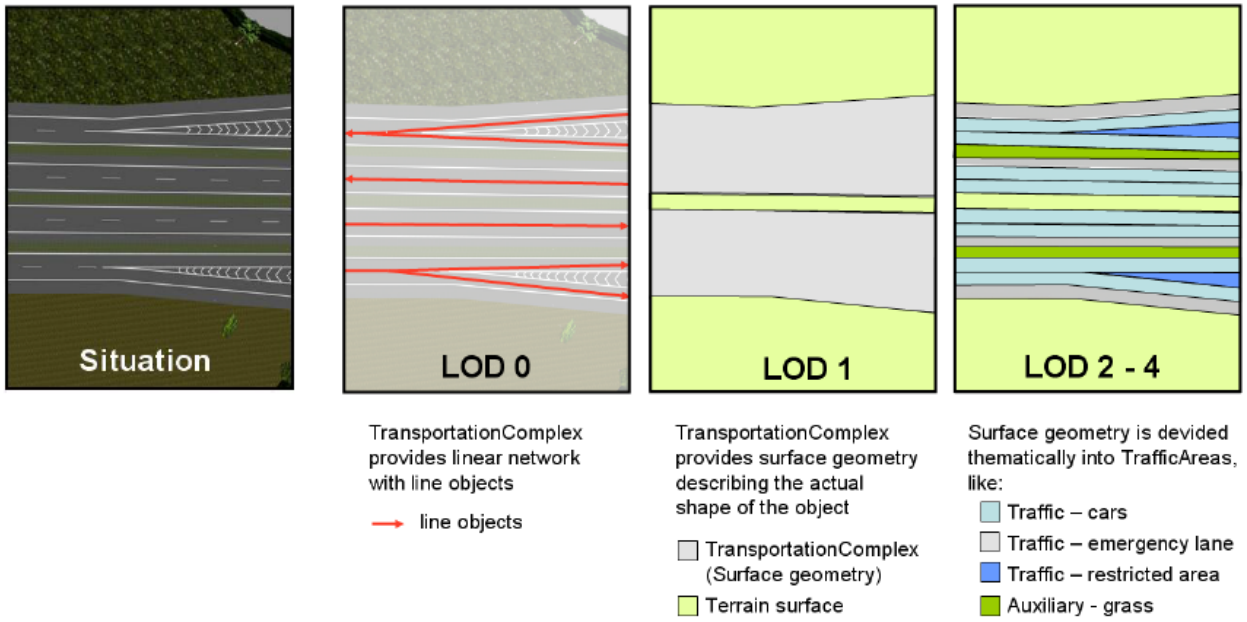
CityGML Transportation module



[2]

[2] Open Geospatial Consortium (2012). *OGC City Geography Markup Language (CityGML) Encoding Standard*.

CityGML Transportation module



[2]

- Road LoD specification not well-developed
- Government officials and road data users identified drawbacks

[2] Open Geospatial Consortium (2012). *OGC City Geography Markup Language (CityGML) Encoding Standard*.

Central object registration

- Government gathers object data in different key registers
- Issues with linking data

Central object registration

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- Issues with linking data

- Moving towards central object register (COR)
- Incorporate 3D data
- Incorporate both linear and areal road data

Motivation

- Government moving towards object-oriented 3D geo-information
- Many road data use cases identified
- Data users benefit from having clear LoD definitions
- CityGML Road LoD specification not well-developed

Research question

How can roads and intersections be modelled in 3D city models at various LoDs such that it suits user needs?

Research question & sub-questions

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Fieldwork

Throughout the research: meeting with experts

Research overview

1. CityGML shortcomings and data needs analysis
2. Improving the data model
3. Creating road data files
4. Discussion & future work

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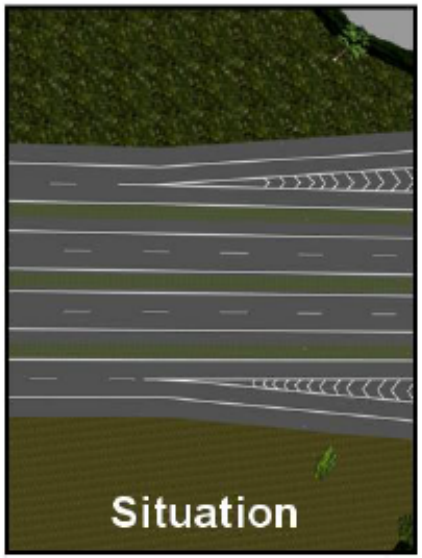
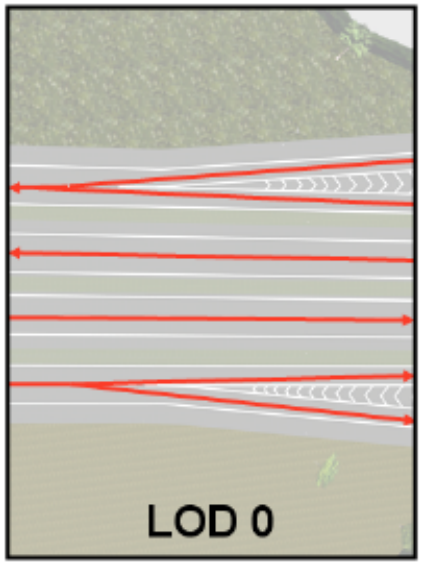
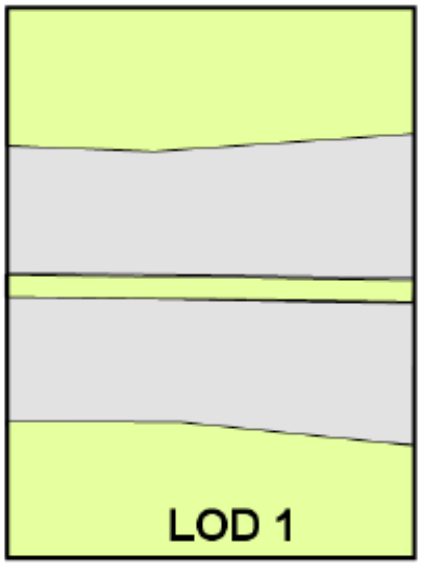
CityGML road modelling





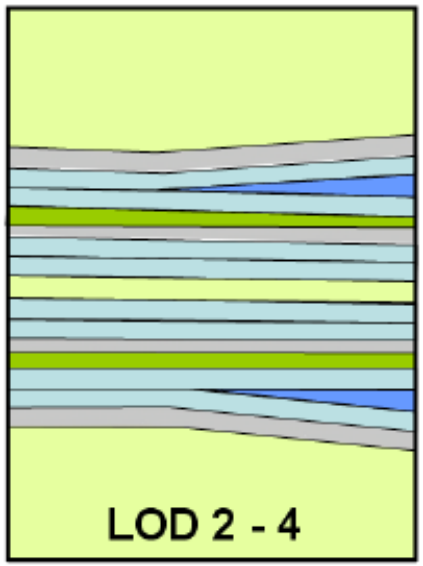
TransportationComplex provides linear network with line objects

→ line objects



TransportationComplex provides surface geometry describing the actual shape of the object

- TransportationComplex (Surface geometry)
- Terrain surface



Surface geometry is devided thematically into TrafficAreas, like:

- Traffic – cars
- Traffic – emergency lane
- Traffic – restricted area
- Auxiliary - grass

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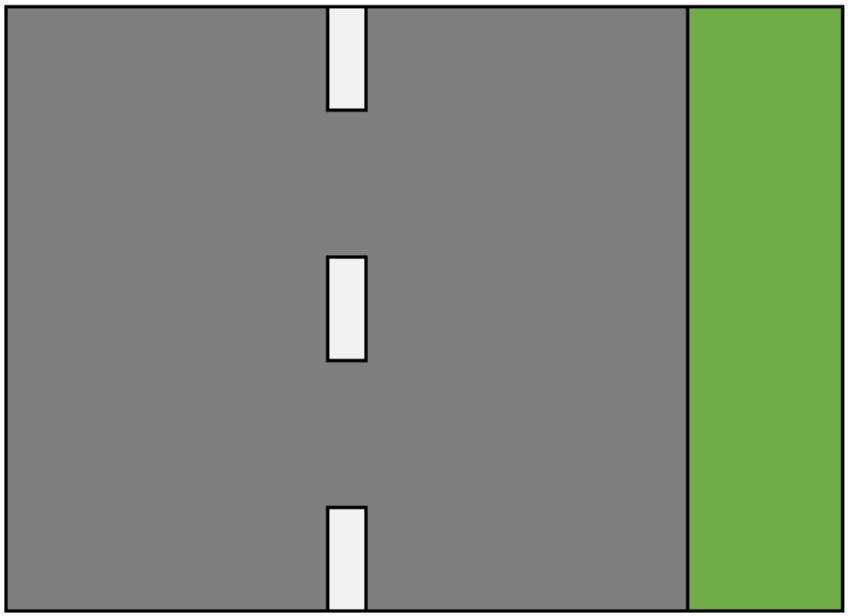
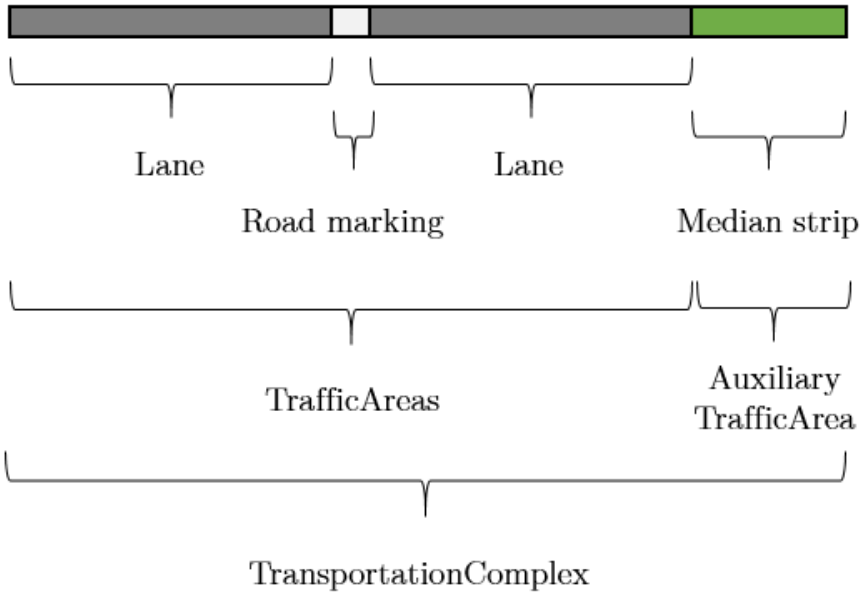
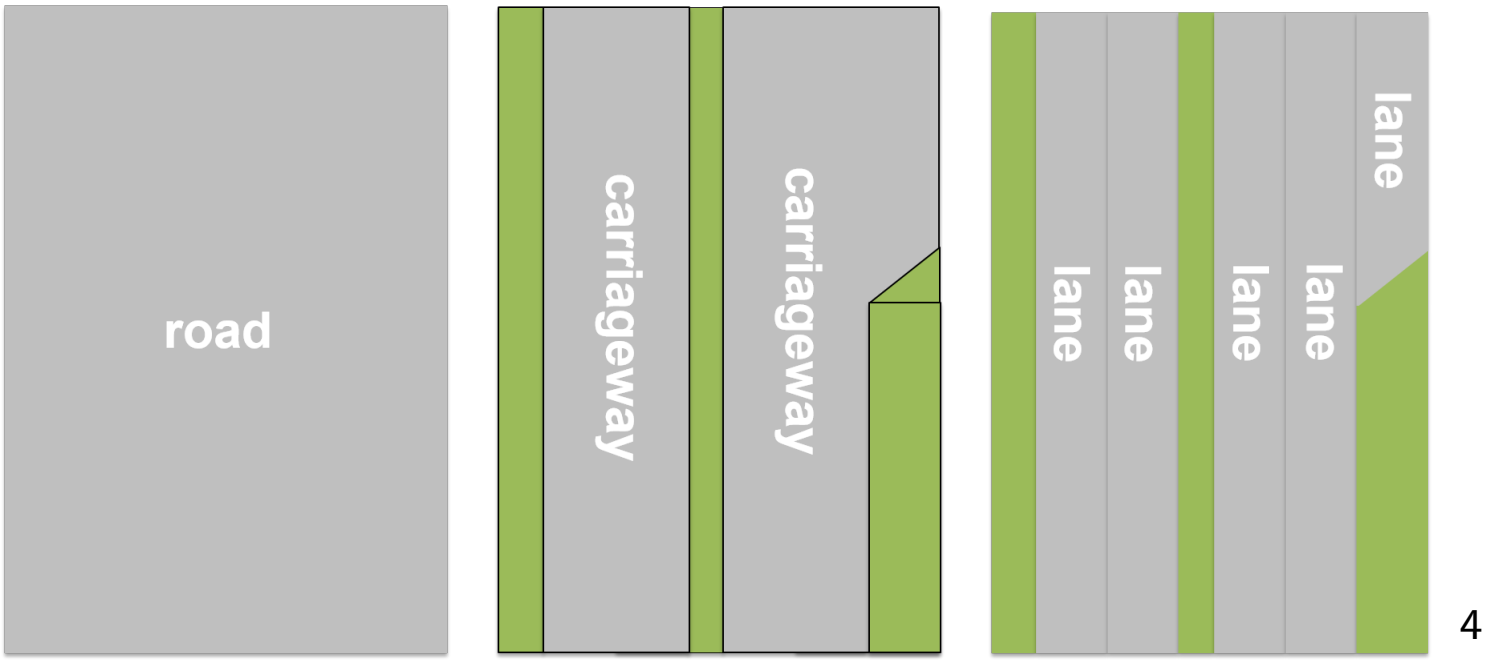
[3] Open Geospatial Consortium (2012). *OGC City Geography Markup Language (CityGML) Encoding Standard*.

CityGML road modelling: LoD2 – LoD4





More strict areal specification needed

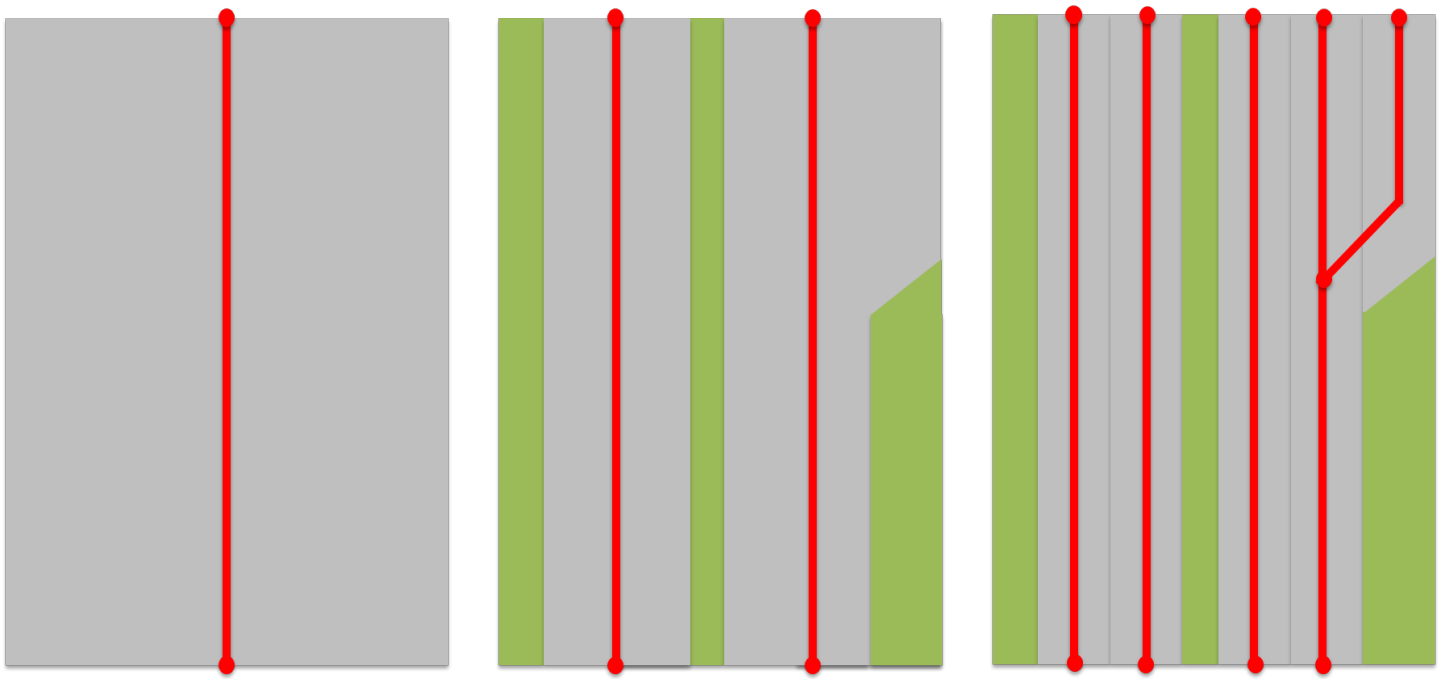


4

LoD1 LoD2 LoD3

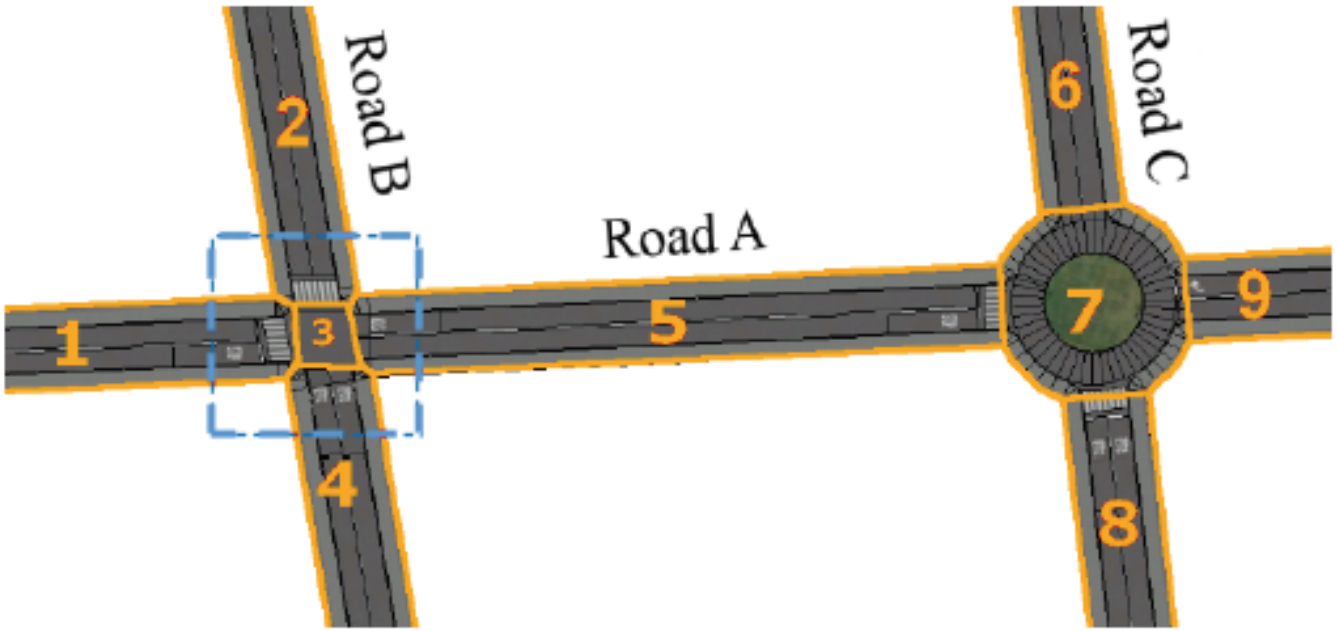
[4] A. Labetski, S. v. Gerwen, G. Tamminga, H. Ledoux, and J. Stoter (2018). "A Proposal For An Improved Transportation Model In CityGML". In: *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-4/W10, pp. 89–96. DOI: 10.5194/isprs-archives-xlii-4-w10-89-2018

LoD0: Linear LoD specification needed



LoD0.1 LoD0.2 LoD0.3

Sections



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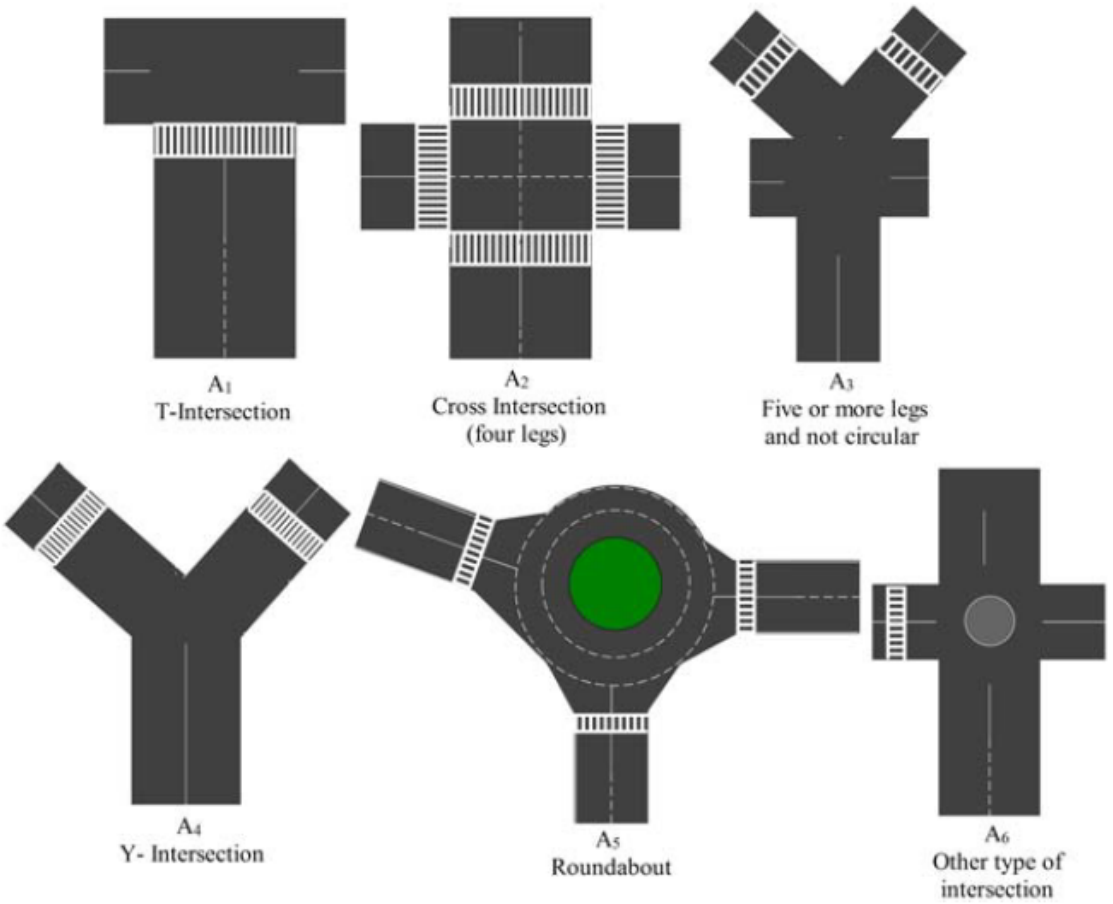
[5] C. Beil and T. H. Kolbe (2017). "CityGML And The Streets Of New York - A Proposal For Detailed Street Space Modelling". In: *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences* IV-4/W5, pp. 9–16. DOI: 10.5194/isprs-annals-iv-4-w5-9-2017

Intersections



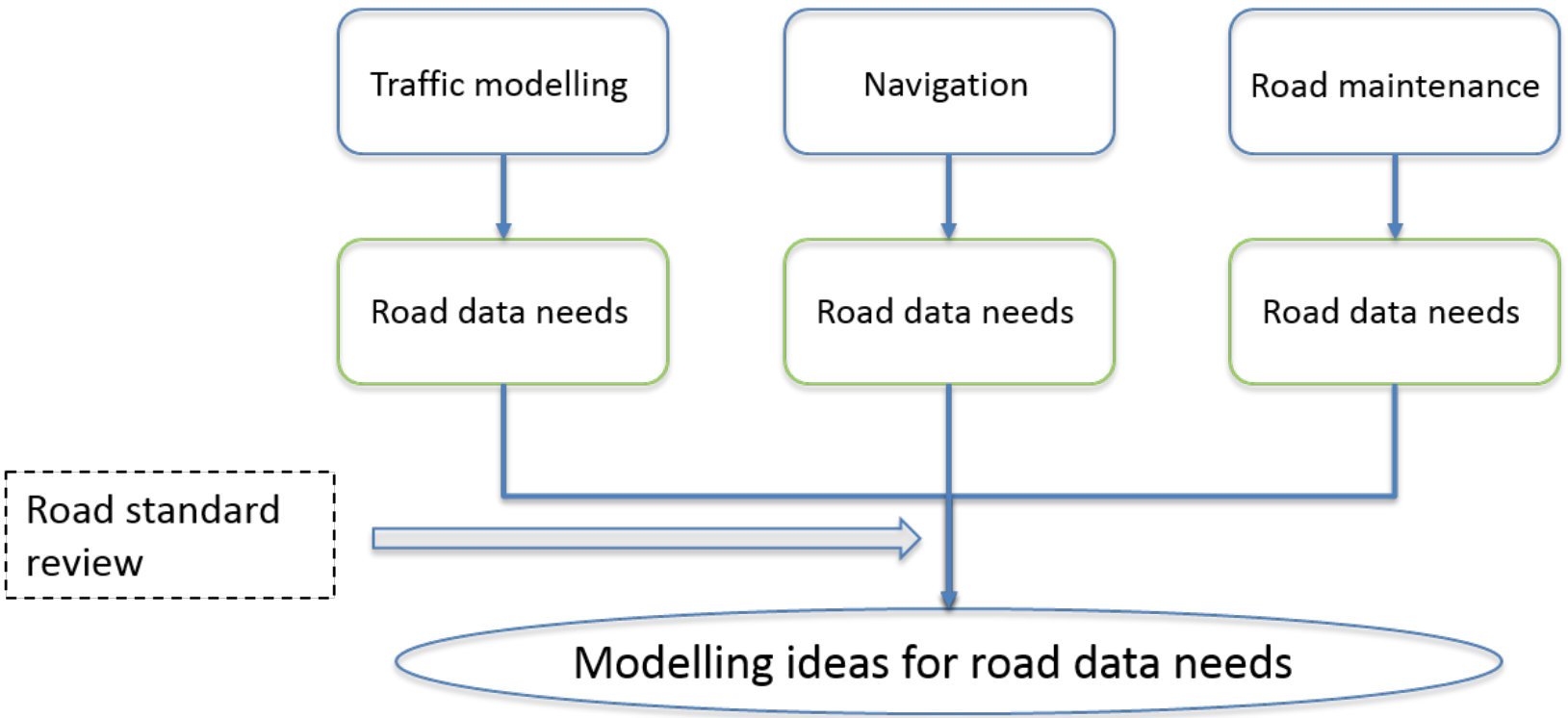
6

[6] C. erbu, D. Oprua, and L. Socaciu (2014). "Ranking the types of intersections for assessing the safety of pedestrians using TOPSIS method". In: *Leonardo Electronic Journal of Practices and Technologies* 13.25, pp. 242–253

Use case data needs analysis

	Areal			Linear		
	LoD1	LoD2	LoD3	LoD0.1	LoD0.2	LoD0.3
Road repair			x			
De-icing roads		x	x		x	x
Disaster management			x			x
Surface heat monitoring		x	x			
Air quality monitoring	x	x	x			x
Visibility analysis		x	x			
Noise mapping	x	x	x			x
Traffic light configuration			x			x
Traffic simulations		x	x		x	x
Routing / navigation				x	x	x
Autonomous driving			x			x

Use case data needs analysis



Data needs

- **LoD specification.** LoD0.1 – LoD0.3, LoD1 – LoD3.
- **Graph structure.** Implement a graph structure such that LoD0.1 up to LoD0.3 can be modelled as a network.
- **Attributes.** Many attributes were identified which might be useful.
- **Road segments and linking representation types.** How to link segments of linear and areal road objects together?
- **Intersections.** Intersections and roundabouts need explicit modelling, including specific turning lanes, turn restrictions, way giving information and stop lines.
- **Connecting to other modules.** Link `Road` surfaces with `Bridge` surfaces when a road is on a bridge.

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CityGML encoding

```
<core:cityObjectMember>
 <tran:TrafficArea gml:id="_A299D47AD4E6D2BB7E0532B0B5B0AE93E">
  <core:creationDate>2014-02-13</core:creationDate>
  <tran:class>local carriageway</tran:class>
  <tran:surfaceMaterial>surfaced pavement</tran:surfaceMaterial>
  <tran:lod2MultiSurface>
   <gml:MultiSurface srsName="EPSG:7415" srsDimension="3">
    <gml:surfaceMember>
     <gml:Polygon>
      <gml:exterior>
       <gml:LinearRing>
        <gml:posList>94273.344 463812.831 0.6688626441047193
         94260.472 463809.828 0.583103089885288 94272.374
         463807.149 0.6979061812650841 94273.344 463812.831
         0.6688626441047193</gml:posList>
       </gml:LinearRing>
      </gml:exterior>
     </gml:Polygon>
    </gml:surfaceMember>
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       <gml:LinearRing>
        <gml:posList>94261.624 463815.323 0.5593409338157872
         94260.472 463809.828 0.583103089885288 94273.344
         463812.831 0.6688626441047193 94261.624 463815.323
         0.5593409338157872</gml:posList>
       </gml:LinearRing>
      </gml:exterior>
     </gml:Polygon>
    </gml:surfaceMember>
   </gml:MultiSurface>
  </tran:lod2MultiSurface>
 </tran:TrafficArea>
</core:cityObjectMember>
```

CityJSON encoding

```
{
  "type": "CityJSON",
  "version": "1.0",
  "CityObjects": {
    "id1": {
      "type": ...,
      "attributes": {
        ...
      },
      "geometry": [{
        "type": ...,
        "lod": ...,
        "boundaries": ...
      }]

    },
  },
  "vertices": [
    ...
  ]
}
```

CityJSON: JSON encoding of CityGML data model

```
"ma_rue": {
  "type": "Road",
  "geometry": [{
    "type": "MultiSurface",
    "lod": 2,
    "boundaries": [
      [[0, 3, 2, 1, 4]], [[4, 5, 6, 666, 12]], [[0, 1, 5]], [[20, 21, 75]]
    ],
    "semantics": {
      "surfaces": [
        {
          "type": "TrafficArea",
          "surfaceMaterial": ["asphalt"],
          "function": "road"
        },
        {
          "type": "AuxiliaryTrafficArea",
          "function": "green areas"
        },
        {
          "type": "TrafficArea",
          "surfaceMaterial": ["dirt"],
          "function": "road"
        }
      ],
      "values": [0, 1, null, 2]
    }
  }]
}
```

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  }]
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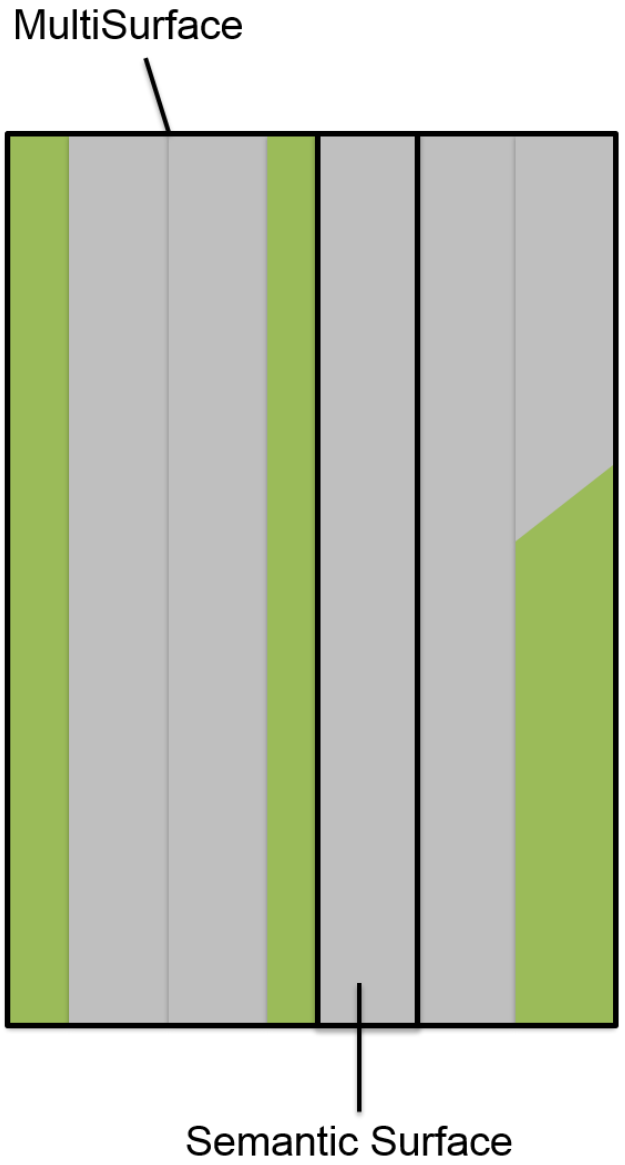


Implementing changes in CityJSON

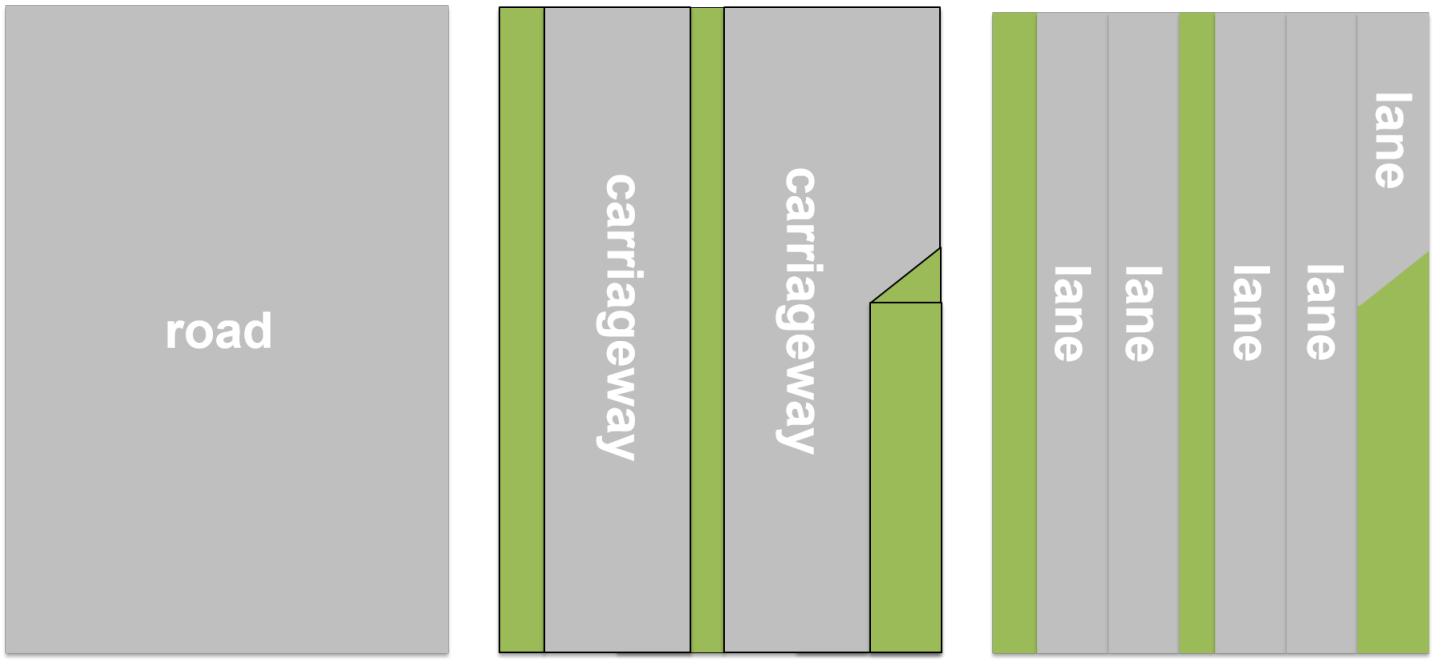
- CityJSON structure defined by JSON schemas
- CityJSON core: encoding of the CityGML data model

Implementing changes in CityJSON

- CityJSON structure defined by JSON schemas
- CityJSON core: encoding of the CityGML data model
- Data model can be extended with Extensions: new CityObjects and attributes can be added.

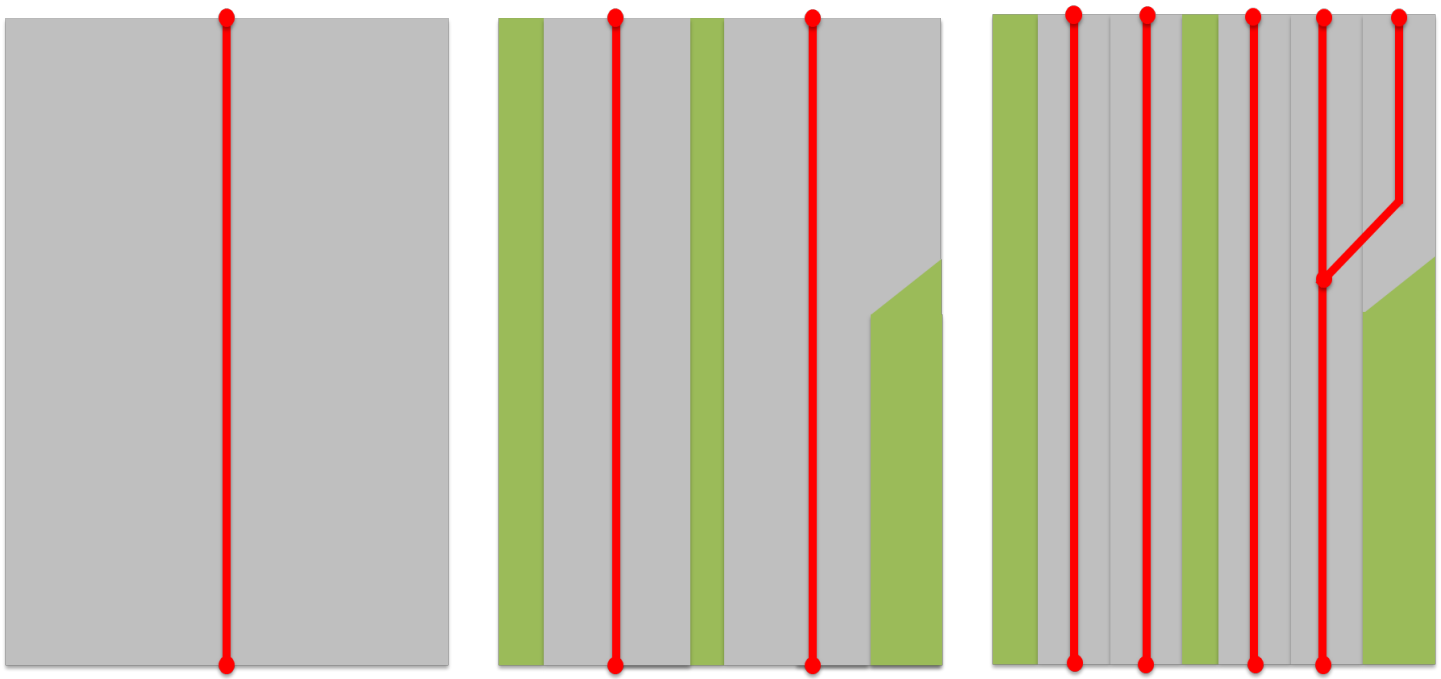
- Implementing data needs: changes in core, and new Extension

Starting point: new LoD specification



LoD1 LoD2 LoD3

Starting point: new LoD specification

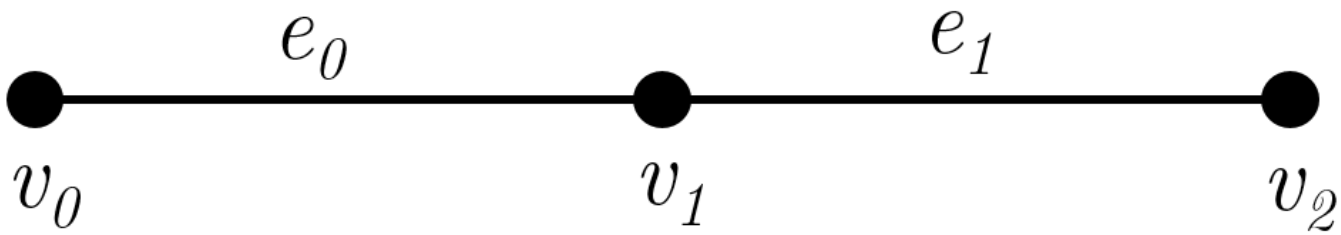


LoD0.1 LoD0.2 LoD0.3

Graph structure

- New CityObject classes in Core: Node and Edge.
- Nodes have attribute edges: incident edges
- Edges have attributes startNode, endNode

- In Extension: RoadNode and RoadEdge
- Graph structure can be reused for other object classes
- This gives the desired topological structure



Network attribute modelling

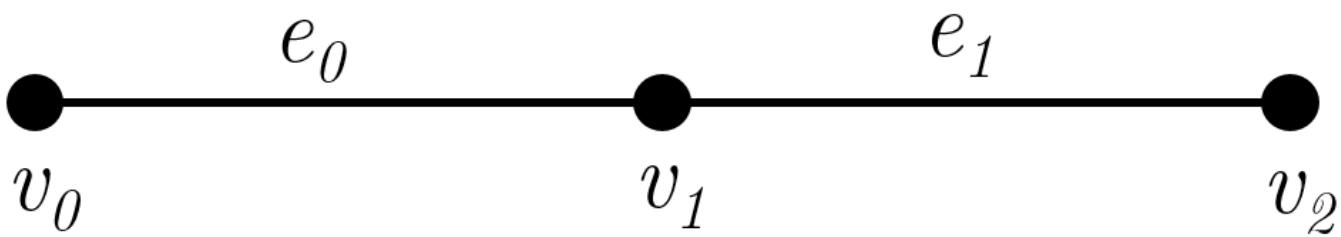
- Many linear attributes from data needs
- No over-fitting data model to assessed use cases
- Geography-related attributes not added: can be deduced from areal data

- Will model: allowed vehicle types, road classification, driving direction, administrator, maximum speed.

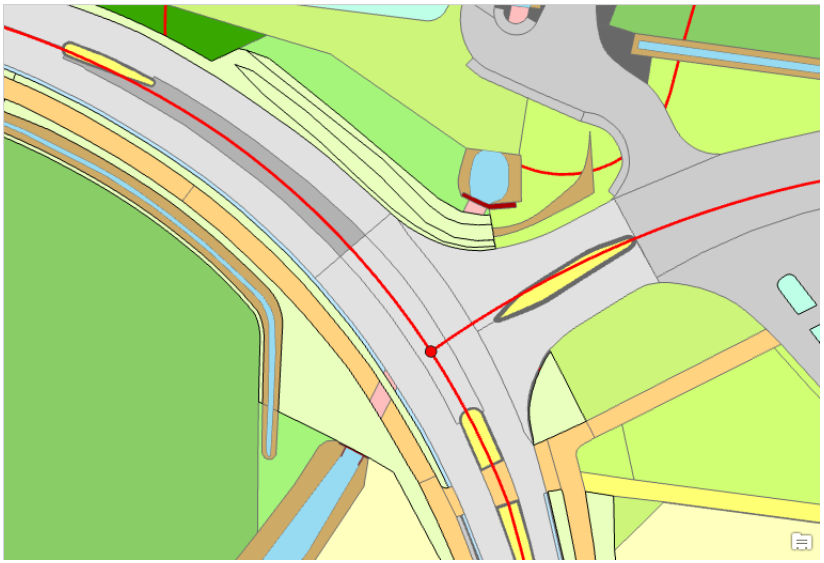
- Other attributes may be added in Extension per use case

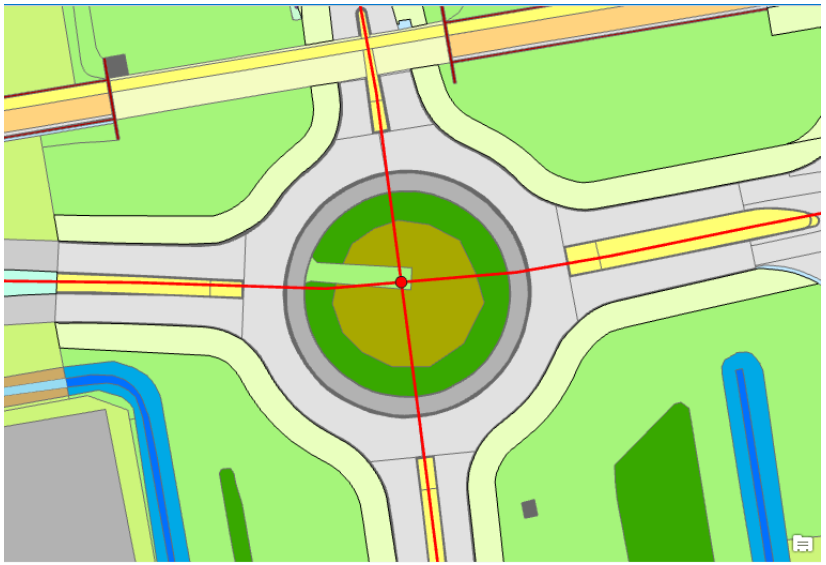
Network attribute modelling

- Linear referencing vs node based attribute modelling.
- Choose attribute based.
- Linear referencing system may always be added.



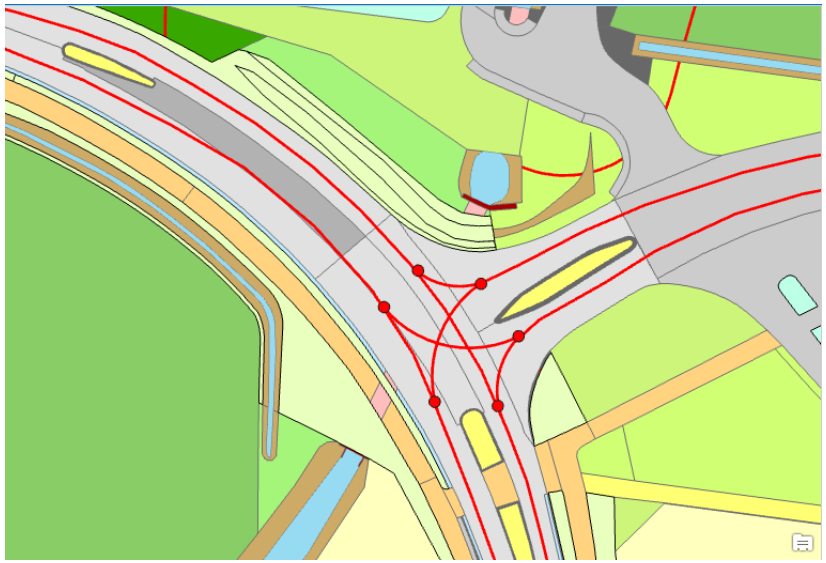
Network intersections: LoD0.1

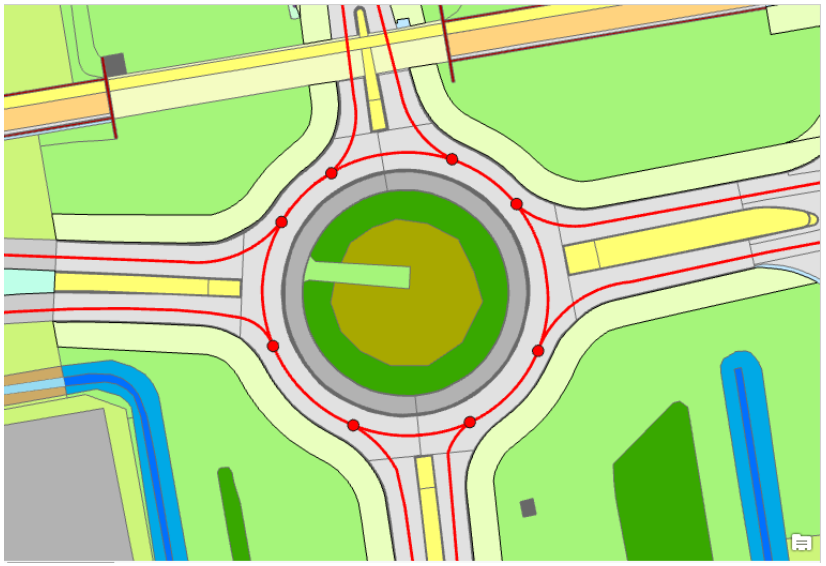




- Add turning restrictions for intersection / roundabout RoadNode

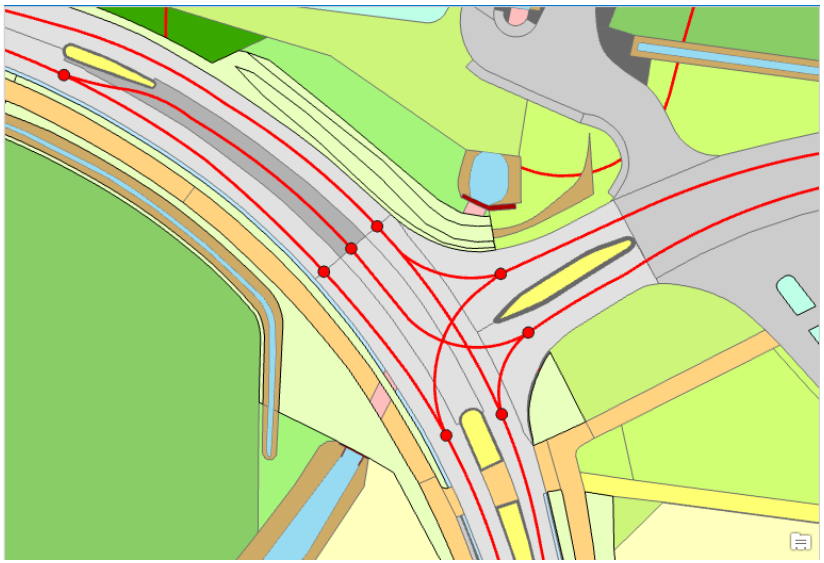
Network intersections: LoD0.2

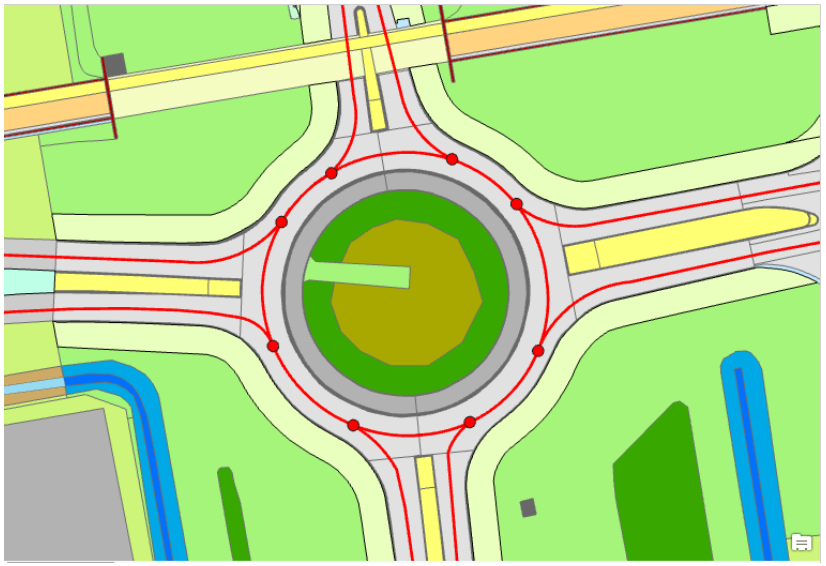




- RoadNodeType: Intersection and Roundabout
- RoadEdgeType: Connecting and Roundabout

Network intersections: LoD0.3





- RoadNodeType: LaneSplit, Intersection and Roundabout
- RoadEdgeType: Connecting and Roundabout

Segments and linking representation types

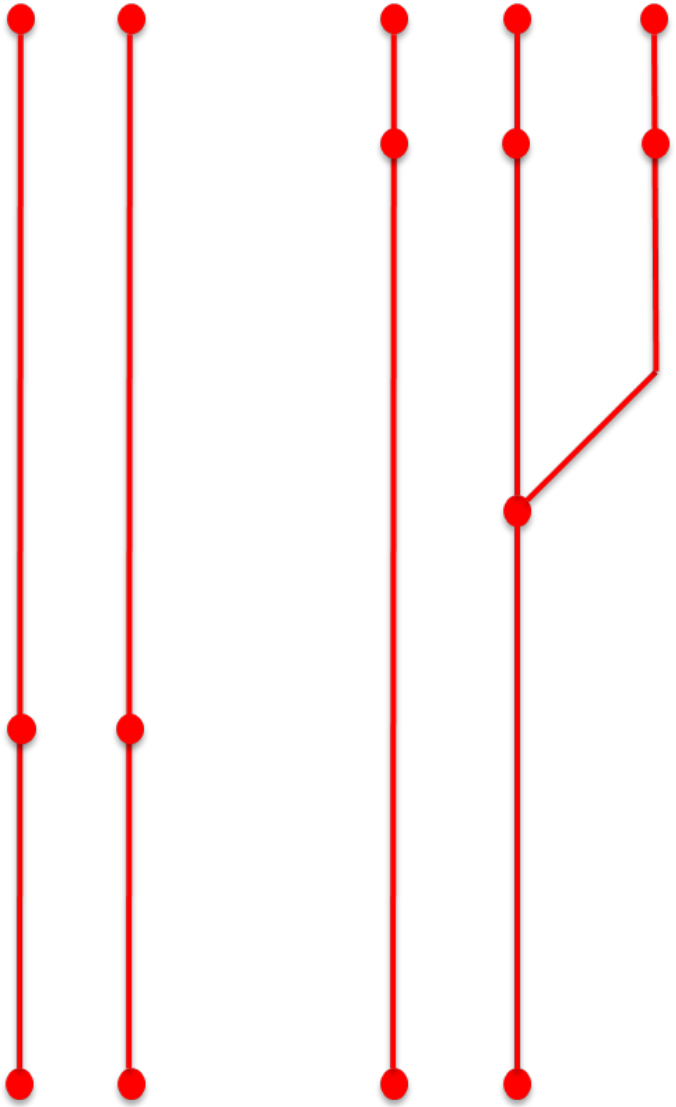
- Central object register: linking representation types.
- Node based attribute changes lead to highly segmented network
- Areal road segmentation already possible through semantic surfaces

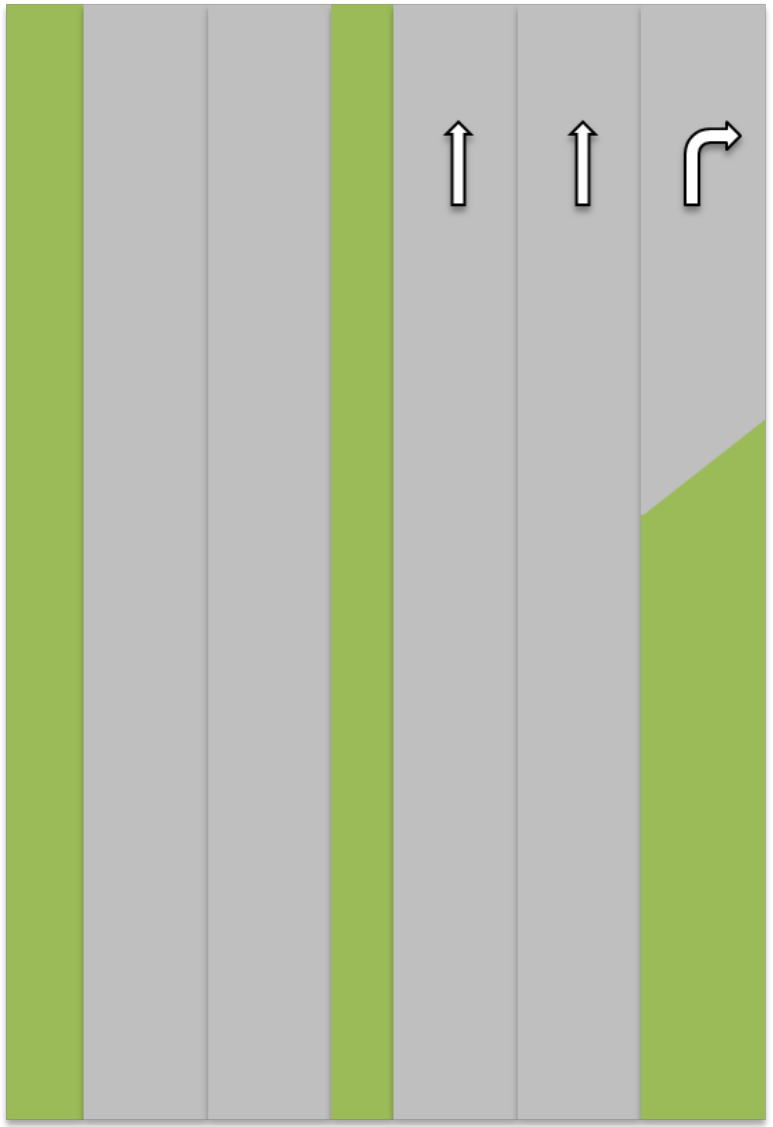
Segments and linking representation types

- Central object register: linking representation types.
- Node based attribute changes lead to highly segmented network
- Areal road segmentation already possible through semantic surfaces

- Choice: linking types on an aggregate level
- Thus: segments implemented differently for linear and areal representations!

Segments and linking representation types





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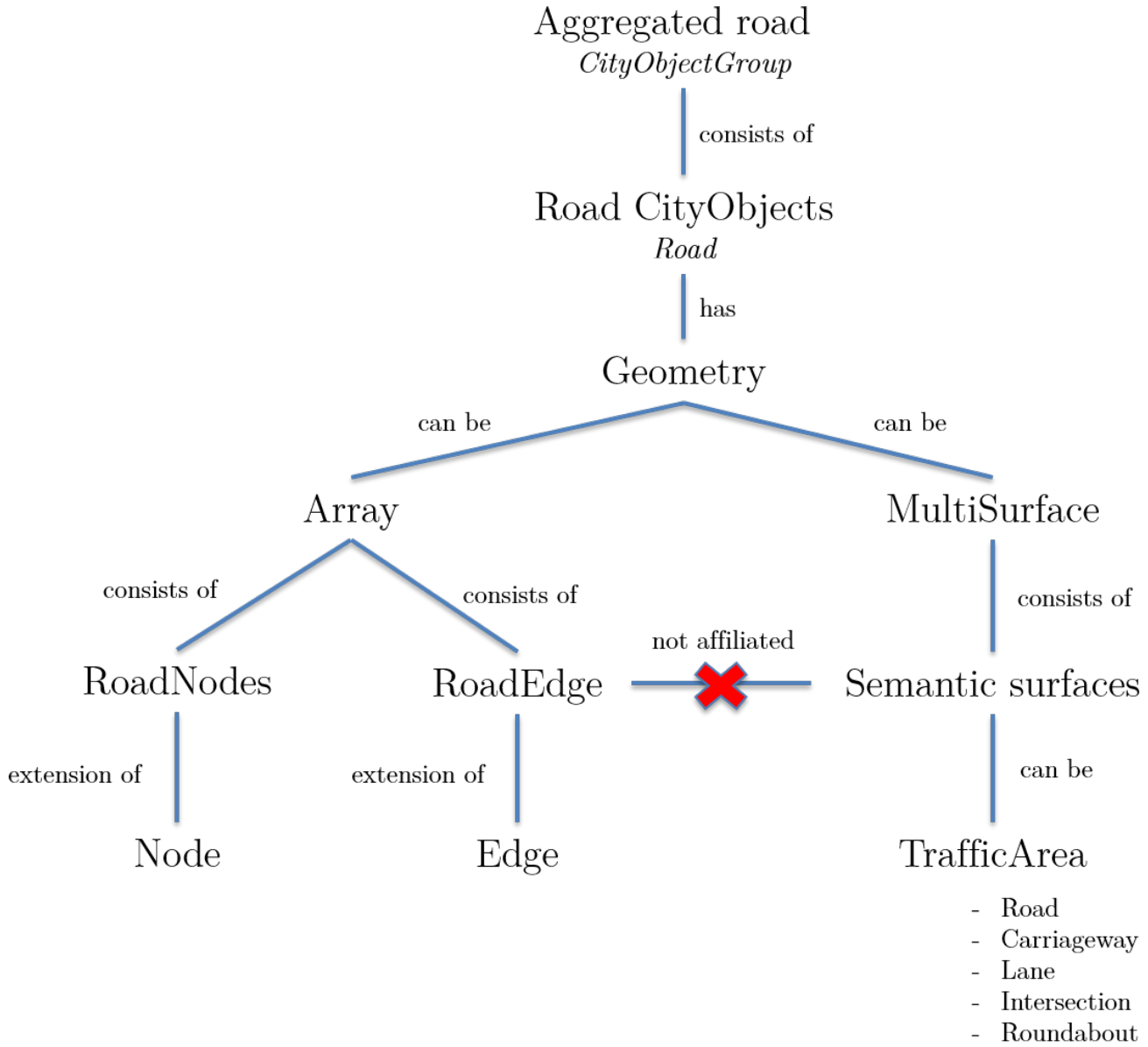

Areal LoD specification

Object	Attribute	Value	Areal LoD1	Areal LoD2	Areal LoD3
Road	roadType	Road	x		
		Carriageway		x	
		Lane			x
		Intersection	x	x	x
		Roundabout	x	x	x
	class		x	x	x
	function		x	x	x
	intersectionID		x	x	x
	streetName		x	x	x
	bridge		x	x	x
	administrator		x	x	x

Research overview

1. CityGML shortcomings and data needs analysis
2. Improving the data model
3. Creating road data files
4. Discussion & future work

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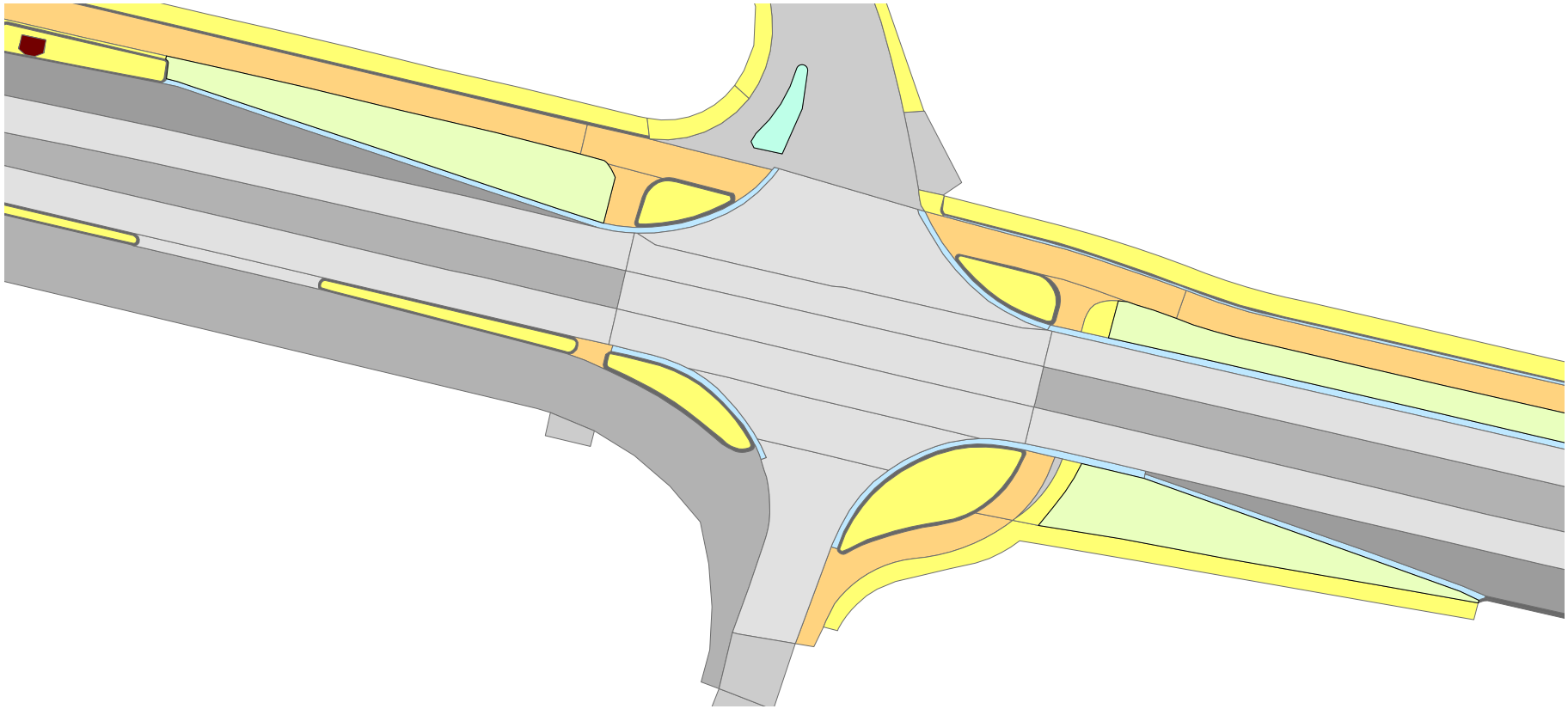
Creating CityJSON road data files

Goal is to reflect on the modelling choices made.

- Source data: areal and linear data from Noord-Brabant
- Provincial road N640
- Create a data file per LoD
- Create a data file linking two representation types

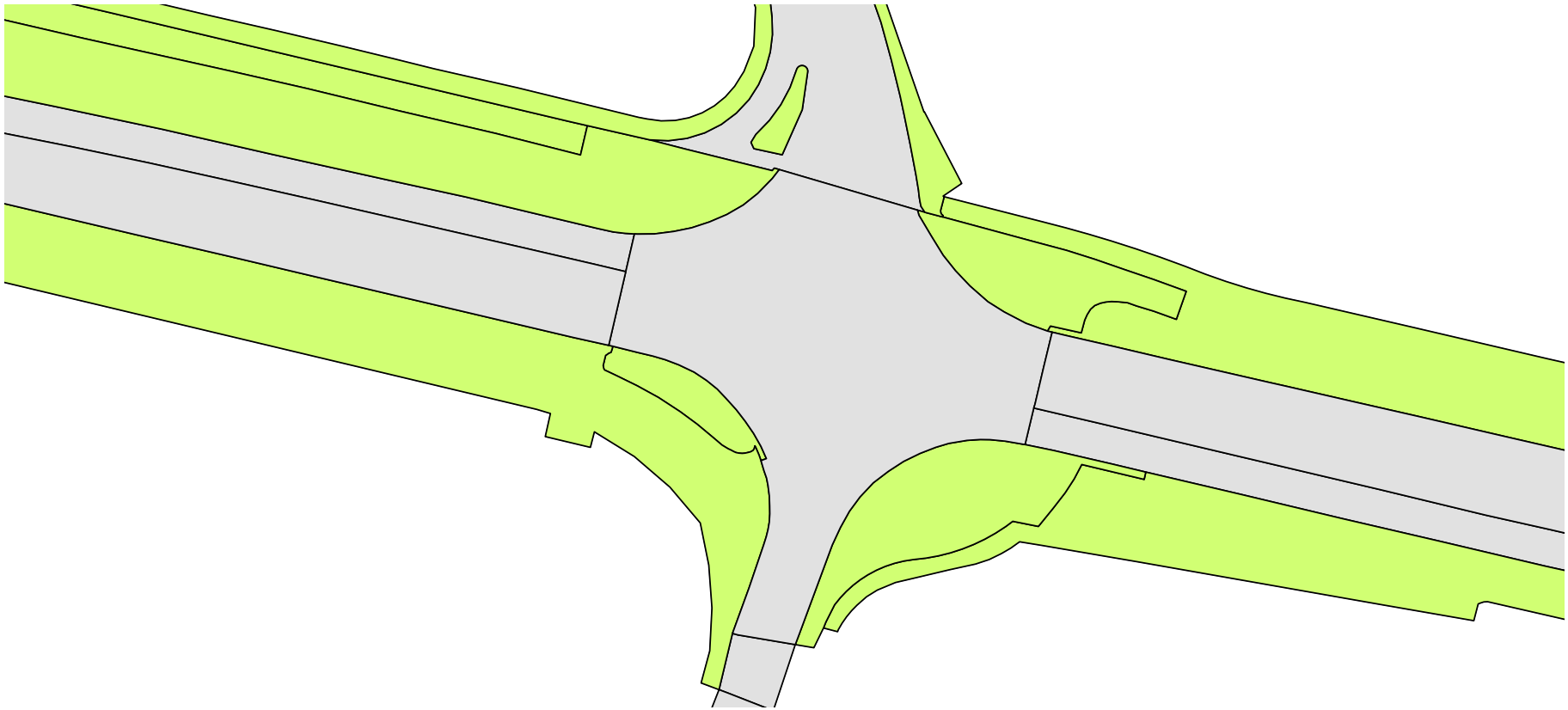
LoD3

- Dataset specified per lane.
- Easy to map to CityJSON



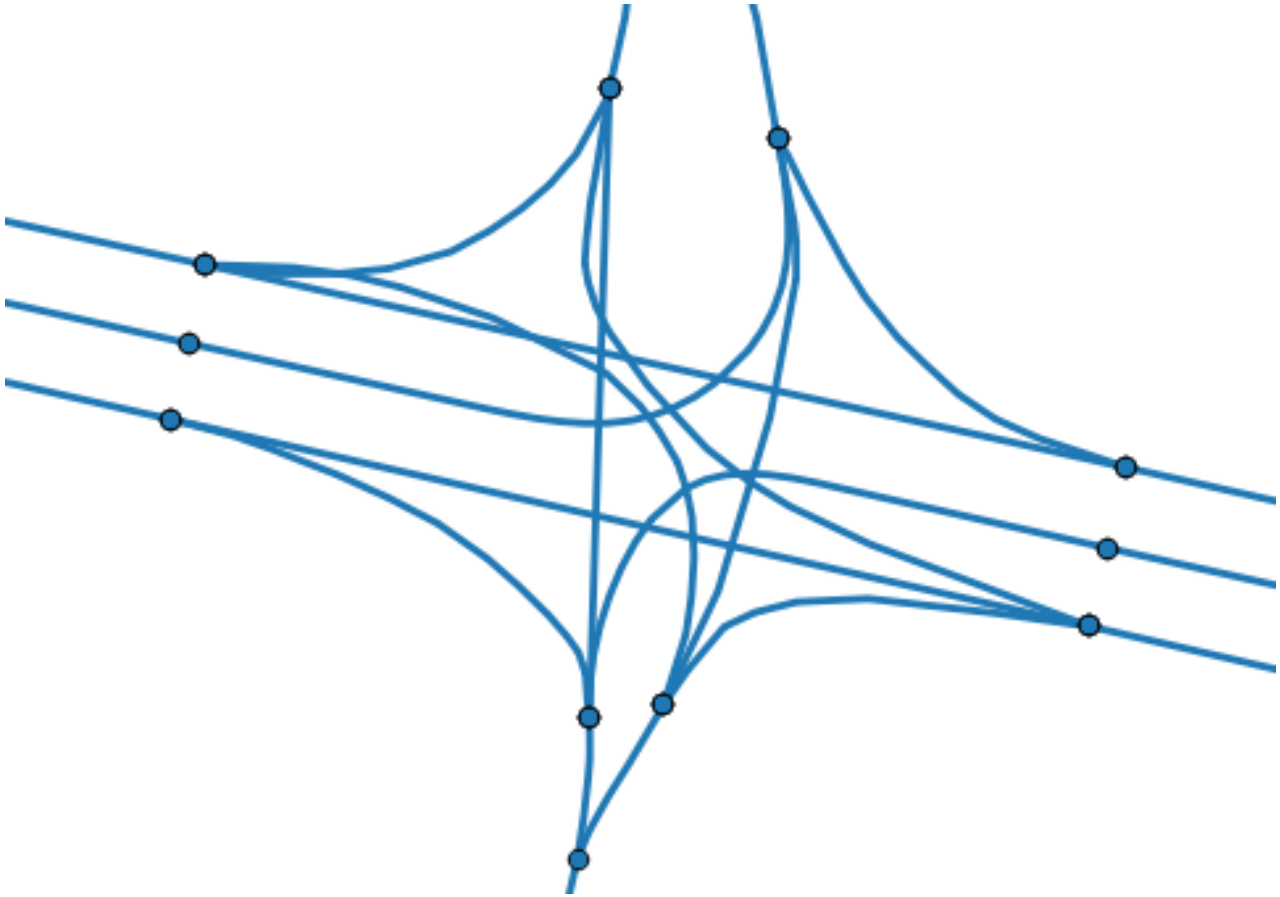
LoD1–2

- Awkward merging
- What to do with `AuxiliaryTrafficArea`?



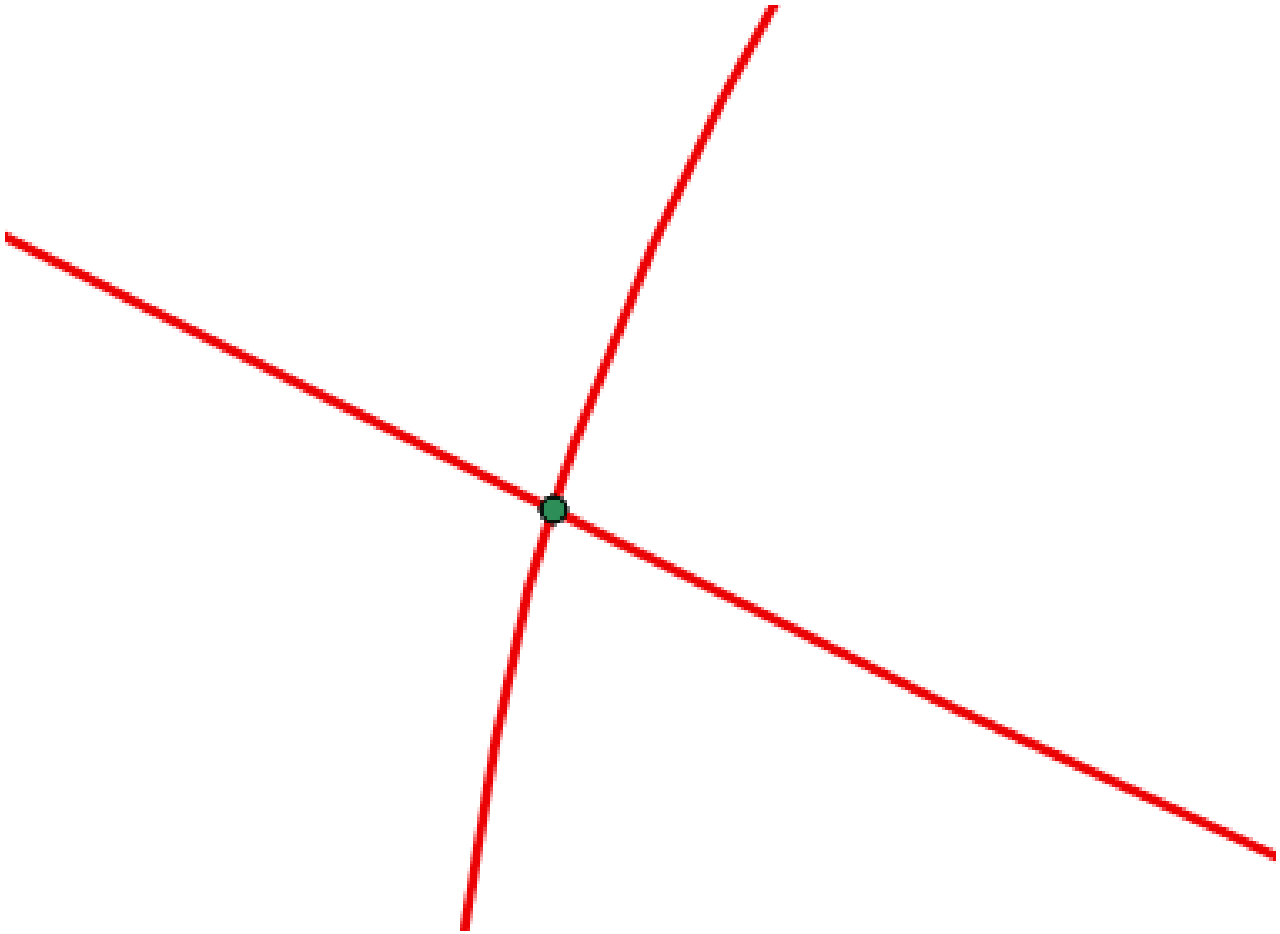
LoD0.2 – 0.3

- Strict geometric modelling: lots of preprocessing
- Nodes with semantics need to be generated, and pointers from RoadNodes to RoadEdges and vice versa established



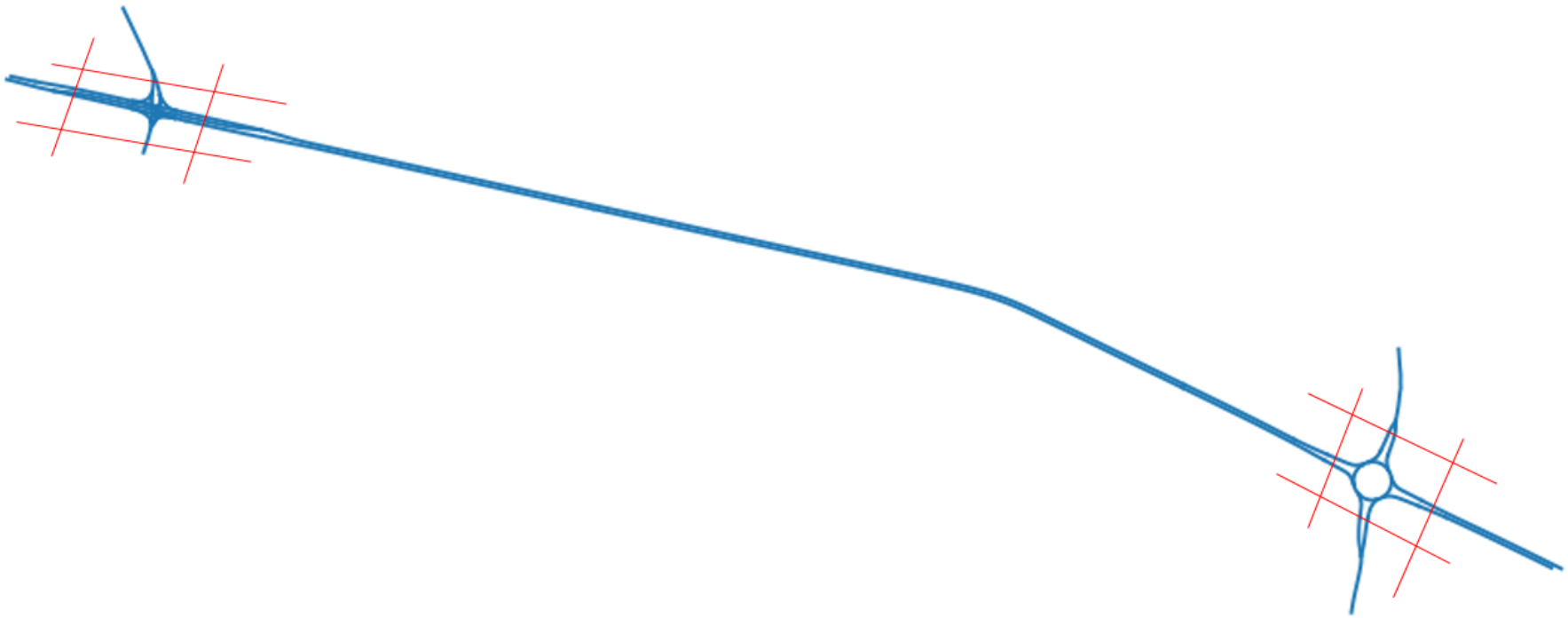
LoD0.1

- Road centre line data present in data set



Linking LoD1 & LoD0.1

- Object defined by hand. This could be done on an existing attribute



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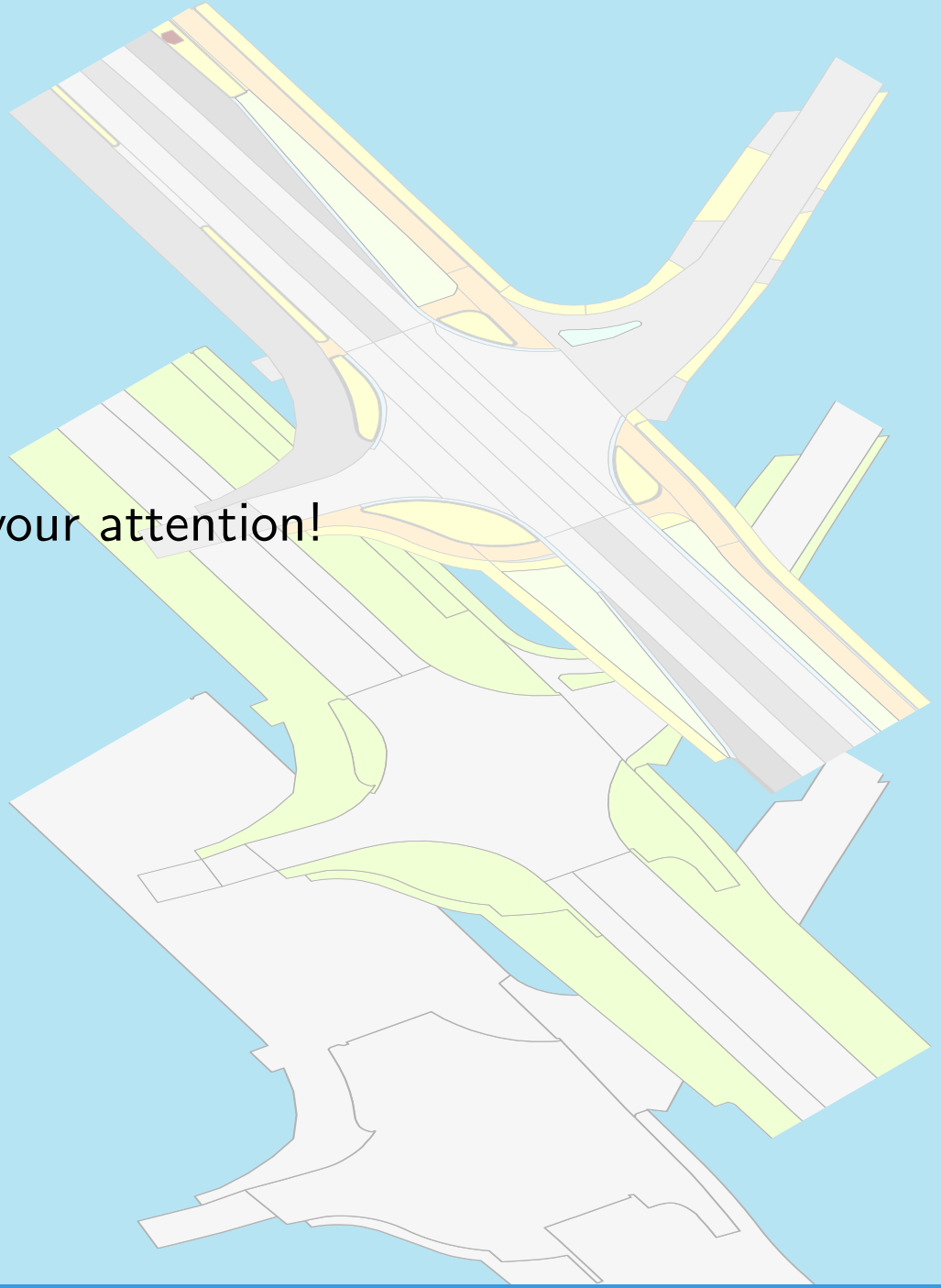
Discussion

- Goal was to accommodate! Accommodate user and provider by giving clear but not over-fit LoD specification.
- Results based on mostly network use cases. Areal LoDs might have extra data needs not assessed.
- Node-based segmentation: low LoD but highly detailed..?

Discussion

- Is linking representation types necessary?
- Is 3D road data necessary?
- How did CityJSON influence design choices? Object-based nature aided linking of representation types. How does this generalise to `Transportation` in CityGML?

Future research

- Focus on roads. How do we incorporate bicycle paths, footpaths, or other Transporation objects like Railway?
- Further specification of areal representation and `AuxiliaryTrafficArea`?
- Add semantic validation of new data model.
- Create general CityJSON road writer program that does data processing itself.
- How to use the graph structure for routing?

Thank you for your attention!