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
## Level of Detail (LoD)

### Computer graphics
- Geometric complexity of modelled object

### 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

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Road modelling

Roads are often modelled as either lines or surfaces.
CityGML Transportation module

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

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- Government officials and road data users identified drawbacks

Central object registration

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

- Government gathers object data in different key registers
- 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
How can roads and intersections be modelled in 3D city models at various LoDs such that it suits user needs?
Research question & sub-questions

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

- What are the use cases of roads and intersections in 3D city models and what are their road data needs?
Research question & sub-questions

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- How can the CityGML transportation data model be improved such that it satisfies the use case data needs?
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Fieldwork

Throughout the research: meeting with experts
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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

Surface geometry is divided thematically into TrafficAreas, like:
- Traffic – cars
- Traffic – emergency lane
- Traffic – restricted area
- Auxiliary - grass

CityGML road modelling: LoD2 – LoD4
More strict areal specification needed

LoD1

LoD2

LoD3

LoD0: Linear LoD specification needed

LoD0.1

LoD0.2

LoD0.3
Intersections

Use case data needs analysis

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</table>
Use case data needs analysis

Traffic modelling
- Road data needs
  - Road standard review

Navigation
- Road data needs

Road maintenance
- Road data needs

Modelling ideas for road data needs
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>
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              <gml:posList>94273.344 463812.831 0.6688626441047193
                94260.472 463809.828 0.583103898885288 94272.374
                463807.149 0.69790611812650841 94273.344 463812.831
                0.6688626441047193</gml:posList>
            </gml:LinearRing>
            <gml:exterior>
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                          463812.831 0.6688626441047193 94261.624 463815.323
                          0.5593409338157872</gml:posList>
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                  </gml:Polygon>
                </gml:surfaceMember>
              </gml:SurfaceMember>
            </gml:Polygon>
          </gml:LinearRing>
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      </gml:MultiSurface>
    </tran:lod2MultiSurface>
  </tran:TrafficArea>
</core:cityObjectMember>
```
CityJSON encoding

```json
{
    "type": "CityJSON",
    "version": "1.0",
    "CityObjects": {
        "id1": {
            "type": ..., 
            "attributes": {
                ...
            },
            "geometry": [{
                "type": ..., 
                "lod": ..., 
                "boundaries": ...
            }
            ]
        },
        "vertices": [
            ...
        ]
    }
}
```
```
"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]
    }
  }
}
```
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]]
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        "values": [0, 1, null, 2]
      }
    ]
  ]
}
```
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
Segments and linking representation types

- Aggregated road
  - CityObjectGroup
    - consists of
  - Road CityObjects
    - Road
      - has
      - Geometry
        - can be
  - Array
    - consists of
      - RoadNodes
        - extension of
          - Node
    - RoadEdge
      - extension of
        - Edge
  - MultiSurface
    - not affiliated
    - Semantic surfaces
      - TrafficArea
        - Road
        - Carriageway
        - Lane
        - Intersection
        - Roundabout
## Areal LoD specification

<table>
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<tr>
<th>Object</th>
<th>Attribute</th>
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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 Transportation 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!