Automatic generation of CityGML LoD3 building models from IFC models

*M.Sc. Geomatics P5 presentation by Sjors Donkers*
Architecture
Where the fields overlap

Geomatics
- Building
- Region
- City
- Country
- World

Architecture
- Building
- Floor
- Section
- Room
- Component
Where the fields overlap

- Geomatics
  - Building
  - Region
  - City
  - Country
  - World

- Architecture
  - Building
  - Floor
  - Section
  - Room
  - Component

- CityGML
- IFC
What is high detail for CityGML?

LoD0
What is high detail for CityGML?

LoD1
What is high detail for CityGML?

LoD2
What is high detail for CityGML?

- LoD $\leq 2$ can be automatically generated
- LoD $\geq 3$ requires manual labour

LoD3
What is high detail for CityGML?

- LoD \( \leq 2 \) can be automatically generated
- LoD \( \geq 3 \) requires manual labour
Research question

Is it possible to generate valid and semantically rich CityGML building models at LoD3 from IFC models, and can this method be extended to LoD4?
Structure

- What is IFC / CityGML and when is it valid?
- Methodology for the conversion
- Experimental results
- Possibilities for LoD4
- Conclusions, recommendations & future work
Conversion from IFC to CityGML

IFC

```
#1=IFCPROJECT('abc101', #101, 'sample
#3=IFCSITE('abc103', #103, $, $, $,
#4=IFCBUILDING('abc104',
  'sample building at 10,
#6=IFCBUILDINGSTOREY('abc1502', $, $, $, .ELEMENT.
#7=IFCBUILDINGSTOREY('abc1503, $, $, .ELEMENT.
#8=IFCBUILDINGSTOREY('abc1504, $, $, .ELEMENT.
#9=IFCRELAGGREGATES('abc1505, $, $, .ELEMENT.
#10=IFCRELAGGREGATES('abc1506, $, $, .ELEMENT.
#11=IFCRELAGGREGATES('abc1507, $, $, .ELEMENT.
#13=IFCRELAGGREGATES('abc1508, $, $, .ELEMENT.
```

CityGML

```
<building>
  ........
  <lod2Solid>
  ........
  <gml:surfaceMember>
    <gml:Polygon gml:id="wallSurface4711">
      <gml:exterior>
        <gml:LinearRing>
          <gml:pos srsDimension="3">32.0 31.0 2.5</gml:pos>
        </gml:LinearRing>
      </gml:exterior>
      <gml:Polygon>
        <gml:surfaceMember>
        ........
        </lod2Solid>
      ........
      </gml:Polygon>
  </gml:surfaceMember>
</building>
```
Conversion from IFC to CityGML

IFC

CityGML

```xml
<lod2Solid>
  ........
  <gml:Polygon gml:id="wallSurface4711">
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  </gml:Polygon>
  ........
</lod2Solid>
```
IFC example

- Many objects
- Complex semantic network
- For content creators
IFC example

- Many objects
- Complex semantic network
- For content creators
IFC example

- Many objects
- Complex semantic network
- For content creators
CityGML LoD3 example

- Few objects
- Simple hierarchical semantics
- For users / analyses
CityGML LoD3 example

- Few objects
- Simple hierarchical semantics
- For users / analyses
Differences

IFC
Differences

IFC

- IfcWallStandardCase
- IfcSlab
- WallSurface
- FloorSurface
- GroundSurface
Validity criteria for CityGML LoD3

• Semantics:
  • Normal vector constraints on surface types
Validity criteria for CityGML LoD3

- Semantics:
  - Normal vector constraints on surface types

  You should be able to walk on a FloorSurface, but not on a CeilingSurface

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Allowed direction(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GroundSurface</td>
<td>Only down</td>
</tr>
<tr>
<td>OuterCeilingSurface</td>
<td>Only down</td>
</tr>
<tr>
<td>OuterFloorSurface</td>
<td>Only up</td>
</tr>
</tbody>
</table>
Validity criteria for CityGML LoD3

• Semantics:
  • Normal vector constraints on surface types

• Geometry:
  • You should be able to walk on a FloorSurface, but not on a CeilingSurface
  • A building has only an exterior shell
Validity criteria for CityGML LoD3

- **Semantics:**
  - Normal vector constraints on surface types

- **Geometry:**
  - It should be able to walk on a `FloorSurface`, not on a `CeilingSurface`.
  - A building has only an exterior shell.

**ISO19107:**
- The shell must be 2-manifold.
Validity criteria for CityGML LoD3

- **Semantics:**
  - Normal vector constraints on surface types

- **Geometry:**
  - CityGML:
    - A building has only an exterior shell
  - ISO19107:
    - The shell must be 2-manifold

Vertices should not be close to other geometries
Degenerate geometry
Degenerate geometry

Floating-point arithmetic:
Degenerate geometry

Floating-point arithmetic:

\[= 0.300000000000004\]
Degenerate geometry

Floating-point arithmetic:  
\[ 0.1 + 0.2 = 0.3 \]

Exact arithmetic:  
\[ 0.1 + 0.2 = 0.3 \]

= 0.300000000000004
Degenerate geometry

Floating-point arithmetic:

Exact arithmetic:

\[ 0.1 + 0.2 = 0.3 \]
Degenerate geometry

Floating-point arithmetic:
$0.1 + 0.2 \neq 0.3$

Exact arithmetic:
$0.1 + 0.2 = 0.3$

Degenerate when:
Float-orientation $\neq$ Exact-orientation
Distance $d = 0$ (float or exact)
Existing converters
Existing converters
Structure

- What is IFC / CityGML and when is it valid?
- Methodology for the conversion
- Experimental results
- Possibilities for LoD4
- Conclusions, recommendations & future work
Methodology for the Conversion

1. **Semantic Mapping**
2. **Geometric Transformation**
3. **Geometric & Semantic Refinement**

Inputs: IFC
Outputs: CityGML
Methodology for the Conversion

1 Semantics mapping
Methodology for the Conversion

1. Semantic Mapping
2. Geometric Transformation
3. Geometric & Semantic Refinement

IFC → 2 Geometric transformation → CityGML
Methodology for the Conversion

3 Refinements

IFC -> Semantic Mapping -> Geometric Transformation -> Geometric & Semantic Refinement -> CityGML
1 Semantic mapping

CityGML has semantics for and between:

- Solids / Objects
  - Trivial attributes

- Faces
  - Boundary surfaces (But not limited to only boundary surfaces!)

- Curves
  - Requires the terrain which is out of scope
1 Semantic mapping

IFC example structure

- Project
  - Site
    - Building
      - Building
1 Semantic mapping

IFC example structure
1 Semantic mapping

IFC example structure

- Storey
- Storey
- Space
- Space
- Roof
- Wall
- Roof
- Beam
- Slab
- Slab

← Geometry
1 Semantic mapping

IFC
• Beam
• Member
• Stairs
• Door
• Roof
• Wall
• Slab
• Window
• ...

CityGML
• Ceiling
• Door
• Floor
• Roof
• Wall
• Window
• Ground
• Closure
1 Semantic mapping

**IFC**
- Beam
- Member
- Stairs
- Door
- Roof
- Wall
- Slab
- Window
- ...

**CityGML**
- Ceiling
- Door
- Floor
- Roof
- Wall
- Window
- Ground
- Closure
1 Semantic mapping

A combination of:

Slab
1 Semantic mapping

A combination of:

1. Type
   - IfcSlab
   - IfcMember
   - IfcRoof

Slab
1 Semantic mapping

A combination of:

1. Type

- FLOOR
- ROOF
- LANDING
- BASESLAB
- USERDEFINED
- NOTDEFINED
1 Semantic mapping

A combination of:

1. Type

- Roof
- Slab
1 Semantic mapping

A combination of:

1. Type

- Roof
- Slab
- Slab
1 Semantic mapping

A combination of:

1. Type
2. Predefined type
1 Semantic mapping

A combination of:

1. Type
2. Predefined type

Constraints:

The object has to be contained in a building

Must be a Space or a subtype of BuildingElement
1 Semantic mapping

A combination of:

1. Type
2. Predefined type

Constraints:

The object has to be contained in a building
Must be a Space or a subtype of BuildingElement
1 Semantic mapping

A combination of:

1. Type
2. Predefined type
3. Decomposed by

Constraints:

The object has to be contained in a building

Must be a Space or a subtype of BuildingElement
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A combination of:

1. Type
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Constraints:

The object has to be contained in a building

Must be a Space or a subtype of BuildingElement
1 Semantic mapping

A combination of:

1. Type
2. Predefined type
3. Decomposed by
4. Surface normal

Constraints:

The object has to be contained in a building
Must be a Space or a subtype of BuildingElement
Methodology for the Conversion

2 Geometric transformation
2 Geometric transformation

1. All IFC geometries are connected using the Boolean union operation

2. Interior geometries are removed
2 Geometric transformation

Real buildings are not watertight!
## 2 Geometric transformation

Concepts for extracting the exterior shell

<table>
<thead>
<tr>
<th>Concept</th>
<th>Total Score</th>
<th>Feasibility / Complexity</th>
<th>Predictability</th>
<th>Number of Artefacts</th>
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# Geometric transformation

Concepts for extracting the exterior shell
- Generated
- Implemented
- Evaluated

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2 Geometric transformation

Concepts for extracting the exterior shell
- Generated
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Morphological closing
Using an oriented cubical structuring element

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**Morphological closing**
Using an oriented cubical structuring element

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2 Morphological closing

Morphological closing = dilation followed by erosion
2 Morphological closing

Morphological closing = dilation followed by erosion

Dilation:
2 Morphological closing

Morphological closing = dilation followed by erosion

Dilation:

Erosion:
2 Morphological closing
2 Morphological closing

1. Geometries are **dilated** thereby closing the gaps
2. Interior geometries are **removed**
3. The exterior shell is **eroded** back to its original size
2 Morphological closing

1. Geometries are **dilated** thereby closing the gaps
2. Interior geometries are **removed**
3. The exterior shell is **eroded** back to its original size
2 Building Installations
2 Building Installations
2 Building Installations
2 BuildingInstallations

- BuildingInstallations are separate objects
- Objects must not overlap each other

1. BuildingInstallations are unioned
2. The building solid is subtracted
Methodology for the Conversion

3 Refinements
Methodology for the Conversion

3 Refinements
3 Refinements - geometric
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
- Solid geometry is made 2-manifold
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
- Solid geometry is made 2-manifold
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- Solid geometry is made 2-manifold
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
- Solid geometry is made 2-manifold
- Degeneracies are removed
3 Refinements - geometric

- Coordinates are rounded in preparation of writing
- The geometry is regularized
- Solid geometry is made 2-manifold
- Degeneracies are removed
3 Refinements - semantic

- Faces without semantics are created during closing
3 Refinements - semantic

- Faces without semantics are created during closing
- Semantics are assigned based on the normal and the neighbours
3 Refinements - semantic

- Faces without semantics are created during closing
- Semantics are assigned based on the normal and the neighbours

Conversion complete!
Implementation

IfcOpenShell
open source ifc geometry engine
Implementation

- Nef polyhedra are used for Boolean operations
Implementation

- Nef polyhedra are used for Boolean operations
- Nef polyhedra in CGAL do not support semantic faces
Implementation

- Nef polyhedra are used for Boolean operations
- Nef polyhedra in CGAL do **not** support semantic faces
- Semantics are reattached after the geometric transformation
Structure

- What is IFC / CityGML and when is it valid?
- Methodology for the conversion
- **Experimental results**
- Possibilities for LoD4
- Conclusions, recommendations & future work
Experimental results
Experimental results – no roof
Experimental results

IFC          CityGML
Experimental results

IFC

CityGML
Experimental results

IFC

CityGML
Experimental results

IFC

CityGML
Experimental results

IFC

CityGML
Validity and quality
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- Geometric validity checked using 3D Validator: All models are valid!
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Artefact area

Percentage of artefact area (%) vs Structuring element width (mm)
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- Computation time ~5-15 minutes
  - With outliers from 6 seconds to 95 minutes
  - Creation of Nef polyhedra and Boolean operations are slow
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- Generated CityGML files are smaller than input IFC files
  - Detriangulation leads to a file size reduction of ~66%
  - ~50% of the file space is dedicated to BuildingInstallations
Structure

- What is IFC / CityGML and when is it valid?
- Methodology for the conversion
- Experimental results
- **Possibilities for LoD4**
- Conclusions, recommendations & future work
Generation of LoD4 rooms
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- Rooms cannot be detected from the geometry
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- IfcSpaces are (almost) equivalent to Rooms in CityGML
Generation of LoD4 rooms

- Rooms cannot be detected from the geometry
- IfcSpaces are (almost) equivalent to Rooms in CityGML
- In the implementation:
  - Geometry from IfcSpaces
  - Semantics base on surface normal
LoD4 experimental results
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Possibilities for LoD4 conversion
Possibilities for LoD4 conversion

• In IFC objects can be linked to spaces
Possibilities for LoD4 conversion

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Possibilities for LoD4 conversion

- In IFC objects can be linked to spaces
- The same semantic mapping can be used
  - But needs to be extended with:
    - Furniture and other LoD4 specific objects
    - Connectivity relations between openings
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- A new source for CityGML LoD3 building models
  - Small additions to the IFC will align the two standards even more
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- Generating LoD4 building models is only a small step away

- The methodology enables the creation of
  - up-to-date
  - high detail models that
  - adhere to the standards of CityGML and ISO19107, thereby
  - increasing the availability of high detail models
  - and the interoperability between Geomatics and Architecture and
  - reducing the costs for the creation of high detail city models
Conclusions

Other uses of this research:

- Semantic mapping for use in a reverse conversion or UBM
- Geometric transformations for the simplification of any CAD model
- Refinement methods to optimize the geometry for analyses
Recommendations

Recommendations for IFC:

- IfcSpace for the exterior of the building
- Add semantics for balconies, dormers, external IfcSpaces
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Recommendations for CityGML:

- Refine the definitions of how to model CityGML
  - For the geometry of BuildingParts & -Installations
  - For the semantics of doors and windows
Future work
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- Mapping of new IFC4 classes and trivial attributes like the address
- Extraction of the terrain intersection curve
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- A higher level of interoperability between IFC and CityGML
  - Alignment of the standards
  - Generation of LoD2 and LoD4 building models
  - Generation of other city objects (tunnels, bridges)
Something extra
Something extra
Something extra
Something extra
Something extra
Automatic generation of CityGML LoD3 building models from IFC models

M.Sc. Geomatics P5 presentation by Sjors Donkers

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