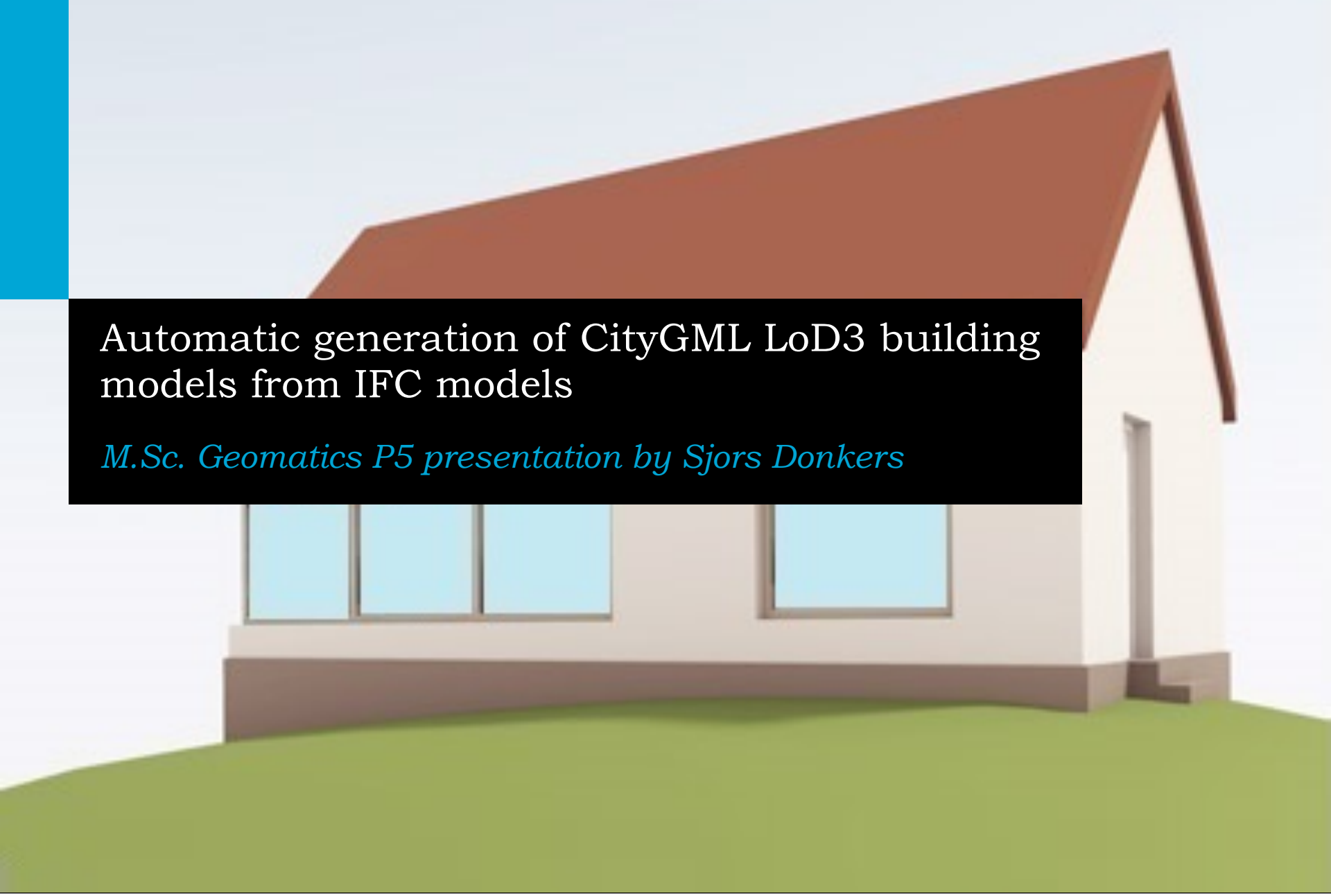
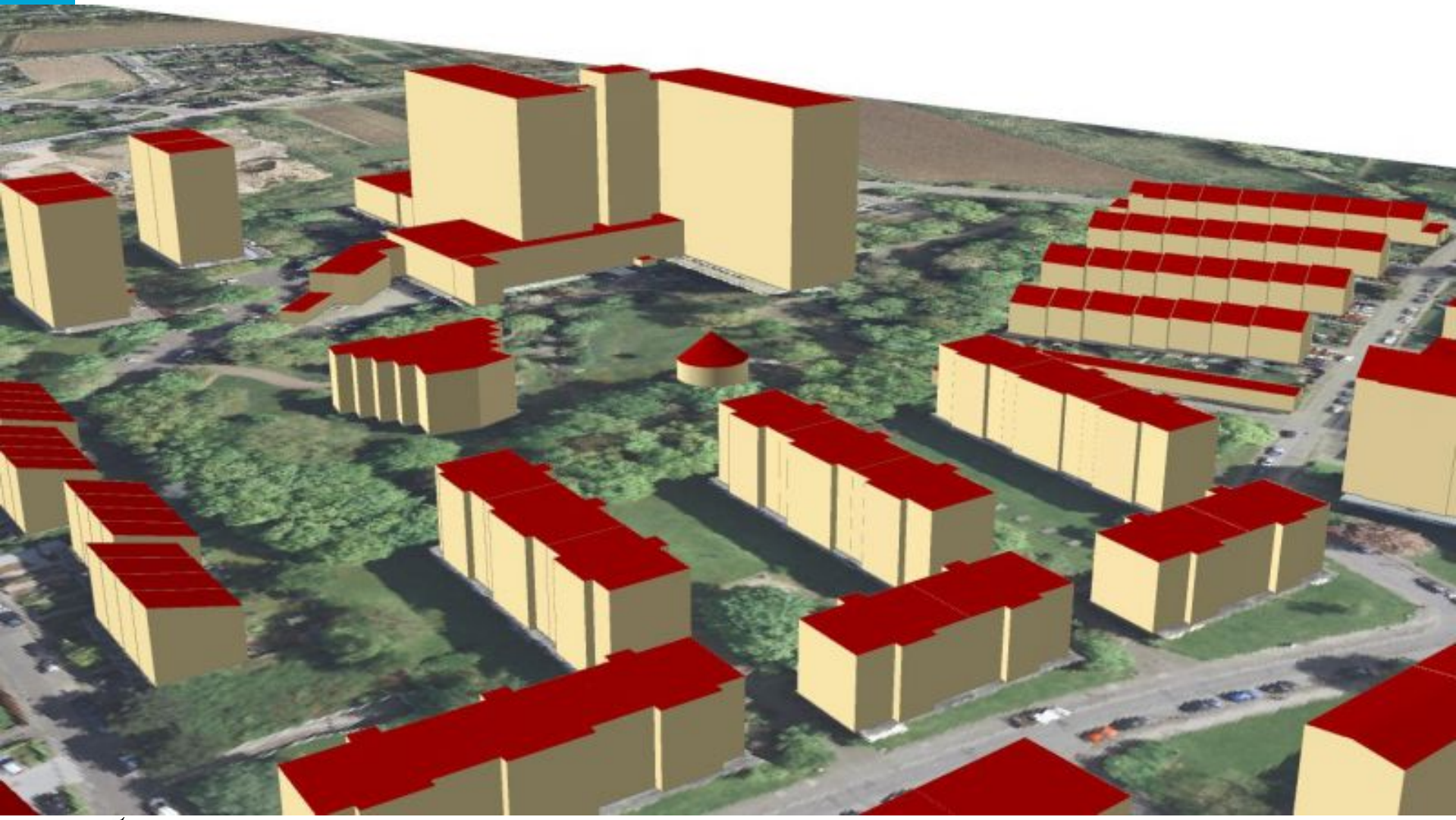


Automatic generation of CityGML LoD3 building models from IFC models

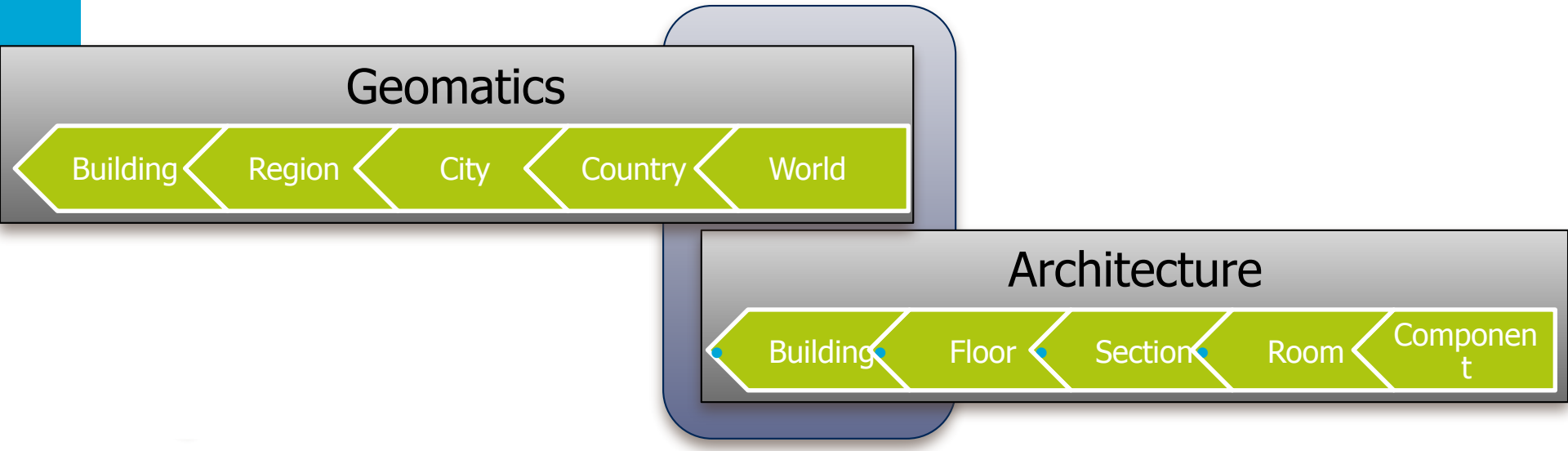
M.Sc. Geomatics P5 presentation by Sjors Donkers

Geomatics

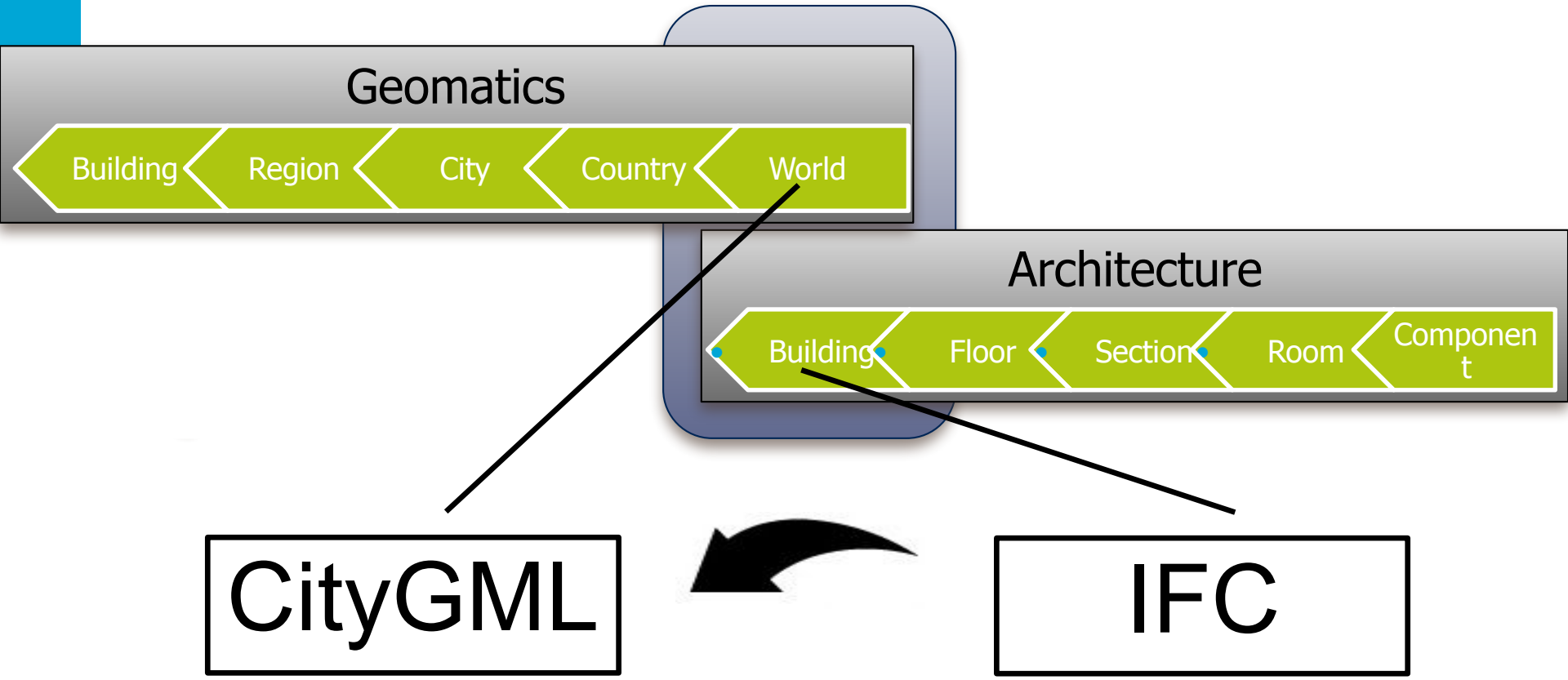


Architecture

Where the fields overlap

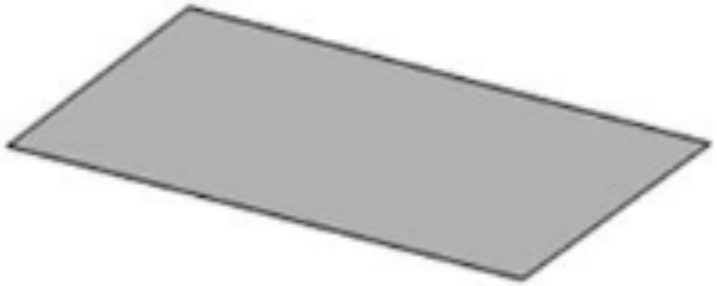


Where the fields overlap



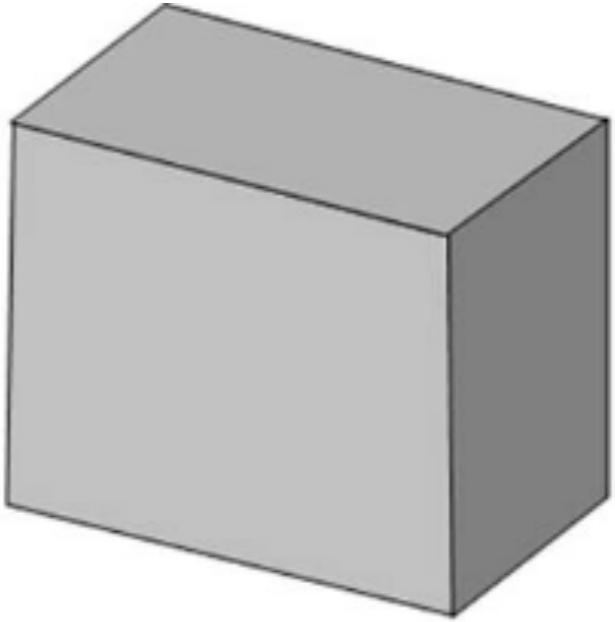
What is high detail for CityGML?

LoD0



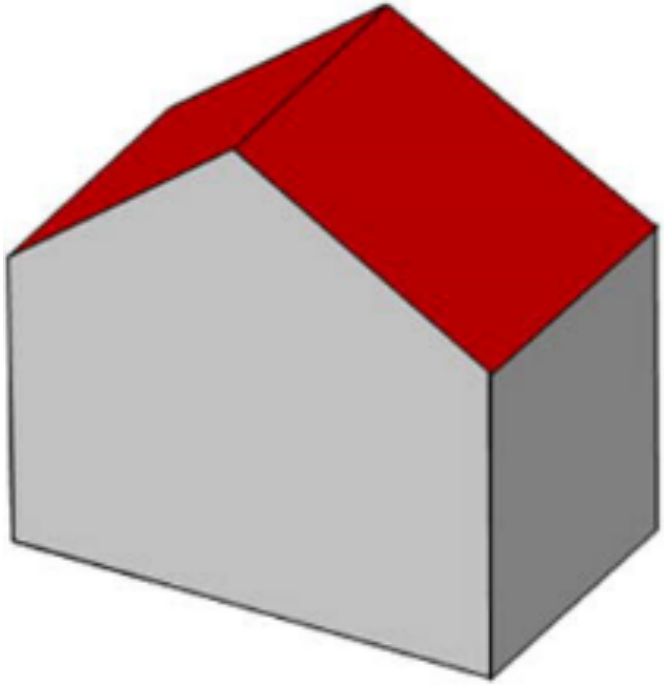
What is high detail for CityGML?

LoD1



What is high detail for CityGML?

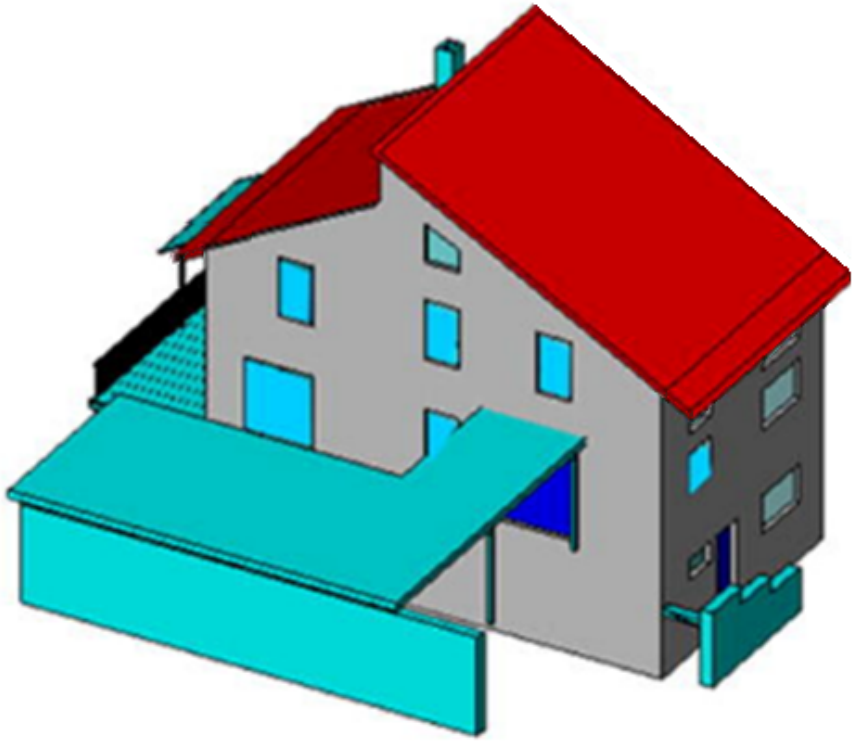
LoD2



What is high detail for CityGML?

- LoD ≤ 2 can be automatically generated
- LoD ≥ 3 requires manual labour

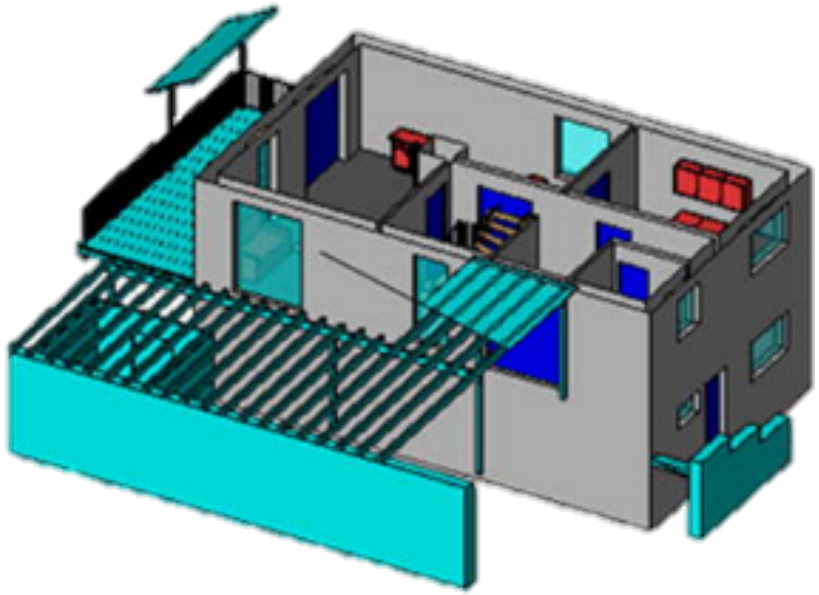
LoD3



What is high detail for CityGML?

- LoD ≤ 2 can be automatically generated
- LoD ≥ 3 requires manual labour

LoD4



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, 'sampl
#3=IFCSITE('abc103', #103, $, $, $,
#4=IFCBUILDING('abc104',
   'sample building at 10
#6=IFCBUILDINGSTOREY('abc
   #1502, $, $, .ELEMENT.
#7=IFCBUILDINGSTOREY('abc
   #1503, $, $, .ELEMENT.
#8=IFCBUILDINGSTOREY('abc
   #1504, $, $, .ELEMENT.
#9=IFCBUILDINGSTOREY('abc
   #1505, $, $, .ELEMENT.
#10=IFCRELAGGREGATES('abc
#11=IFCRELAGGREGATES('abc
#13=IFCRELAGGREGATES('abc
```

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>
.............
</building>
```

Conversion from IFC to CityGML

IFC

```
#1=IFCPROJECT('abc101', #101, 'sampl
#3=IFCSITE('abc103', #103, $, $, $,
#4=IFCBUILDING('abc10
   'sample buildi
#6=IFCBUILDINGSTOREY('abc
   #1502, $, $, .ELEMENT.
#7=IFCBUILDINGSTOREY('abc
   #1503, $, $, .ELEMENT.
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```
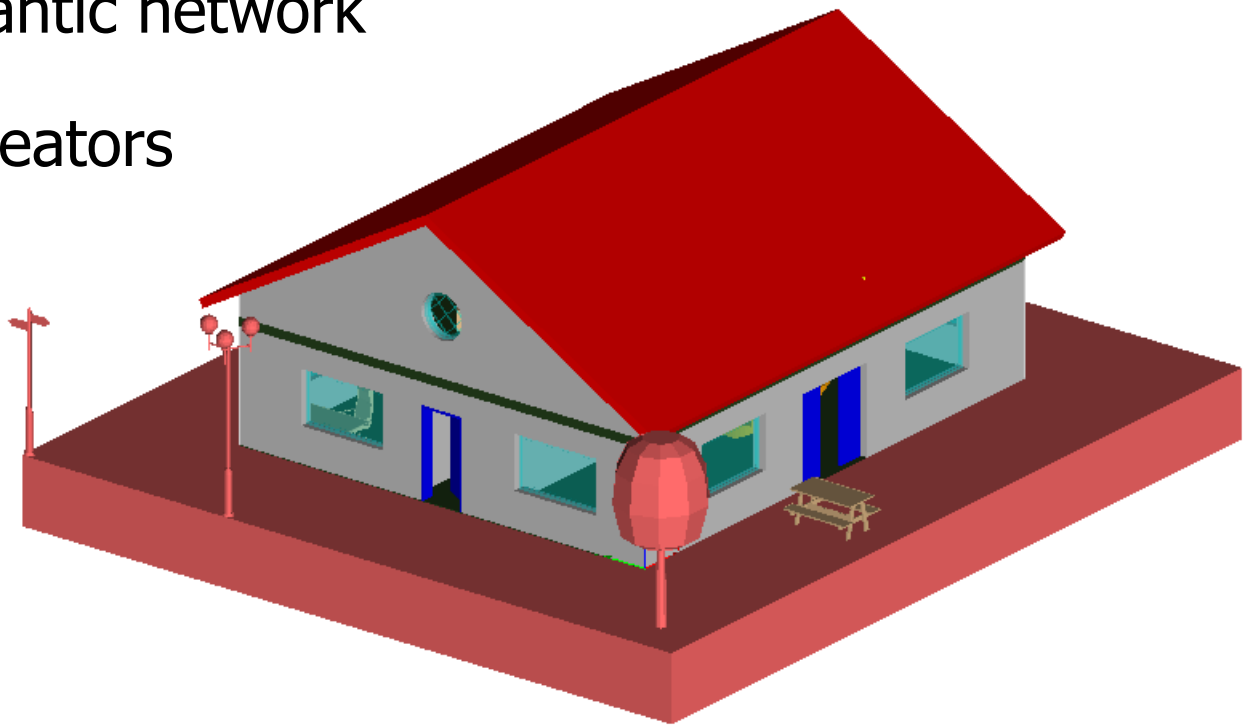

CityGML

```
<lo
.....
    <gml
      <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>
.....
</building>
```

IFC example

- Many objects
- Complex semantic network
- For content creators



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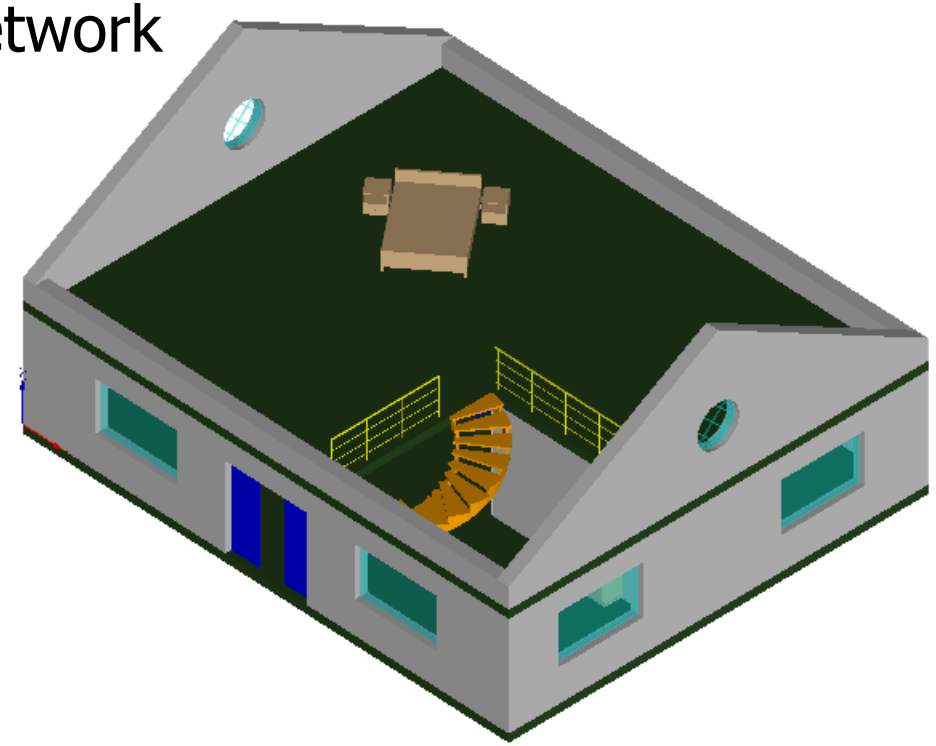

IFC example

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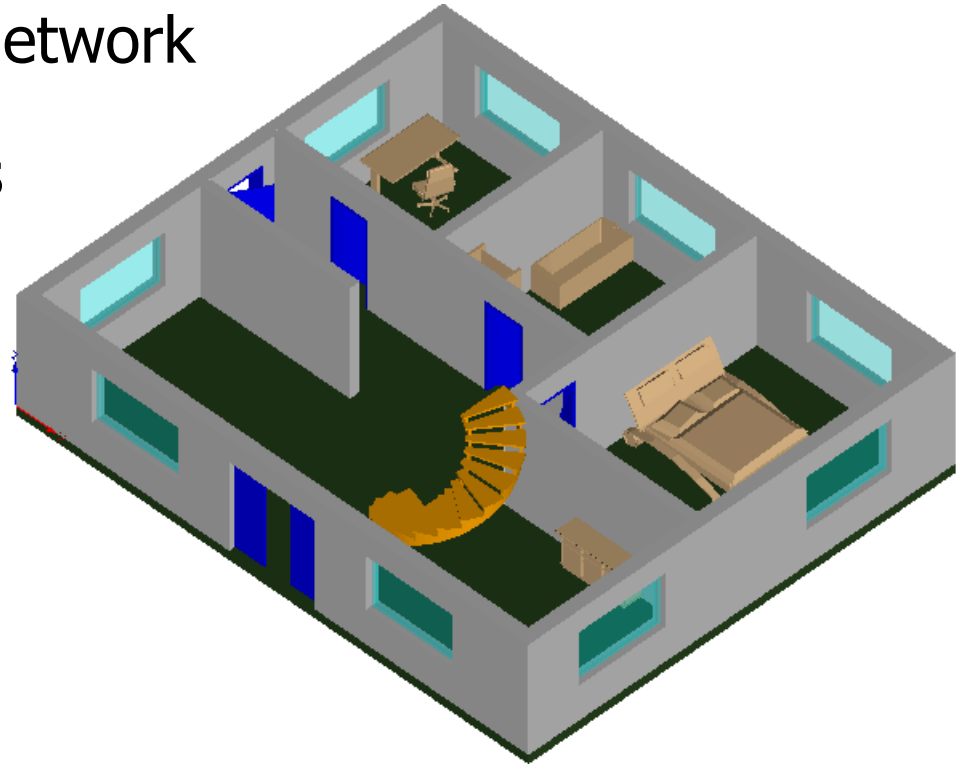
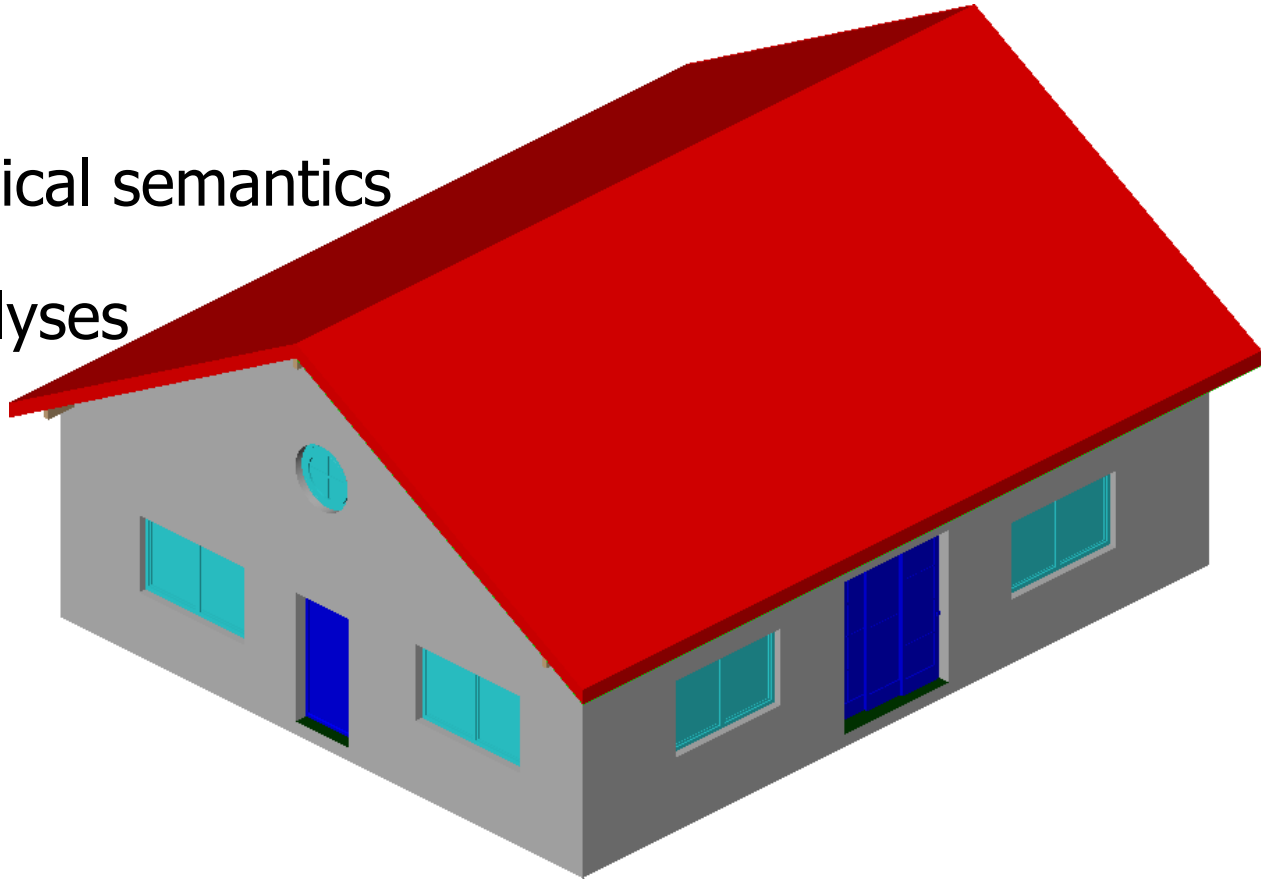


CityGML LoD3 example

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



CityGML LoD3 example

- Few objects
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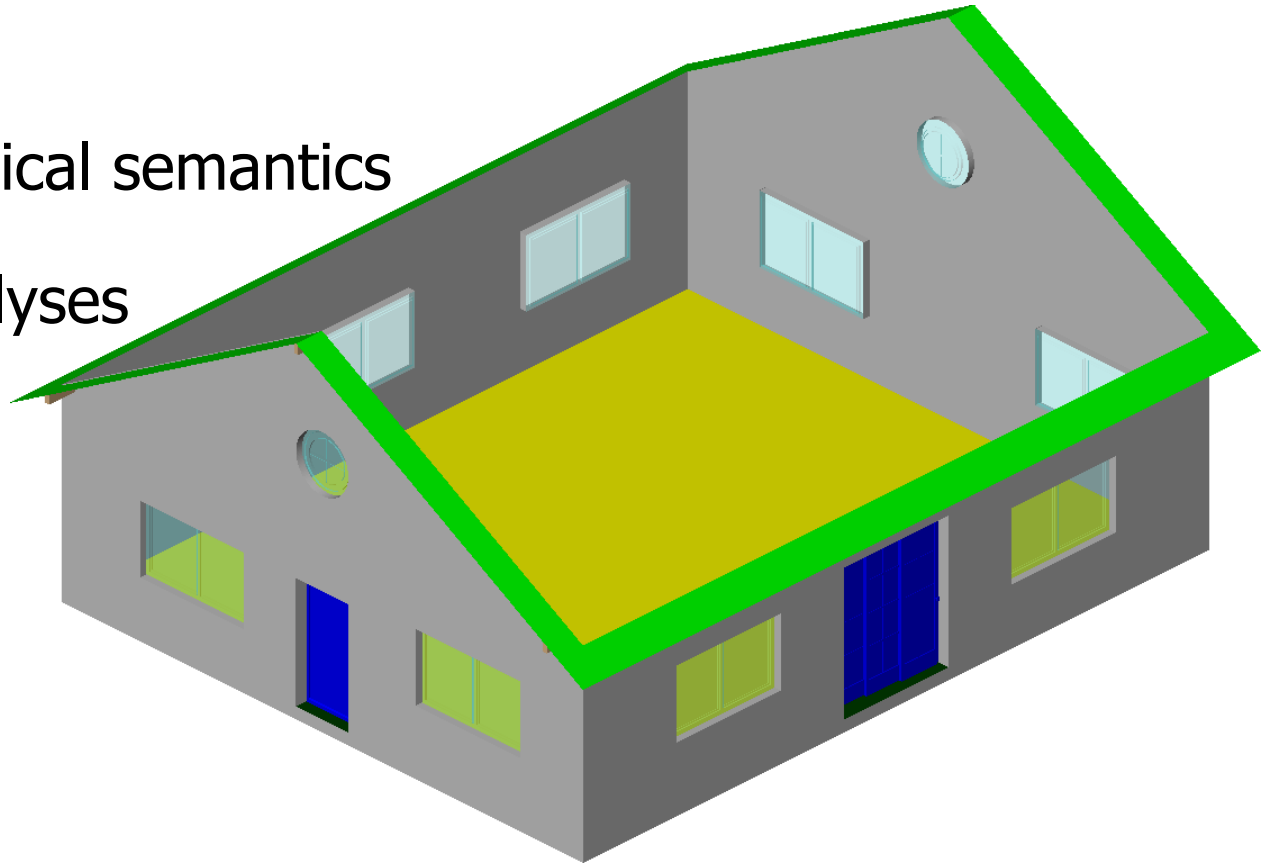
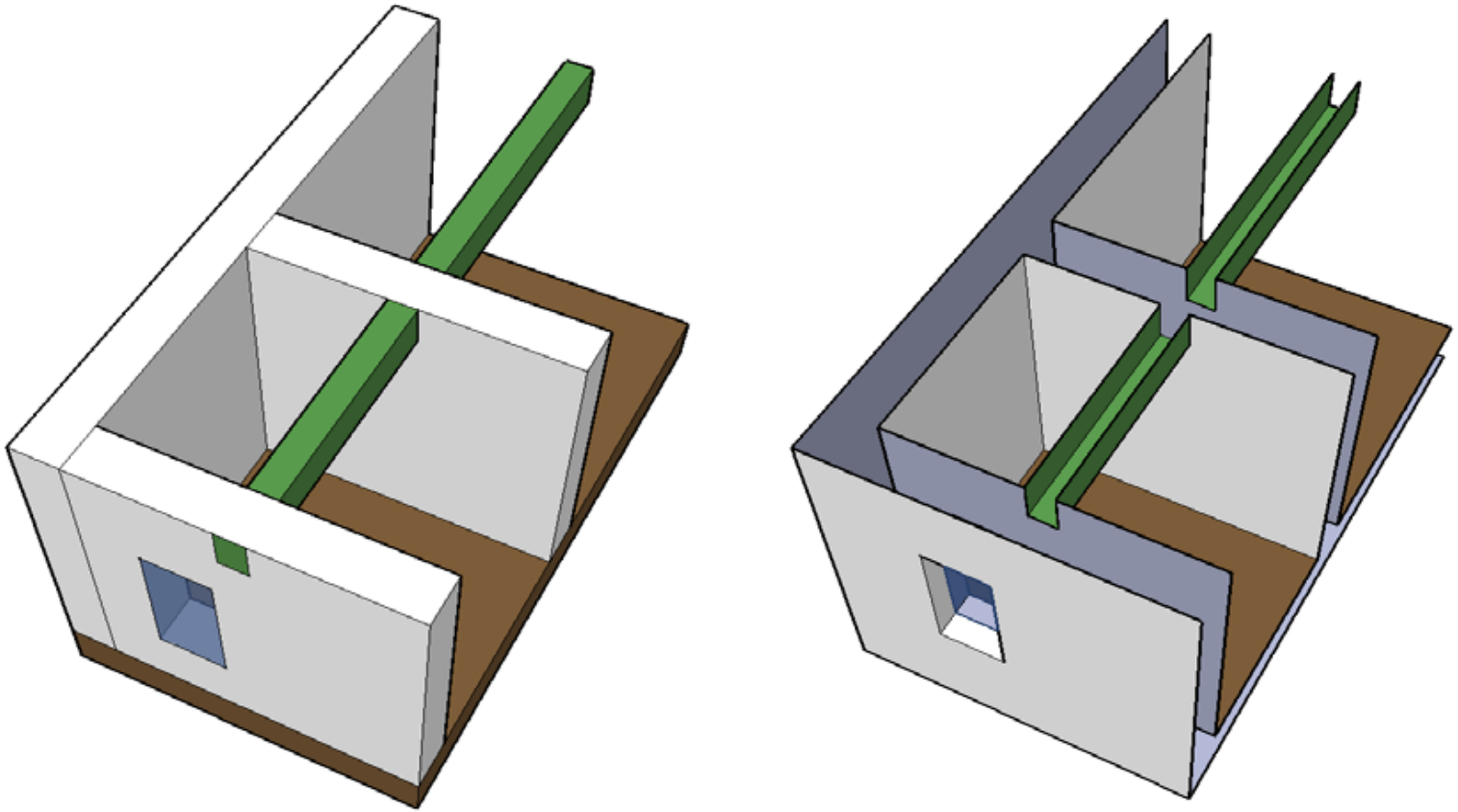


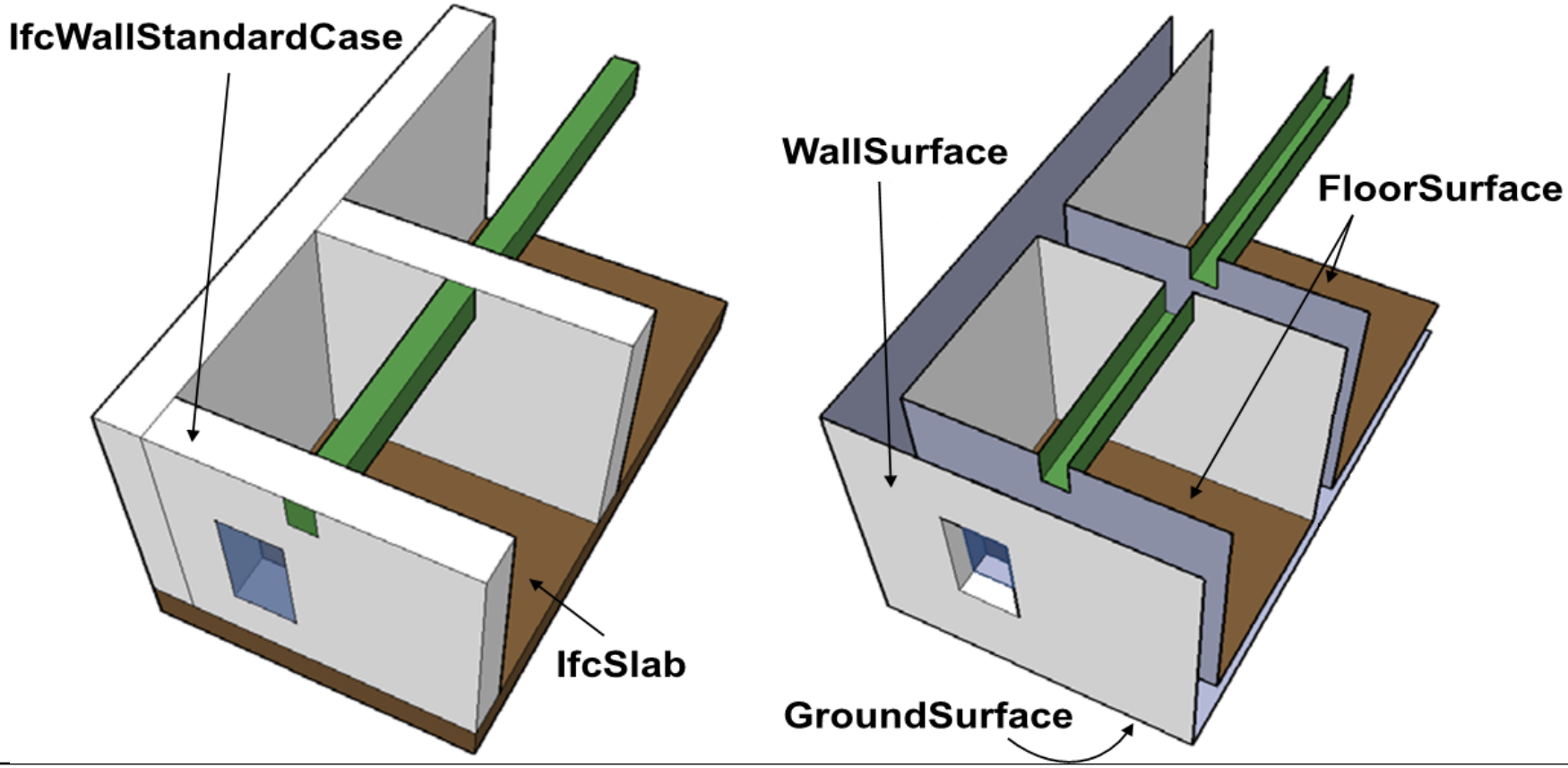
Differences

IFC



Differences

IFC



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

Surface type	Allowed direction(s)
GroundSurface	Only down
OuterCeilingSurface	Only down
OuterFloorSurface	Only up

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

CityGML:

Validity criteria for CityGML LoD3

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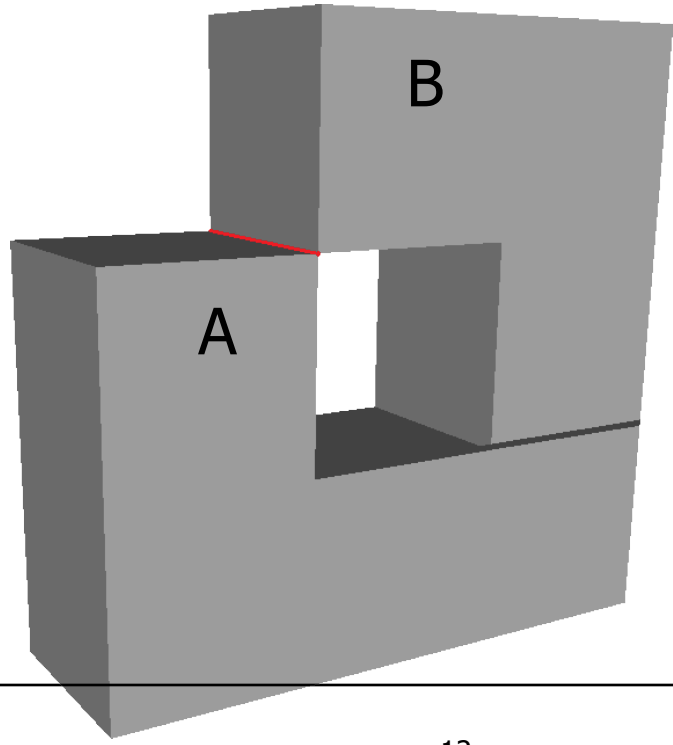
CityGML:

ISO19107:

- The shell must be 2-manifold



Validity criteria for CityGML LoD3

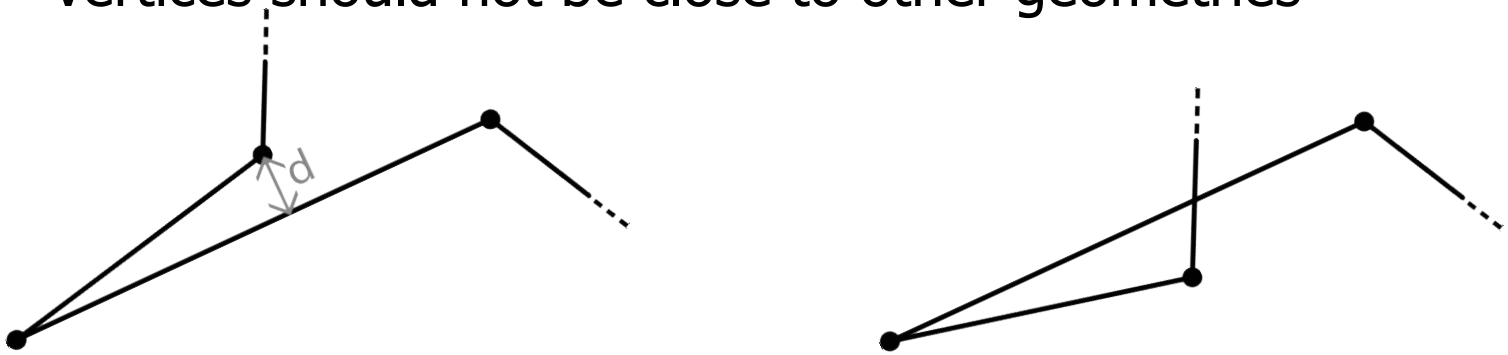
- Semantics:
  - Normal vector constraints on surface types

- 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:

$$= 0.30000000000004$$

Degenerate geometry

Floating-point arithmetic:

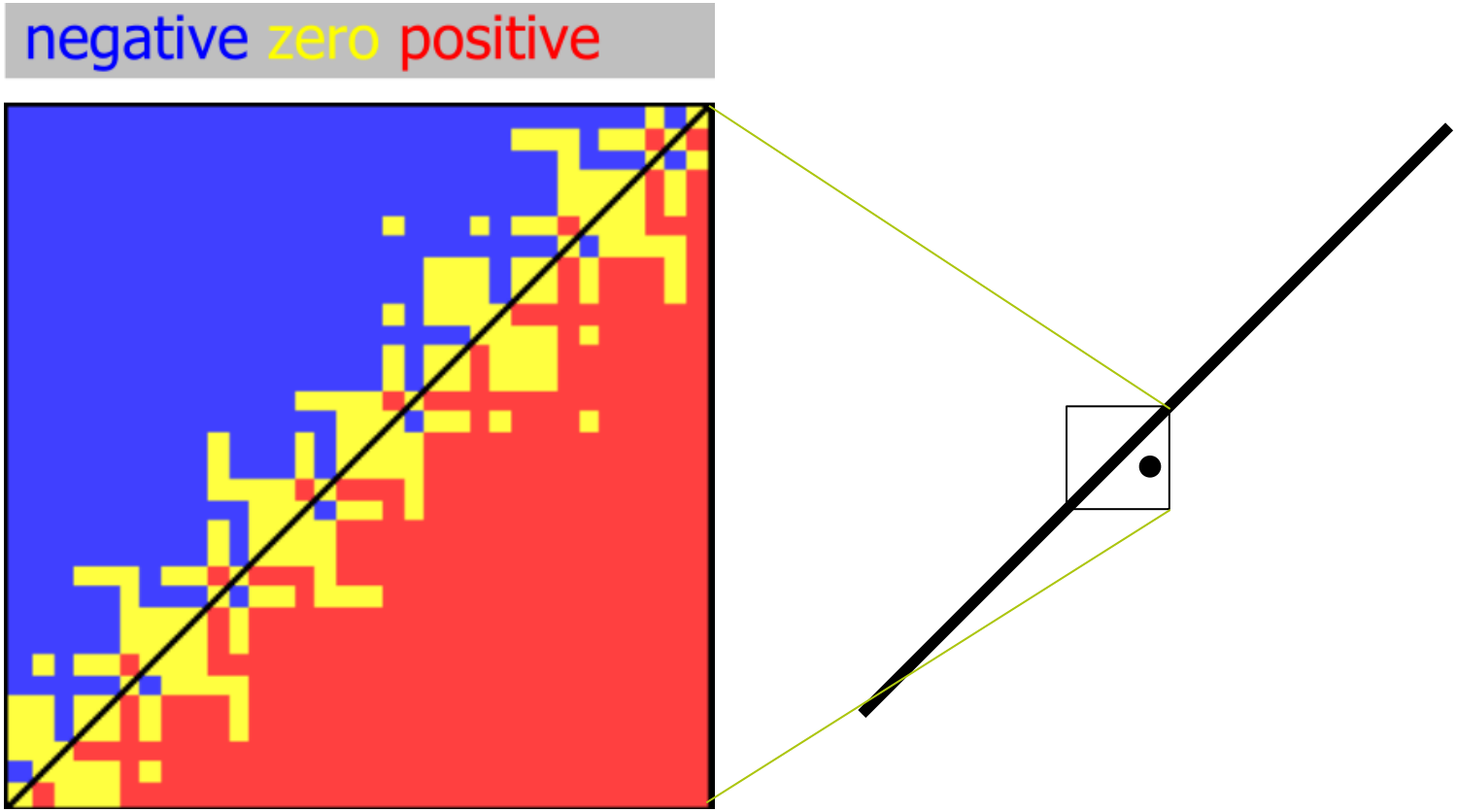
$= 0.30000000000004$

Exact arithmetic:
$0.1 + 0.2 = 0.3$

Degenerate geometry

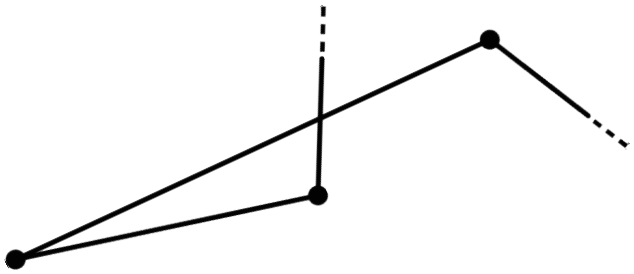
Floating-point arithmetic:

Exact arithmetic:
0.1 + 0.2 = 0.3

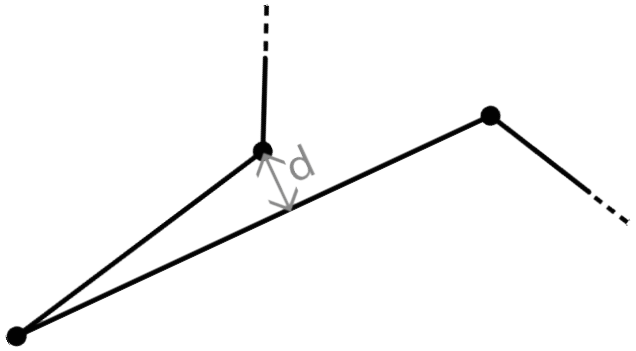


Degenerate geometry

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



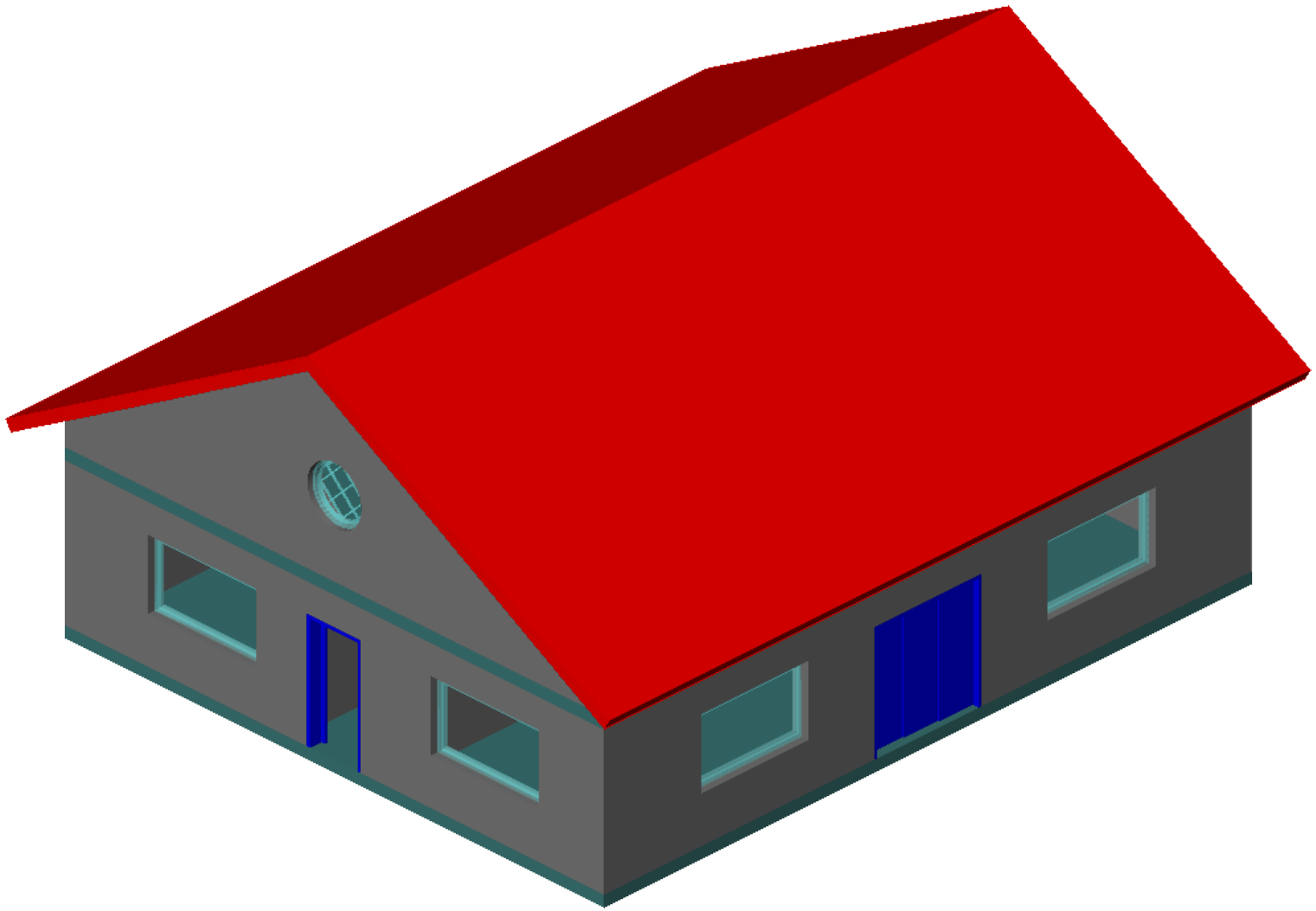
Exact arithmetic:
$0.1 + 0.2 = 0.3$



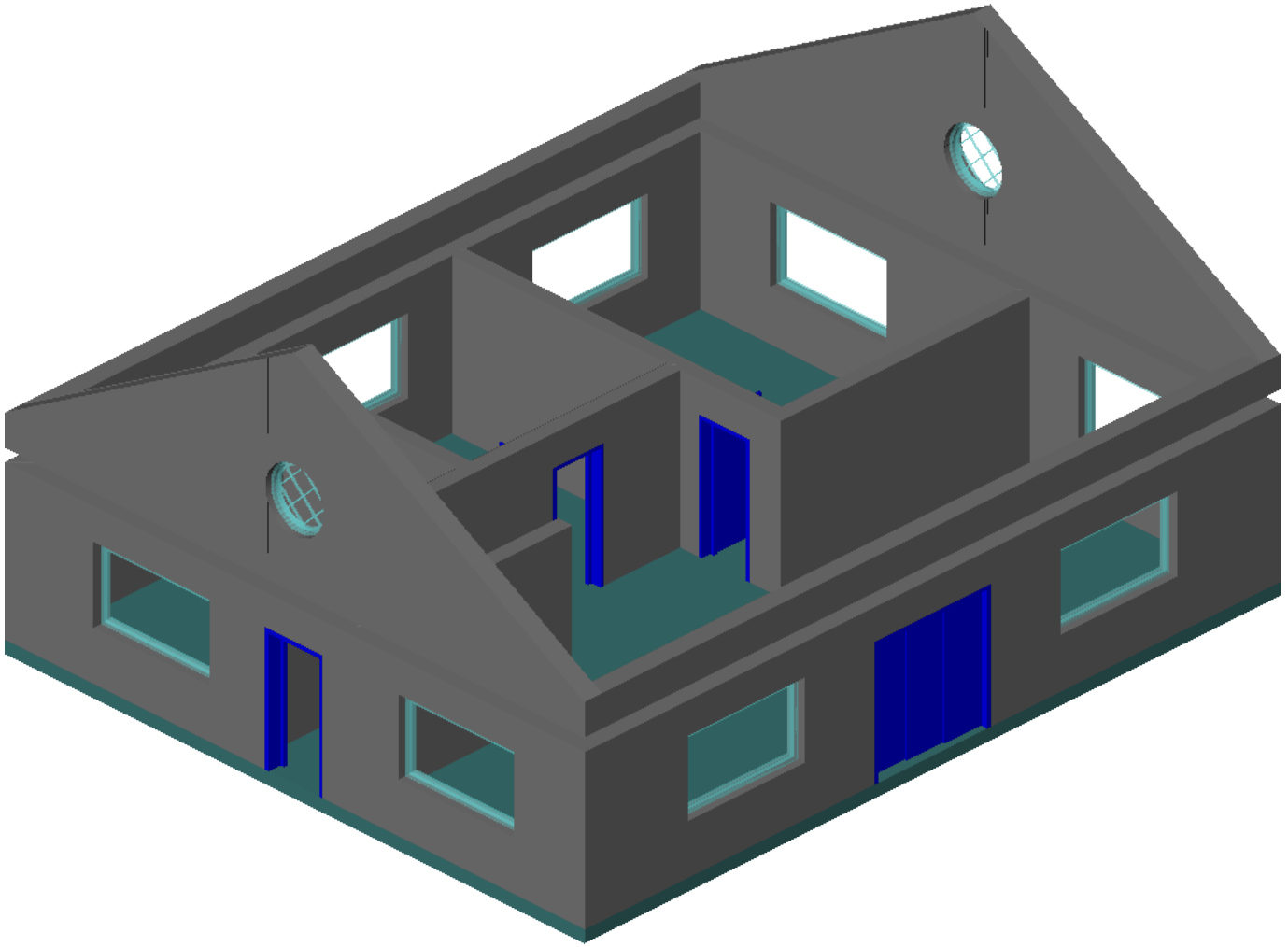
Degenerate when:

- Float-orientation ≠ Exact-orientation
- Distance d = 0 (float or exact)

Existing converters



Existing converters



Structure

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- **Methodology for the conversion**
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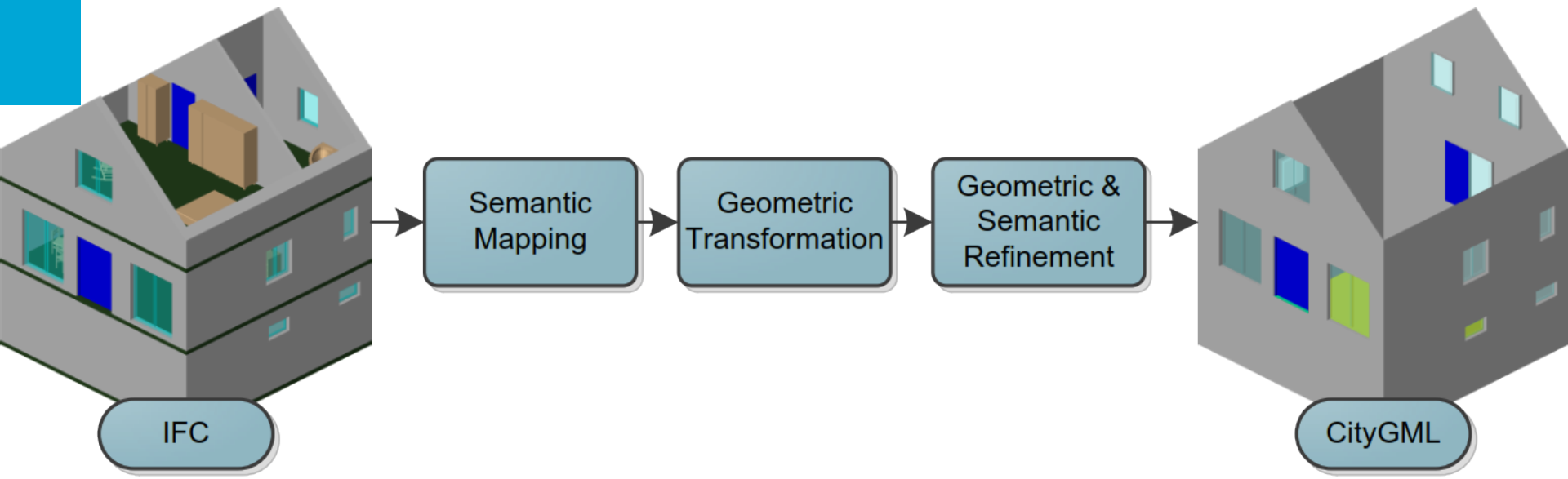
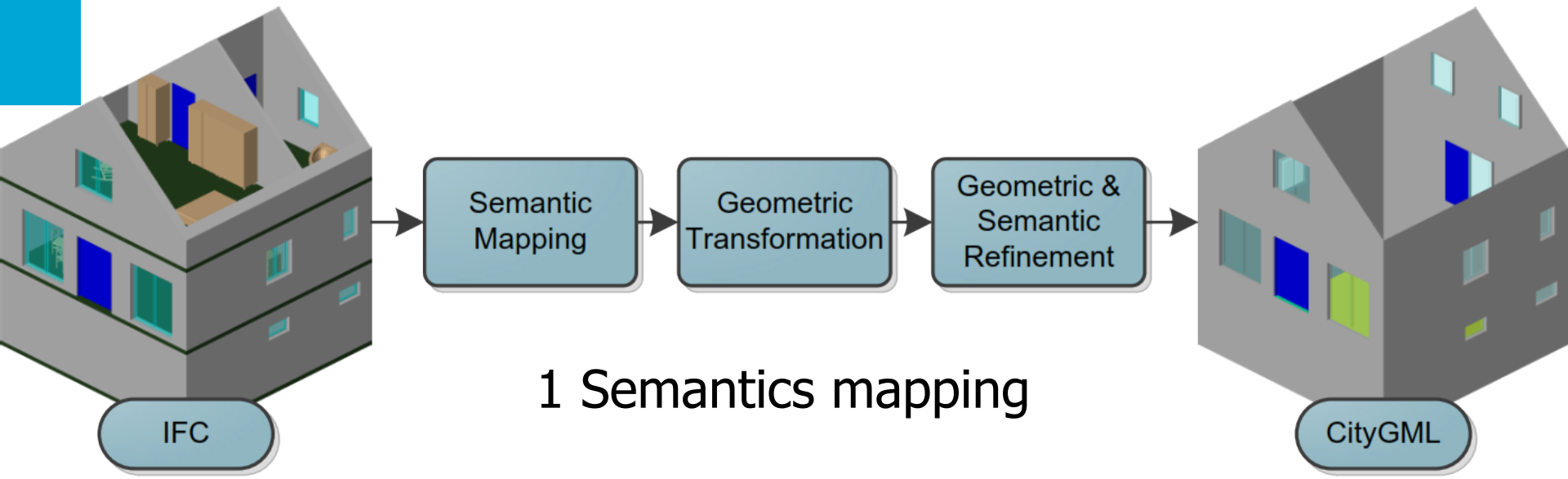
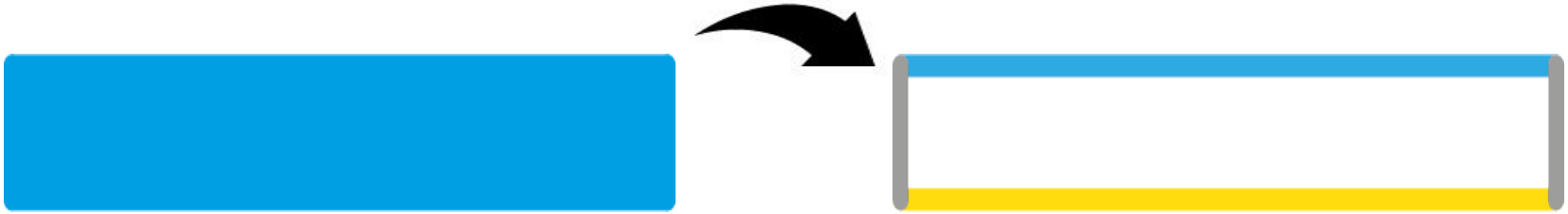
Methodology for the Conversion



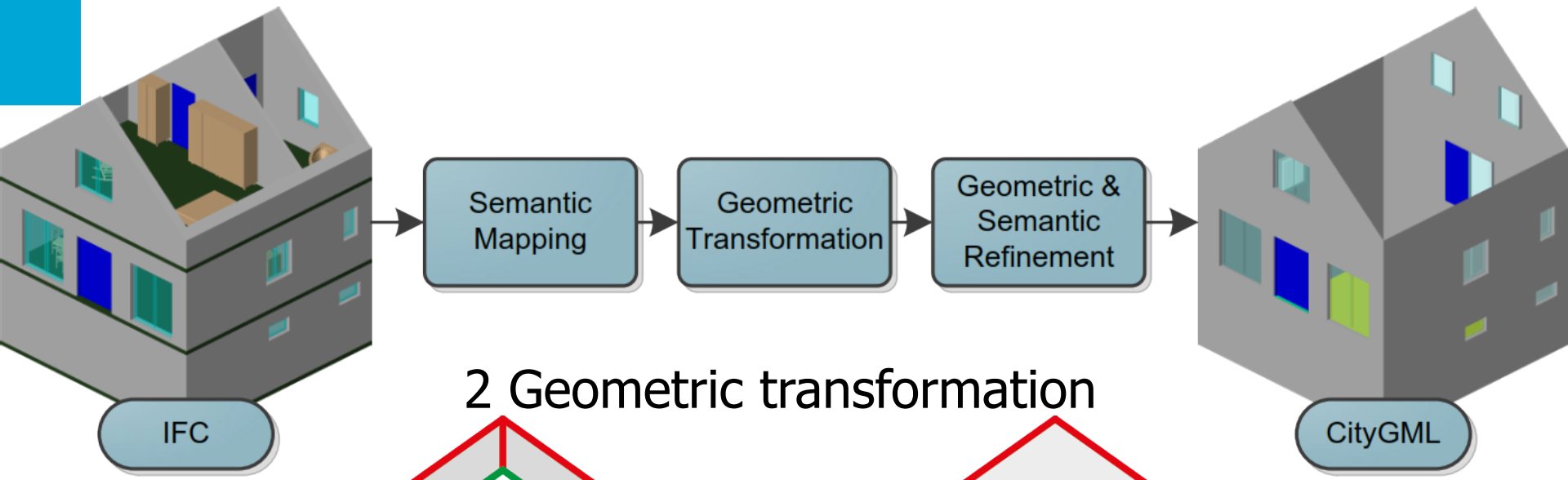
Methodology for the Conversion



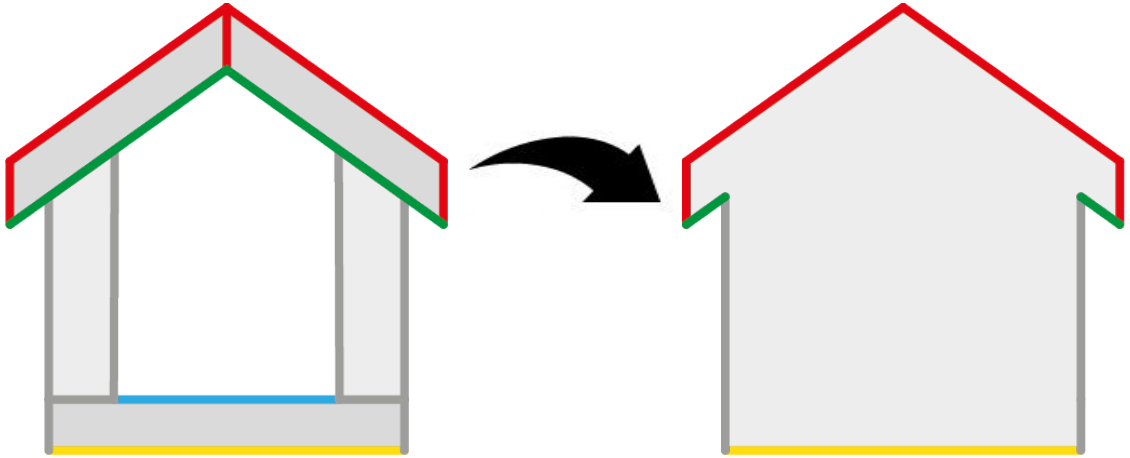
1 Semantics mapping



Methodology for the Conversion



2 Geometric transformation



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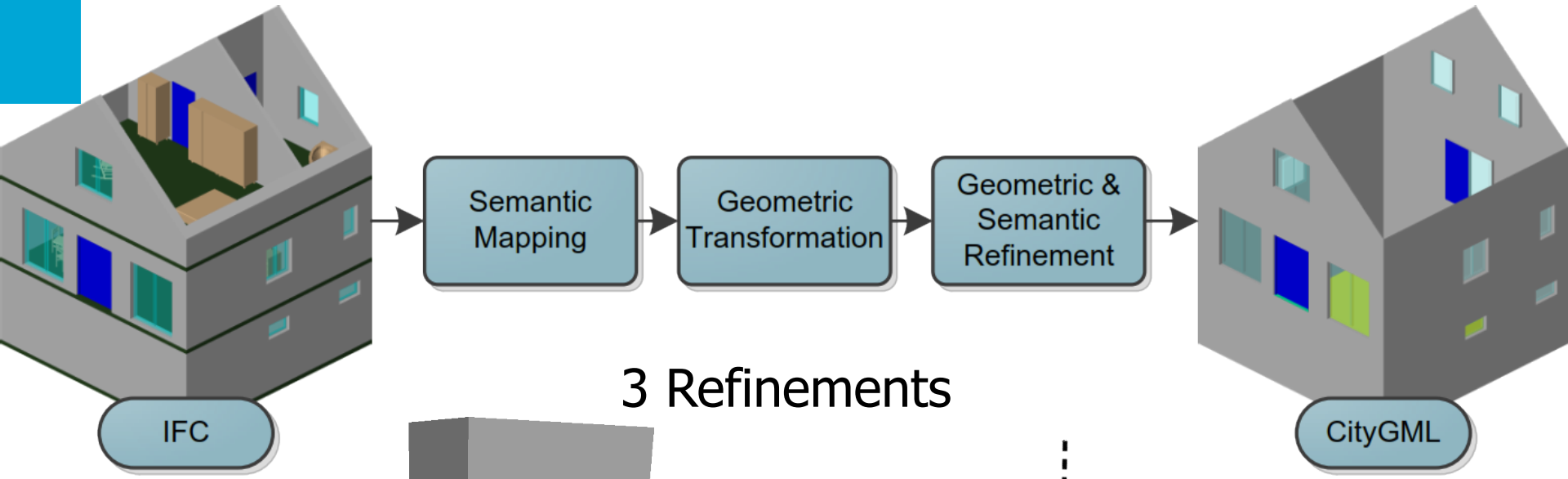
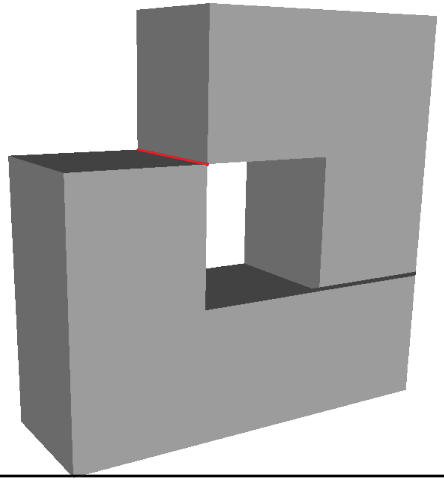
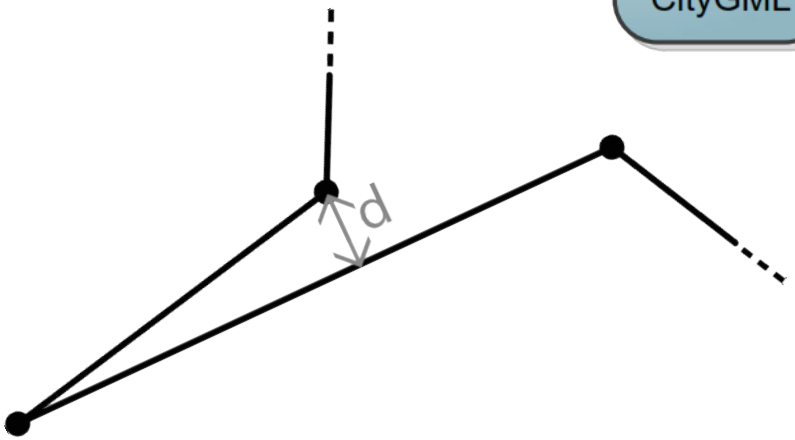


3 Refinements





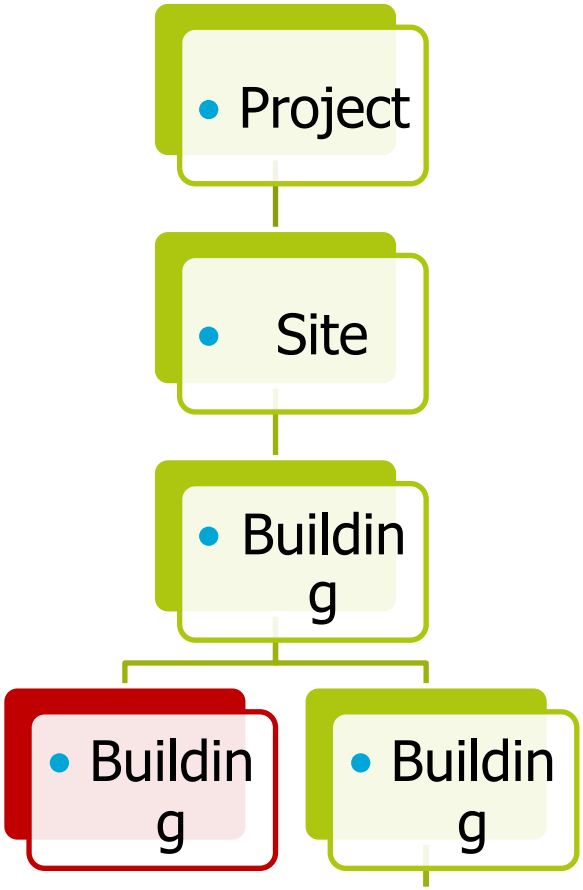
1 Semantic mapping

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

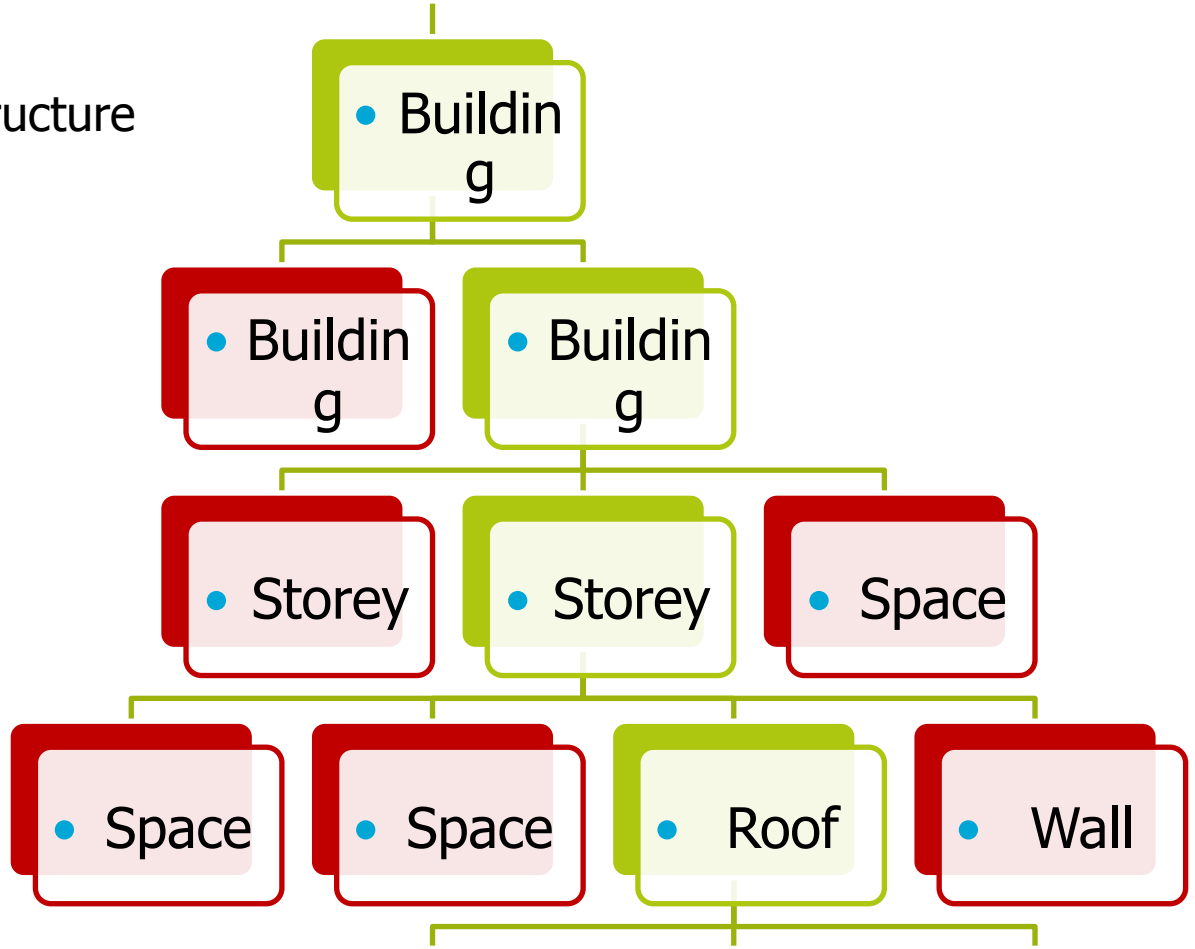
1 Semantic mapping

IFC example structure



1 Semantic mapping

IFC example structure



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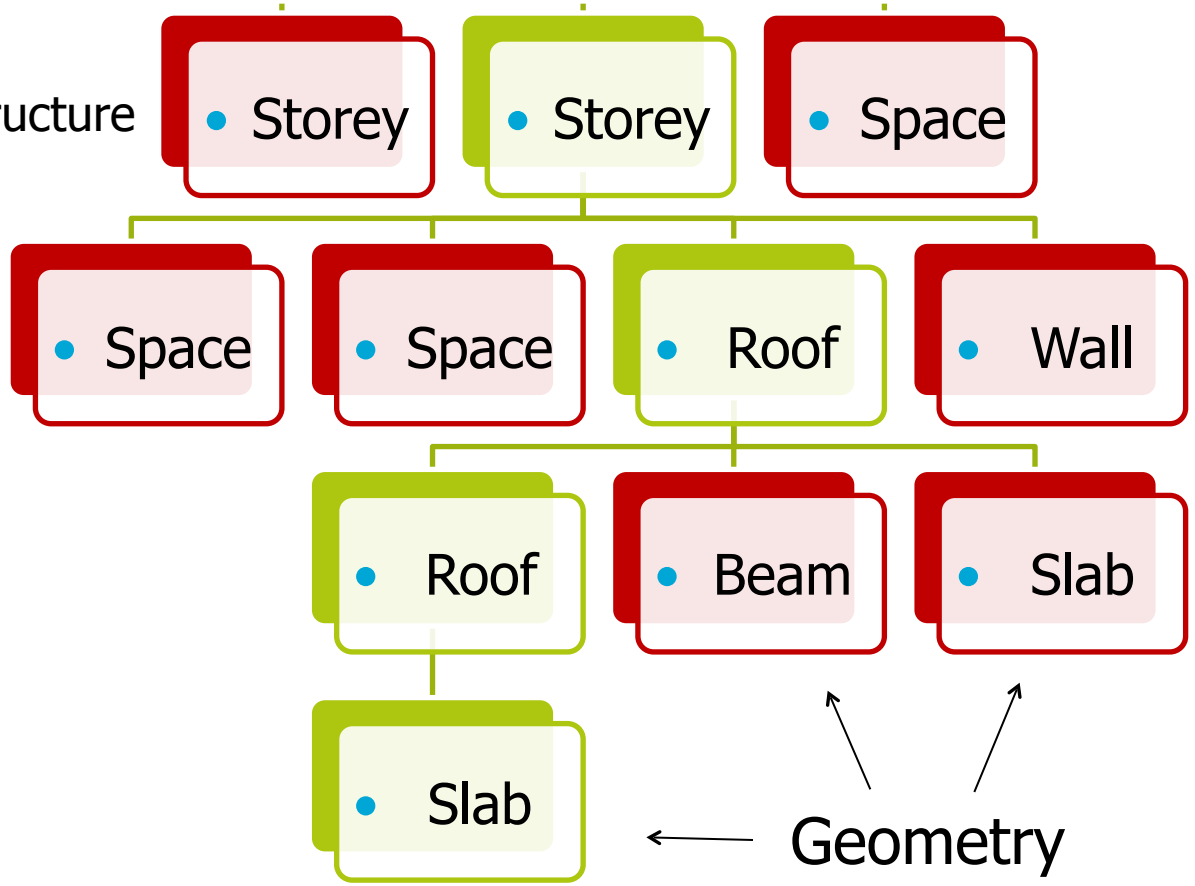
IFC example structure



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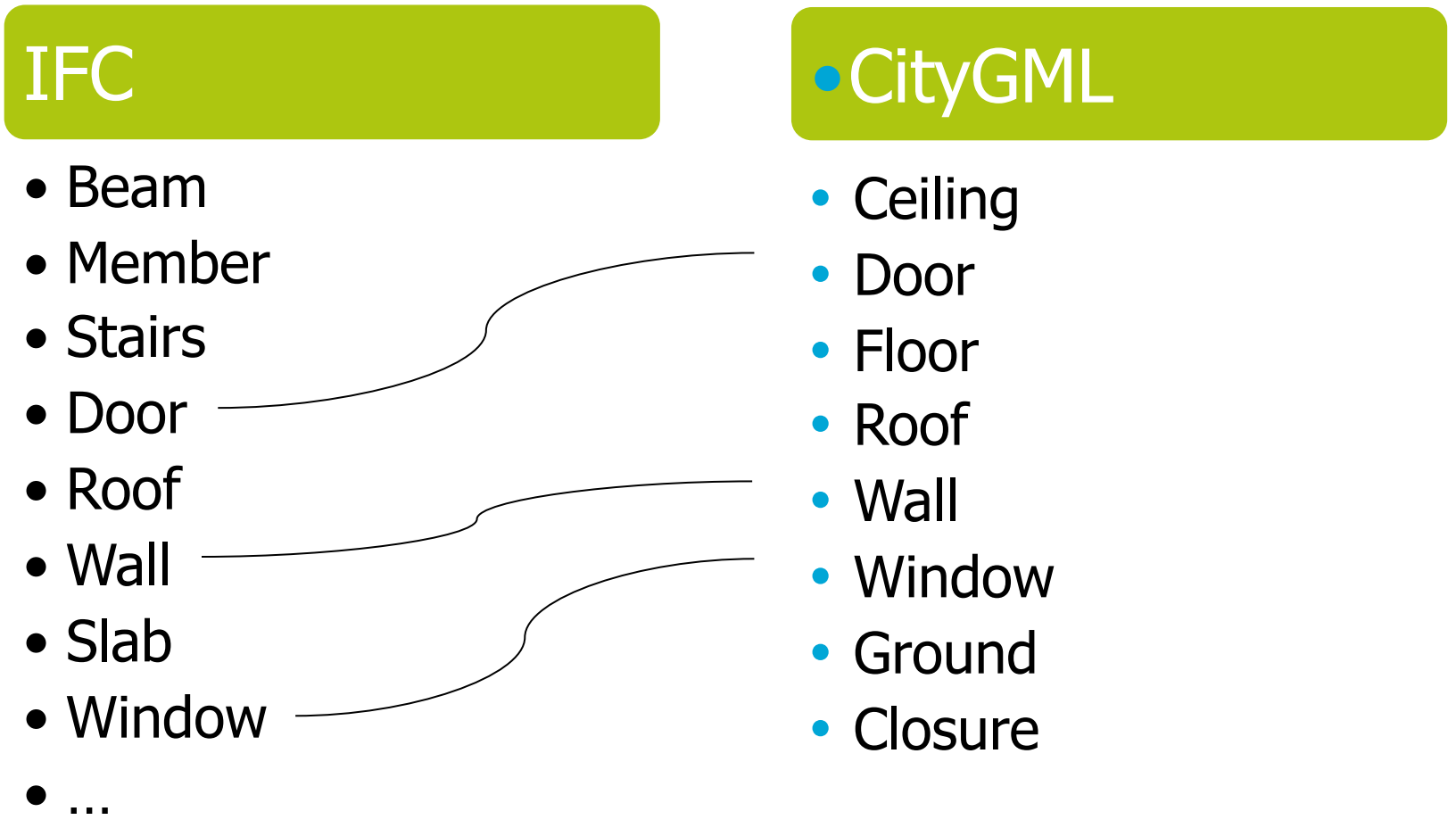

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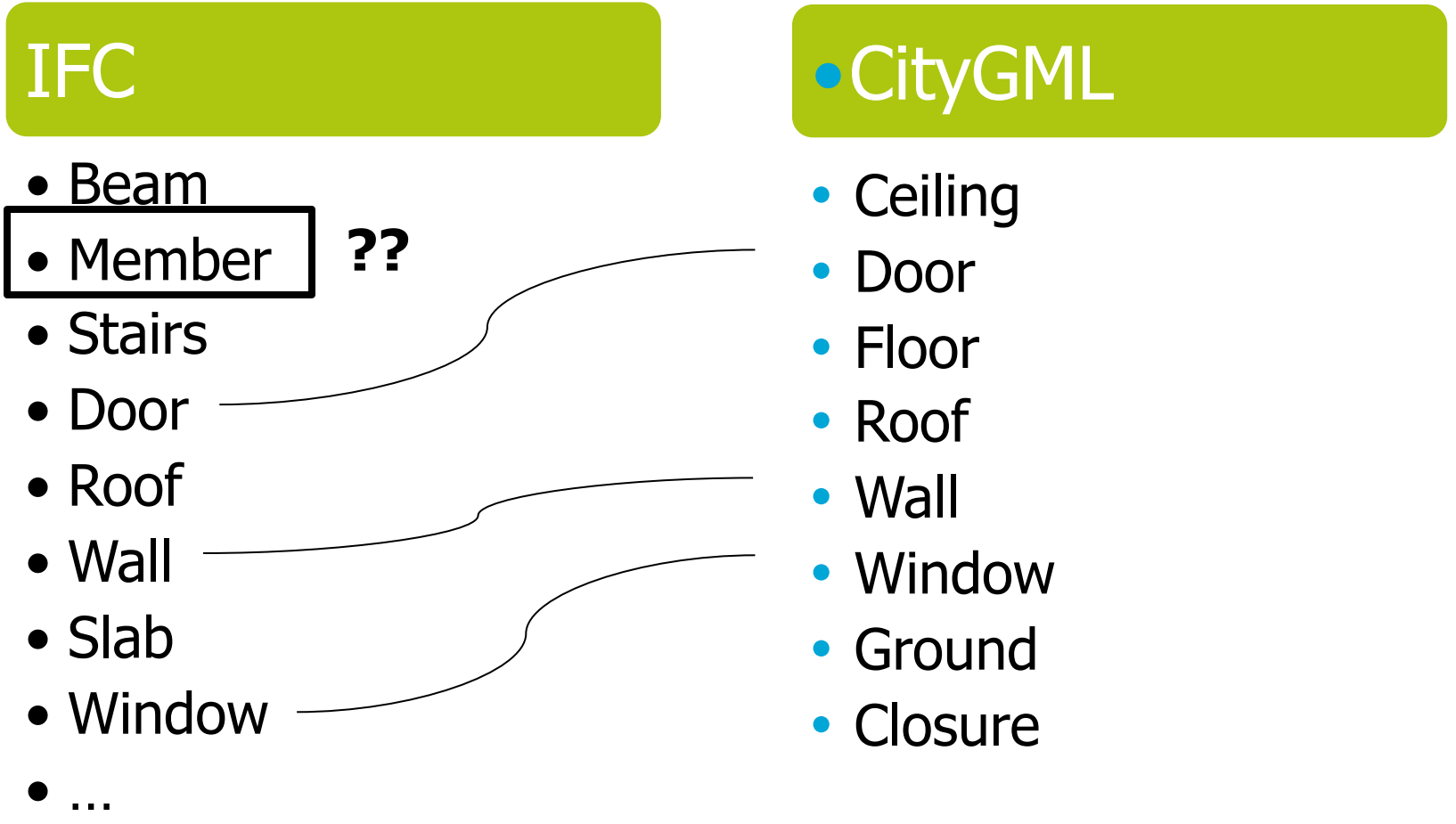
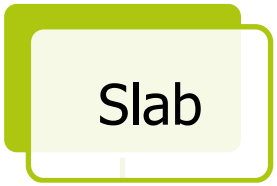


1 Semantic mapping

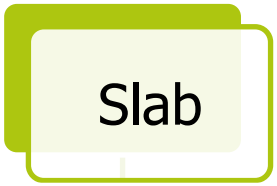
A combination of:



1 Semantic mapping

A combination of:

1. Type
   - IfcSlab
   - IfcMember
   - IfcRoof

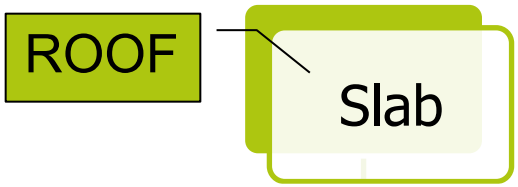


1 Semantic mapping

A combination of:

1. Type

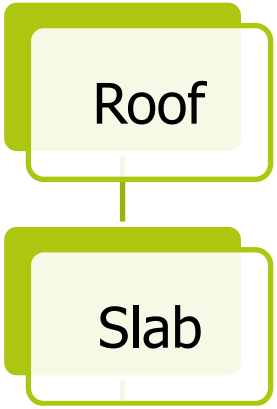
- FLOOR
- ROOF
- LANDING
- BASESLAB
- USERDEFINED
- NOTDEFINED



1 Semantic mapping

A combination of:

1. Type



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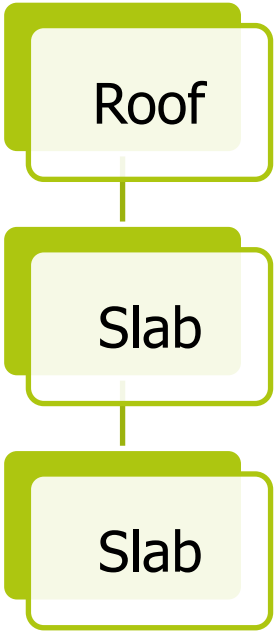
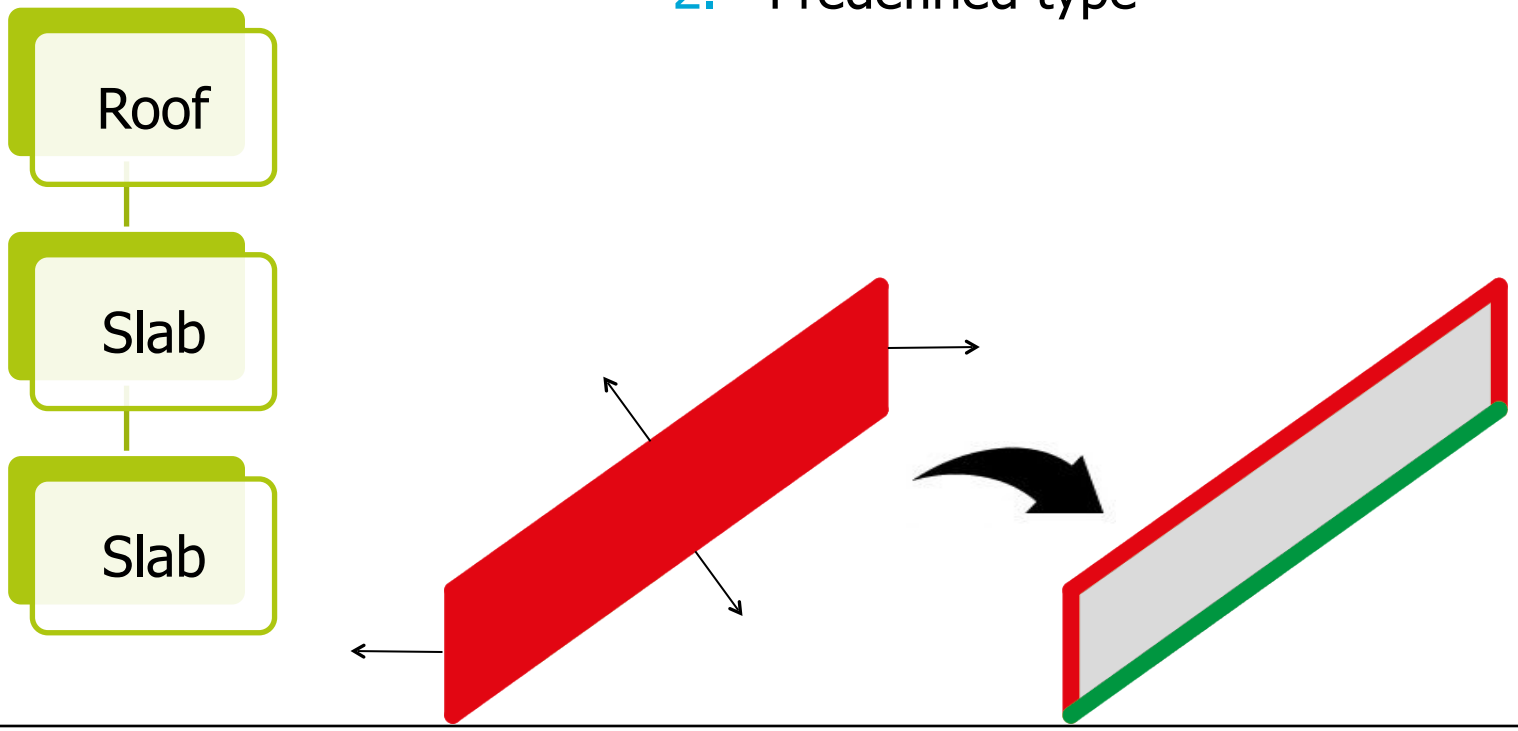


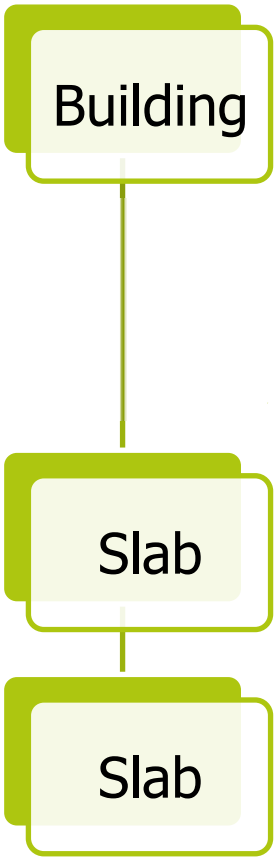
1 Semantic mapping

A combination of:

1. Type
2. Predefined type



1 Semantic mapping



A combination of:

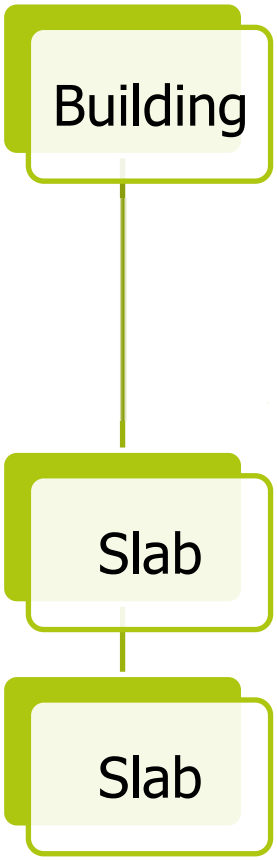
1. Type
2. Predefined type

Constraints:

The object has to be contained in a building

Must be a Space or a subtype of BuildingElement

1 Semantic mapping



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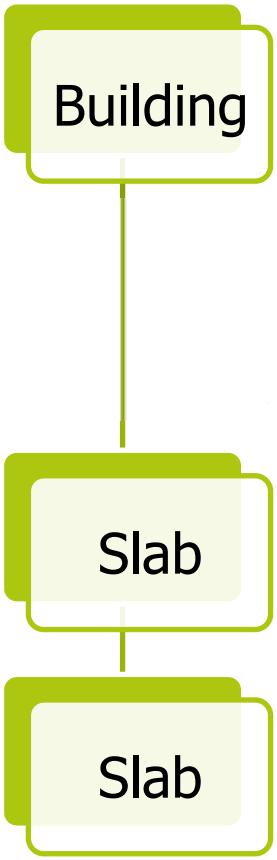


A combination of:

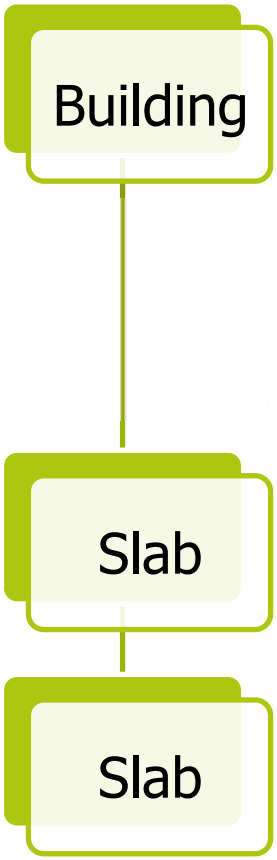
1. Type
2. Predefined type
3. Decomposed by

Constraints:

The object has to be contained in a building

Must be a Space or a subtype of BuildingElement

1 Semantic mapping



A combination of:

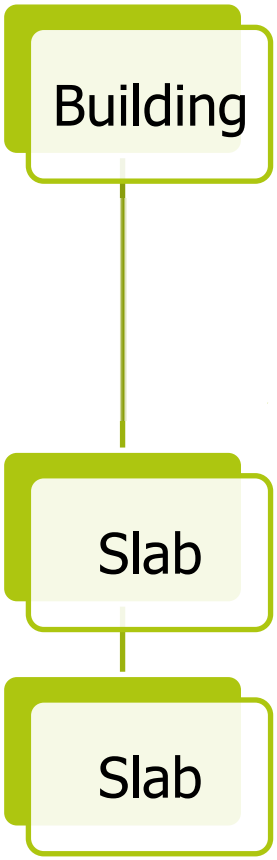
1. Type
2. Predefined type
3. Decomposed by

Constraints:

The object has to be contained in a building

Must be a Space or a subtype of BuildingElement

1 Semantic mapping



A combination of:

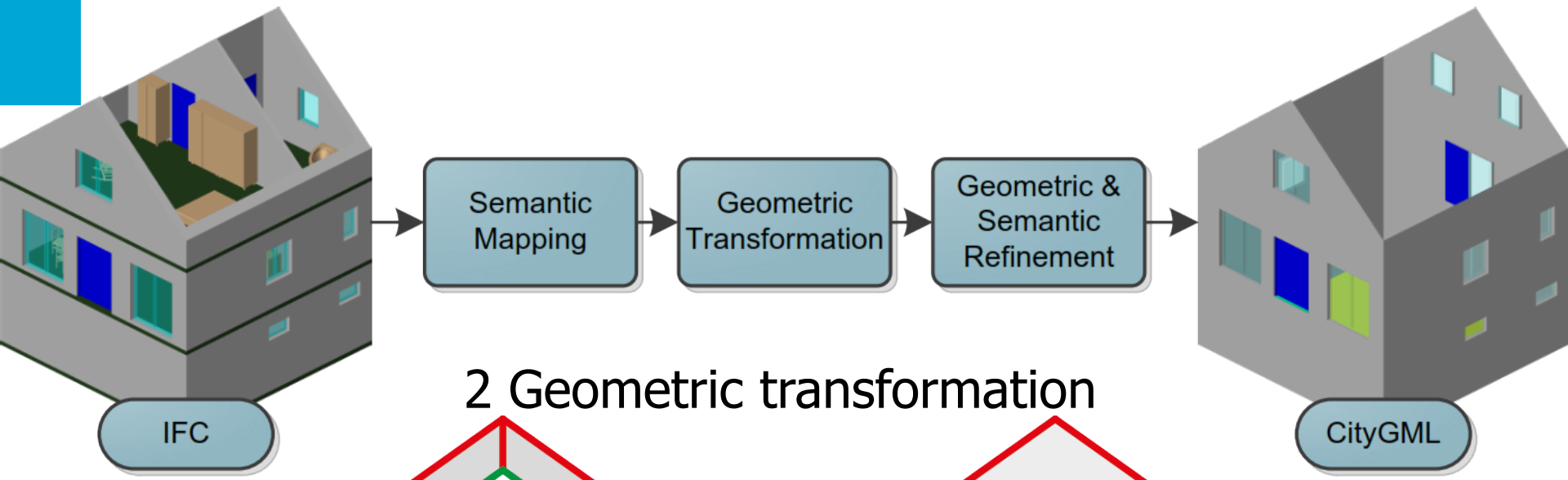
1. Type
2. Predefined type
3. Decomposed by
4. Surface normal

Constraints:

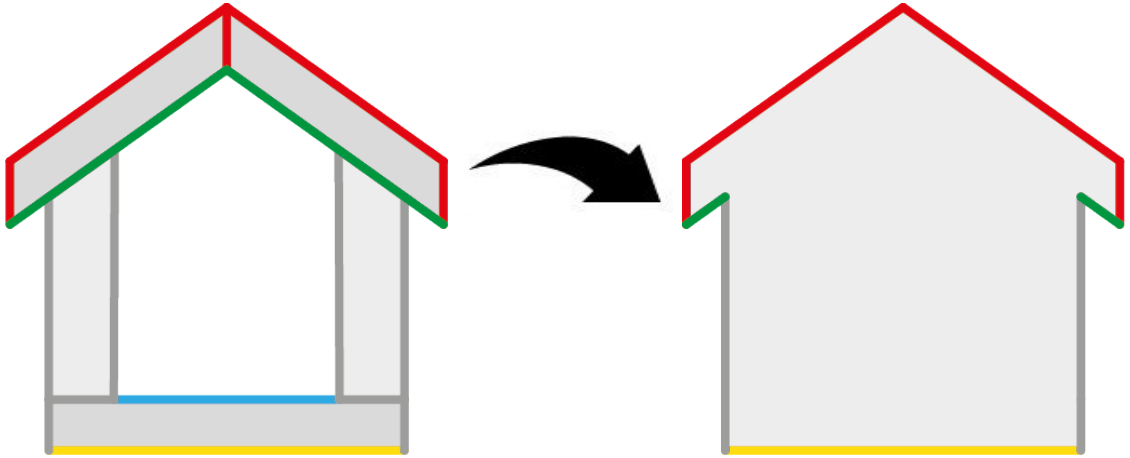
The object has to be contained in a building

Must be a Space or a subtype of BuildingElement

Methodology for the Conversion



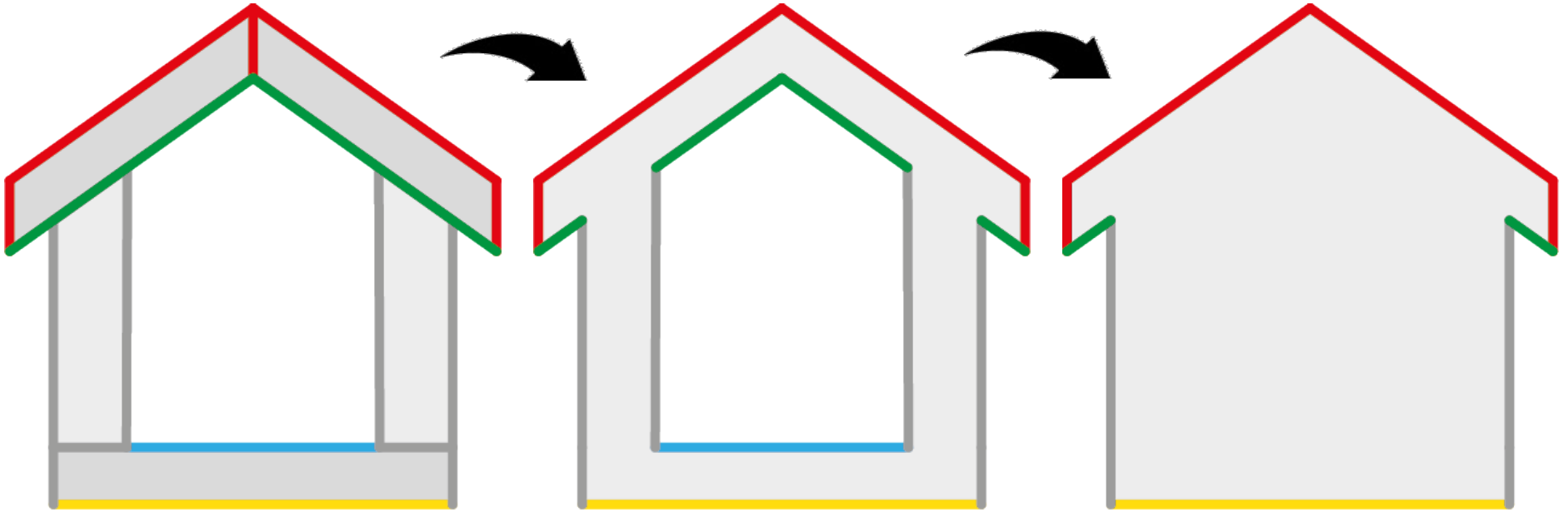
2 Geometric transformation



2 Geometric transformation

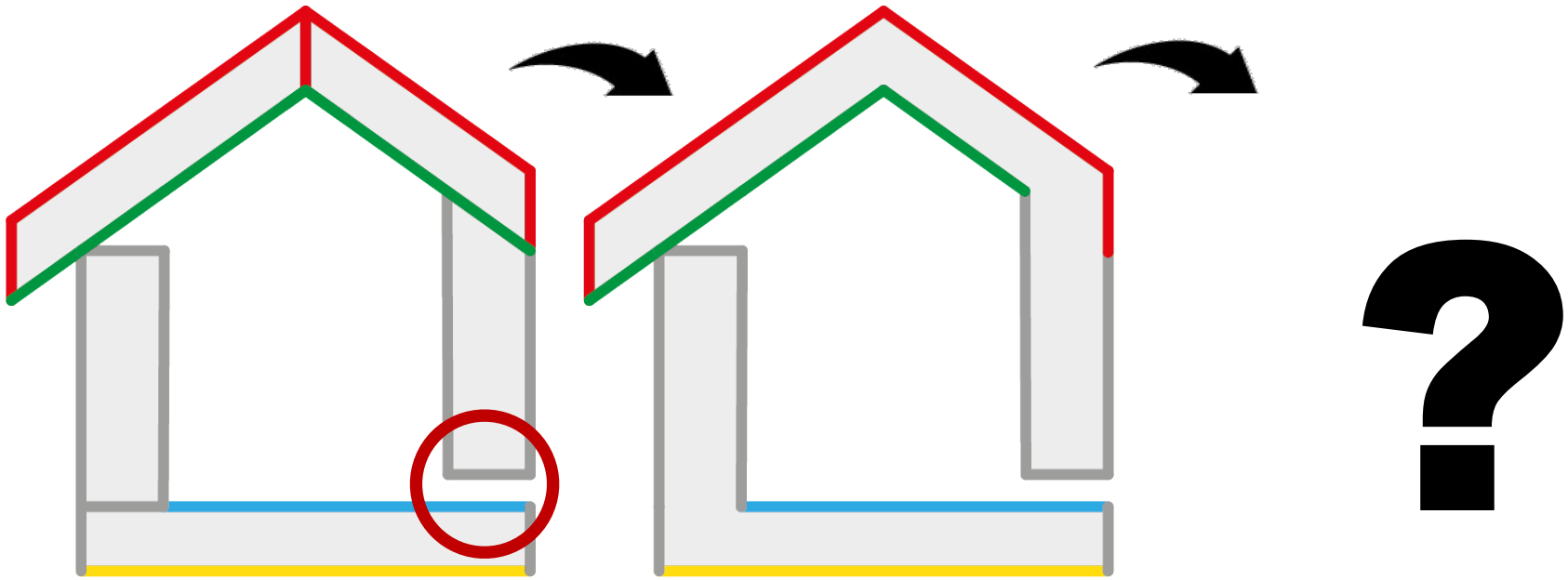
1. All IFC geometries are connected using the Boolean union operation

2. Interior geometries are removed



2 Geometric transformation

Real buildings are not watertight !



2 Geometric transformation

Concepts for extracting the exterior shell

Concept	Total Score	Feasibility / Complexity	Predictability	Number of Artefacts	Shape of Artefacts	Amount of Detail	Transferability of Semantics
Morphological closing	28	5	5	4	5	5	4
Heuristic carving	26	4	4	4	4	5	5
Patching	26	3	5	4	4	5	5
Vertex normal closing	22	4	3	3	3	5	4
Procedural modeling	20	2	1	3	4	5	5
Best matching model	18	2	1	5	5	1	4
Shrink wrapping	16	2	1	3	3	4	3
Scaling	16	1	3	1	1	5	5

2 Geometric transformation

Concepts for extracting the exterior shell

- Generated
- Implemented
- Evaluated

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Scaling	16	1	3	1	1	5	5

2 Geometric transformation

Concepts for extracting the exterior shell

- Generated
- Implemented
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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

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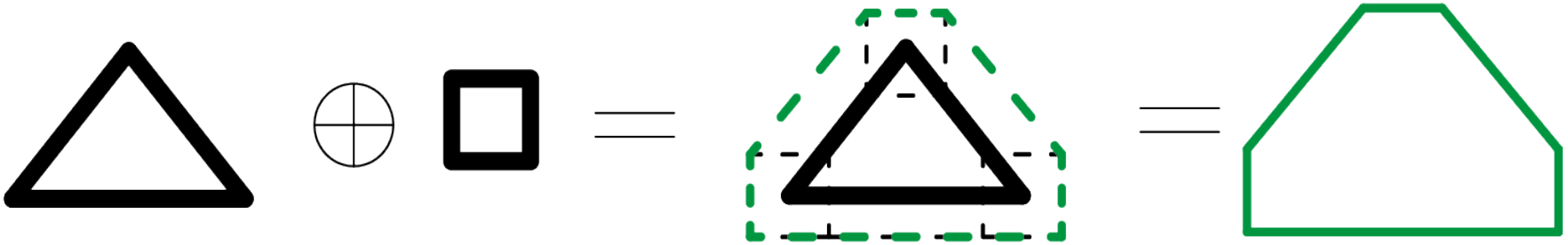
Dilation:



2 Morphological closing

Morphological closing = dilation followed by erosion

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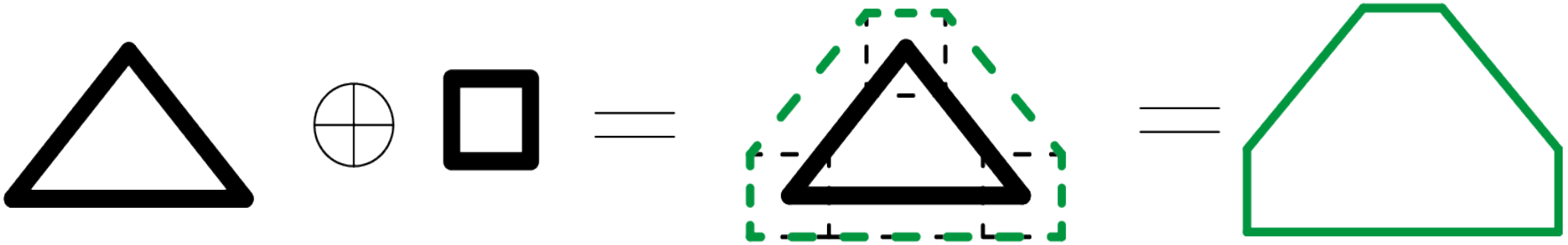
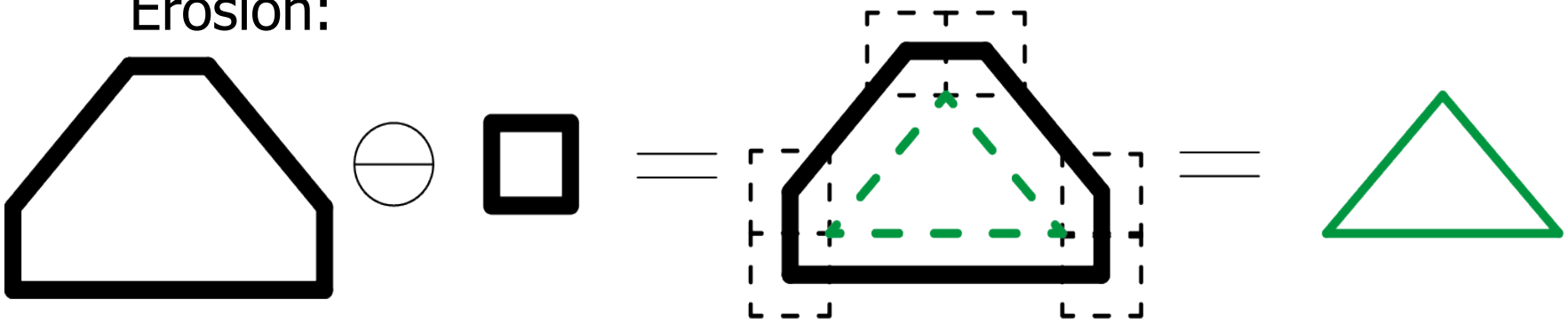
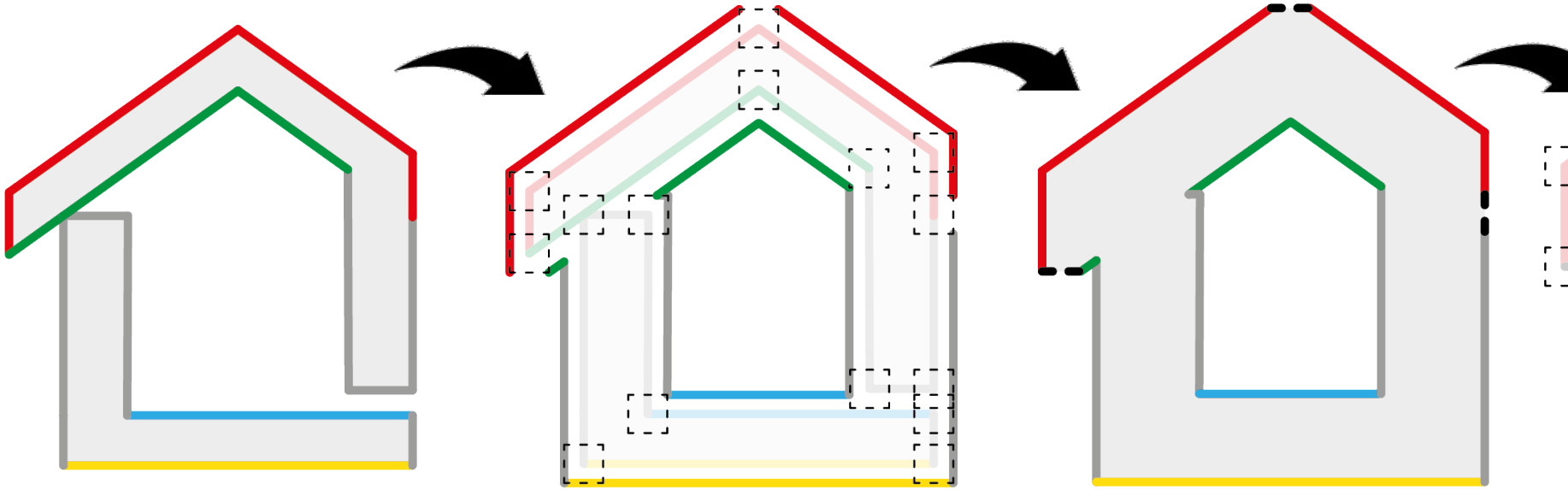


Erosion:

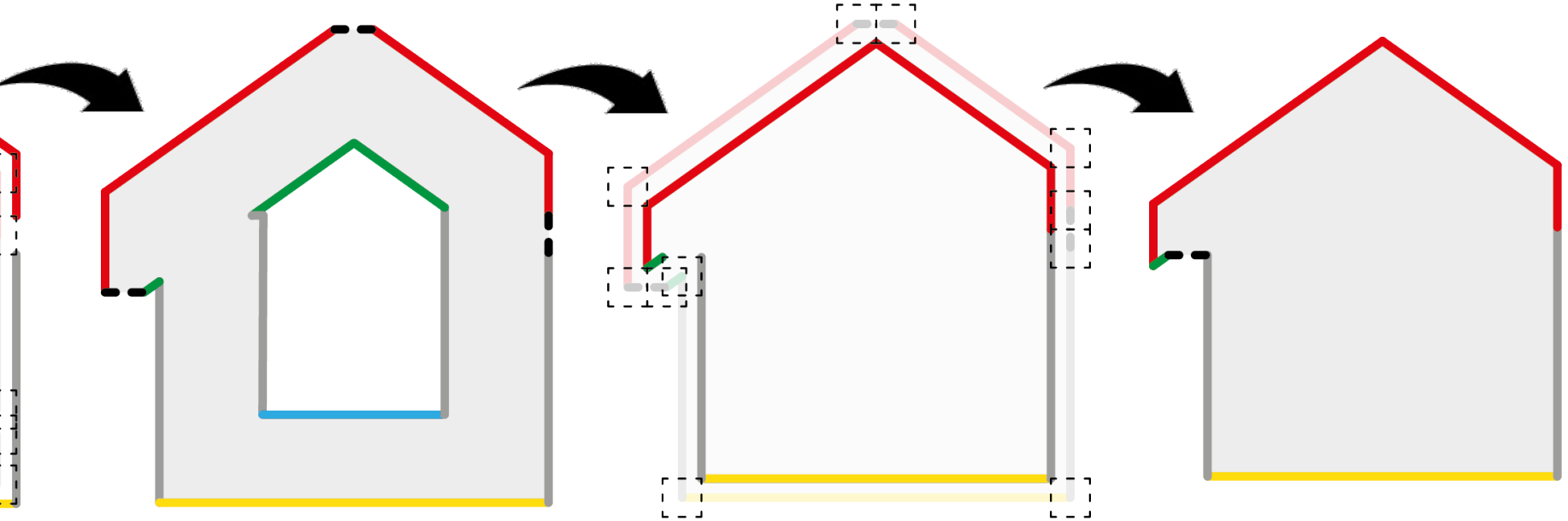


2 Morphological closing



2 Morphological closing

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



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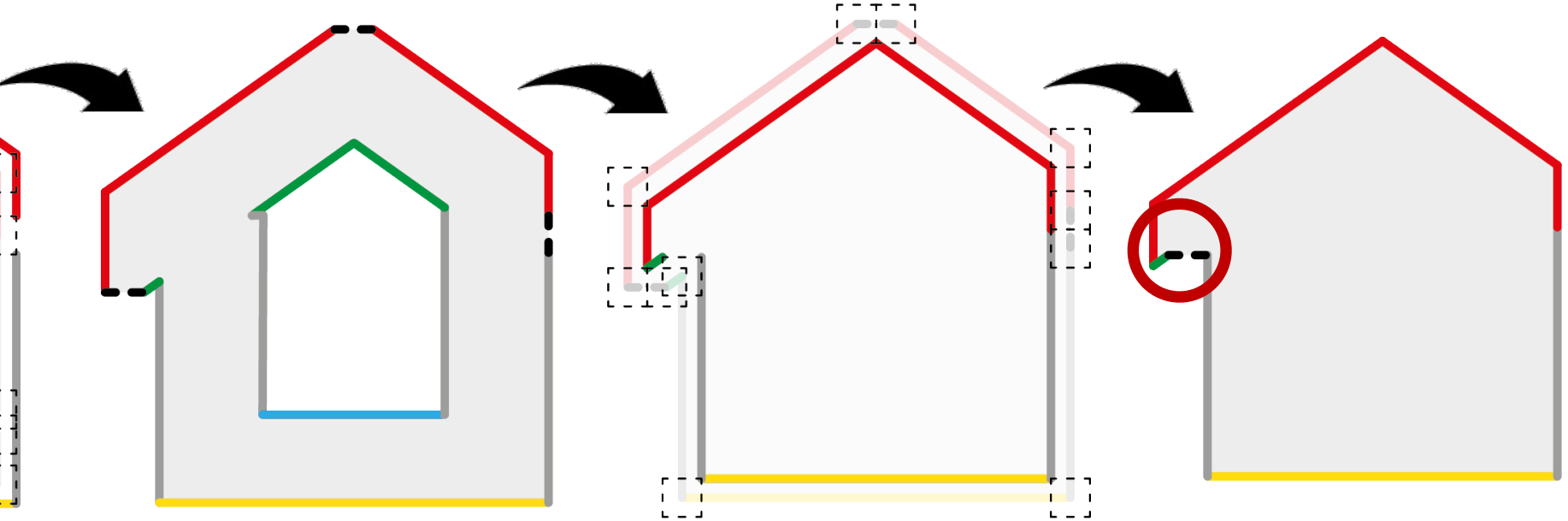

2 BuildingInstallations

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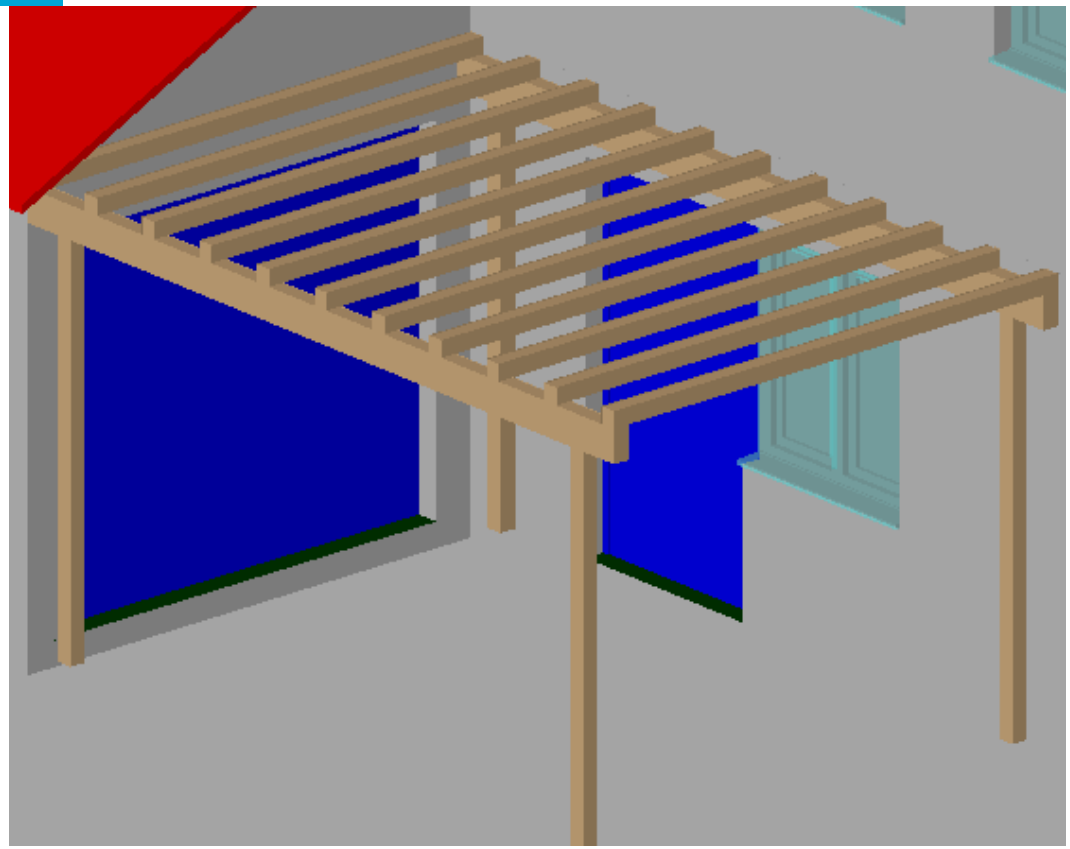
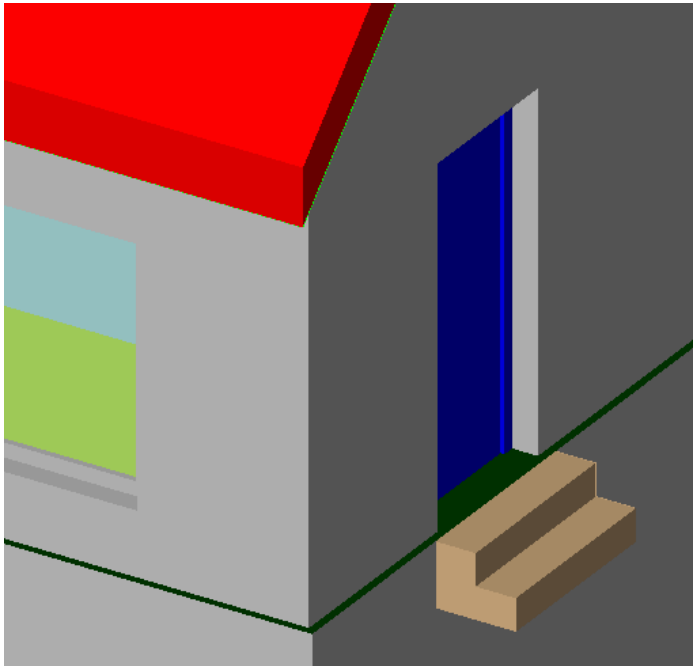




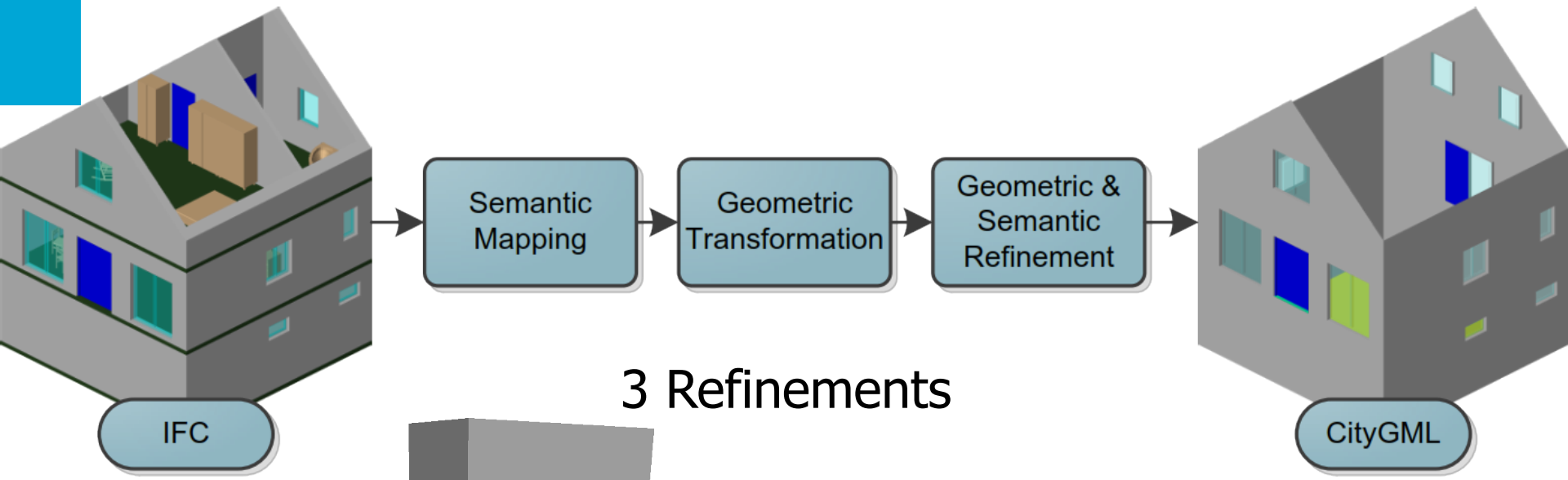
2 BuildingInstallations

2 BuildingInstallations

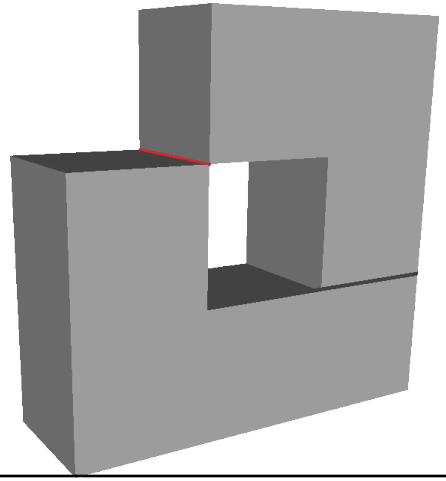
- BuildingInstallations are separate objects
- Objects must not overlap each other

1. BuildingInstallations are unioned
2. The building solid is subtracted

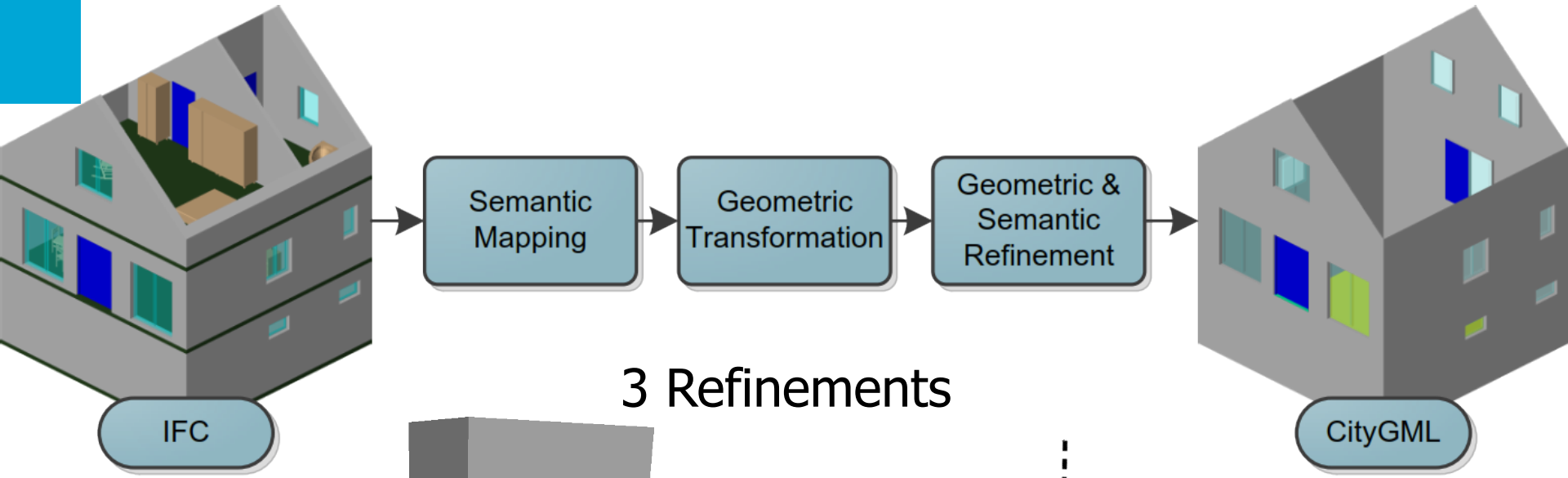
Methodology for the Conversion



3 Refinements



Methodology for the Conversion



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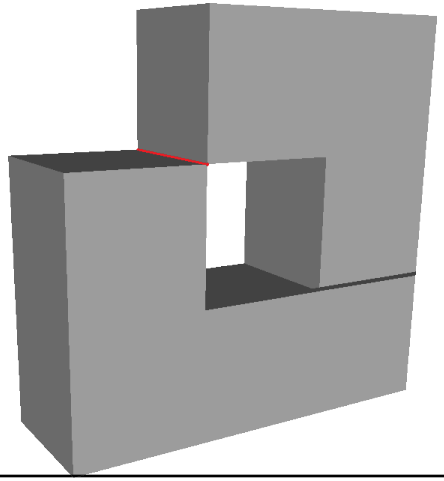

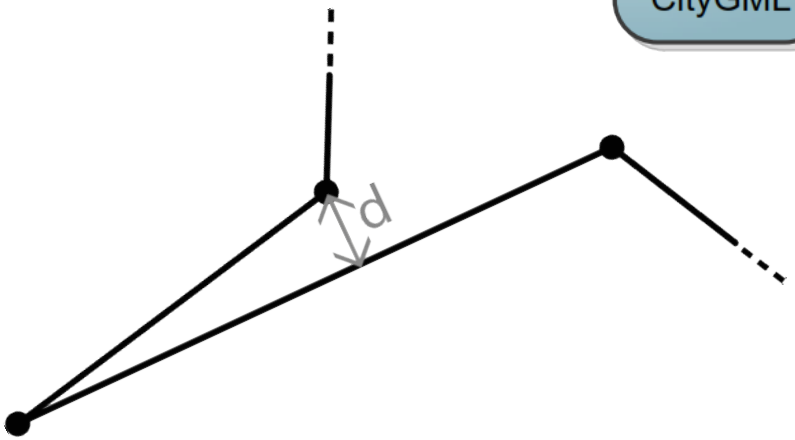

3 Refinements - geometric

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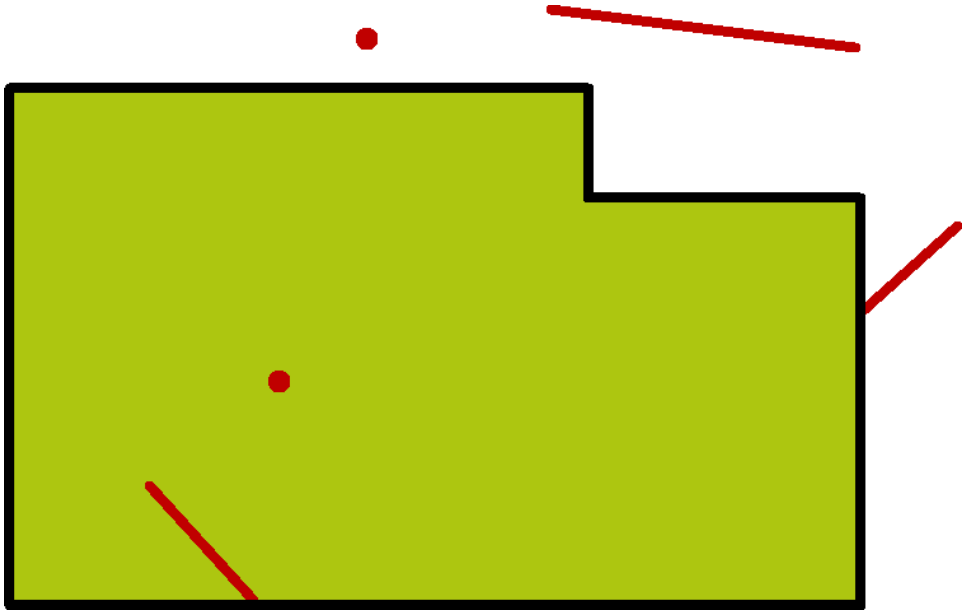
- The geometry is regularized



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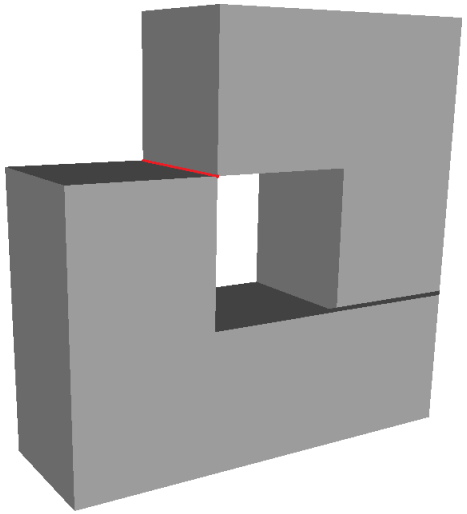
- Solid geometry is made 2-manifold



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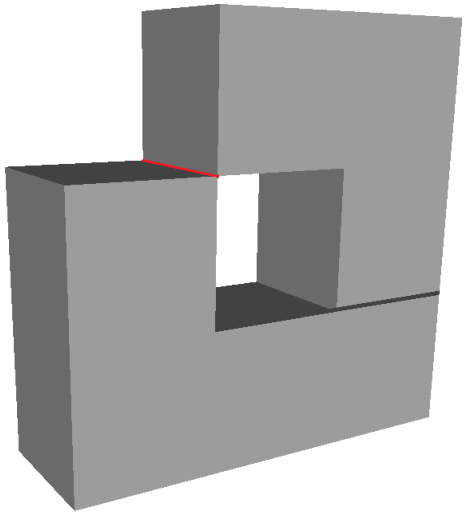

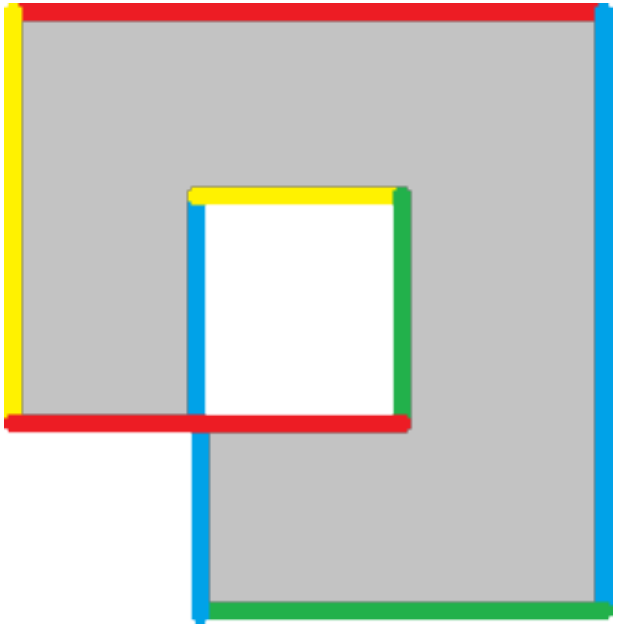

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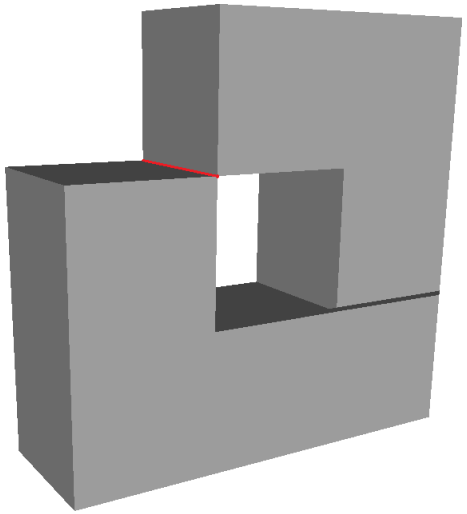

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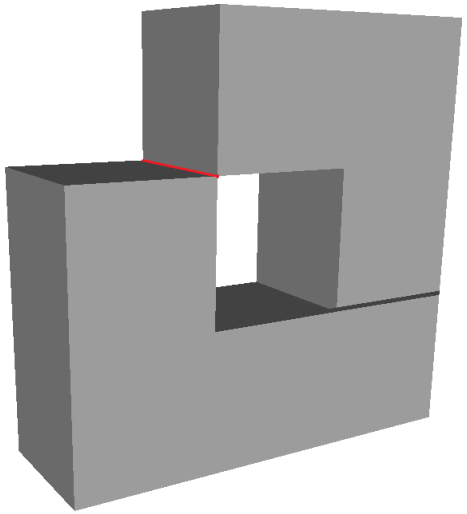
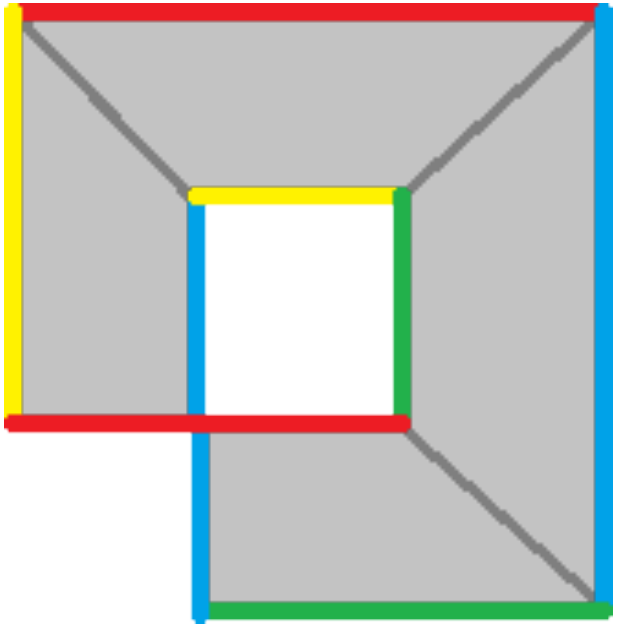
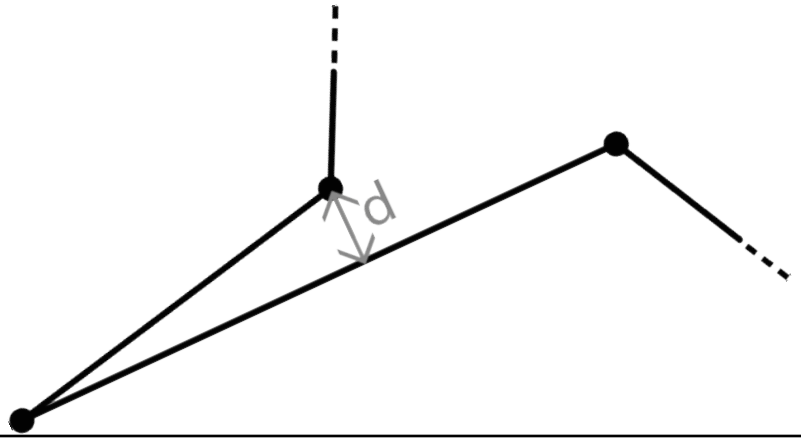
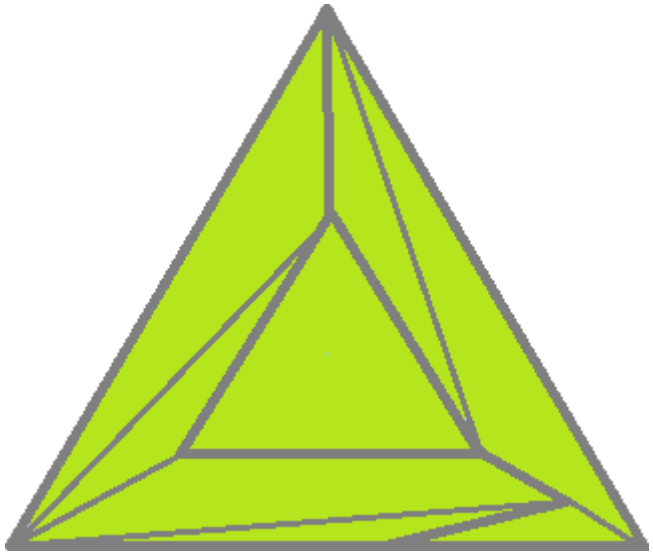




3 Refinements - geometric

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





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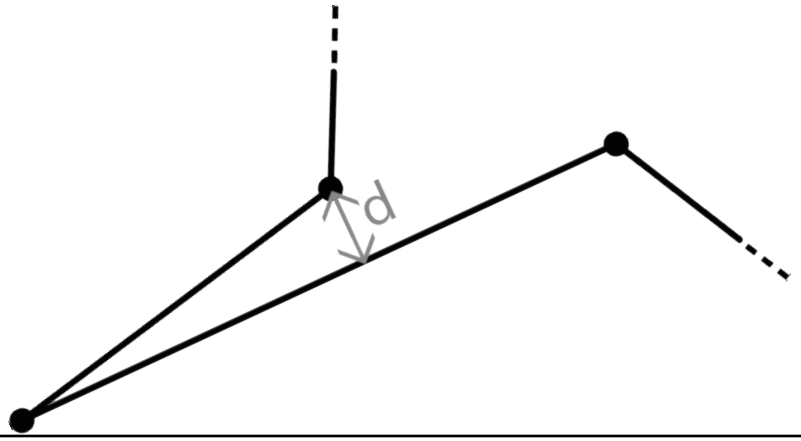
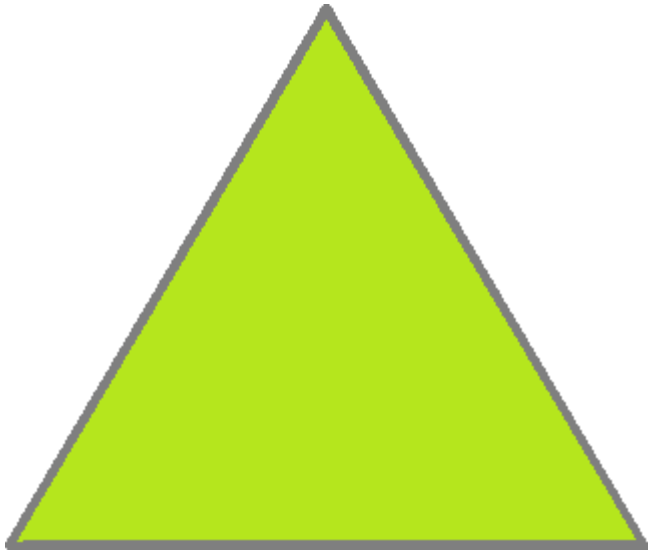
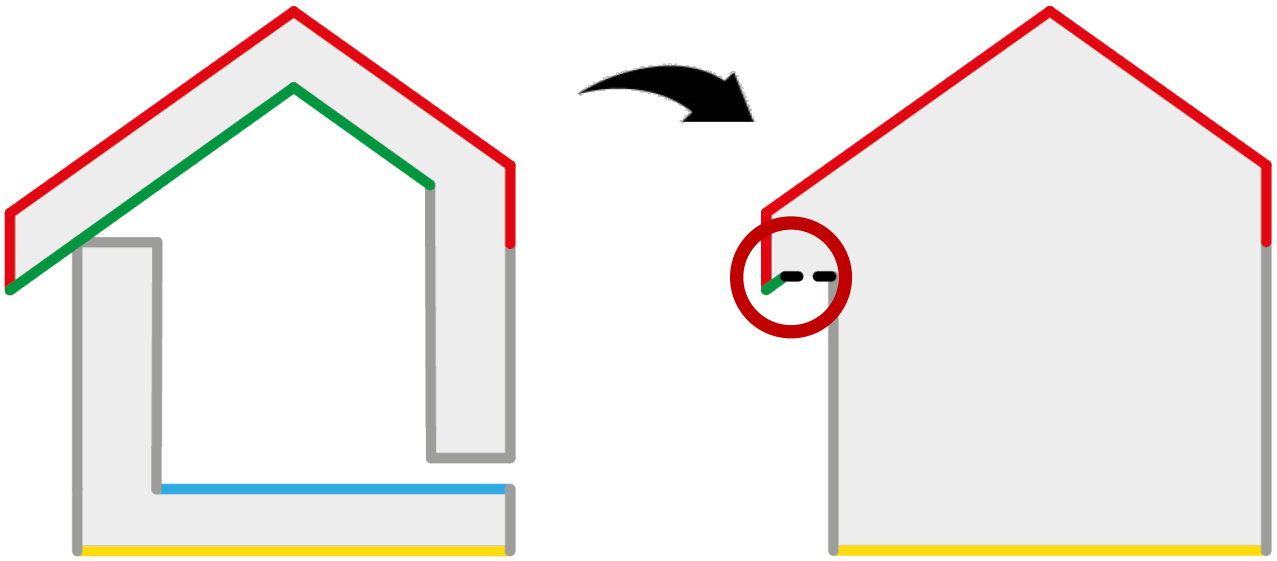




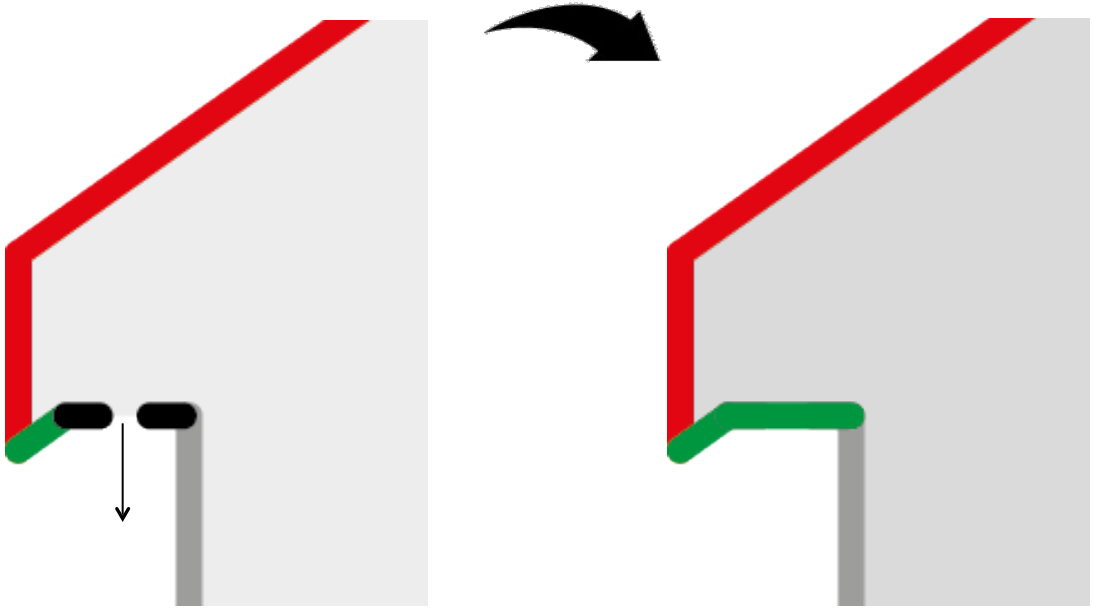
3 Refinements - semantic

- Faces without semantics are created during closing



3 Refinements - semantic

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



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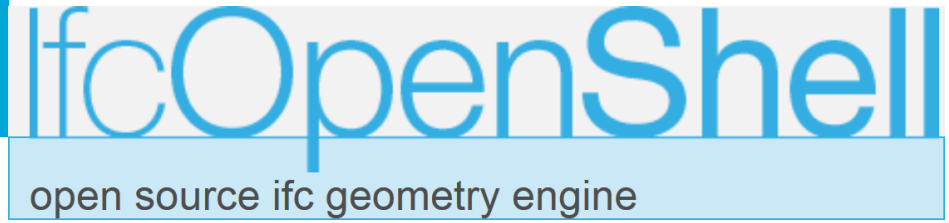
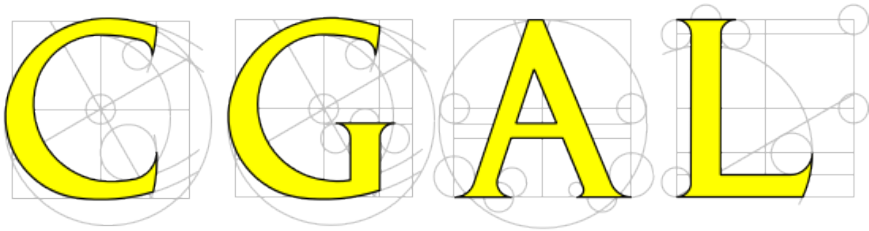
Conversion complete!

Implementation





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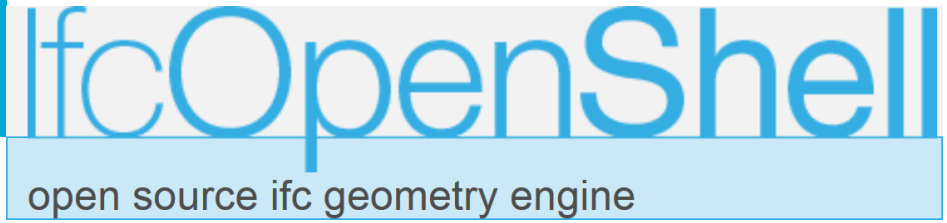
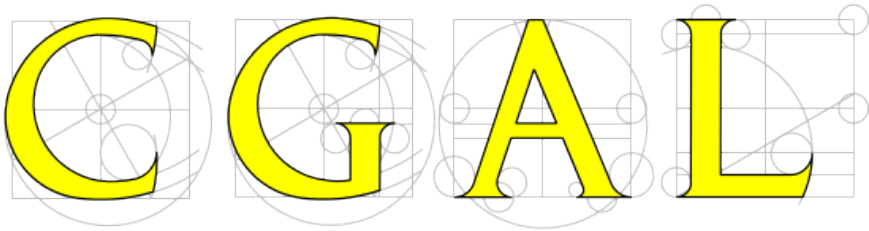
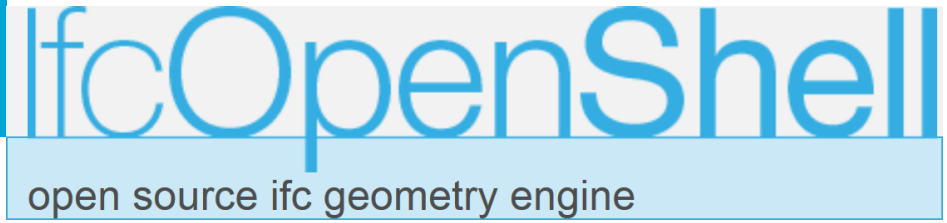
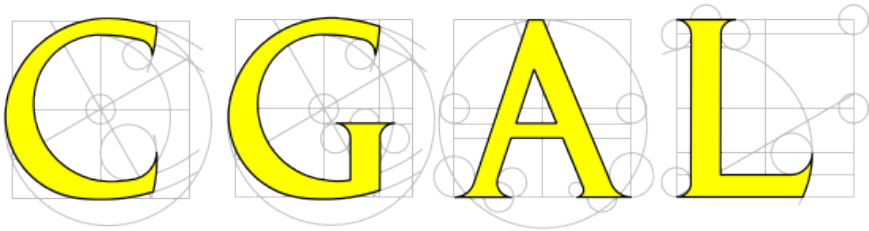




- Nef polyhedra are used for Boolean operations

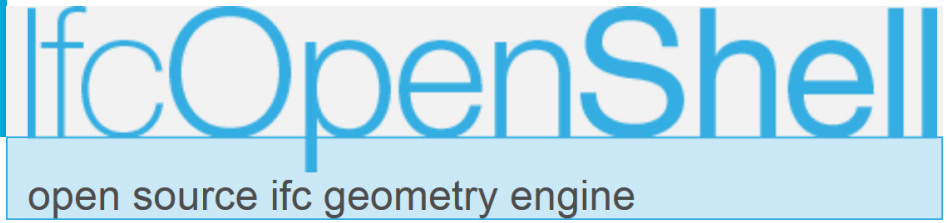
Implementation

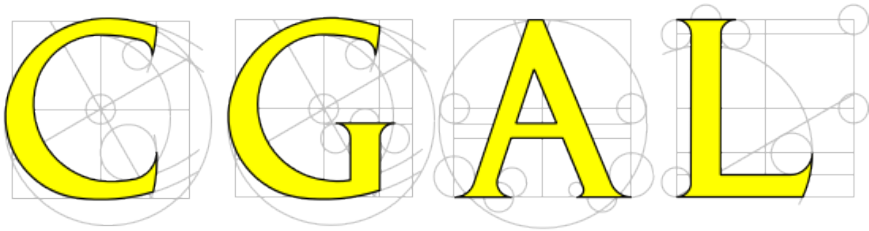




- Nef polyhedra are used for Boolean operations
- Nef polyhedra in CGAL do not support semantic faces

Implementation



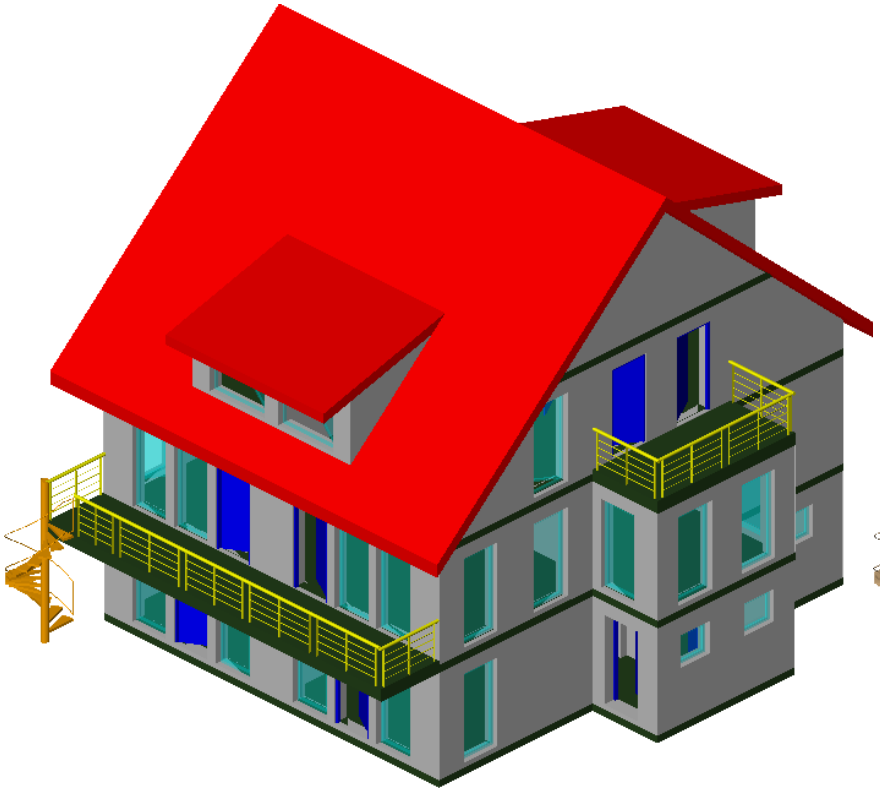


- Nef polyhedra are used for Boolean operations
- Nef polyhedra in CGAL do not support semantic faces
- Semantics are reattached after the geometric transformation

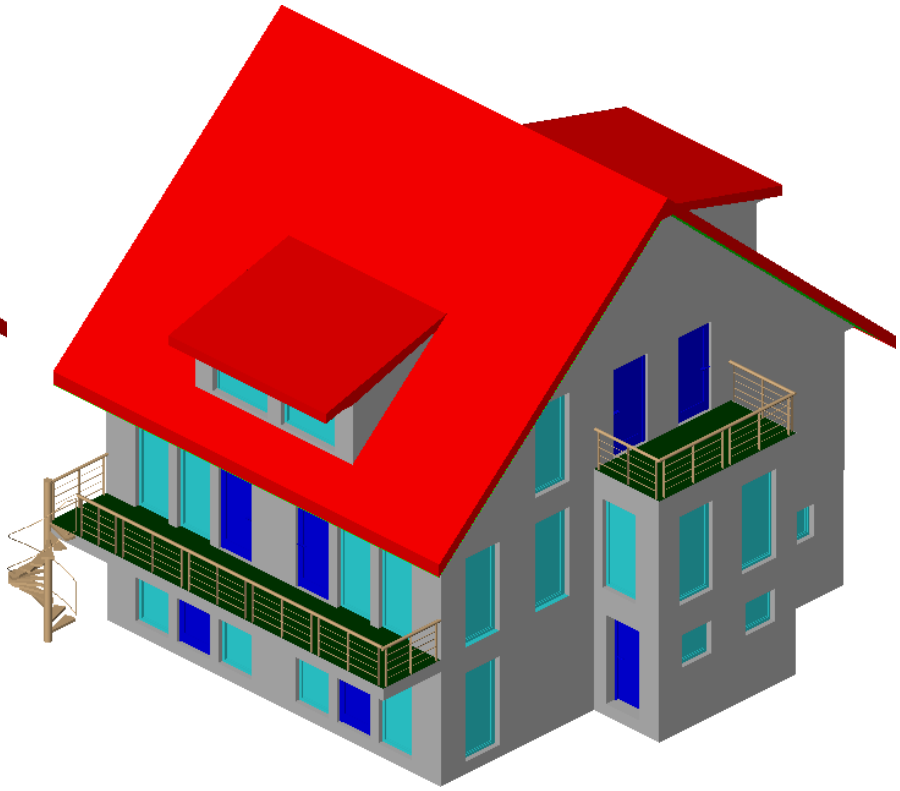
Structure

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

Experimental results

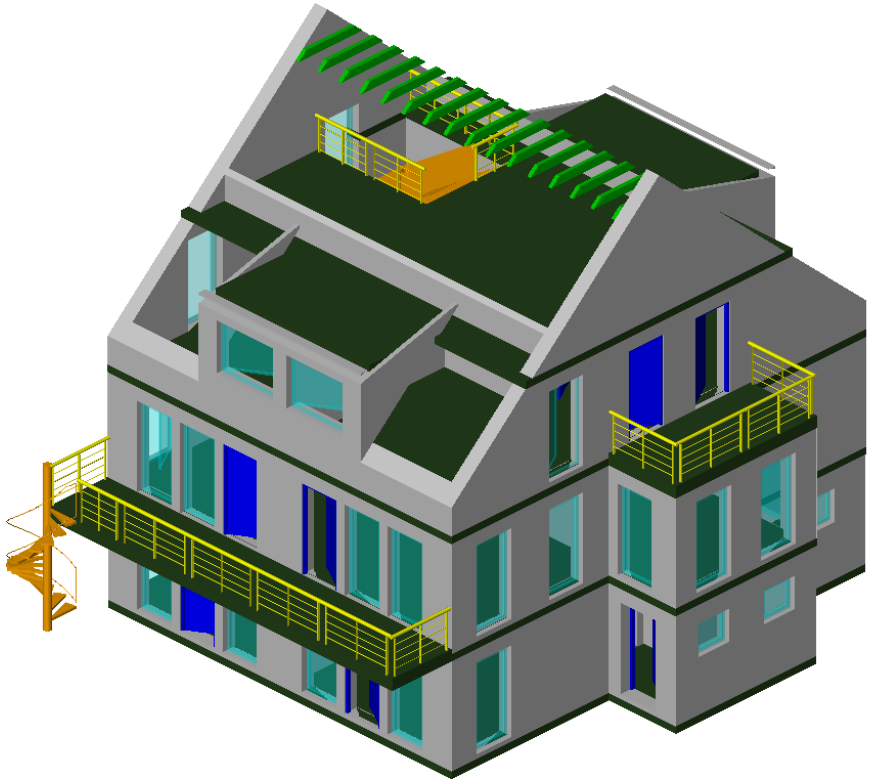


IFC



CityGML

Experimental results – no roof



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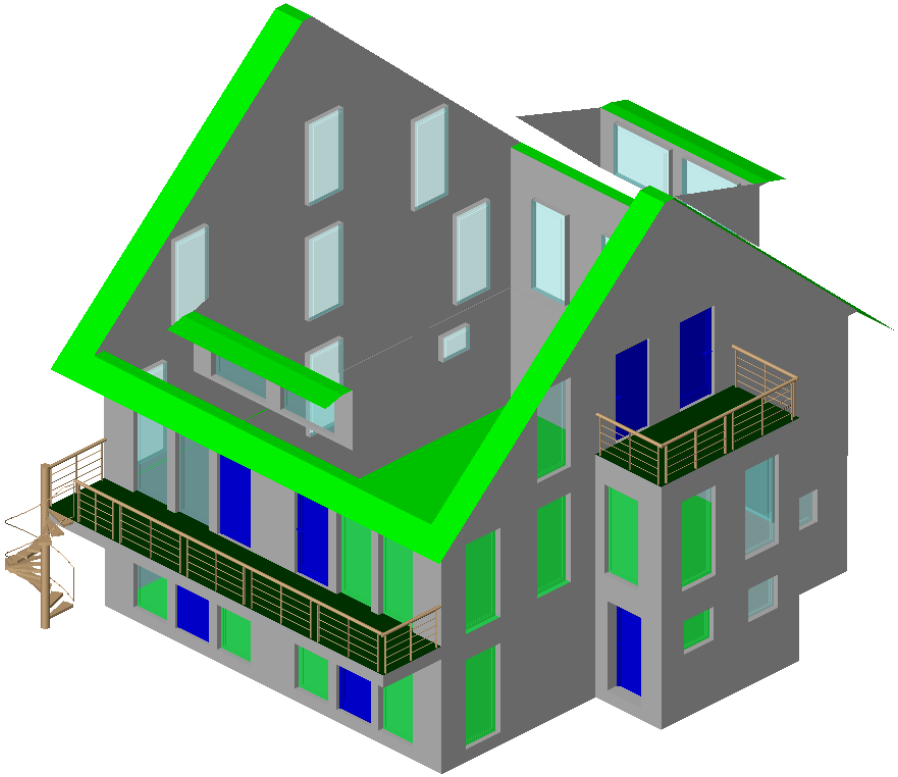
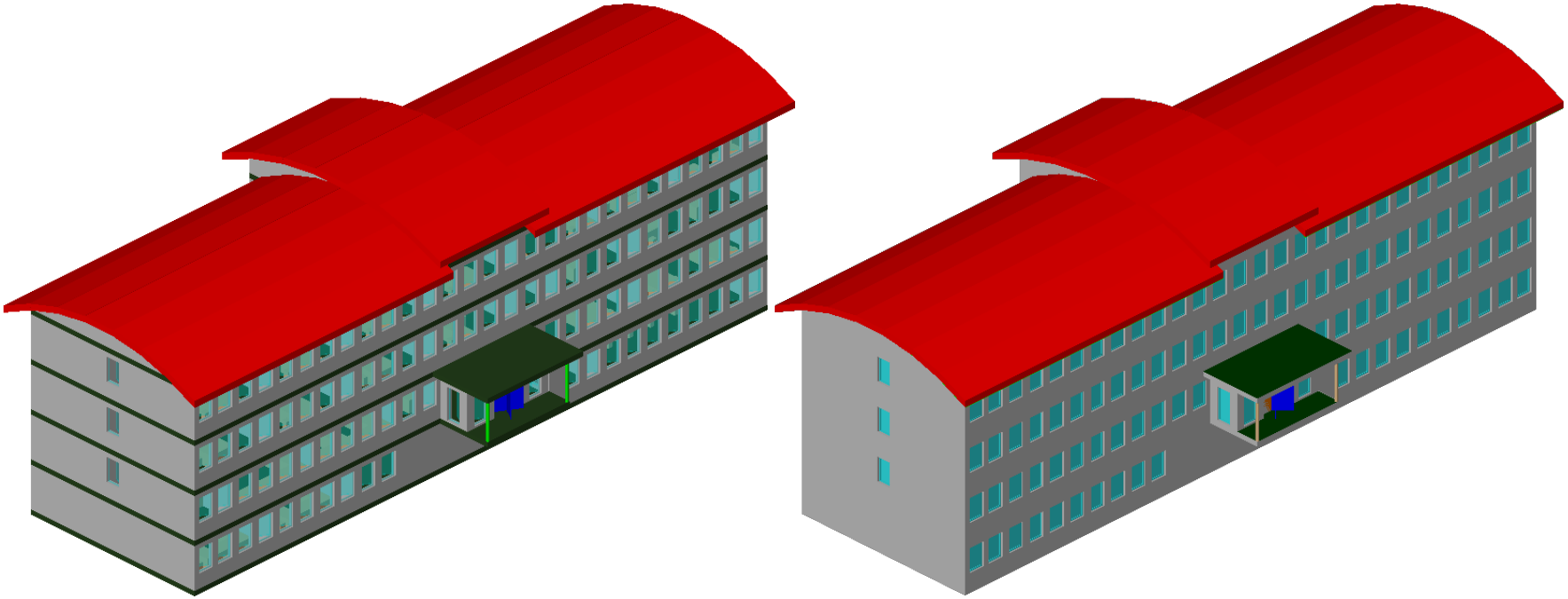


CityGML

Experimental results



IFC

CityGML

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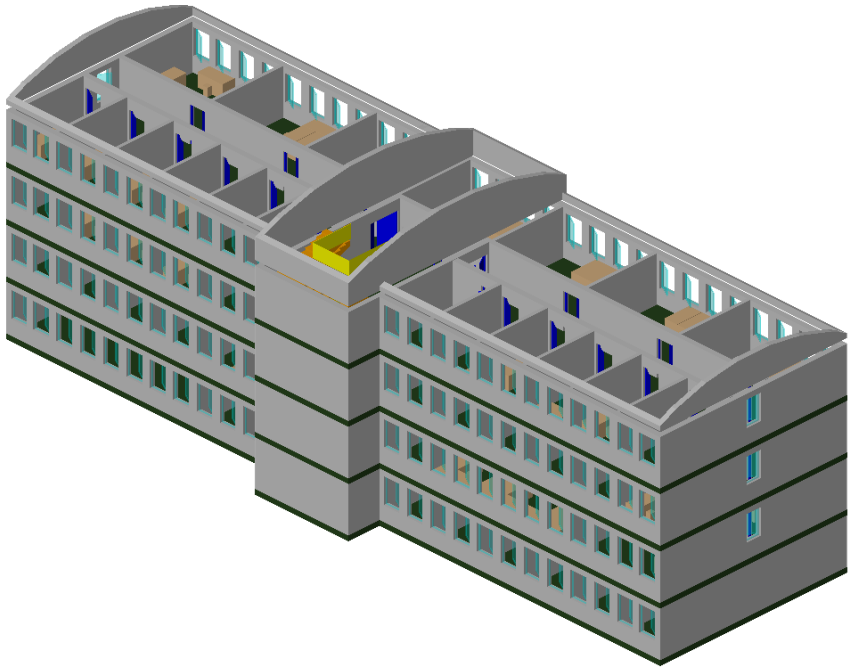
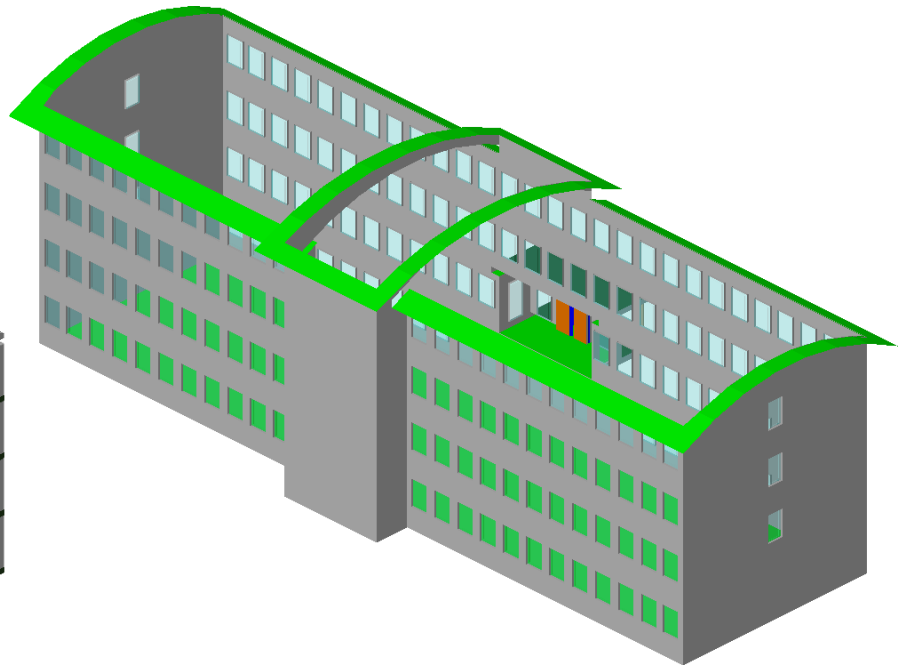
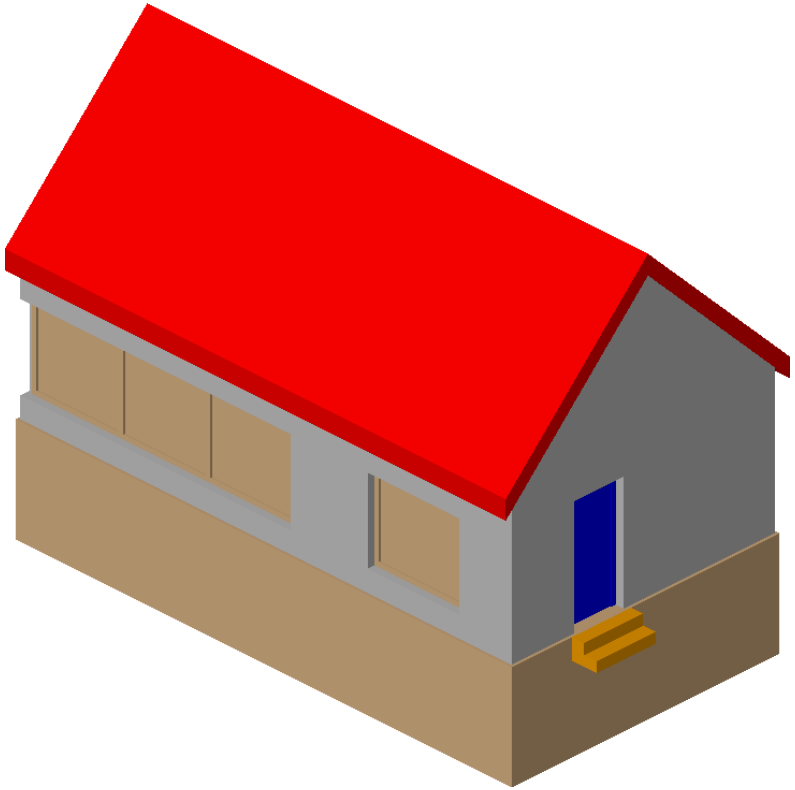


IFC



CityGML

Experimental results



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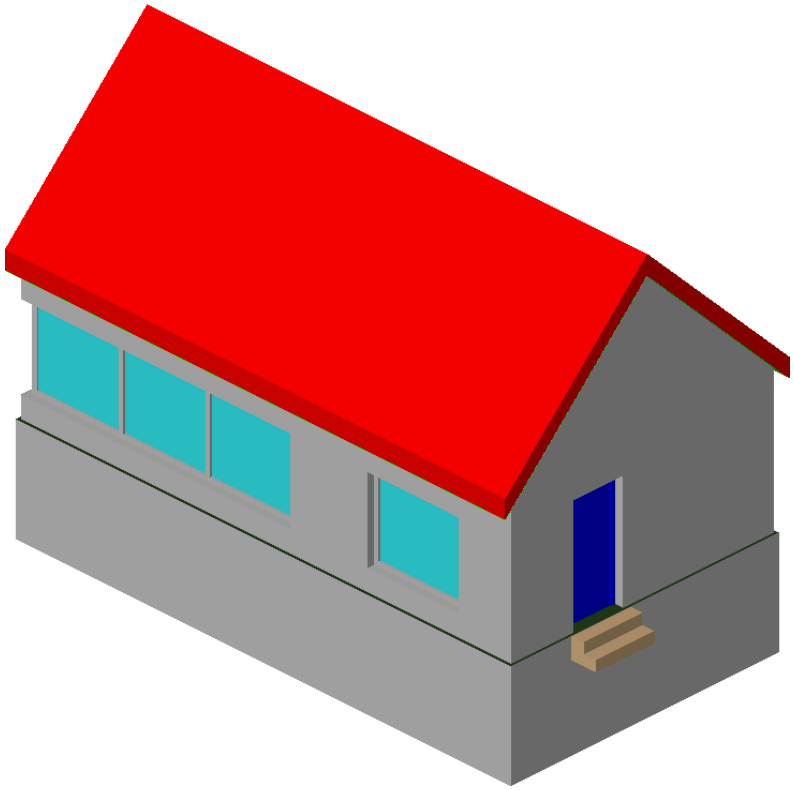

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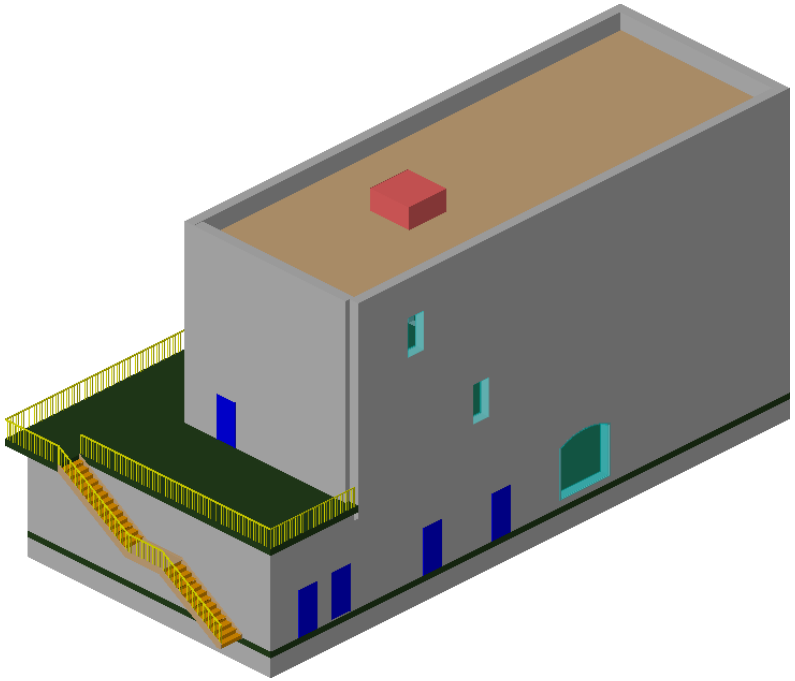

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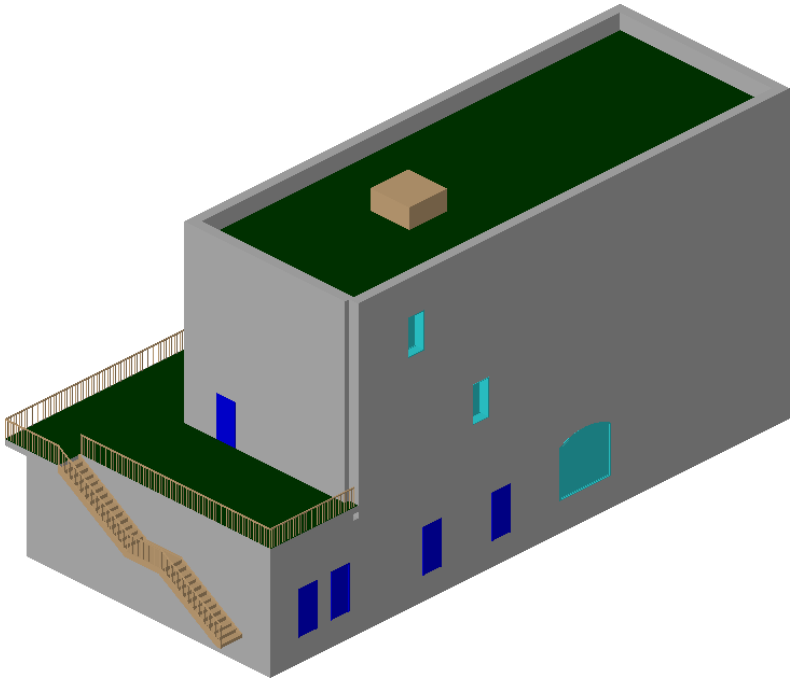

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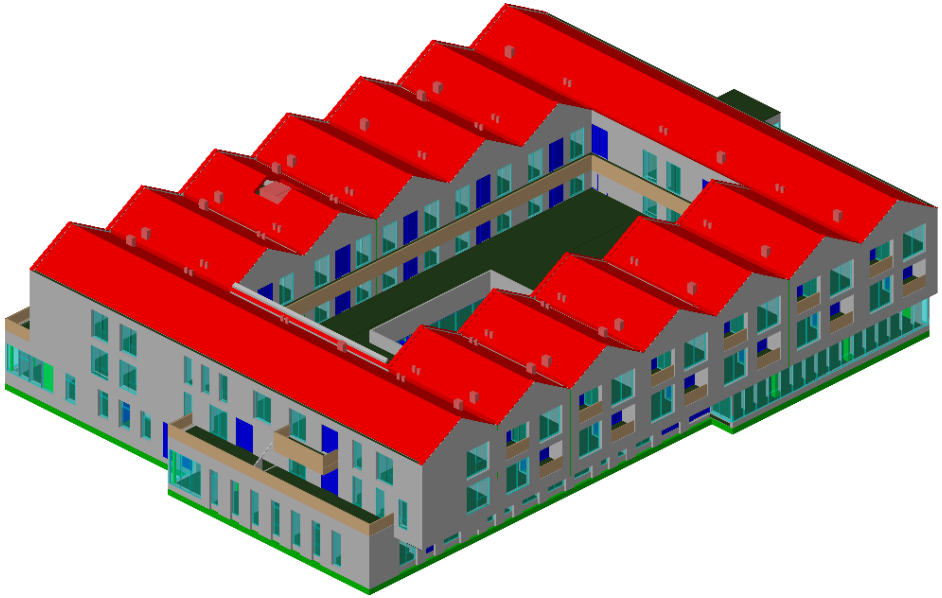

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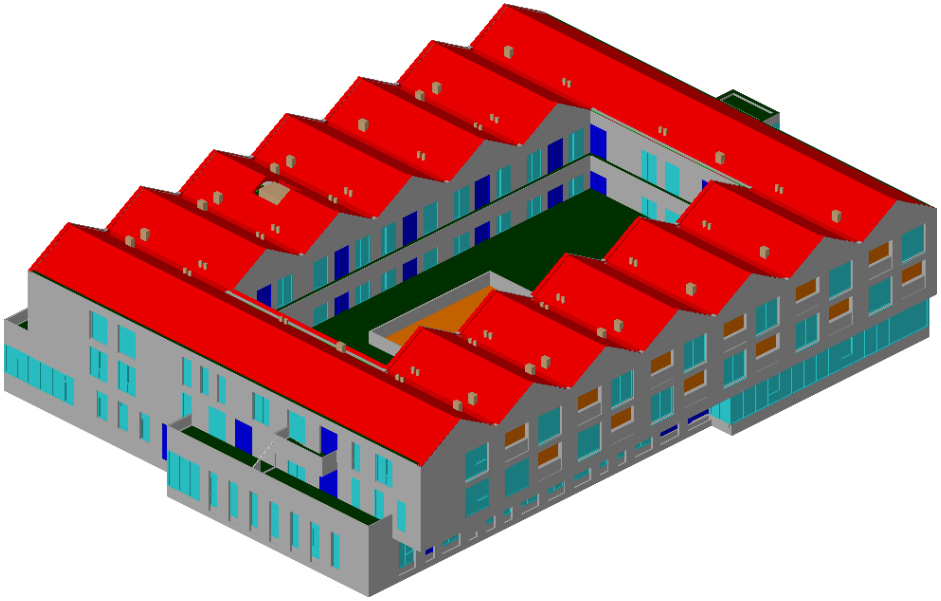

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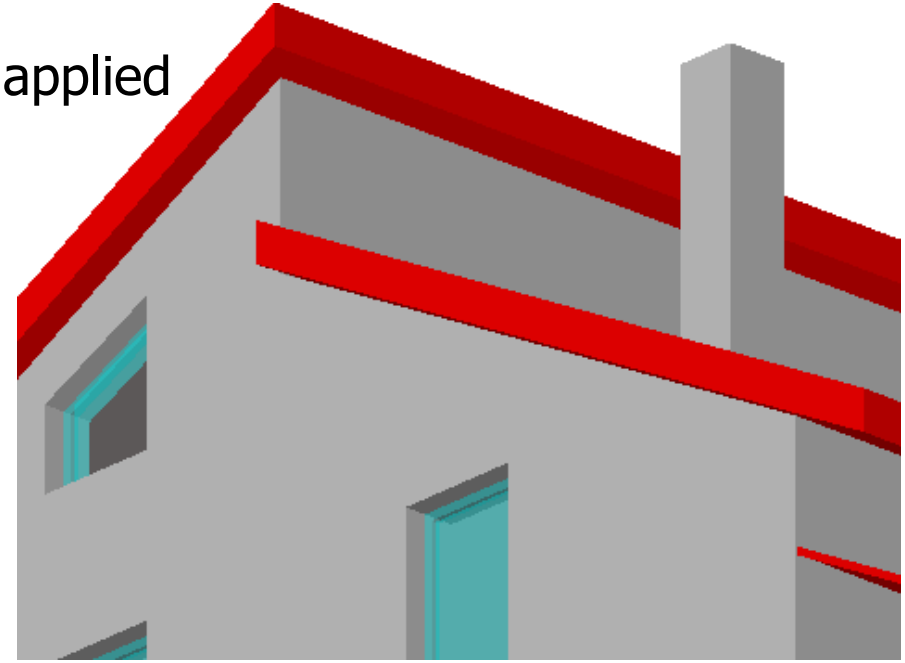

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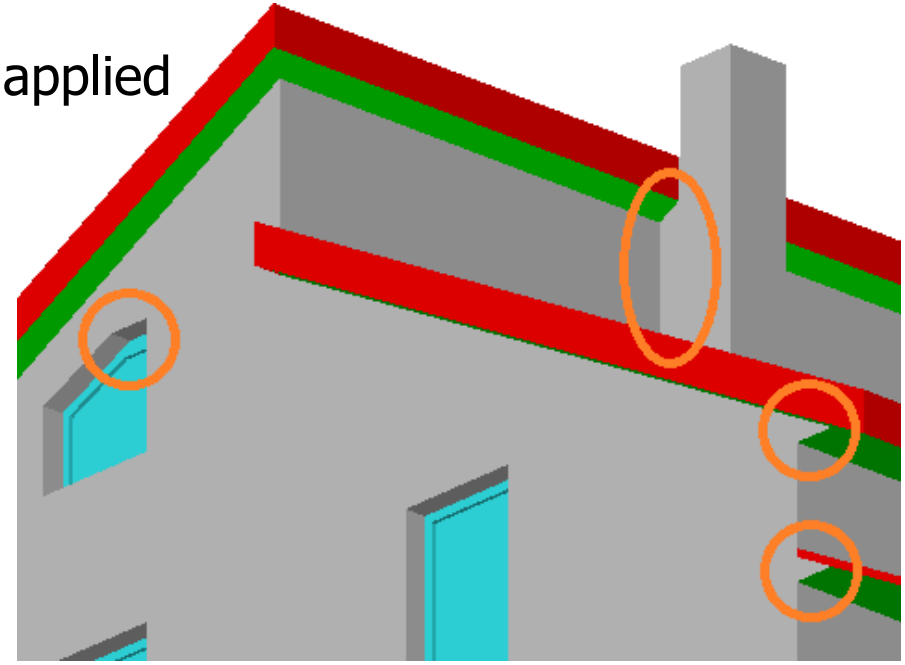

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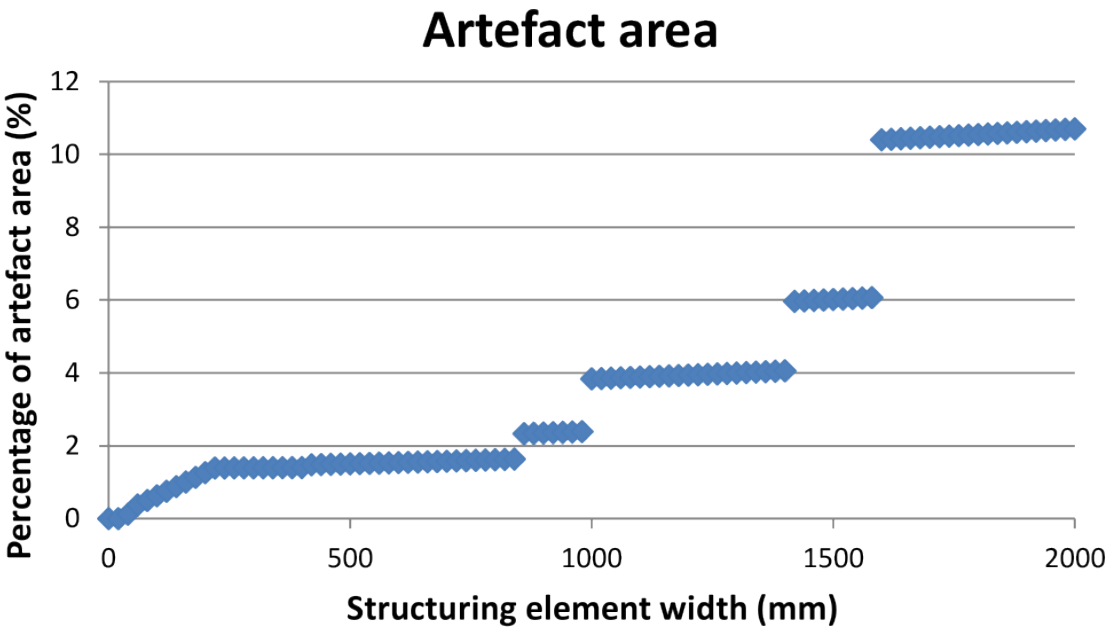

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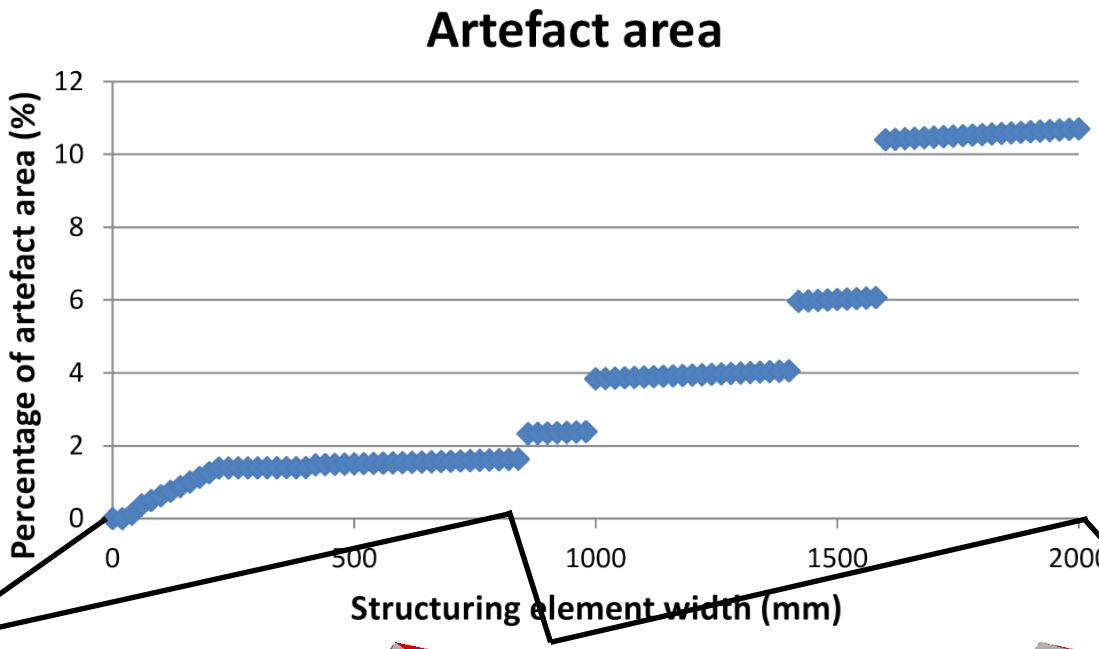

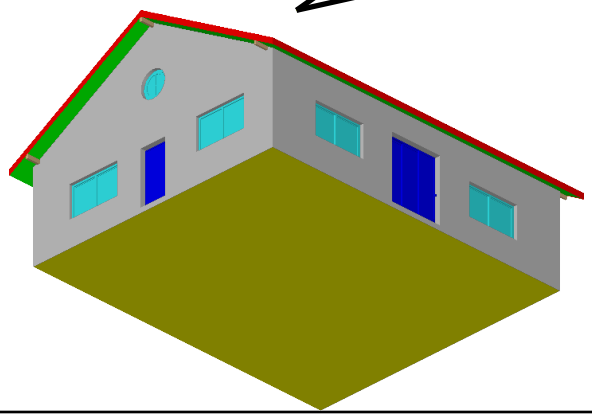

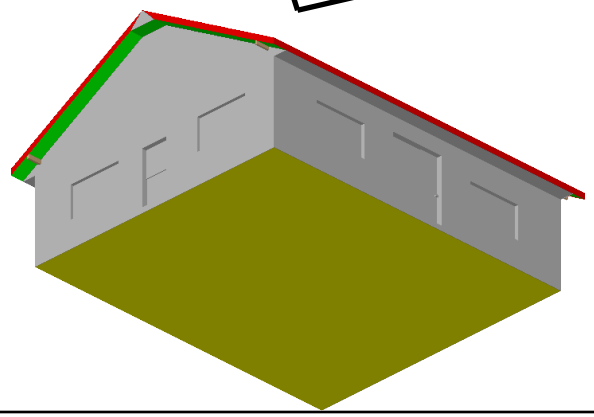

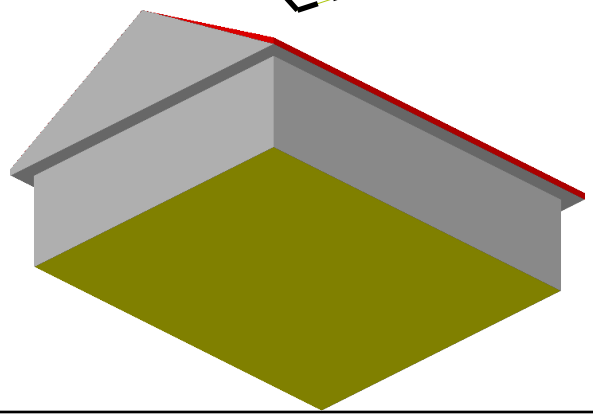

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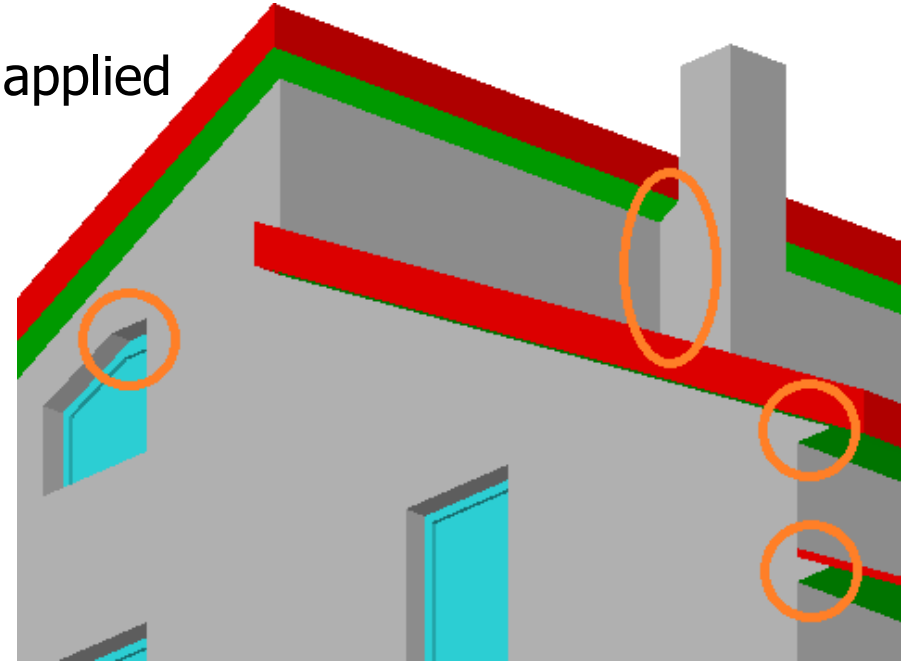

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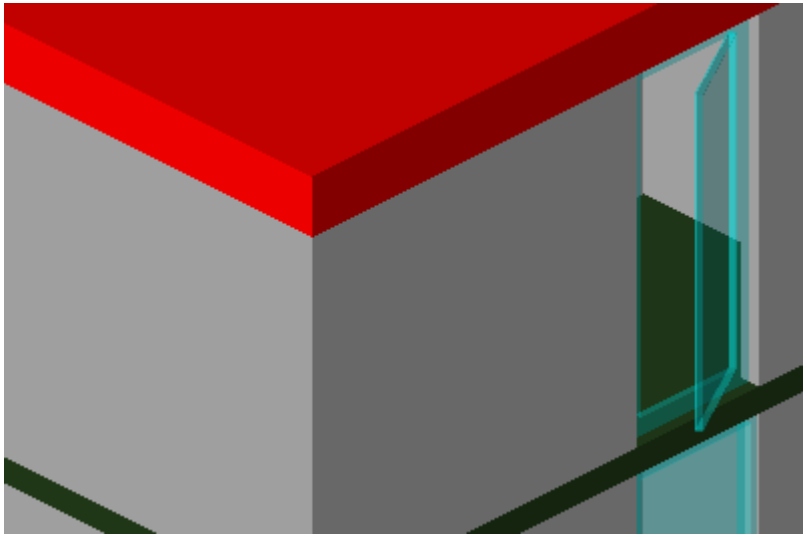

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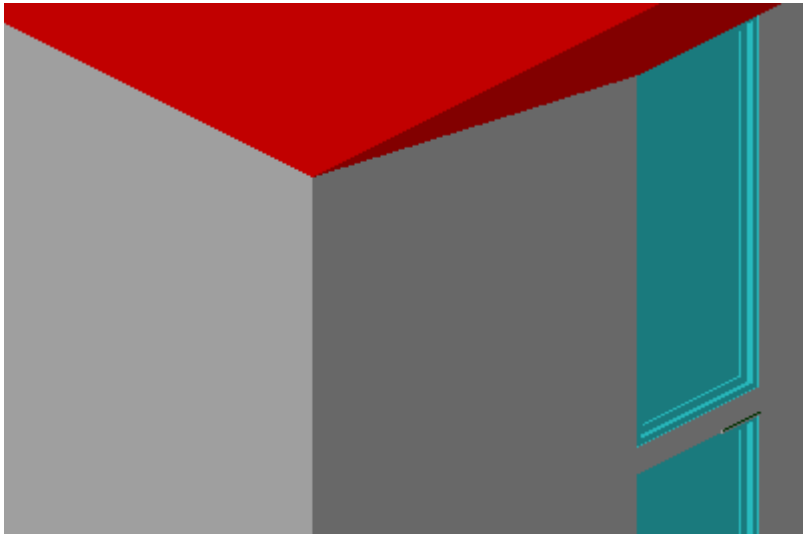

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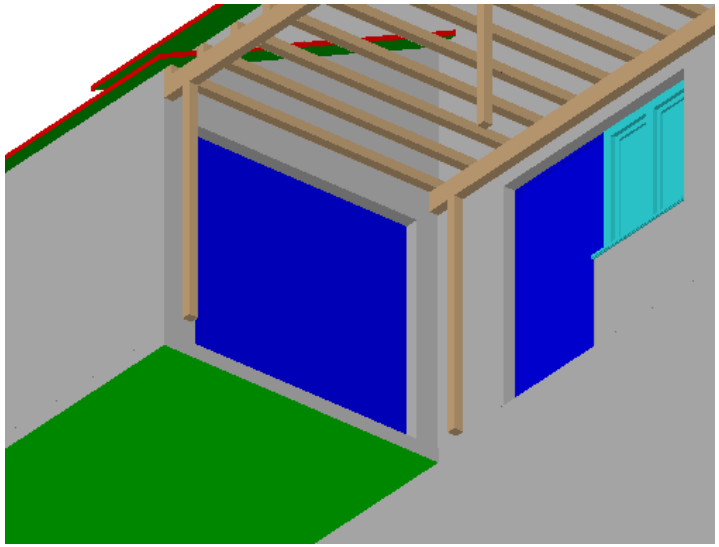

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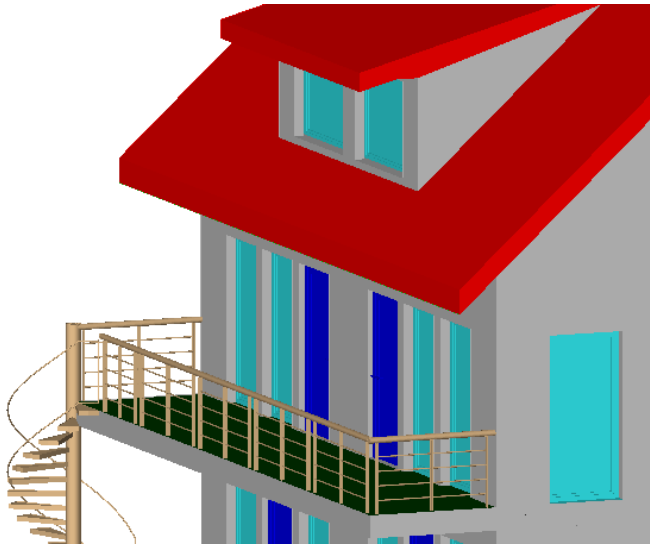
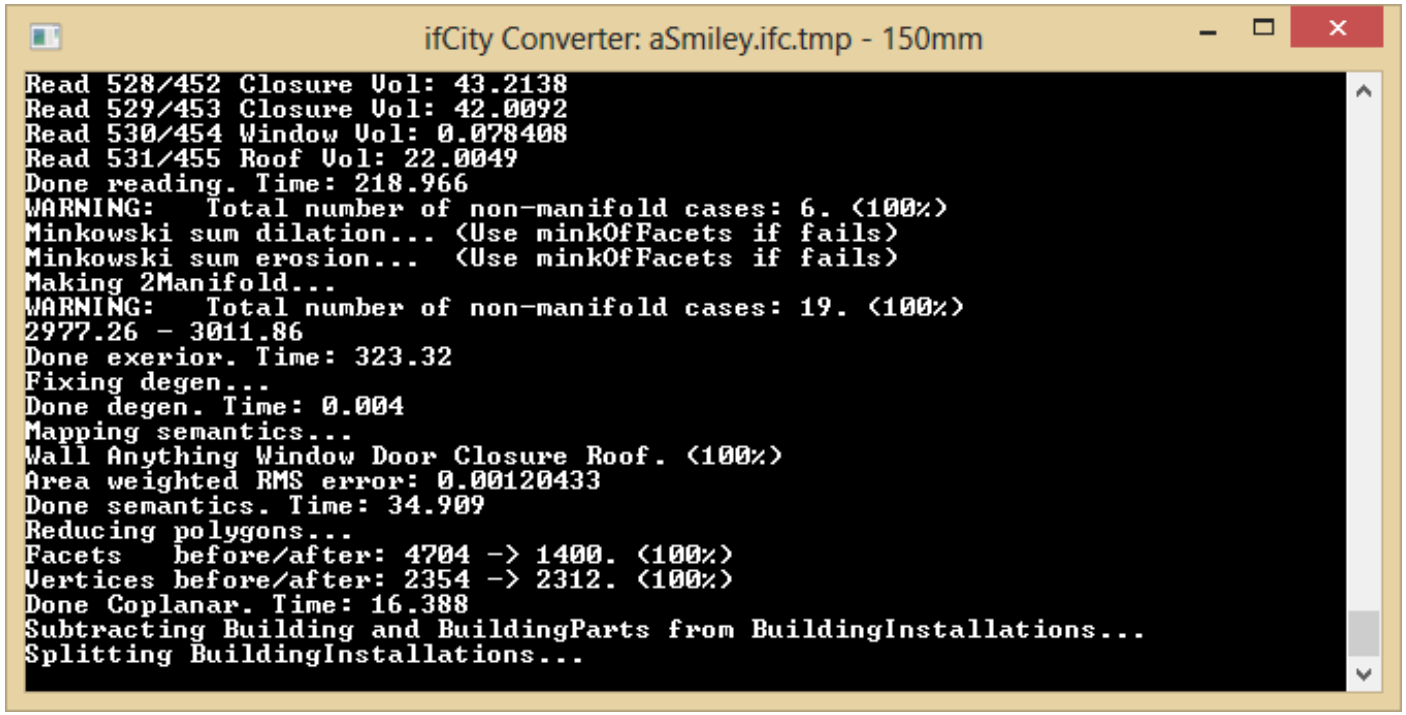


Conversion evaluation



Conversion evaluation

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- Morphological closing roughly double the computation time
- 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?
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- Experimental results
- **Possibilities for LoD4**
- Conclusions, recommendations & future work

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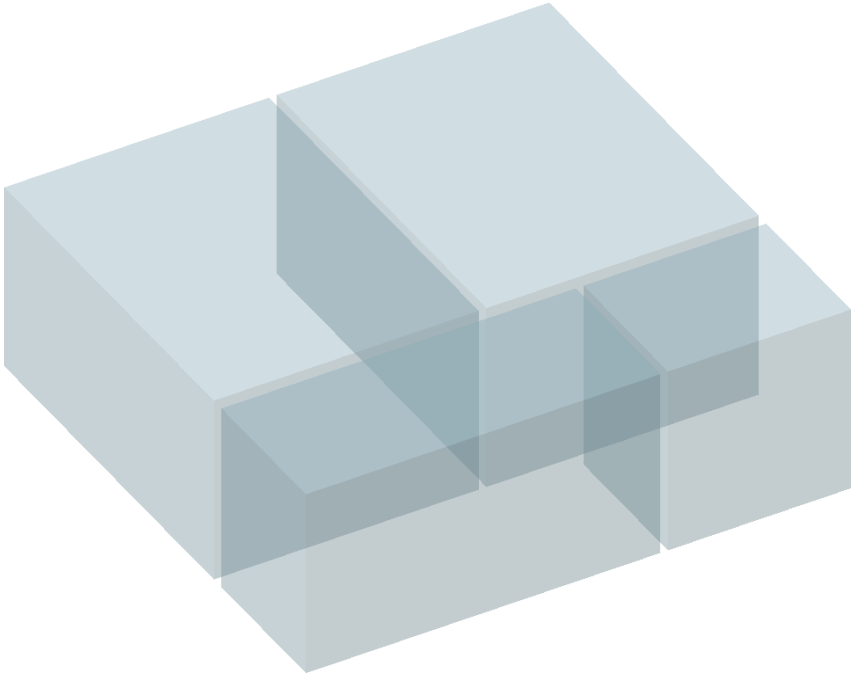

Generation of LoD4 rooms

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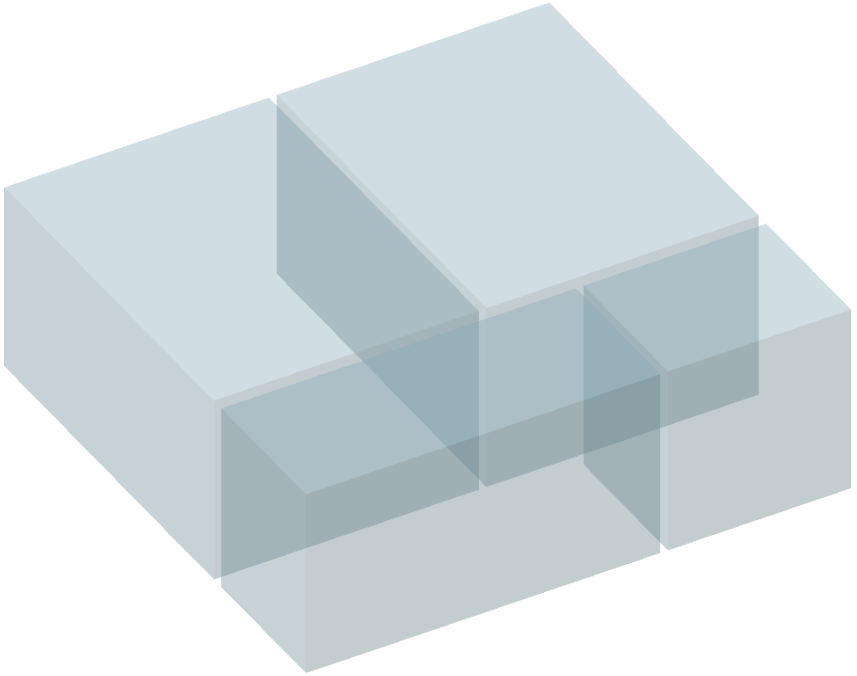
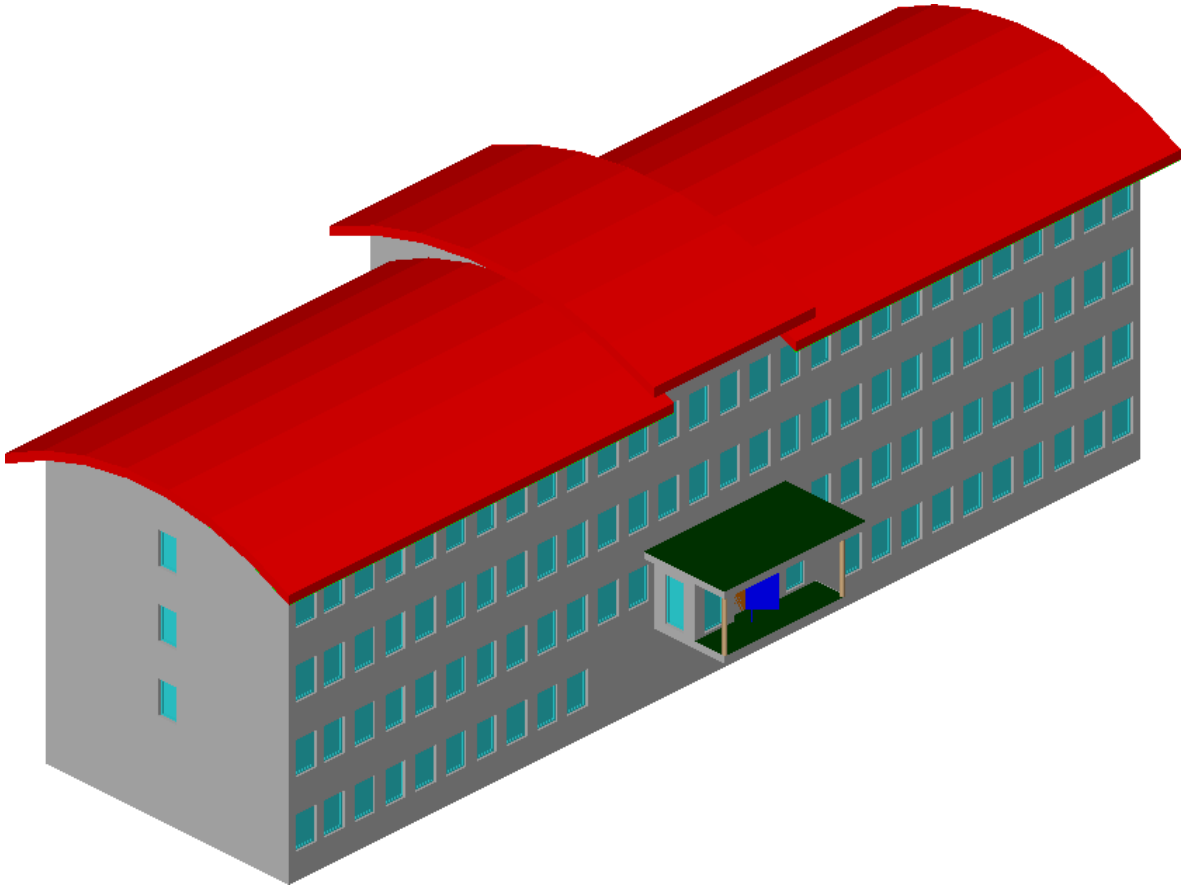
- In the implementation:
  - Geometry from IfcSpaces
  - Semantics base on surface normal



LoD4 experimental results



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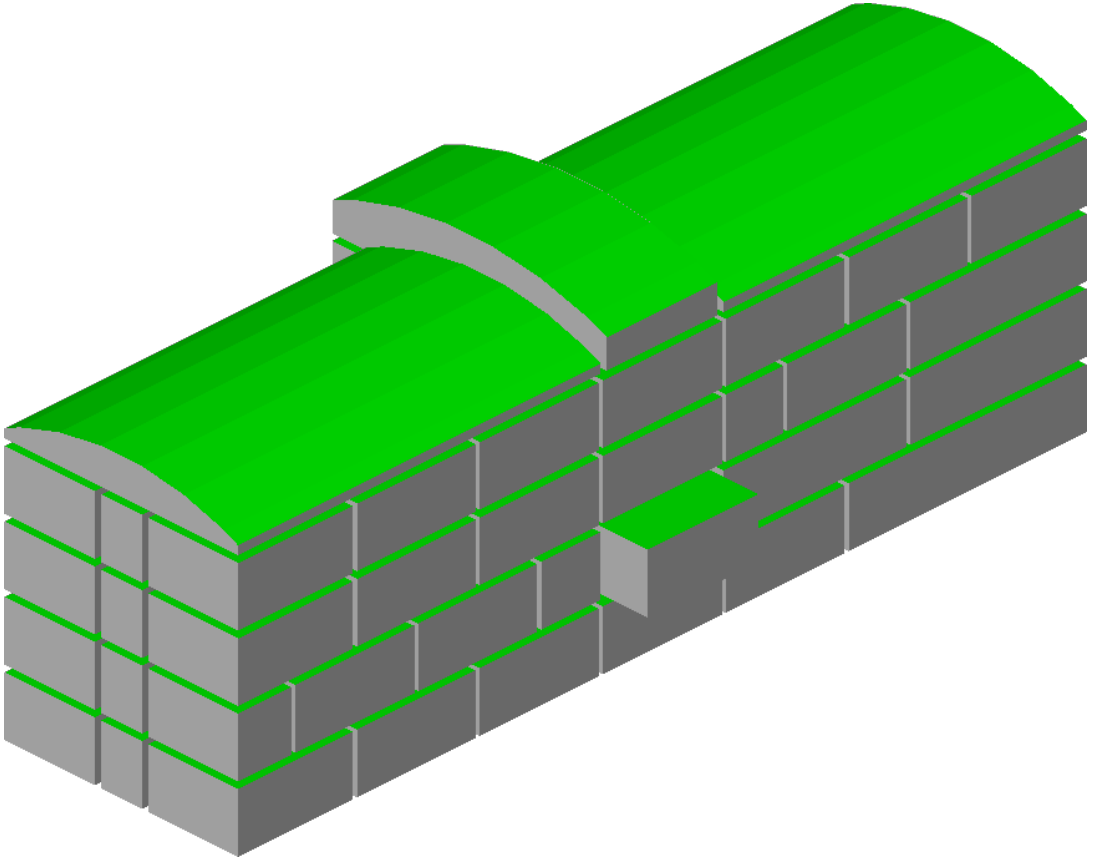

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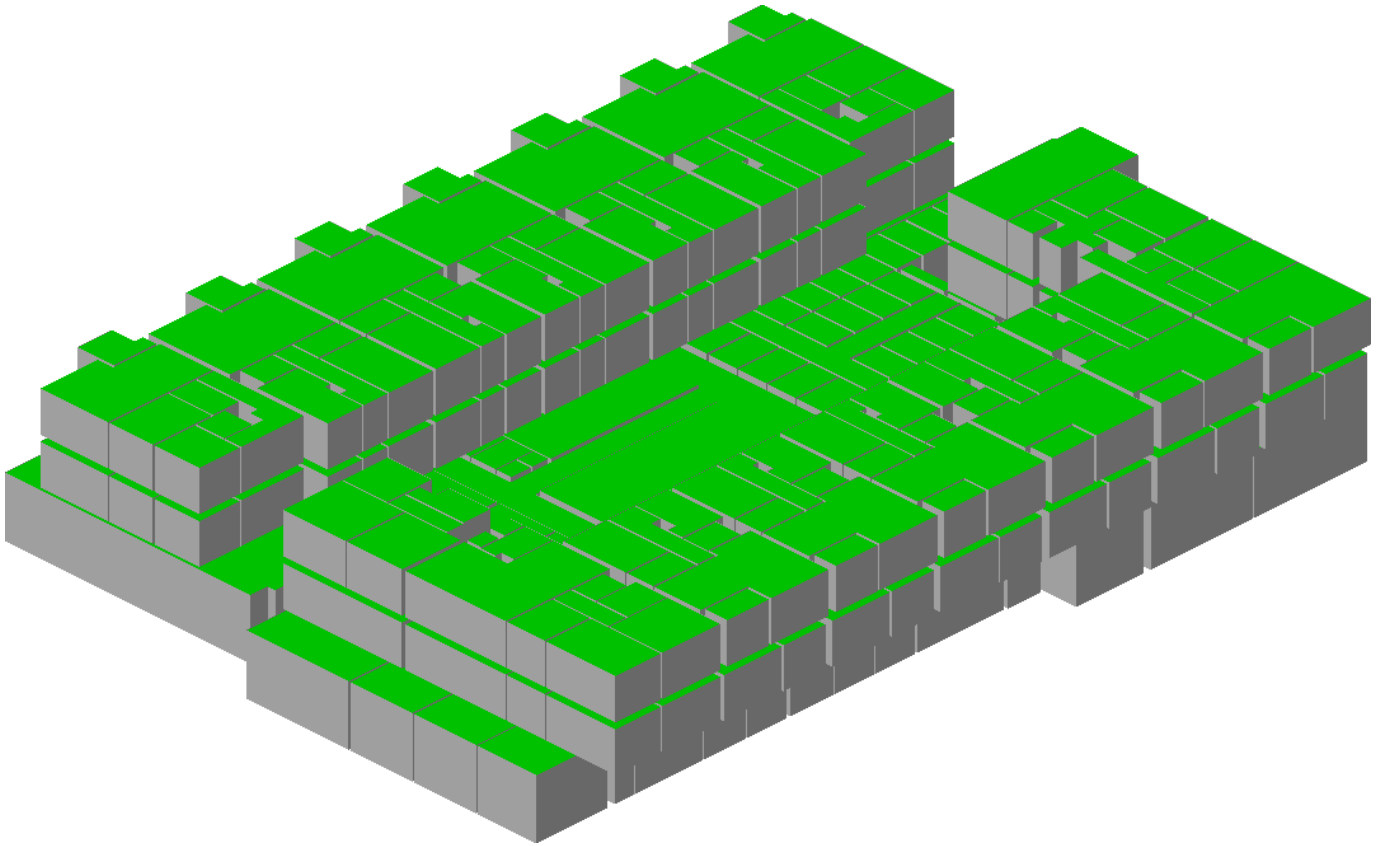

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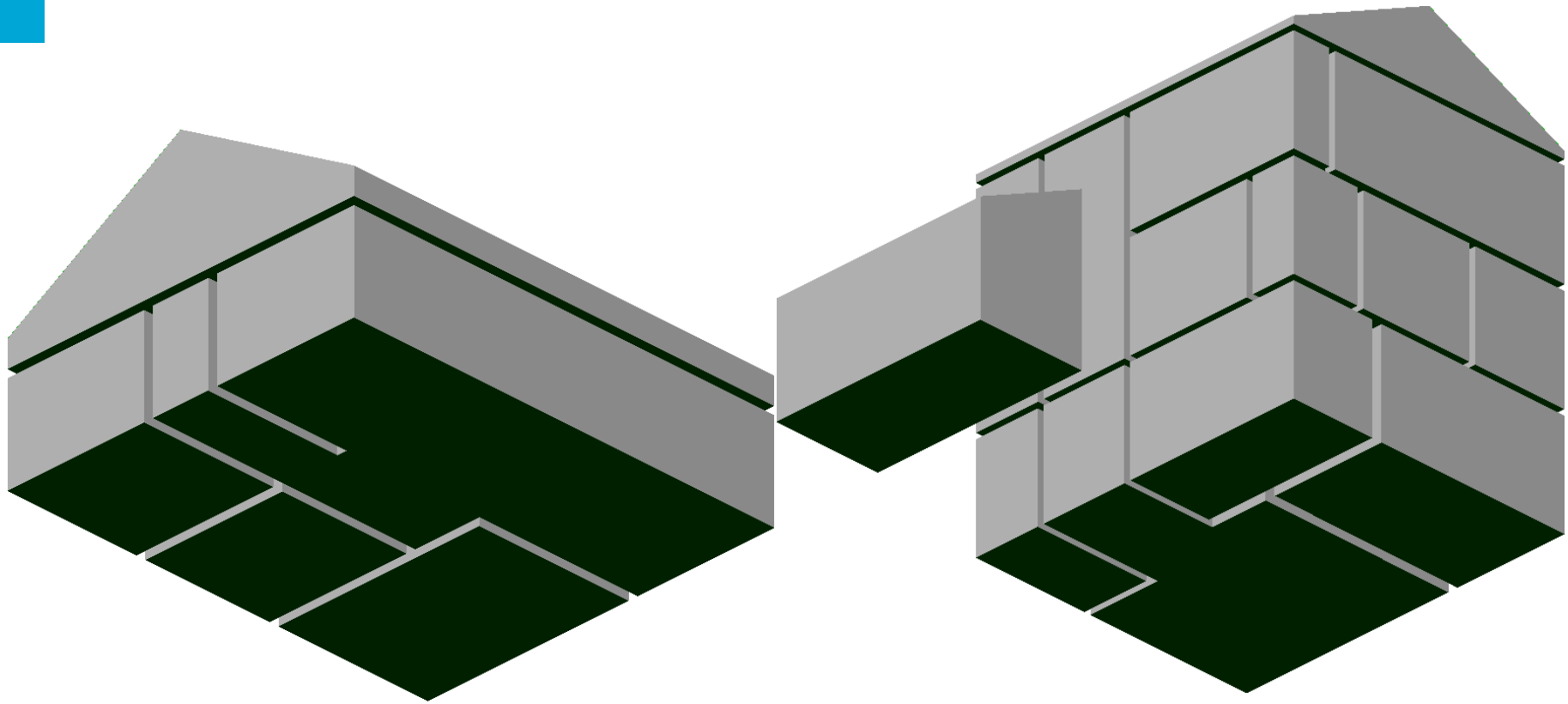

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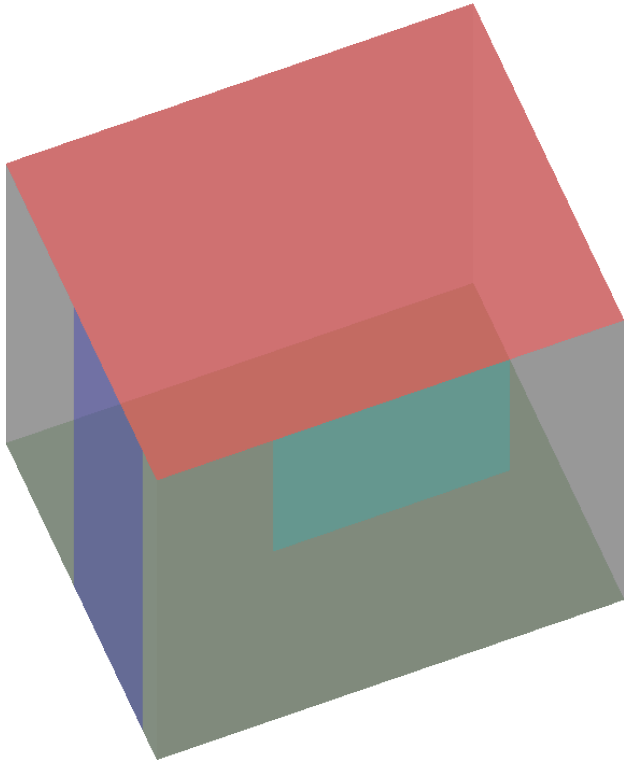

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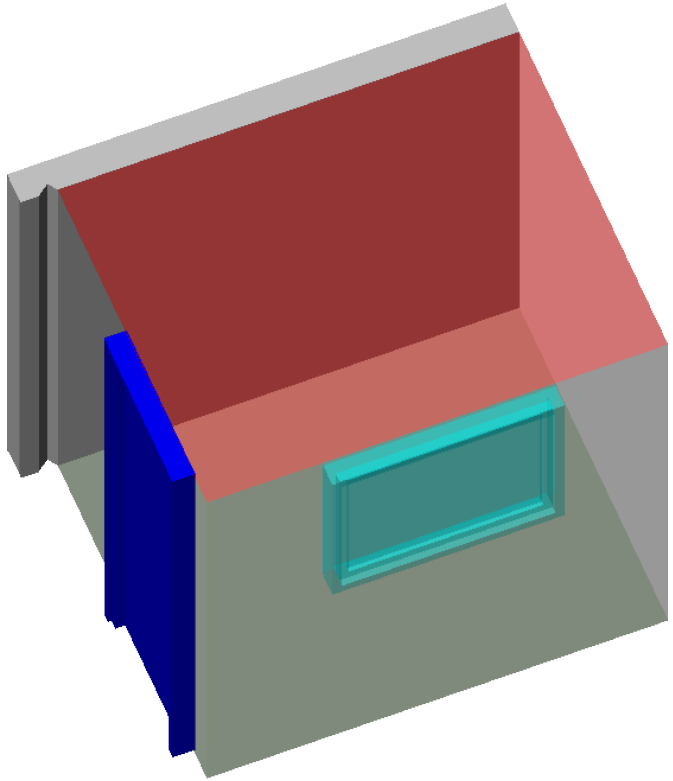
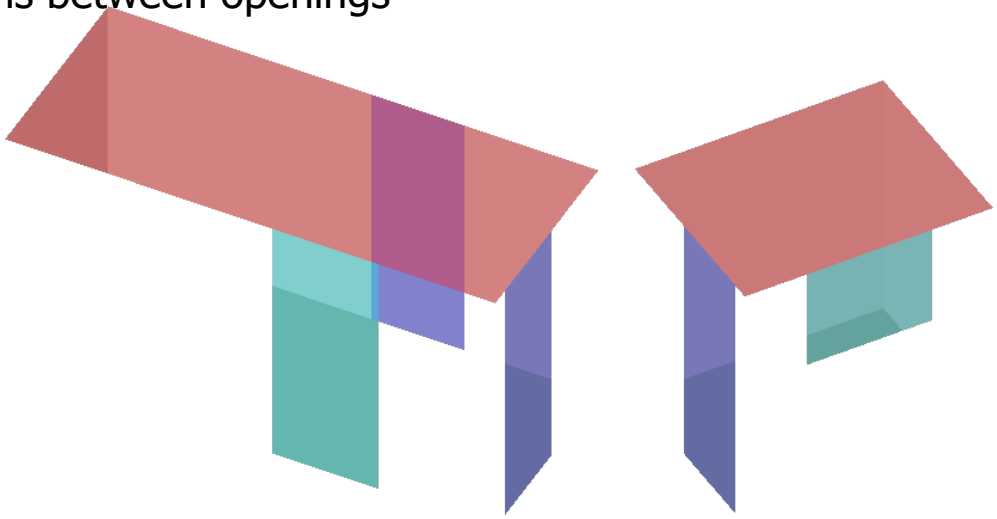


Possibilities for LoD4 conversion

- 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
- 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

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- 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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- Extraction of the terrain intersection curve

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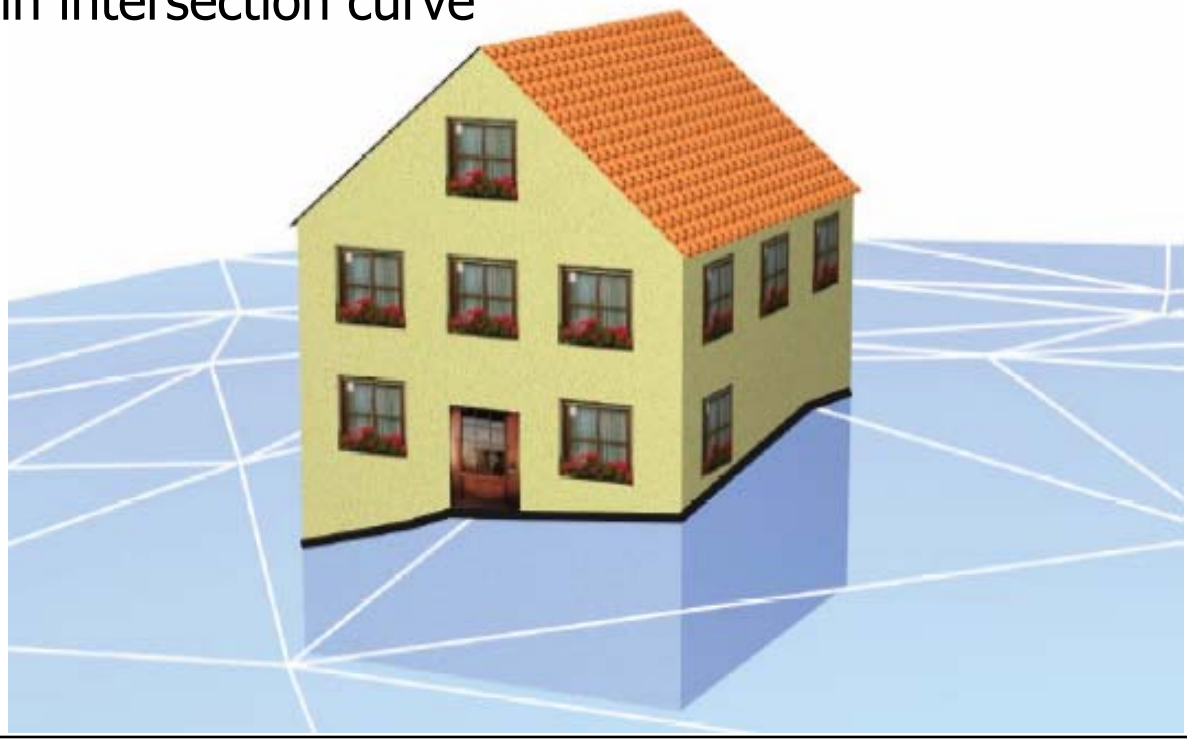
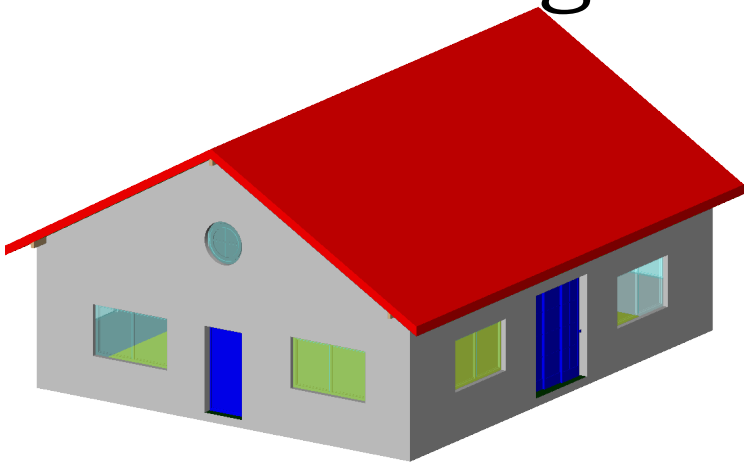


Future work

- Mapping of new IFC4 classes and trivial attributes like the address
- Extraction of the terrain intersection curve
- 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



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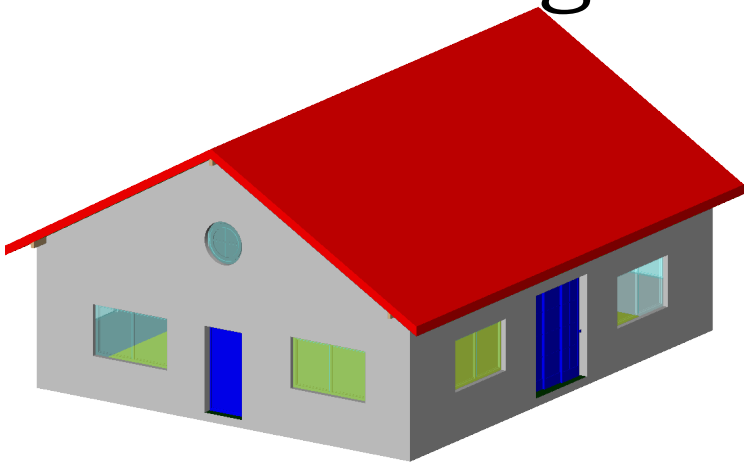

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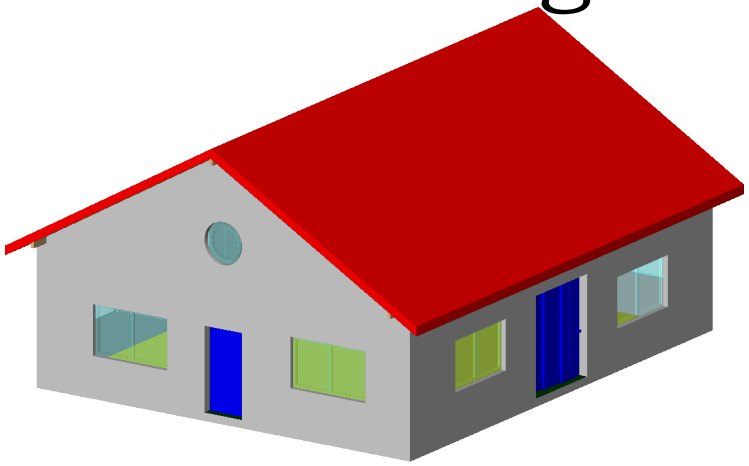

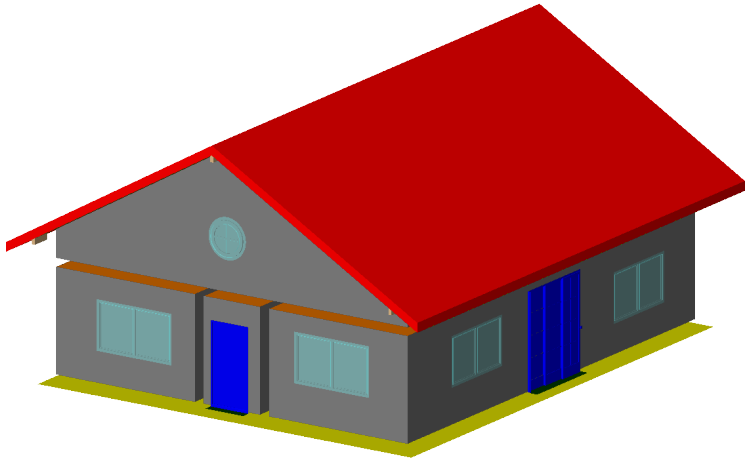

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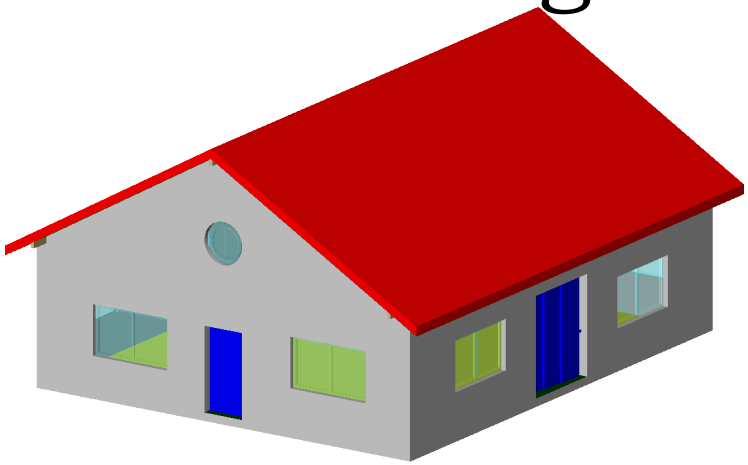

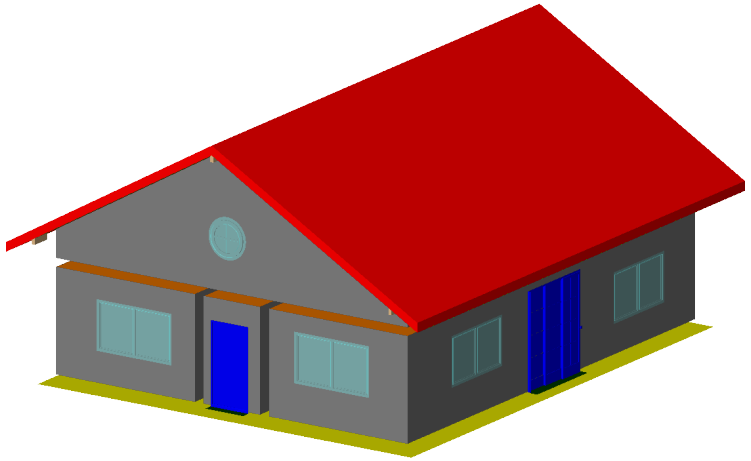

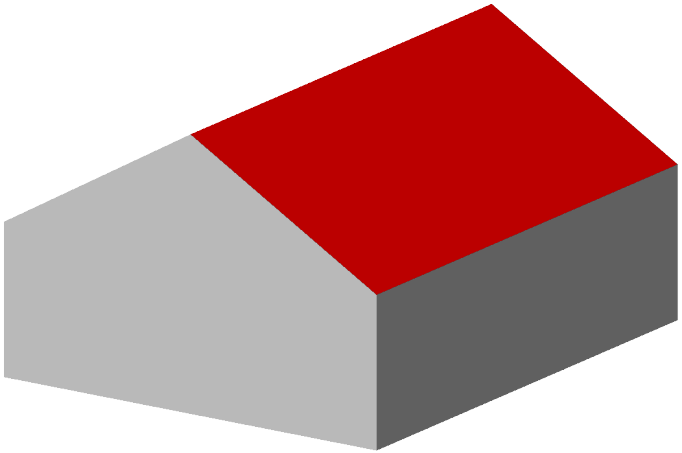

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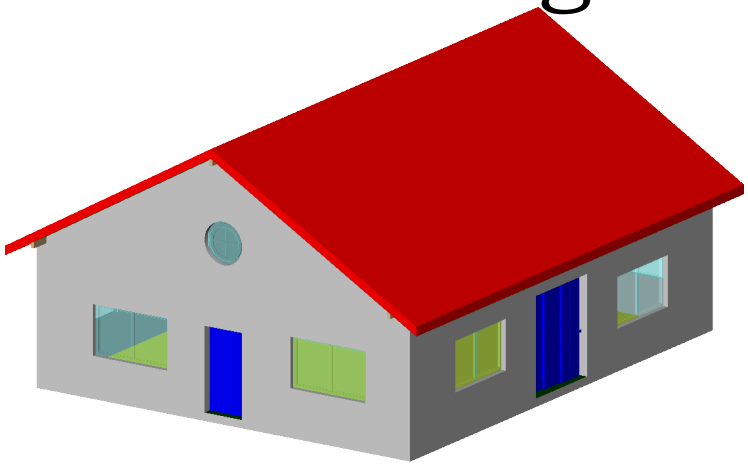

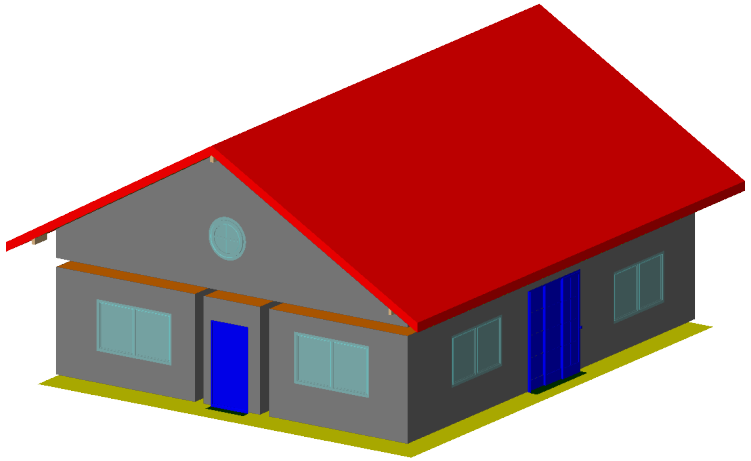

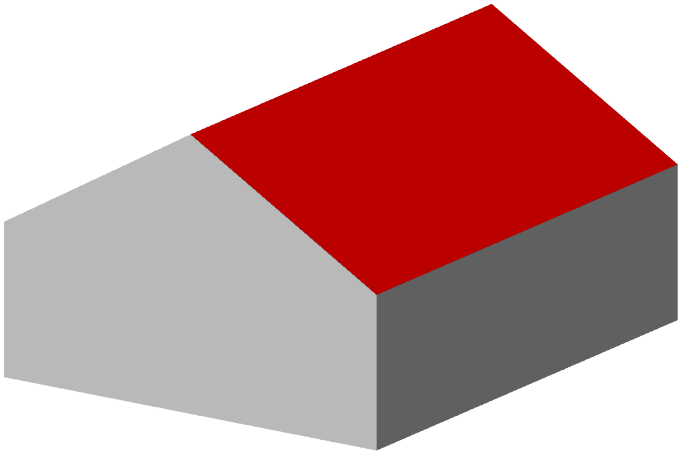

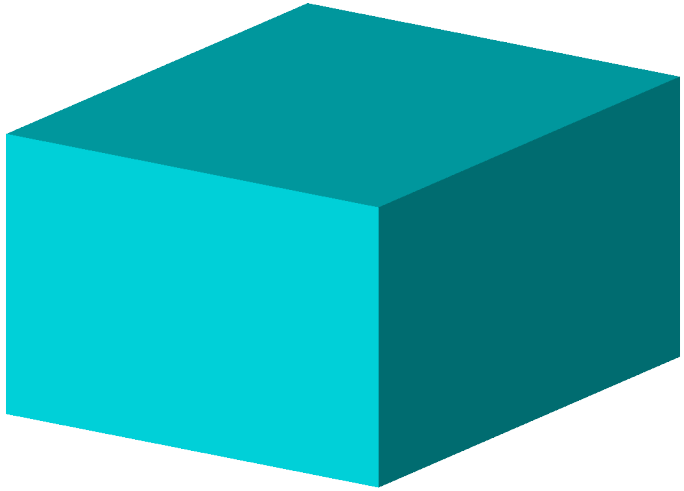

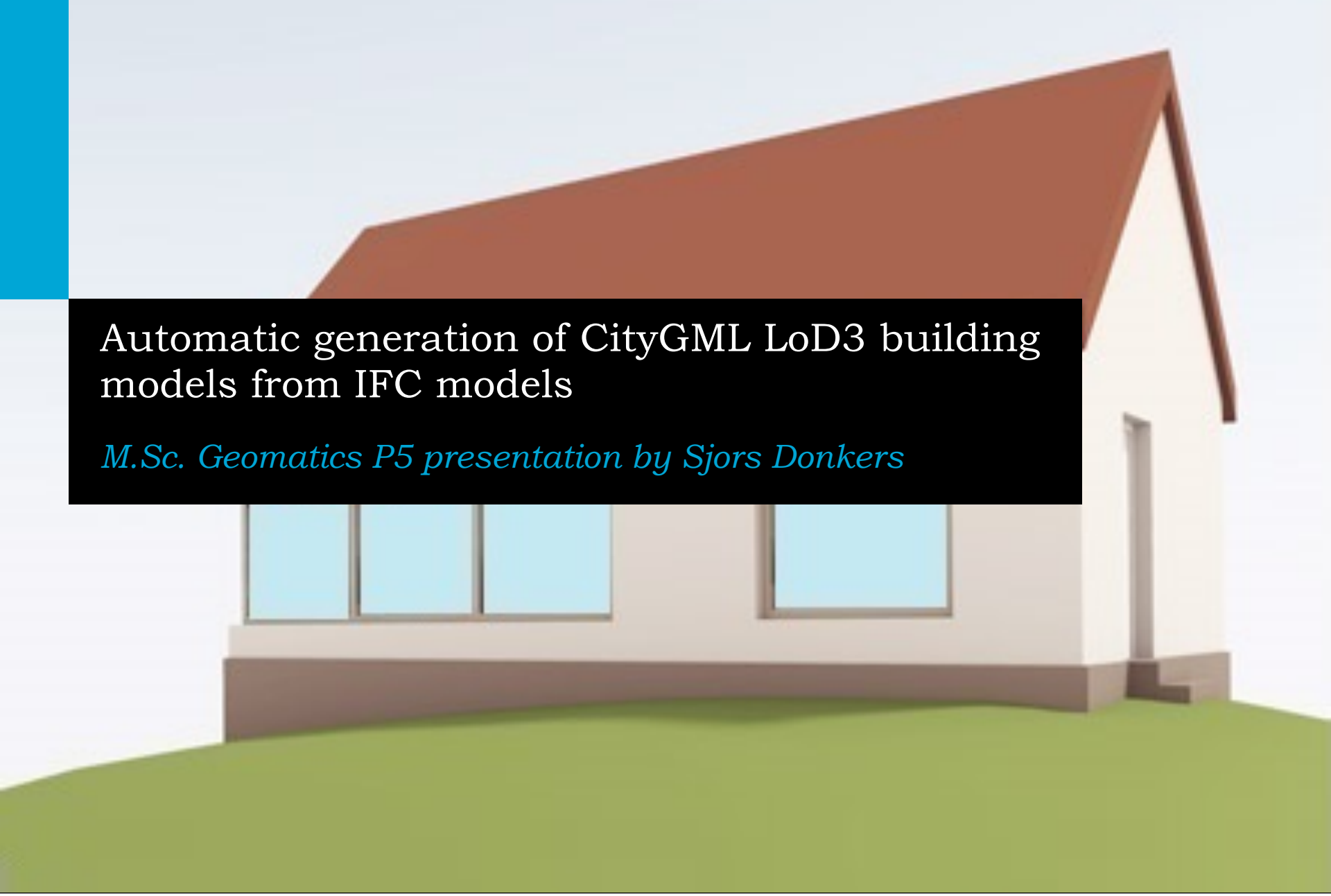

Automatic generation of CityGML LoD3 building models from IFC models

M.Sc. Geomatics P5 presentation by Sjors Donkers