3RD INTERNATIONAL CONFERENCE ON
SMART ENERGY SYSTEMS AND
4TH GENERATION DISTRICT HEATING
COPENHAGEN, 12–13 SEPTEMBER 2017

AALBORG UNIVERSITY
DENMARK
VERIFYING GEOMETRY IN URBAN BUILDING ENERGY MODELS

Ina De Jaeger a
Glenn Reynders a
Yixiao Ma b
Dirk Saelens a

a KU Leuven, Building Physics Section
b VITO, Unit Smart Energy & Built Environment
EFRO-SALK GeoWatt Project
“Towards a Sustainable Energy Supply in Cities”

Research topics
- Building models
- Optimal design
- Thermal network control
- Flexibility
- Geothermal energy
- Fault detection

Common case
- City of Genk (B)

Illustration by Annelies Vandermeulen
Introduction
Introduction

LOD1 ridge-based

→ Too simple?

LOD2

→ Too complex?
Introduction

How does LOD2 differ from LOD1?

- In terms of geometrical input?
- In terms of energy simulation outcome?
Introduction

How does LOD2 differ from LOD1?

- In terms of geometrical input?
- In terms of energy simulation outcome?
Introduction

How does LOD2 differ from LOD1?
- In terms of geometrical input?
- In terms of energy simulation outcome?

How can LOD2 be simplified?
Methodology
Methodology
Methodology

5 approaches to model a district:

- LOD1 ridge-based approach
  - Top = ridge height
- LOD1 half-roof-based approach
  - Assumption: story is at least 3m high
  - Top = ridge height – (story height/2)
- LOD 2 approach
  - Geometry defined through LiDAR
- LOD2 with 8 orientations approach
  - Geometry is labelled N, NE, E, SE, S, SW, W, NW
- LOD2 with 4 orientations approach
  - Geometry is labelled N, E, S, W
Methodology

GRB (for geometrical data)

Ridge height
- 3.4 - 8.1 m
- 8.1 - 8.9 m
- 8.9 - 9.8 m
- 9.8 - 10.5 m
- 10.5 - 11.8 m

Workflow
- Input data

 участие

CityGML

(Import)

TEASER (Data enrichment)

(Export)

IDEAS

TABULA (for statistical data)

LOD2 (for geometrical data)

LOD2
- 8 orient
- 4 orient

LOD1
- ridge-based

LOD2
- half-roof-based
Methodology

Defined key performance indicators

- **Related to geometry:**
  - Ground floor area [m²]
  - Heated floor area [m²]
  - Heated volume [m³]
  - Total loss surface area [m²]

- **Related to energy performance:**
  - Peak power [kW]
  - Total energy use [kWh]
  - Specific energy use [kWh/m²]
  - Overheating risk of dayzone [Kh]
Methodology

 Reporting KPIs

- **Percentage Error (PE)**
  
  \[ PE = \frac{\text{Reference} - \text{Forecast}}{\text{Reference}} \]

- **Mean Percentage Error (MPE)**
  
  \[ MPE = \frac{1}{n} \sum_{1}^{n} PE \]

- **Standard Deviation Percentage Error (\(\sigma_{PE}\))**
Results

LOD1 vs LOD2 (percentage errors)

LOD1
- Ridge-based

LOD1
- Half-roof-based

Total loss surface area [-]

Total energy use [-]
## Results

**LOD1 vs LOD2**

<table>
<thead>
<tr>
<th>KPI → APPROACH ↓</th>
<th>Ground floor area [-]</th>
<th>Heated floor area [-]</th>
<th>Heated volume [-]</th>
<th>Total loss surface area [-]</th>
<th>Peak power [-]</th>
<th>Total energy use [-]</th>
<th>Specific energy use [-]</th>
<th>Overheating [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE</td>
<td>LOD1 Ridge-based</td>
<td>0.00 0.00</td>
<td>-0.15 0.16</td>
<td>-0.44 0.18</td>
<td>-0.31 0.08</td>
<td>-0.33 0.14</td>
<td>-0.54 0.17</td>
<td>-0.36 0.19</td>
</tr>
<tr>
<td>LOD1 Half-roof-based</td>
<td>0.00 0.00</td>
<td>-0.15 0.16</td>
<td>-0.14 0.17</td>
<td>-0.14 0.08</td>
<td>-0.18 0.13</td>
<td>-0.23 0.15</td>
<td>-0.08 0.16</td>
<td>-0.19 0.17</td>
</tr>
</tbody>
</table>

💡 **Standard deviation is unneglectable, why do they differ?**

 Lod2 approach includes:

- Roof type
- Building extensions
Analysis of the LOD2 model

Main volume and extensions are quantified in terms of:

- Ground floor area
- Building height (= height of roof edges)
- Building volume (= volume below roof)
- Roof height
- Roof volume
- Roof shape factor (RSF)
  - Logic: $V = A \times h \times RSF$
  - Pitched roof: RSF = 0.5
  - Hip roof: RSF = 0.33
## Results

### Analysis of LOD2

<table>
<thead>
<tr>
<th>Category</th>
<th>Total number</th>
<th>Roof type [%]</th>
<th>Number of extensions [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gable</td>
<td>Hip</td>
</tr>
<tr>
<td>All</td>
<td>12136</td>
<td>84.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Detached</td>
<td>6673</td>
<td>85.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Semi-detached</td>
<td>4248</td>
<td>84.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Terraced</td>
<td>1215</td>
<td>80.2</td>
<td>5.3</td>
</tr>
<tr>
<td>Small</td>
<td>3034</td>
<td>82.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Medium</td>
<td>3034</td>
<td>87.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Large</td>
<td>3034</td>
<td>87.3</td>
<td>6.8</td>
</tr>
<tr>
<td>Extra-large</td>
<td>3034</td>
<td>80.1</td>
<td>9.8</td>
</tr>
<tr>
<td>1 floor</td>
<td>1175</td>
<td>44.2</td>
<td>3.4</td>
</tr>
<tr>
<td>2 floors</td>
<td>4687</td>
<td>85.4</td>
<td>6.9</td>
</tr>
<tr>
<td>3 floors</td>
<td>6030</td>
<td>90.7</td>
<td>7.1</td>
</tr>
<tr>
<td>4 floors</td>
<td>244</td>
<td>92.2</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Results

- LOD2 with limited orientations vs LOD2

**Total loss surface area [-]**

- LOD2
  - 4 orientations

- LOD2
  - 8 orientations

**Total energy use [-]**
Results

LOD2 with limited orientations vs LOD2

<table>
<thead>
<tr>
<th>KPI → APPROACH ↓</th>
<th>Ground floor area [-]</th>
<th>Heated floor area [-]</th>
<th>Heated volume [-]</th>
<th>Total loss surface area [-]</th>
<th>Peak power [-]</th>
<th>Total energy use [-]</th>
<th>Specific energy use [-]</th>
<th>Overheating [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE MPE σPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOD1 Ridge-based</td>
<td>0.00 0.00 -0.15 0.16 -0.44 0.18 -0.31 0.08 -0.33 0.14</td>
<td>-0.54 0.17</td>
<td>-0.36 0.19</td>
<td>-0.15 0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOD1 Half-roof-based</td>
<td>0.00 0.00 -0.15 0.16 -0.14 0.17 -0.14 0.08 -0.18 0.13</td>
<td>-0.23 0.15</td>
<td>-0.08 0.16</td>
<td>-0.19 0.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOD2 4 orientations</td>
<td>0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
<td>0.01 0.02</td>
<td>0.01 0.02</td>
<td>0.03 0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOD2 8 orientations</td>
<td>0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
<td>0.01 0.02</td>
<td>0.01 0.02</td>
<td>0.03 0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† LOD2 with limited orientations favored

[when focusing on energy use]

† No significant differences between 4 and 8
Conclusion

GIS enables to include **spatial dimension** more accurately within DES

<table>
<thead>
<tr>
<th>KPI → APPROACH ↓</th>
<th>MPE of Total energy use [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOD1 Ridge-based</td>
<td>-0.54</td>
</tr>
<tr>
<td>LOD1 Half-roof-based</td>
<td>-0.23</td>
</tr>
<tr>
<td>LOD2 4 orientations</td>
<td>0.01</td>
</tr>
<tr>
<td>LOD2 8 orientations</td>
<td>0.01</td>
</tr>
</tbody>
</table>

- LOD1 not capable to represent LOD2
- LOD2 with all orientations not needed
- Too simple
- Too detailed

**Future work:**
- Are these 600 buildings representative?
- Allowable percentage error?
Questions?

Thank you!

Ina De Jaeger
ina.dejaeger@energyville.be