From CityGML-Energy ADE to EnergyPlus and back: Some experiences

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Vienna, 31 May 2016

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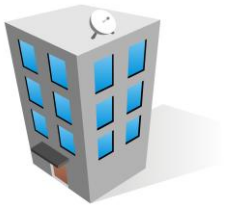
Overview

- Introduction
- Constraints & prerequisites
- Implementation
- Experimental results
- Conclusions

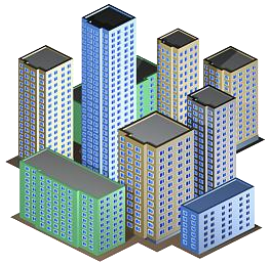
Introduction

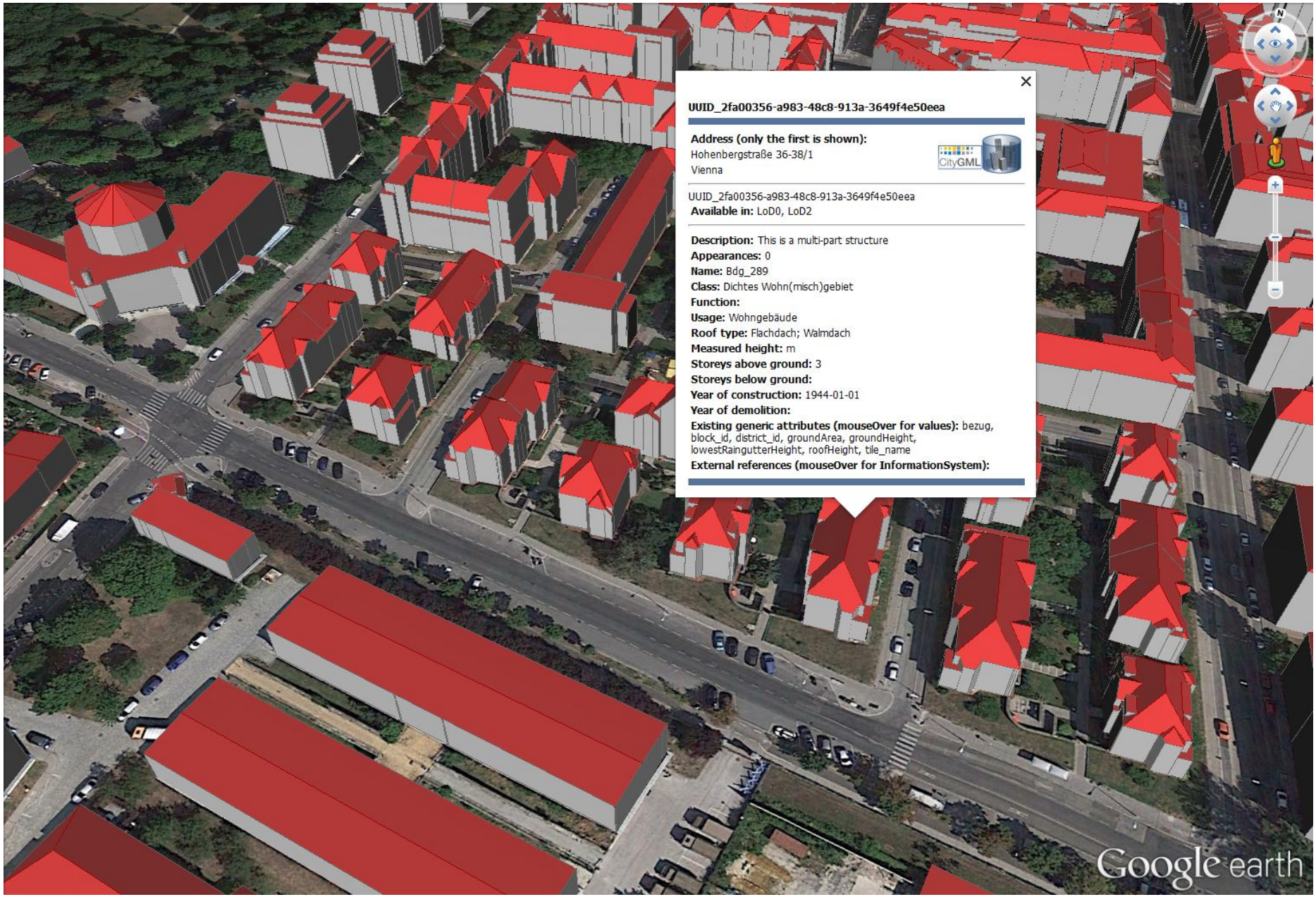
Energy and cities

- Single building:
  - Many tools – but **single** building
  - Detailed description of the building (physical properties, usage, lightning, ...)
  - Detailed simulation results
  - Fine-grained time resolution



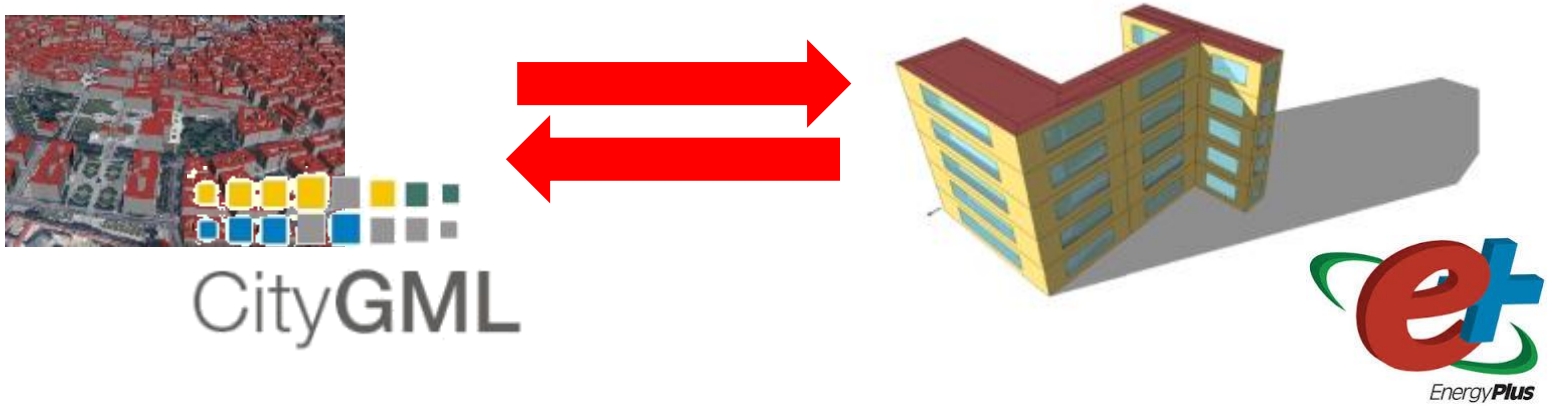
- Urban scale:
  - **Top-down approaches,** based on econometric & technological data
    - (Often) coarse spatial results
    - (Often) coarse time resolution
  - **Bottom-up approaches,** based on statistical and engineering data
    - Heterogeneous data (sometimes) available at single building level
    - Semantic 3D city models as information hub for energy-related applications?



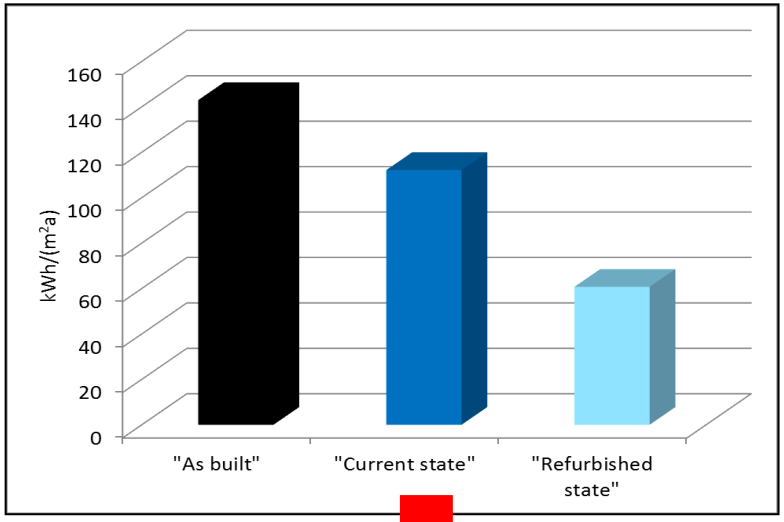

UUID_2fa00356-a983-48c8-913a-3649f4e50eea
Address (only the first is shown):
Hohenbergstraße 36-38/1
Vienna
CityGML
UUID_2fa00356-a983-48c8-913a-3649f4e50eea
Available in: LoD0, LoD2
Description: This is a multi-part structure
Appearances: 0
Name: Bdg_289
Class: Dichtes Wohn(misch)gebiet
Function:
Usage: Wohngebäude
Roof type: Flachdach; Walmdach
Measured height: m
Storeys above ground: 3
Storeys below ground:
Year of construction: 1944-01-01
Year of demolition:
Existing generic attributes (mouseOver for values): bezug, block_id, district_id, groundArea, groundHeight, lowestRaingutterHeight, roofHeight, tile_name
External references (mouseOver for InformationSystem):
Google earth

Idea

- Exploit data available from existing 3D city model (CityGML + Energy ADE)
- Couple with dynamic simulation software (EnergyPlus)
  - Exploit the benefits of a full-fledged dynamic simulation tool
  - Enhance the time resolution (from monthly values to hourly values)
  - Use real weather data instead of statistical data
- Transfer results back to CityGML



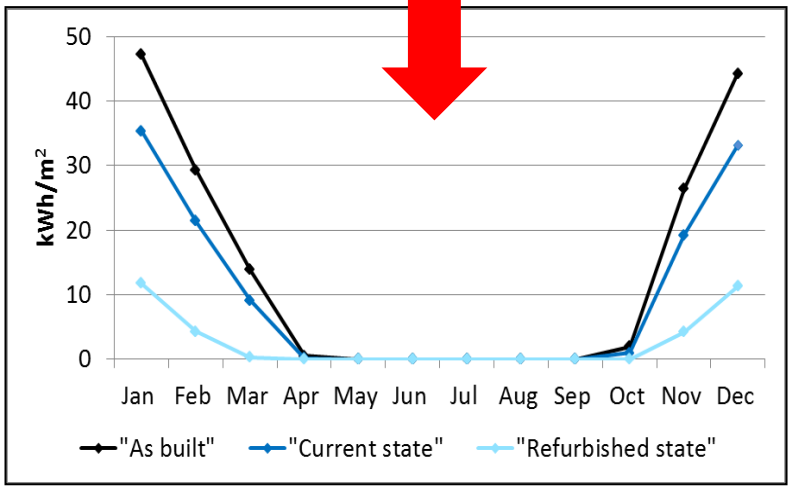
Enhancement of time resolution by means of dynamic simulations

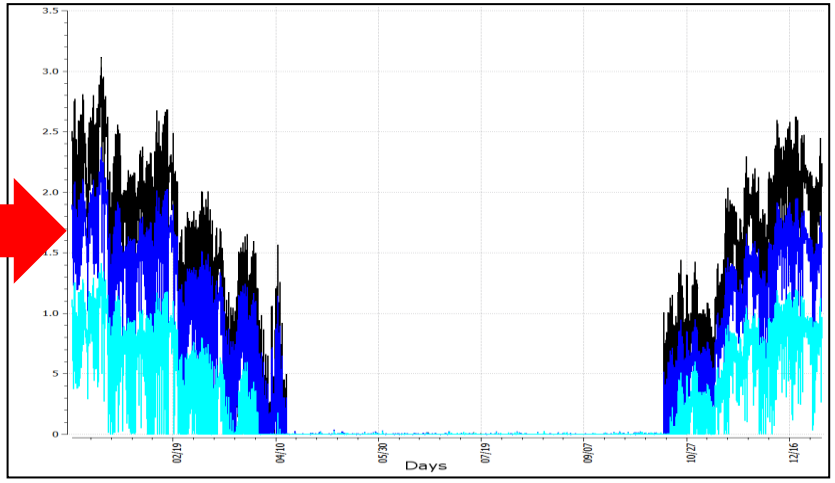


Yearly values

Monthly values

Hourly values





EnergyPlus

- **Single building** energy simulation program
- Developed by the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL)
- Used to model energy consumption (heating, cooling, ventilation, lighting and plug and process loads), as well as water use in building
- Wrt. data model
  - Over **1600** classes to describe buildings
  - IDD (Input data dictionary, schema)
  - IDF (input data file)

Previous related work

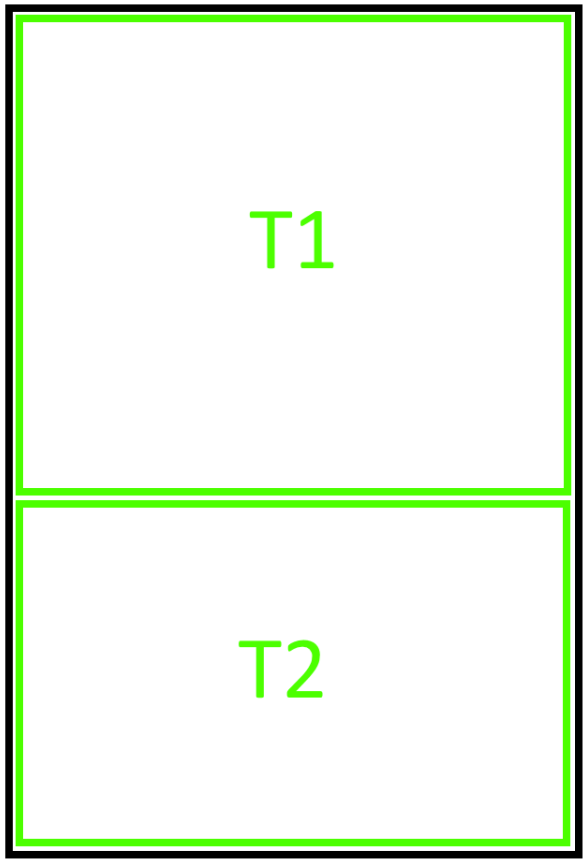
- D. Banfi, 2013, **Energiebedarfsanalyse urbaner Räume anhand des semantischen Modells und Austauschformats CityGML,** TU München
  - UML model of the EnergyPlus data format from IDD file
  - Mapping of CityGML (LoD2, LoD3) → EnergyPlus, BUT:
    - Converts only thematic surfaces, no other properties
    - Limited to 1 building
    - Only 1 thermal zone
  - Implemented in Ruby
  - Proposes a data model to store results

Overall current improvements

- Adoption of Energy ADE v0.6
  - Core module
    - e.g. *ThermalZone*, *ThermalBoundary*, *ThermalComponent* classes)
  - *Occupancy* module
    - e.g. *UsageZone*, *Occupancy*, *Facilities*
  - Construction & Materials module
  - TimeSeries & Schedules module

Constraints & prerequisites

Constraints & Prerequisites



- Definition of the thermal hull
  - Until EnergyADE v0.5: geometries only through CityGML *_boundarySurfaces*

  → Sometimes problematic:
  Energy Plus needs precise geometries for each *ThermalBoundary*

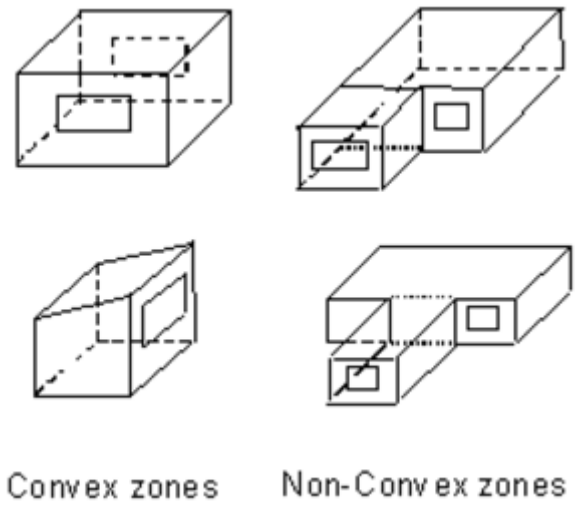
  - Since EnergyADE v0.6: *surfaceGeometry* attribute added to *ThermalBoundary* class

  → More flexibility

Constraints & Prerequisites

- In EnergyPlus: 1 ThermalZone = 1 UsageZone
  - with multiple usage zones, need to „aggregate“ them to 1
- EnergyPlus needs to distinguish between adjacent Ceiling and Floors (currently only „IntermediaryFloor“ in Energy ADE v0.6)
- EnergyPlus constructions only support up to 10 layers
- Use a local coordinate reference system
  - Shift geometries close to coordinate system origin (0,0,0)
  - Tolerance for adjacent geometries 1 mm

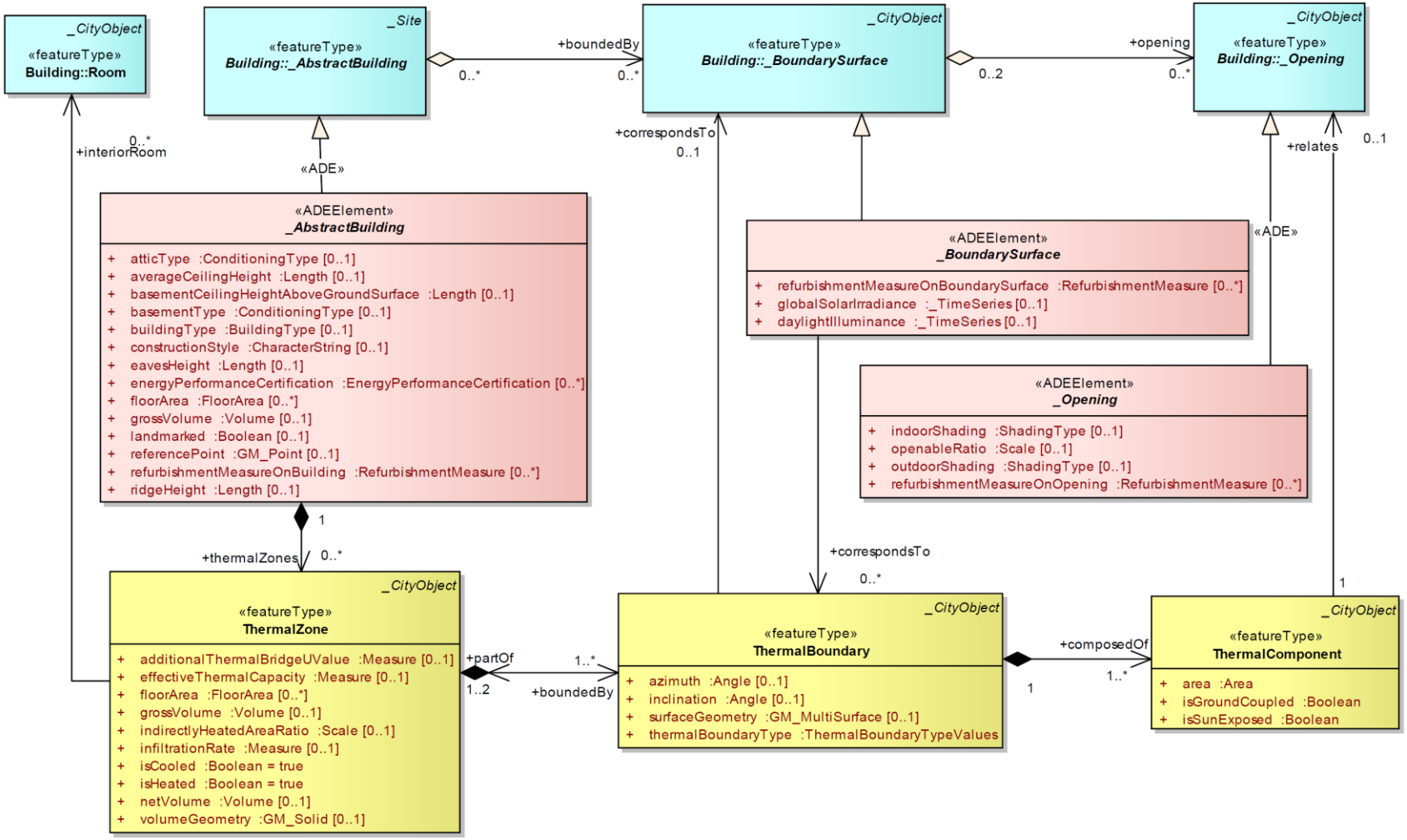
Constraints & Prerequisites



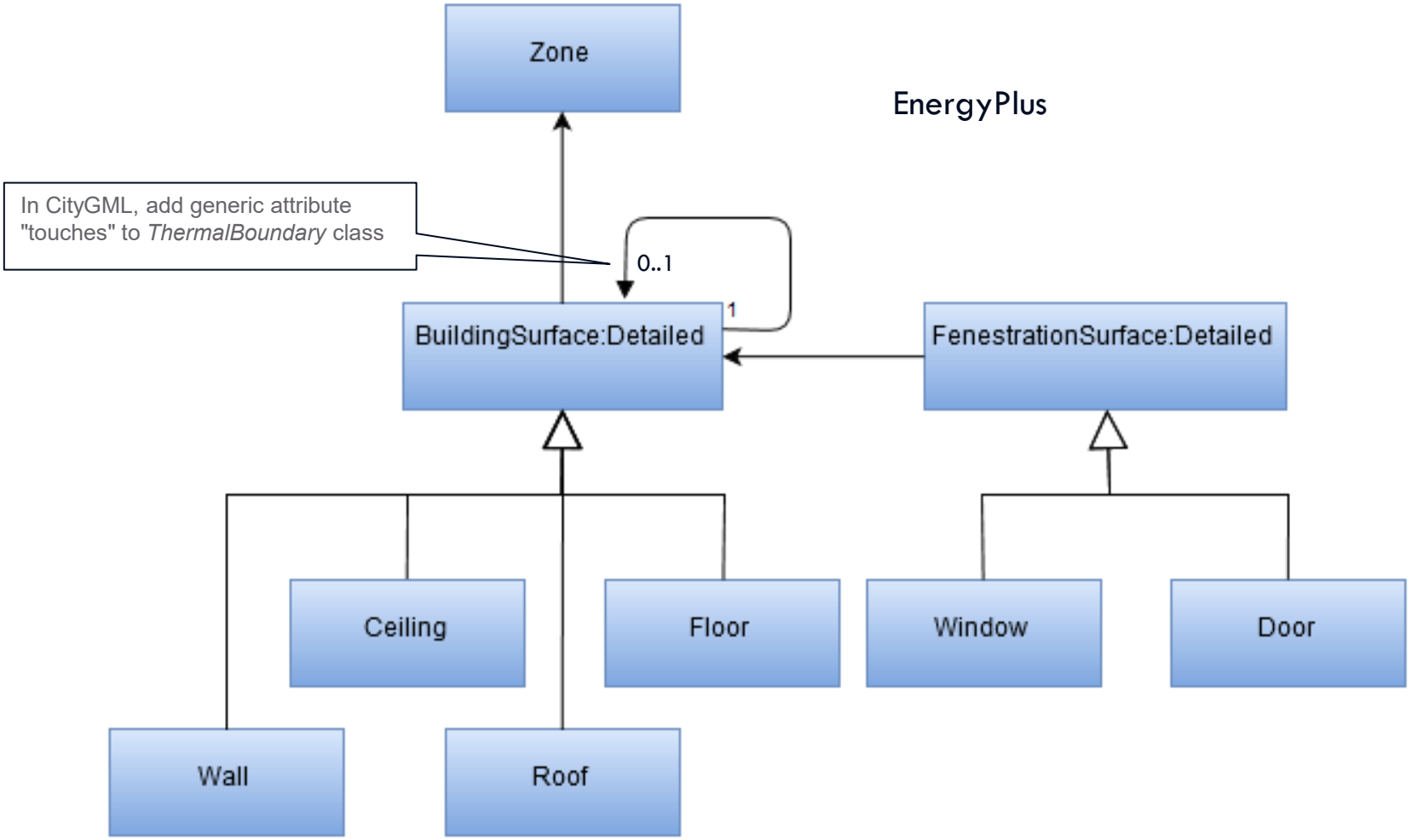
- Zones need to be convex, if a simulation is required with *exterior and interior solar irradiance*

→ Pre-processing required
(not topic of this work)

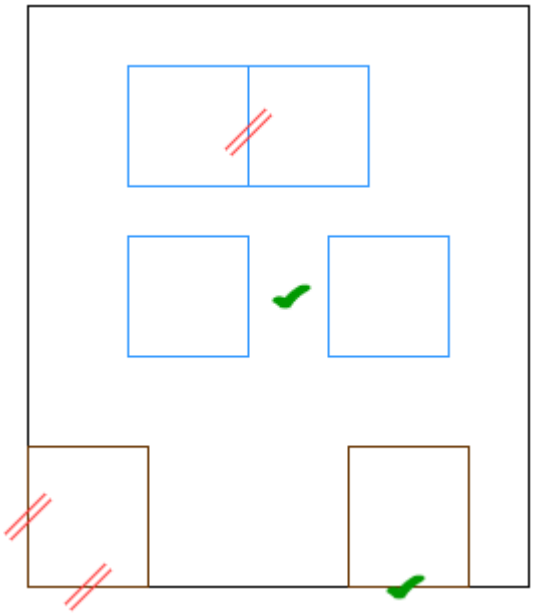
Constraints & Prerequisites



Constraints & Prerequisites



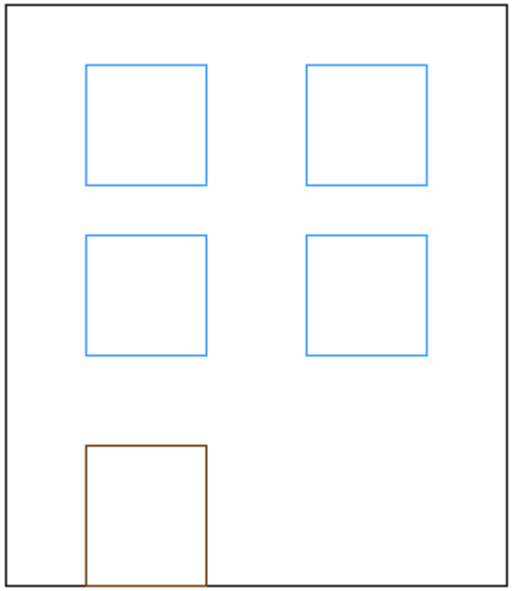
Constraints & Prerequisites



Openings:

- Walls do not contain holes
- Openings modelled as additional geometry
- Openings relate to walls
- Opening must be of regular shape (rectangular)
- Opening must not „touch“ each other
- Openings must not share 2 edges with walls

Constraints & Prerequisites



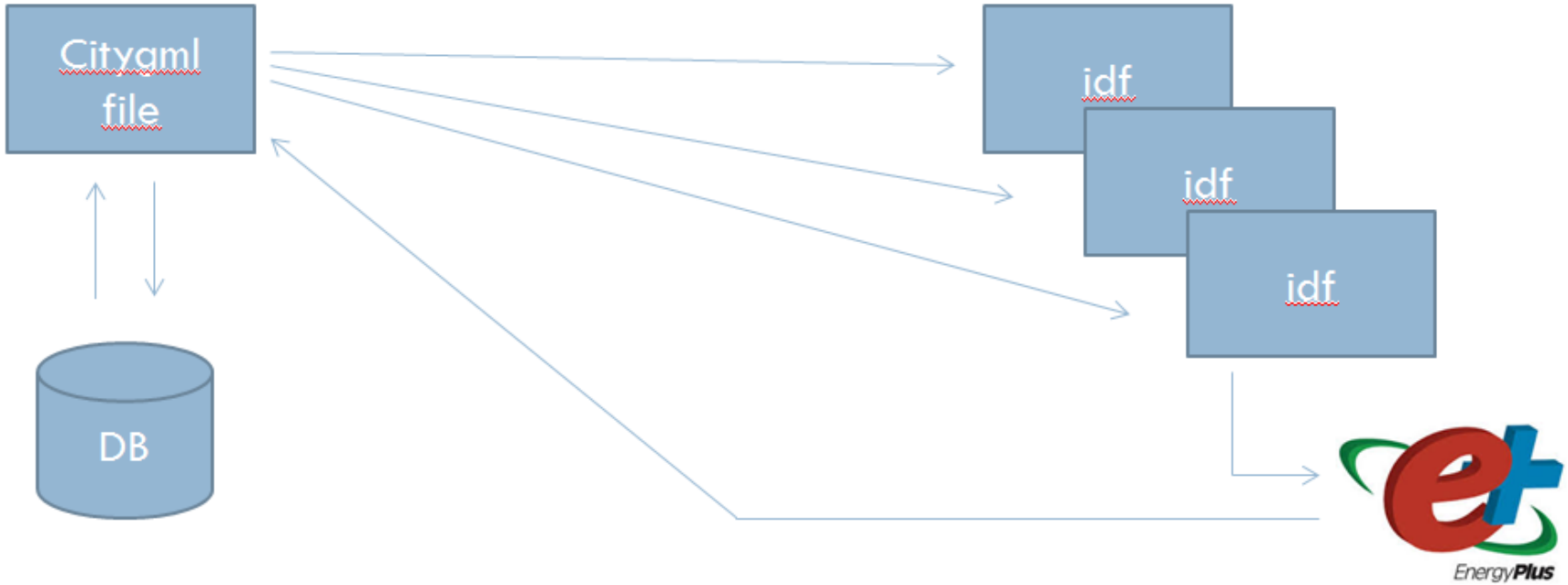
Workaround to add openings to LoD2 building (if desired):

- Model windows/doors as *ThermalBoundary* with *surfaceGeometry*
- Identify them with a *generic attribute* (+ *touches*)

```
<energy:ThermalBoundary gml:id="id_window_thermalboundary_1s">
    ...
    <gen:stringAttribute name="touches">
        <gen:value>#id_wall_thermalboundary_1s</gen:value>
    </gen:stringAttribute>
    <gen:stringAttribute name="surface_type">
        <gen:value>Window</gen:value>
    </gen:stringAttribute>
</energy:ThermalBoundary>
```

Implementation

General Workflow



- Generate CityGML file
- Translate to Input Data Files (IDF)
- Simulate with EnergyPlus
- Write the results back to CityGML

EnergyPlus

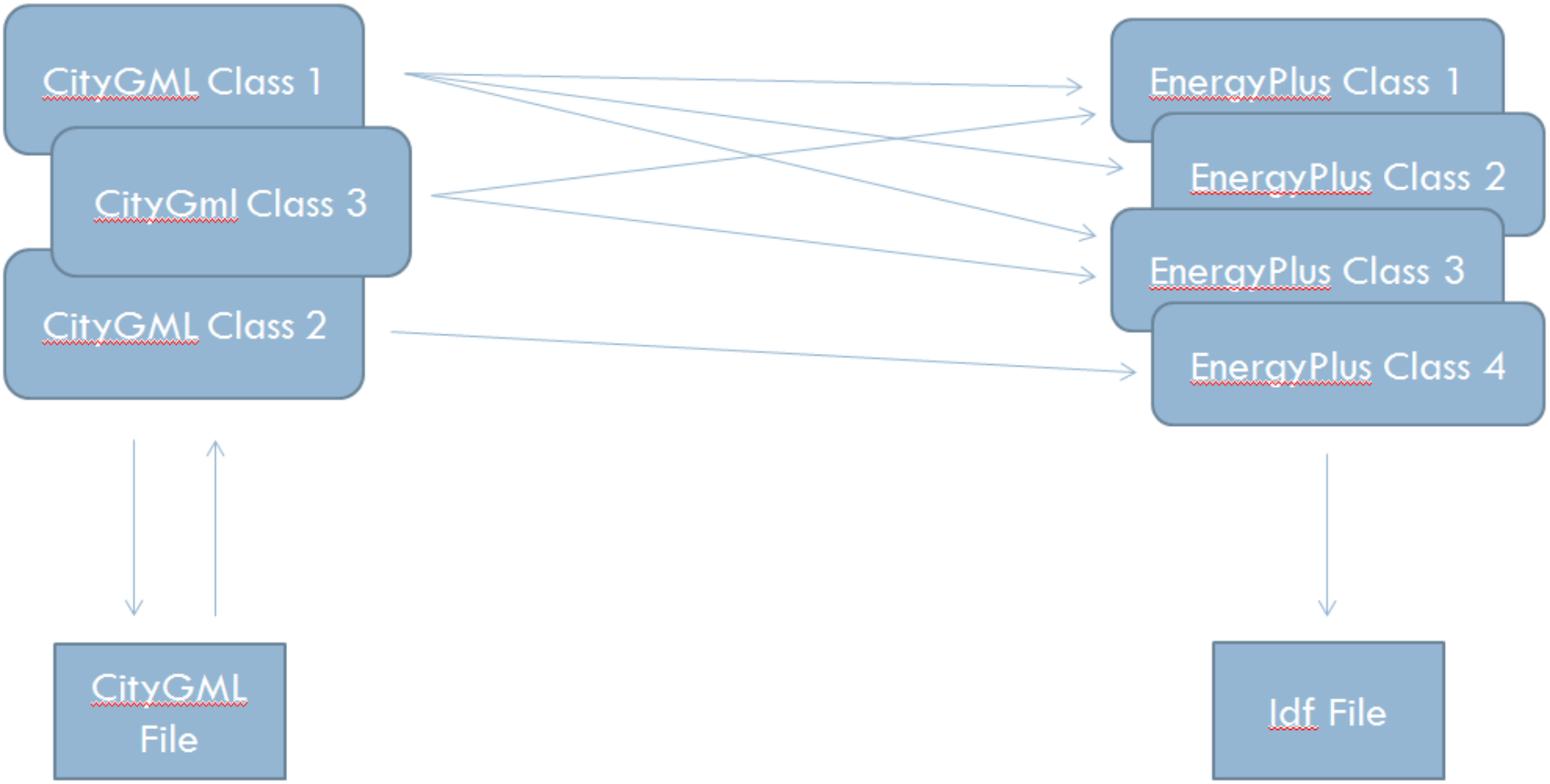
- Data model
  - IDD (Input data dictionary, schema)
  - IDF (input data file)

- Semi-automatically generated UML diagram (via Enterprise Architect script)
  - Graphical representation
  - Possibility to automatically generate Java classes
  - Some manual editing/checks needed

- Over**1600 classes** in 59 Packages

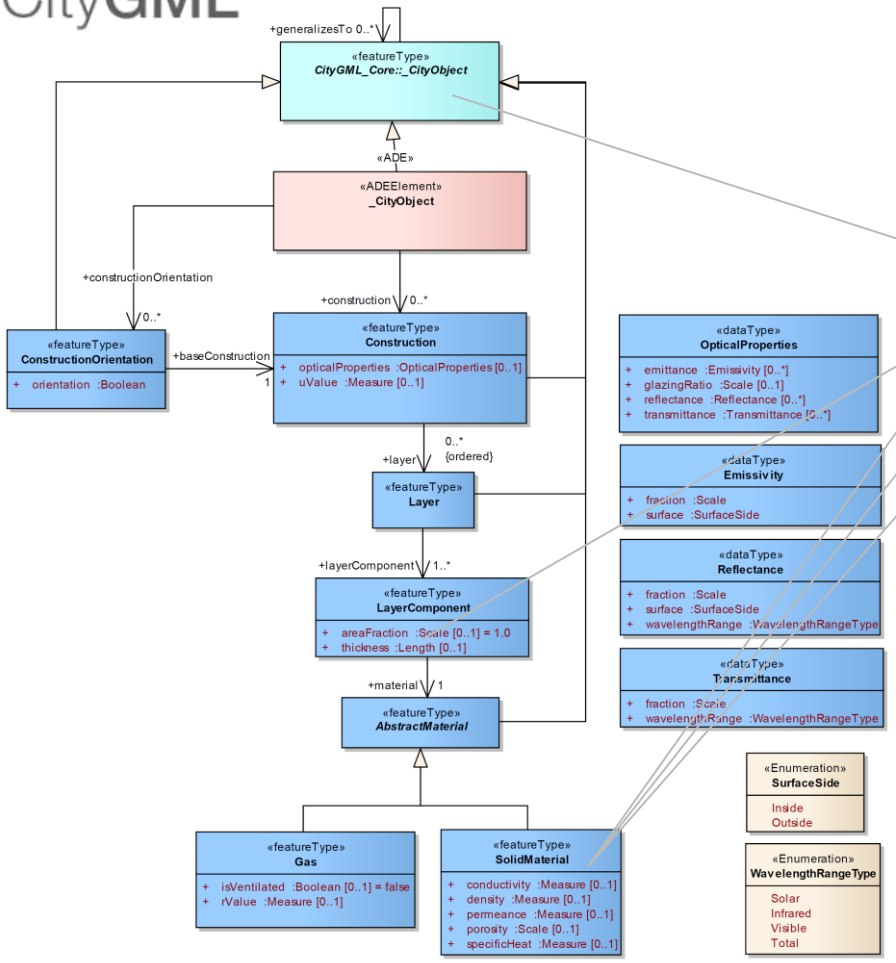
  → Identified ~60 classes needed for simulation

Mapping CityGML to EnergyPlus



Mapping Materials (example)

CityGML



Material

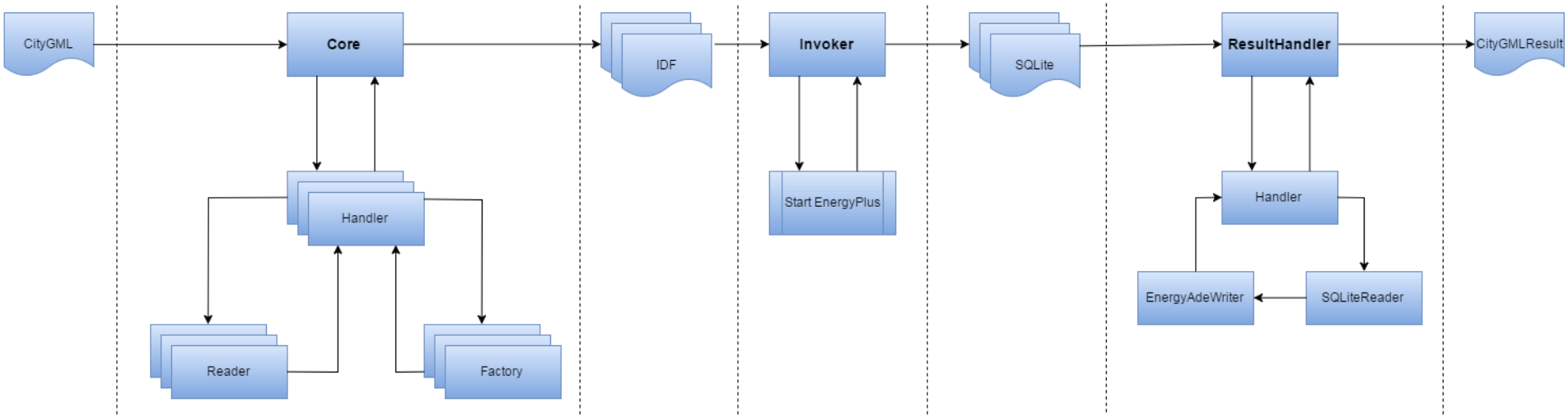
+Name[1] : string
+Roughness[1] : Roughness
+Thickness[1] : double
+Conductivity[1] : double = 0
+Density[1] : double = 0
+SpecificHeat[1] : double = 100
+ThermalAbsorptance[0..1] : double
+SolarAbsorptance[0..1] : double
+VisibleAbsorptance[0..1] : double

«enumeration»
EnergyPlus::**Roughness**

+Smooth
+VeryRough
+Rough
+MediumRough
+MediumSmooth
+Smooth
+VerySmooth

EnergyPlus

Detailed workflow



- 3 Modules
  - Core
    - Input: CityGML file
    - Output: IDF File(s)
    - Based on the Java citygml4j APIs
  - Invoker
    - Input: IDF File(s)
    - Output: Energy Plus simulation results (SQLite files)
  - ResultHandler
    - Input: Energy Plus simulation results (SQLite files)
    - Output: Enriched CityGML file

Simulation results

- (Currently) following results are exported to CityGML:
  - _BoundarySurface(s)
    - GlobalSolarIrradiance (yearly, time interval 1 hour)
  - ThermalZone(s)
    - EnergyDemand Cooling (yearly, time interval 1 hour)
    - EnergyDemand Heating (yearly, time interval 1 hour)
  - Building
    - EnergyDemand Cooling (yearly, time interval 1 hour)
    - EnergyDemand Heating (yearly, time interval 1 hour)

Experimental results

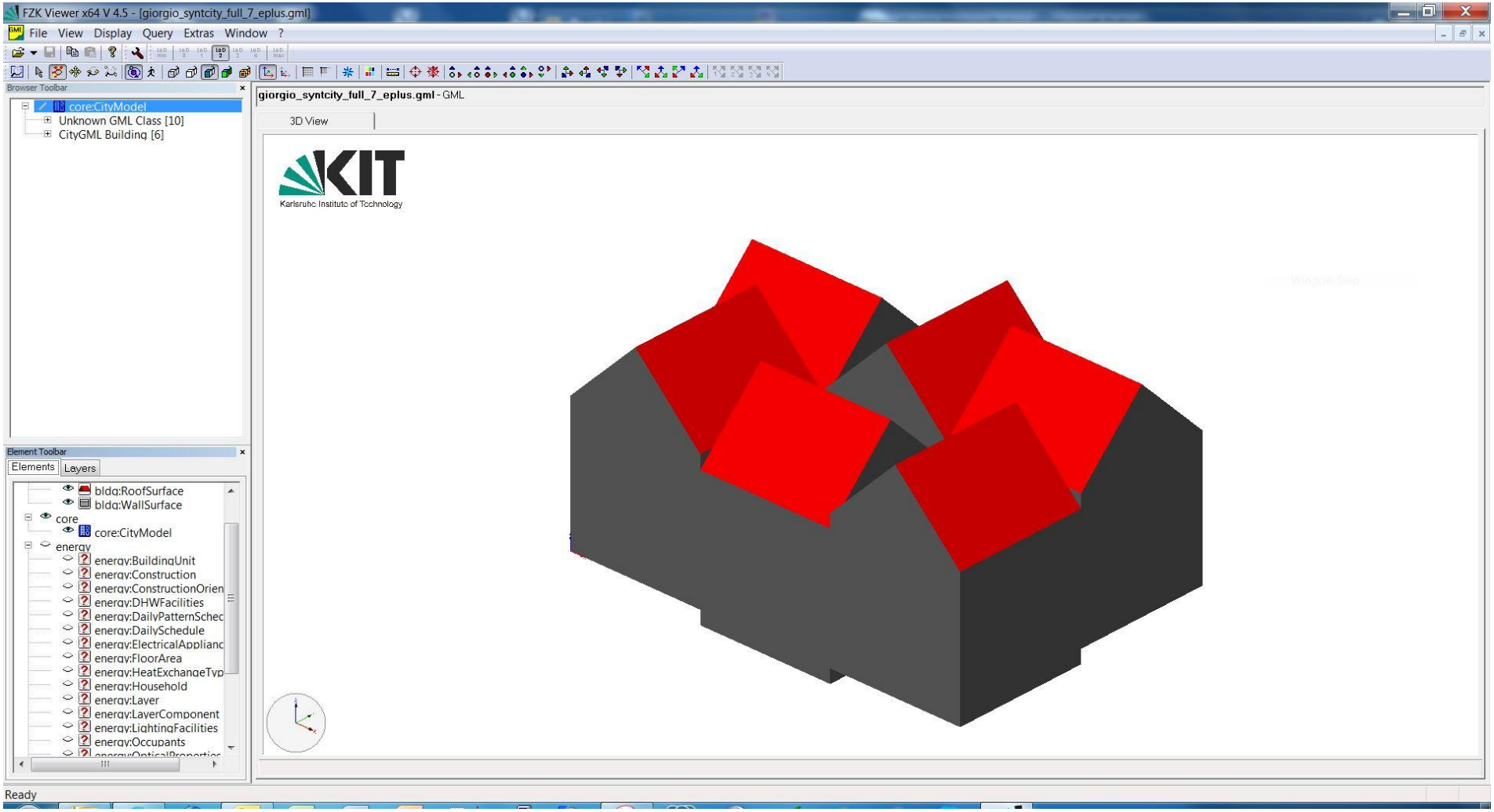
Experimental results

- 2 test cases
  - Multiple buildings, single zones
  - Single building, multiple zones

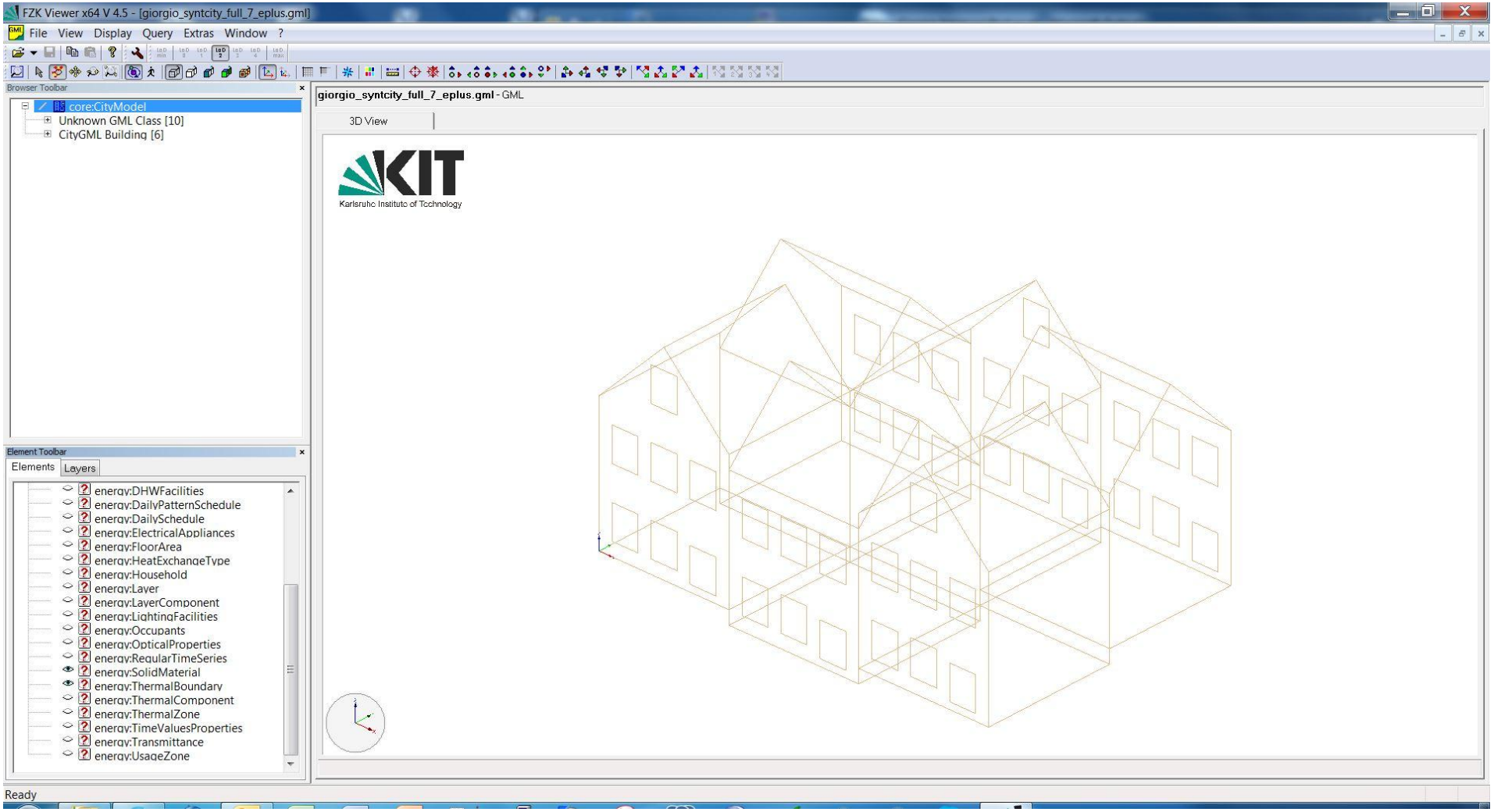
Experimental results

- 6 single-zone buildings
- Convex zones
- Characterised as
  - 4 residential buildings
  - 1 commercial
  - 1 school
- Each zone has Electrical Appliances, DHW and Lighting facilities
- Typical load profiles and schedules for Austria

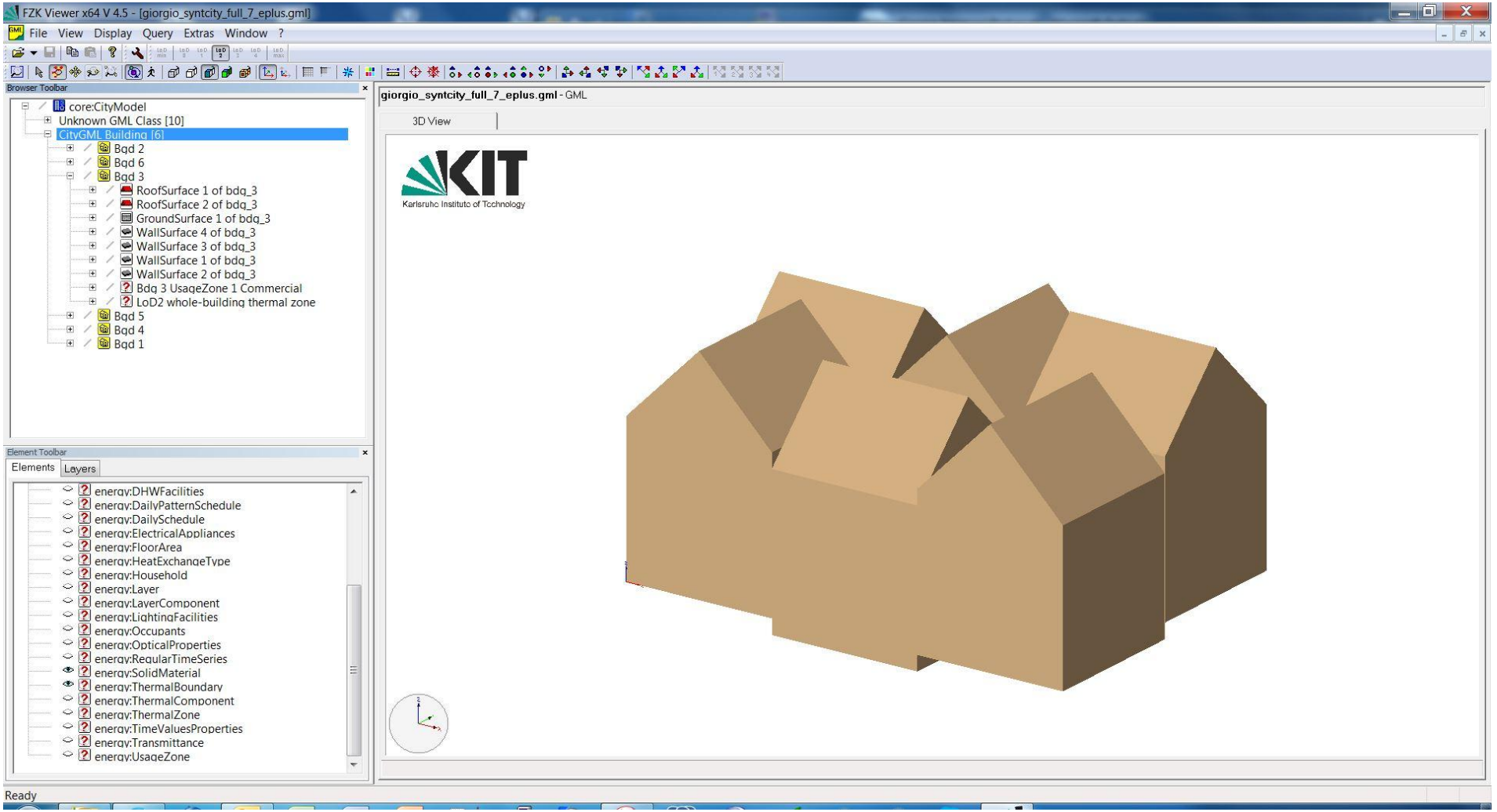
Experimental results



Experimental results



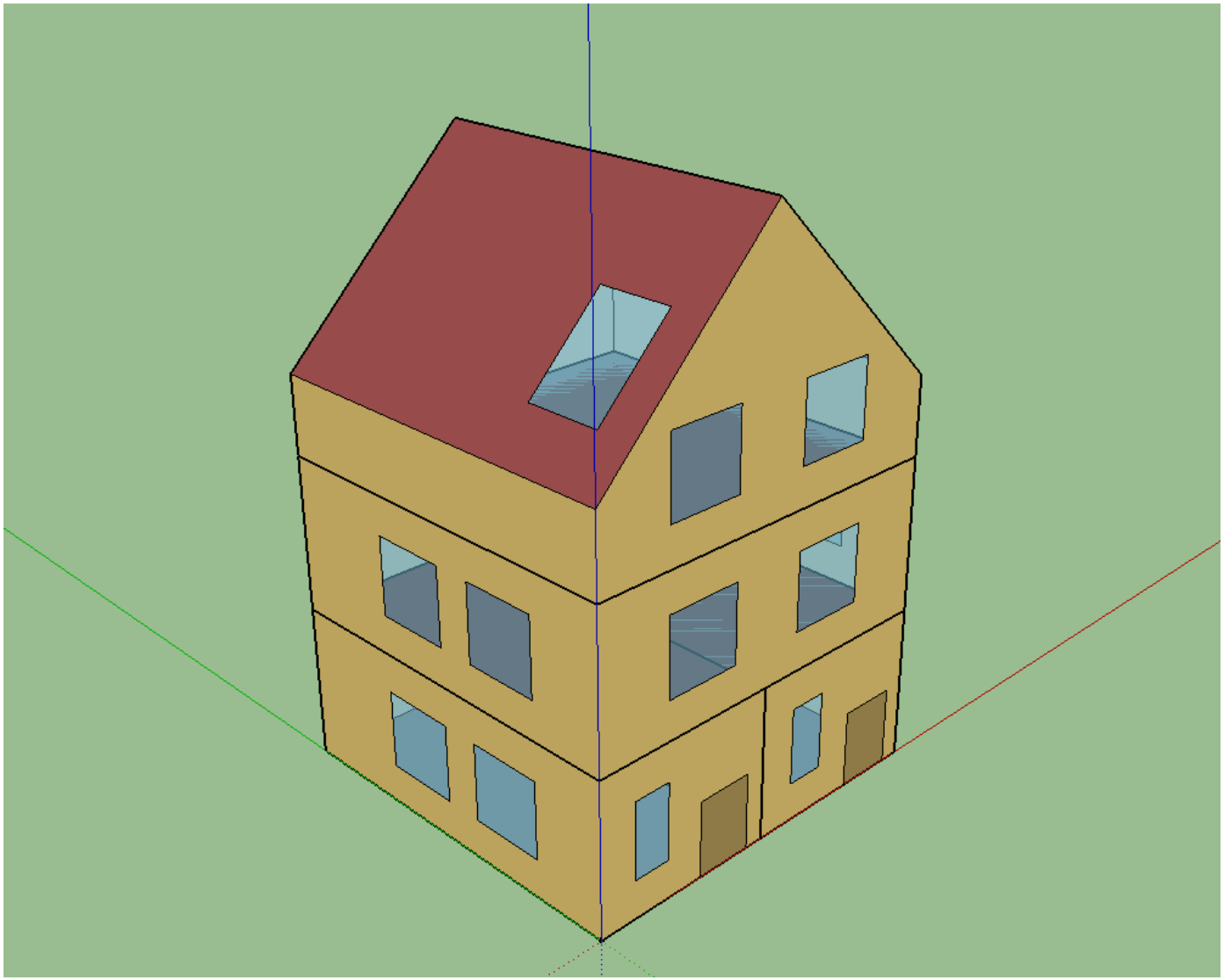
Experimental results



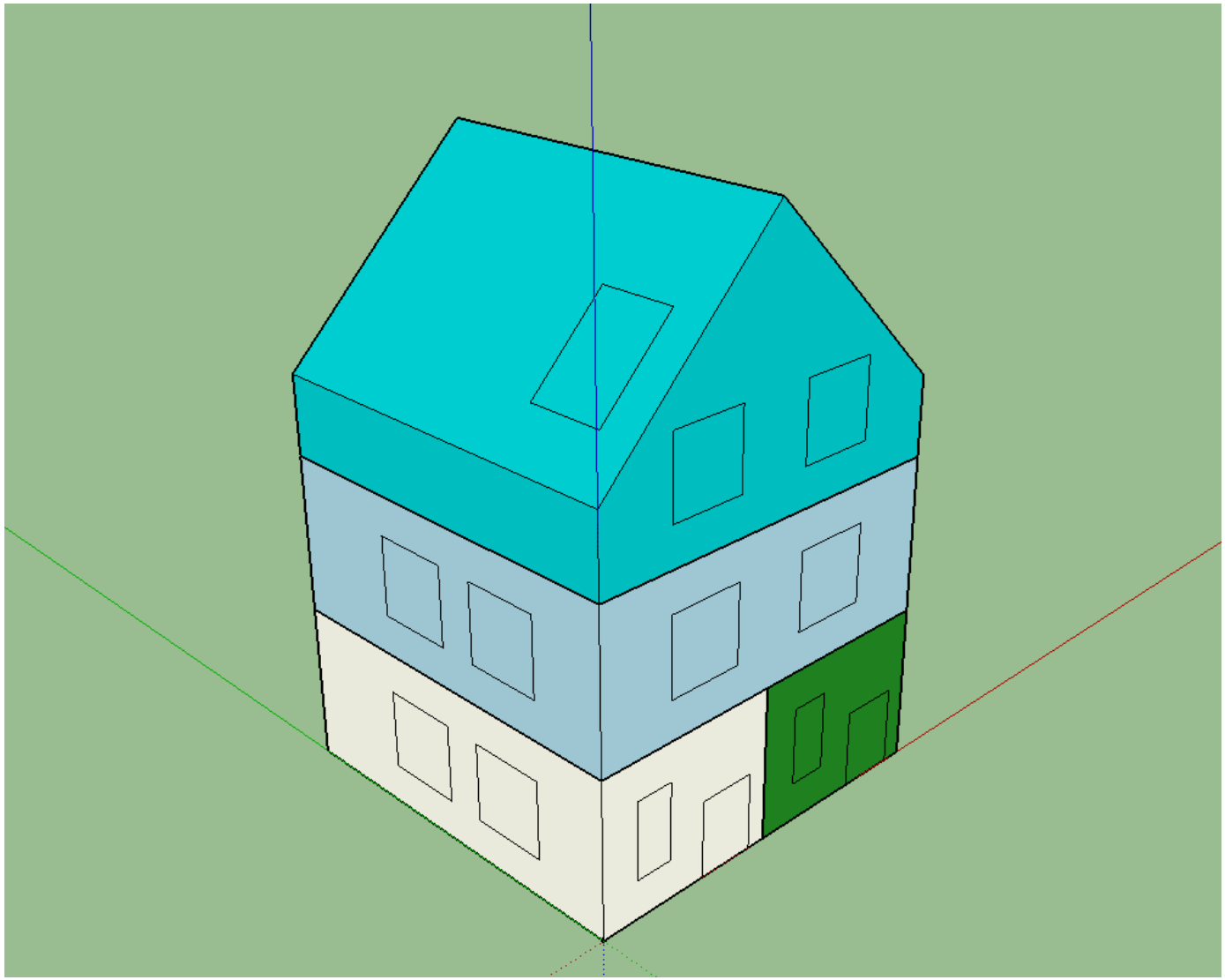
Experimental results

- Single 4-zone building
- Convex zones
- Characterised as
  - 2 residential
  - 1 commercial
  - 1 school
- Each zone has Electrical Appliances, DHW and Lighting facilities
- Typical load profiles and schedules for Austria

Experimental results



Experimental results



Experimental results

```
<bldg:Building gml:id="id_bdg_1">
  <energy:energyDemands>
    <energy:EnergyDemand gml:id="id_energy_demand_SpaceHeating_id_bdg_1">
      ...
      <energy:energyAmount>
        <energy:RegularTimeSeries gml:id="id_bdg_1_timeseries_energydemand_SpaceHeating">
          ...
          <energy:timeInterval unit="hour">1</energy:timeInterval>
          <energy:values uom="W"> ... </energy:values>
          ...
        </energy:RegularTimeSeries>
      </energy:energyAmount>
    </energy:EnergyDemand>
  </energy:energyDemands>
</bldg:Building>
<bldg:WallSurface gml:id="id_bdg_1_ws_2">
  ...
  <energy:globalSolarIrradiance>
    <energy:RegularTimeSeries gml:id="id_bdg_1_ws_2_timeseries">
      ...
      <energy:timeInterval unit="hour">1</energy:timeInterval>
      <energy:values uom="W"> ... </energy:values>
    </energy:RegularTimeSeries>
  </energy:globalSolarIrradiance>
  ...
</bldg:WallSurface>
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  ...
  <energy:energyDemands>
    <energy:EnergyDemand gml:id="id_energy_demand_SpaceCooling_UUID_715f392f-a110-4bbe-addd-4af84299b8d5">
      ...
      <energy:energyAmount>
        <energy:RegularTimeSeries gml:id="UUID_715f392f-a110-4bbe-addd-4af84299b8d5_timeseries_energydemand_SpaceCooling">
          <energy:timeInterval unit="h">1</energy:timeInterval>
          <energy:values uom="W"> ... </energy:values>
        </energy:RegularTimeSeries>
      </energy:energyAmount>
    </energy:EnergyDemand>
  </energy:energyDemands>
</energy:ThermalZone>
```

Conclusions

Conclusions

- Interface between CityGML and EnergyPlus:
  - converts data from CityGML to IDF file(s)
  - launches EnergyPlus simulation(s)
  - extracts EnergyPlus results from SQLite databases and integrates them back into CityGML
  - is based on Energy ADE v0.6

- Constraints / Limitations:
  - Zones need to be convex to fully exploit EnergyPlus
  - 1 ThermalZone = 1 UsageZone
  - EnergyPlus geometrical (& topological) model sometimes tricky
    - Handling of openings may require some workaround
    - Relations between adjacent walls
    - Distinction between adjacent ceiling & floors

- Lessons learned
  - Energy ADE v0.6 allows to link CityGML to EnergyPlus
  - Contribute to feedback for Energy ADE v0.7

Outlook

- WIP: Further testing with real data (e.g. from Vienna city model)

- Planned improvements
  - Add geometries for computation of shadowing from nearby buildings
  - Consider other EnergyPlus classes to extend simulation options
  - Further integration of *Energy Use and System* module

Thank you for your attention

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Master Thesis: "Conceptual Modelling and Implementation of a bidirectional data interface between CityGML and EnergyPlus" (due summer 2016)
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ACKNOWLEDGEMENTS
Stefan Hauer, Aurelien Bres (AIT)