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

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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?
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

  - 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

- In CityGML a ThermalZone knows which ThermalBoundaries/BoundarySurfaces it consists of.
- In EnergyPlus a BuildingSurface/FenestrationSurface knows to which Zone it belongs (the opposite).
- Touching surfaces of different zones?
  - \( \rightarrow \) CityGML generic attribute ".touches".

In CityGML, add generic attribute "touches" to ThermalBoundary class.
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)

```xml
<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

CityGML Class 1 → EnergyPlus Class 1
CityGML Class 2 → EnergyPlus Class 2
CityGML Class 3 → EnergyPlus Class 3

CityGML File → Idf File
Mapping Materials (example)

```
<enum>
    EnergyPlus::Roughness
    +Smooth
    +VeryRough
    +Rough
    +MediumRough
    +MediumSmooth
    +Smooth
    +VerySmooth
</enum>
```
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
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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