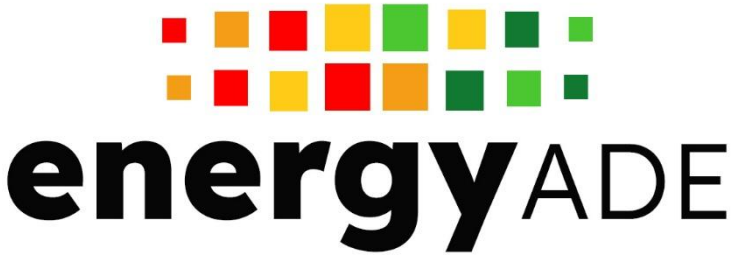

Still alive and… evolving!

Giorgio Agugiaro, Rushikesh Padsala, Volker Coors

TU Delft

Hochschule für Technik Stuttgart

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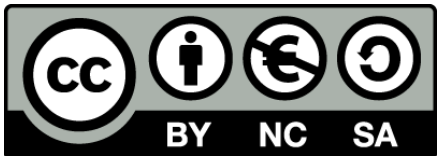

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Part 1

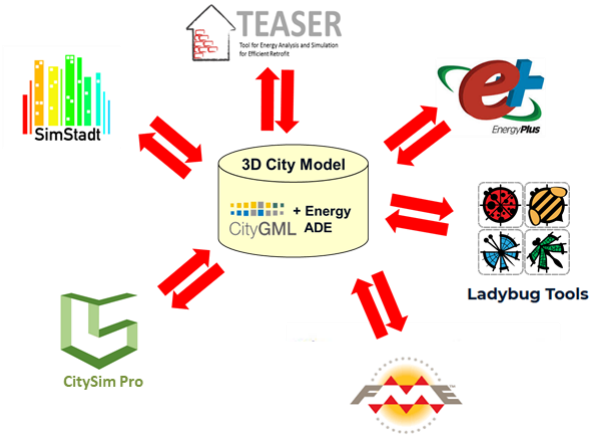
A brief history of the Energy ADE

Energy ADE

- Ease data interoperability for Urban Energy Modelling
  - Between different software tools
  - Between different stakeholders

- Define (and store) energy-related data in a standard, open, urban data model
  - Allow for multi-scale energy modelling

- Based on multidisciplinary cooperation between CityGML users, data producers, software vendors, …, and scientists



Energy ADE 1.0

- International consortium started in 2014
  - Over the years, participation of up to ca. 20 institutions, 11+ countries

- Open, consensus-based development
  - **Version 1.0** released in **June 2018**
  - Wiki: http://en.wiki.energy.sig3d.org

Further details:
Agugiaro, G., Benner, J., Cipriano, P., Nouvel, R., 2018
The Energy Application Domain Extension for CityGML: Enhancing interoperability for urban energy simulations. Open Geospatial Data, Software and Standards 2018 3:2. https://opengeospatialdata.springeropen.com/articles/10.1186/s40965-018-0042-y (open access)

Energy ADE 1.0: Availability

- **Energy ADE 1.0**
  - Data model (UML)
  - XSD file (for XML-based CityGML)
  - Some test data
  - Limited software support (FME, KIT ModelViewer)

- **Energy ADE 1.0 "KIT profile":** *subset* of classes, attributes, etc.
  - Data model (UML)
  - XSD file
  - Supported by
    - FME and KIT ModelViewer
    - SimStadt, CitySim (for data export)
    - 3D City Database (database, importer/exporter, WFS)
  - Used in several national/international projects since 2018

https://3d.bk.tudelft.nl/gagugiaro/pdf/2020_06_Energy_ADE_OGC.pdf

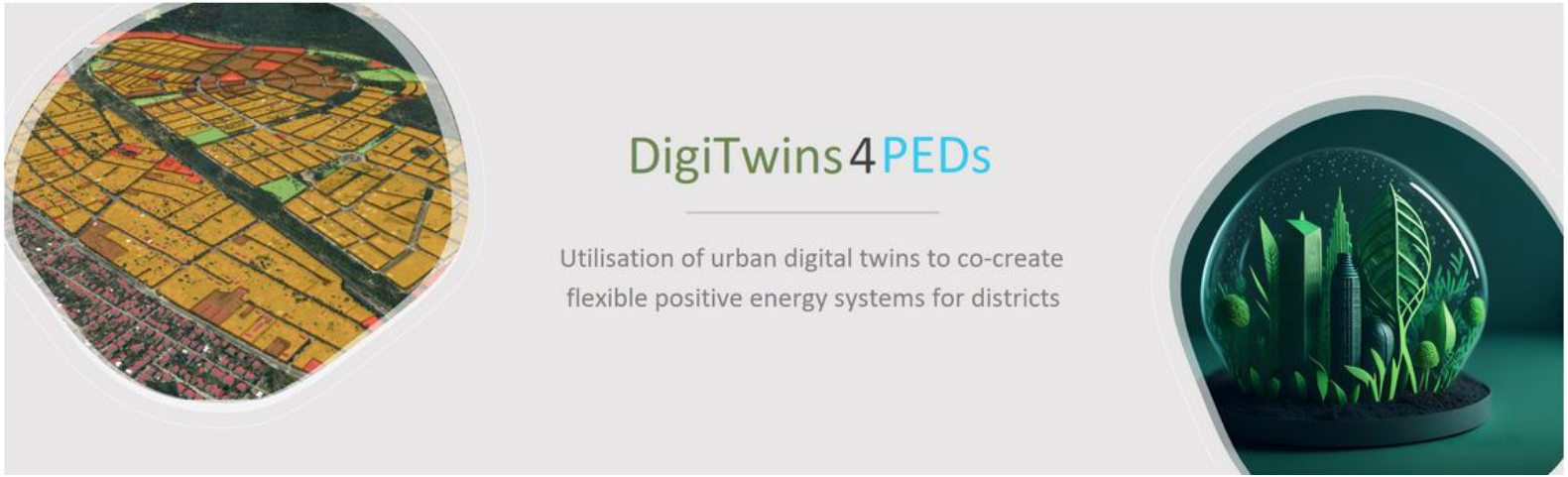
What has happened since 2018?

- **Lessons learned:**
  - Energy ADE 1.0:
    - Needed to bridge UBEM with 3D city models, but…
    - …too complex in certain parts (e.g. Energy Systems module)
    - Lack of
      - modelling guidelines for non-experts
      - sufficient example data for learning
      - sufficient software support
  - Energy ADE 1.0 KIT profile:
    - better software support
    - smaller and easier to use, but…
    - …many things lost for the sake of simplification

- **2019: Energy ADE 2.0**
  - Drops Energy Systems Module
  - Otherwise only corrections and very minor changes from version 1.0
  - Development stopped in 2019

What has happened since 2018?

- More ADEs created with some relevance for energy
  - **Utility Network ADE** (2018)
  - **i-UR ADE** (Information Infrastructure for Urban Revitalization) (2020)
  - **Food-Water-Energy ADE** (2021)
- **CityGML 3.0**, in particular the **Core** and the **Dynamizer** modules (2021)
- EU project **DigiTwins4PEDs** (2023-2026): **Time to update the Energy ADE!**



https://digitwins4peds.eu

Part 2

Towards Energy ADE 3.0

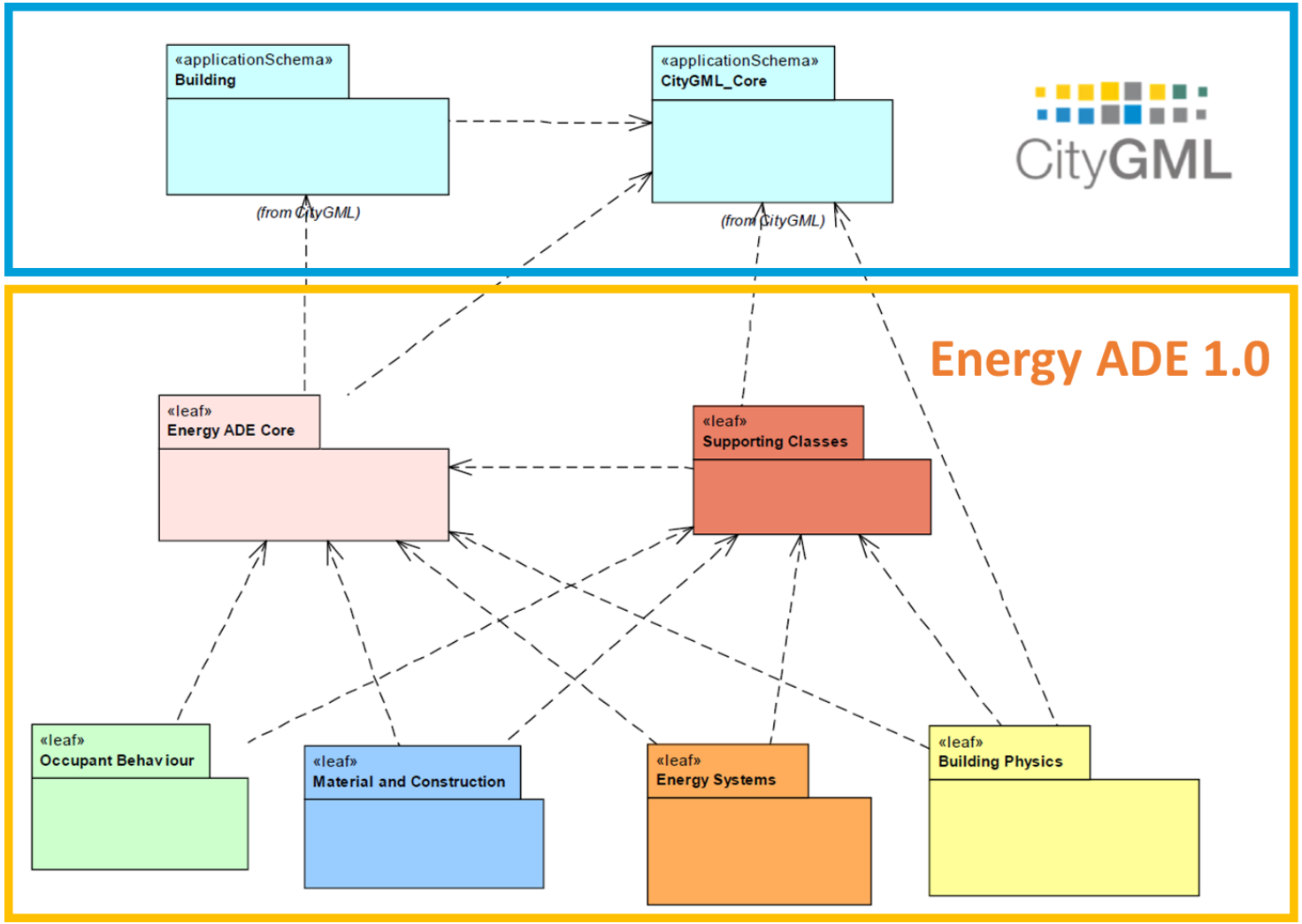
Energy ADE 3.0: Main characteristics

Goals

- Keep the modular structure
- Keep compatibility with KIT Energy ADE 1.0
- Build upon Energy ADE 1.0 (and 2.0)

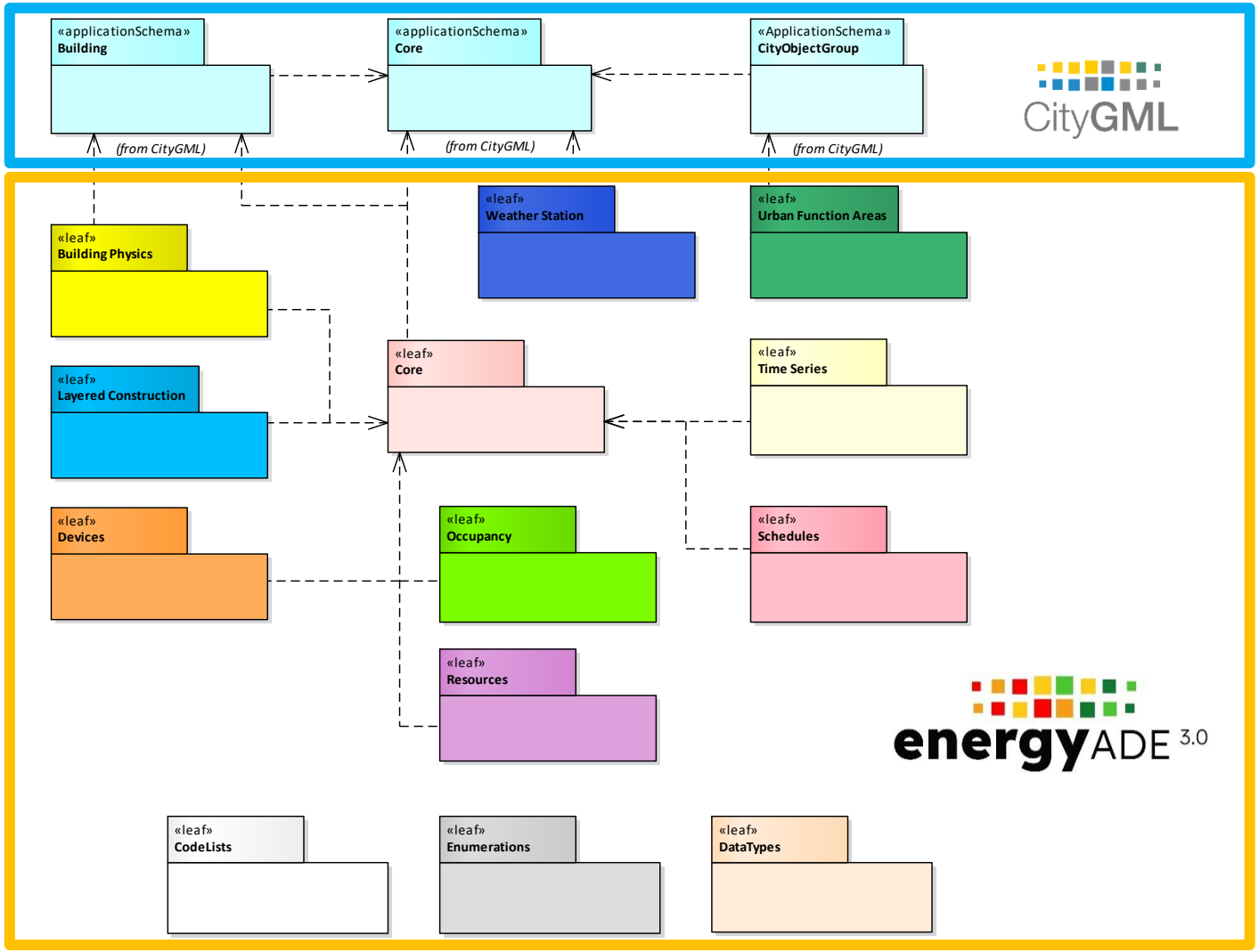
Characteristics

- Updates based on accumulated past experiences
  - Simplify/redesign the data model in certain places
  - Backport some ideas from CityGML 3.0
- Designed for CityGML **2.0**, but keeping in mind the future mapping to CityGML **3.0**
- Avoid past pitfalls!!!
  - Provide good **documentation**
  - Provide **modelling rules**
  - Provide sufficient **example data**
  - **Implement** it! 😊



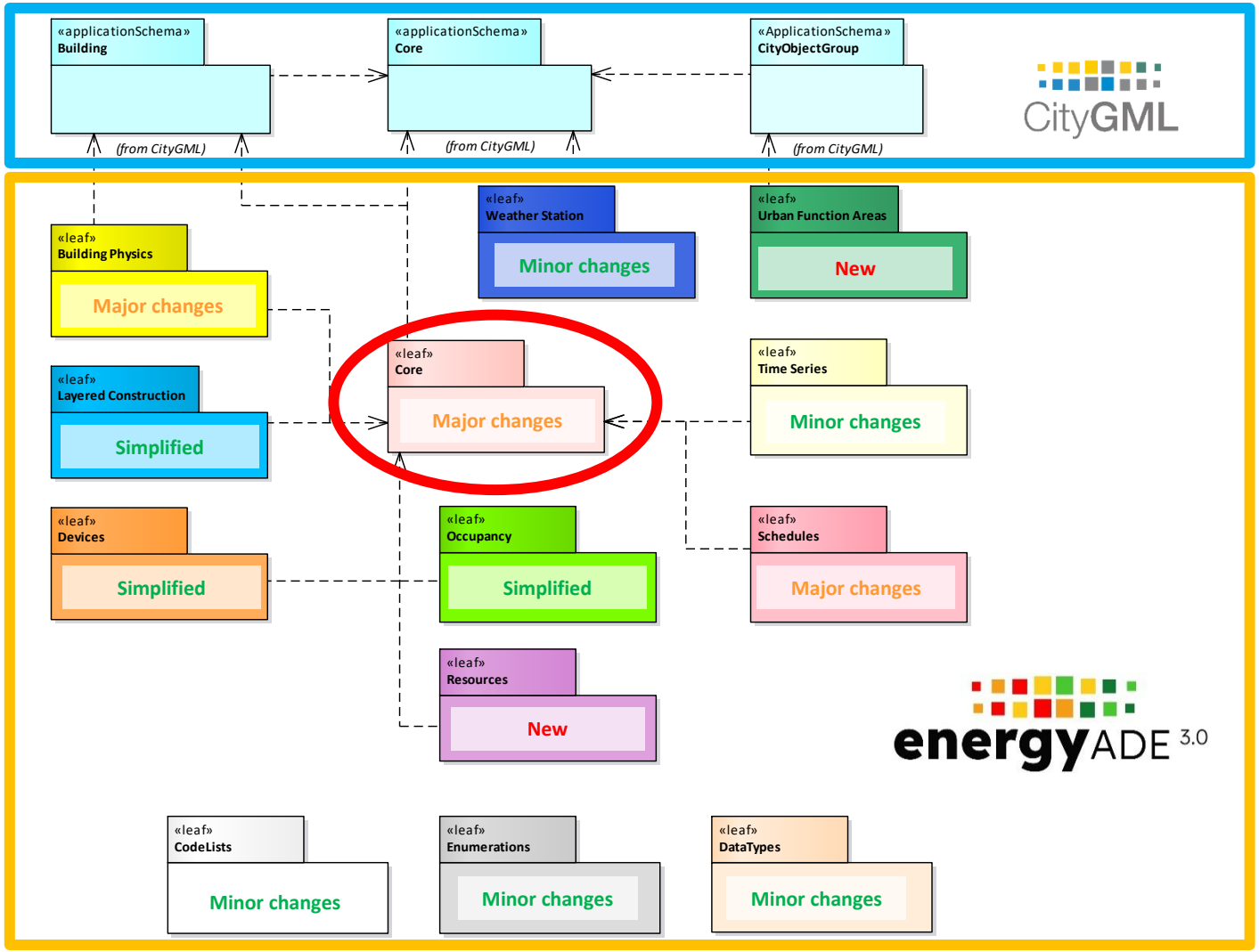
TU Delft 3Dgeoinfo

DigiTwins4PEDs



TU Delft 3Dgeoinfo

DigiTwins4PEDs

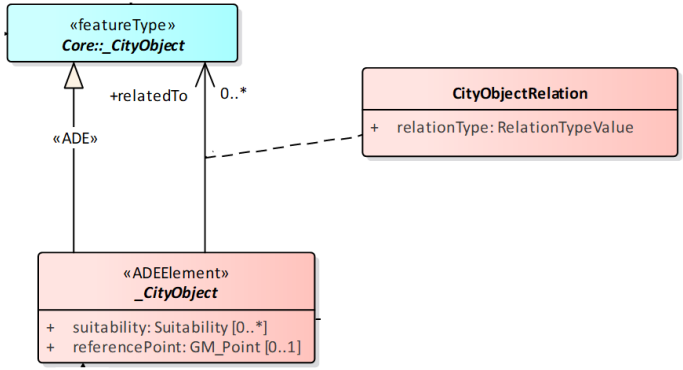


Core module

- Same as before:
  - Contains abstract base classes for other modules
  - Extends CityGML classes **_CityObject** and **_AbstractBuilding**

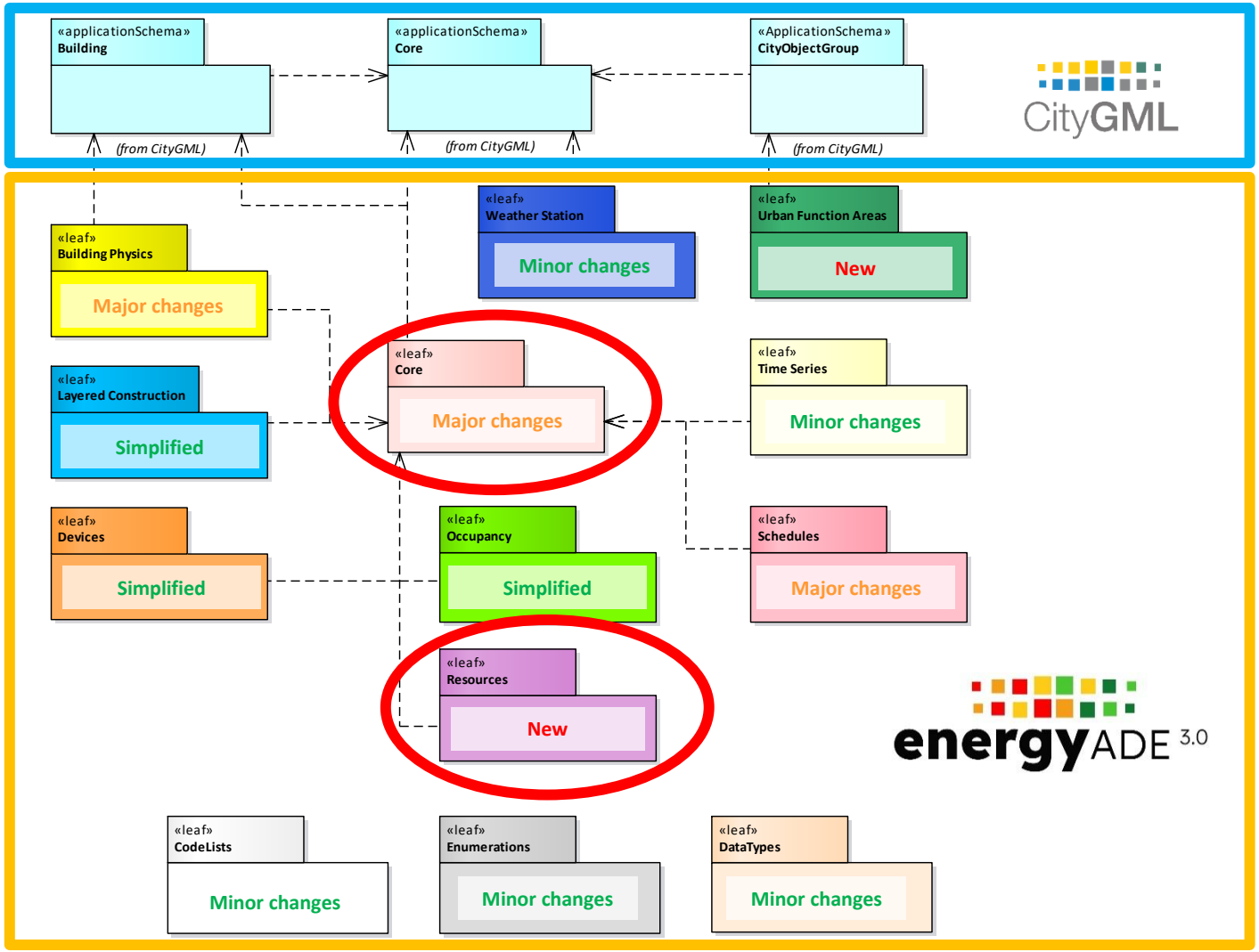
- **New:** Backports from CityGML 3.0:
  - All city objects can be represented with a **point geometry**
  - Class **CityObjectRelation** for arbitrary relations between cityobjects

- **New:** Minor adjustments for future mapping to CityGML 3.0
  - <<Type>> stereotype replaced with <<featureType>>



TU Delft 3Dgeoinfo

DigiTwins4PEDs



New **Resources** module

- The main idea is that *every* city object can...
  - ...demand/consume... produce/generate... store/accumulate...
  - ..."something" (i.e. a *resource*)

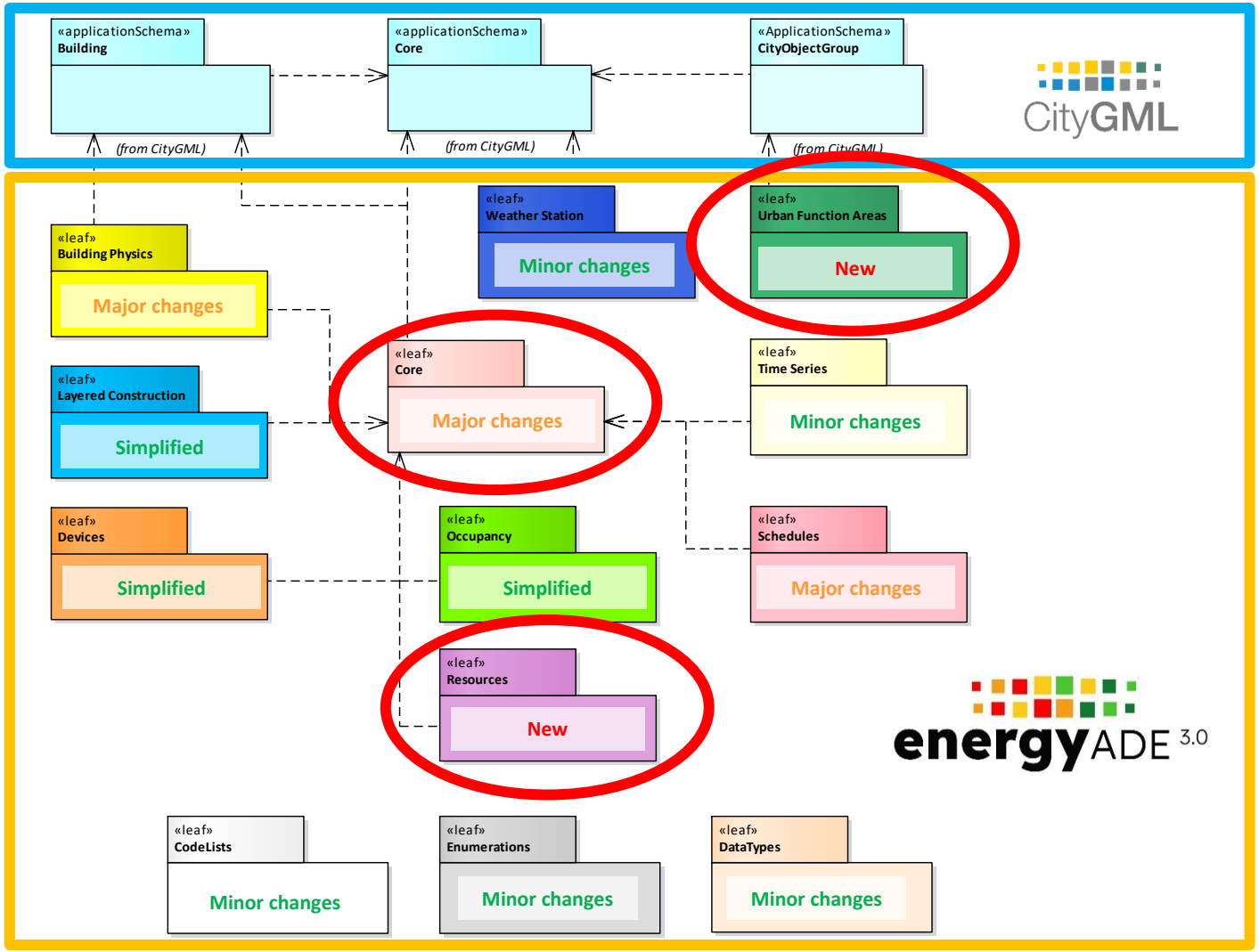
- This "something" is **Energy**, but also **Water**, **Food**, **Waste**, **ConstructionMaterial**, ...
  - The quantity can be expressed as a (yearly) amount, or as a time series (or both)
  - Values can be provided as absolute or specific values (+ normalization value)
  - Example: Energy demand expressed in kWh/year, or kWh/year/m^2

- It is now possible to deal with
  - *actual* and *potential* values,
  - *simulated* and *measured* values

- This module reworks and integrates some concepts from **Food-Water-Energy ADE**
- Energ ADE 1.0: Only **EnergyDemand** class

TU Delft 3Dgeoinfo

DigiTwins4PEDs



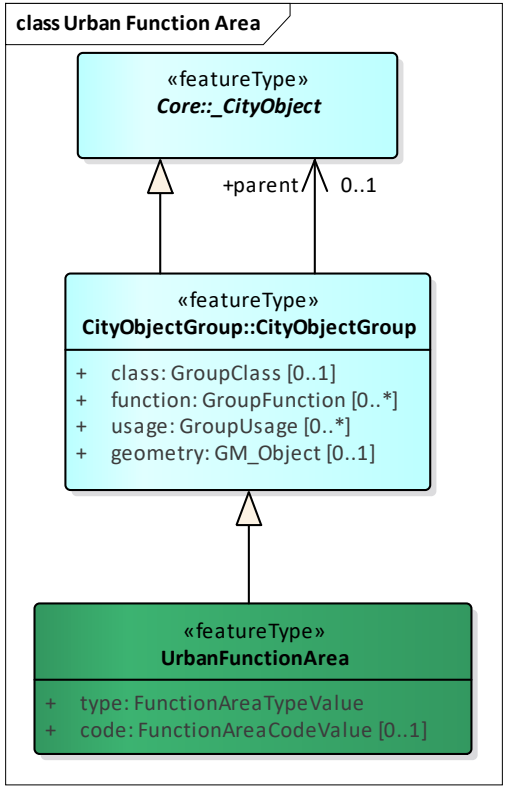
New **Urban function areas** module

- Idea: present **aggregated results**, using different grouping strategies

- Define **spatial entities** that identify portions of space to
  - group (city)objects or
  - identify certain areas

- These spatial entities can be **hierarchically grouped**
  - They can follow administrative boundaries
    - E.g. block, neighbourhood, district, city, etc.
  - Or they can follow a regular pattern
    - E.g. grid cells (e.g. statistical/census data)

- This module takes inspiration from **i-UR ADE**

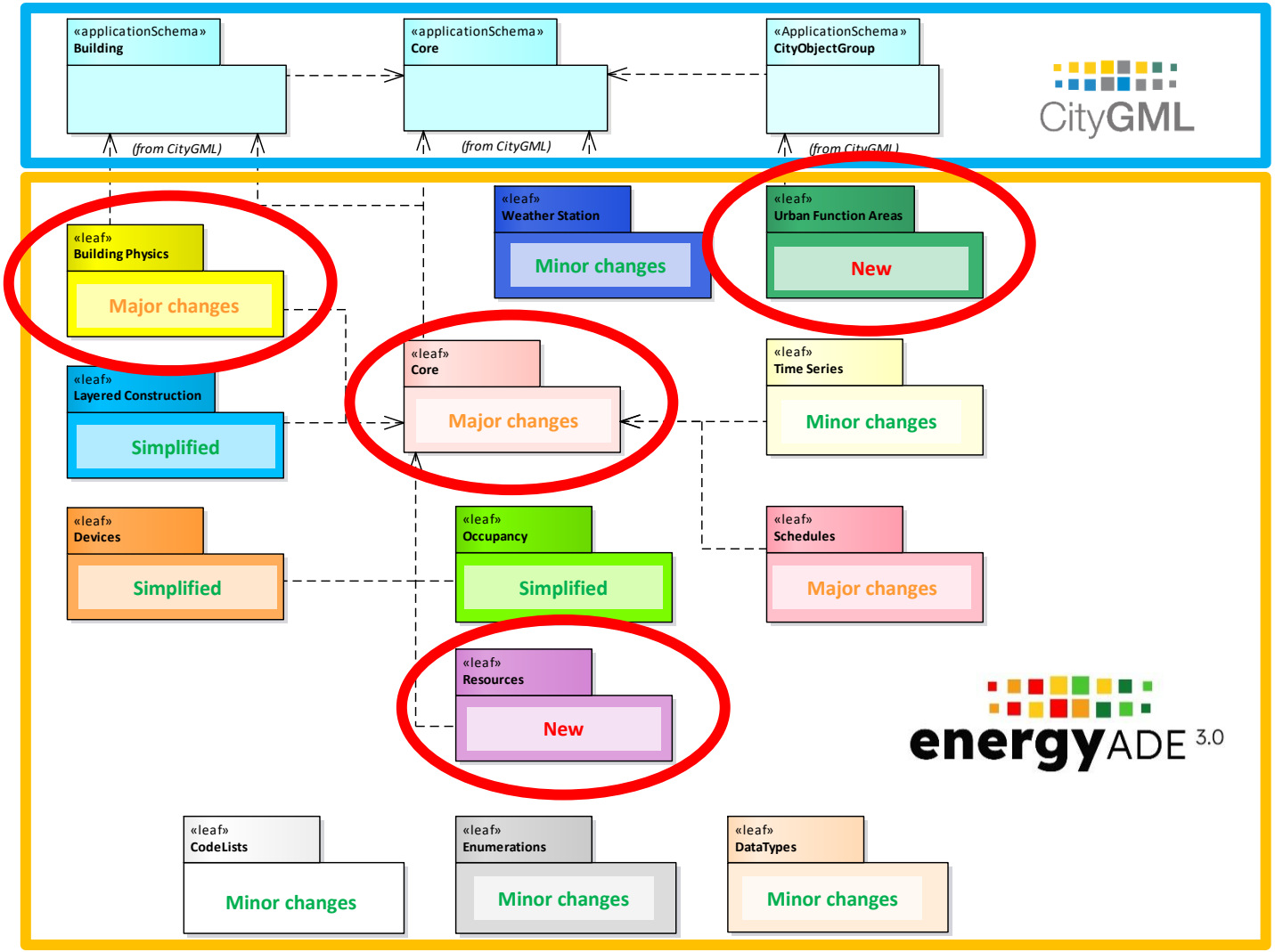


New **Urban function areas** module

Cooling energy demand in Rotterdam (The Netherlands) at **building** and at **neighbourhood level**

TU Delft 3Dgeoinfo

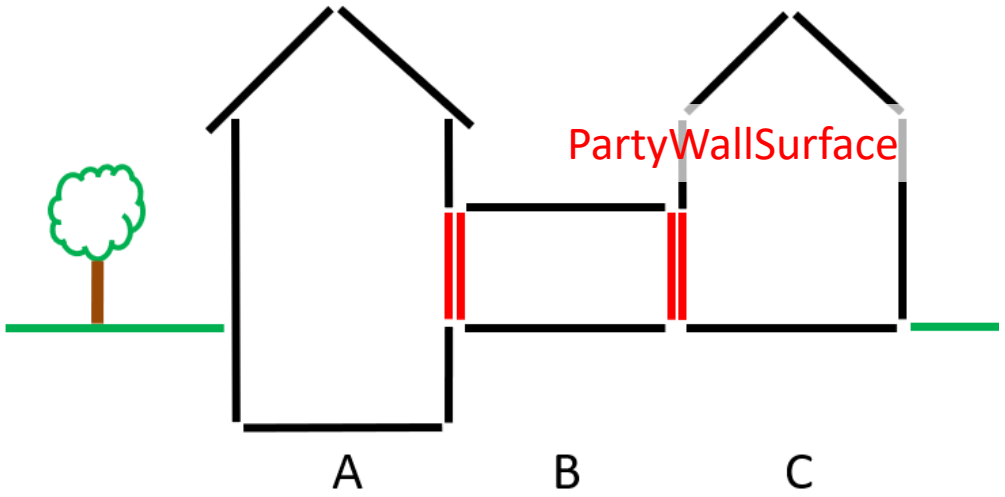
DigiTwins4PEDs



Redesigned **Building physics** module

Still WIP!

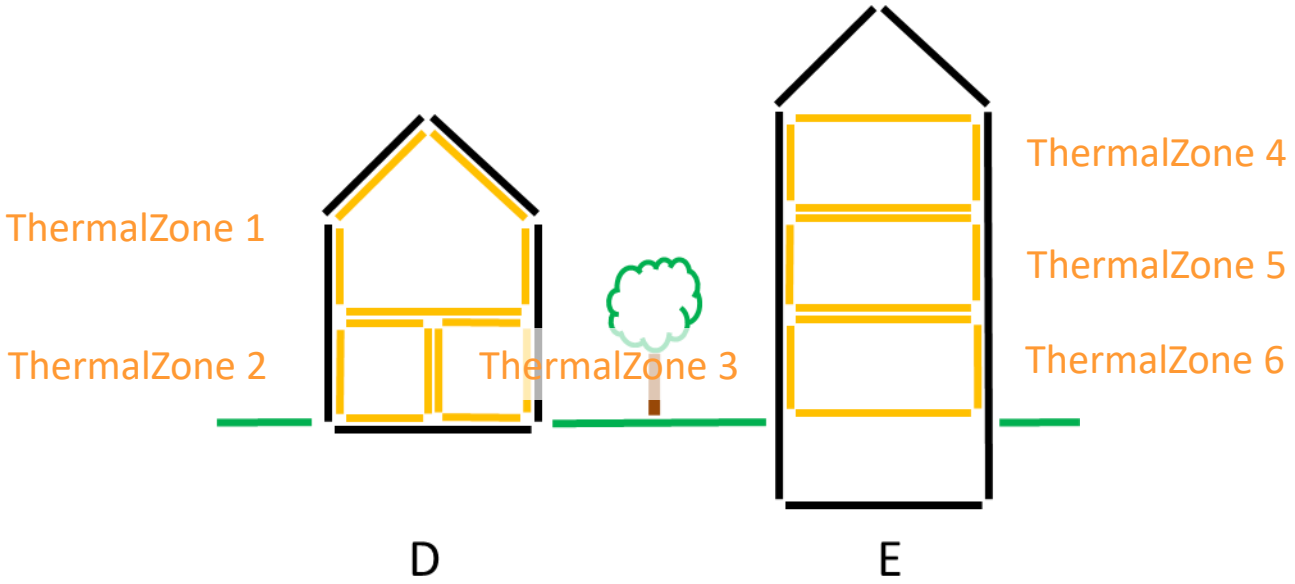
- Contains classes to define a **thermal zone**, **thermal boundaries**, and **thermal openings**, as well as their geometrical and physical parameters



Redesigned **Building physics** module

Still WIP!

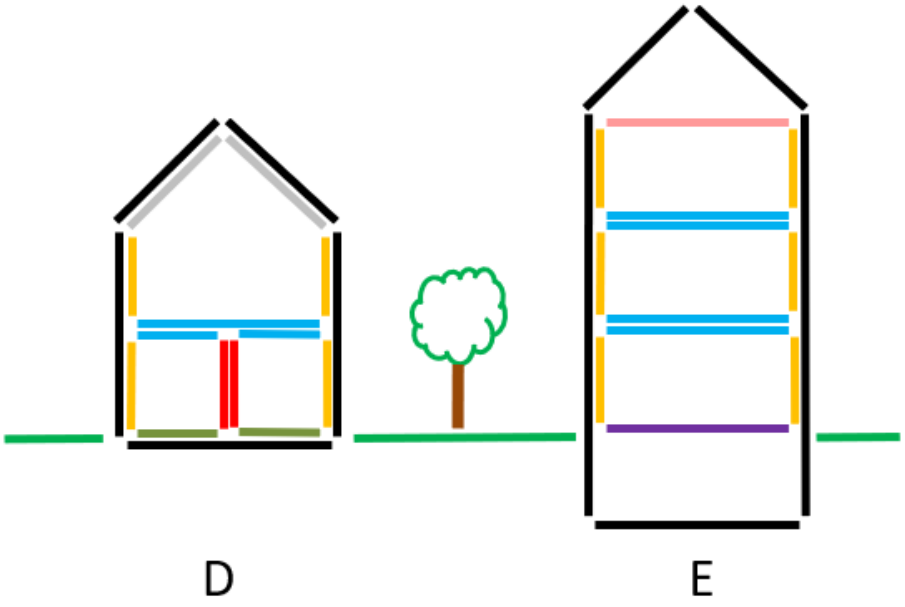
- Allows to create **thermal zones**...



Redesigned **Building physics** module

Still WIP!

- Allows to create **thermal zones**, and to define their boundaries by means of **thematic surfaces**



RoofSurface

(exterior) WallSurface

AtticFloorSurface

IntermediateFloorSurface

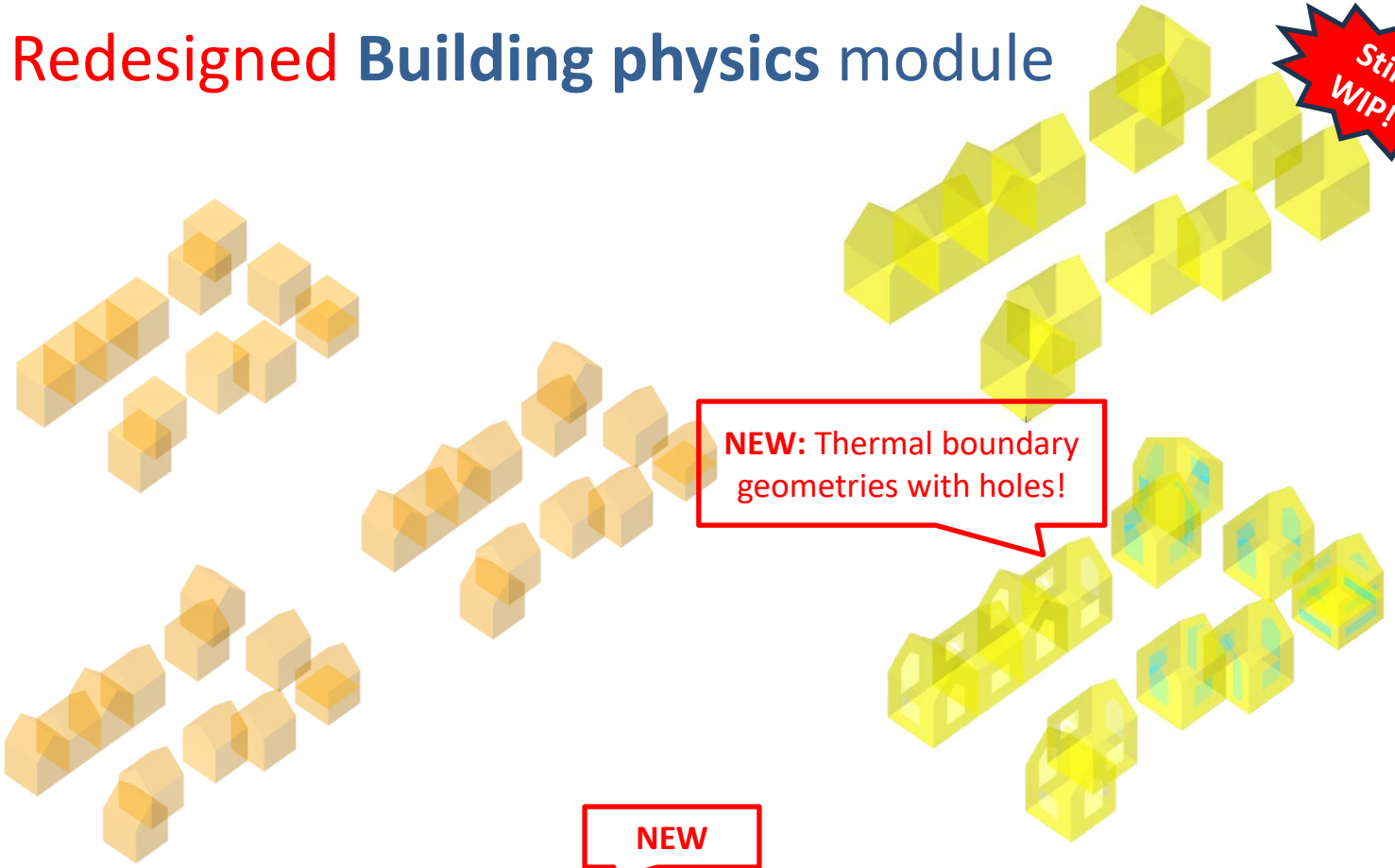
BasementCeilingSuirface

PartyWallSurface

GroundSurface

Redesigned **Building physics** module

Still WIP!



NEW: Thermal boundary geometries with holes!

NEW

Thermal zones, **LoD1 to LoD3** (solid geometries)

NEW

Thermal boundaries (+ thermal openings), **LoD2 and LoD3**, multi-surface geometries

Part 3

Available resources

Documentation

CityGML

energyADE 3.0

Beta 7

UML diagrams

CityGML

energyADE 3.0

Beta 7

Specifications

Documentation: Modelling rules

DigiTwins4PEDs

History
Updates
Resources
Tests
Conclusions

Example 6: LoD3 building modelled via thematic surfaces and with openings. Roof edge extruded downwards to create the LoD3 envelope. Openings are "simply" cut into the hull surfaces. No overhangs With ADE attributes for thematic surfaces and openings, information about azimuth, inclination, sky view factor, etc. can be stored.	
Special case 6.1: Single LoD3 thermal zone, with thermal boundaries and thermal openings. All LoD3 thermal boundaries/opening coincide exactly with the building LoD3 thematic surfaces/openings • Basically, same rules as for Case 5.1 • One thermal zone must be created. Set property *coincidesWithLoD3Hull* of the thermal zone to **TRUE** • The thermal zone can optionally be modelled as a LoD3 solid geometry. If applicable, XLinks can be used to reference the homologous polygons of the LoD3 solid • Neither the LoD3 thermal boundaries nor the LoD3 thermal openings must be modelled. The corresponding building LoD3 thematic surfaces and openings must be used instead • *LayeredConstructions* (i.e. U and g values) are associated to the building thematic surfaces/openings	

4.3.2 Using the new ADE classes for thermal boundaries

The Energy ADE 3.0 adds four new classes derived from *_BoundarySurface*: *PartyWallSurface*, *AtticFloorSurface*, *IntermediateFloorSurface*, and *BasementCeilingSurface*. Figure 22 and Figure 23 provide simple, schematic examples of when to use such new classes to model adjacent buildings and thermal zones, respectively. In these examples, class *PartyWallSurface* is represented in red and is intended to be used when modelling:

- Party walls between two adjacent buildings (e.g. between buildings A and B, and B and C)
- Party walls between two adjacent thermal zones (e.g. in building D)

Class *IntermediateFloorSurface* is represented in azure (see buildings D and E), and is intended to be used to model the horizontal surface subdividing two thermal zones, unless they correspond with the following two special cases.
Class *AtticFloorSurface* is used to model the horizontal surface of a thermal zone which is located under an "empty" space which is not modelled as a thermal zone. An example of such empty space could be an attic under the roof (see building E).
Class *BasementCeilingSurface* is used to model the horizontal surface of a thermal zone which is located above an "empty" space which is not modelled as a thermal zone. An example of such empty space could be an underground garage (see building E).

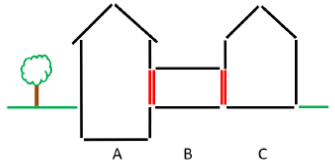


Figure 22. Schematic examples of surfaces modelled using class *PartyWallSurface* (in red).

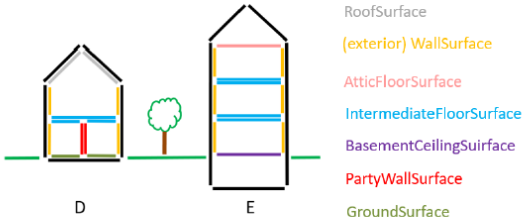


Figure 23. Schematic examples of thermal boundary surfaces modelled using different classes.

4.4 Occupancy module

4.4.1 Rule 5: Modelling and writing *Address* objects

Address objects must be always modelled as belonging to the respective parent *Building* (or *BuildingPart*) objects, as in standard CityGML. Additionally, in accordance with Rule 1 and as suggested by the annotations in the UML diagrams of the Occupancy module, the association between *BuildingUnit* and *Address* is of type "byReference", therefore it must be written using an XLink. An example is provided in Figure 17 (line 18).

4.4.2 Modelling geometries of *UsageZone* and *BuildingUnit* objects

Rule 2 applies also to modelling the geometries of *UsageZone* and *BuildingUnit* objects. All (optional) representations by means of solid geometries (for LoD1, LoD2 and LoD3), inherited from *AbstractBuildingPartition*, can be either explicit, or references to geometries used elsewhere, but within the same building *and* the same LoD. For example, if a LoD2 usage zone corresponds geometrically to the LoD2 thermal zone that is part of, then XLinks can be used between the LoD2 solid of the usage zone and the LoD2 solid of the thermal zone.

"Alderaan" test datasets

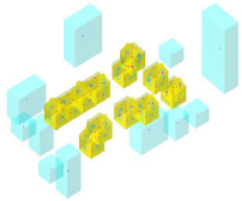
Alderaan_ADE_Building_Physics.gml

CityGML:
- CityObjectGroup
- Building, BuildingPart
- (Building) GroundSurface, WallSurface, RoofSurface
- (Building) Window
- Address
- Appearance, X3DMaterial

Energy ADE 2.0:
- CityObjectRelation
- ADE Building, ADE BuildingPart
- BasementCeilingSurface, IntermediateFloorSurface, PartyWallSurface
- ThermalZone

This file is the same as the previous one, but it adds ThermalZone objects, which are modelled via solid geometries (LoD1, LoD2 and LoD3) and via thermal boundaries (LoD2 and LoD3) and thermal openings (LoD3).

This dataset uses classes from the Energy ADE 2.0 Core and Building physics modules.



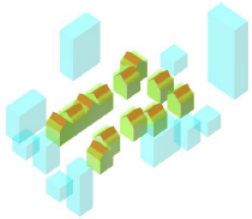
Alderaan_ADE_ThermalZone_CoincidesWithLoD2Hull.gml

CityGML:
- CityObjectGroup
- Building, BuildingPart
- (Building) GroundSurface, WallSurface, RoofSurface
- Address
- Appearance, X3DMaterial

Energy ADE 2.0:
- CityObjectRelation
- ADE Building, ADE BuildingPart
- PartyWallSurface
- ThermalZone

This file is contains ThermalZone objects which are modelled via solid geometries (LoD1, LoD2 and LoD3). The LoD2 representation via thermal boundaries coincides with the building envelope defined by the thematic surfaces. Therefore, thermal boundaries are not defined explicitly, instead each thermal zone has the coincidesWithLoD2Hull attribute set to TRUE.

This dataset uses classes from the Energy ADE 2.0 Core and Building physics modules.



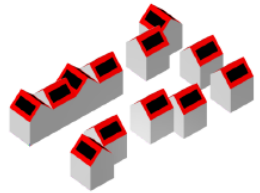
Alderaan_ADE_Devices.gml

CityGML:
- Building, BuildingPart
- (Building) GroundSurface, WallSurface, RoofSurface
- Address
- Appearance, X3DMaterial

Energy ADE 2.0:
- CityObjectRelation
- ADE Building, ADE BuildingPart
- Boiler, HeatPump, LightingDevice, GenericEletricalDevice, GenericDevice
- MovableShadingDevice
- ElectricalStorageDevice, ThermalStorageDevice
- GenericSolarCollector, SolarThermalCollector, PhotovoltaicCollector, PhotovoltaicThermalCollector

This file contains only the 11 "core" buildings, modelled only in LoD2 via thematic surfaces, and without shared walls. Additionally, all city objects are modelled via referencePoints.
The buildings contain objects from all classes of the Devices module. In particular, solar collectors are modelled in LoD2 and LoD3.

This dataset uses classes from the Energy ADE 2.0 Core and Devices modules.



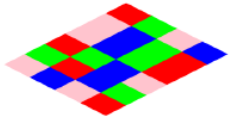
Alderaan_ADE_UrbanFunctionAreas.gml

CityGML:
- Appearance, X3DMaterial

Energy ADE 2.0:
- UrbanFunctionArea
- Energy
- Water

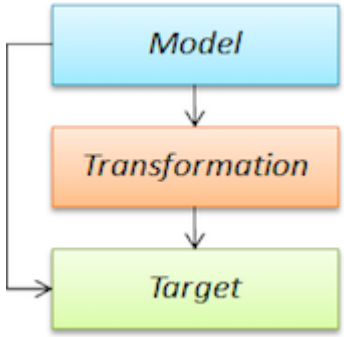
This file contains several UrbanFunctionAreas objects, organised in 3 hierarchical levels. The first-level object contains 6 second-level objects, which again contain each 4 third-level objects. The image on the right represents only the 24 third-level objects.
Each UrbanFunctionArea object is represented via a multisurface geometry and a referencePoint.
Some Energy and Water objects are associated with the UrbanFunctionArea objects, in order to provide an example of resources associated at each level.

This dataset uses classes from the Energy ADE 2.0 Core, Urban function areas and Resources modules.



XSD file

- Available for **beta7**
- Automatically derived from the UML diagrams using ShapeChange
- Manually checked, commented and "cleaned up"

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      <enumeration value="continuous"></enumeration>
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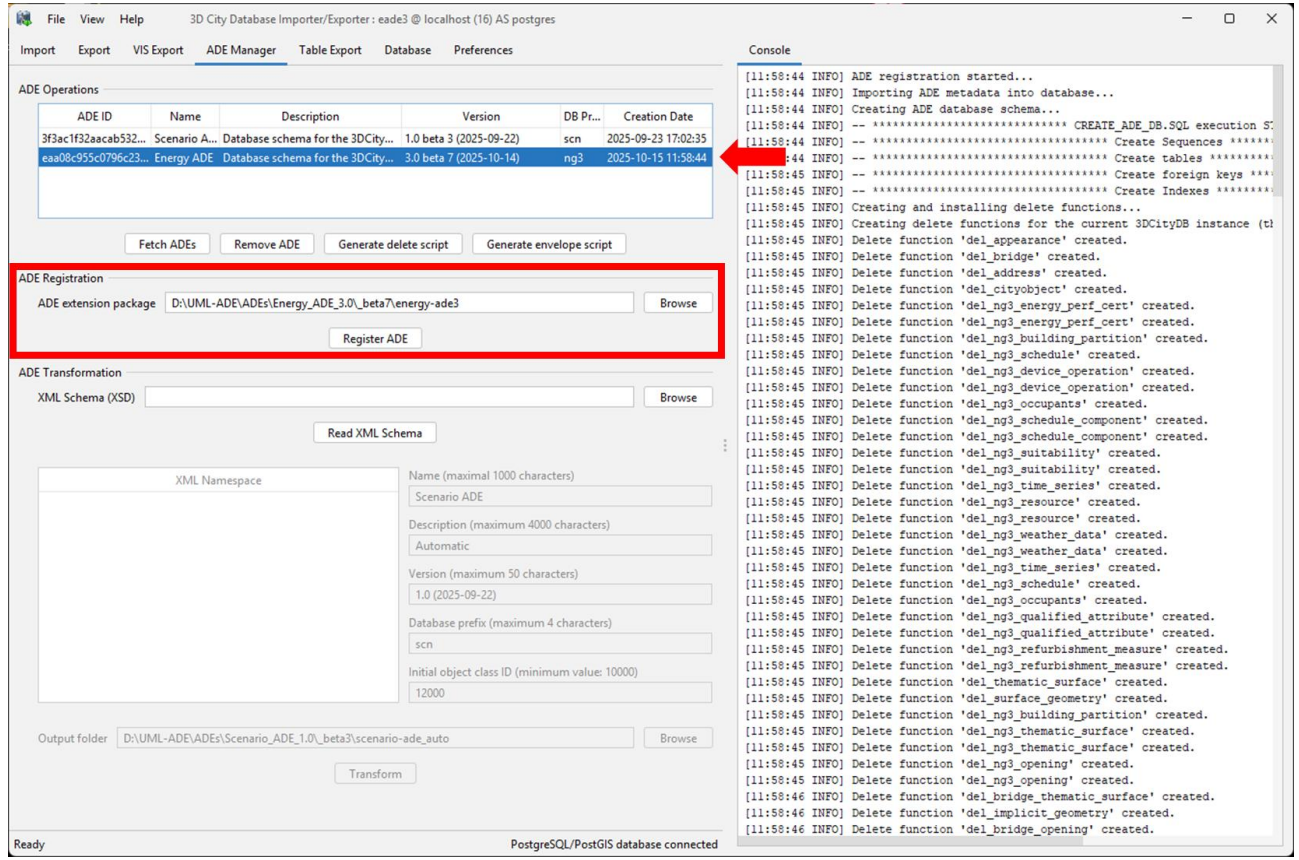
    </restriction>
  </simpleType>

  <simpleType name="NetworkConnectionStatusValueType">
    <restriction base="string">
      <enumeration value="connected"></enumeration>
      <enumeration value="disconnectedButConnectable"></enumeration>
      <enumeration value="disconnectedAndNotConnectable"></enumeration>
      <enumeration value="unknown"></enumeration>
    </restriction>
  </simpleType>
```

3DCityDB schema

DigiTwins4PEDs



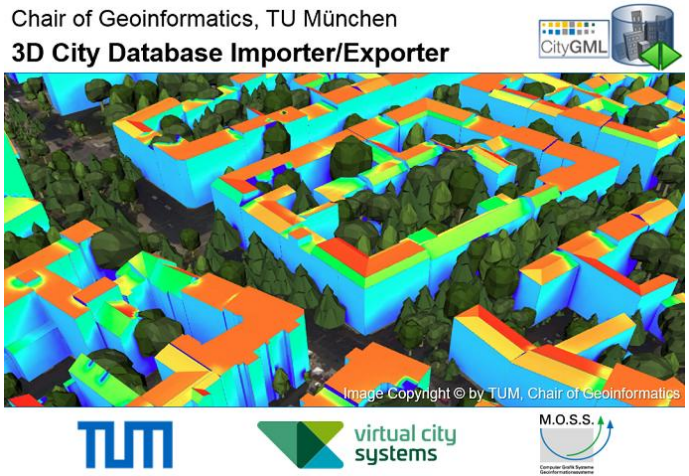
3DCityDB: Importer/Exporter

The CityGML Database
3D City DB

Java-based libraries for citygml4j and citydb

- Currently available:
  - Data types module (partial)
  - Time series module
  - Weather station module
  - Resources module
  - Urban function areas module
  - Core module (partial)
    - ADE _AbstractBuilding
    - WeatherData
    - RefurbishmentMeasure

- Developed by HFT Stuttgart



FME Workbench

DigiTwins4PEDs

- History
- Updates
- **Resources**
- Tests
- Conclusions

READ ME - Setup before running this workbench

Summary:
This workbench was created with **FME Form 2024.2.4.0** and will import **Energy ADE 3.0** data into the chosen 3DCityDB schema.
Default schema is the "citydb" one. Please be aware that any previously loaded Energy ADE 3.0 data will be deleted and replaced. "Normal" CityGML data will be left untouched, i.e. neither overwritten nor deleted.

Prerequisites:
1) The Energy ADE 3.0 database schema is already installed
2) "Normal" CityGML data (i.e. without Energy ADE contents) has already been imported into the database using the Importer/Exporter.

Workbench setup:
In the Navigation panel here on the left, check the User Parameters and the Database Connections entries and set:
1) the **input CityGML file name** (best if you put the file in the subfolder ./citygml_input_file)
2) the **target database schema name** (default it "citydb")
3) the **Energy ADE 3.0 xsd file** (default is to the ./xsd subfolder; generally no need to change it)
3) the database **connection parameters**.

The very **first time you load this workbench**, you will have to add the connection and edit the connection parameters.
a) Go to the menu Tools\FME Options;
b) Choose the "Database Connections" tab;
c) **Right-click** and import the connection stored in the ./db_connection/3dcitydb_connection_no_credentials.xml file. A connection named "**Shared 3DCityDB connection**" will be loaded and appear in the Navigator tab.
d) Open it and enter your connection parameters, test and save the connection. From now on, you will be able to connect to your 3DCityDB instance.

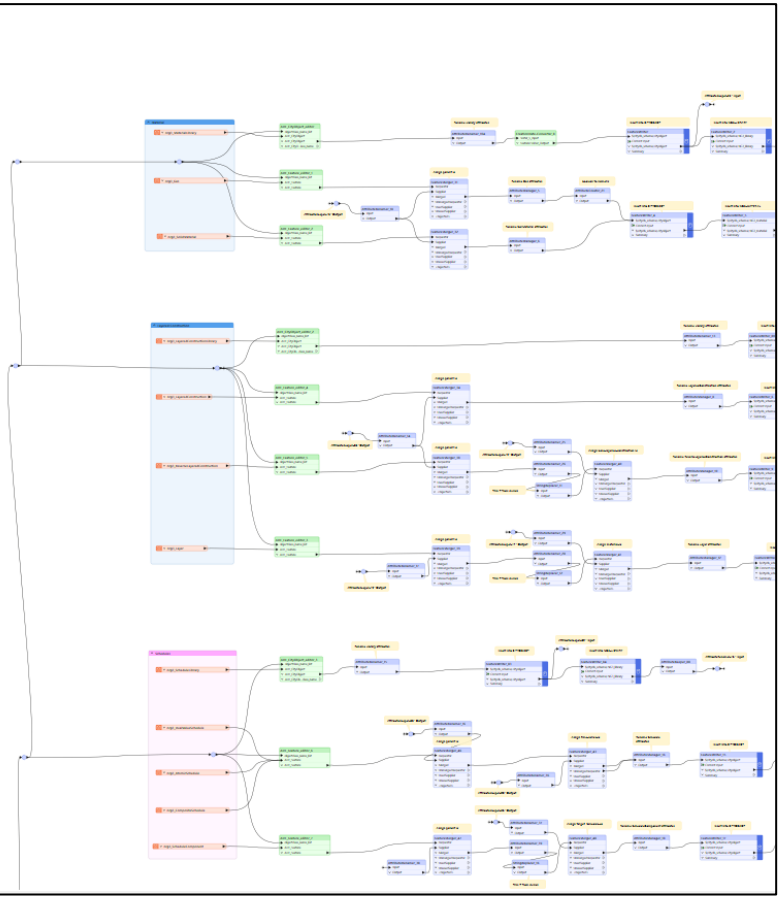
Running the workbench:
Simply run the workbench, however **BEWARE: do not "Enable feature caching"!** See menu Run (or open the Run icon).
Depending on the size of your input data, the workbench might stop with a generic error. It generally means that you have consumed all available memory for caching data.

Last update: 14 October 2025

This workbench has been created by:

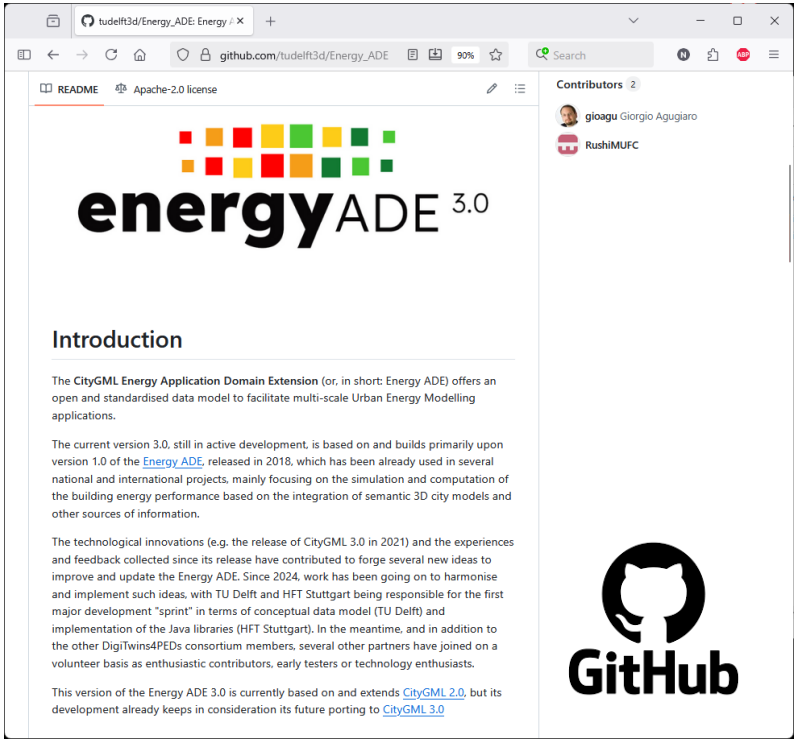
Dr. Giorgio Agugiaro
3D Geoinformation group
Delft University of Technology
The Netherlands

https://3d.bk.tudelft.nl/gagugiaro/



Open repository

- GitHub **open** since September 2025
  - https://github.com/tudelft3d/Energy_ADE



Part 4

First tests and implementations

DigiTwins4PEDs

DigiTwins4PEDs

Utilisation of urban digital twins to co-create flexible positive energy systems for districts

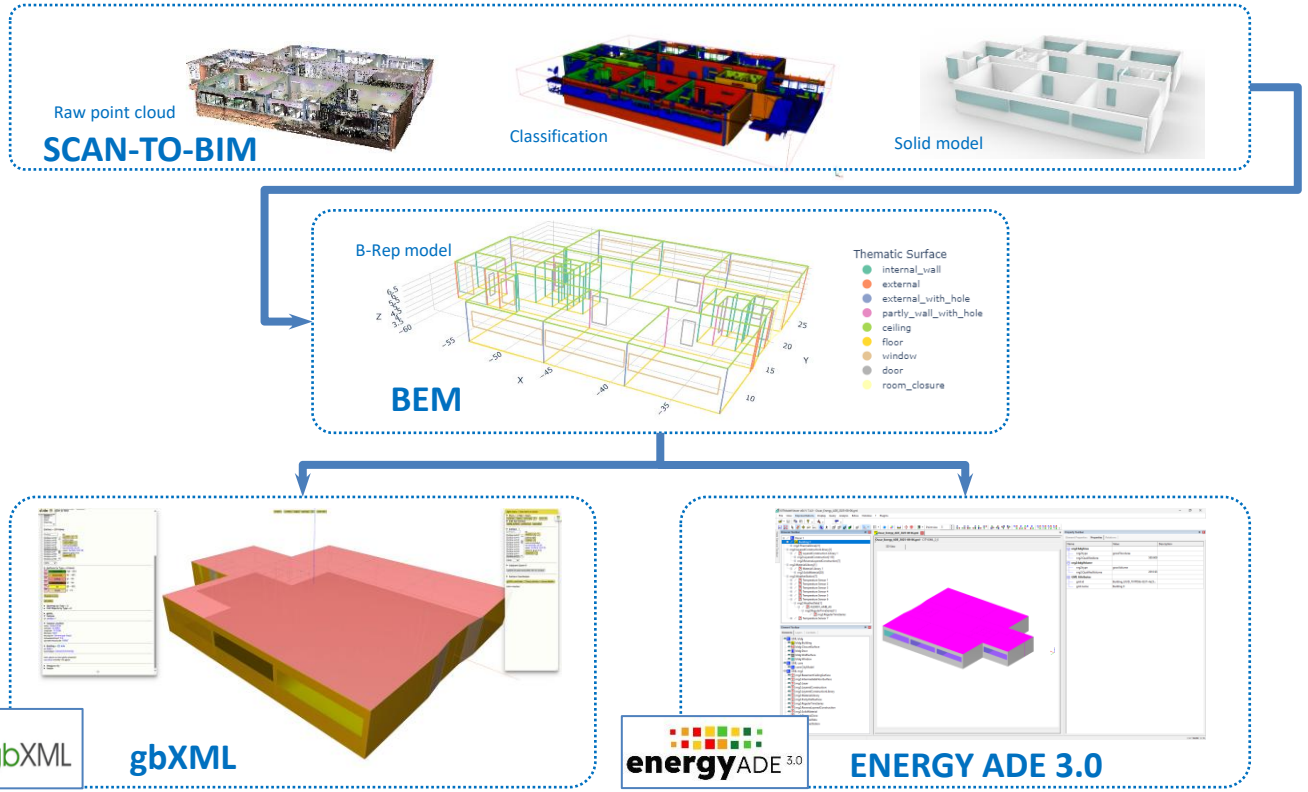
https://digitwins4peds.eu

- **Rotterdam**, Netherlands
- **Stuttgart**, Germany
- **Vienna**, Austria
- **Wrozlaw**, Poland

Gemeente Rotterdam

Stadt Wien

Early testers / technology enthusiasts

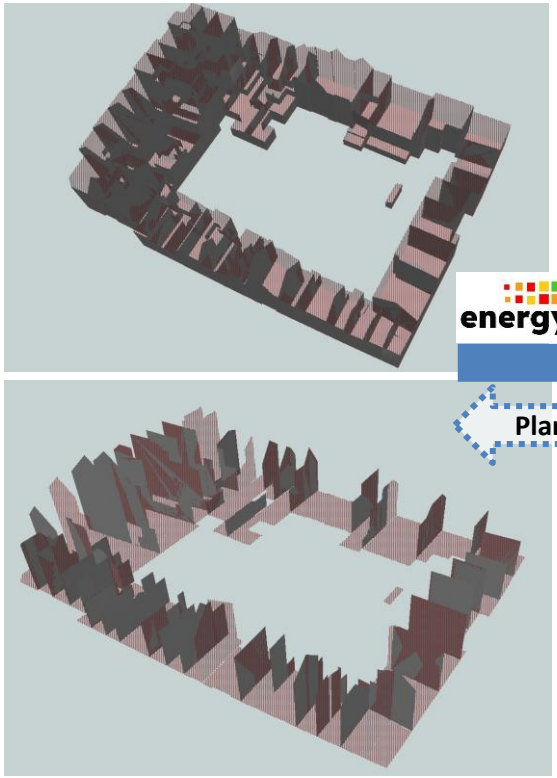


PhD work of **O. Roman**

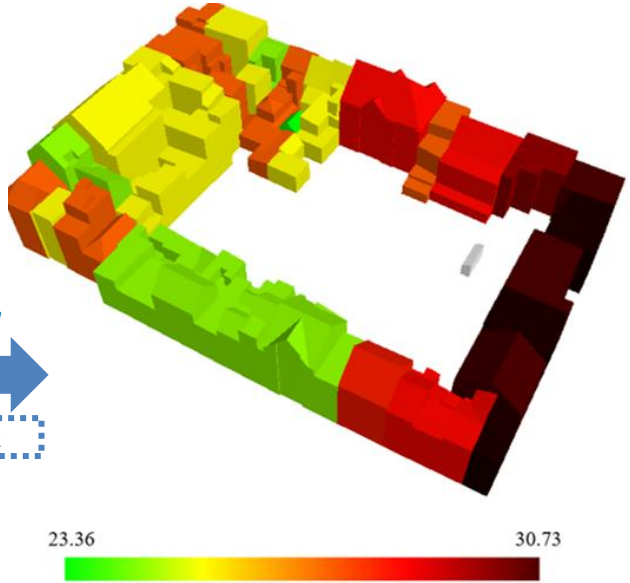
FONDAZIONE BRUNO KESSLER

Early testers / technology enthusiasts

Calculate the heat exchange also considering shared/party walls



Simulate mean indoor temperature using **Energy Plus** in a block in the city of Antwerp



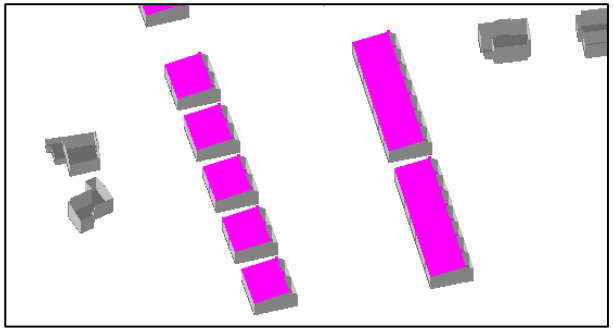
PhD work of **R.D. Morales**

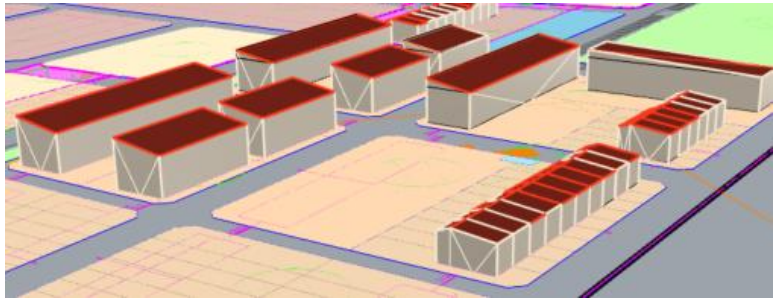
Universiteit Antwerpen

Early testers / technology enthusiasts

DigiTwins4PEDs

- Use **Devices module** to map and characterise existing PV systems and store key data for calculations
- Energy ADE database schema populated with *ad-hoc* Python code
- Plan (future) buildings **including PV**





Slide courtesy of **C. Pérez, J. Spohr** and **J. Salom**

MAKING PEDs

IREC
Shaping Energy for a Sustainable Future

Part 5

Conclusions and outlook

Conclusions

- Current updates to the Energy ADE enhance its current capabilities
  - Resources and Urban Function Area valuable additions
- Development based on CityGML 2.0 technologies, but already looking at CityGML 3.0
- Focus not only on data model, but also on accompanying resources
  - **Beta7** made publicly available in September 2025 to test, learn, and improve further

- **Development is still on-going!**
  - It will continue on an open basis, with more institutions joining
  - **Beta8** in the works

- Interested? Do you want to contribute? **GET IN TOUCH!** 😊
  - https://www.citygmlwiki.org/index.php?title=CityGML_Energy_ADE_V._3.0

Thanks for your attention!

Still alive and… evolving!

Acknowledgements
Zhihang Yao (HFT), Camilo León-Sánchez (TUD), Thomas H. Kolbe (TUM), Jérôme Kämpf (Idiap)