Using CityGML with EnergyADE Data in Ladybug Tools

P5 Presentation

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Presentation Structure

- 1. Introduction of Master Thesis Topic
- 2. Theoretical Background and Related Work
- 3. Research Methodology and Conceptual Design
- 4. Technical Implementation – Test Data Preparation
- 5. Technical Implementation - Grasshopper Workflow
- 6. Results Analysis and Conclusion
- 7. Future Work

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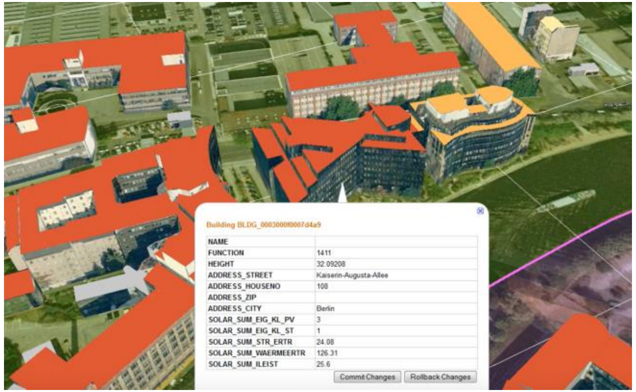
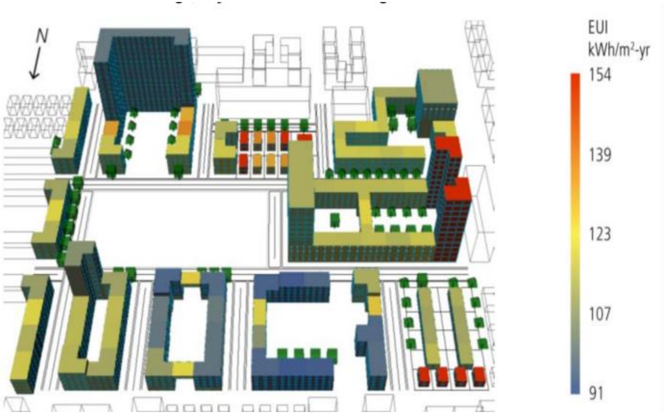
1. Introduction

- **Urban energy simulation** provides insights in energy demand/consumption, sun energy potential, comfort index, CO_2 emission etc.



Energy Atlas Berlin. A key tool was developed for energy & water infrastructure planning.



Energy simulation of a mixed-use district development in Boston, MA, USA.

1. Introduction

- **Ladybug tools:** free, open-source, python packages.
- **Honeybee** is the ‘bug’ of energy in the family. Access to Daysim, Open Studio and EnergyPlus, Therm and Radiance.
- 3 major advantages: ease of use, low cost of adoption and high level of customization.

LADYBUG HONEYBEE BUTTERFLY DRAGONFLY

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1. Introduction

- Ladybug tools are integrated into Rhino Grasshopper (GH).
- Rhino Grasshopper is a <u>visual programming interface</u>. It has a few nice features: ‘Drag-and-Drop’, ‘WYSIWYG’, (Iron)Python.
- Workflow of Ladybug tools: 3D geometry (GH) + local metrological data (.EPW file) + simulation parameters = simulation results

LADYBUG HONEYBEE BUTTERFLY DRAGONFLY

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1. Introduction

Demo Time! ☺

A. Drag-and-drop: Define building/zone programs in Honeybee.
B. ‘WYSIWYG’: Color building surfaces by surface types.

LADYBUG HONEYBEE BUTTERFLY DRAGONFLY

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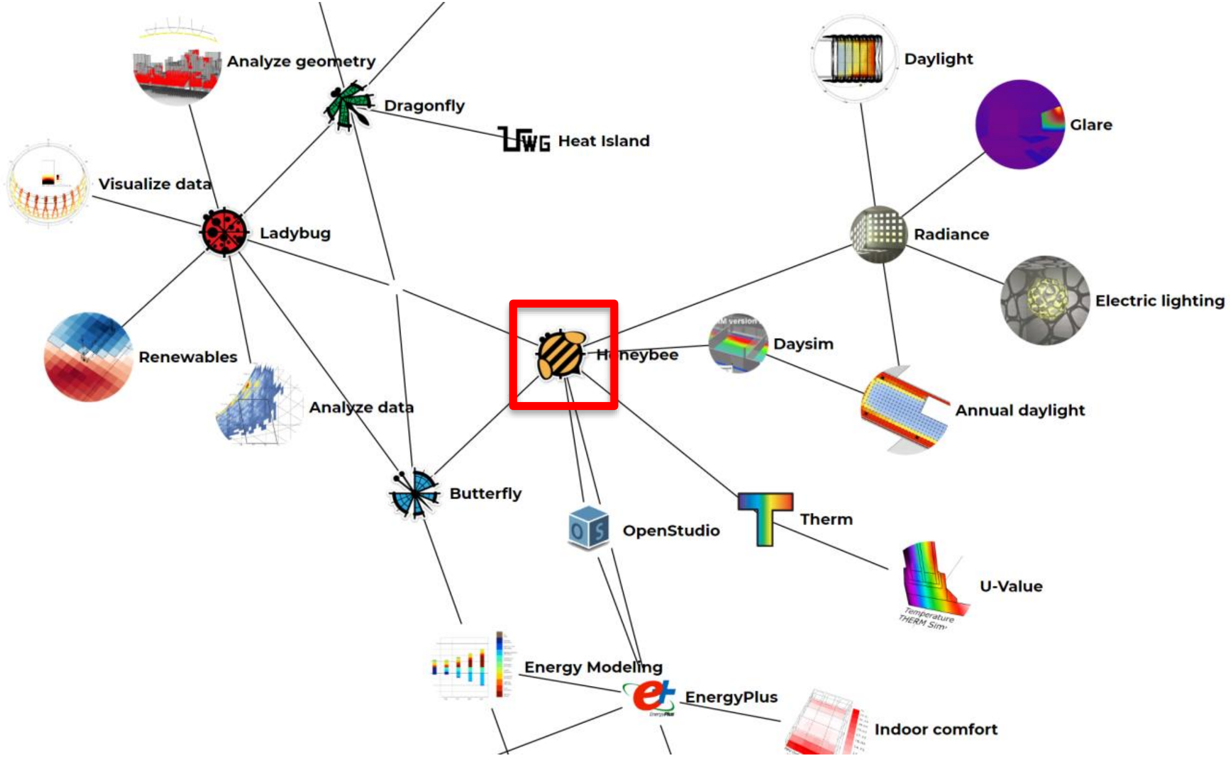
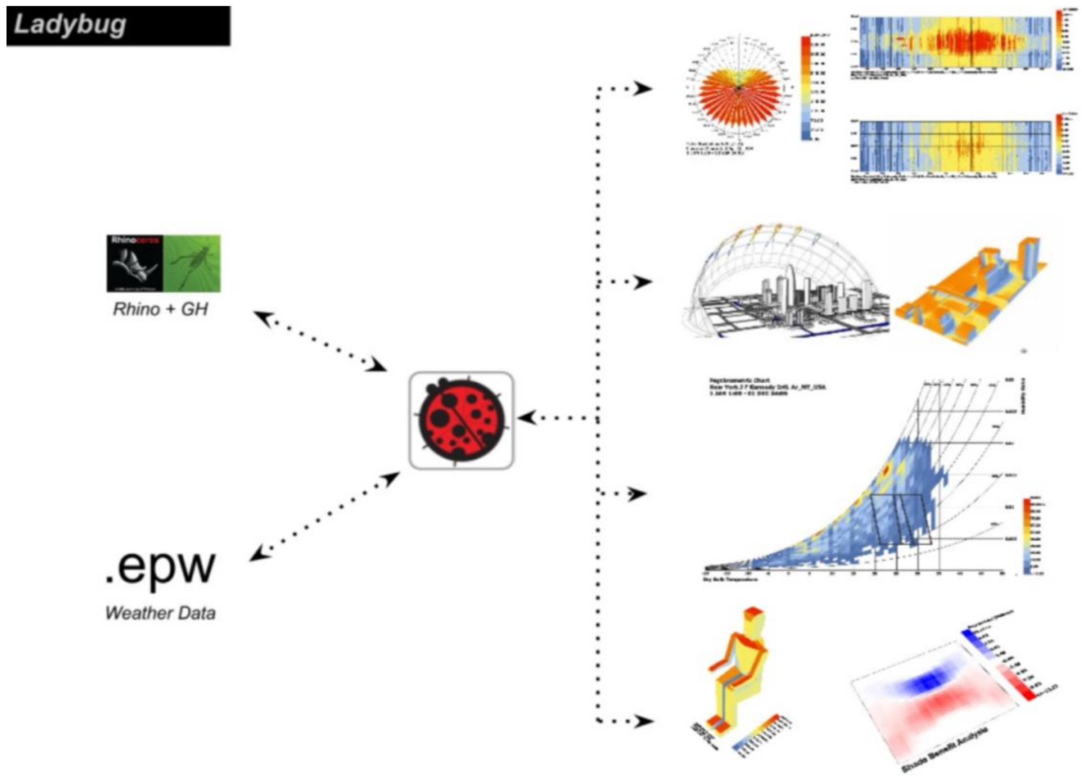
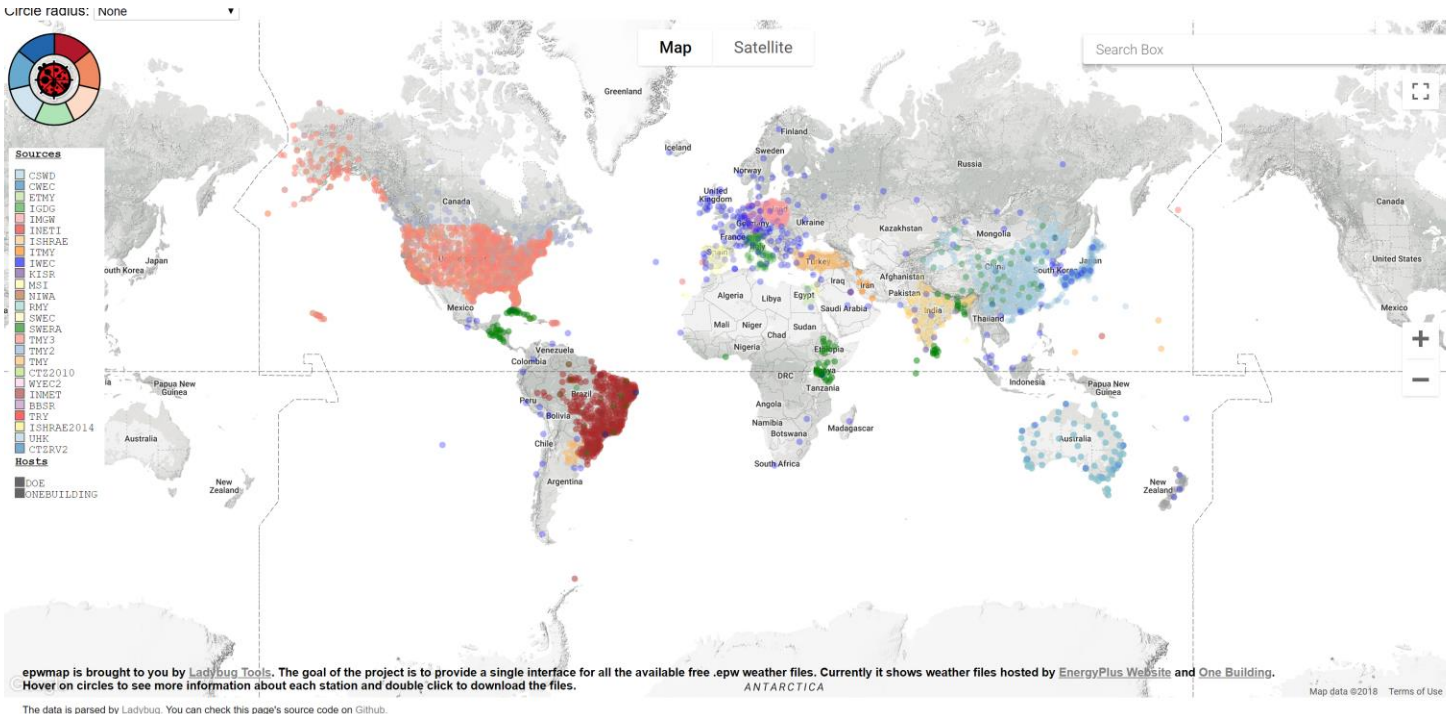


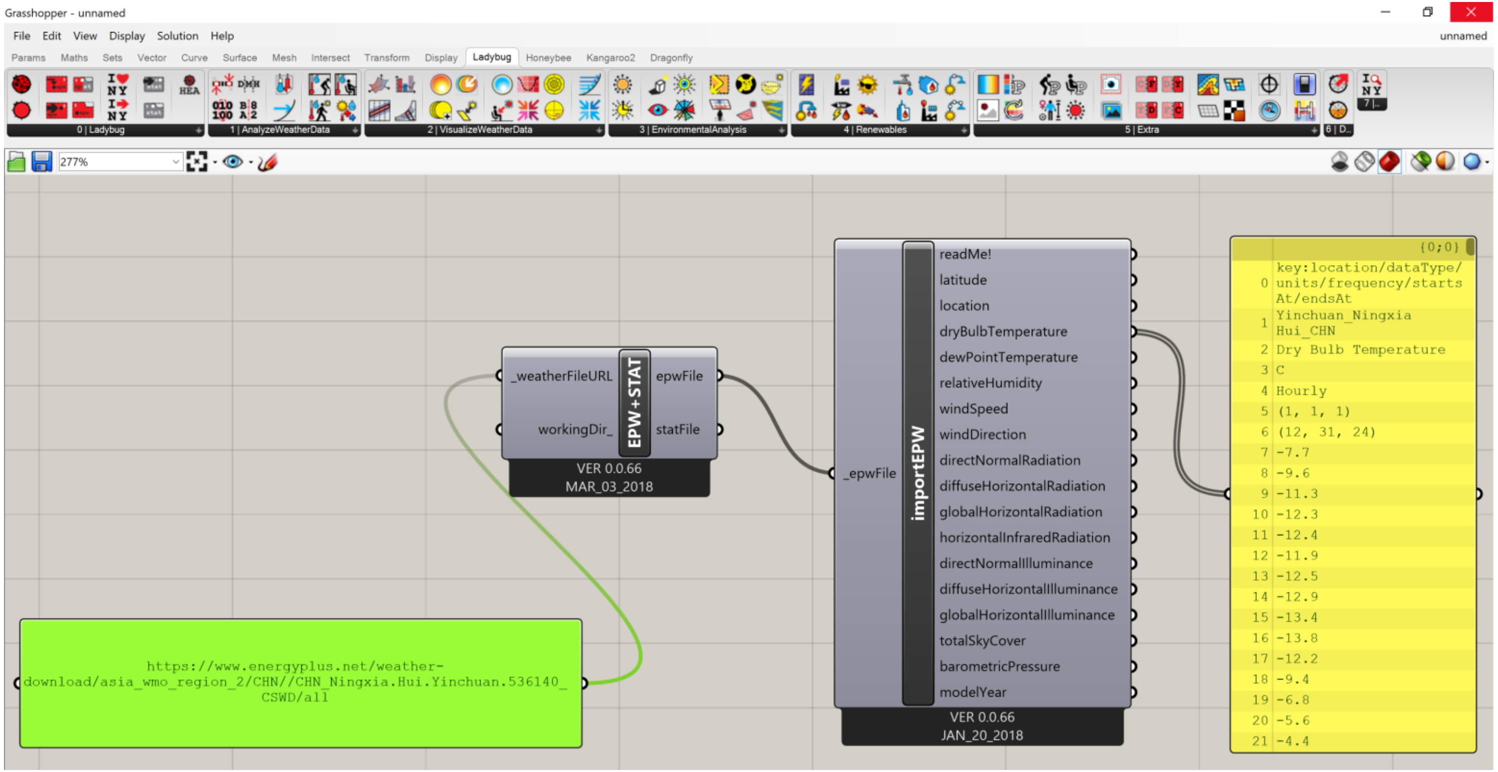
Ladybug tools provides access to many simulation engines.



Ladybug workflow and functions.



Weather Data Map from Ladybug Team.



Content of .EPW file.

1. Introduction

- Ladybug tools have their disadvantages: Manually Creating Rhino Geometries + Entering/Selecting Parameters.
- Prone to errors, not feasible and oversimplify the situation (same values apply to every object).
- What if Geometries + Attributes (Parameters) are already available in one piece of data?

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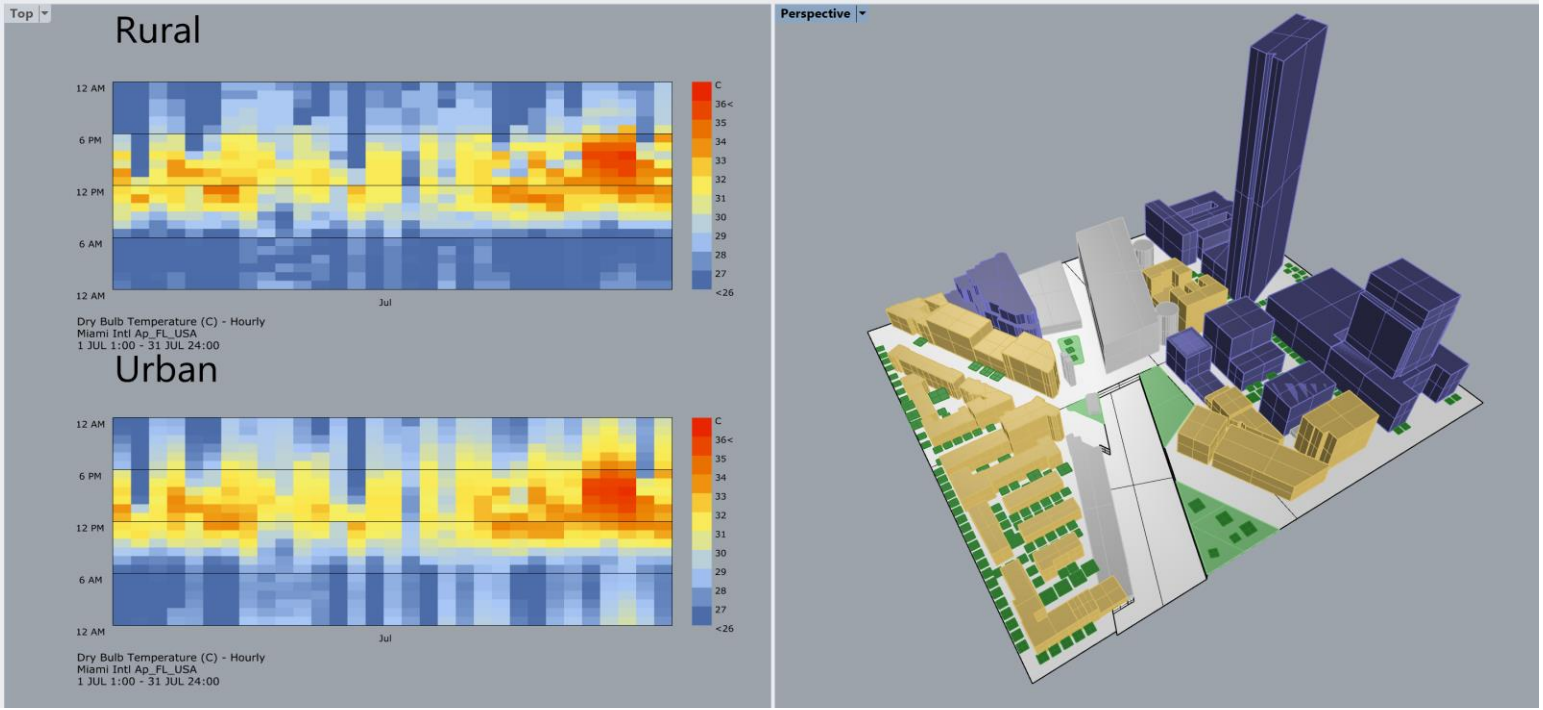
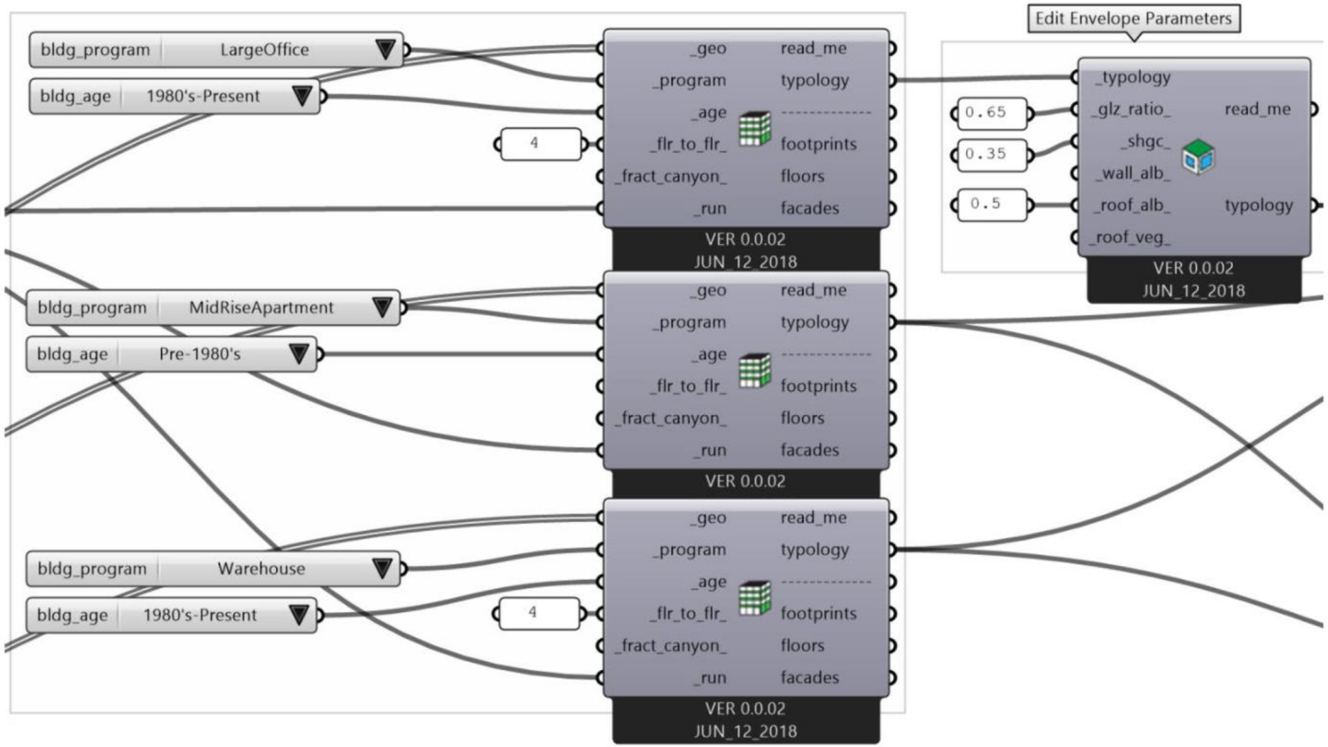


Dragonfly implementation example (UHI study)

Define Building Typologies



Dragonfly implementation example (UHI study)

1. Introduction

What if Geometries + Attributes (Parameters) are already available in one piece of data?

CityGML + EnergyADE!

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1. Introduction

- **CityGML** :Open standardized XML-based data model for virtual 3D city. It could be expanded by Application Domain Extensions (ADEs).
- **EnergyADE:** modules of Building Physics, Occupants Behavior, Material & Construction.
- Demo Time! CityGML Example in Notepad++ and FZK Viewer.

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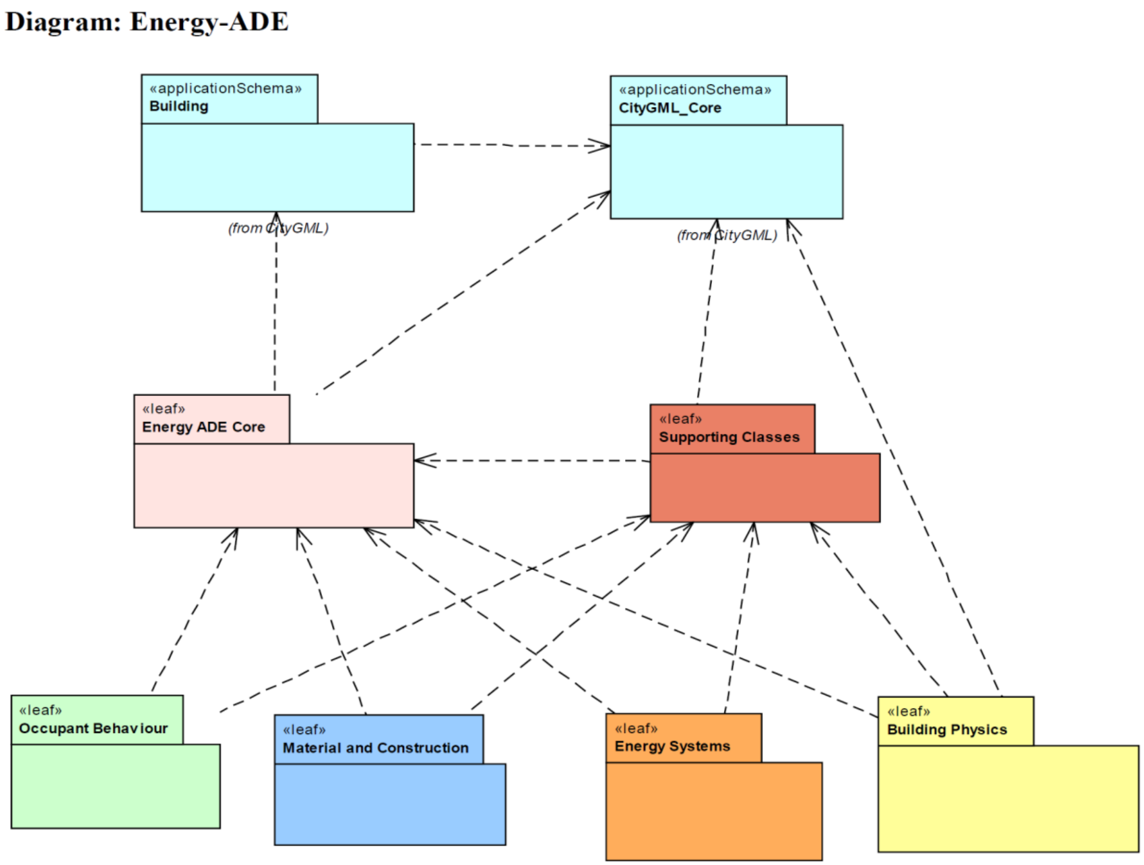

UML Diagram CityGML Energy ADE. [8]

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1. Introduction

- **BUT**, Rhino+GH does NOT take CityGML as inputs.
- If even it does, classes and attributes in CityGML EnergyADE may not be same as Honeybee input parameters.

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1. Introduction

- **Research Objective:** How to utilize CityGML with EnergyADE data in urban energy simulation process when using Ladybug tools?
  - 1. What key parameters are needed using Honeybee?
  - 2. Where are these key attributes located in CityGML EnergyADE data schema?
  - 3. How to retrieve both geometry and semantic from CityGML data? After doing that, how to organize, store, transform these information?

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1. Introduction

- The goal of this research is to:
  - 1. Create mapping between CityGML EnergyADE to Honeybee;
  - 2. Retrieve, organize, store and transform mapped information from CityGML data to Honeybee.

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2. Theoretical Background and Related Work

- Perez, Diane, and Darren Robinson believe good input data should be “Ontology” and CityGML is a good example.
- They also propose a workflow of data management for urban environment simulation.
- Urban energy simulation methodologies could be categorized as macro-simulation, micro-simulation and hybrid of the two.

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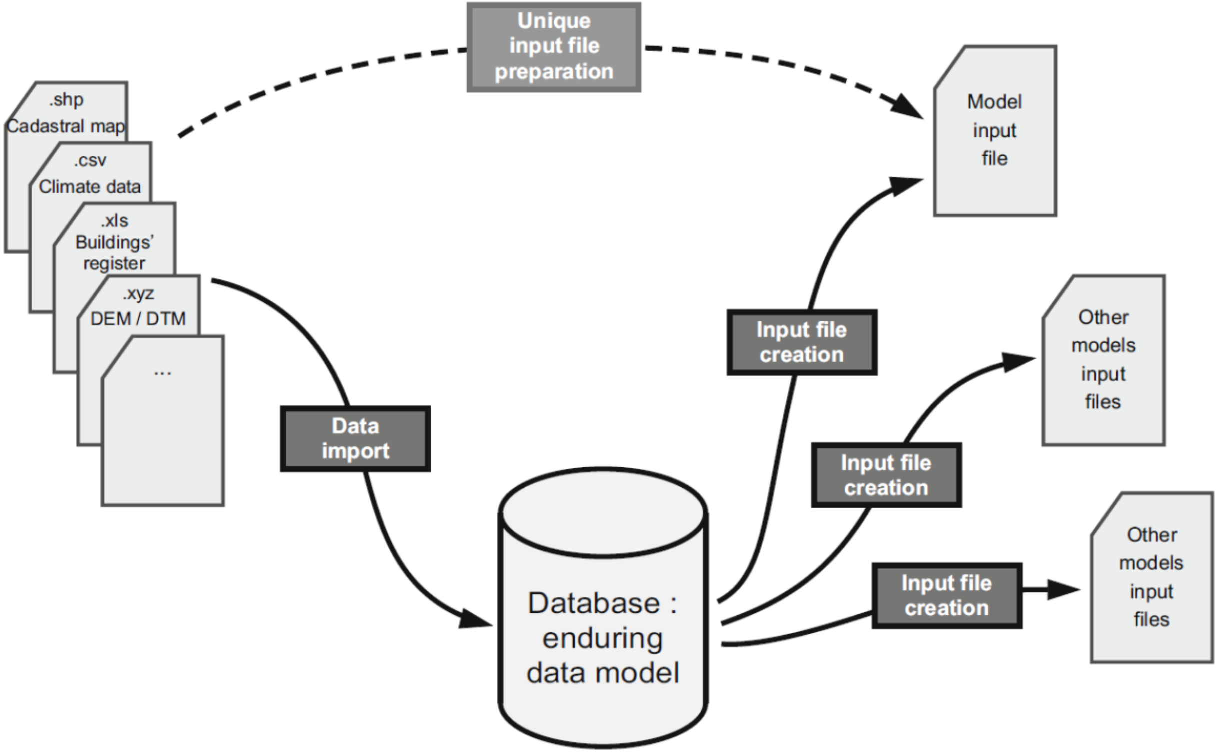
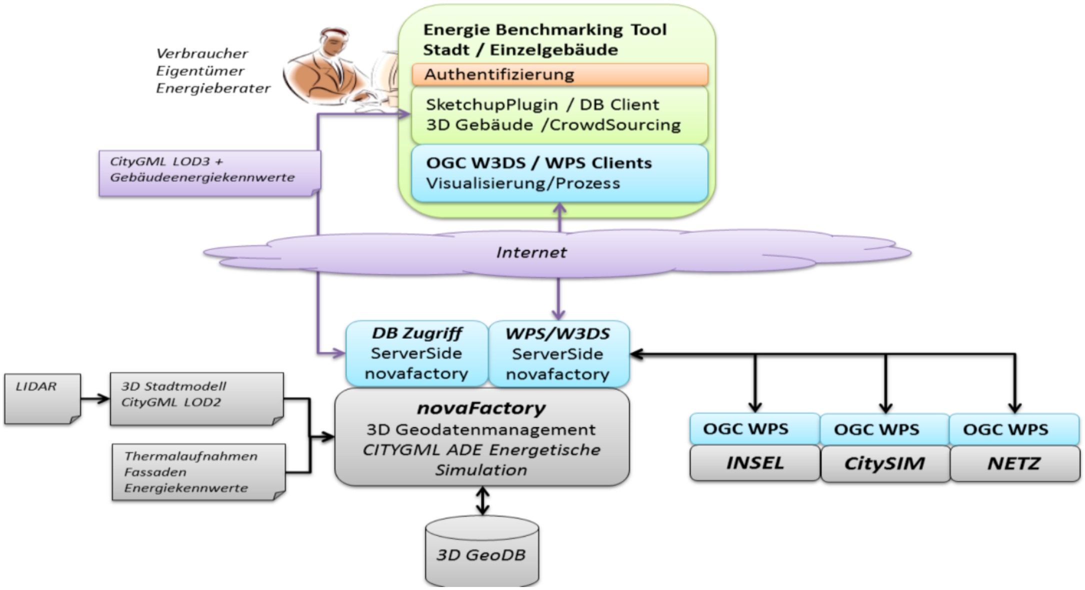


Proposed data management process for Urban Environment Simulation.

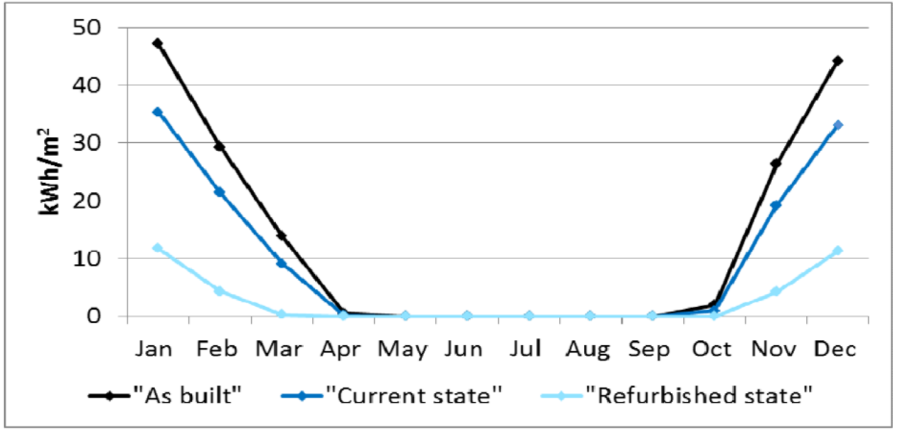
2. Theoretical Background and Related Work

- SimStadt, a modular platform utilizes LOD1 and LOD2 CityGML data for urban scale energy demand simulation. It saves virtual 3D City model inside 3DCityDB and run the energy simulation by CitySim.



2. Theoretical Background and Related Work

- Giorgio Agugiaro took two approaches to estimate heating energy demand of buildings: one is estimation and the other is by using EnergyPlus simulation. He suggested that both approaches are complementary, not alternatively .



Monthly net energy demand of three different scenarios.

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3. Methodology and Experimental Design

- The approach to answer above questions :

Data Model Summarizing
- Honeybee Input Parameters
- CityGML EnergyADE Data Schema

Data Mapping
- Mapping between EnergyADE and Honeybee

Data Retrieving
- Retrieve information from CityGML data.

Data Transformation
- Transfer to Honeybee inputs

3.1 Data Model Summarizing

- 1. What key parameters are needed using Honeybee?
- 2. Where are these key attributes located in CityGML EnergyADE data schema?

3.1.1 Energy Modelling Concepts of Honeybee and CityGML EnergyADE

- Honeybee: thermal zones (HBZone) - thermal surfaces (HBSurface). Windows are modelled as belongs to surfaces.

- CityGML EnergyADE data : building - thermal zone(s) - thermal boundaries. Windows are modelled as thermal openings.

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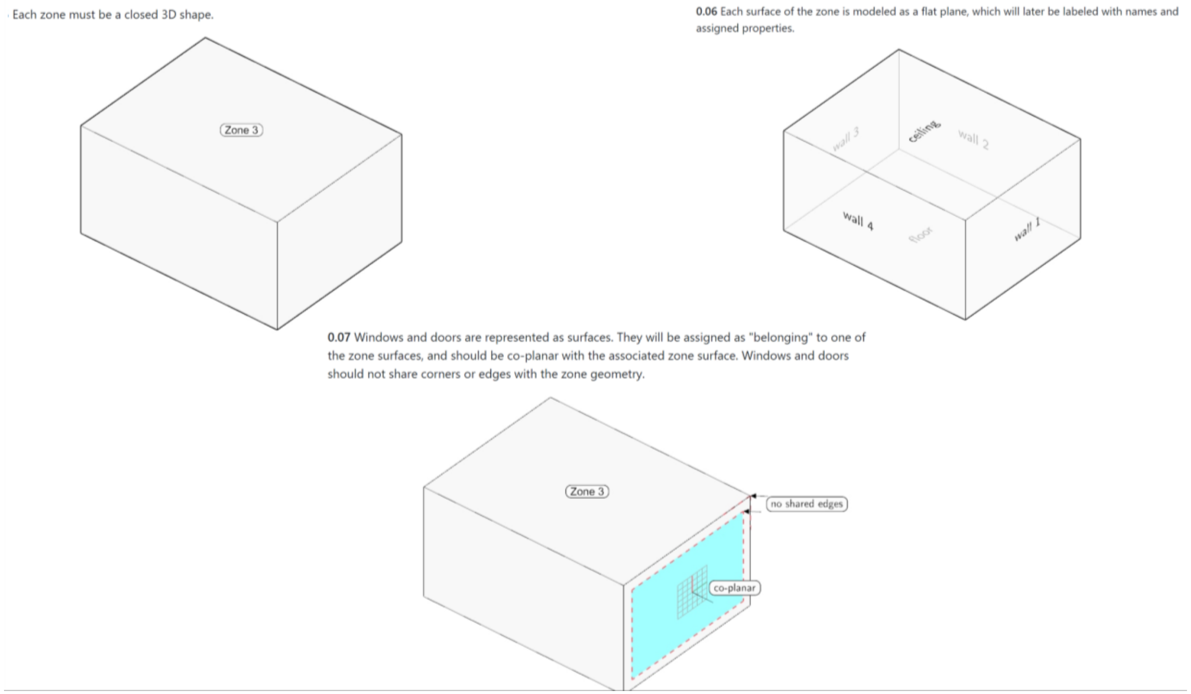
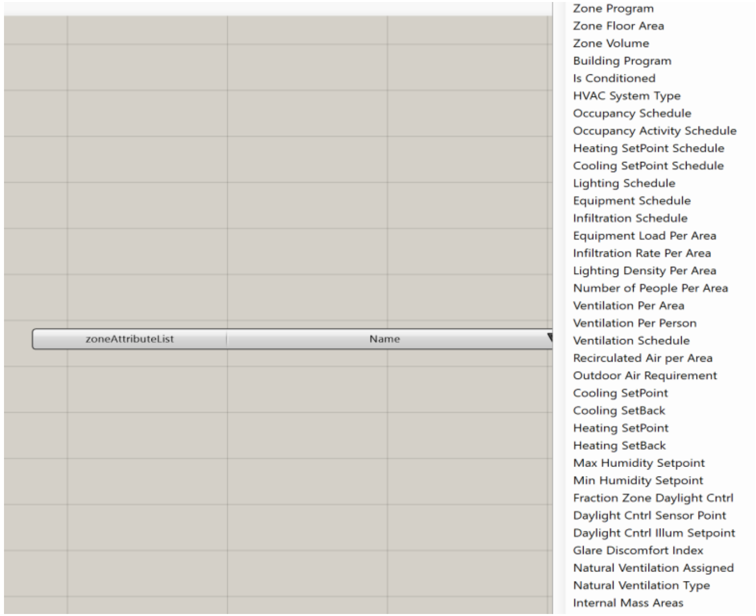
3.1.1 Energy Modelling Concepts of Honeybee and CityGML EnergyADE



Geometry modelling concepts of Honeybee.

3.2 Data Mapping

- Honeybee provides two very handy components SrfAttributeList and ZoneAttributeList.
- Two tables are created for Honeybee parameters (Zone Attributes and Surface Attributes).



3.2 Data Mapping

HBSurface Attributes	Semantic Meaning of Attributes
Radiance Material	The name of a material from default libraries or customized material from material customization components.
EnergyPlus Construction	The name of an EnergyPlus construction from default libraries or customized construction from EnergyPlus construction customization components.
Surface Type	Values indicating different HBSurface types: 0- 'WALL', 0.5- 'UndergroundWall', 1- 'ROOF', 1.5-'UndergroundCeiling', 2- 'FLOOR', 2.25- 'UndergroundSlab', 2.5- 'SlabOnGrade', 2.75- 'ExposedFloor', 3- 'CEILING', 4- 'AIRWALL', 5- 'WINDOW', 6- 'SHADING'
Boundary Condition	Different boundary conditions of HBSurface: outdoors, surface, adiabatic, ground.
Shade Material Name	A customized shade material generated by shade material component.
Shading Schedule Name	A schedule which indicates when the shades are raised or lowered.

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3.2 Data Mapping

HBZone Attributes	Semantic Meaning of Attributes
Building Program	A built-in library with different types of buildings defined by loads and schedules, such as Office, Retail, MidriseApartment, Warehouse and etc.
Zone Program	Zone program is child class of building program which is usually defined by different zones function. For example, MidriseApartment::Apartment and MidriseApartment::Corridor.
Zone Floor Area	Floor area value of the zone with unit m2.
Zone Volume	Volume value of the zone with unit m3.
Is Conditioned	True or false to decide if HBZone is conditioned with an ideal Air Load System.
Occupancy Schedule	A list of data indicating change of occupancy rate by time.
Lightning Schedule	A schedule that indicates when lightning is on or off.
Equipment Schedule	A schedule that indicates when equipment is on or off.
Equipment Load Per Area	The maximum rate of equipment energy consumption with unit w/m2.
Infiltration Rate Per Area	The desired rate of outside air infiltrated into the HBZone per square meter with unit m3/m2.s (cubit meter per square meter per second).
Lighting Density Per Area	The desired lightning load per square meter with unit w/m2.
Number of People Per Area	The number of people per square meter inside HBZone at peak occupancy level with unit ppl/m2 (people per square meter).
Ventilation Per Area	The desired minimum rate of outside air per square meter going into HBZone with unit m3/m2.s.
Ventilation Per Person	The desired minimum rate of outside air per person going into HBZone through mechanical systems. The unit is m3/person.s.
Ventilation Schedule	The schedule for ventilation.
Cooling SetPoint	A number represents the thermostat cooling setpoint in degrees Celsius.
Cooling SetBack	A number represents the thermostat cooling setback in degrees Celsius.
Heating SetPoint	A number represents the thermostat heating setpoint in degrees Celsius.
Heating SetBack	A number represents the thermostat heating setback in degrees Celsius.
Max Humidity SetPoint	A number represents the humidistat maximum humidity setpoint in %.
Min Humidity SetPoint	A number represents the humidistat minimum humidity setpoint in %.

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3.2 Data Mapping

- By checking up EnergyADE UML diagram, corresponding CityGML EnergyADE classes with attributes are matched.

Honeybee HBSurface-based Approach Parameters	CityGML with EnergyADE Attributes
Radiance Material	AbstractMaterial:Gas AbstractMaterial:SolidMaterial
EnergyPlus Construction	AbstractConstruction:Construction
Surface Type	ThermalBoundary::thermalBoundaryType
Boundary Condition	--
Shade Material Name	ThermalOpening::indoorShading ThermalOpening::outdoorShading
Shading Schedule Name	--

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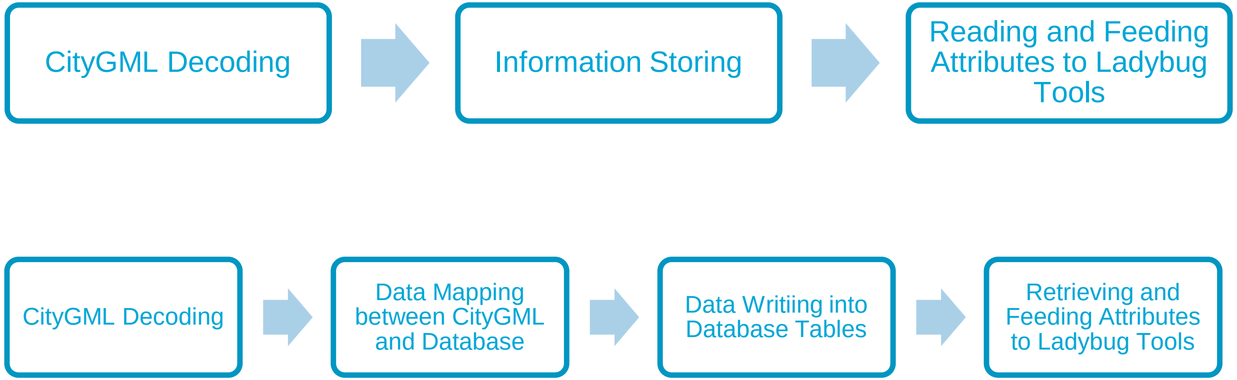
3.3 Data Retrieving

- There are two potential approaches:
- A. File-based approach
- 2. Database approach



3.3 Data Retrieving

- Based on the following considerations, this research focus only on database approach, not on file-based approach:
  - ‘Hard-code’ vs. Feature Manipulation Engine (FME) + 3DCity Database (3DCityDB) importer;
  - Compatibility and expansibility to other applications.
  - Quality of input data.
  - Data maintenance or update in the future;
  - Information sharing or cooperate during working process;
  - User friendly and prior programming knowledge.☺

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3.4 Data Transformation

- Reconstruction of geometries, semantics and conversion of formats and units.

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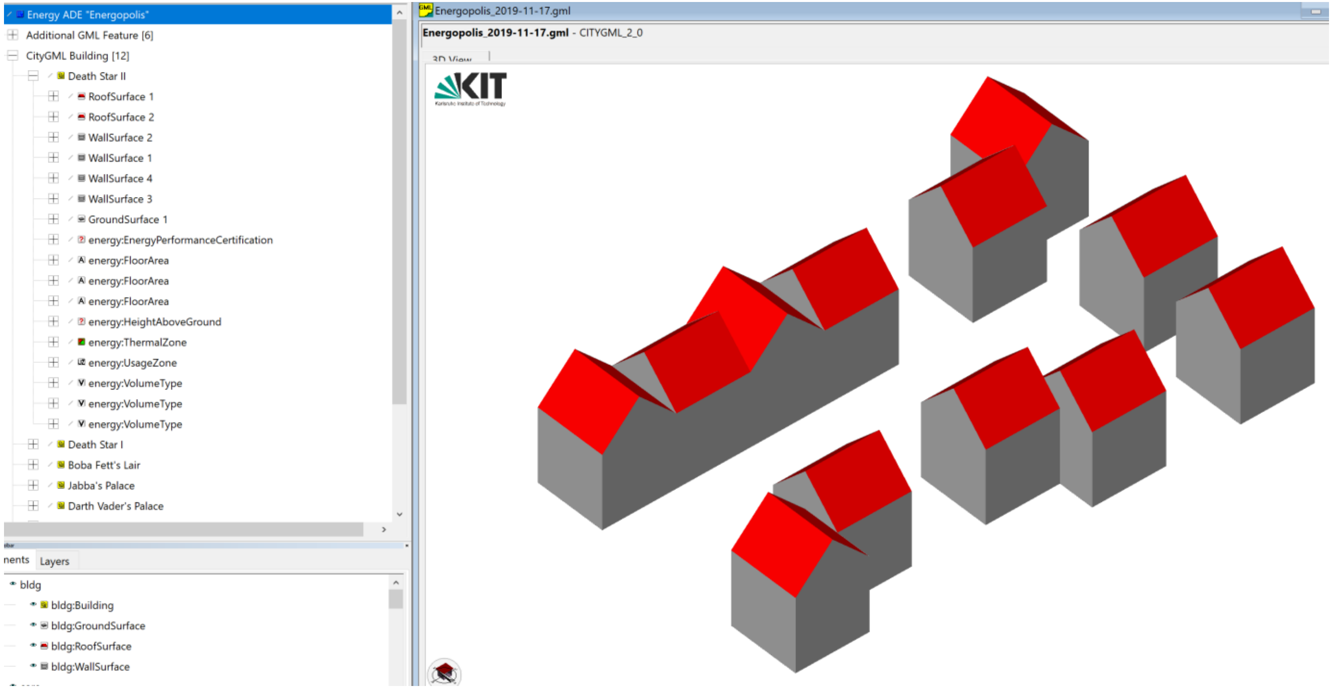
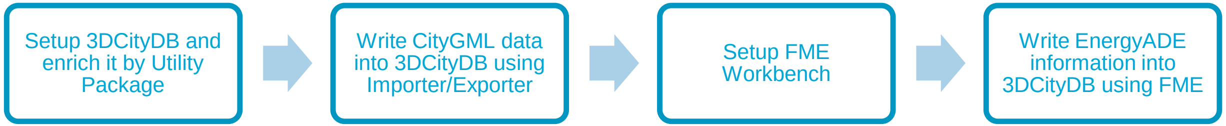
4.1 Implementation – Test Data



4.2 Setup Database Approach

- FME is used for CityGML decoding and data mapping.
- 3DCityDB is enhanced by 3DCityDB Utility Package to provides schema for EnergyADE.
- The implementation process of setting up database approach is like figure below:



4.2.1 3DCityDB Setup

- The affiliation between classes is managed by table OBJECTCLASS with foreign keys parent_id and root_id.

- Predefined sequences of 3DCityDB are designed to start from 1 and increment 1 each time。

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4.2.1 3DCityDB Setup

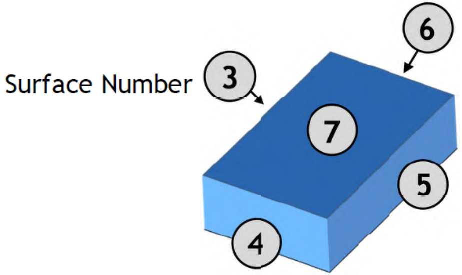

Figure 30: LoD 1 building - closed volume bounded by a CompositeSurface which consists of single polygons

SURFACE_GEOMETRY

ID	GMLID	PARENT_ ID	ROOT_ ID	IS_ SOLID	IS_ COMPOSITE	GEOMETRY	SOLID_ GEOMETRY
1	UUID_lod1	NULL	1	1	0	NULL	GEOMETRY for Solid
2	lod1Surface	1	1	0	1	NULL	NULL
3	Left1	2	1	0	0	GEOMETRY for surface 3	NULL
4	Front1	2	1	0	0	GEOMETRY for surface 4	NULL
5	Right1	2	1	0	0	GEOMETRY for surface 5	NULL
6	Back1	2	1	0	0	GEOMETRY for surface 6	NULL
7	Roof1	2	1	0	0	GEOMETRY for surface 7	NULL

Geometry storage in 3DCityDB.

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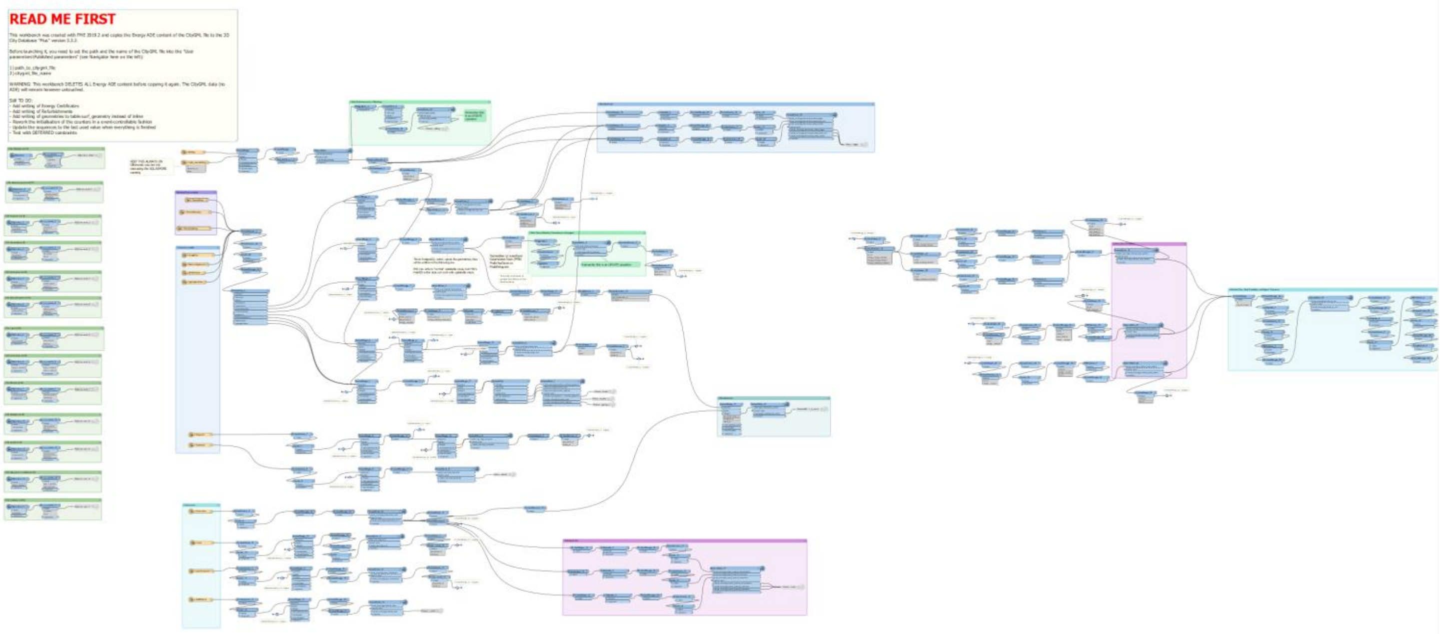
4.2.2 Install 3DCityDB Utility Package

- 3DCityDB has its limitations:
  - Class information is ‘scattered’
  - It has not provided direct support of EnergyADE

- 3DCityDB Utility Package solve these problems using following methods:
  - Trigger functions are added to some views to make them ‘updatable’.
  - 3DCityDB Utility Package creates schema for EnergyADE data model.

4.2.3 FME Workbench Setup



FME Workbench built to write data into 3DCityDB

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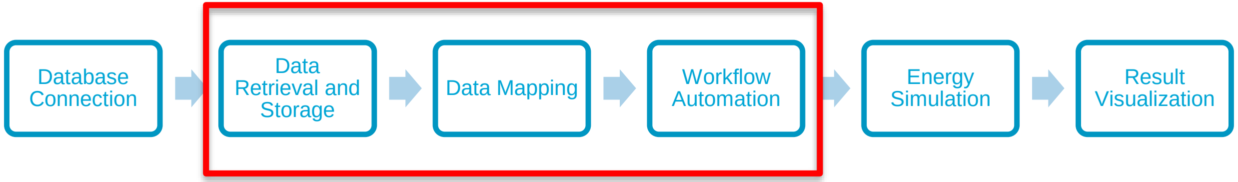
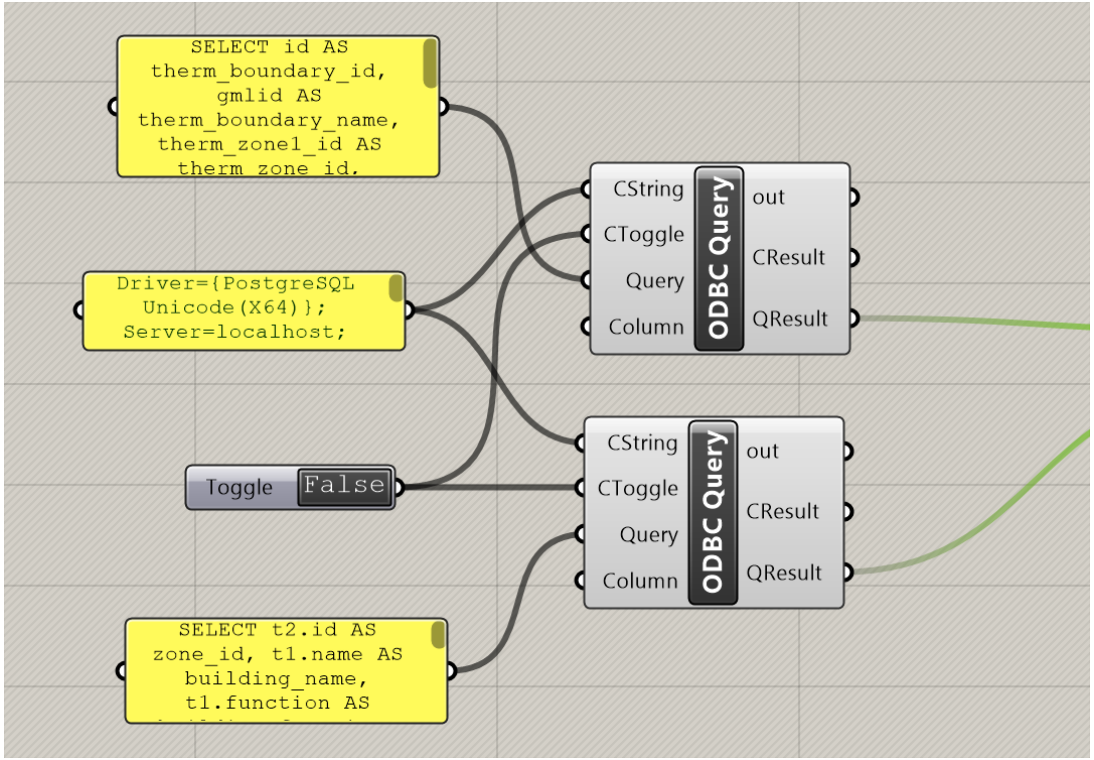
5. Implementation of Grasshopper Honeybee Workflow

- Grasshopper Honeybee workflow consists of following key procedures:



- Database connection is achieved by implementing Rhino Grasshopper component Slingshot! or GHPython Remote + Psycopg2.
- Honeybee output results are saved as entries in .CSV file.
- Honeybee provides powerful result visualization functions.

5. Implementation of Grasshopper Honeybee Workflow



Slingshot! implementation.

5. Implementation of Grasshopper Honeybee Workflow

	A	B	C	D	E	F	G
1	Date/Time	Calendar Ye	GIORGIO'S_	PAOLA'S_P	GIOVANNI'	AURONTE'	YODA'S_HU
2	01/01 01:00:00		285589.4	285589.4	285589.4	285589.4	285589.4
3	01/01 02:00:00		285589.4	285589.4	285589.4	285589.4	285589.4
4	01/01 03:00:00		285589.4	285589.4	285589.4	285589.4	285589.4
5	01/01 04:00:00		285589.4	285589.4	285589.4	285589.4	285589.4
6	01/01 05:00:00		797092.8	797092.8	797092.8	797092.8	797092.8
7	01/01 06:00:00		1679436	1679436	1679436	1679436	1679436
8	01/01 07:00:00		1875513	1875513	1875513	1875513	1875513
9	01/01 08:00:00		1675174	1675174	1675174	1675174	1675174
10	01/01 09:00:00		733154.9	733154.9	733154.9	733154.9	733154.9
11	01/01 10:00:00		507240.9	507240.9	507240.9	507240.9	507240.9
12	01/01 11:00:00		507240.9	507240.9	507240.9	507240.9	507240.9
13	01/01 12:00:00		507240.9	507240.9	507240.9	507240.9	507240.9
14	01/01 13:00:00		507240.9	507240.9	507240.9	507240.9	507240.9
15	01/01 14:00:00		507240.9	507240.9	507240.9	507240.9	507240.9
16	01/01 15:00:00		507240.9	507240.9	507240.9	507240.9	507240.9
17	01/01 16:00:00		878080.9	878080.9	878080.9	878080.9	878080.9
18	01/01 17:00:00		1871250	1871250	1871250	1871250	1871250
19	01/01 18:00:00		2625718	2625718	2625718	2625718	2625718
20	01/01 19:00:00		3533636	3533636	3533636	3533636	3533636

Honeybee Energy Simulation Results in .csv file.

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5.1 Data Retrieval and Storage

- SQL queries are sent to 3DCityDB to retrieve data
- Use ordered lists to store all attributes.
- Grasshopper uses Data Tree, an ordered collection of lists . Only geometry information is saved in data tree.
- Transformation between nested lists and data tree is carried out by list2tree component.

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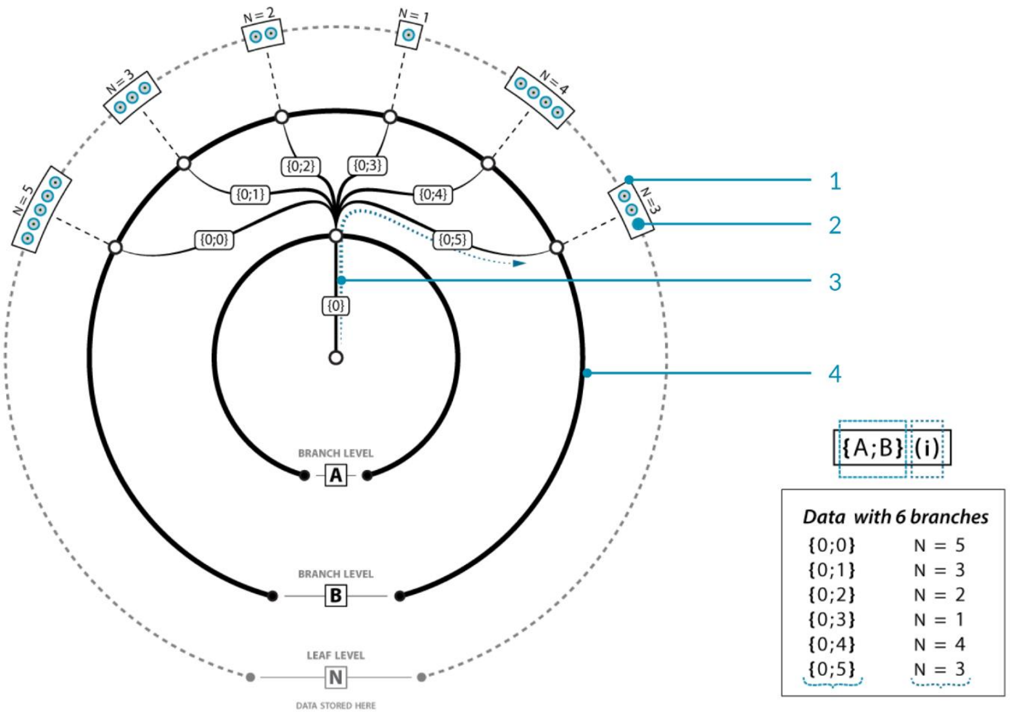
5.1 Data Retrieval and Storage



Data Tree Representation Example.

5.2 Data Mapping (Reconstruction, Transformation)

Honeybee HBZone-based Approach Parameters	CityGML with EnergyADE Attributes of Classes
Building Program	_AbstractBuilding::function _AbstractBuilding::type
Zone Program	_AbstractBuilding::function _AbstractBuilding::type
Zone Floor Area	ThermalZone::floorArea
Zone Volume	ThermalZone::volume
Is Conditioned	ThermalZone::isCooled or ThermalZone::isHeated
Occupancy Schedule	UsageZone:Occupants::occupancyRate
Lightning Schedule	LightningFacilities::operationSchedule
Equipment Schedule	ElectricalAppliances::operationSchedule
Equipment Load Per Area	ElectricalAppliances::electricalPower
Infiltration Rate Per Area	ThermalZone::infiltrationRate
Lighting Density Per Area	LightningFacilities::electricalPower
Number of People Per Area	UsageZone:Occupants::numberOfOccupants
Ventilation Per Area	--
Ventilation Per Person	--
Ventilation Schedule	UsageZone::ventilationSchedule
Cooling SetPoint	--
Cooling SetBack	--
Heating SetPoint	--
Heating SetBack	--
Max Humidity SetPoint	--
Min Humidity SetPoint	--

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5.2 Data Mapping (Reconstruction, Transformation)

- A mapping decision has been made as following: roof – 1, outerWall – 0, intermediaryFloor – 2, groundSlab – 2.5, basementCeiling – 1.5, atticFloor – 2.75. It is realized by python dictionary.

Honeybee HBSurface-based Approach Parameters	CityGML with EnergyADE Attributes
Radiance Material	AbstractMaterial:Gas AbstractMaterial:SolidMaterial
EnergyPlus Construction	AbstractConstruction:Construction
Surface Type	ThermalBoundary::thermalBoundaryType
Boundary Condition	--
Shade Material Name	ThermalOpening::indoorShading ThermalOpening::outdoorShading
Shading Schedule Name	--

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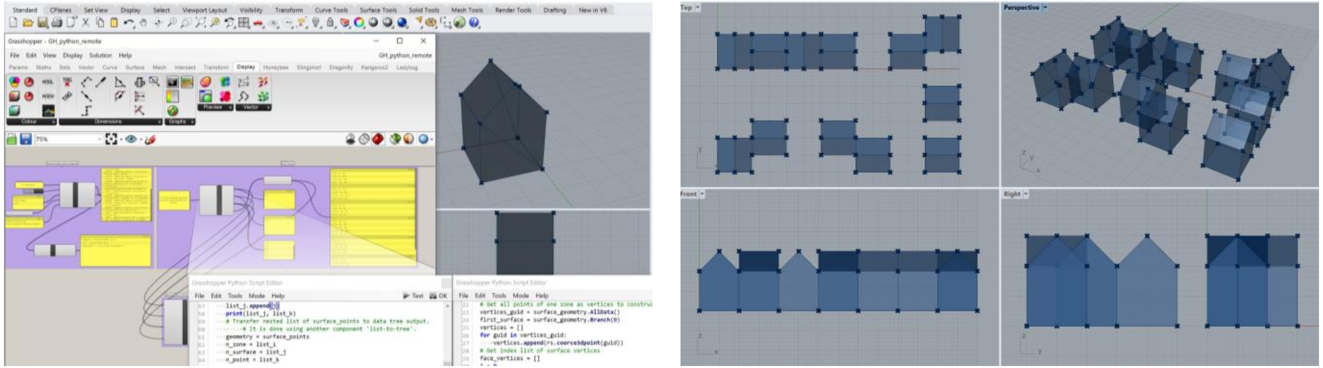
5.2 Data Mapping (Reconstruction, Transformation)

- Two methods have been tested to reconstruct surface geometries: Mesh Approach and (Brep)Surface Approach.

- Keep in mind the **ORDER** of inputs and outputs.

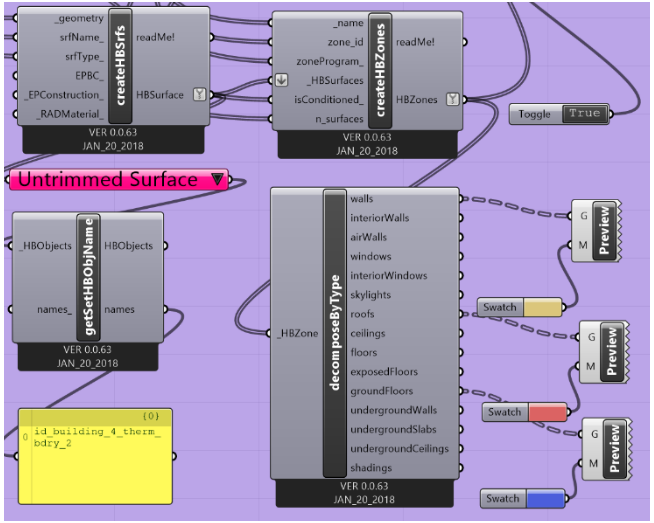


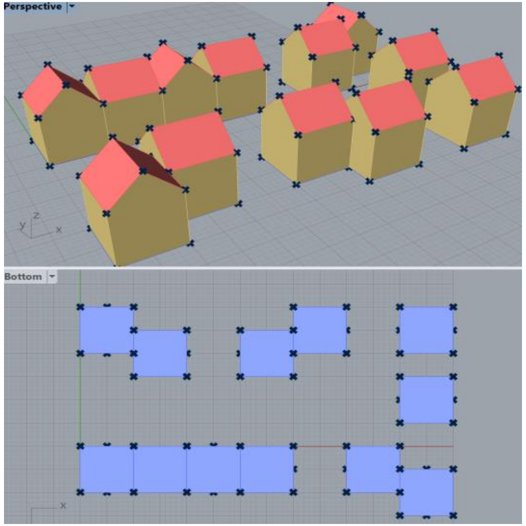
Mesh Approach vs. Surface Approach.

5.3 Honeybee Simulation Workflow Automation

- Automation of surface-based workflow is done by customizing two createHBSrfs and createHBZones.

- Inputs lists of createHBZones need to be spliced to sub lists for different zones based on number of surfaces per zone.





Check if Input Lists of Attributes are successfully assigned to corresponding HBSurface and HBZone.

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6. Results Analysis, Conclusion and Future Work

- Data models of CityGML EnergyADE shares great similarities with input parameters of Honeybee.
- Database approach has proved itself to be more ‘light-weighted’, flexible and convenient.
- Original Honeybee energy simulation workflow could be optimized and automated.
- It is always essential to keep the sequential order of inputs lists.

- In general, this research has provided an applicable workflow of utilizing CityGML EnergyADE data in Ladybug tools (Ladybug + Honeybee) with both efficiency and productivity...

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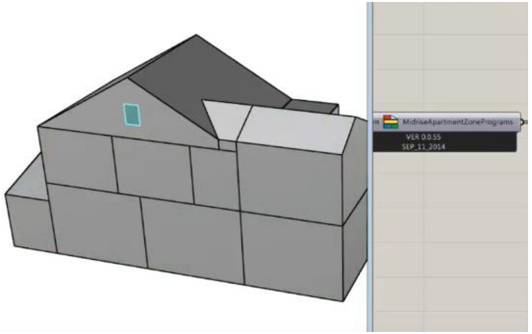
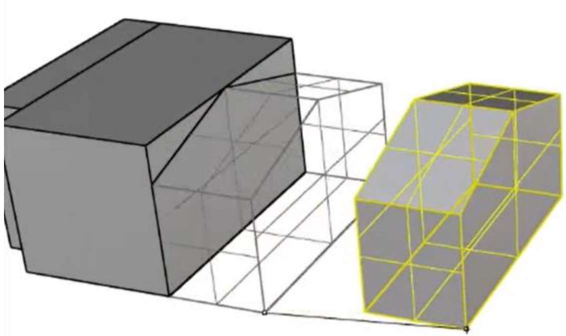
7. Future Work

- Current research could be expanded in following aspects:
  - Energy modeling of more buildings on larger scale with multiple zones. ;
  - Better mapping with material and constructions
  - Dealing with complex geometries and spatial relationships

In general, future work on using EnergyADE data in Rhino Grasshopper would focus on larger scale, more realistic and complex simulation scenarios.





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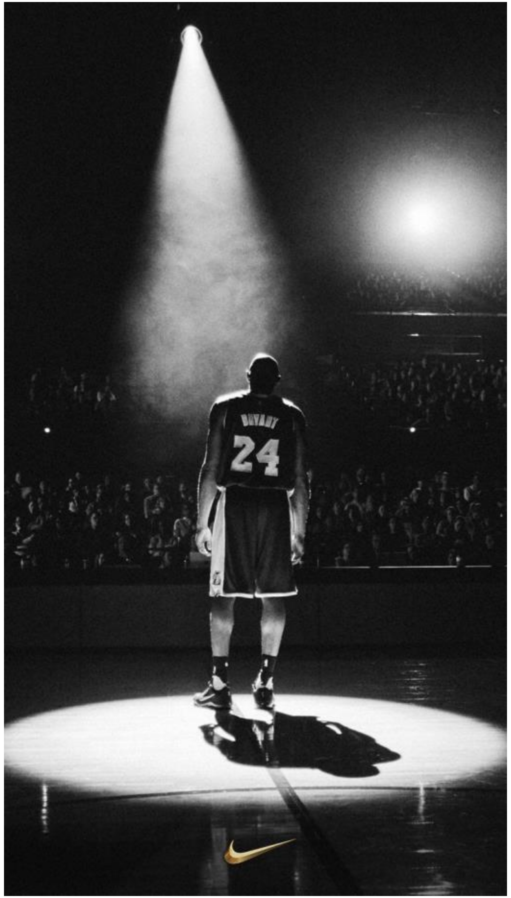
- My friends motivated me with their integrity, kindness and courage, leading me away from reckless decisions and silly mistakes.

TU Delft

Acknowledgement

A True Hero Never Dies.



Thank you!