HIDALGO2
CENTRE OF EXCELLENCE

Training 2

November 27, 2025

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EuroHPC Joint Undertaking

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Summary Day 2: Application and Case Studies with Ktirio

Time	Activity
09:00 - 09:30	**Recap and Q&A from Day 1**
09:30 - 10:45	**Introduction to Ktirio (General Overview)**
10:45 - 11:00	☕ *Coffee Break*
11:00 - 12:30	**Technical Presentation: Data Handling & Weather Data Manipulation**
12:30 - 13:30	🍴 *Lunch Break*
13:30 - 15:00	**Case Study 1: Optimization of a Building (Hands-on)**
15:00 - 15:15	☕ *Coffee Break*
15:15 - 16:30	**Case Study 2 and Further Optimization**
16:30 - 17:00	**Q&A Session and Closing Remarks**

Presentation of Ktirio and UB pilot in HiDALGO2

Context

Building sector in the EU [1]:

- **36%** of GHG emission
- **40%** of final energy consumption

Horizon 2050 objectives:

- Double annual energy renovation rates in the next 10 years [2]
- E.g. **700 000** renovation/year in France

➔ Building Energy simulation:

- Accurately assess energy performance of existing buildings
- Identify sources of energy savings (anomalies and areas for improvement)
- Compare and evaluate renovation and/or energy management strategies
- Ensure the optimal management of buildings

[1]: https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-lut-17_en
[2]: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

CoE HiDALGO2 project

Map of EuroHPC JU super-computers

Pilots

Urban Air project

Urban Building Model

Renewable Energy sources

Wildfires

Material Transport in Water

CoE HiDALGO2 project

Map of EuroHPC JU super-computers

Pilots

Urban Air project

Urban Building Model

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Material Transport in Water

Urban Building Model Pilot

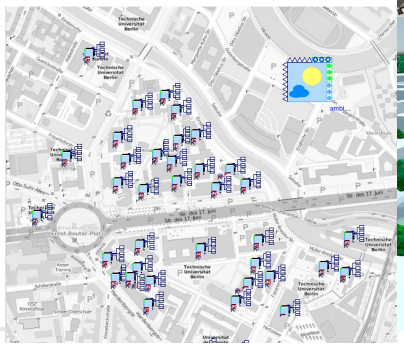
Ktirio

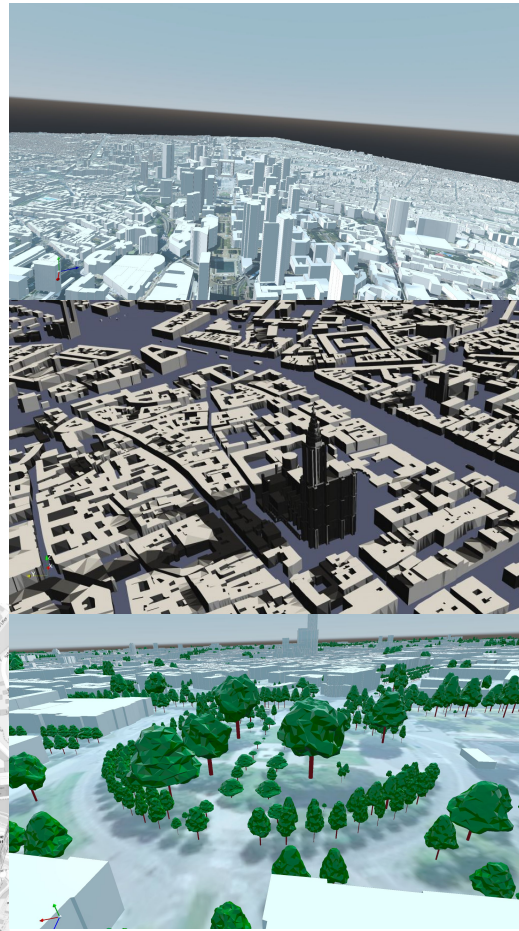
A platform for building energy modeling and simulation that enables computing energy consumption and losses in buildings including comfort estimations. ktirio is built on a large set of Open Source Software (OSS) such as Feel++ or OpenStreetMap.

KUB is based on the Feel++ toolchain.

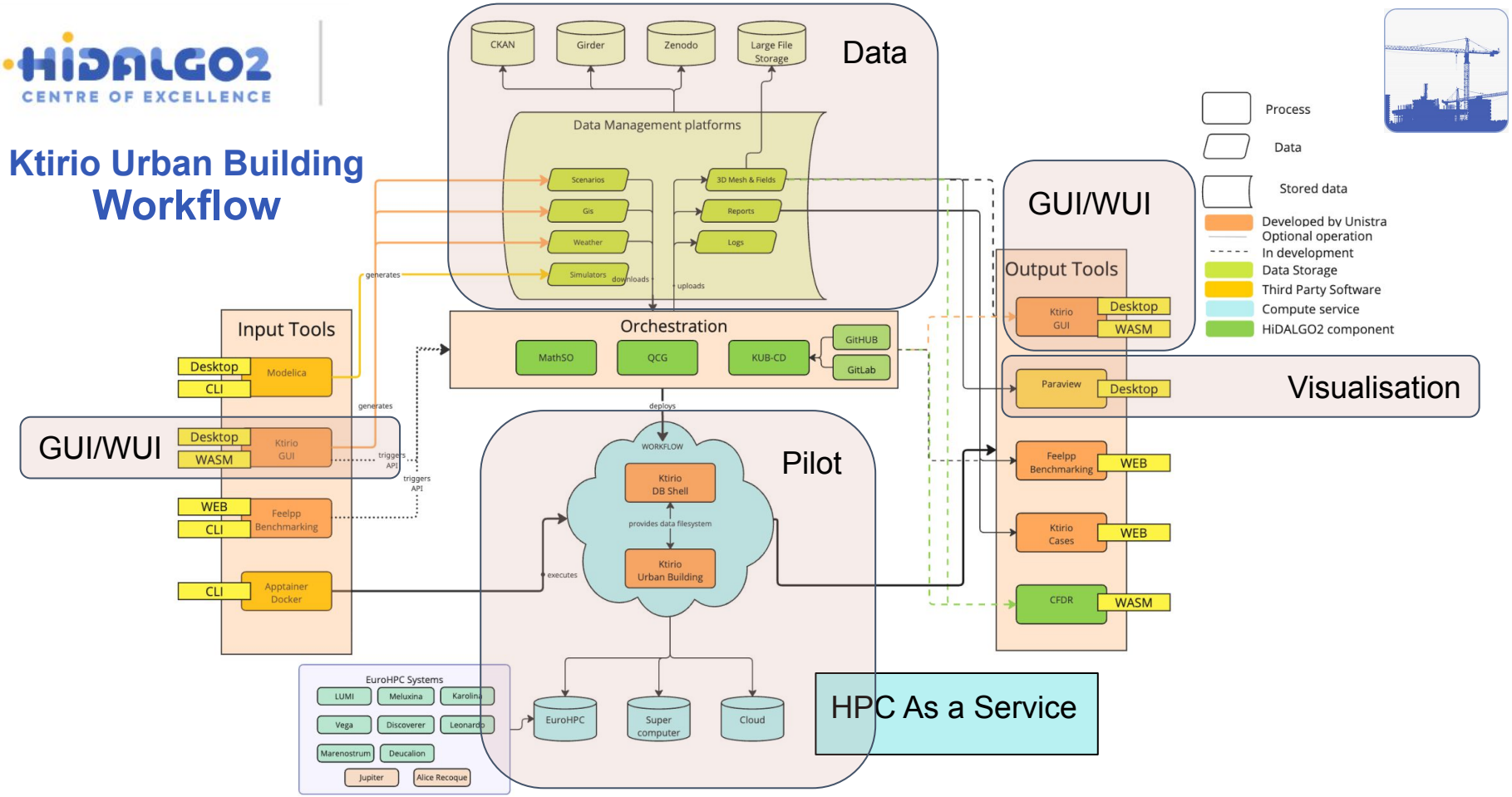
Feel++ is a comprehensive framework designed to tackle problems based on Ordinary Differential Equations (ODEs) and Partial Differential Equations (PDEs).

Using modern C++ (C++17 and C++20) standards coupled with a Python layer through Pybind11,
Feel++ enables seamless parallelism and is equipped with default communicators that simplify handling complex computational tasks.

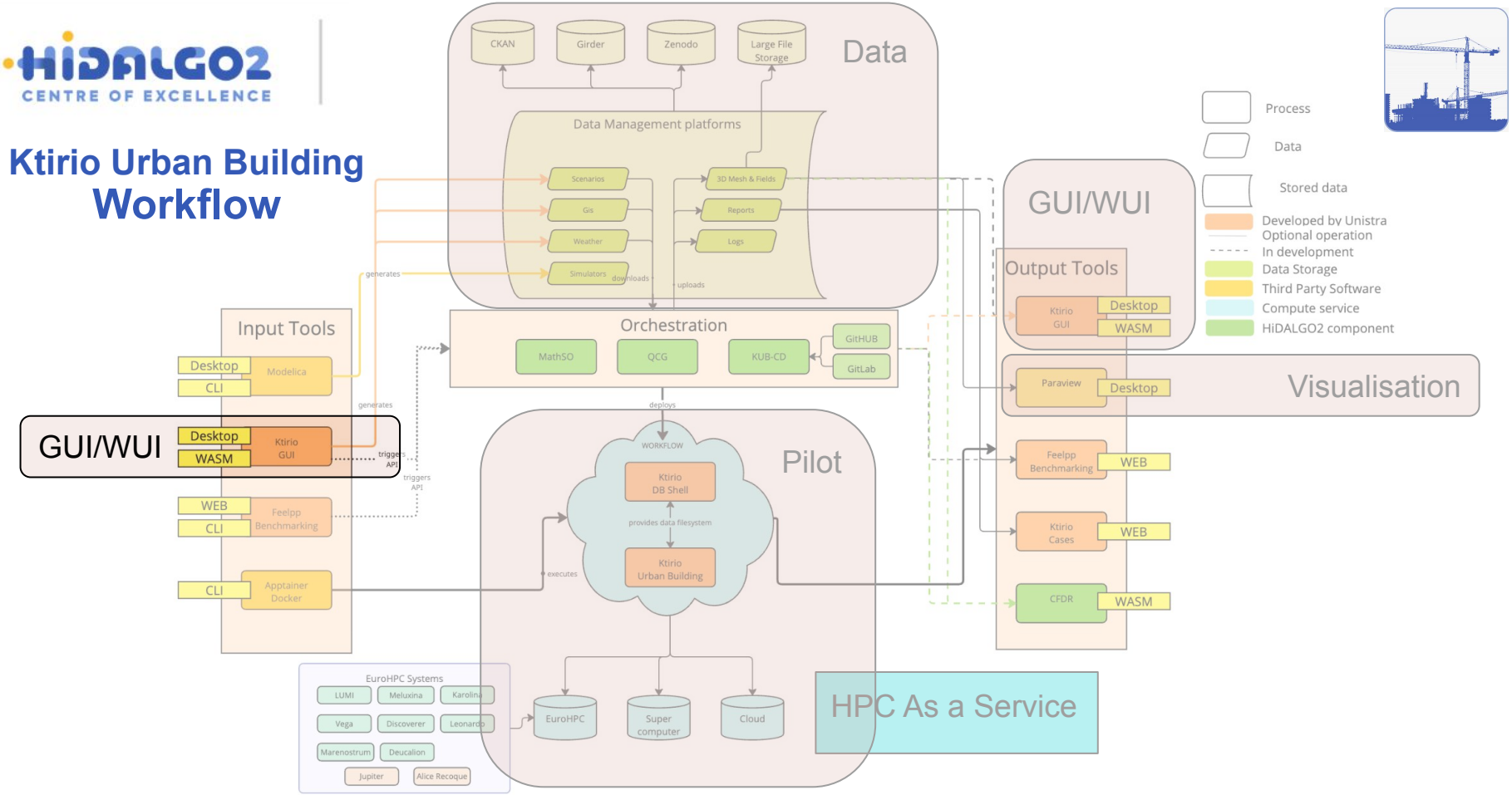




Ktirio Urban Building Workflow

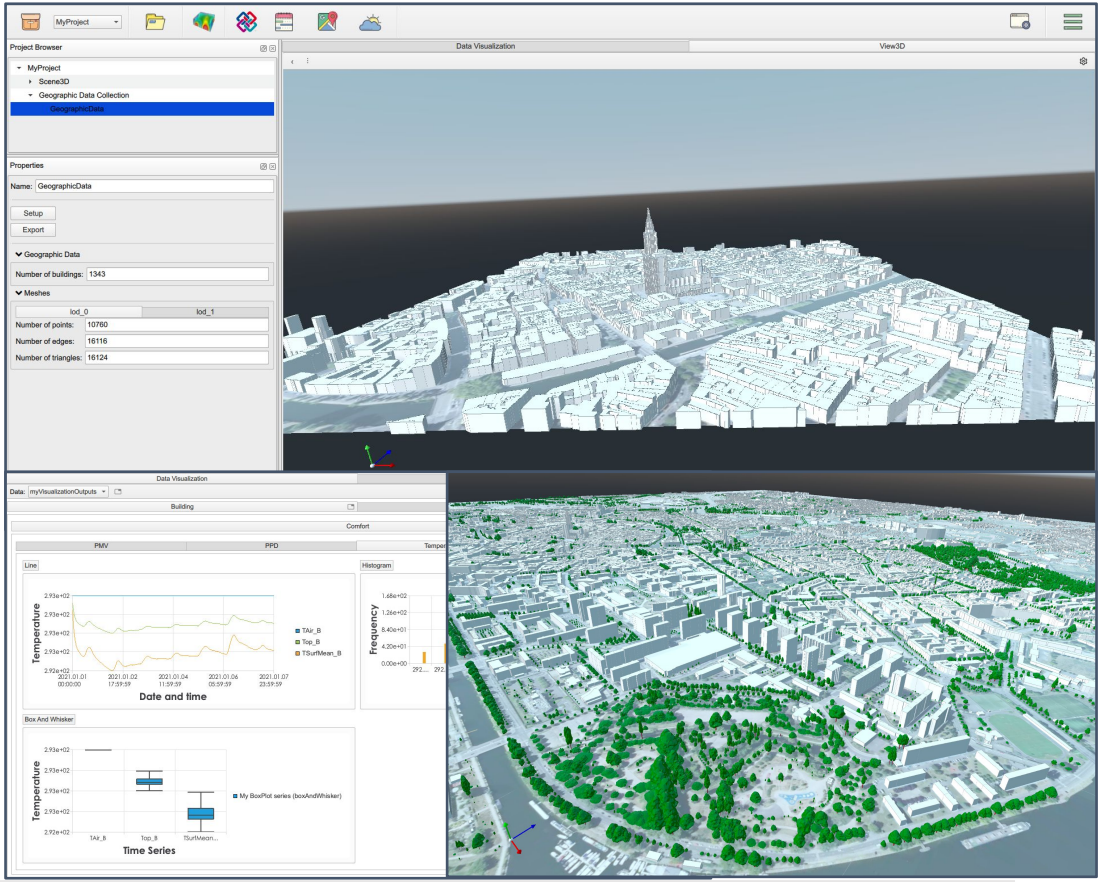


Ktirio Urban Building Workflow



Ktirio-GUI

- Ktirio-GUI: user interface for energy simulation from building to city scale
- User friendly interface enabling visualization, preparation and management of input data for energy simulation
- Visualization of all data types: geographical, geometry, weather, solar masks, vegetation
- Allowing to launch energy simulations using EuroHPC supercomputers using SLURM
- Enabling visualization of building simulation outputs



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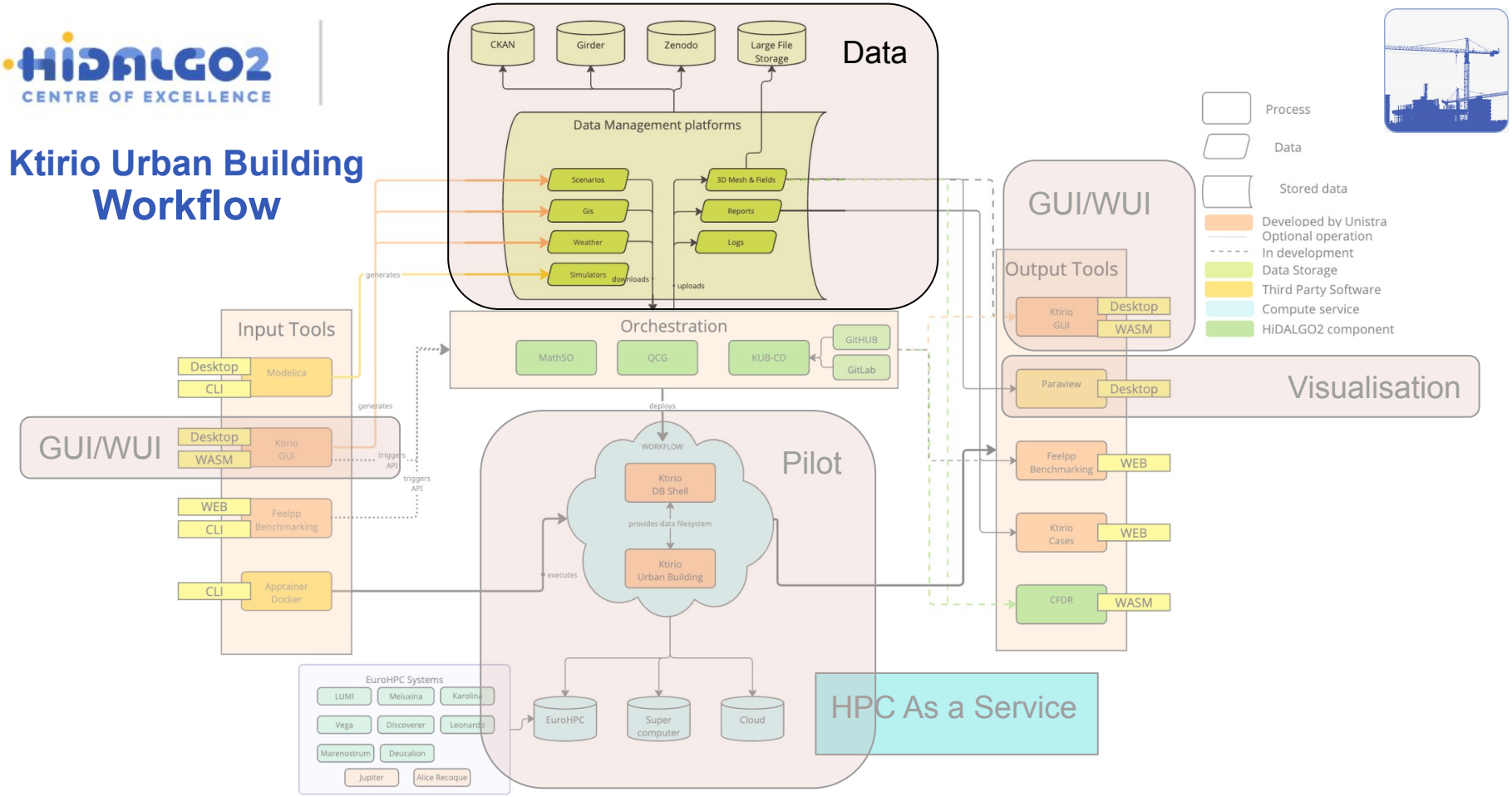
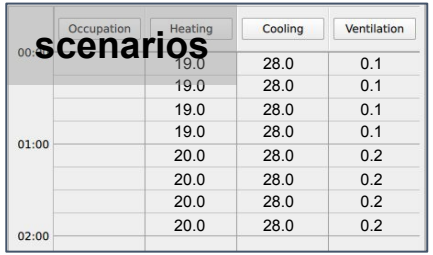
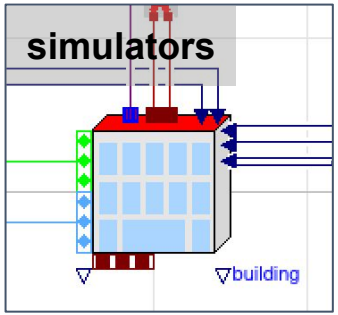


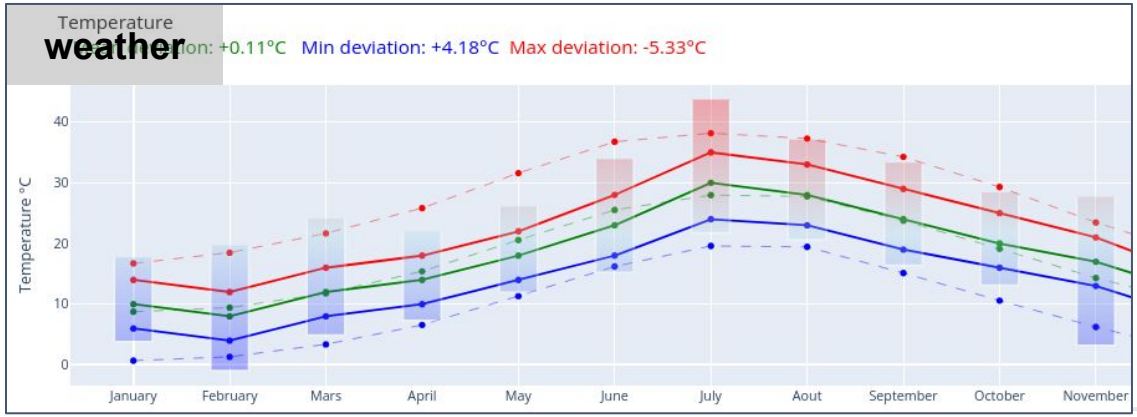
Input Datas

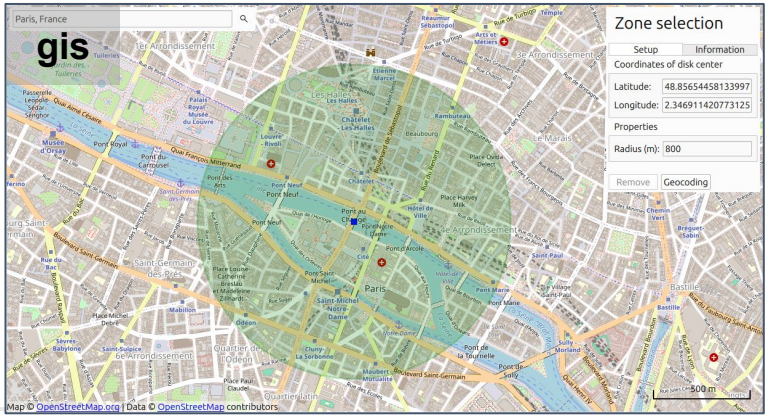
Files Format:

- MSH
- JSON
- CSV
- FMU





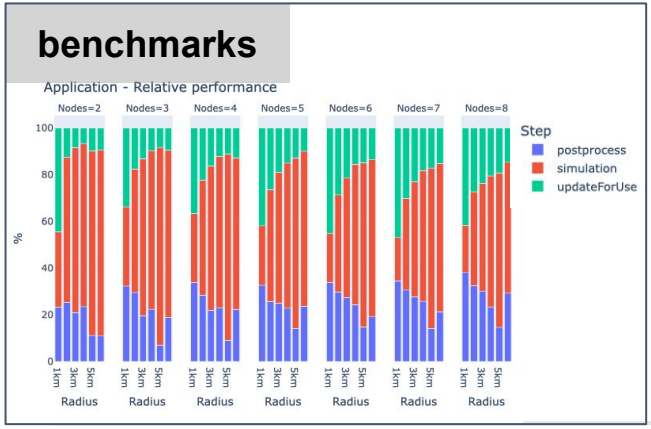


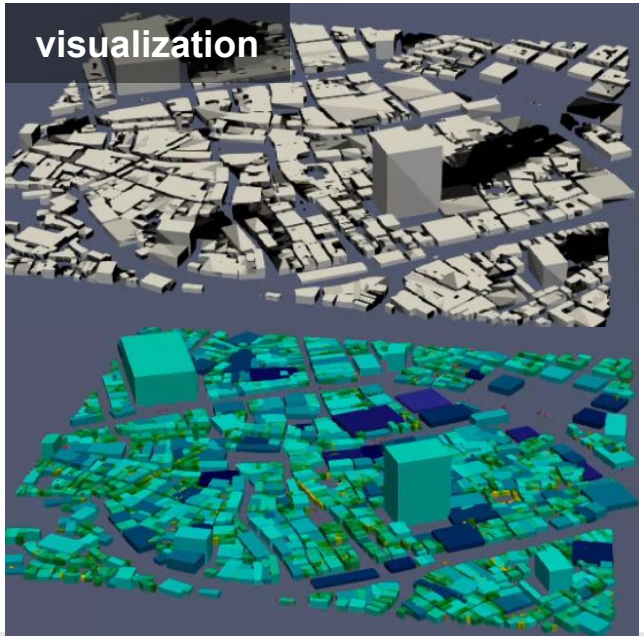


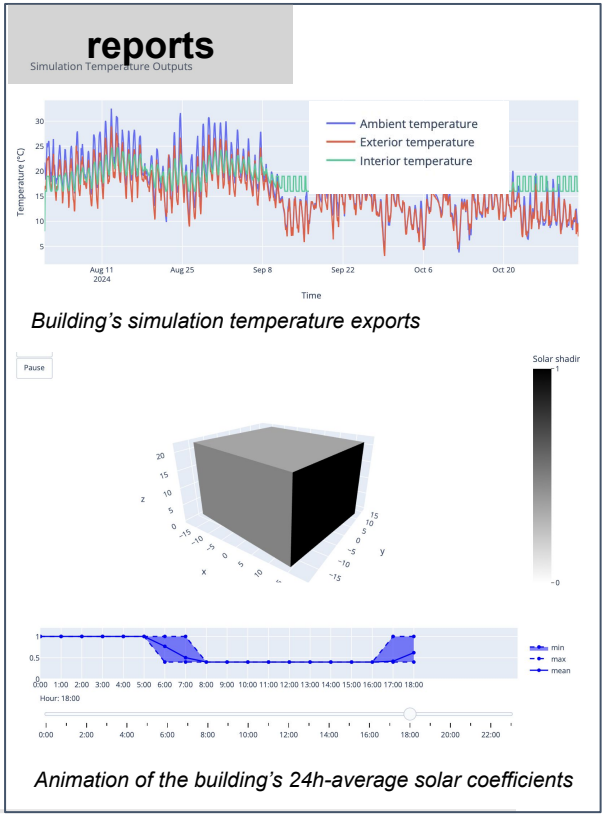
Output Datas

Files Format:

- JSON
- HDF5
- ENSIGHT GOLD



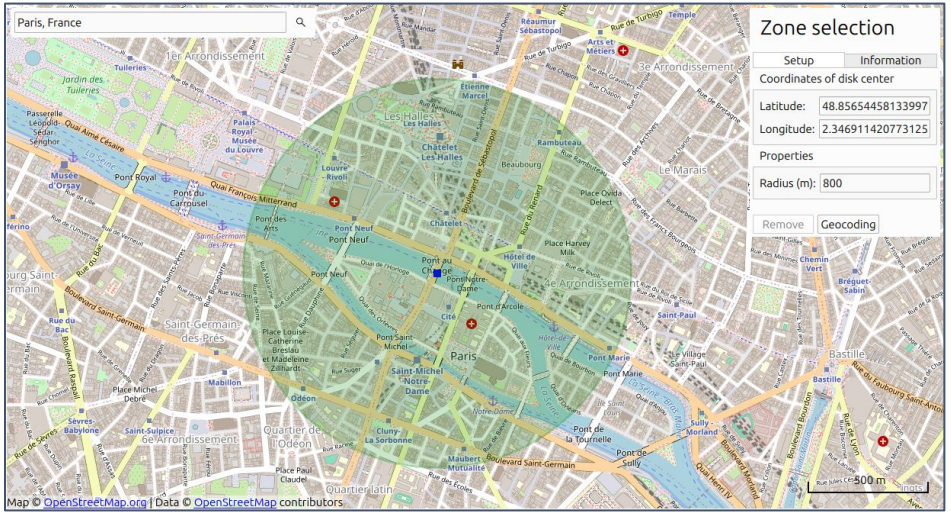




GIS (Geographic Information Systems)

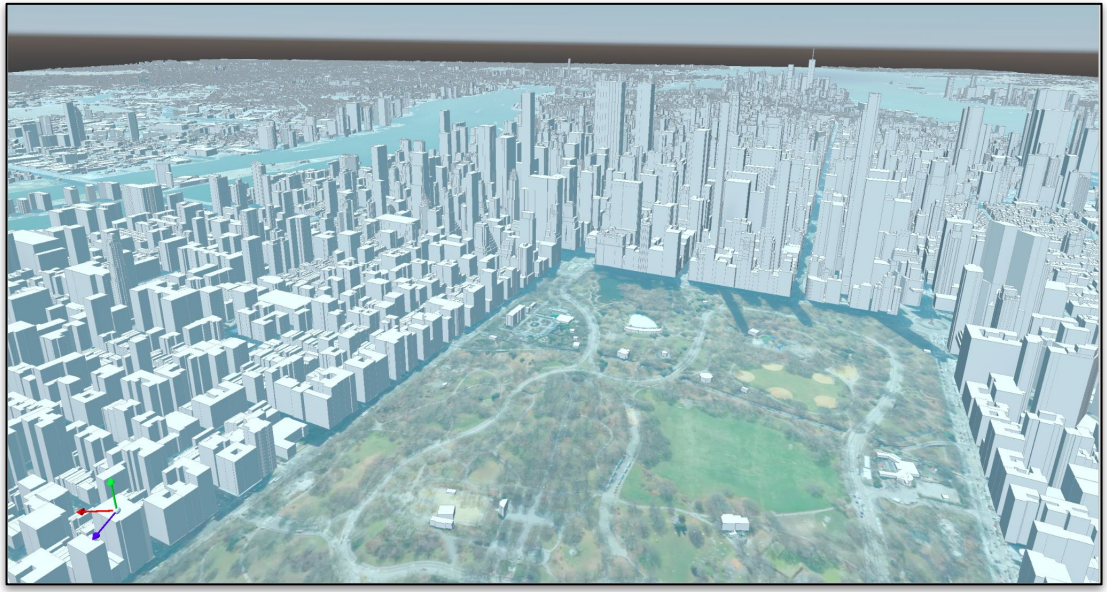
Information about buildings:

- From openStreet Map
- Coordinates (latitude and longitude)
- Coordinates in the projected plane
- Height
- Altitude
- Type (House, Farm, School, Office, …)
- Identification number
- Roof shape
- If the building is divided into several parts



Mesh Generation

- **Integrate** all components such as buildings, terrain, and trees into a cohesive mesh.
- **Ensure** conformity and water-tightness for robust simulations.
- **Assign** marked entities with attributes like type (e.g., building, tree) and subtype (e.g., trunk, roof, floor), including local numbering for identification.
- **Utilize Ktirio-Geom**, a specialized tool for generating and adapting meshes for 3D city models, including repair and optimization.



Mesh (Building Modeling)

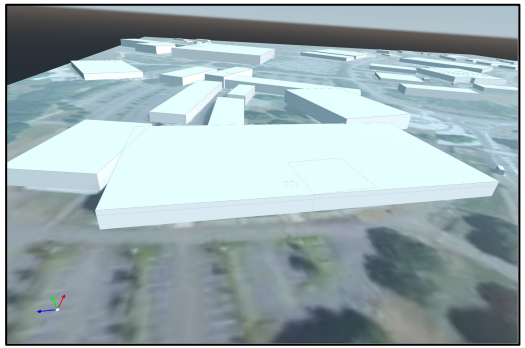
Multi-fidelity representation of urban model

LoD 0 | LoD 1 | LoD 2

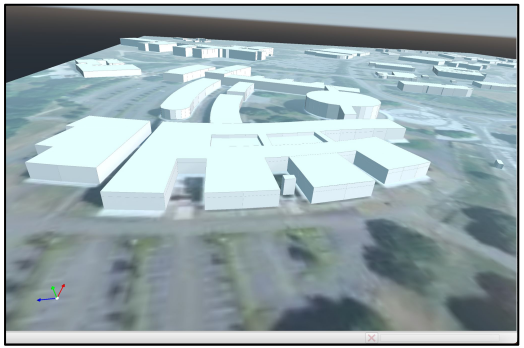
From OpenStreetMap – Web tiled map.

BIM data in IFC format

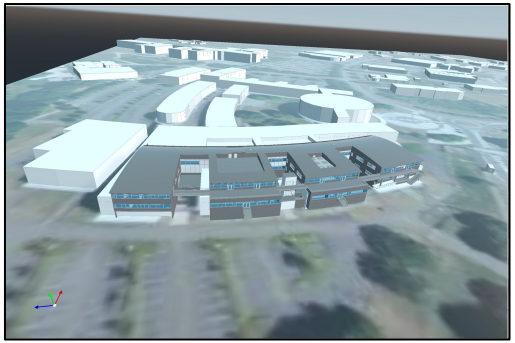
LoD-0: Oriented Bounding Boxes



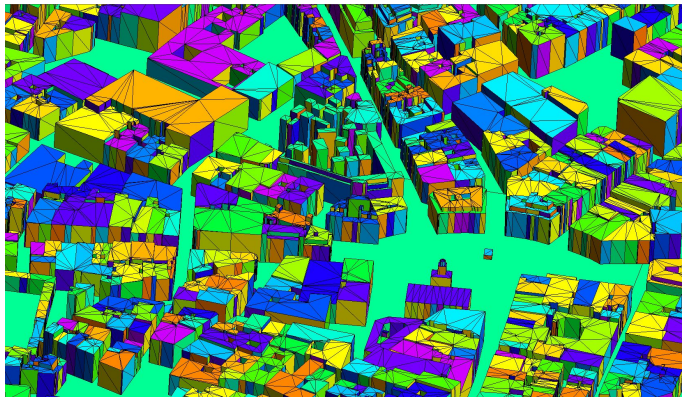
LoD-1: Multi-polygon extrusion + roof



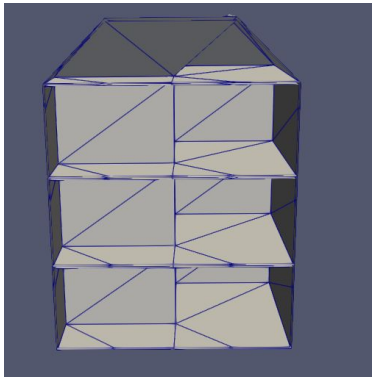
LoD-2: Detailed representation

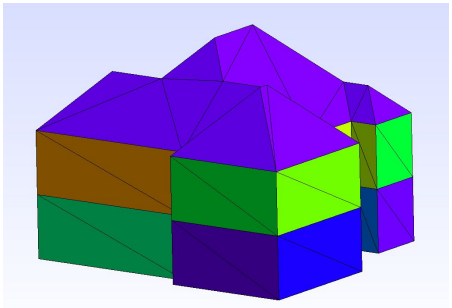


Mesh (Building Modeling)



Options menu for buildings in the GUI

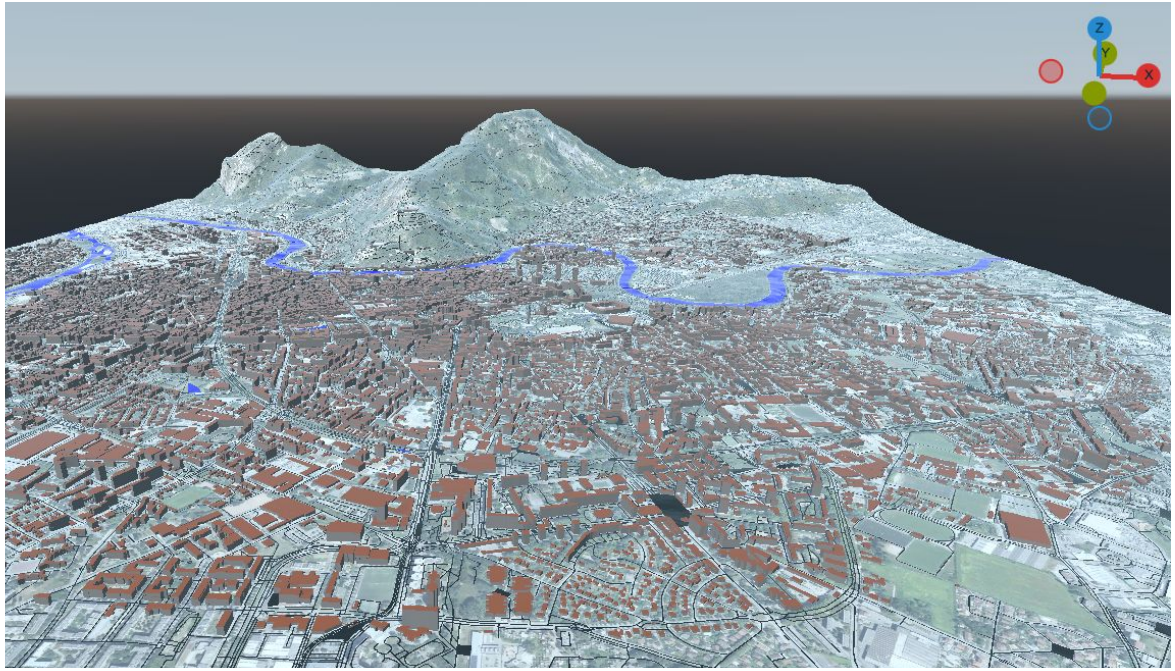




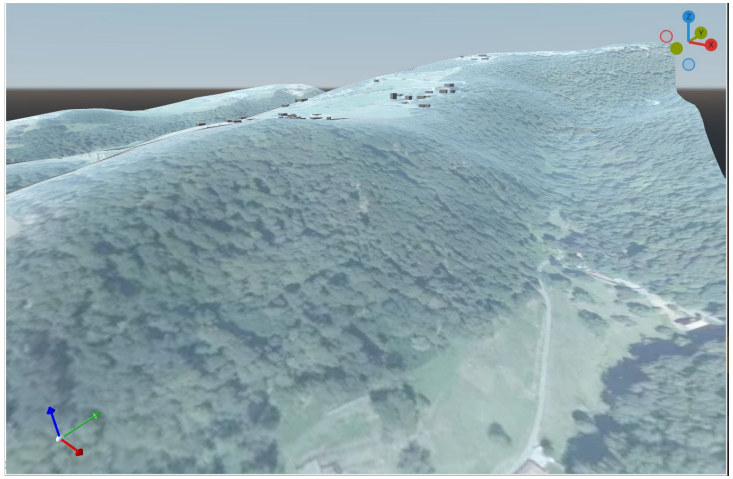
Mesh (Modeling the Building environment)

Why ?

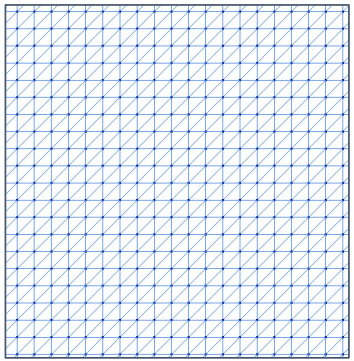
- **Topography** : shapes airflow & runoff.
- **Rivers/lakes** : drainage, storage, thermo-hydro exchange.
- **Parks/green** : albedo, roughness, evapotranspiration → cooling.
- **Roads** : imperviousness, emissions/heat, wind corridors.
- **Modeling** : parameters & boundary conditions set by mesh labels.



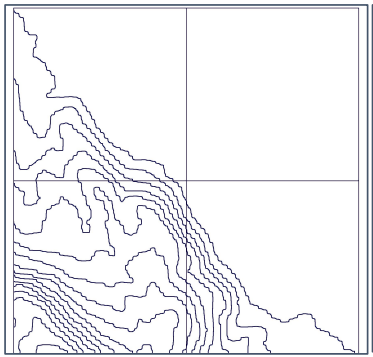
Mesh (Terrain Modeling)



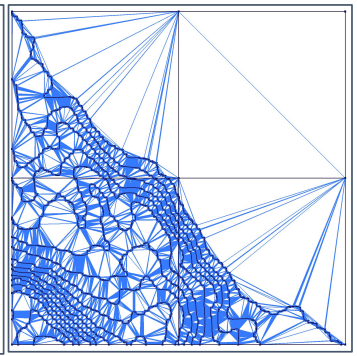
1. Generate structured triangle grid from Raster image
2. Compute contour lines (marching triangles)
3. Generate constrained mesh from isolines (CGAL)
4. Polyline simplification (CGAL)
5. Feature processing and meshing (roads, water bodies, parks, …)
6. Feature corefinement with elevation mesh
7. Merge tiles



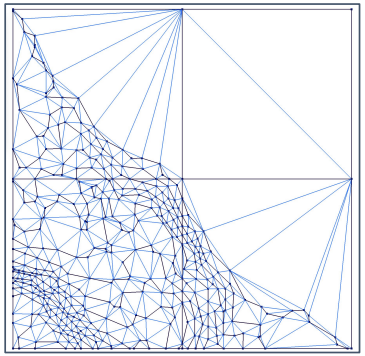
Structured triangle grid (~ 250 000 vertices)



16 isolines (each 30m)



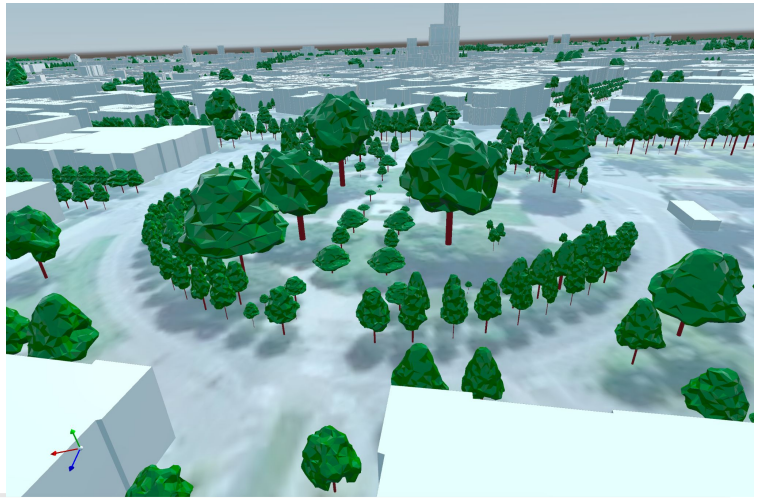
Constrained triangulation before simplification (~16 000 vertices)



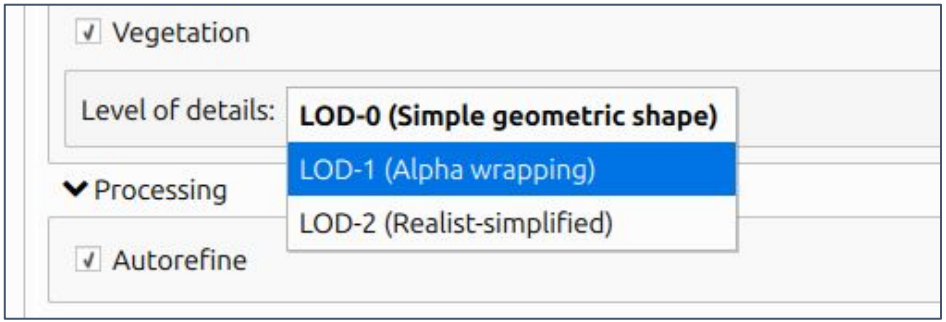
Constrained triangulation after simplification (~316 vertices)

Mesh (Vegetation Modeling)

- **Impact on Building simulation**: simulate environmental impact, such as solar masking effects on buildings.
- **References tree library** : Currently supports three types of trees.
- **Data source** : Vegetation data is retrieved from OpenStreetMap.



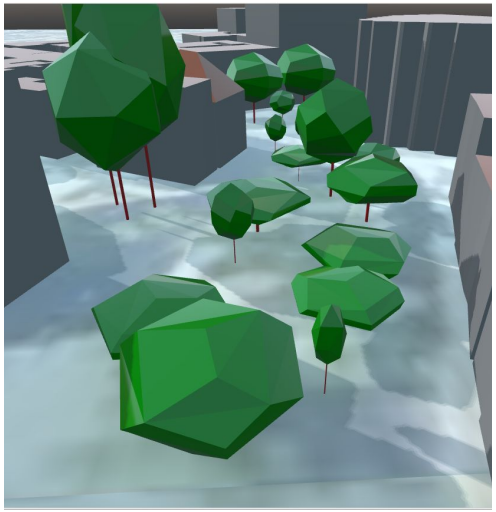
Options menu for vegetation in the GUI



Mesh (Vegetation Modeling)

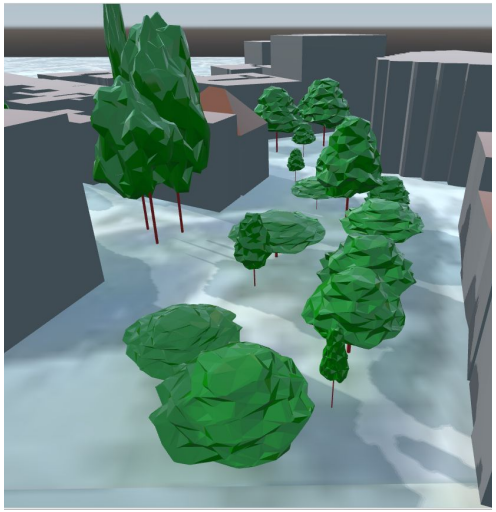
LoD 0

Simple geometric shape



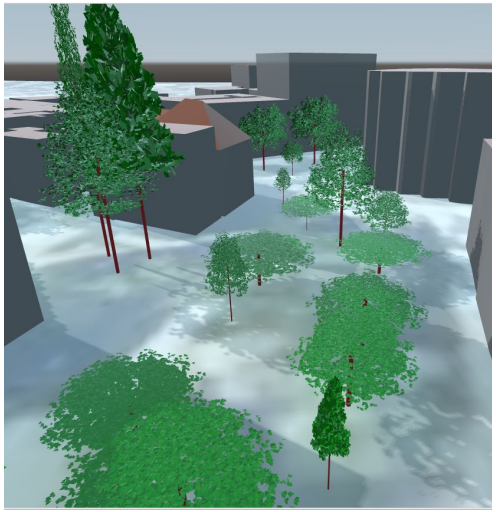
LoD 1

Alpha wrapping
(based on LoD-2)



LoD 2

Realistic simplified



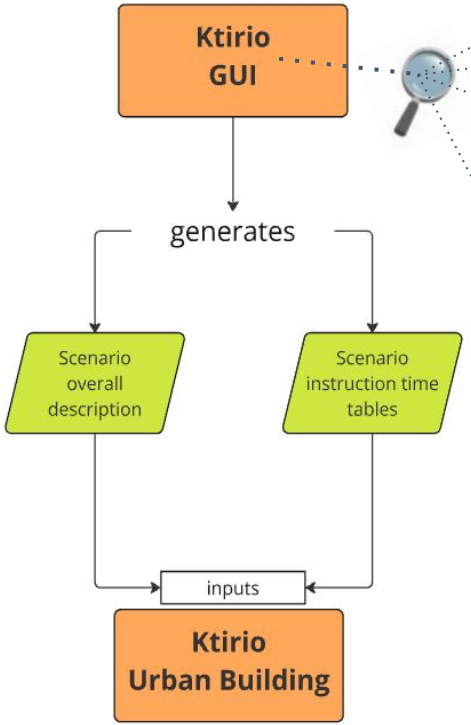
Weather

- Weather data from stations or forecasting models
  temperature at 2m, wind conditions,
  solar radiations, …

Options:

- ❑ Resolution and precision varies depending on the model used
- ❑ Adjustable step time (15min, 30 min, 1h, 2h)

Scenario



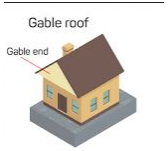
Scenario Edition

	Occupation	Heating	Cooling	Ventilation
00:00		19.0	28.0	0.1
		19.0	28.0	0.1
		19.0	28.0	0.1
		19.0	28.0	0.1
01:00		20.0	28.0	0.2
		20.0	28.0	0.2
		20.0	28.0	0.2
		20.0	28.0	0.2
02:00				

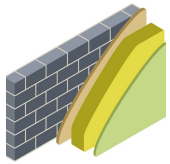
- **Create scenarios** to assign *heating, cooling, and ventilation* setpoints by building category, based on schedules, weekdays, or vacation periods.
- **Take into account internal gains**: appliances and human heat sources.
- **Create and allocate custom scenarios** or exclude specific building types from simulations.using Ktirio-GUI

Instruction	**Parameters**
Schedule	Hour / day / month / vacation / weekend
Heating	Set point temperature for inside thermal zone
Cooling	Set point temperature for inside thermal zone
Ventilation	Volume of air renewed by hour
Internal gains	Appliances heat sources Human heat sources

Simulator (Physical Models)



Roof Shape

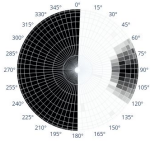


Materials

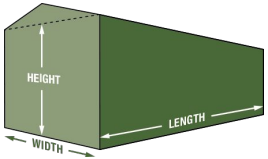
Heating/Cooling

Modelica Language

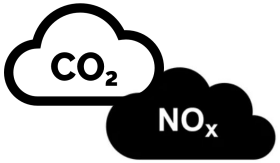
FEEL++



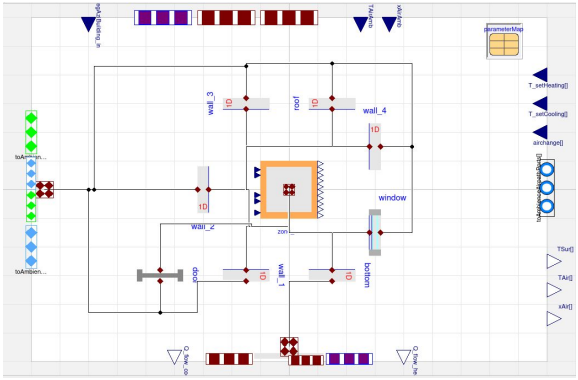
Shading



Dimensions



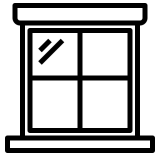
Pollutants



Multi-zone models

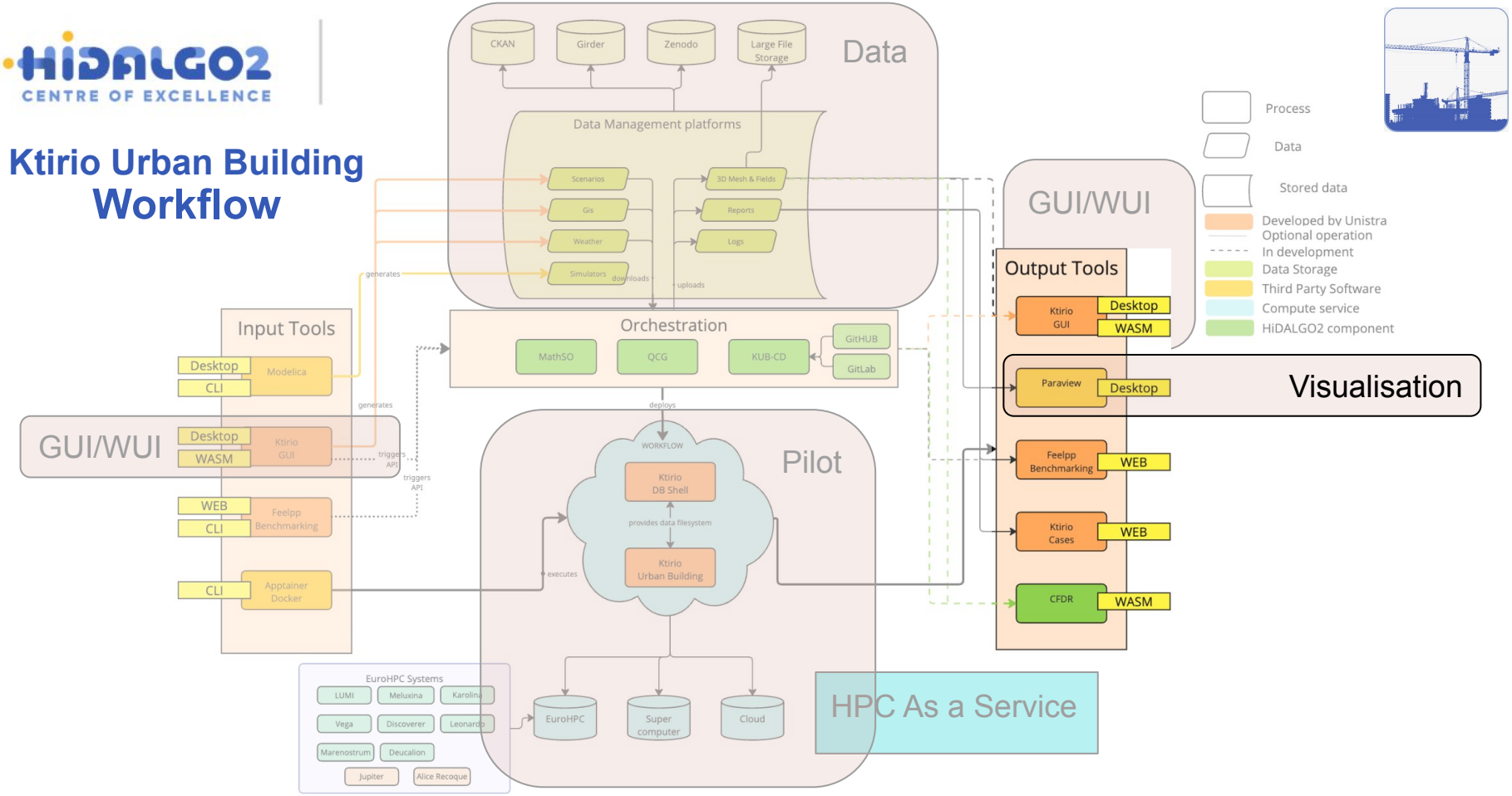
Comfort indicators

Weather

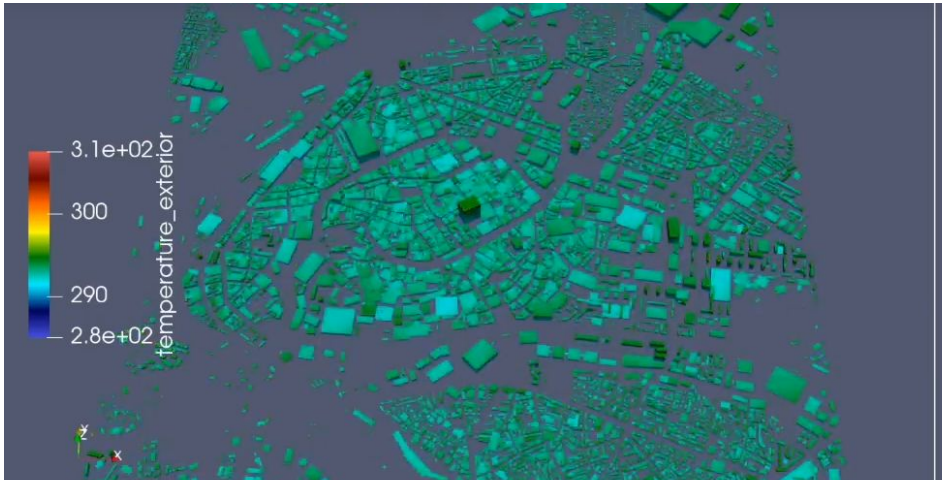


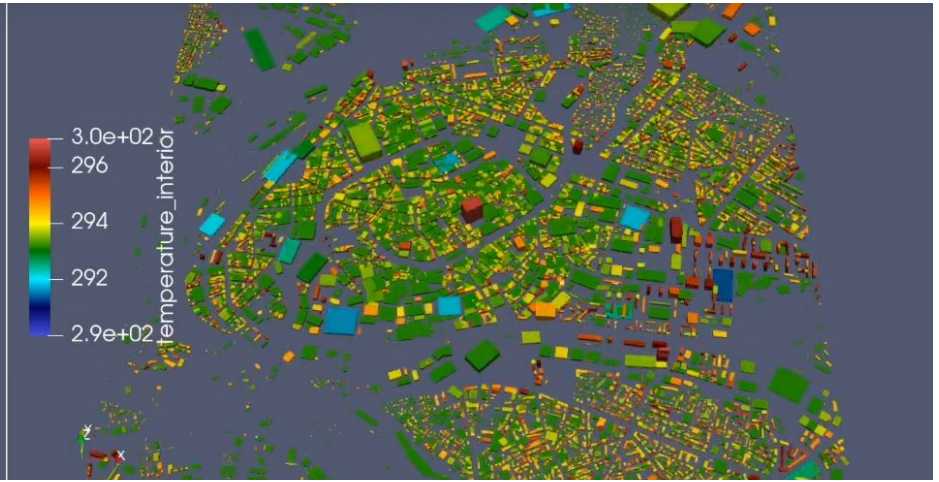
Windows

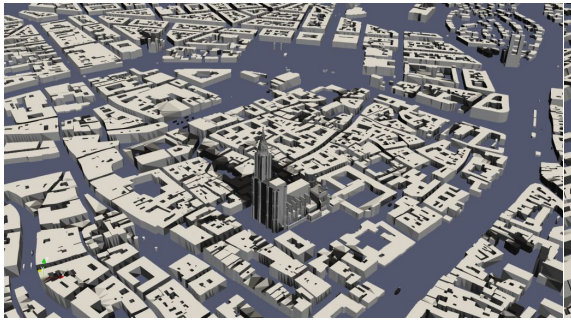
Ktirio Urban Building Workflow

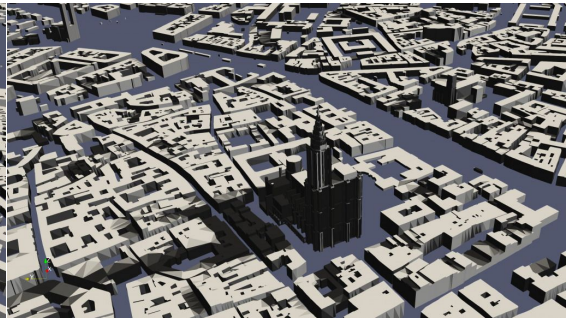


Visualization using Paraview
3D visualization of simulation results





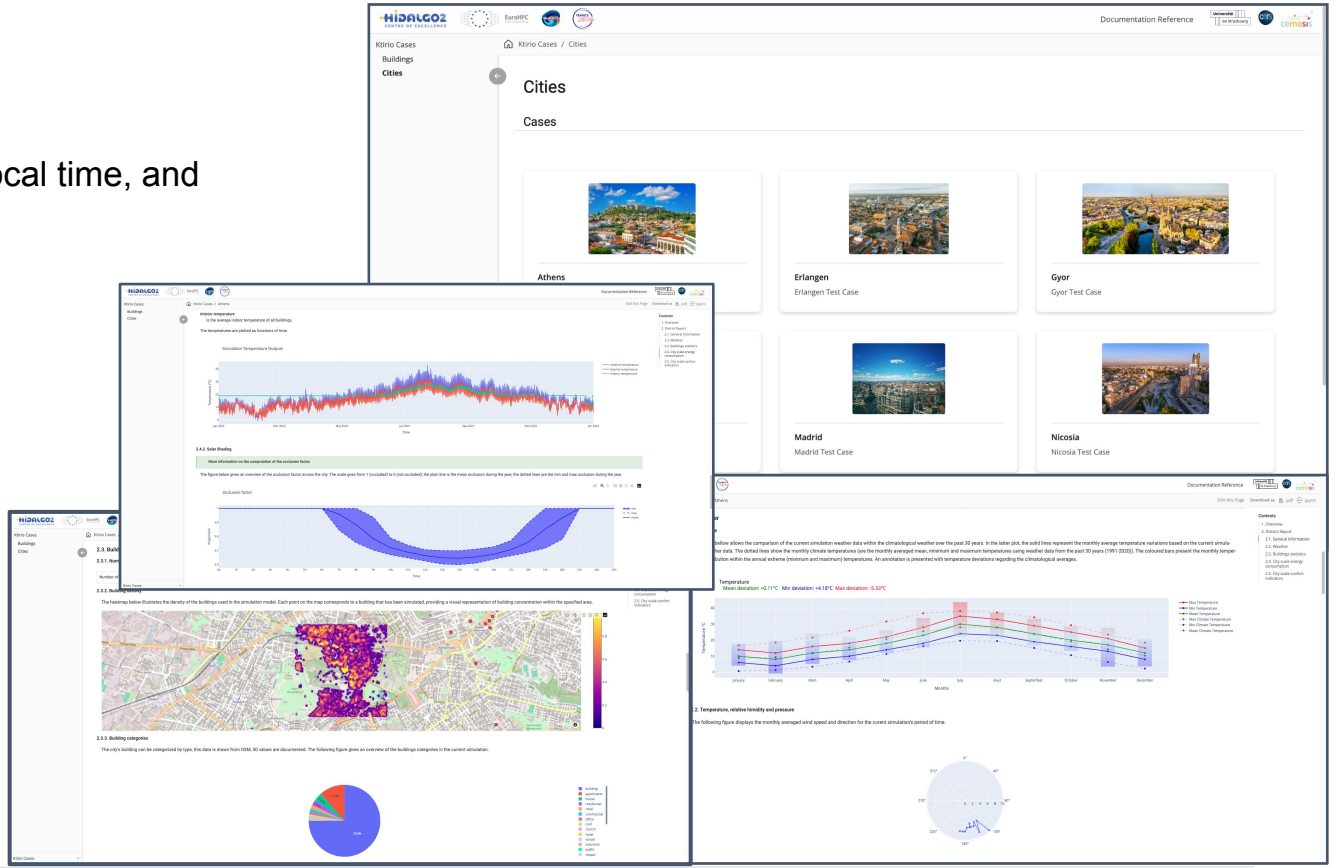




Ktirio.cases reports

What data are visualized ?

- Overview on city location, local time, and simulation parameters
- Buildings data: number, categories, density,
- Weather: observations from OpenMeteo, computing statistics and deviation from climatological means
- City scale energy consumption, heating, cooling, solar shading

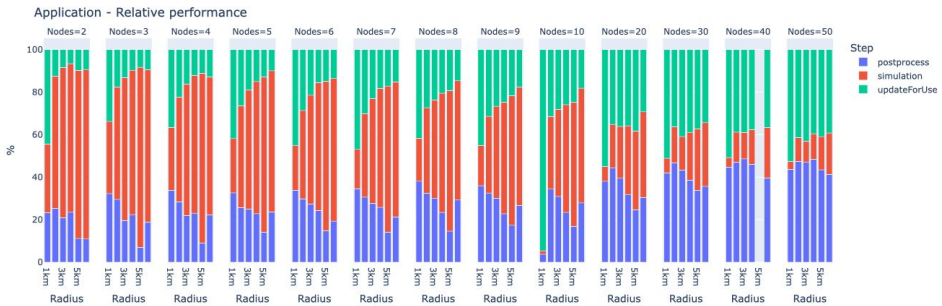


feelpp.benchmarking Framework for KUB

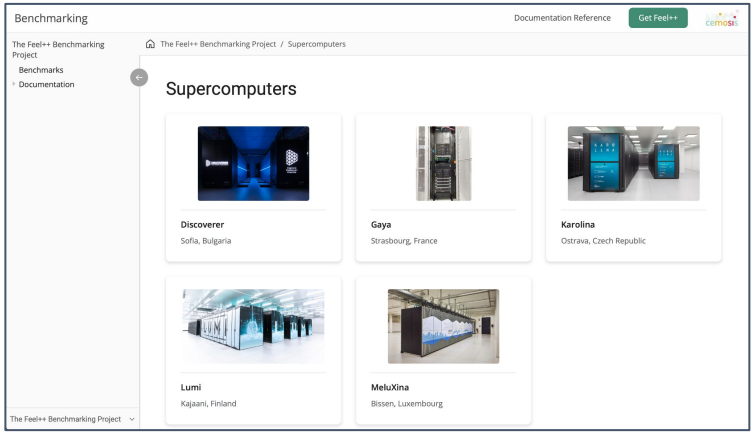
How KUB uses feelpp.benchmarking ? (https://bench.ktirio.fr)

	Location	Heating systems	Quadrature Order	LOD	Period	Radius	# nodes
S1	Paris	Ideal	3	0	1 day, winter	1 – 6 km	2 – 50
S2	Paris-Berlin	Ideal	3	0	1 day, winter	5 km	2 – 50
S3	Paris	Ideal	0 – 5	0	1 day, winter	3 km	2 – 10

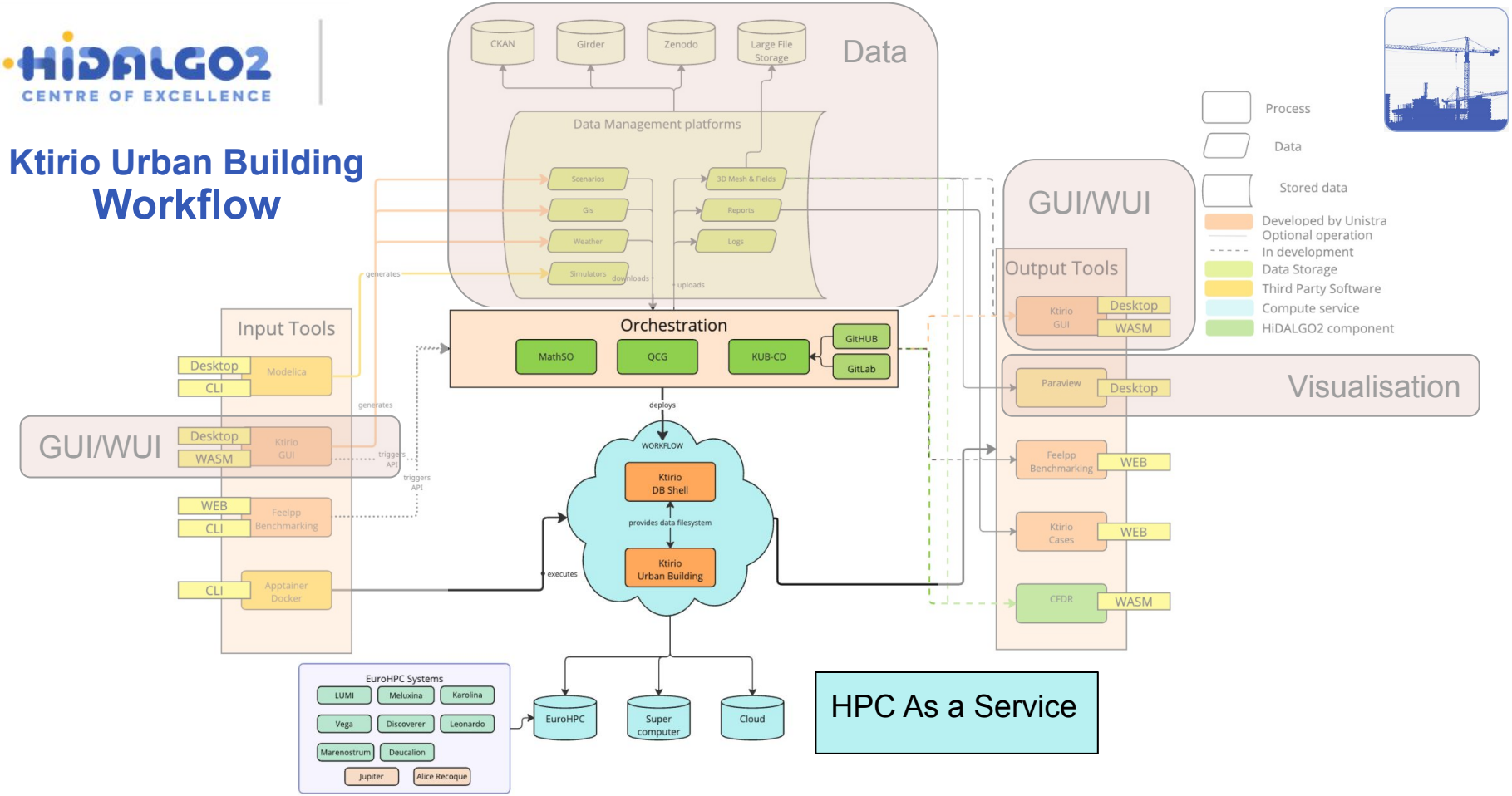
UB Scenarios benchmarked

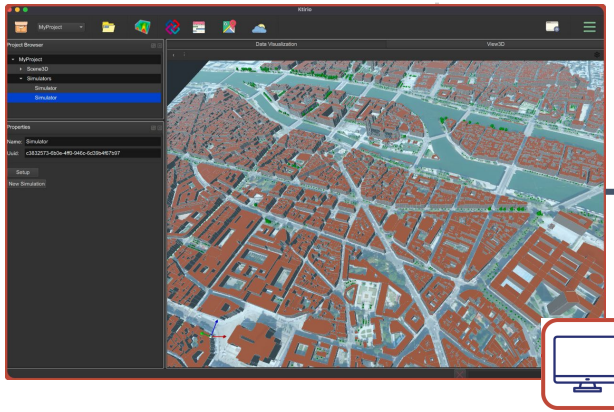


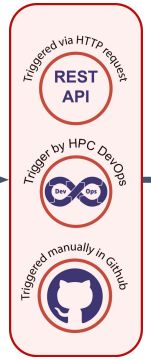
UB stages' relative performance – Paris – 1 - 6km – 2-50 nodes

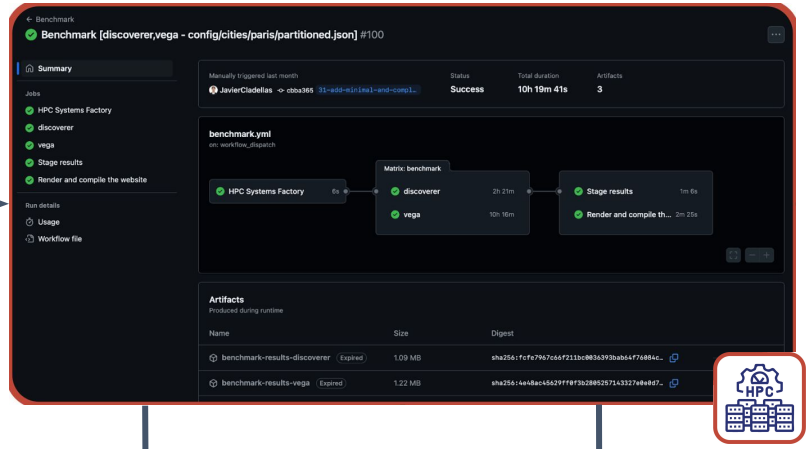


Ktirio Urban Building Workflow



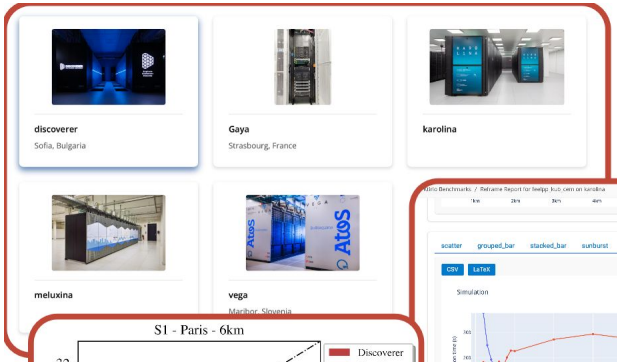


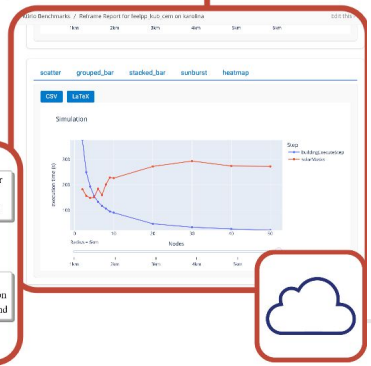


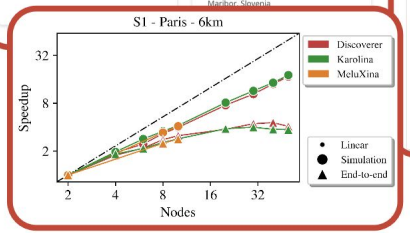


Uploads

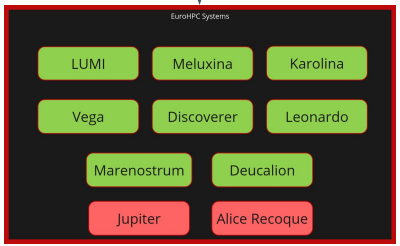
Deploys





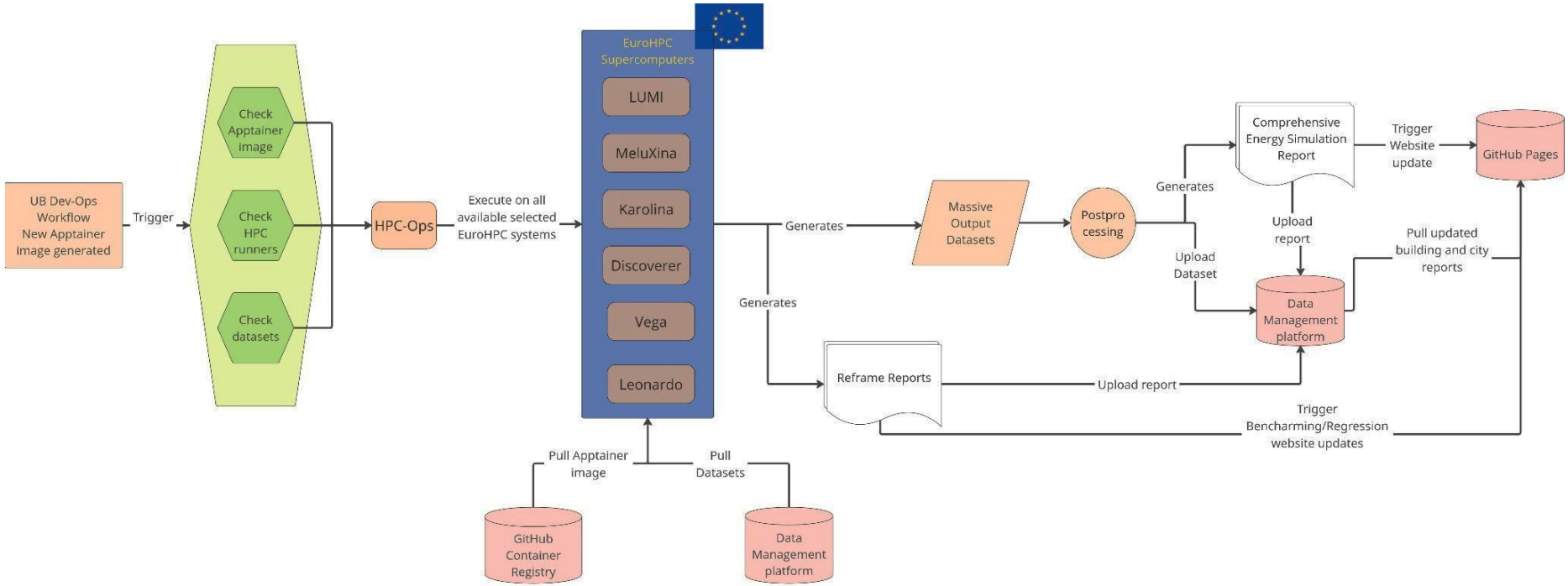


Trigger website reports

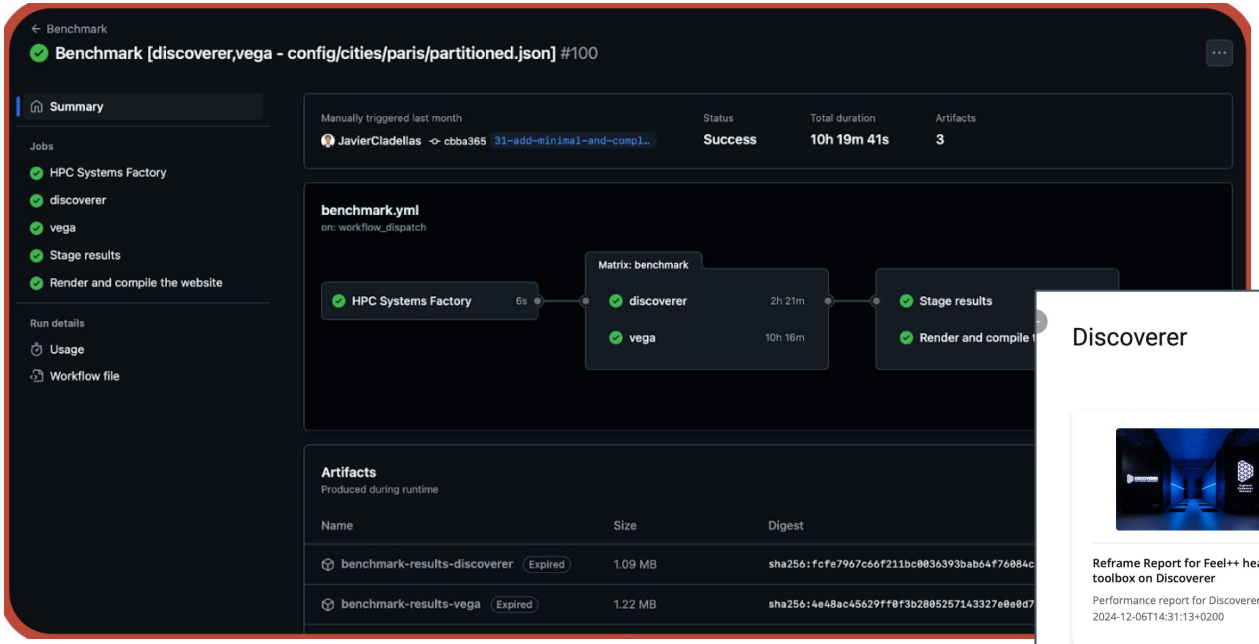


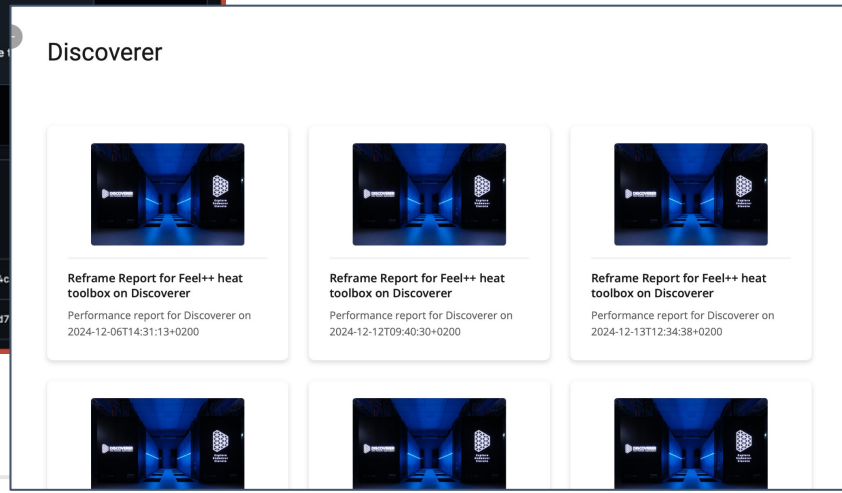
https://bench.ktirio.fr

Submission to HPC Cluster



Presentation of monitoring status



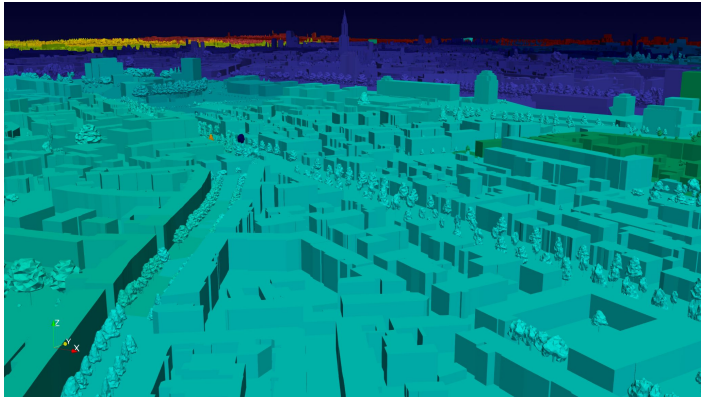


Benchmarks history of a Feel++ application on Discoverer

Partitioning Strategies are essential

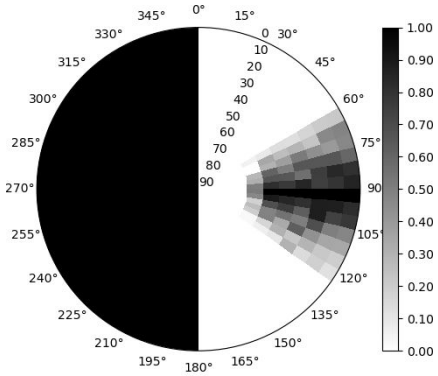
Partitioning

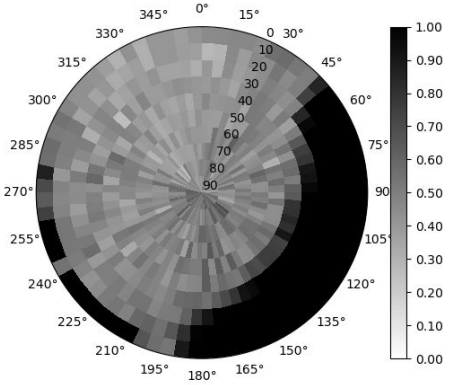
- **Objective**：Distribute terrain, buildings, and vegetation entities efficiently for High-Performance Computing (HPC) applications.
- **Requirements**：Ensure spatial partitioning so that nearby objects remain within the same partition for computational coherence.
- **Methodology**：Implement partitioning algorithms based on mesh adjacency graphs, leveraging mesh conformity to optimize performance.



Computing Shading Masks

Definition: Shading mask quantify the percentage of blocked solar radiation for a building surface, depending on the sun's position

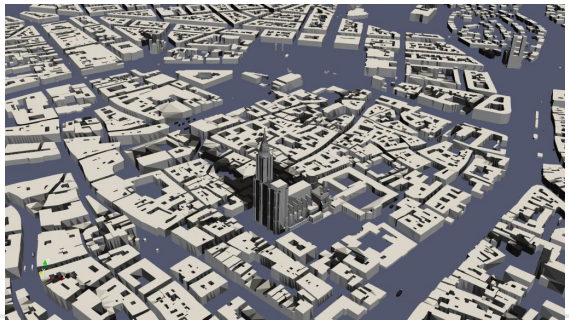


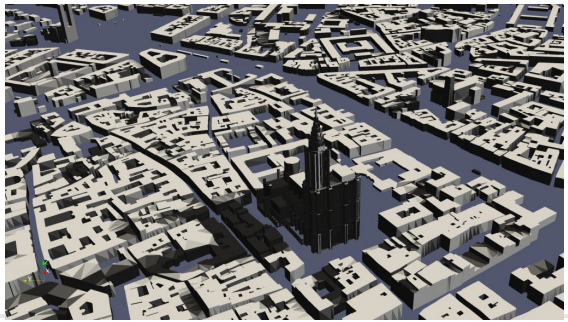


0 [white] : no obstruction
1 [black] : total obstruction

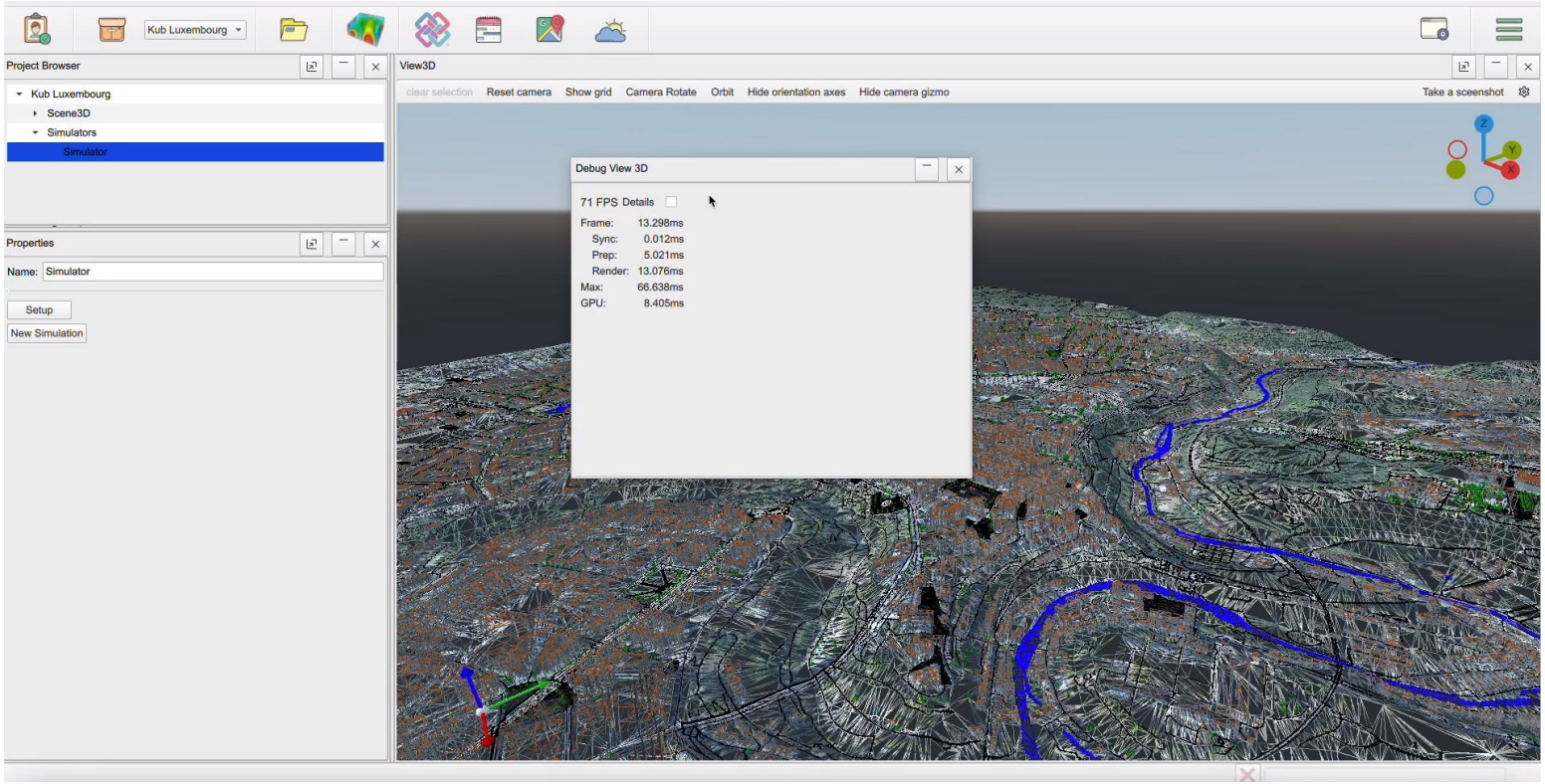
In Ktirio-Feel++

- Monte Carlo method and ray tracing techniques used for computations
- Computations in parallel across multiple CPU cores



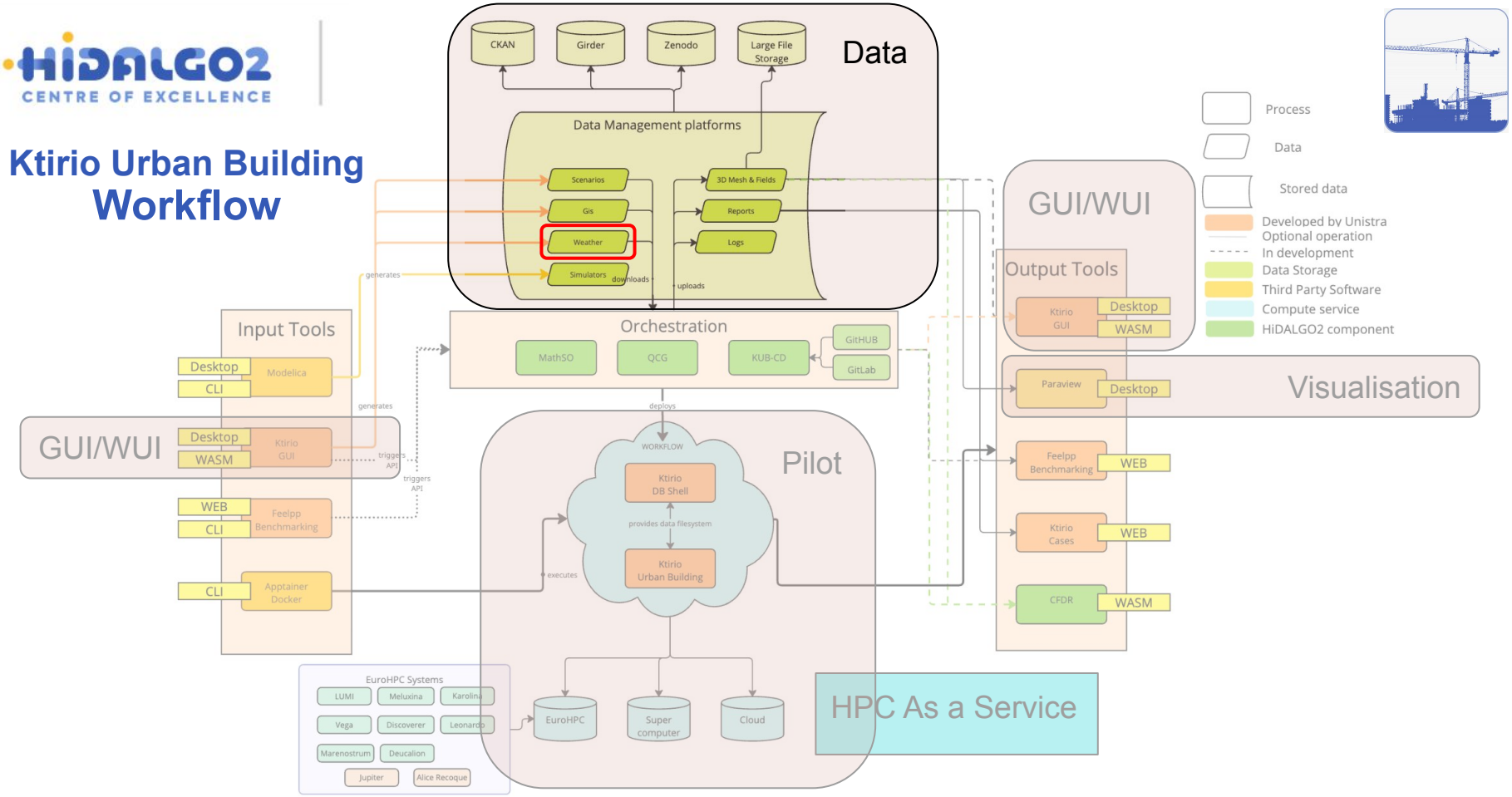


Demo: 1) simulation using Karolina and 2) video demo

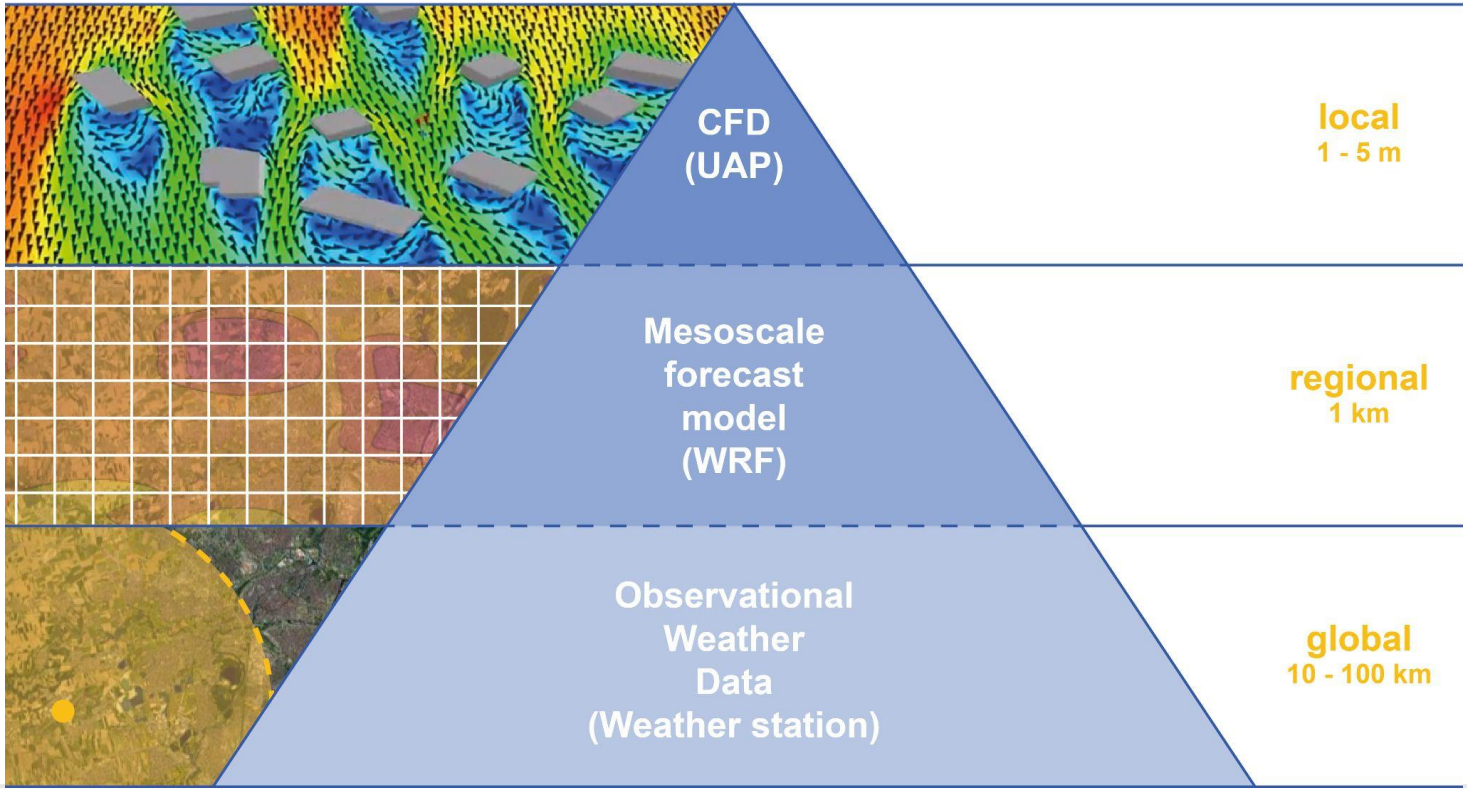


Technical Presentation, Data Handling and Weather Data Manipulation

Ktirio Urban Building Workflow



Meteorological data



Meteorological data type

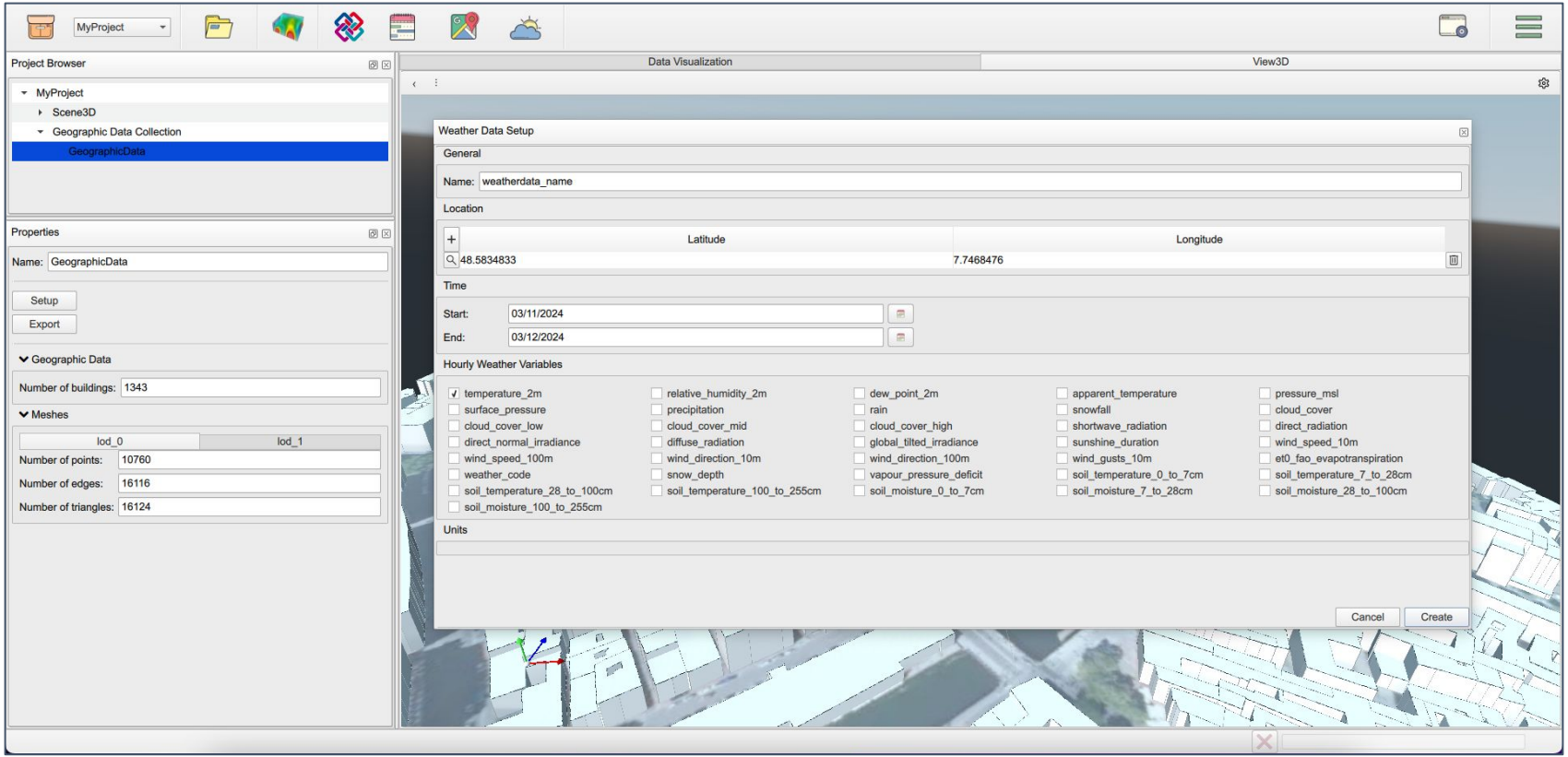
📜 **Historical data:** Past observations records used for model validation and understanding long-term trends.

📐 **Reference data:** Standardized 30-year averages (e.g., TMY(Typical Meteorological Year), TRY(Test Reference Years)) defining typical conditions for building simulations.

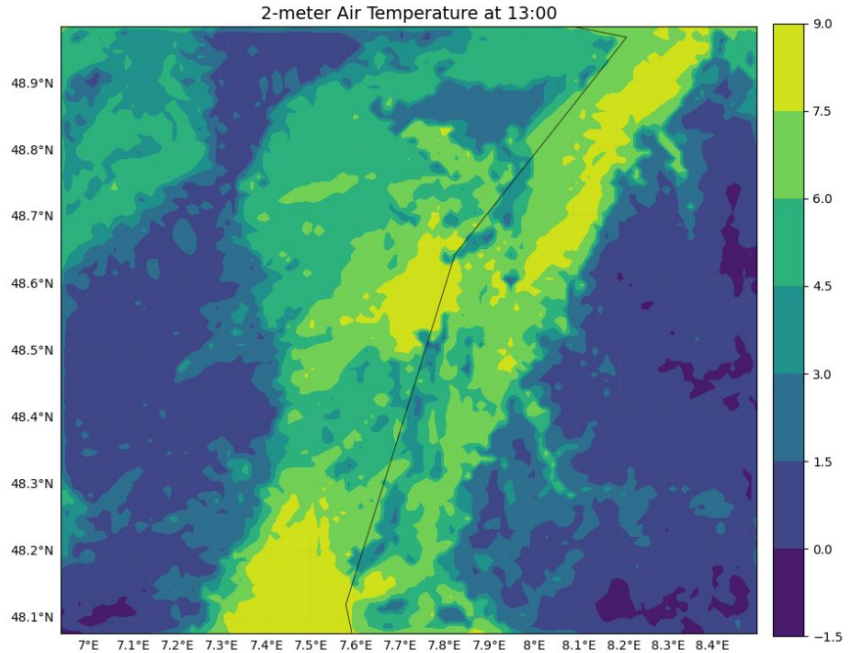
⚡ **Short-term forecasts:** Numerical Weather Prediction (NWP) models providing hours-to-days outlooks for model predictive control (MPC) and adaptive HVAC strategies.

🌍 **IPCC-scale projections:** Scenario-based climate models (GCMs, SSPs) predicting long-term climate evolution and future building performance impacts (e.g., cooling demand).

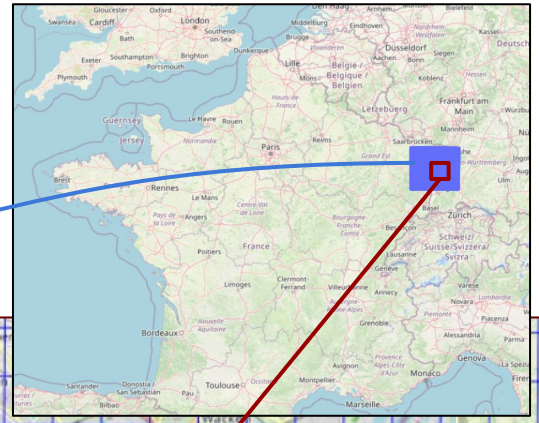
Preparation of weather data via Ktirio.GUI

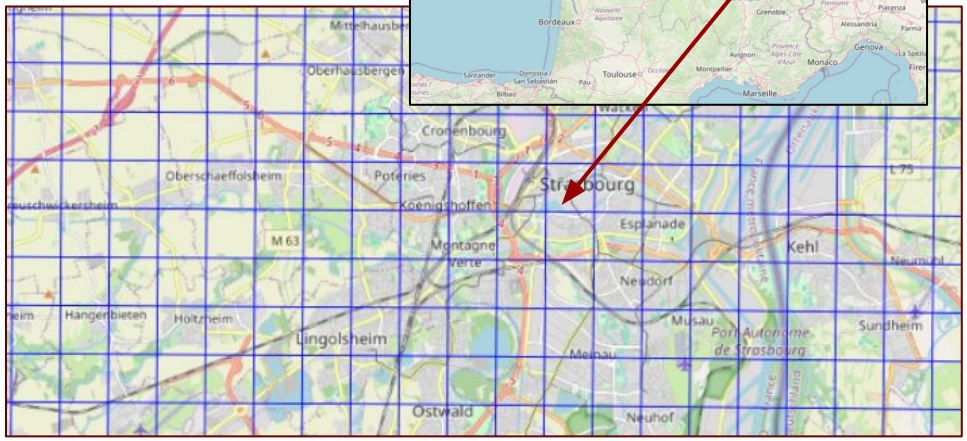


Mesoscale weather data with a grid resolution of 1 km



Strasbourg region
Eastern France



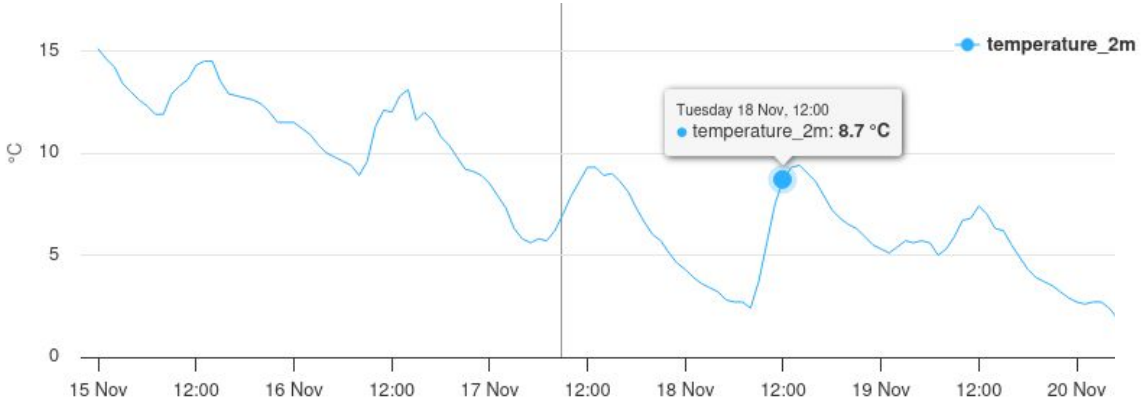


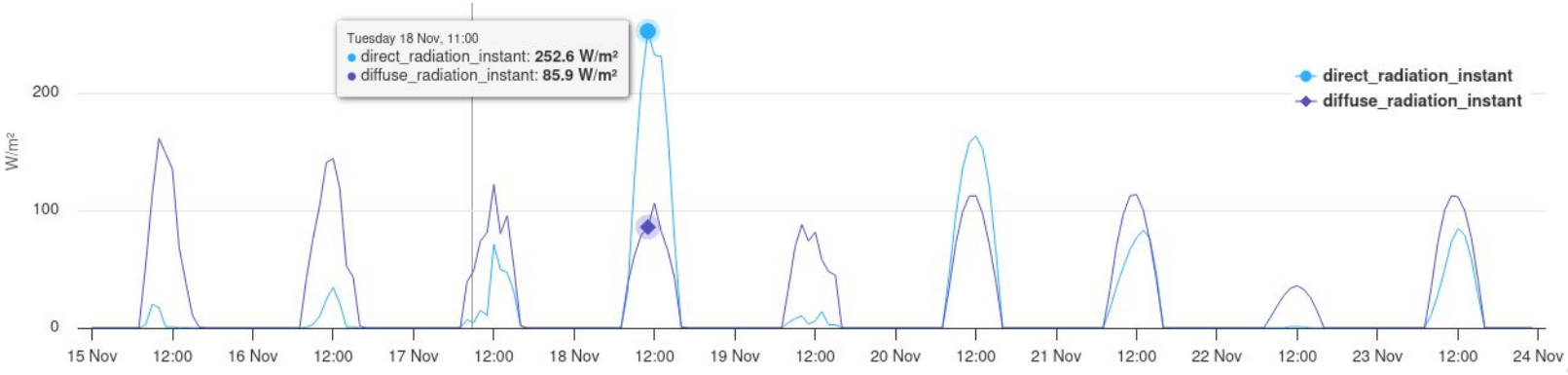
WRF weather grid

Hourly parameters used in Building Simulation

Variable	Unit	Description
temperature_2m	°C (°F)	Air temperature at 2 meters above ground
relative_humidity_2m	%	Relative humidity at 2 meters above ground
wind_speed_10m	km/h (m/s)	Wind speed at 10 meters above ground.
wind_direction_10m	°	Wind direction at 10 meters above ground.
surface_pressure	hPa	Atmospheric air pressure reduced to mean sea level (msl) or pressure at surface
direct_radiation	W/m²	Direct solar radiation as average of the preceding hour on the horizontal plane and the normal plane (perpendicular to the sun)
diffuse_radiation	W/m²	Diffuse solar radiation as average of the preceding hour
cloud_cover	%	Total cloud cover as an area fraction

Open Meteo


temperature_2m
Tuesday 18 Nov, 12:00
temperature_2m: 8.7 °C
°C
15
10
5
0
15 Nov
12:00
16 Nov
12:00
17 Nov
12:00
18 Nov
12:00
19 Nov
12:00
20 Nov


Tuesday 18 Nov, 11:00
direct_radiation_instant: 252.6 W/m²
diffuse_radiation_instant: 85.9 W/m²
direct_radiation_instant
diffuse_radiation_instant
W/m²
200
100
0
15 Nov
12:00
16 Nov
12:00
17 Nov
12:00
18 Nov
12:00
19 Nov
12:00
20 Nov
12:00
21 Nov
12:00
22 Nov
12:00
23 Nov
12:00
24 Nov

Open Meteo

- Open-source weather API
- Forecast API:
  - Provides hourly forecasts up to 16 days depending on the model.
- Historical API: hourly data can be found going back to the 2000s and as far back as 1950, but with less detail depending on the model.

Weather Model	National Weather Provider	Origin Country	Resolution	Forecast Length	Update frequency
ICON	Deutscher Wetterdienst (DWD)	Germany	2 - 11 km	7.5 days	Every 3 hours
GFS & HRRR	NOAA	United States	3 - 25 km	16 days	Every hour
ARPEGE & AROME	Météo-France	France	1 - 25 km	4 days	Every hour
IFS & AIFS	ECMWF	European Union	25 km	15 days	Every 6 hours
UKMO	UK Met Office	United Kingdom	2 - 10 km	7 days	Every hour
KMA	KMA Korea	Korea	1.5 - 13 km	12 days	Every 6 hours

Heat wave

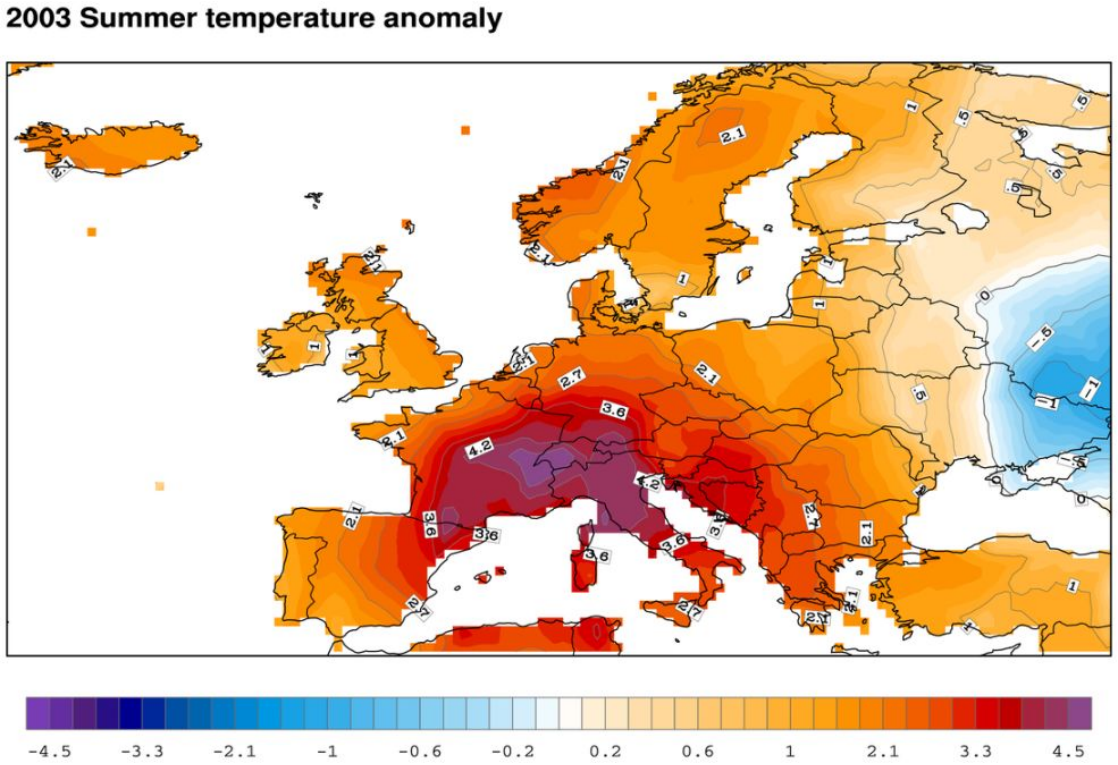
Definition

A heatwave is a period of intense and sustained heat, both day and night, over an extended period (at least 3 days).

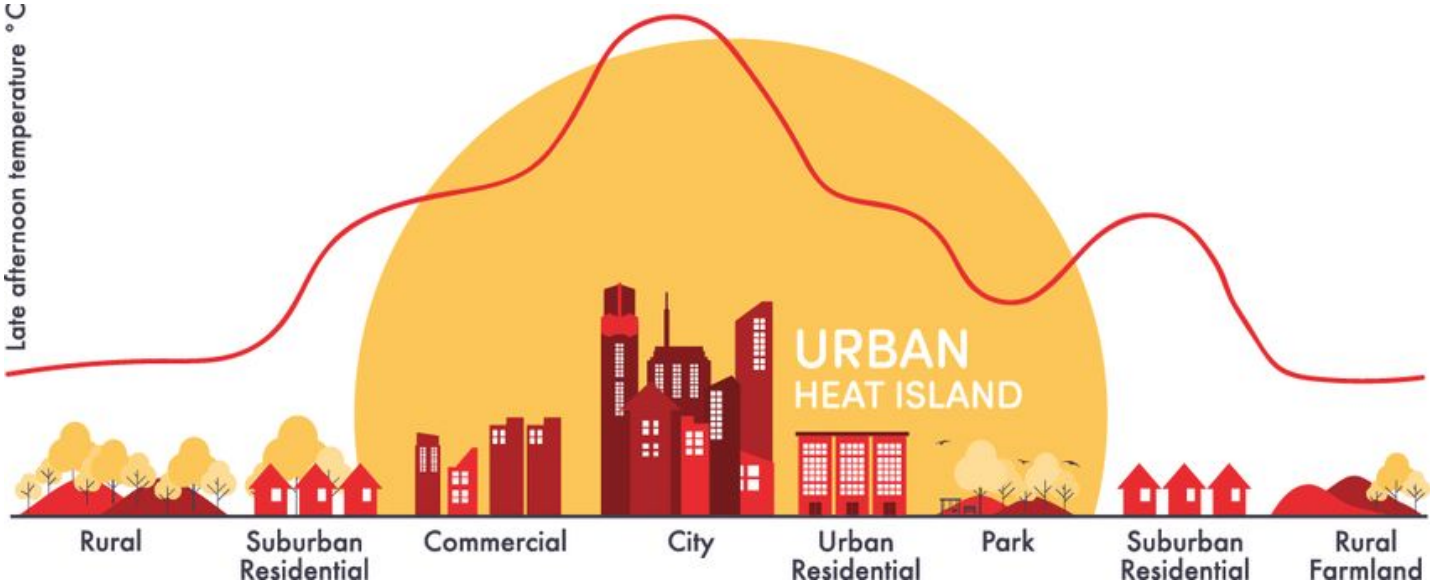
Impact of Climate Change

Records of heat waves since 1947 clearly show that the frequency and intensity of these events have increased as a result of climate change. Heat waves in France, which occurred on average once every five summers before 1989, have become an annual occurrence since 2000.

2003, a landmark year in Europe for heat waves



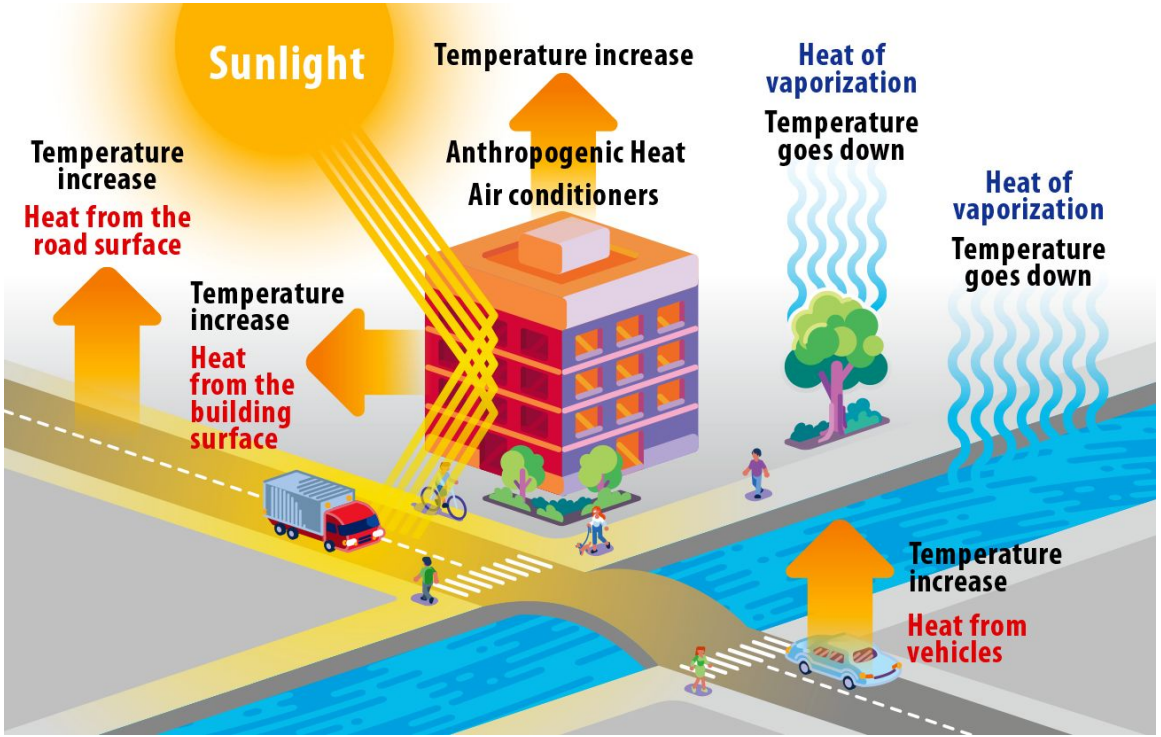
Urban heat island (Definition)



Source: Fuladlu, Kamyar & Riza, Müge & Ilkan, Mustafa. (2018). THE EFFECT OF RAPID URBANIZATION ON THE PHYSICAL MODIFICATION OF URBAN AREA.

Urban heat island (Causes)

The Urban Heat Island effect is driven by the replacement of cooling vegetation with heat-absorbing asphalt and concrete, effectively eliminating natural evapotranspiration. This thermal buildup is trapped by dense "urban canyon" geometries that obstruct airflow and is further intensified by anthropogenic waste heat ejected from vehicles and air conditioning systems.



HIDALGO2
CENTRE OF EXCELLENCE

Model Construction

Different model used inside our simulation

EuroHPC
Joint Undertaking

Grant number: 101093457

The physical models inside Ktirio Urban Building

1. Model Structure

- **Multizone Model: One thermal zone per floor** of the building.
- **Objective:** Calculate the **zone air temperature** and the resulting **energy consumption**.

2. Energy Balance

- **Conduction & Inertia: Multi-layer RC model**
- **Solar Gains:** Advanced radiation modeling (Perez Model), dynamic shading management (Ray Tracing), and window transmission (based on angle of incidence).
- **Convection/Radiation:** Precise calculation of convection (roughness, wind) and **Infrared** exchanges.
- **Ventilation:** Constant air change rate (single-flow VMC).
- **Climatic Data:** Utilizes a extensive dataset (temperature, wind speed/direction, radiation, **sky vault temperature**).

3. Systems and Control

- **HVAC Modeling:** Pre-sizing of the **radiator/boiler** nominal heat output
- **Active Control: Closed-loop control system** (thermostat type) adjusting heating output to maintain **setpoints** (time-varying).

4. Validation

- **Proven Reliability:** Successfully validated against **BESTEST Case 600** and **Case 600FF (Free-Float)**, confirming both accurate load calculation and envelope thermal behavior.