SOBIGDATA RESEARCH INFRASTRUCTURE

Urban Digital Twin for Disaster Resiliency and Recovery

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DEGLI STUDI
DELL'AQUILA

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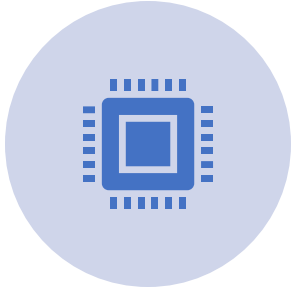
Digital Twins in Modern Urban Planning

Virtual replicas of physical regions, such as cities or urban areas are referred to as Urban Digital Twins.

- Created using from IoT sensors, Geographic Information Systems, and many other technologies.
- Helping policymakers manage transportation networks, energy grids, and environmental conditions.
- With many cities worldwide investing in their development and implementation.

Motivation for the Systematic Mapping Study

Existing **literature reviews on Digital Twins and Smart Cities lack a specific focus on urban planning and disaster resilience.**



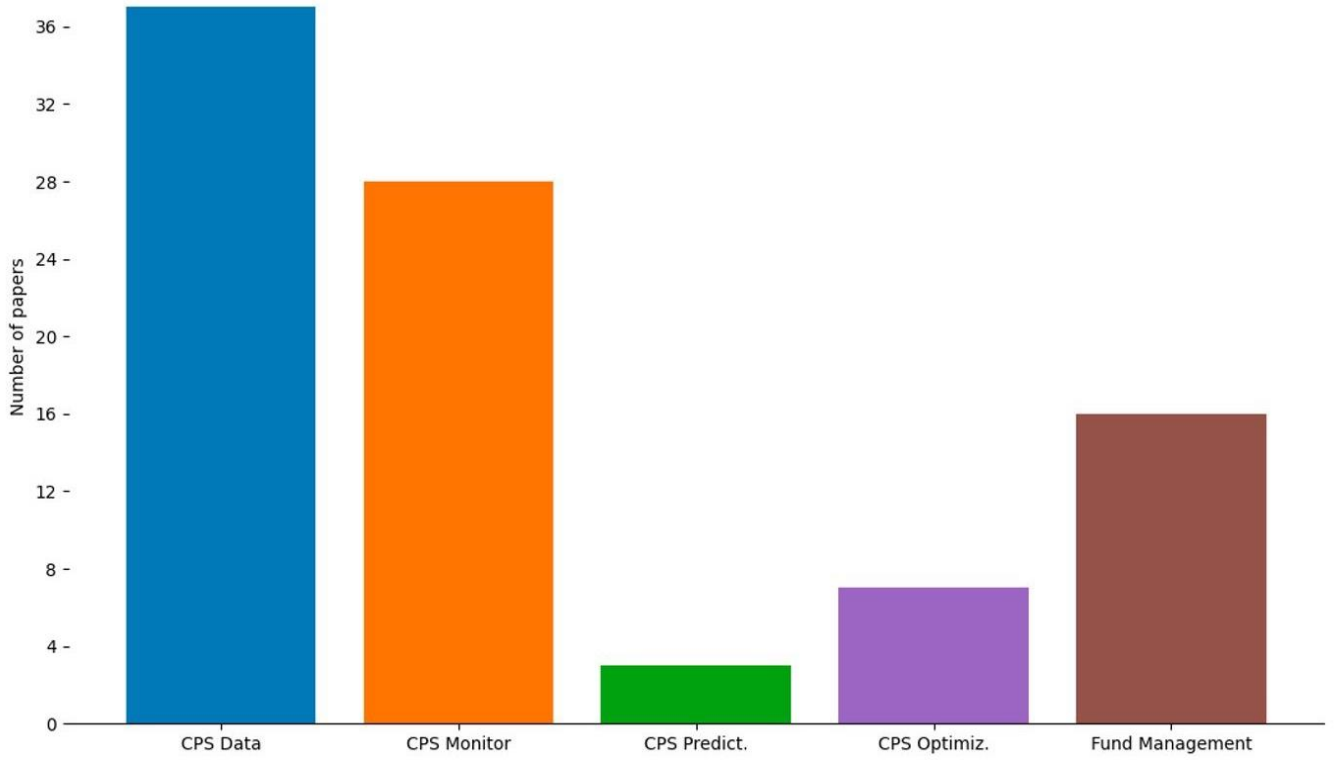
Understanding if Urban Digital Twins (UDTs) have **the potential to revolutionize** Territory Management.

Outlining the **state of the art in Software Engineering for UDTs, crucial for advancing research in this area.**

Therefore, the **systematic mapping study** aimed **to analyze the existing literature focusing on breadth over depth to identify research gaps and areas for further investigation.**

What is the purpose of these Territory Management DTs?

Digital Twins might be investigated for a variety of reasons.



How are these DTs engineered?

What does the DT optimize?

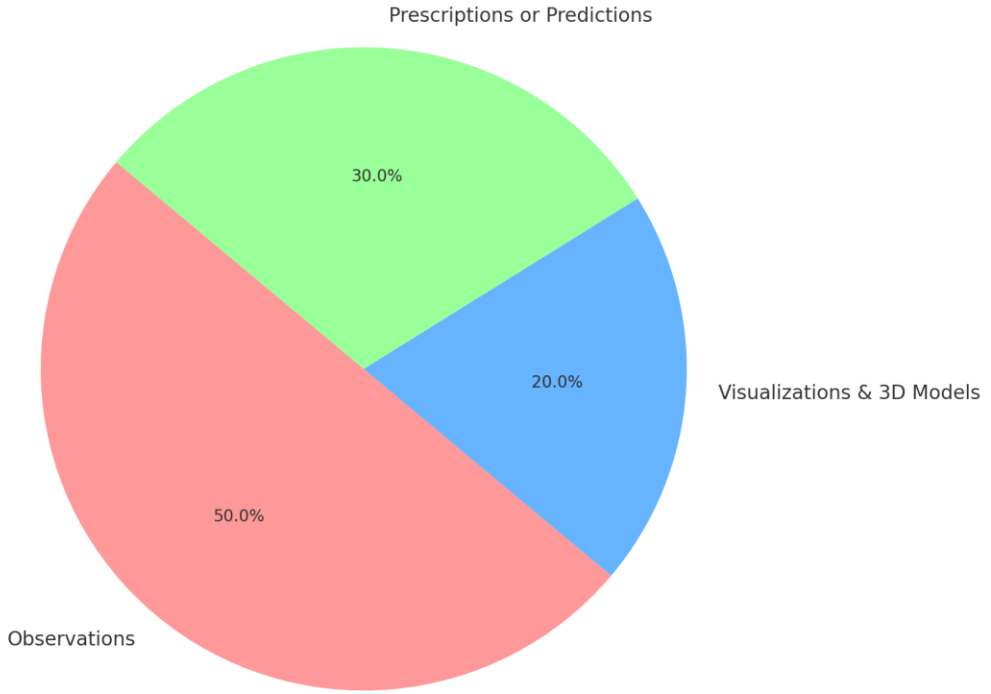
Of the papers analyzed: 47% optimized the Counterpart CPS, 20% were about continuous optimization of the Digital Twin, and 33% were used for to optimize both.

To which does a Digital Twin react to?

Of the reviewed papers over 60% were only reacting to the CPS coming from sensors and user interaction. The rest while still maintaining continuous interaction with the CPS, included also (in equal partitions) either User Specifications (via User Inputs) or coming from Simulations.

Which output does it produce?

The main and only category of outputs for over 50% of the papers was just Observations representing the current state of the twinned system.



Technology readiness level of Urban Digital Twins?

Readiness levels are described as follows:

- Proof of Concept (TRL 1-3), includes evaluations in which at least basic principles of the research can be observed.
- Technology (TRL 4-6), includes evaluations where technology is at least evaluated.
- System (TRL 7-9), includes evaluations in which at least a system prototype is demonstrated in an operation environment.

The average level for the DTs we looked at was **4.25**, no article reached a TRL in the range of 7-9. The main cause of this was that DTs were really broad in scope.

Commonly used Technologies

Point Cloud Elaboration: Four papers use point cloud elaboration.

Convolutional Neural Network (CNN): Two papers use CNN as a method for generating risk assessment heatmaps.

XGBoost: One paper uses XGBoost, which is an optimized distributed gradient boosting library, to create a heatmap.

REVIT, ARCGIS are the other two tools that appeared in the full-text read.

Let's name the I/O formats

Common Inputs

Pictures either aerial or non-aerial (e.g. to create risk assessment heatmaps or city visualization interfaces).

Point Cloud (e.g. for risk assessment heatmaps or building GIS).

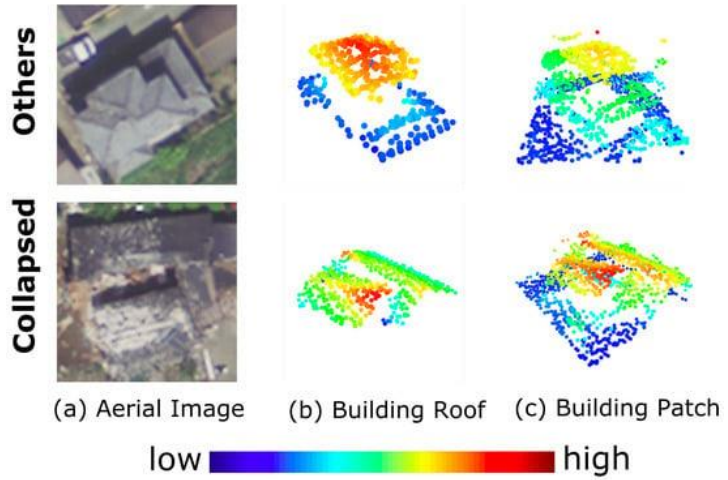
CSVs which include geospatial, pollutant, and city life . Some other make use of XML, RDF, and OWL.

Common Outputs

Heatmaps: Two papers generate heatmaps as an output, one for risk assessment and another for city .

UI Interfaces for city visualization or for risk assessment.

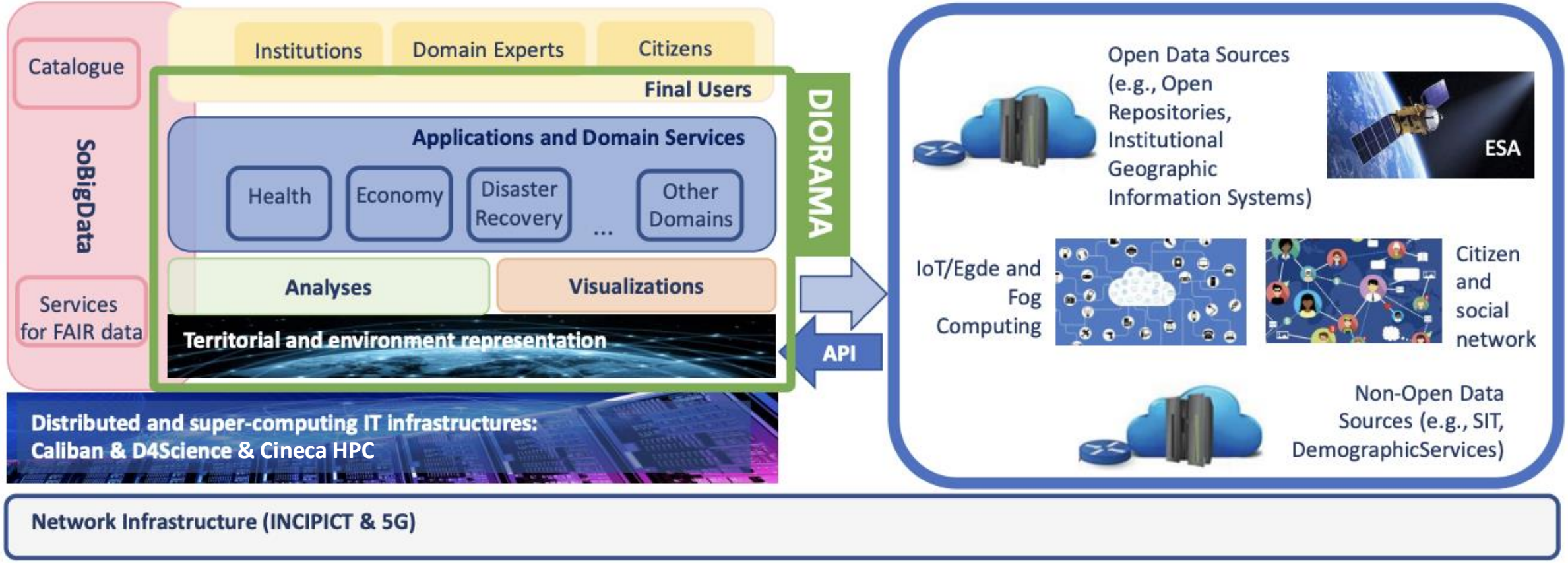
Text based outputs:
e.g. knowledge discovery system.



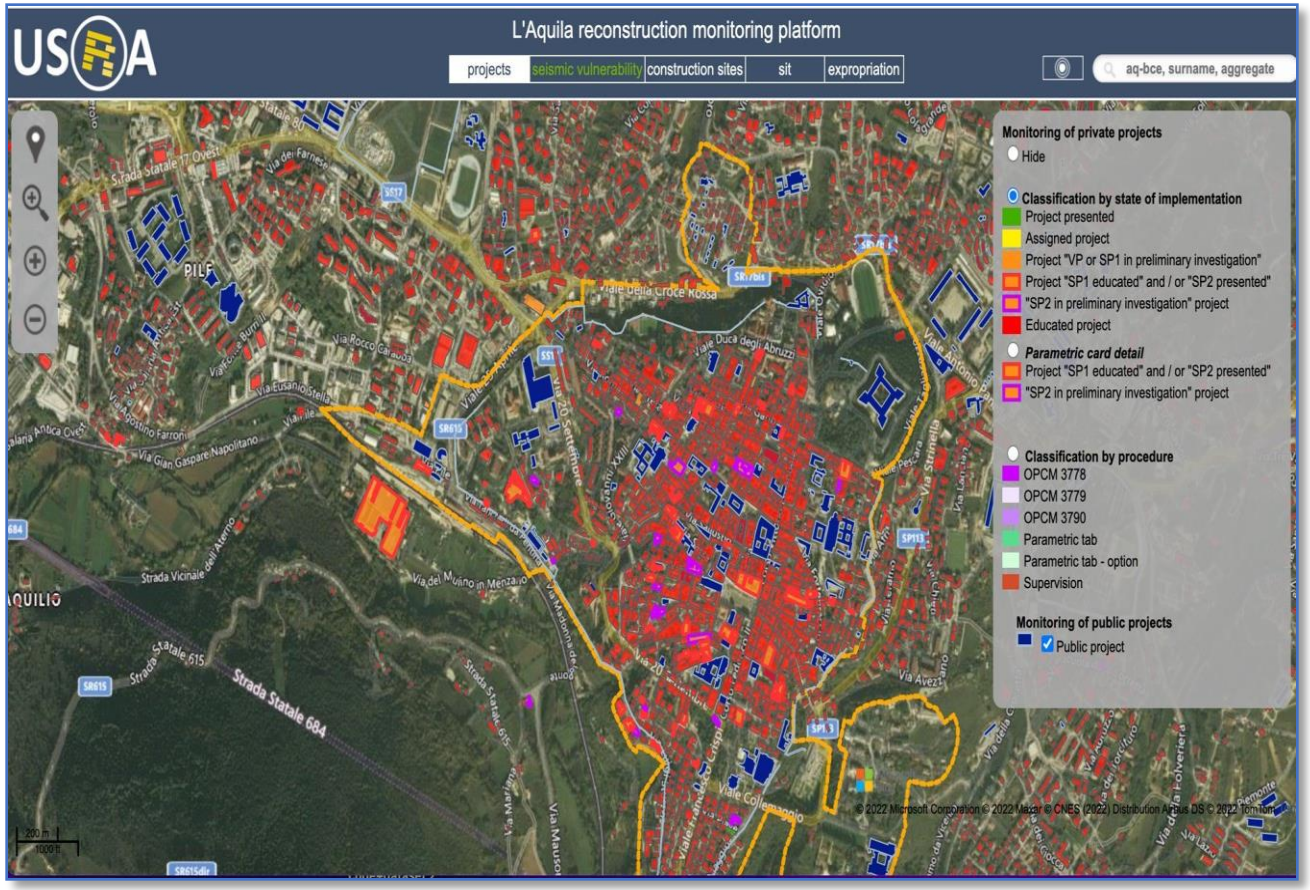
How can we address the need for Integrated Models and Platforms?

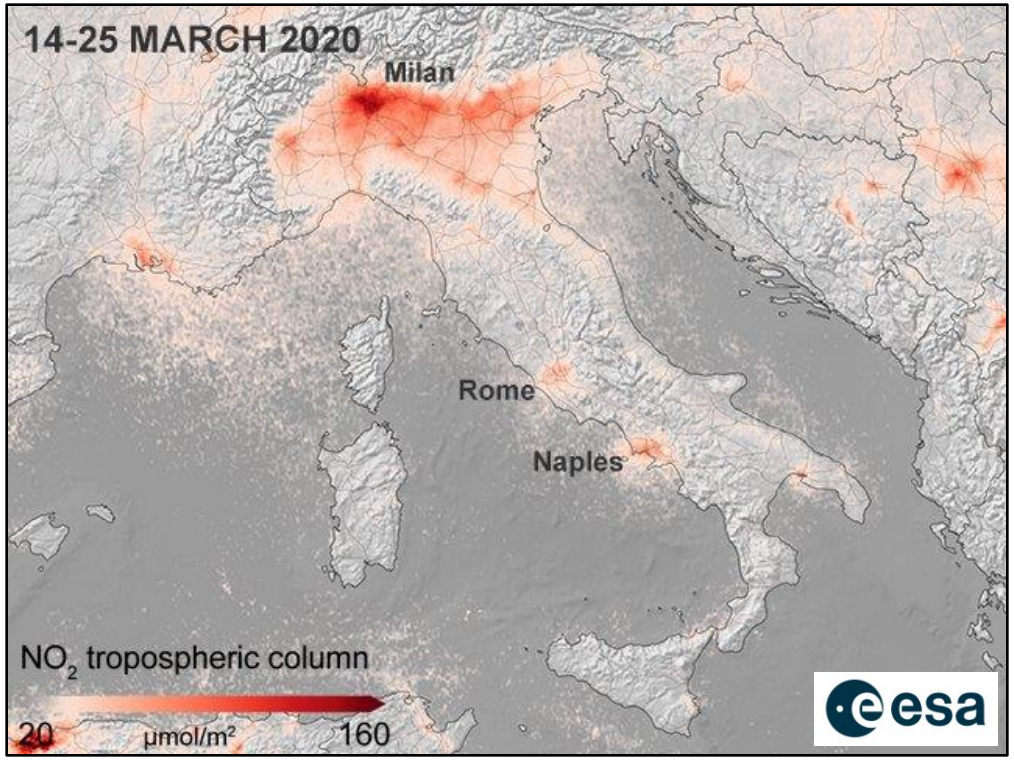
- It is a real challenge to produce a Multi-Dimensional Model that represents the territory at various level of abstraction.
- Dashboards and plots should be elastic to various roles and levels of Expertise.
- Dimensions should not be isolated and their impact on each other should be measurable and observable.
- Cross-dimensional changes are often defined via simple relations and could be shown in simulations.

Multi-View Urban Digital Twin : DIORAMA



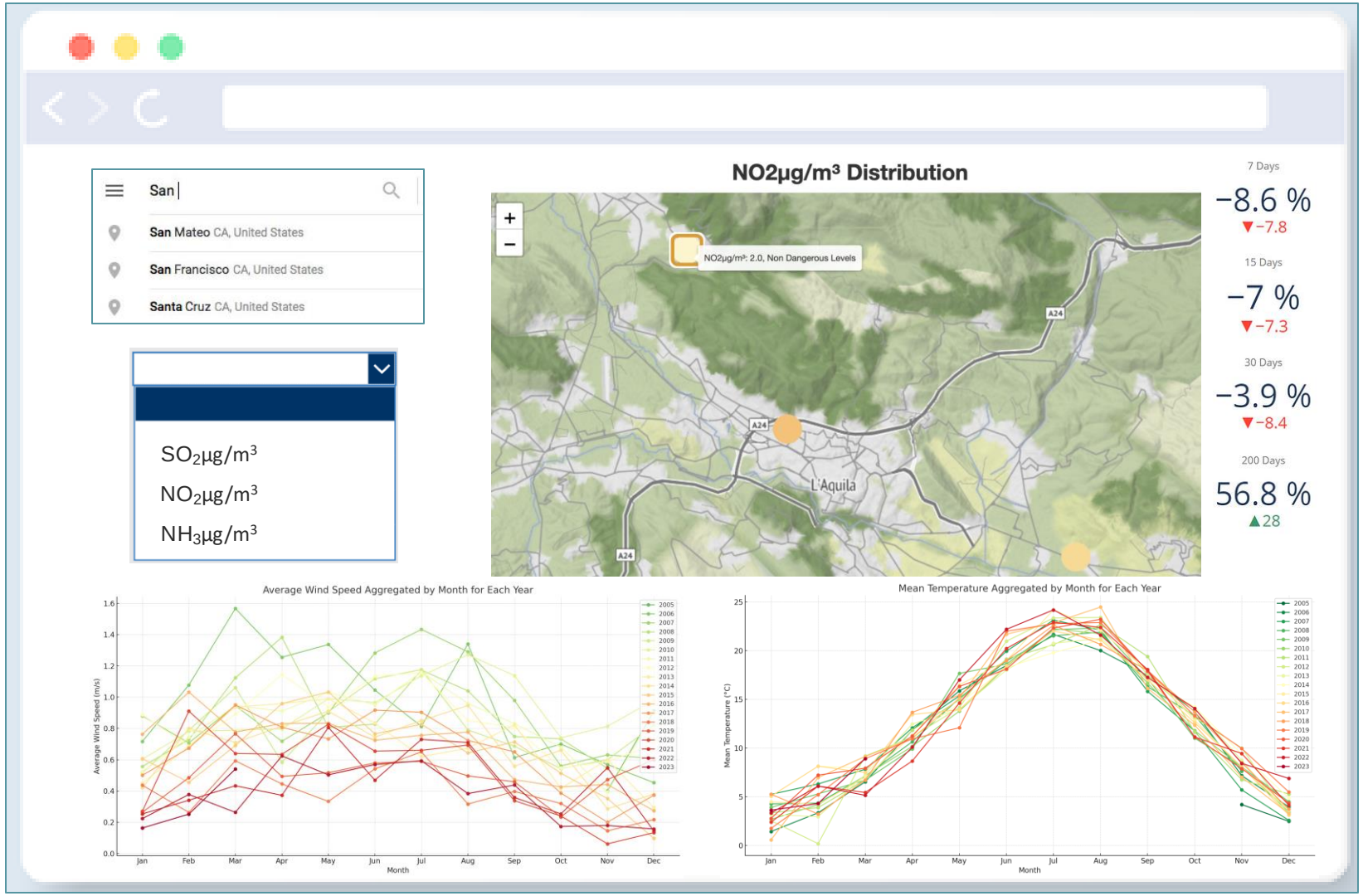
Current Heterogeneous Monitoring Efforts



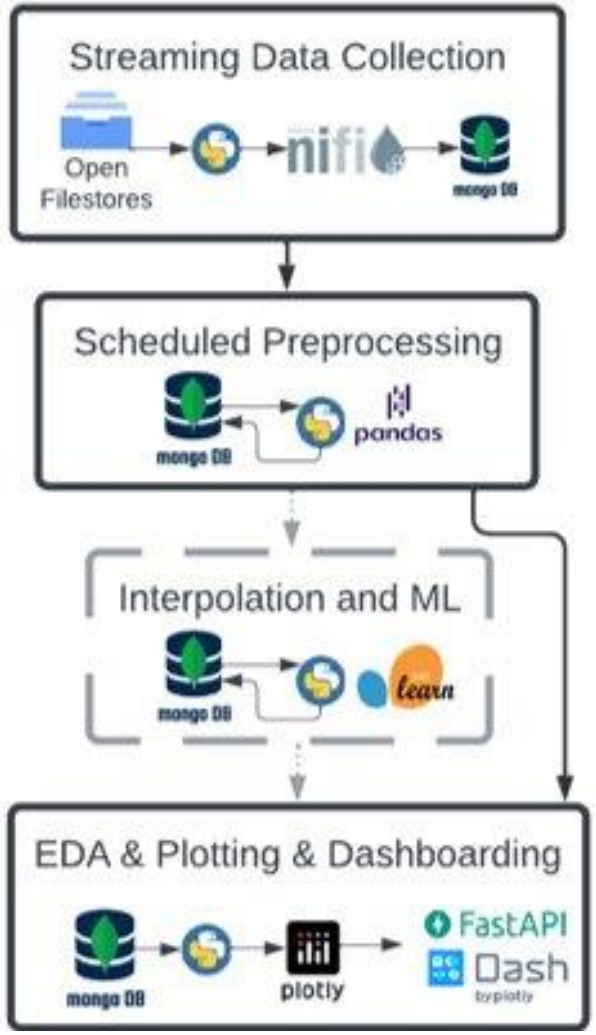


A MVP Example Pollutant Monitoring Analysis

- The plots displayed in the mocked up UI have been already implemented on the aggregated sets.
- imputation is going to be the next focus of these dashboards.

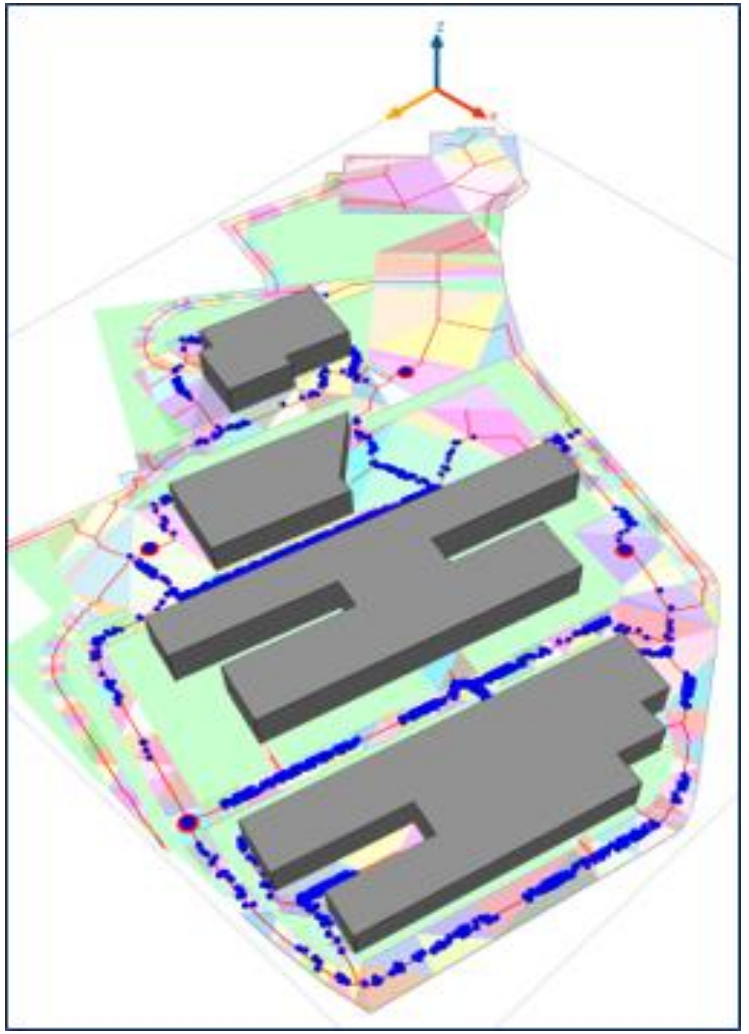


What have we started to use?



Multi-Dimensional Integrated Dashboard

Built using Walkability set (ESA), that emphasize the pedestrian-friendliness and accessibility of various services in L'Aquila region. By evaluating roads and sidewalks based on their condition, safety, and other factors that influence walkability to key services and amenities.



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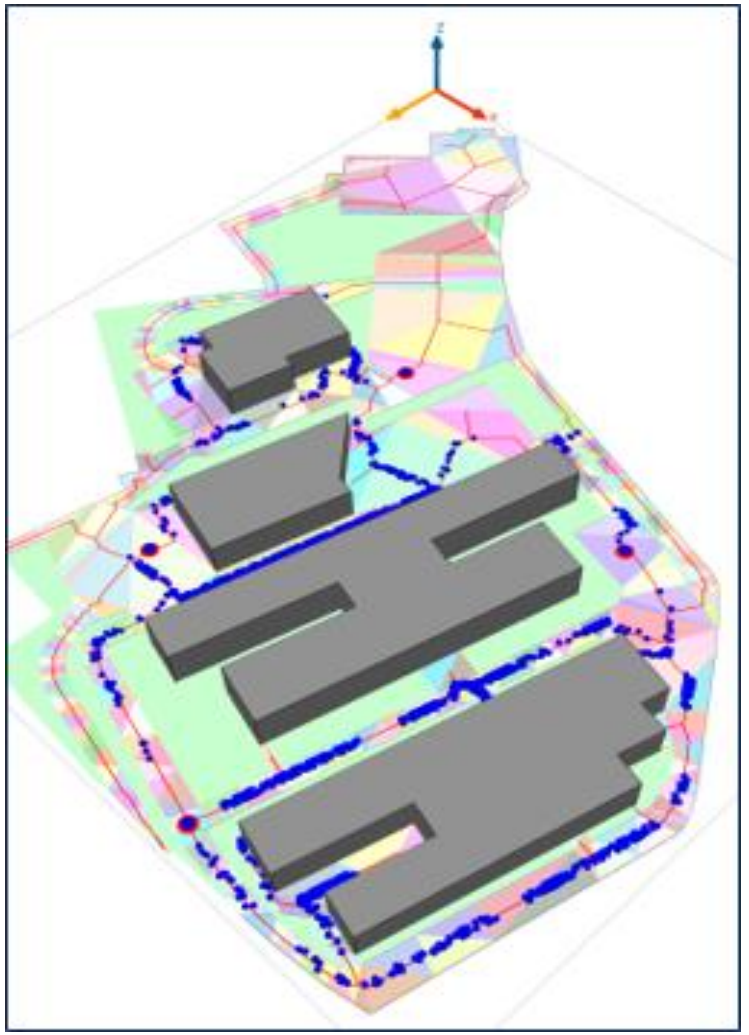
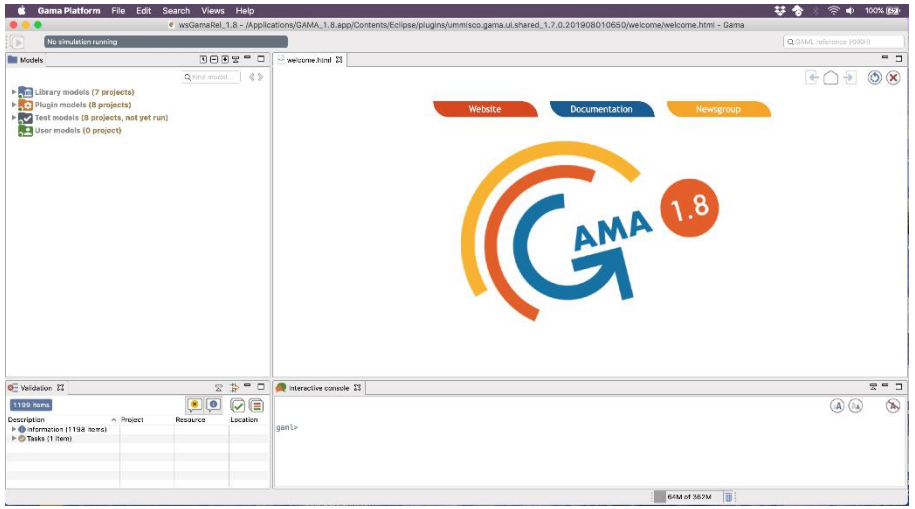
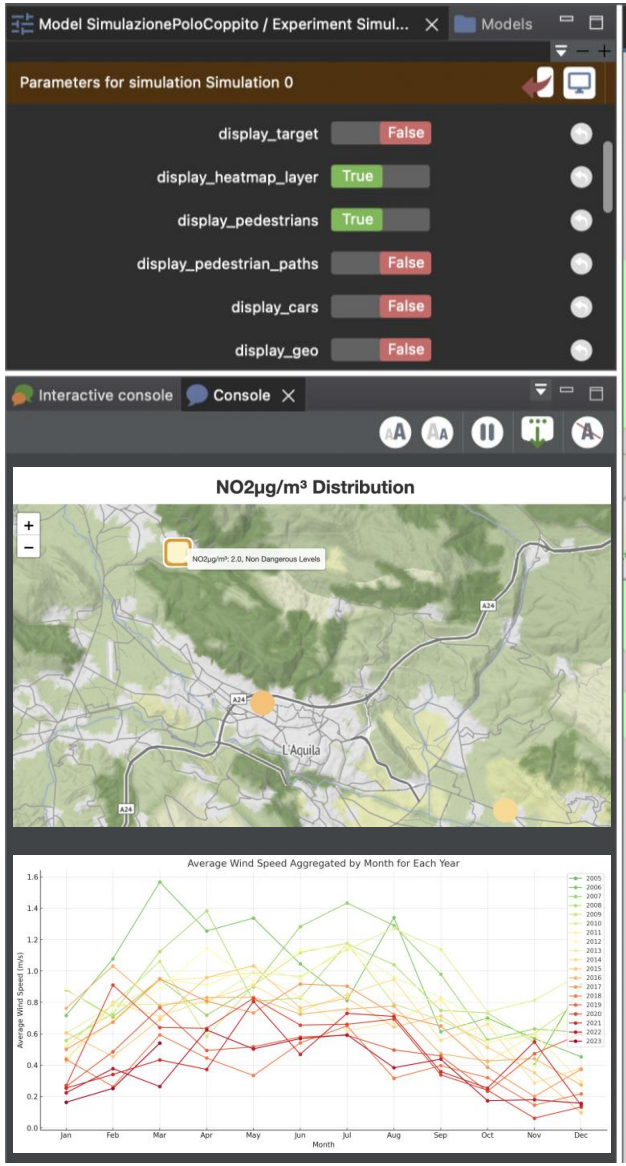
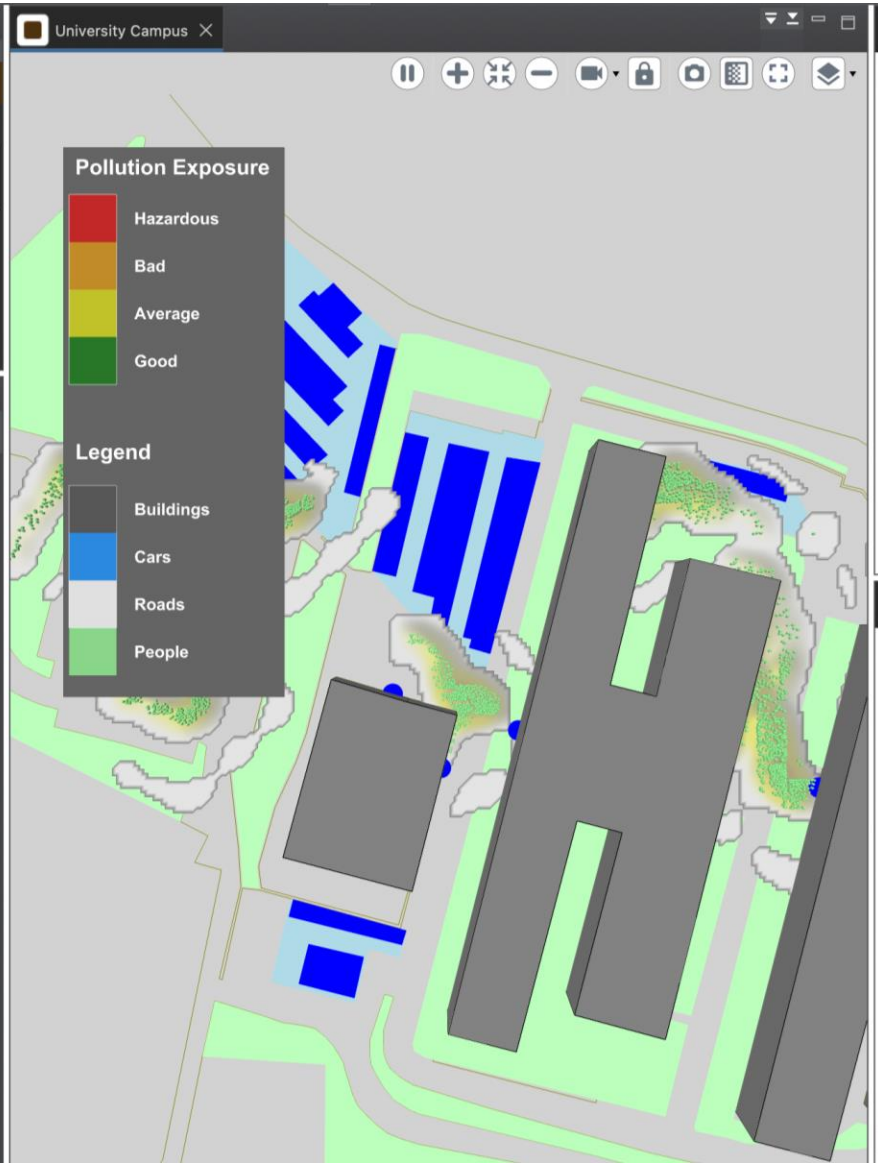


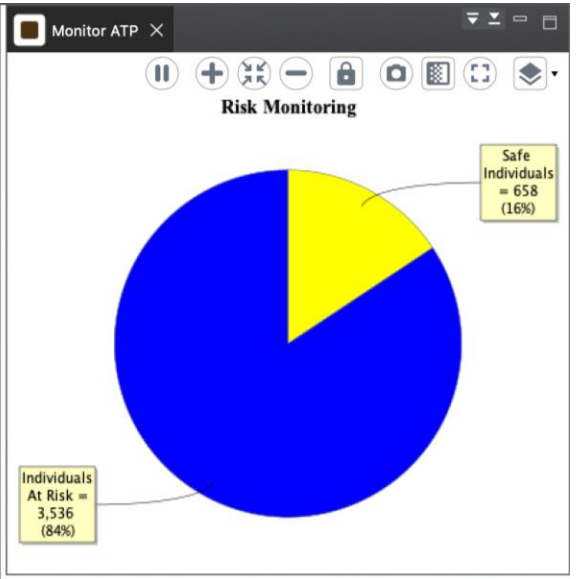
Chosen software was the **Gama Platform:** a modelling environment to build spatially aware multi-agent simulations.

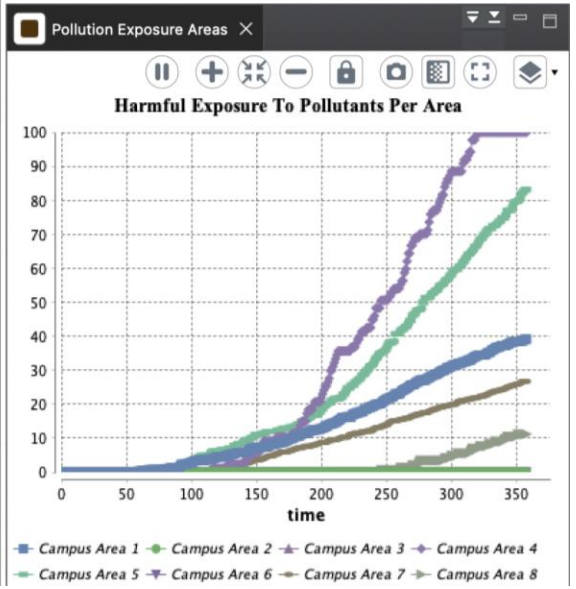
It is able to import and render georeferenced **shapefile** **to run accurate simulations**.




Model SimulazionePoloCoppito / Experiment Simul...
Models
Parameters for simulation Simulation 0
display_target False
display_heatmap_layer True
display_pedestrians True
display_pedestrian_paths False
display_cars False
display_geo False
Interactive console
Console
NO2µg/m³ Distribution
L'Aquila
Average Wind Speed Aggregated by Month for Each Year
Month

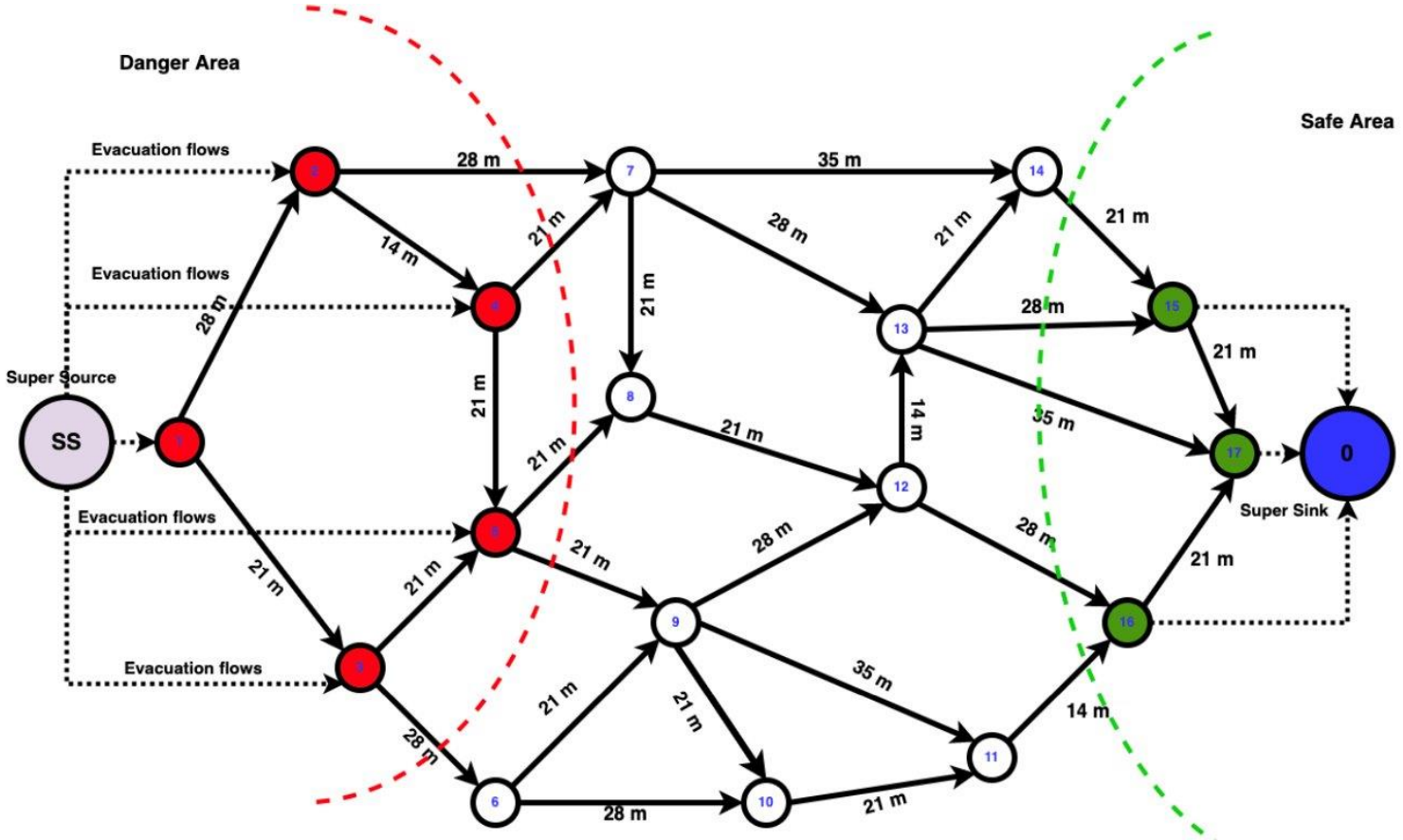

University Campus
Pollution Exposure
Hazardous
Bad
Average
Good
Legend
Buildings
Cars
Roads
People


Monitor ATP
Risk Monitoring
Safe Individuals = 658 (16%)
Individuals At Risk = 3,536 (84%)


Pollution Exposure Areas
Harmful Exposure To Pollutants Per Area
time
Campus Area 1
Campus Area 2
Campus Area 3
Campus Area 4
Campus Area 5
Campus Area 6
Campus Area 7
Campus Area 8

Evacuation Network Simulation

We plan to add to the proposed solution additional simulations that emphasize the pedestrian-friendliness and accessibility of evacuation flows.



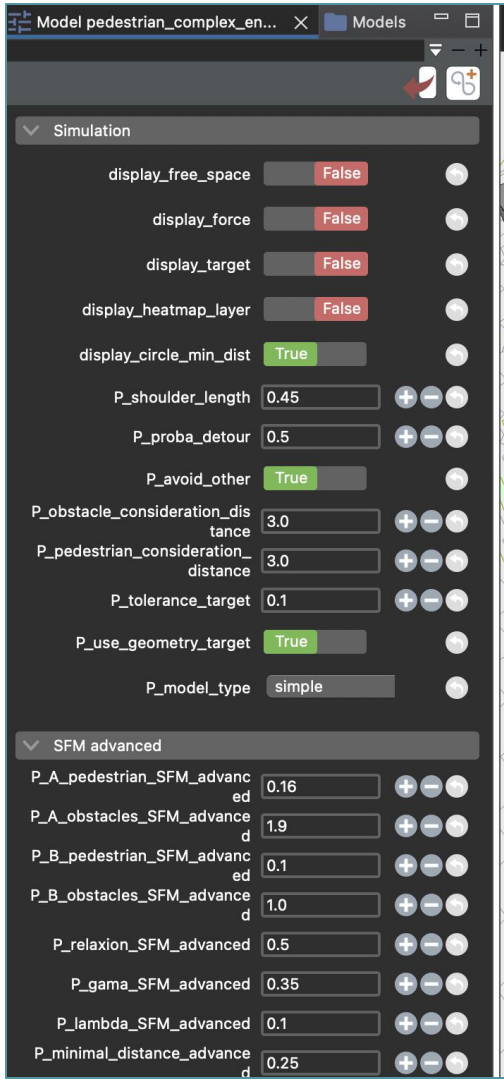
In collaboration with Professor Arbib's Research Group

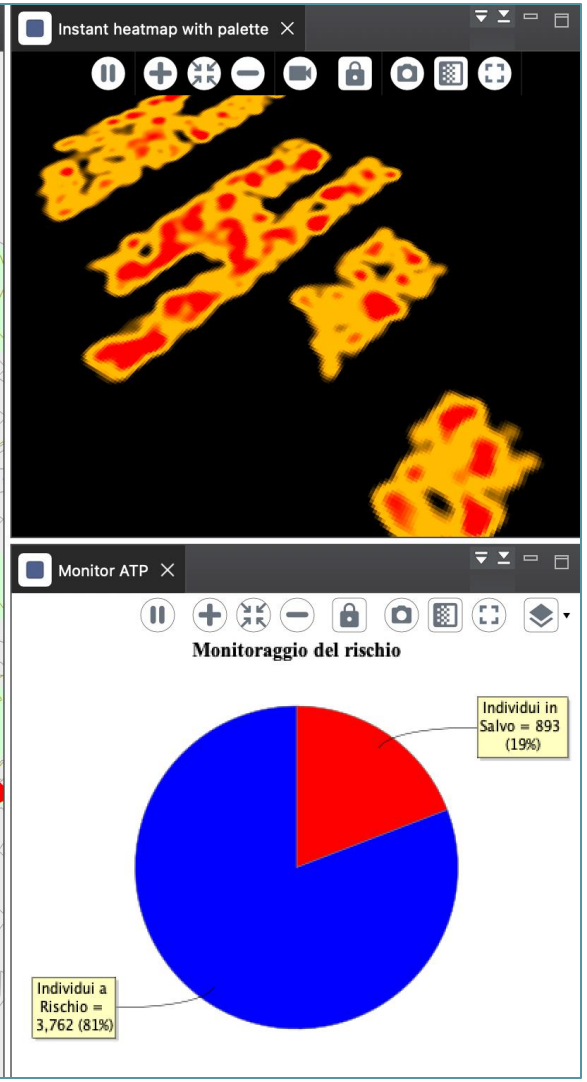
Experiment customizability and Reporting

The simulation is built by extracting pedestrian paths from the previously described.

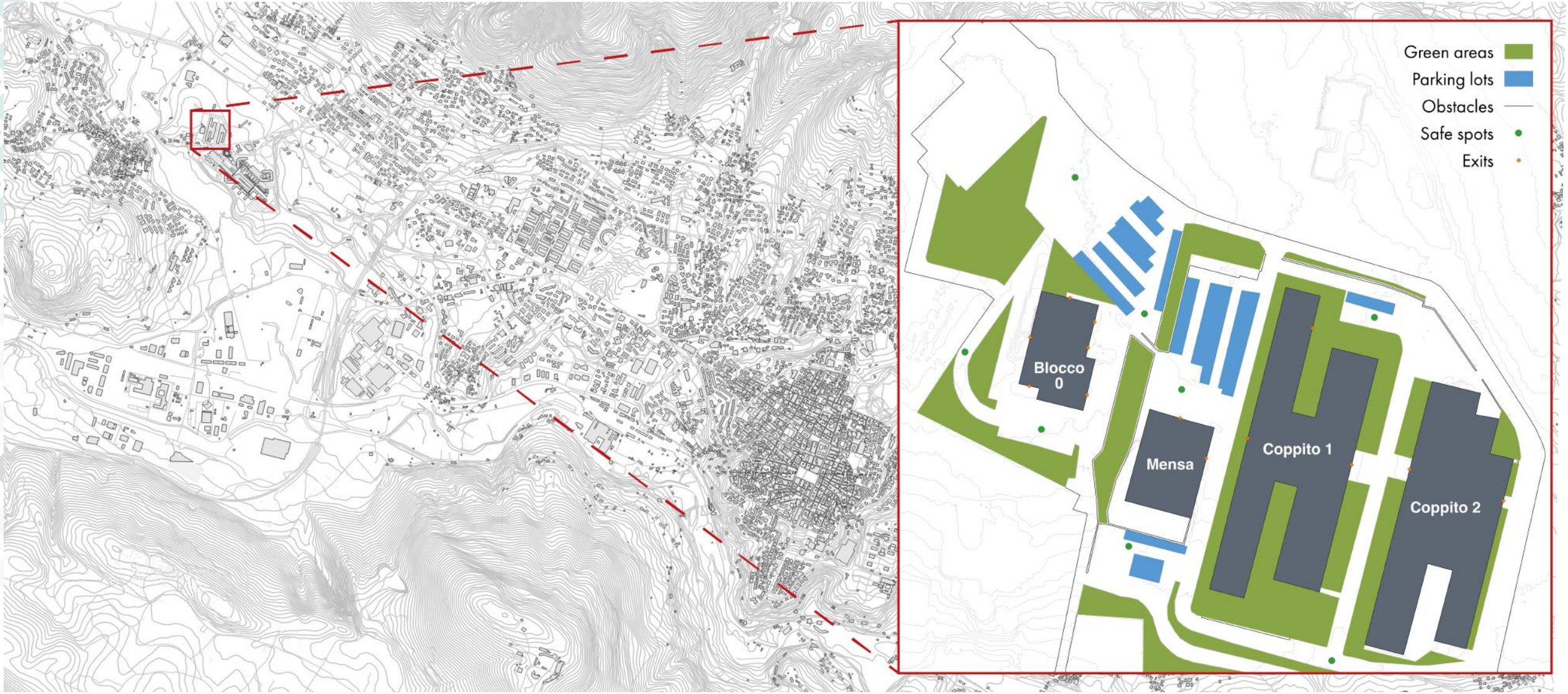
We plan to add to the proposed solution additional simulation layers that emphasize the pedestrian-friendliness and accessibility of evacuation flows.

In collaboration with Professor Di Ludovico's Research Group





Campus Evacuation Simulation



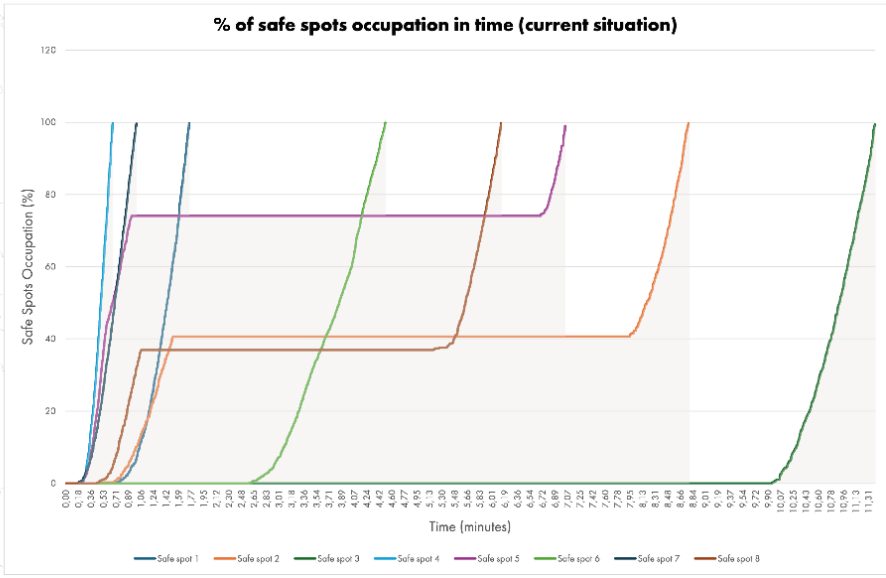
Sceario 0

Scenario 1

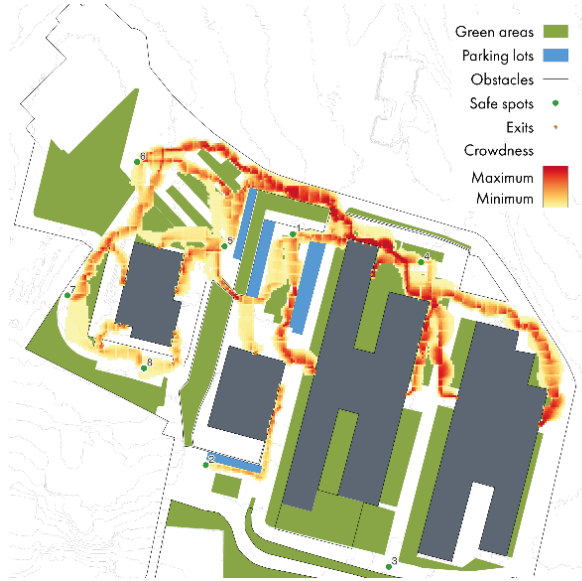
Campus Evacuation Simulation Results

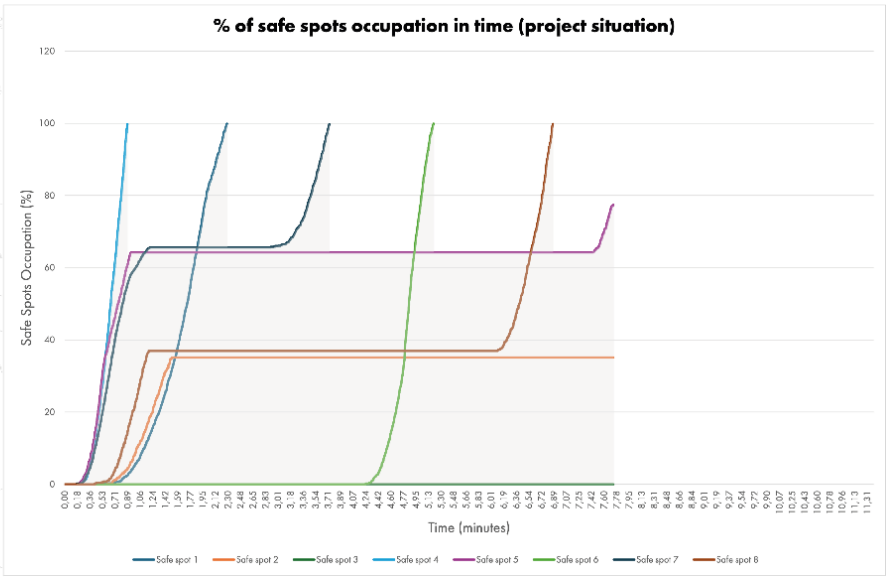
SCENARIO 0

Tecniques of Urban Design Safety-based (UDS-b)

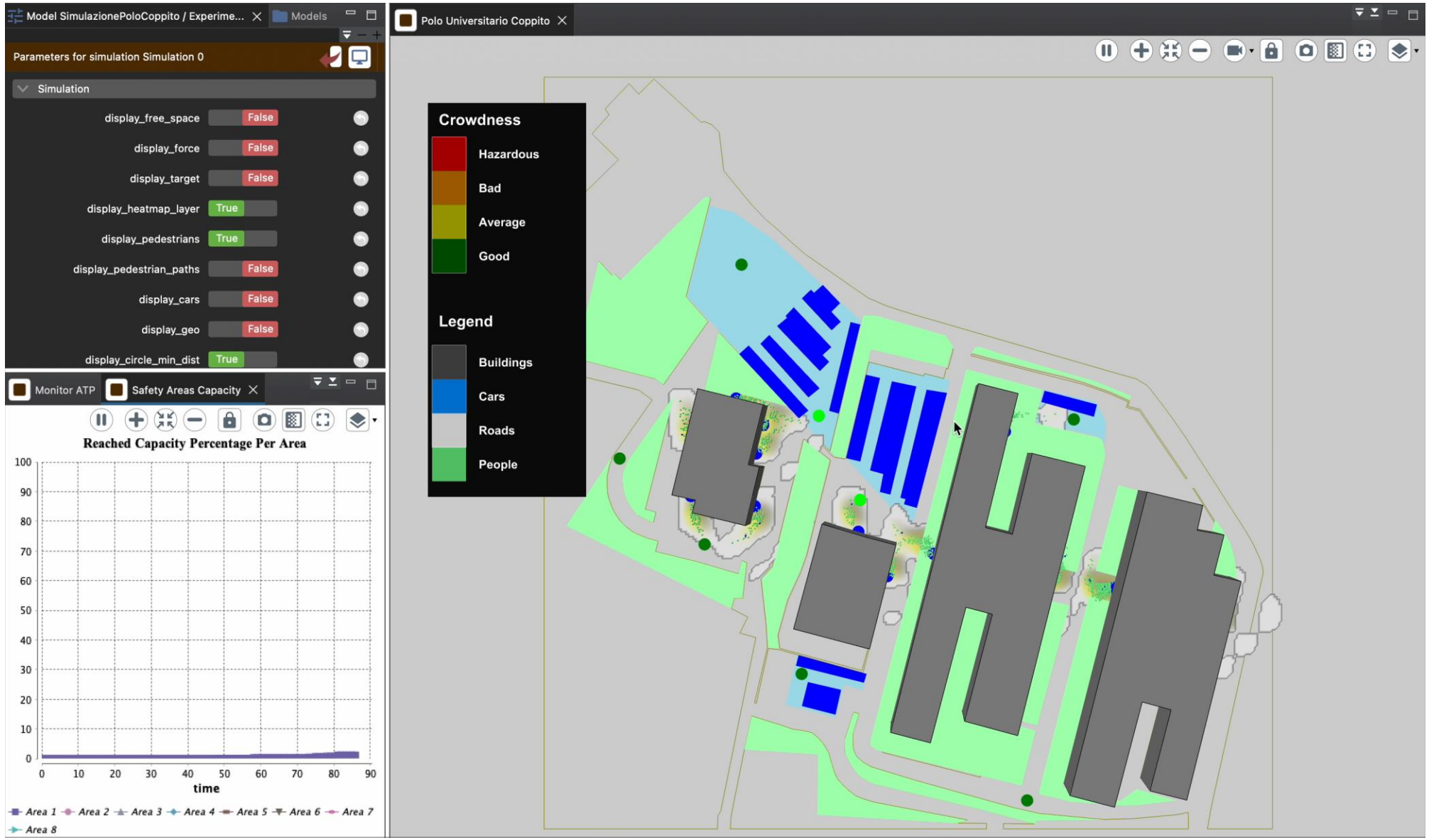


SCENARIO 1

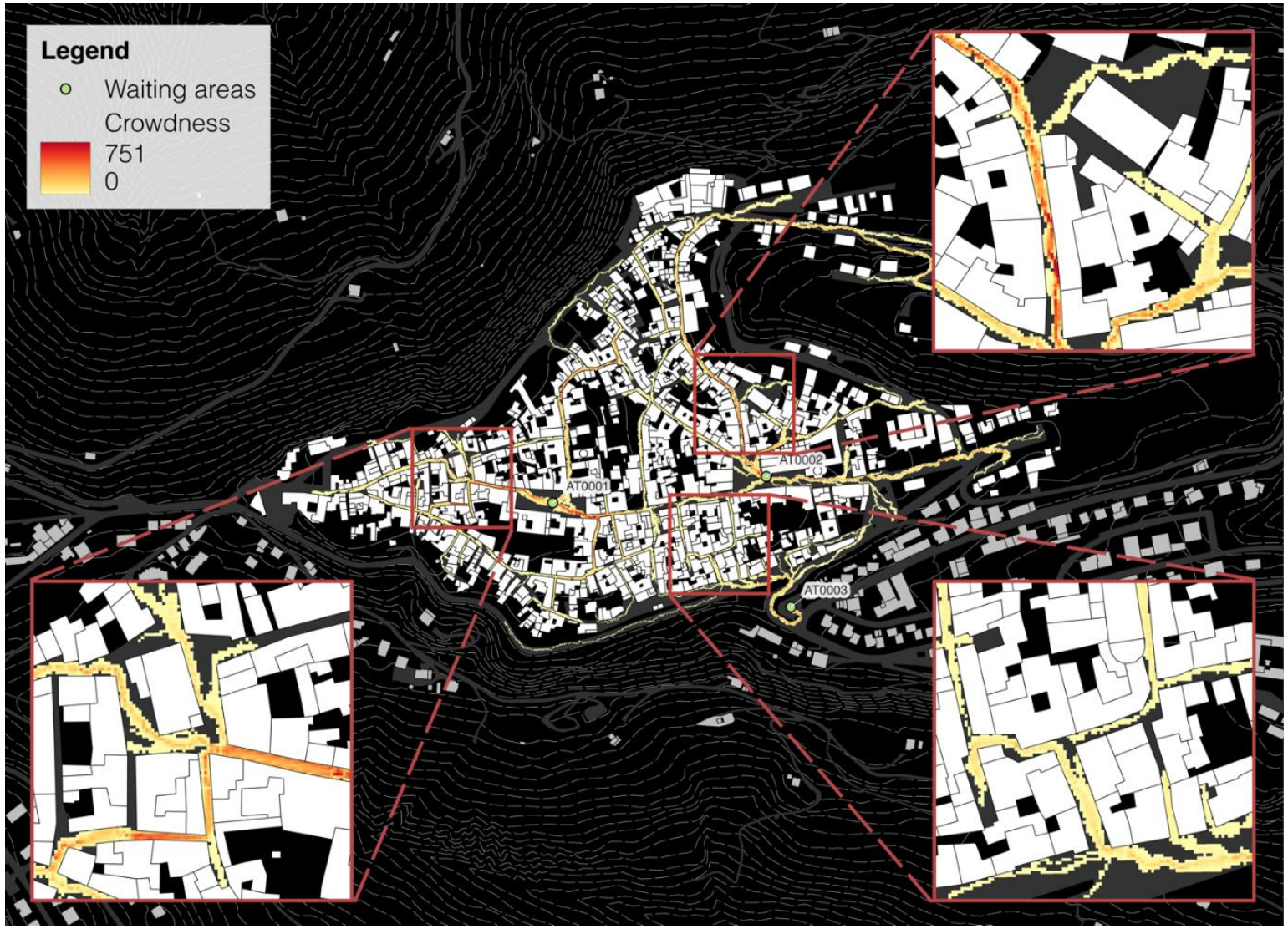




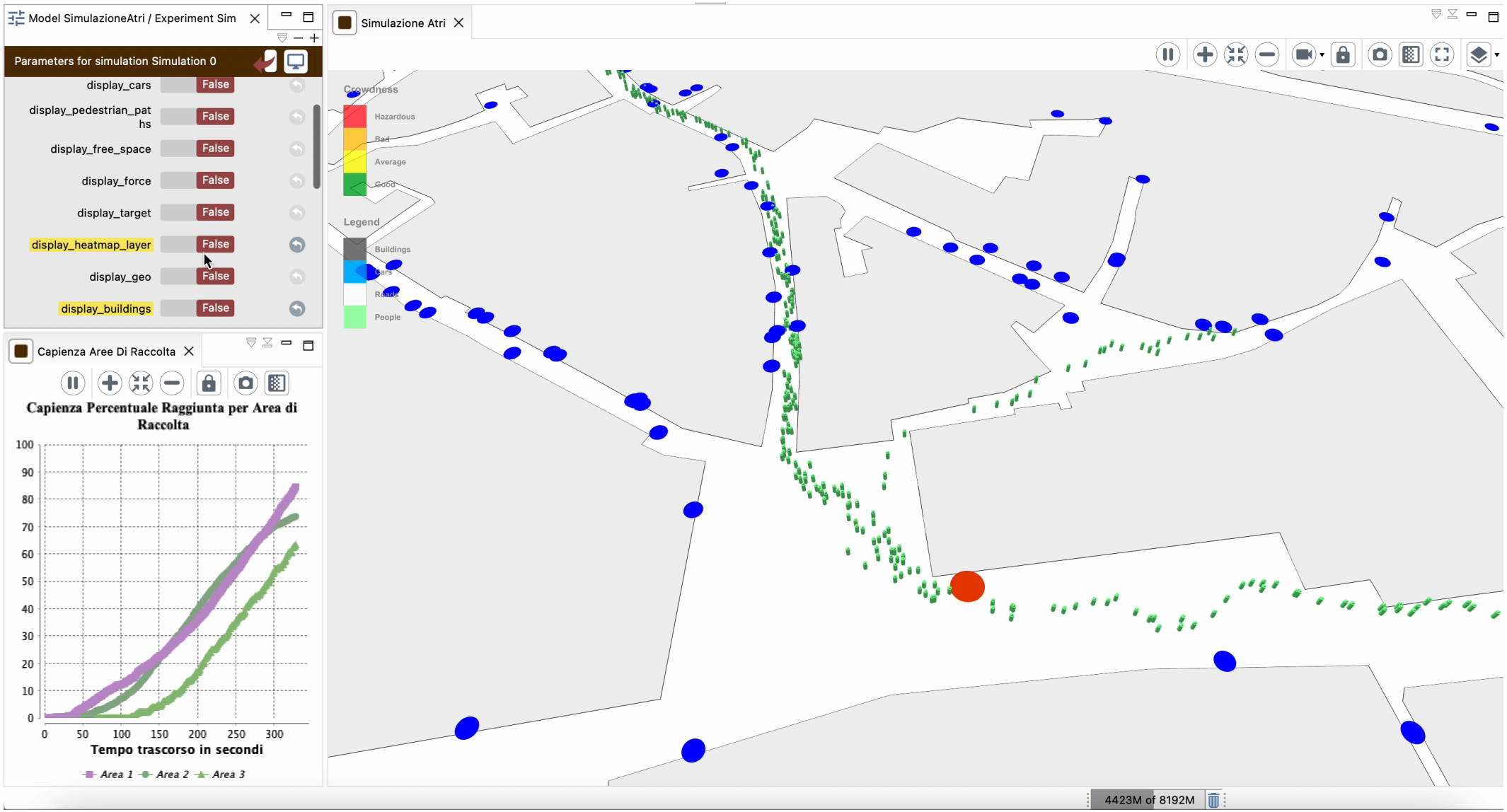
Campus Evacuation Simulation Video Demo



Small Town Demo

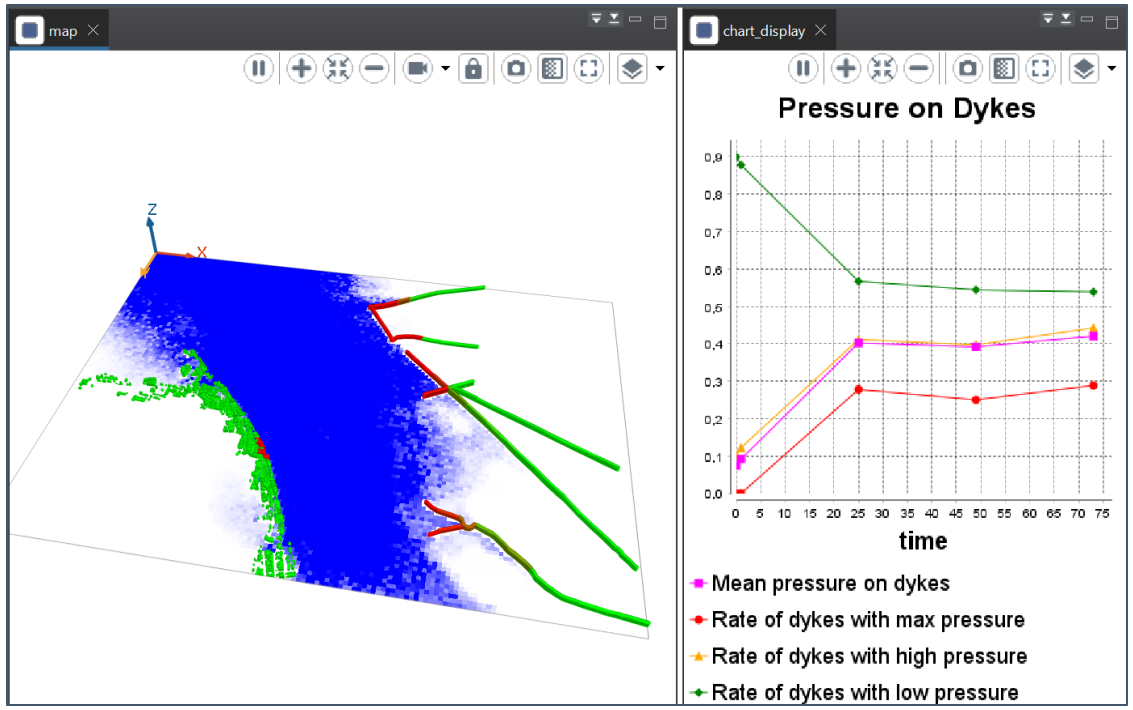


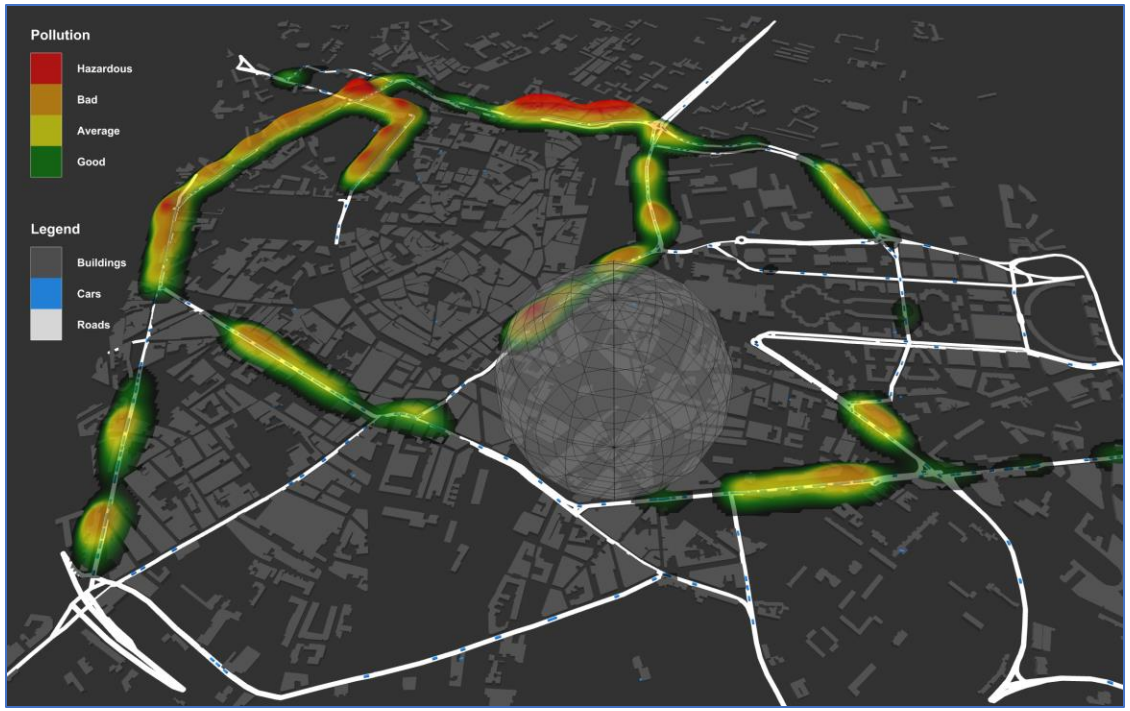
Small Town Demo



Other use cases

The employed tech stack is able to handle flooding and air quality monitoring, as shown by the toy models available in GAMA.





Potential Urban Digital Twin Goals

- Operational Research for Evacuation Safety
  - Objective: To identify optimal safety spots for efficient and secure evacuation during emergencies, ensuring quicker and safer evacuation routes for residents.
- Sophisticated **Debris** Simulation Models and **Solar Irradiance**
  - Impact: Improved disaster management planning, enabling quicker clearance and safer navigation in post-disaster scenarios.
- Detailed Building Interior Modeling and Expand Use Cases
  - Objective: Collect detailed models of building interiors to develop efficient queue systems through internal navigation routes. Emergency path planning.
- Multi-Dimensional Integration QoL Metrics, Broad Emergency Resilience in Serverless Mode and much more.

Final Considerations

- UDTs are still at an early stage, and a significant gap remains between the concept and its real-world implementation.
- The lack of standardization, high costs, and limited understanding of the benefits can slow down their deployment.
- HPC and Research Infrastructures are already helping with this project.

Thanks For Your Attention!
Questions?