BSA 2024 Building Simulation Applications

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Assessment and mapping of the urban heat island effect: a preliminary analysis on the impact on urban morphology for the city of Turin, Italy

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Introduction

Cities and urban areas are characterized by specific microclimates and weather conditions, typically impacted by **various factors and phenomena**, such as the **Urban Heat Island (UHI)** effect, resulting in:

- ❑ Different energy needs for buildings, compared to the surrounding rural environment
- ❑ Different levels of outdoor comfort conditions, as well as indoor comfort conditions in non-conditioned built environments.

To study solutions for energy efficiency and sustainability in urban areas, an approach encompassing a larger scale (district or city-scale) is often required, with the adoption of **Urban Building Energy Modelling (UBEM)** tools.

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Introduction

In order to get representative findings from UBEM simulations, weather data are required to account for local microclimatic aspects. However:

- In many cases the only available weather file is developed from **weather stations installed in the surrounding rural environment** (e.g., airports).
- Even if an urban weather station is available, **the UHI effect can show different magnitudes in the different neighbourhoods**.
- The application of **tools for UHI assessment** for a whole city can be computationally demanding.

As a whole, the lack of accurate weather data can undermine the UBEM simulation accuracy.

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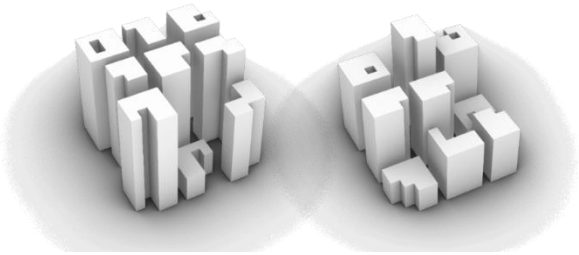
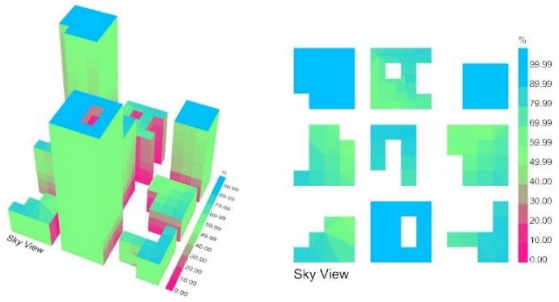
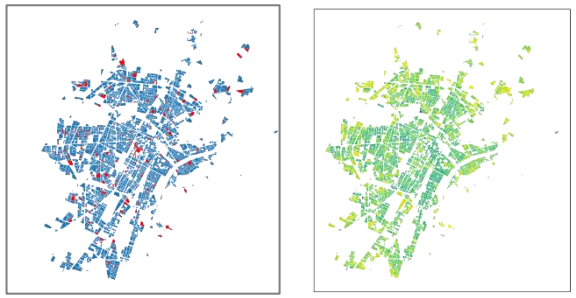
Aims

Given these premises, this work aims to show the preliminary results of a methodology proposed for identifying typical urban configurations to:

1. **Simplify the characterization of the UHI phenomenon and its variability** among the districts of a city
2. Developing **maps** to support professionals and public administrations with the assessment of the UHI phenomena and the definition of proper boundary conditions for BPS and UBEM simulations







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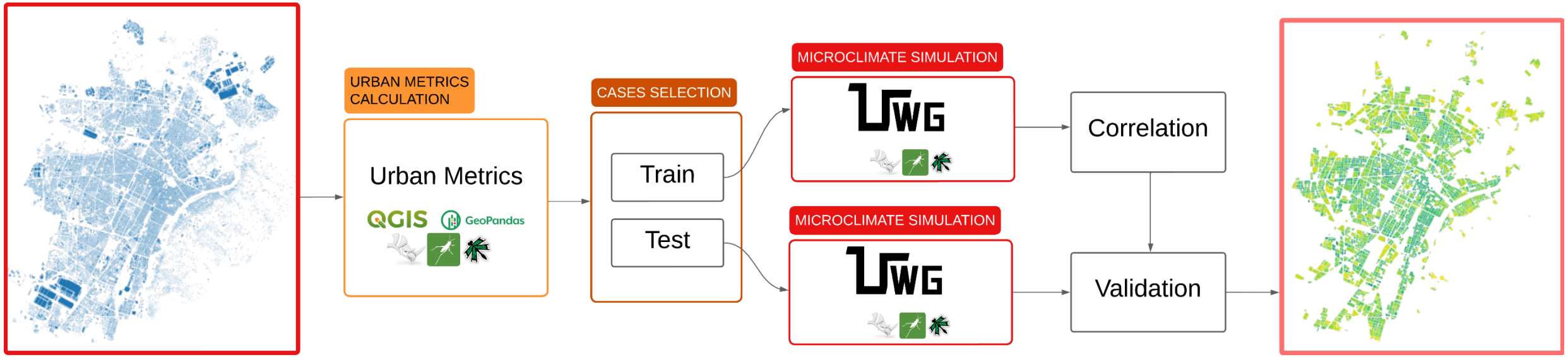
Proposed methodology

Workflow of the proposed methodology – focus on **urban morphology**



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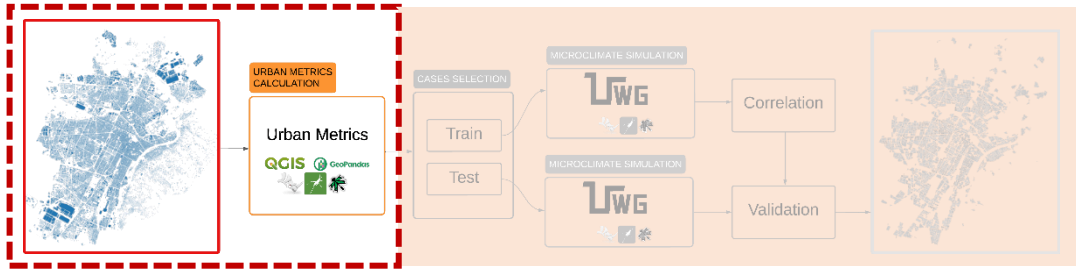
Proposed methodology: urban metrics calculation



1. All buildings in the city are grouped into **urban blocks**, defined based on the parcel area to which they belong.
2. **Urban blocks** are then filtered based on number of buildings, area, and shape, excluding blocks which have no buildings, are highly irregular or are too small.
3. **Ten urban metrics** are then calculated:

- ❑ Floor Area Ratio (**FAR**)
- ❑ Green Ratio (**GR**)
- ❑ Shape Factor (**SF**)
- ❑ Sky View Factor (**SVF**)
- ❑ Surface Coverage (**SC**)
- ❑ Relative Compactness (**REC**)
- ❑ Vertical to Horizontal Ratio (**VtH**)
- ❑ Volume Area Ratio (**VAR**)
- ❑ Average Building Height (**ABH**)
- ❑ Average Building Distance (**ABD**)

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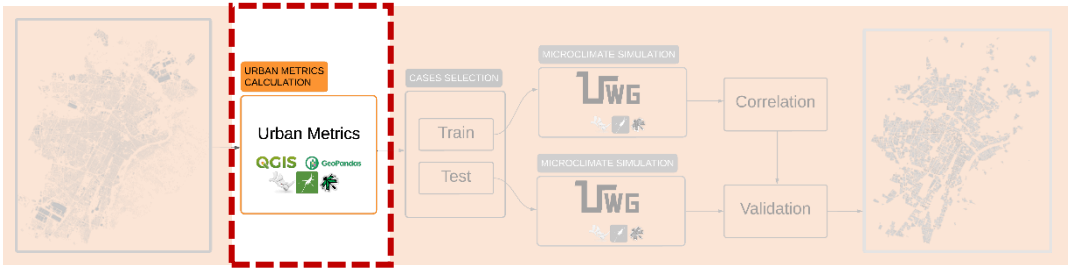
Proposed methodology: urban metrics calculation

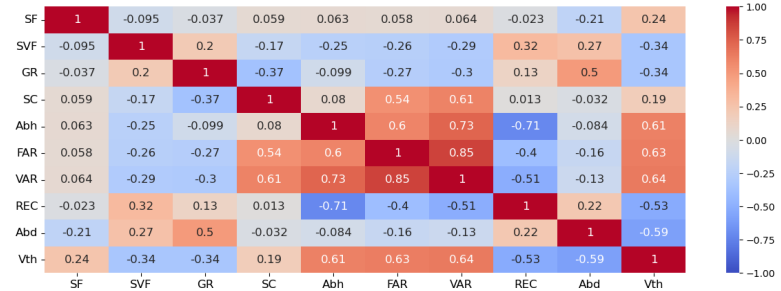


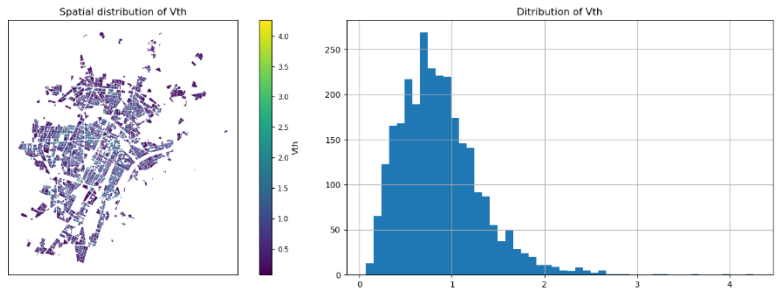
4. A **correlation analysis** is performed in order to identify those metrics highly correlated with one another.

   A **subset of metrics is selected** based on the correlation analysis and on the adopted tool for UHI assessment.

5. For the selected metrics, their **statistical distributions** are determined.

6. A **sampling of metrics values** is performed to identify cases of interests (e.g., minimum, 10th percentile, Q_1, median, Q_3, 90th percentile for each statistical distribution)





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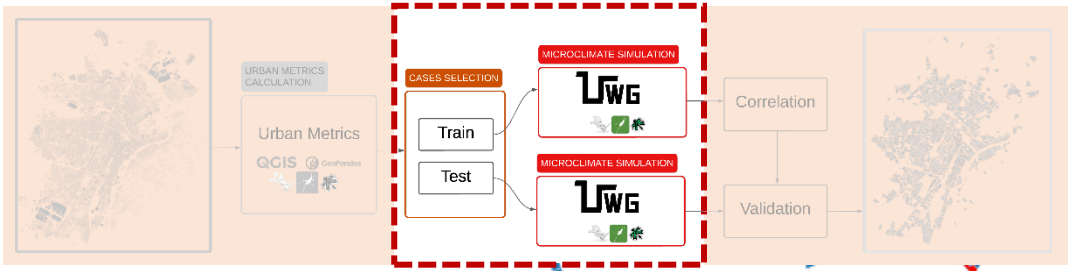
Proposed methodology: urban blocks simulation



6. The **urban blocks** with the closest morphological features to those selected from the statistical distributions of the chosen urban metrics are identified.
7. Those blocks are then **modelled and simulated with tools for UHI assessment** (e.g., UWG by MIT) in order to generate weather data of interest (e.g., HDD_{18} or CDD_{18}).

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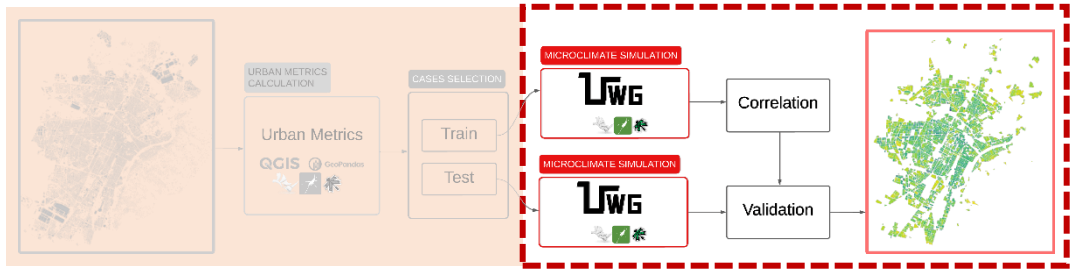
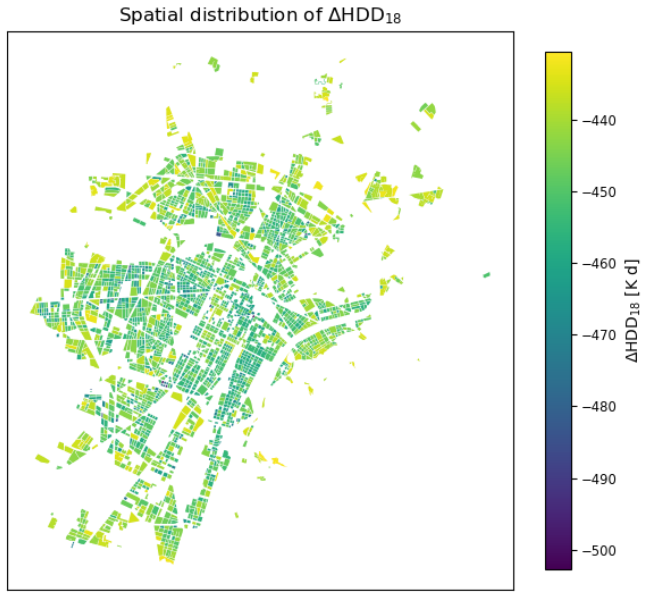
Proposed methodology: correlations and mapping

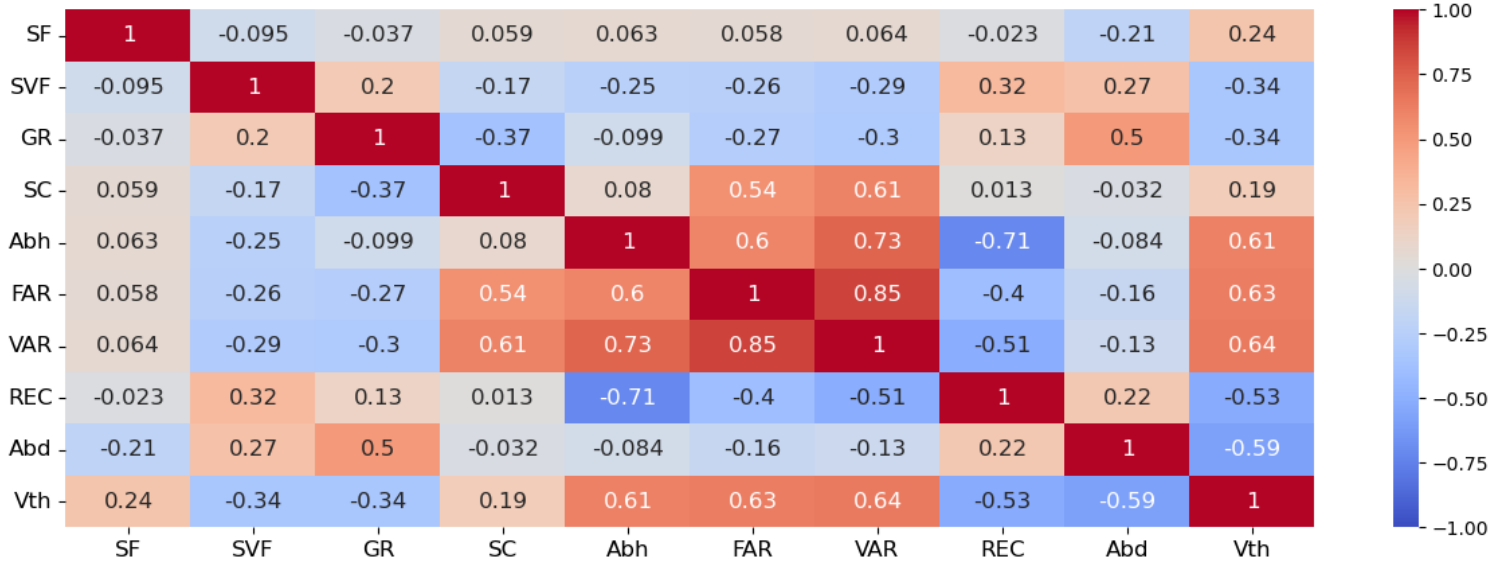


8. **Statistical correlations** between the outputs of interest (e.g., HDD_{18} or CDD_{18}) and the urban metrics are developed.
9. A new set of urban blocks is randomly chosen and simulated with tools for UHI assessment, and results compared to those obtained through the generated correlations for **validation purposes.**
10. If validation is successful, **maps for the whole city are generated.**



Application to the city of Turin (1)

- Identification of **2'804 urban blocks**, after filtering outliers
- Selection of the following urban metrics: **SC**, **GR**, **ABH** and **VtH**



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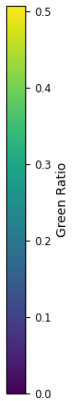
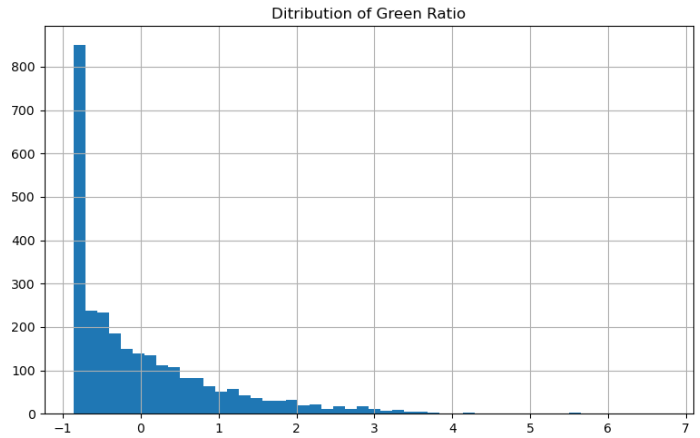
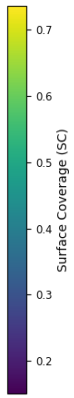
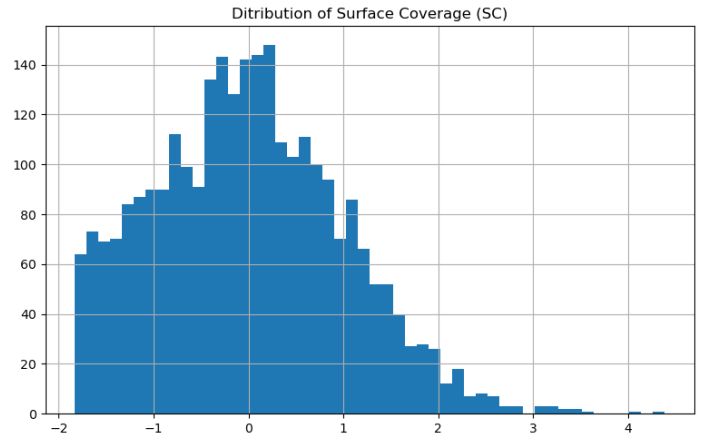
Application to the city of Turin (2)

- Statistical distribution o the selected urban metrics: **SC**, **GR**, **ABH** and **VtH**









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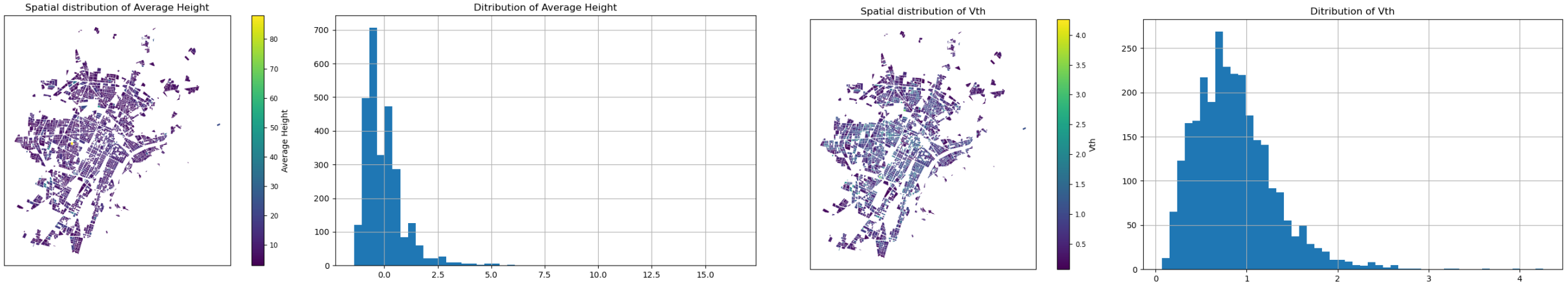
Application to the city of Turin (3)

- Statistical distribution of the selected urban metrics: **SC**, **GR**, **ABH** and **VtH**



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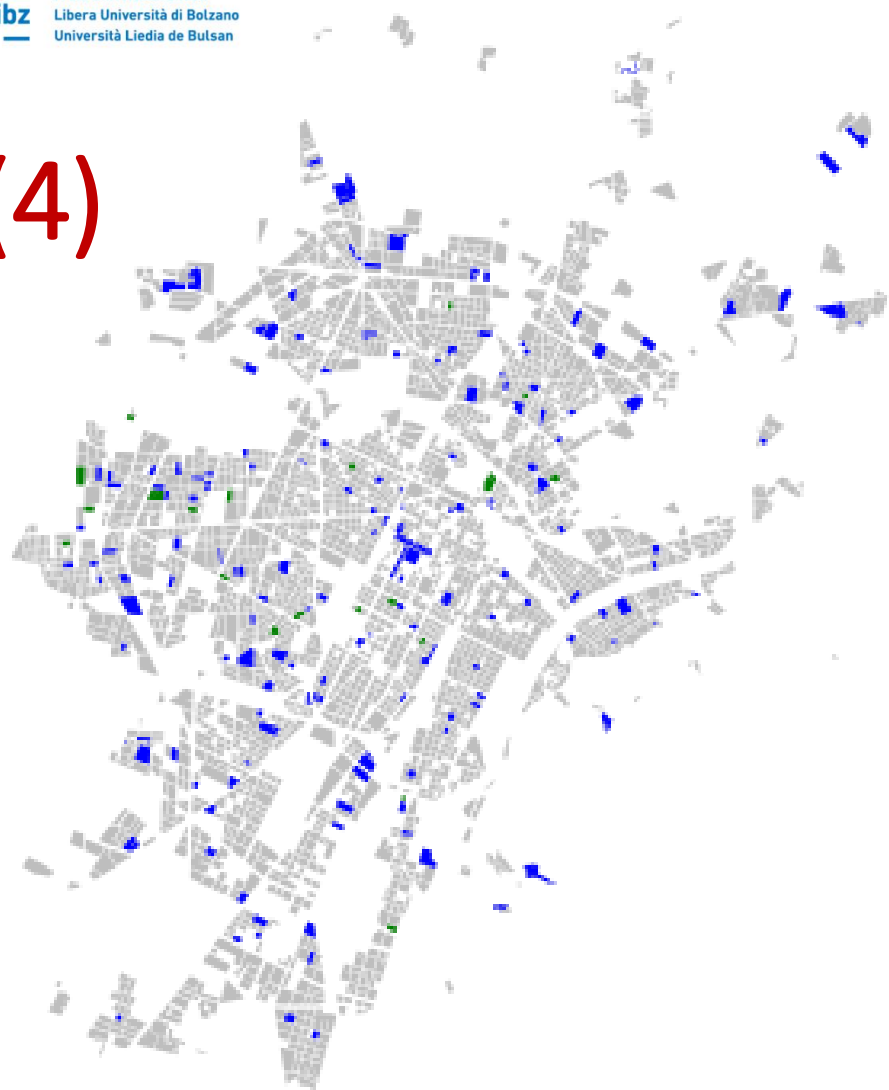
Application to the city of Turin (4)

- Selection of urban blocks for the correlation development:
  170 blocks (6 %)

- Selection of urban blocks for validation:
  20 blocks (0.7 %)



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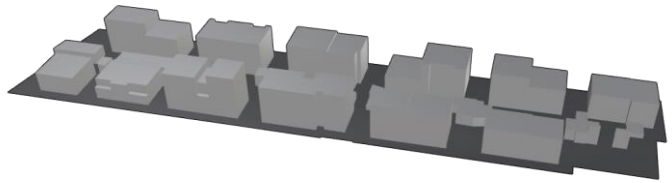
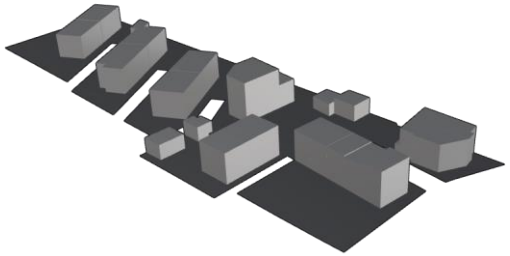
UWG

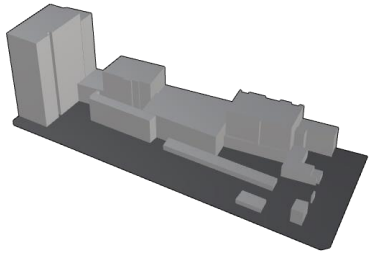
Application to the city of Turin (5)

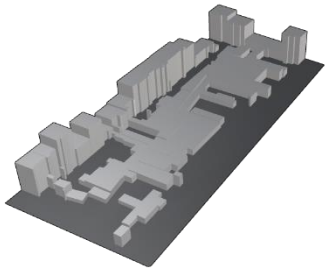
Modelling and simulation of the selected urban blocks with UWG

- **Model Basis**: Geometry of urban blocks
- **Vegetation Parameters**: Defined using Green Ratio (GR) information
- **Other Parameters (not investigated in this preliminary application)**: set to UWG default values according to the U.S. DOE typical values.









Metrics Used for UHI effect:

- Variation of Heating Degree Days (HDD_{18})
- Variation of Cooling Degree Days (CDD_{18})

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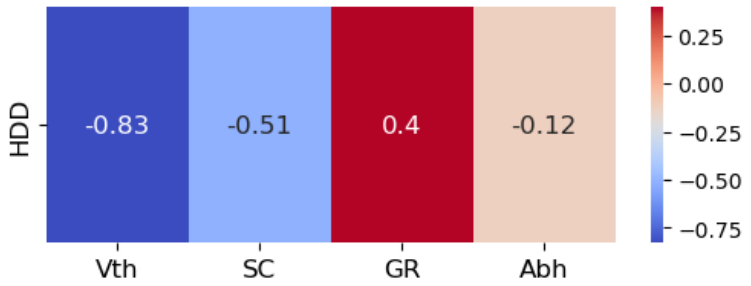
Application to the city of Turin: RESULTS

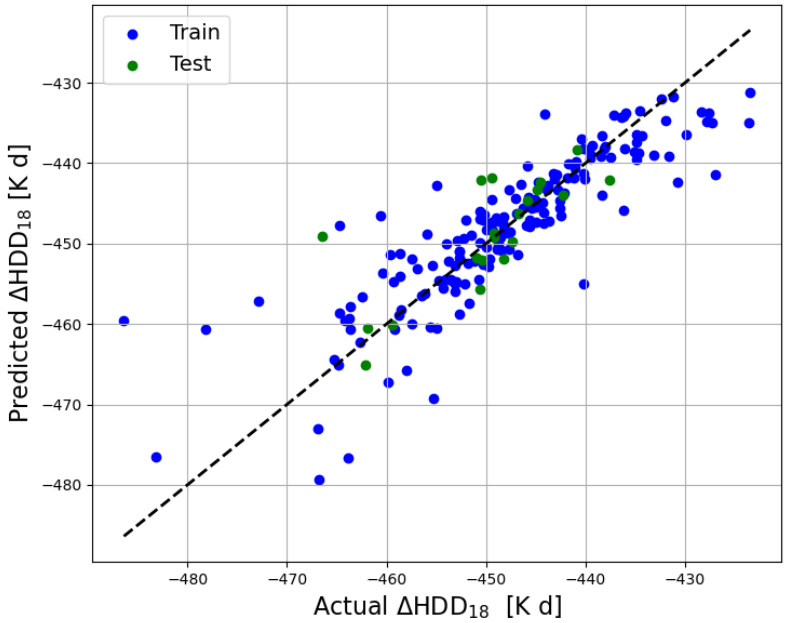
A first attempt of a linear correlation carried for both the metrics.

$$\Delta HDD_{18} = -426.09 - 33.49 \cdot SC + 9.35 \cdot GR - 17.19 \cdot VtH - 0.12 \cdot ABH$$

- **Training:**
  - **RMSE** of **5.47 [K d]**
  - **R^2** of **0.74**



- **Test:**
  - **RMSE** of test cases **5.13 [K d]**



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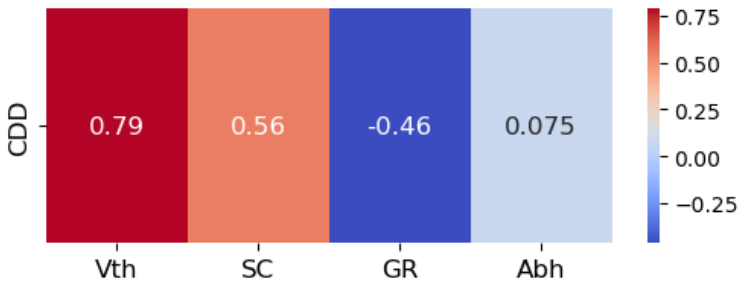
Application to the city of Turin: RESULTS

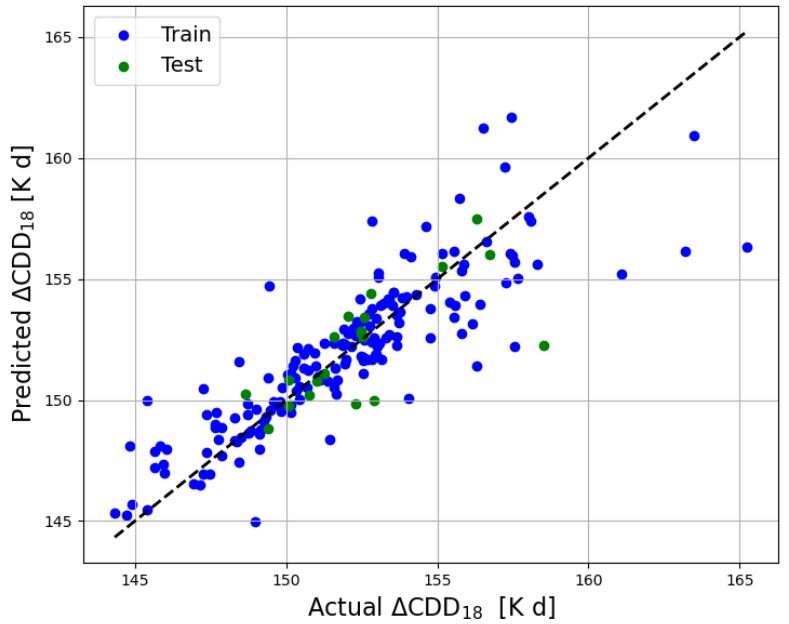
As first attempt of a linear correlation carried for both the metrics.

$$\Delta CDD_{18} = 145.3 + 11.51 \cdot SC - 8.06 \cdot GR + 5.29 \cdot VtH - 0.055 \cdot ABH$$

- **Training:**
  - **RMSE** of **1.89 [K d]**
  - R^2 of **0.73**



- **Test:**
  - **RMSE** of test cases **1.81 [K d]**



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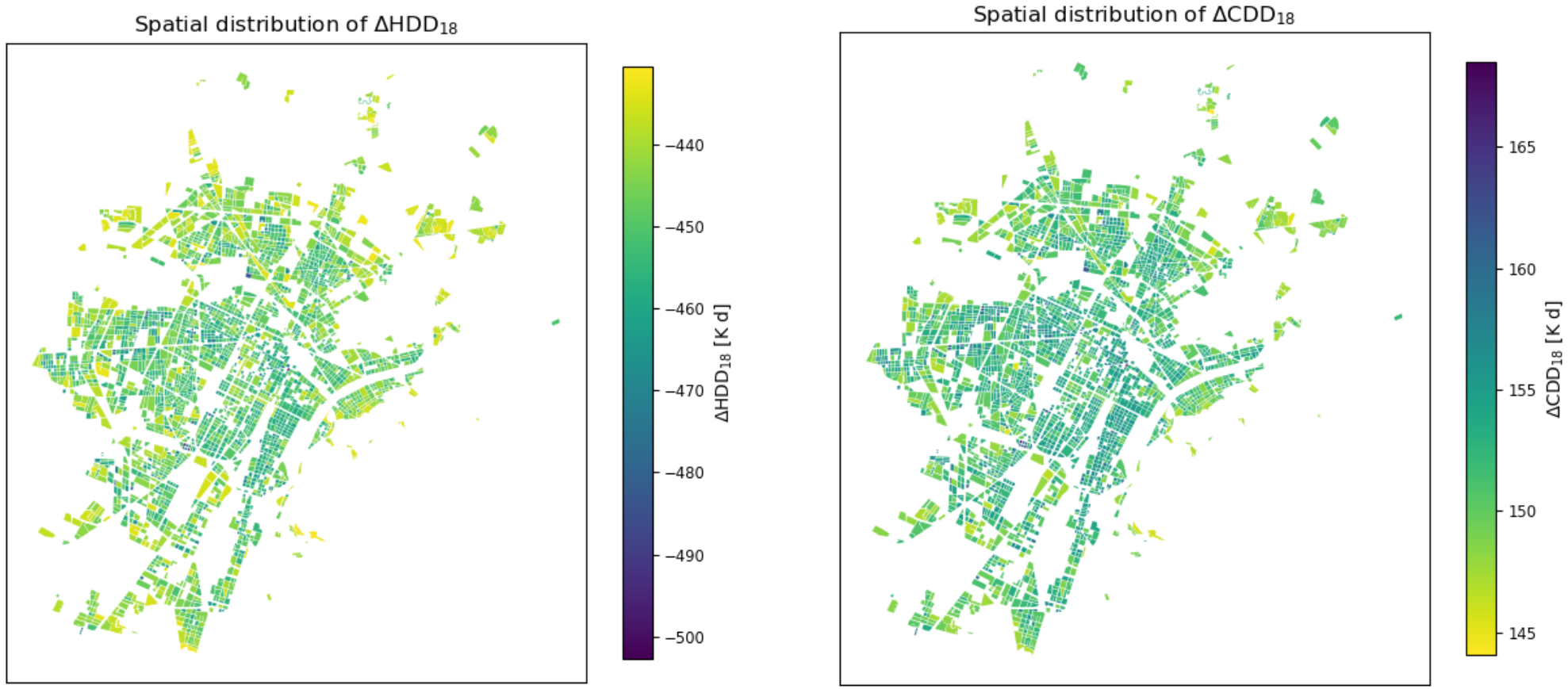

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Conclusion

The preliminary analysis performed for Turin, allowed to conclude that:

- There is a clear correlation between UHI effect and urban context.
- The average variation with respect to the rural weather condition is significant:
  - ΔHDD_{18}: **-450 K d (-14 %)**
  - ΔCDD_{18}: **152 K d (+75 %)**
- A certain degree of variability of the phenomenon can be observed inside the city:
  - Spread of ΔHDD_{18}: **72 K d (2.3 %)**
  - Spread of ΔCDD_{18}: **24.4 K d (12 %)**

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Conclusion

The preliminary proposed workflow allows to:

- **Map** the urban climate starting from the urban metrics
- Reduce the **computational time**

It can be:

- Easily applied to **other cases and metrics**
- Integrated with other techniques to obtain microclimate data

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Limitation and future steps

Main limitations of this study:

- ❑ So far, the focus was put primarily on urban morphological aspects
- ❑ The adopted tool, UWG, does not account for wind speed variation, a critical variable in the Urban Heat Island (UHI) effect

Future steps:

- ❑ Integrate other parameters, such as building archetypes and anthropic heat generation
- ❑ Employ more sophisticated algorithms to better correlate the phenomena
- ❑ Conduct real-case validations

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Questions and Comments

Gregorio Borelli[1], Ballarini Ilaria[2], Vincenzo Corrado[2] , Gasparella Andrea[1] and Pernigotto Giovanni[1]

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[2]Politecnico di Torino, Italy

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CRiStAll

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