Sustainable and Circular Urban Futures: GIS-Based Green Roof Modelling for UHI Mitigation and Agroecological Food Production

"A Case Study of Padova, Italy"

Oltre La Globalizzazione: Transizioni/Transitions, Florence Univeristy

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1. Introduction

- Padua has experienced significant urban growth over the years, UHI is one of the consequences, where urban areas experience higher temperatures than their rural surroundings.

- Studies have shown that the UHI effect in Padua can lead to temperature differences of up to 7°C between urban and rural areas (Battistella, L., & Noro, M., 2015).

- Mitigation strategies, such as increasing green spaces and using reflective materials in construction, are being explored to counteract the UHI effect and improve thermal comfort in the city (Musco, F. *et al.*, 2016).

- Green infrastructure mitigates Padua's Urban Heat Island (UHI) effect by lowering temperatures through shade and evapotranspiration, while improving air quality and supporting biodiversity.

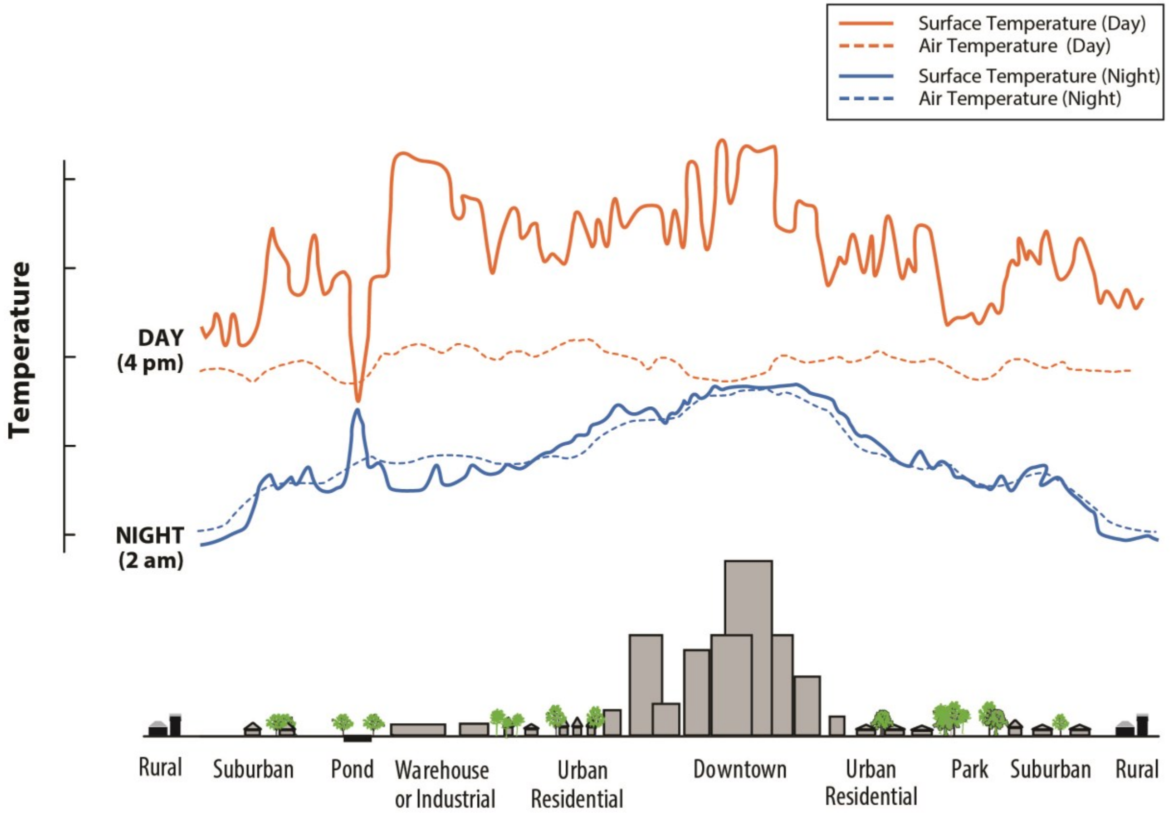

Fig.1: Comparison of Surface and Air Temperature Variations in Rural and Urban Areas

U.S. Environmental Protection Agency (EPA). (2024). *Heat Island Effect*. Retrieved from https://www.epa.gov/heatislands.

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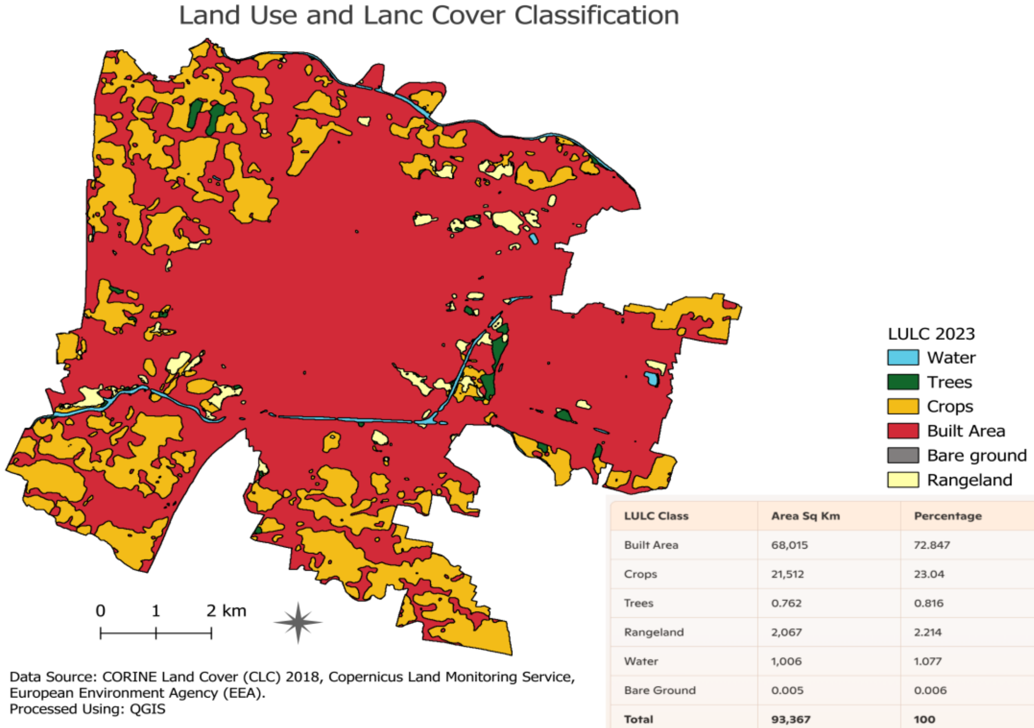
2. Study Area

- Padua is a city located in Veneto, in the Northeast of Italy (Figure 3), 35 km west of Venice.
- The municipality area (Figure 3) covers **93 km2** and, as of 2024, its population counts about **216,366 inhabitants** (ISTAT, 2024).
- According to the CORINE Land Cover dataset, only from 2017 to 2024, the built-up area in Padova city has increased by **4%.**



LULC Class	Area Sq Km	Percentage
Built Area	68,015	72.847
Crops	21,512	23.04
Trees	0.762	0.816
Rangeland	2,067	2.214
Water	1,006	1.077
Bare Ground	0.005	0.006
Total	**93,367**	**100**

Fig.2: Land Use and Land Cover Map (2023)

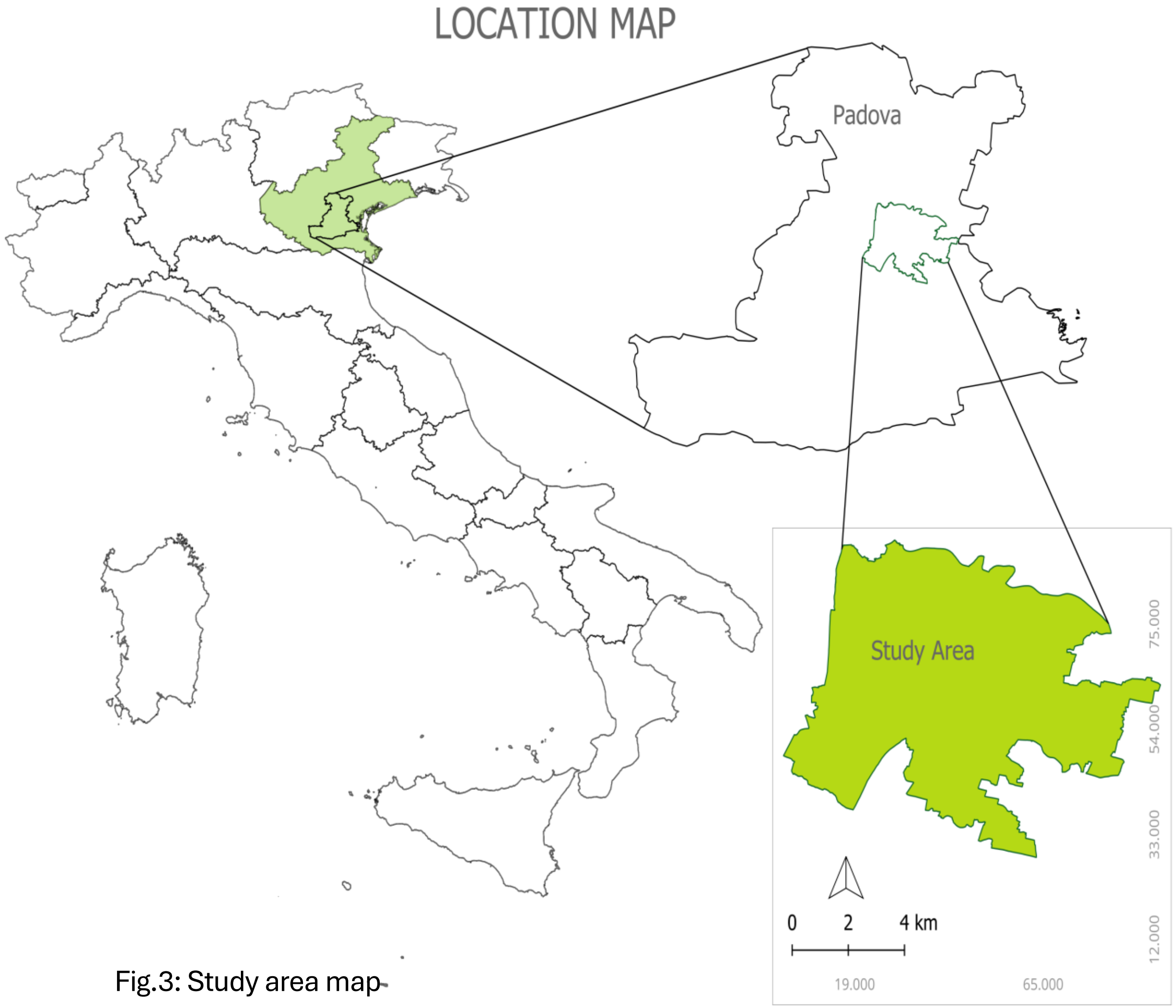


Fig.3: Study area map

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3. Problem Statement

- Green infrastructure (GI) offers a viable solution to these challenges by promoting urban sustainability.
- While traditional ground-level GI options like parks and urban forests are commonly explored and implemented, rooftop interventions, particularly green roofs, remain underexplored.
- Green roofs mitigate the Urban Heat Island (UHI) effect by lowering surface and air temperatures through evapotranspiration and shading, which reduces energy consumption and improves air quality.
- Furthermore, when integrated with agroecological practices, green roofs can transform underutilized urban spaces into productive landscapes, providing urban ecosystem services such as enhanced biodiversity, pollinator support, and urban food security through organic crop production and food sovereignty.

Fig.4: Benefits of green rooftops

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4. Research Objectives

Evaluate the potential of green roofs and photovoltaic installations in Padova using GIS tools.

Investigate the role of rooftop green infrastructure (GI) in UHI mitigation and carbon sequestration, promoting climate justice for vulnerable people by providing thermal comfort.

Explore the integration of rooftop agroecology for enhancing urban resilience and food production.

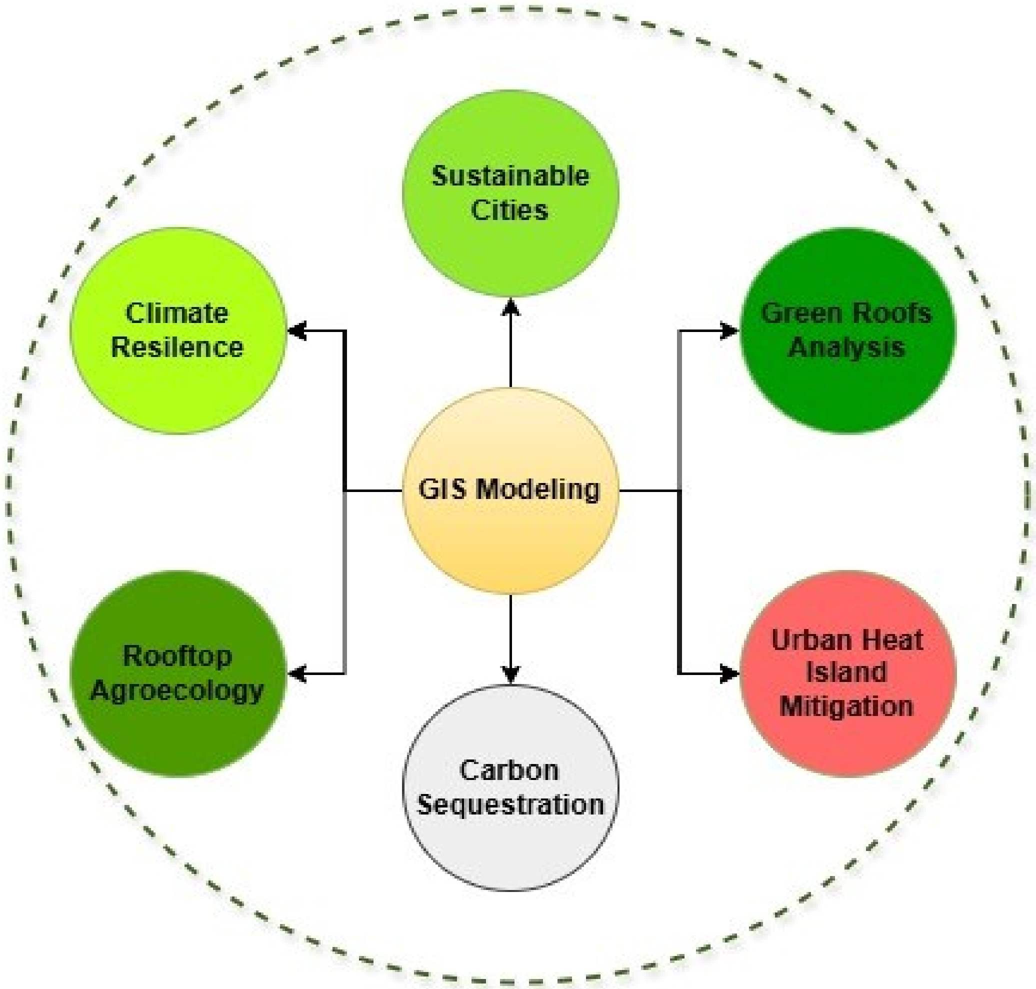

Fig. 5: GIS Modelling: Key to Sustainable Cities and Climate Resilience

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5. Methodology

- The workflow integrates multisource **geospatial data** and open-source processing tools to extract rooftop characteristics for rooftop agroecology and rooftop greening and solar panel installation.

- Input data includes **LiDAR datasets** for high-resolution elevation modelling, which is the base of our analysis, **Sentinel-2**, **MODIS** and **Landsat 8** satellite imagery for surface temperature extraction, UHI, land use and land cover **(LULC)** classification, **Ortho mosaic images** for visual referencing, and area-of-interest **(AOI) boundaries** to focus the analysis.

- The processing pipeline utilizes **Google Earth Engine** for cloud-based satellite data analysis**,** **QGIS** for spatial data analysis and mapping, and **RStudio** for statistical computations and analysis.

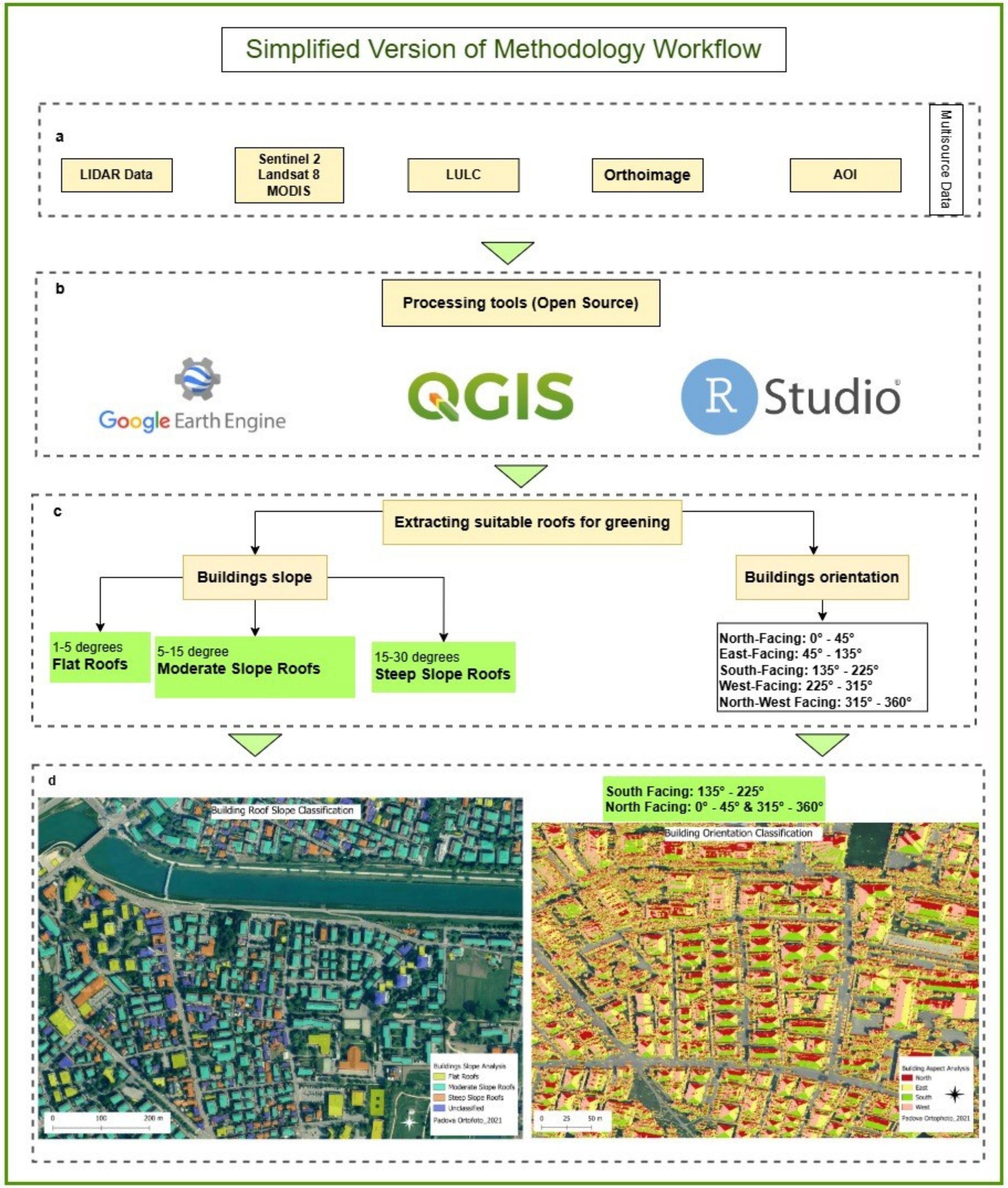

Fig. 6: Methodology workflow

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6. Result

- The preliminary results of this study reveal: A total of **3,263 km²** of flat roofs →**intensive green roofs** and **rooftop agroecology.**

- And **4,755 km²** of hipped roofs → extensive green depending on their slope and orientation.

- **1,921 km²** is suitable for photovoltaic installations.

No	Type of Roof	Sum in Area Km2
1	Flat roof	3,263
2	Hip roof	4,755
3	Steep roof	1,921
4	Total area	9,939

Table 1: Total Area of Each Roof Type (km²)

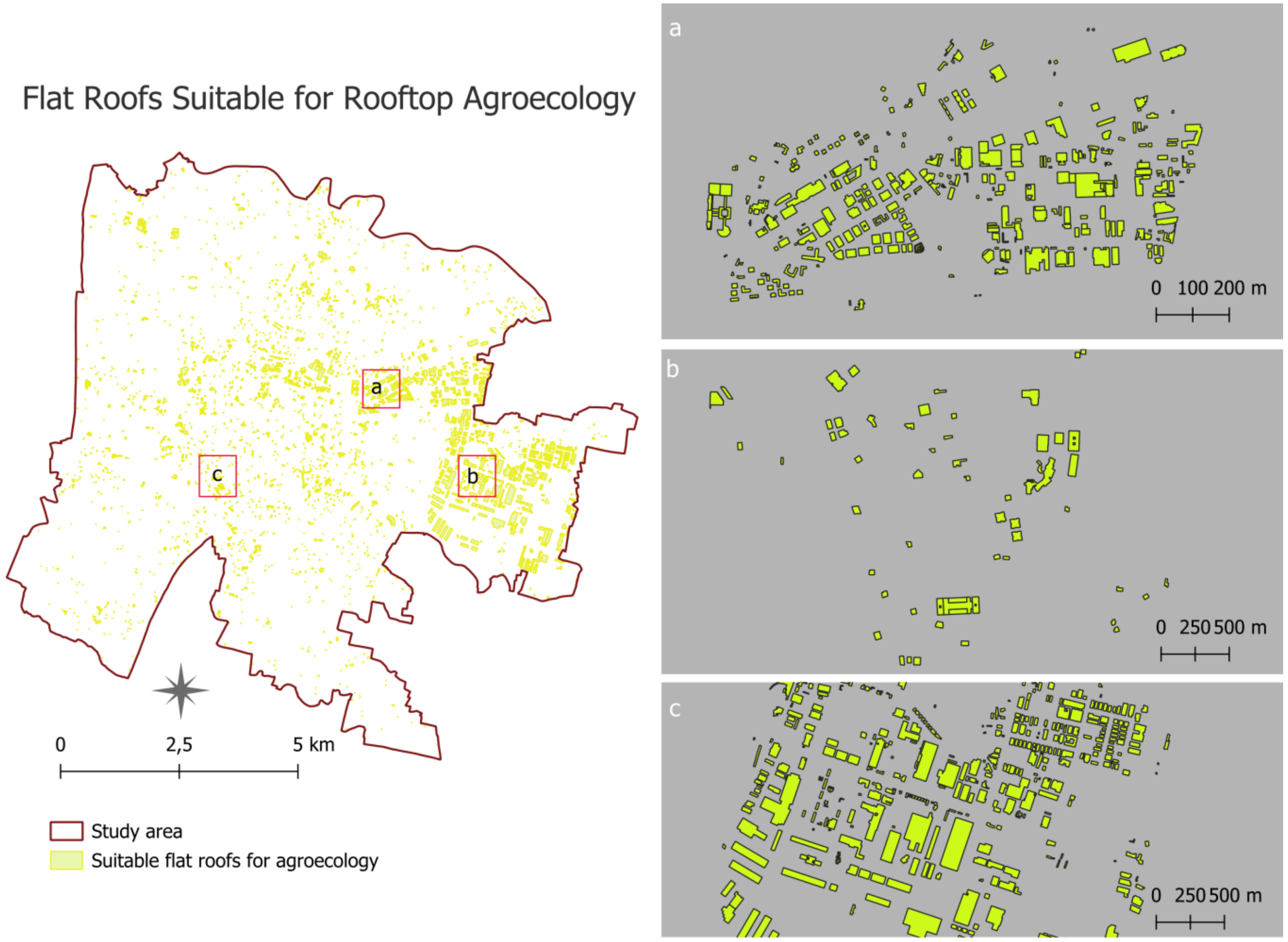

Fig.7: Flat roofs suitable for rooftop agroecology

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6. Result(continued)

Hip roofs Map

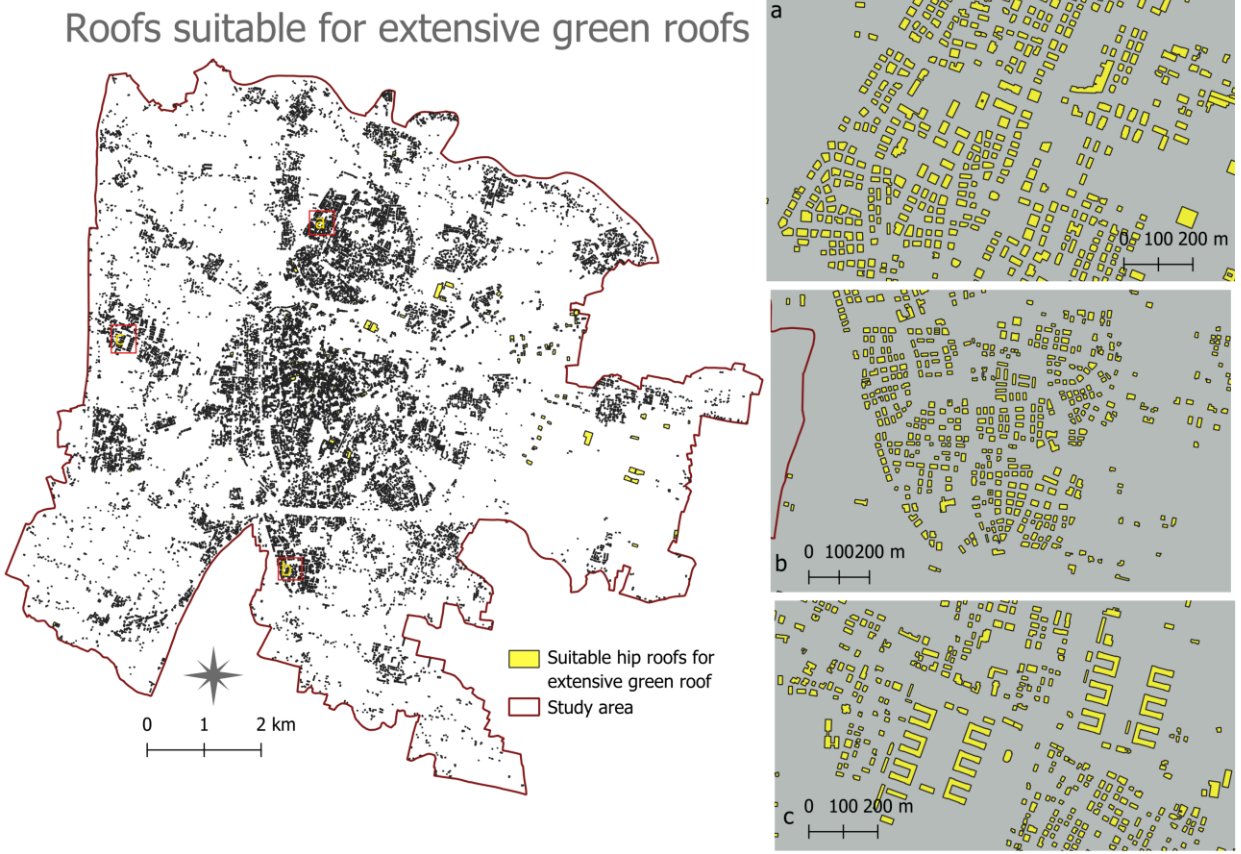

Fig.8: Hip roofs suitable for extensive green roofs

Steep roofs map

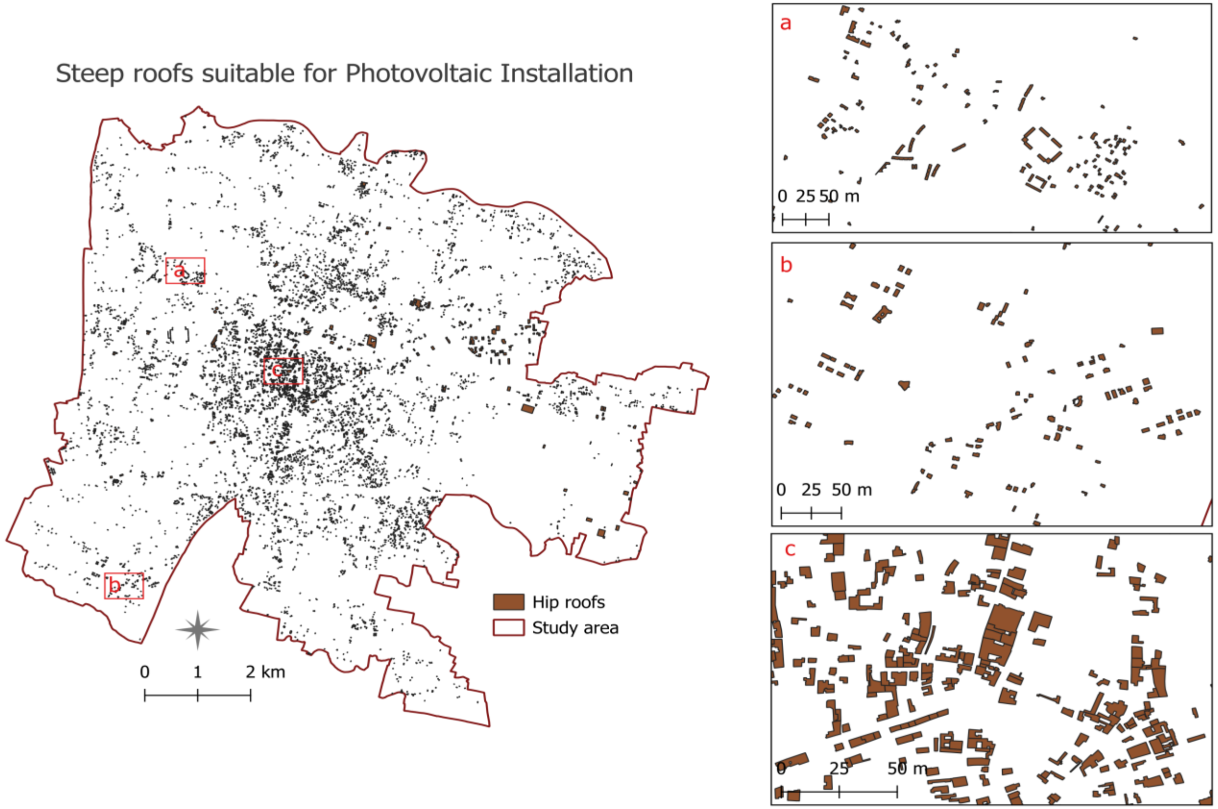

Fig.9: Steep roofs suitable for photovoltaic installation

6. Result

NDBI Map

NDVI Map

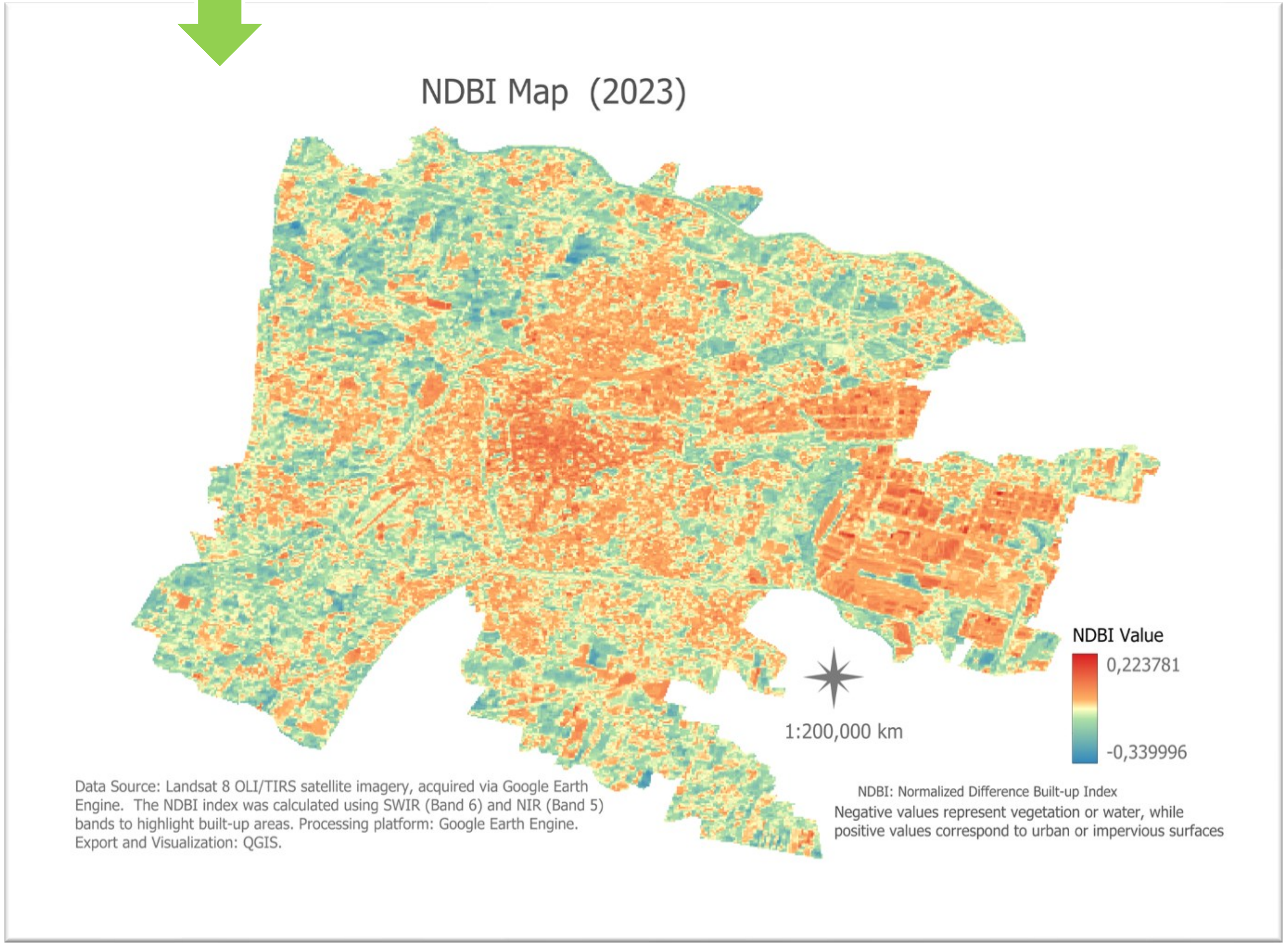

Fig.10: Normalized Difference Built-up Index map (2023)

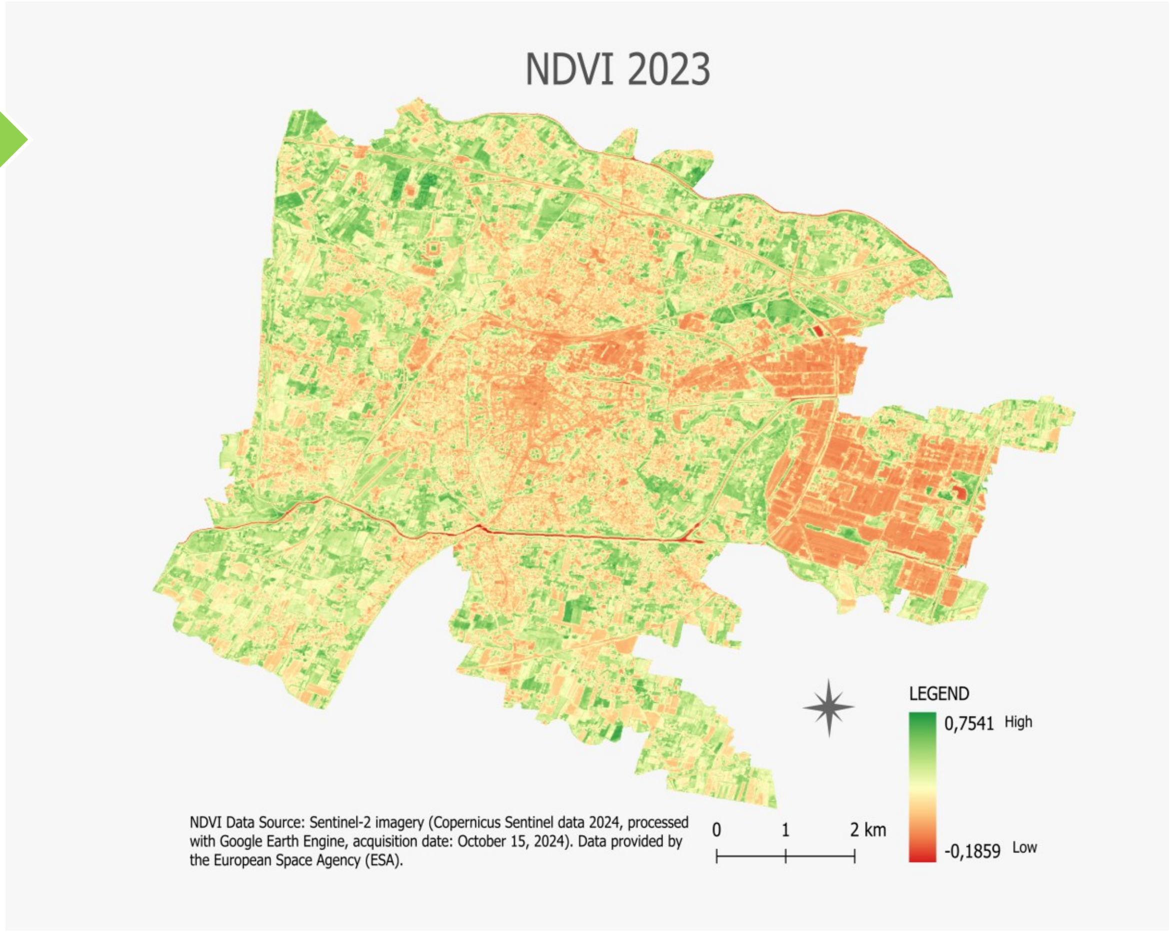

Fig.11: Normalized Difference Vegetation Index Map(2023)

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6. Result

Aspect Analysis result

Urban Heat Island Map

Fig. 12: Aspect analysis map

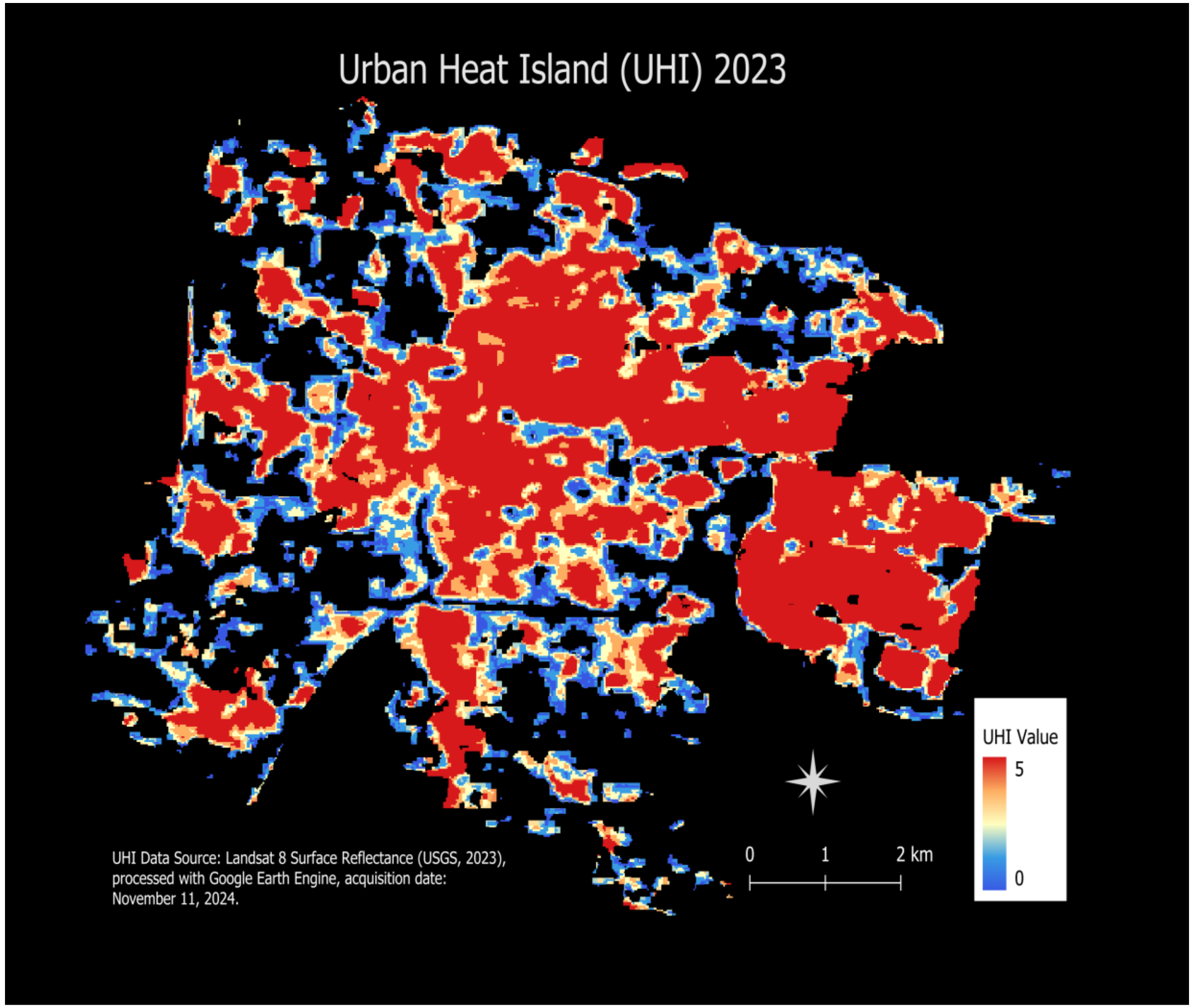

Fig. 13: Urban Heat Island Map of Padua for the Year 2023

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6. Results (in progress)

- We aim to achieve the following outcomes upon completing the project:
    - UHI mitigation potential; promoting climate justice for vulnerable people, such as elderly, children and people with migration background.
    - Agroecological outcomes: food production and biodiversity conservation;
    - Carbon sequestration capacity;
    - Comprehensive priority analysis of green roof installation.

Fig.14: Image Source: http://webgl3d.info/ex/workInProgress.html

7. Policy and Planning Implications

- This study provides critical insights with significant implications for urban planning and policy aimed at mitigating the urban heat island (UHI) effect and other related climate change hazards in Padova.

- Green roofs mitigate UHI through evapotranspiration, enhance building insulation, and improve urban biodiversity, stormwater management, and air quality. They also promote local food security and equity. Policymakers can leverage these benefits with targeted incentives, such as subsidies or zoning regulations, to encourage adoption.

- Furthermore, this research is aligned with the United Nations Sustainable Development Goals (SDGs) 2030 Agenda, addressing multiple goals, including Good Health and Well-being (Goal 3), Zero Hunger (Goal 2), Sustainable Cities and Communities (Goal 11), Reduced Inequalities (Goal 10), Industry, Innovation, and Infrastructure (Goal 9), Climate Action (Goal 13), and Gender Equality (Goal 5).

Fig.15: Green roofs and SDGs.

8. Conclusion

Summary of Findings:

- Our analysis identified 3,26 km² of flat roofs suitable for agroecology, 4,75 km² of moderately sloped roofs for greening, and 1,92 km² of steep roofs ideal for solar panel installations.
- These findings demonstrate the potential for urban sustainability interventions in Padova.
- Our findings support urban greening initiatives in alignment with SDG 2030 goals and the need for sustainable urban planning

Limitations:

- The analysis is constrained by the availability of updated building footprint data and high-resolution satellite imagery, which could enhance the accuracy of roof classification and suitability assessments.

Future Research Directions:

- Future studies could incorporate detailed rooftop logistic and structural analysis and economic feasibility assessments.

Thank you for your time and attention!

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