Multisensory Outdoor Environmental Study for Enhancing Urban Population Resilience to Climate Change

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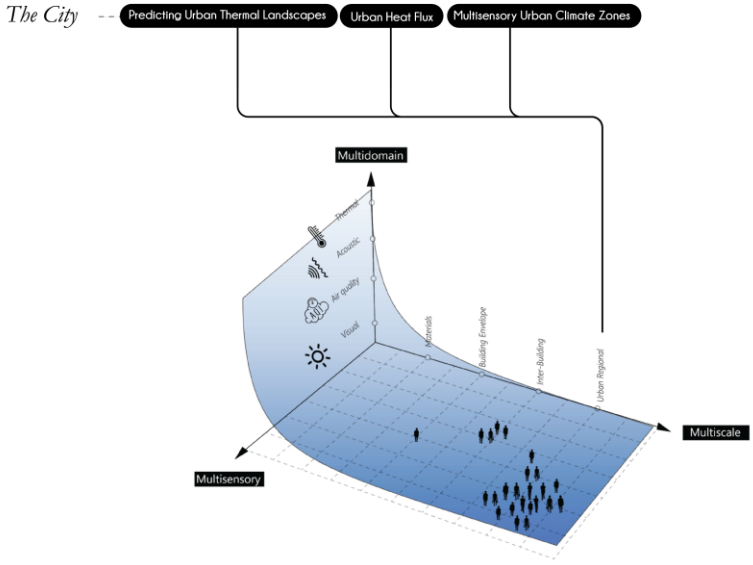
SONATA
situation aware orchestration of adaptive architecture

1

The **thermal environment** of a city is well mapped. The **human response** to it is not. We argue that closing this gap requires moving **beyond morphology to human physiology.**
From static urban zones to the bodies navigating them, from average vulnerability to individual resilience, from **what cities measure to what people feel**.

2

Human Dynamics Observatory.



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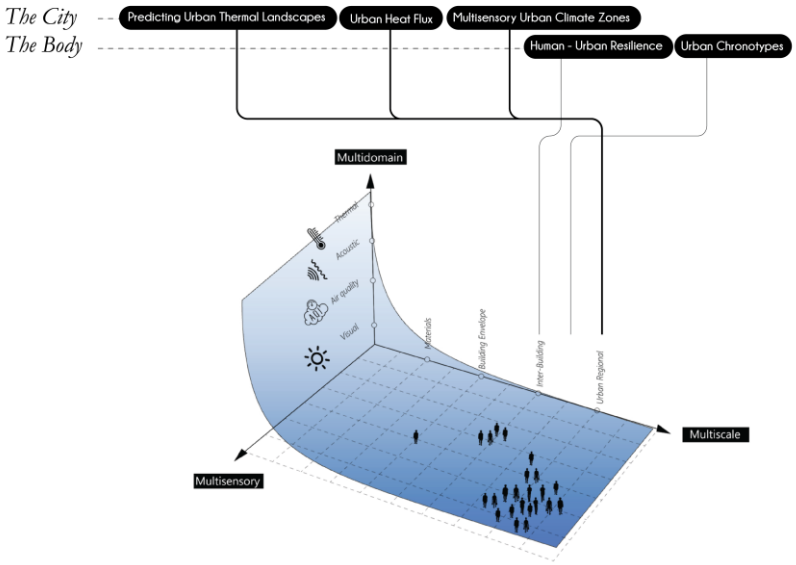

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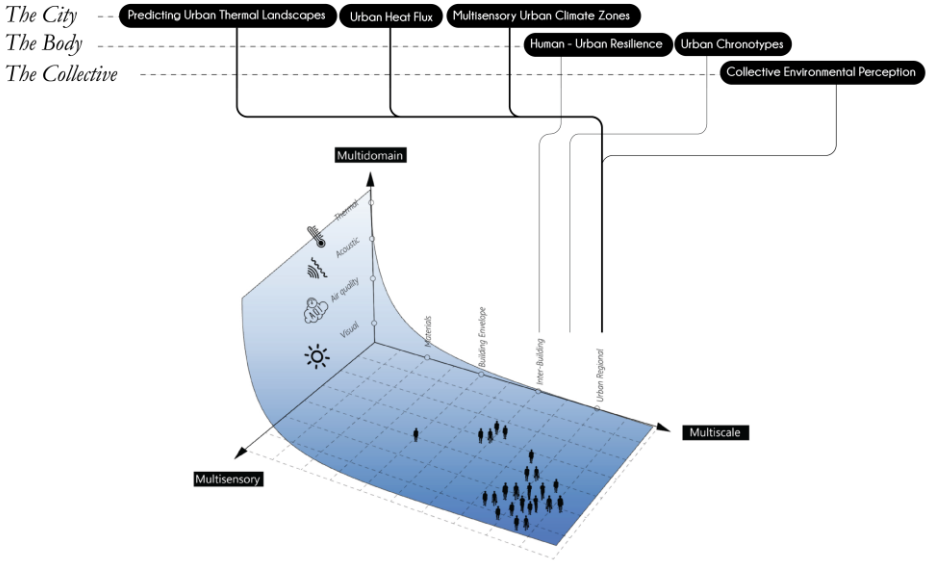

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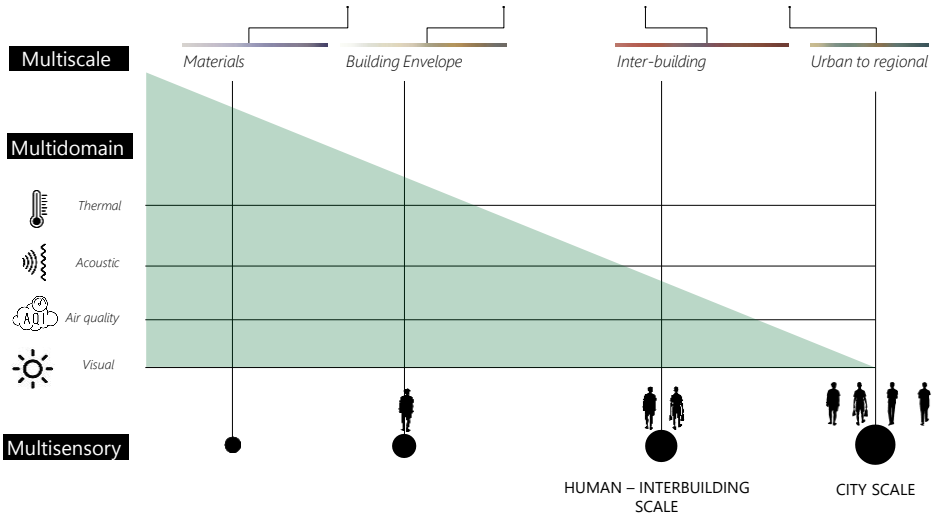
Sensing the Environment

Urban Climate Dynamics Observatory.



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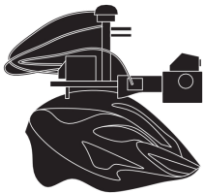
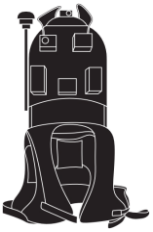
GETTING AN INSIDER'S PERSPECTIVE:

Multidomain stressors detected via mobile-to-wearable sensing, potentially crowdsourced.

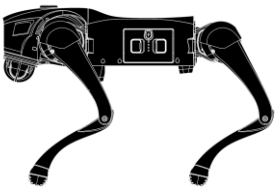
Mobile Weather Station (Van)



Wearable Weather Station (Helmet)



Wearable Weather Station (Backpack)



More than human sensing prototype (Robot Dog)

How to catch-and-handle urban resilience need in complex, dense and polluted urban areas?

Cureau et al. Environmental research, 2024

Pigliautile and Pisello, BAE, 2020

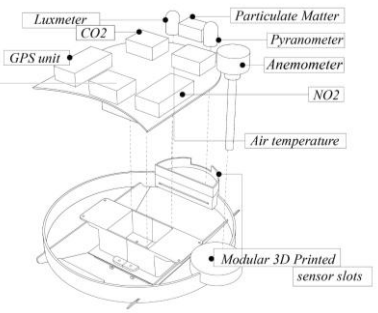
Pigliautile and Pisello Sci Tot Env 2018

Wearable + Autonomous Sensing

Experimental Campaign in Perugia.

Pilot Design: EAPLAB

Robot: Eagle Projects, Perugia.



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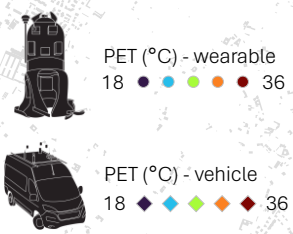
Toward Multisensory Environment

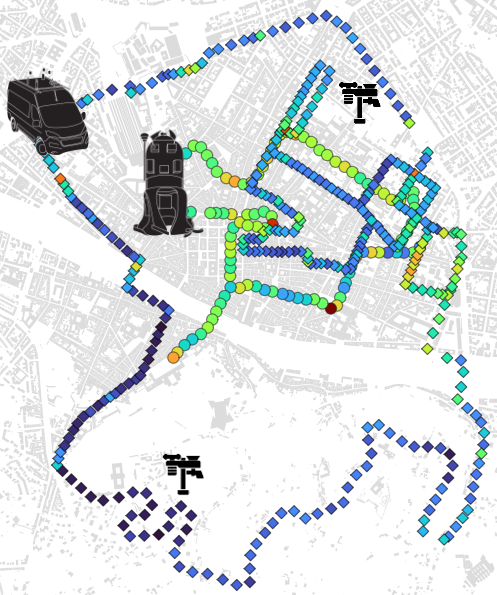
Human - Inter - Building Scale

Wearable sensing identifies Climatopes

(special climates of local places Wilmers, 1991, Oke, 2012)

Mapping Physiological Equivalent Temperature (PET)





Hyperlocal mobile-to-wearable monitoring:

- Diurnal temporal variability: same path repeated in the morning, noon, and afternoon.
- PET as a heat stress metric as it includes physiological information.
- Mobile monitoring to identify hyperlocal PET extremes.
- Vehicle vs pedestrians, they do not report the same information: wearable device detects hot spots that are not observed with the vehicle, but the vehicle monitors a larger area.

**necessity of a hybrid network of mobile multiscalesystems for properly assessing risk and vulnerability.*

Cuteau et al. Environmental research, 2024

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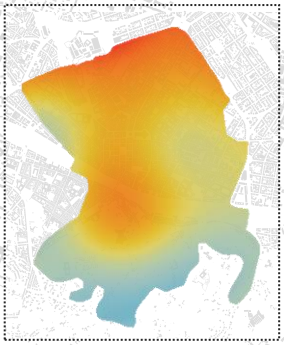
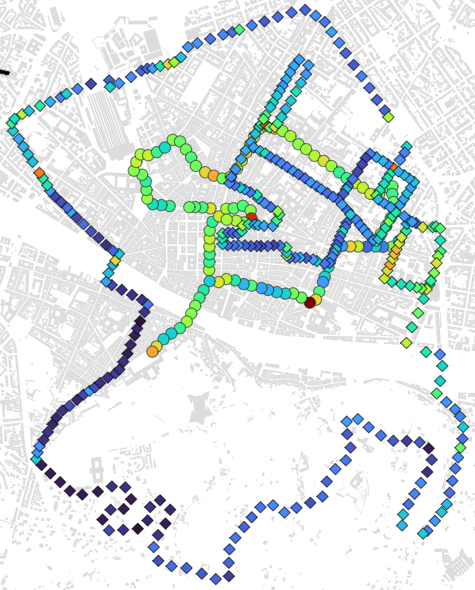
Toward Multisensory Environment

Human - Inter - Building Scale

Kriging spatial interpolation (15/09/2021 midday)





Ordinary Kriging:

- Simplified interpolation, fast computation.
- Acceptable error in predicting air temperature distribution (Leave-one-out cross-validation):
  *RMSE = **0.29 – 0.59 °C** summer (CV = 1% - 3%)*
  *RMSE = **0.36 – 0.54 °C** winter (CV = 2% - 13%)*
- Vehicle-only (validated with the backpack data):
  *RMSE = **0.76 – 1.15 °C** summer (CV = 3% - 6%)*
  *RMSE = **0.74 – 1.63 °C** winter (CV = 5% - 42%)*
- Backpack-only (validated with the vehicle data):
  *RMSE = **0.87 – 1.31 °C** summer (CV = 3% - 6%)*
  *RMSE = **0.81 – 1.37 °C** winter (CV = 5% - 25%)*

Van-only fails to pinpoint precise hotspots as indicated by the monitoring data.

Cureau et al. Environmental research, 2024

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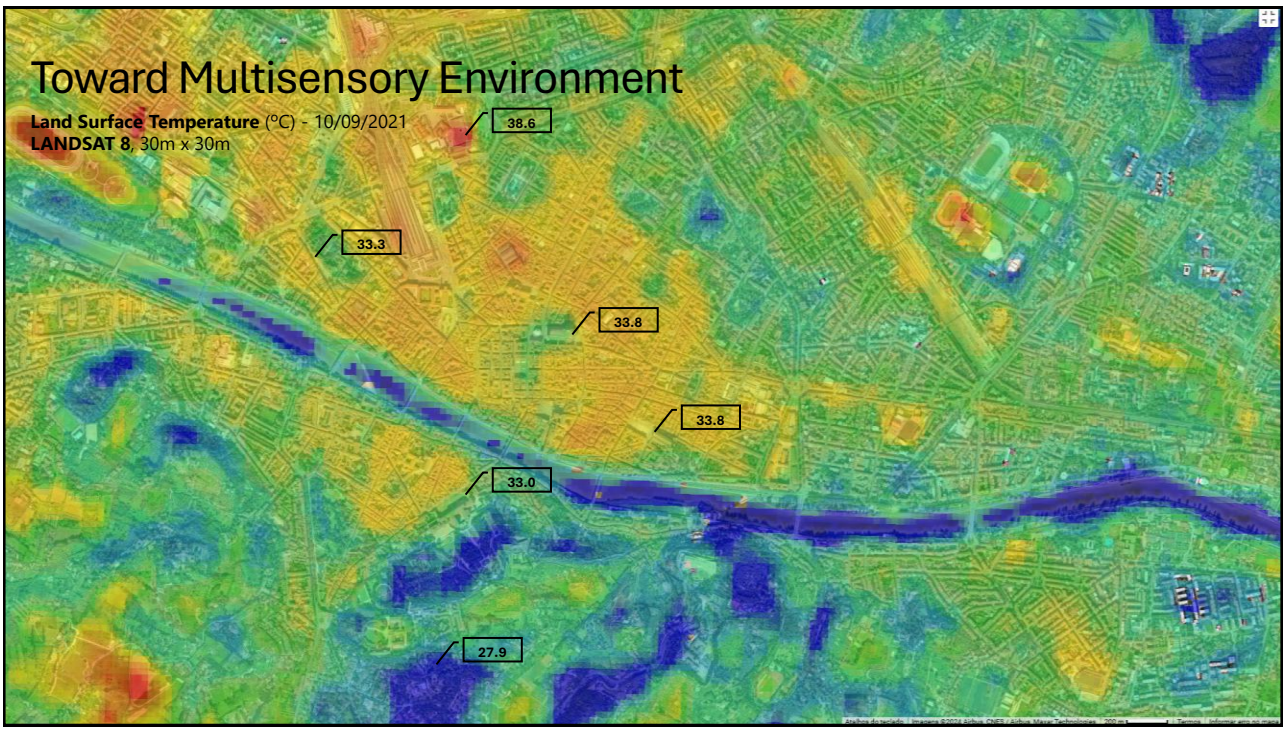
Toward Multisensory Environment

Land Surface Temperature (°C) - 10/09/2021
LANDSAT 8, 30m x 30m



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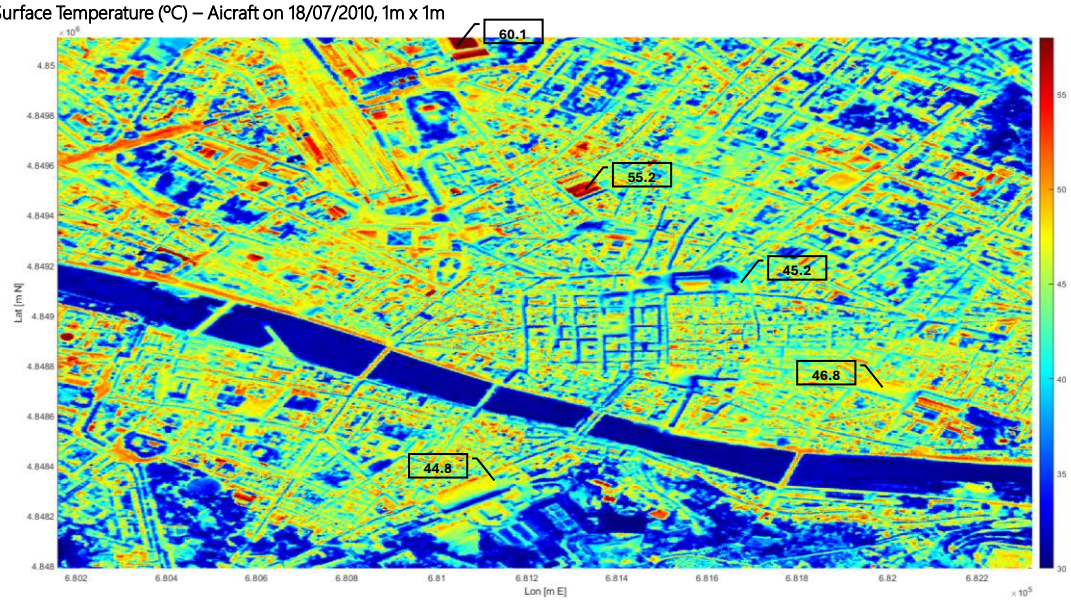
Toward Multisensory Environment

Land Surface Temperature (°C) – Aicraft on 18/07/2010, 1m x 1m



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Sensing the Environment through Human-Centric Approaches

The Indoor-Outdoor Problem

Urban thermal conditions are spatially complex and impossible to capture with fixed sensors. We don't know what people actually experience at street level.

Indoor thermal comfort models do not capture fully human multisensory experience and social dynamics.

Our Approach

Multidomain – Multisensory – Social - Physiological analysis for Whole wellbeing approach through

- Environmental data (spatial-temporal granularity and dynamics
- ML techniques
- Diverse data including social networking analysis and physiology measurements (safety, security, vulnerability)

Observing, predicting, mitigating exposure risks via HUMAN CENTRIC, implementation driven complexity

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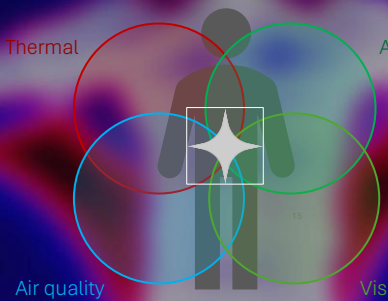
Schweiker et al. BAE, 2020

Chinazzo et al. BAE, 2022

Human comfort depends on the combination and interaction of several **environmental stimuli** that are simultaneously experienced. This happens both in indoors and outdoors



Personal and contextual factors
(gender, age, background, etc.)

MULTI-DOMAIN APPROACH: cross-modal effects + contextual effects

Beyond thermal-only issues for comprehensive environmental comfort assessments:
Human comfort is A MULTI- DOMAIN ISSUE, since our perception and potential vulnerability is influenced by a wide range of factors

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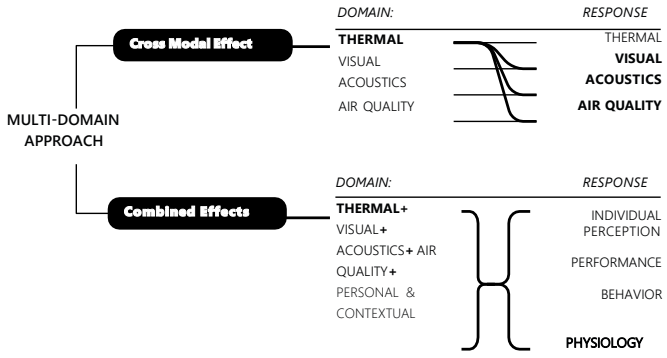
Schweiker et al. BAE, 2020

Chinazzo et al. BAE, 2022

THE ROLE OF MULTIPLE STRESSORS IN HUMAN PERCEPTION AND VULNERABILITY: BEYOND THERMAL-ONLY ISSUES

Human perception depends on the combination and interaction of several environmental stimuli that are simultaneously experienced + personal and contextual factors.



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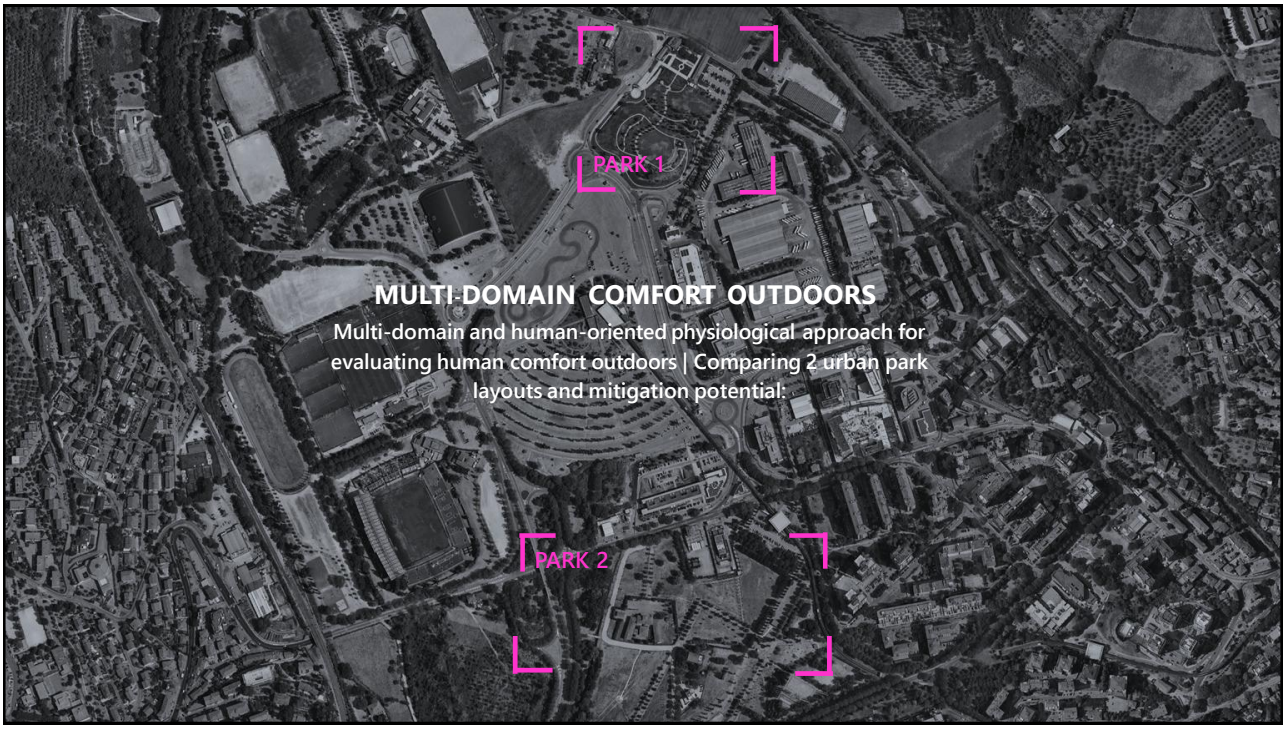

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Sensing the Environment

Multidomain Human Comfort - Outdoors

MULTI-DOMAIN COMFORT OUTDOORS: FOCUS ON ACOUSTICS AND SOUND-MASKING

Monitoring and survey (>300pax) in all the domains

MULTI-DOMAIN COMFORT WALK:
•Environmental monitoring (backpack, digital sonometer, and microphone recordings)
•Comfort survey

Case studies:
Park and a nearby commercial hub: both places dedicated to leisure activities.

Park 1 / Urban park (UP)

Commercial hub (CH)

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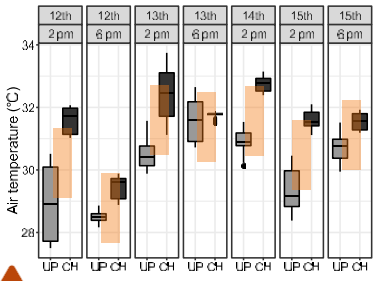
Sensing the Environment

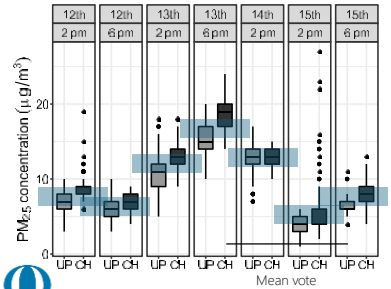
Multidomain Human Comfort - Outdoors

Multidomain-designed urban park much preferred vs commercial hubs despite physics-based observation are equivalent → **Understood via cross-modal effects**



CH was always hotter (worse microclimate) : better thermal comfort evaluation at the UP.

	Mean vote	
	UP	CH
Thermal comfort	*0.6*	*-0.3*



	UP	CH
Air quality perception	*1.3*	*-0.8*

Comparable air quality level, inconsistent perception.

Cureau, et al.
Forum Acusticum 2023

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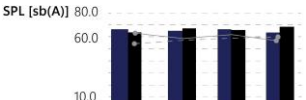
Sensing the Environment

Multidomain Human Comfort - Outdoors

Multidomain-designed urban park much preferred vs commercial hubs despite physics-based observation are equivalent

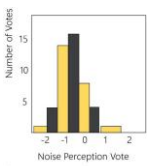
WATER SOUND-MASKING CROSS-MODAL EFFECT

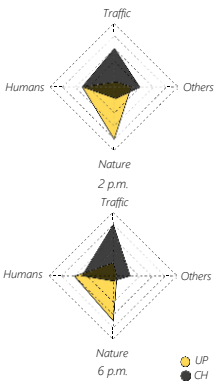
- *Sound pressure levels were always higher at the UP.*
- *Both places were perceived as noisy (negative mean vote).*
- *Slightly worse assessment for the CH, even though the sound pressure level was higher at the UP.*

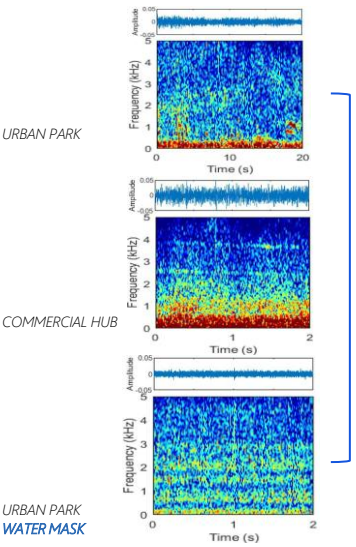


	Day 1	Day 2	Day 3	Day 4
UP2	66.4	64.2	65.9	63.2
UP6	63.7	67.1	65.3	67.8
CH2	55.8	57.2	59.5	59.9
CH6	62.8	58.1	62.2	57.2

	Mean vote	
	UP	CH
Noise perception	*-0.6*	*-1.0*
Acoustic quality	*0.7*	*-0.7*







Cureau, et al.
Forum Acusticum 2023

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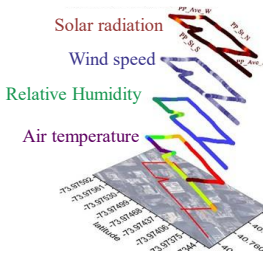
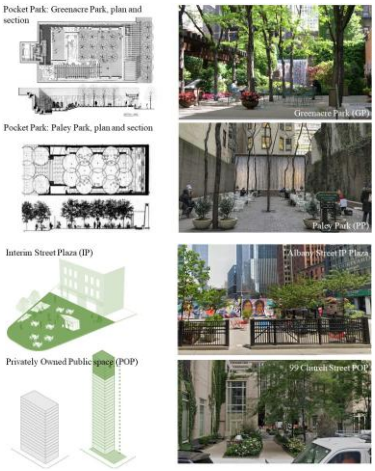
Multidomain Human Comfort - Outdoors

Strategic Urban Pocket Parks (SUPP) for subjective and objective multi-domain comfort

Multi-domain comfort assessment in the outdoors



Cyberphysical approach in NYC Paley Pocket park July 26th, 2019 heatwave



Rosso et al., Energy and Buildings, 2022

Rosso et al., Journal of Environmental Management, 2024

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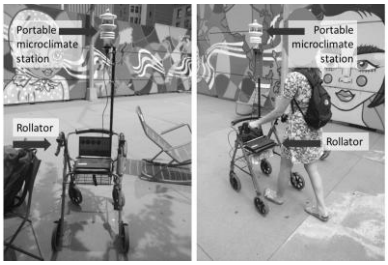
Multidomain Human Comfort - Outdoors

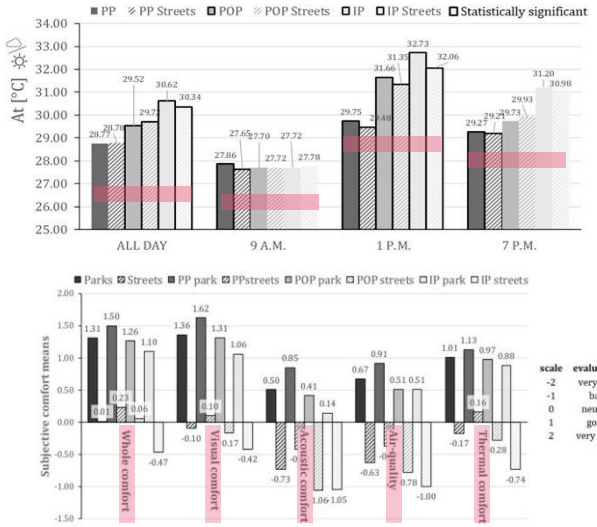
Multi-domain comfort in the outdoors Strategic Urban Pocket Parks (SUPP) for subjective and objective multi-domain comfort



Perceived wellbeing does not mirror microclimate analysis.

Drivers from other-than-thermal domains influence thermal perception.

Contextual variables (gender, job, attitudes) matter in determining citizens' wellbeing and resilience.



Rosso et al., Journal of Environmental Management, 2024

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Integrated Sensing of Environment and Human Dynamics

Predicting Urban Surface Temperatures with CNN

The Outdoor Problem

Urban thermal conditions are spatially complex and impossible to capture with fixed sensors. We don't know what people actually experience at street level.

Our Approach

CNN trained on paired RGB + thermal images and mobile environmental data predicts surface temperature maps at pedestrian scale: radiant heat exchange at the body level.

Mobile Monitoring · Thermal Imaging · Deep Learning

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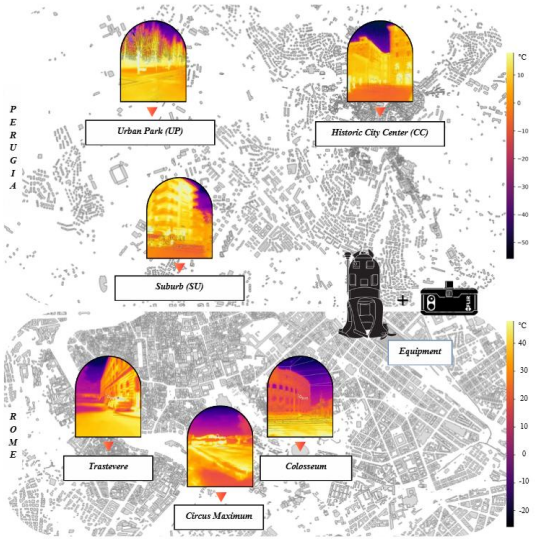
Integrated Sensing of Environment Human Dynamics

Predicting Urban Surface Temperatures with CNN



Zarbo et al. in progress

Mobile Monitoring · Thermal Imaging · Deep Learning

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Sensing the Environment

Predicting Urban Surface Temperatures with CNN

CNN (convolutional neural network), U-NET, MLP (multilayer perceptron) concatenated into a unified latent representation.

Zarbo et al. (under review)

Mobile Monitoring · Thermal Imaging · Deep Learning

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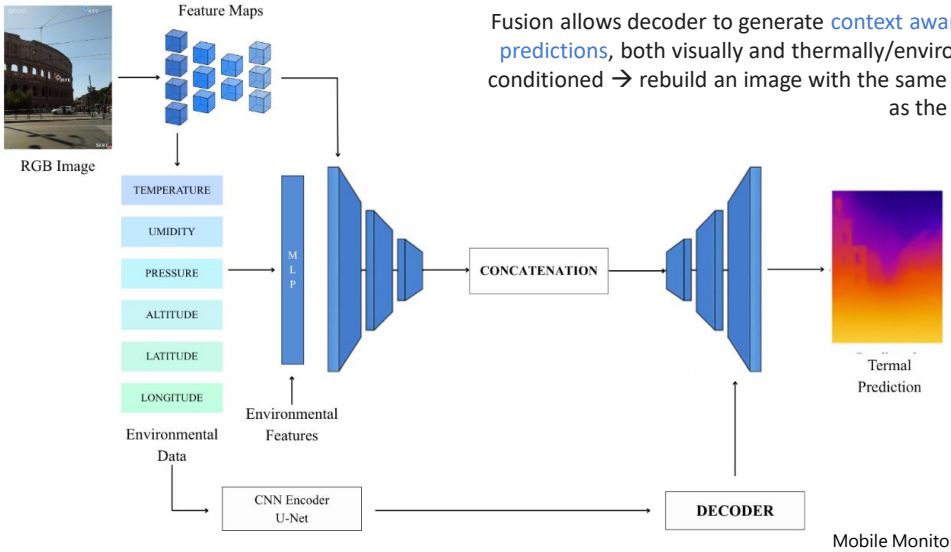
Sensing the Environment

Predicting Urban Surface Temperatures with CNN



Fusion allows decoder to generate context aware thermal predictions, both visually and thermally/environmentally conditioned → rebuild an image with the same resolution as the input RGB

Zarbo et al. (under review)

Mobile Monitoring · Thermal Imaging · Deep Learning

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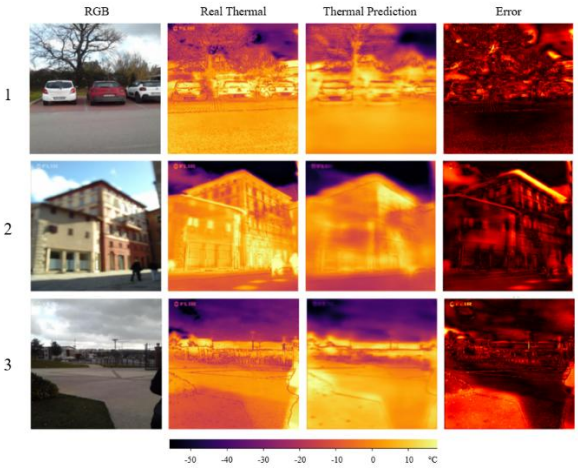
Sensing the Environment

Predicting Urban Surface Temperatures with CNN



Zarbo et al. (under review)

Scene	Real Thermal Image: Mean Surface Temperature	Predicted Thermal Image: Mean Surface Temperature	Range	RMSE	CV(RMSE)
1	6.06°C	6.11°C	29.1°C	3.57°C	12.3%
2	-9.57°C	-14.85°C	75.3°C	10.14°C	13.5%
3	4.37°C	6.18°C	29.2°C	4.36°C	14.9%

Despite the variation in absolute RMSE values, the relative error normalized to the scene-specific thermal range remained remarkably consistent across scenes (12.3–14.9%), indicating that the model maintains stable predictive performance across markedly different thermal regimes (<100 kB to train >25k parameters).

The model does not simply approximate heat. It reconstructs spatial thermal patterns
→ **Immediate urban risk and design implications**

Mobile Monitoring · Thermal Imaging · Deep Learning

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Sensing the Environment

Estimating urban heat storage flux at the scale where people walk

The Problem

Urban storage heat flux (ΔQs) — the energy absorbed by surfaces and released overnight — is one of the hardest terms to quantify in the urban energy budget. Existing methods rely on satellite imagery (coarse resolution, cloud-dependent) or flux towers (spatially fixed). Neither captures what pedestrians actually experience inside street canyons influenced by **URBAN THERMAL PERSISTENCE**

Our Approach

Wearable pedestrian sensing + personal weather stations → Gaussian-weighted pedestrian-level forcing → ENVI-met 3D microclimate simulation at 5 m resolution → Land Surface Temperature → Thermal Variability Scheme (TVS) adapted for the first time to micro-scale. Validated against GOES-16 and Landsat-8 across 5 NYC locations, 2 seasons

Cerquetelli, et al. Sustainable Cities and Society, 2026

Urban storage heat flux · Pedestrian-level monitoring · Land surface temperature

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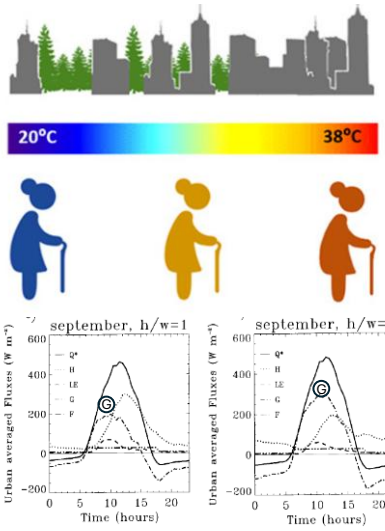
Subsurface Urban Heat Island - Storage (ΔQs)

Why ΔQs Matters for Resilience

- **Mortality increases** by about 4% during heatwaves, rising further with intensity and duration (Anderson & Bell, 2011)
- Mortality risk: each extra day with Tmax > 35 °C is linked to +0.45 deaths/100,000 (general population) and +4.7 deaths/100,000 (≥64 yrs) (Tuholske et al., 2021)
- **Stable nighttime layers** (sustained by urban heat storage) **trap pollutants**, worsening ozone and PM concentrations (Ulpiani, 2020)
- **Amplified multidomain risk**: pollutant concentrations are 20–30% higher in UHI zones than suburban areas, compounding heat stress and air quality impacts (Mandjoupa, 2025)
- **Geometry dependence**: deep canyons (high H/W) trap more radiation and store more heat, reducing turbulent fluxes. G is the counterpart and often used as a proxy for ΔQs, since it represents the ground heat flux at the surface (Masson, 2000)
- **Urban thermal persistence**: cities are not only hotter than rural areas but also stay hot for much longer due to heat storage — up to 10–40% longer in the air and even 200% longer at the surface and subsoil level (Li et al., 2024)

Estimating urban thermal persistence at the scale where people walk



Urban storage heat flux · Pedestrian-level monitoring· Land surface temperature

Cerquetelli, et al. Sustainable Cities and Society, 2026

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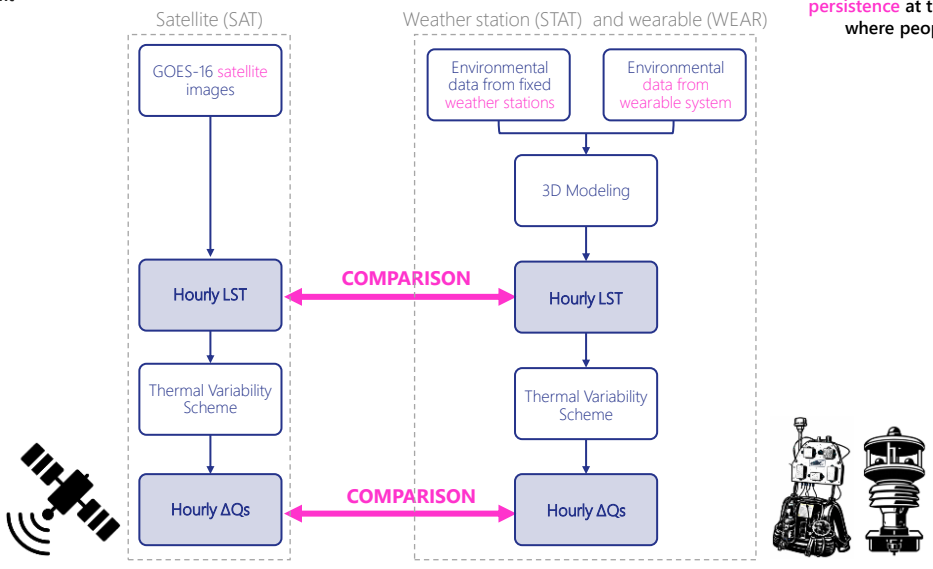
Sensing the Environment

Estimating urban thermal persistence at the scale where people walk



Urban storage heat flux · Pedestrian-level monitoring· Land surface temperature

Cerquetelli, et al. Sustainable Cities and Society, 2026

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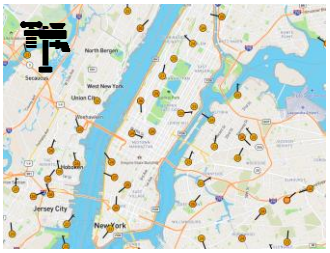
Methodology

Environmental data – fixed weather stations

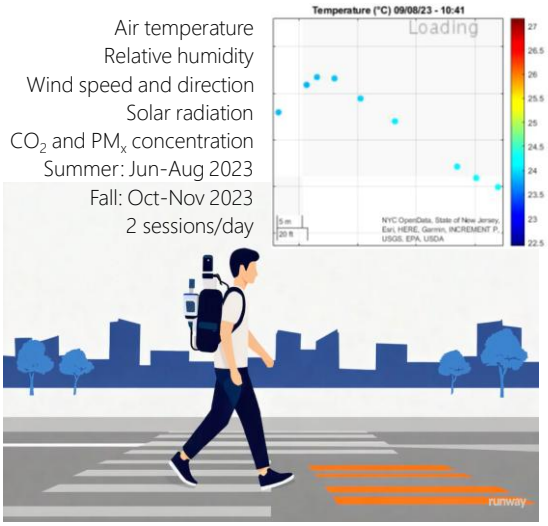


Source: Weather Underground, 2024.

Fixed weather stations:

- Weather Underground - personal weather station network: air temperature, relative humidity, wind speed, atmospheric pressure, precipitation
- 5 min resolution
- Known height above the ground level
- Cross-validation to ensure reliability of data

Air temperature
Relative humidity
Wind speed and direction
Solar radiation
CO_2 and PM_x concentration
Summer: Jun-Aug 2023
Fall: Oct-Nov 2023
2 sessions/day

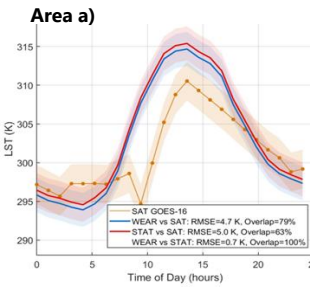


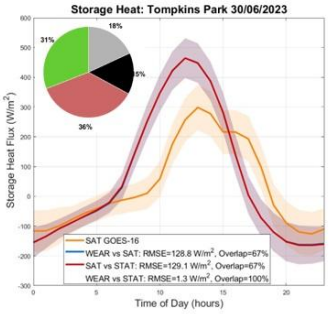
Urban storage heat flux · Pedestrian-level monitoring· Land surface temperature

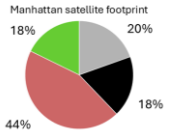
Cerquetelli, et al. Sustainable Cities and Society, 2026

Results

LST - Summer



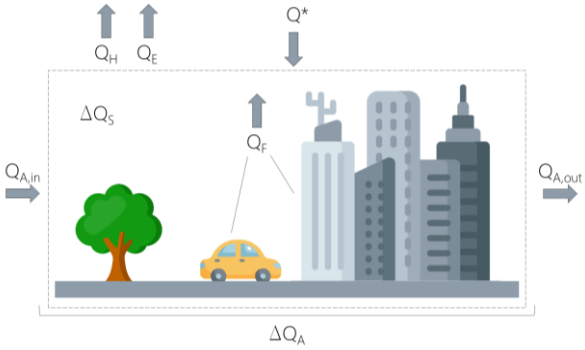




- Coefficient of variation < 2%
- Better correspondence → insight-consistent land cover fractions
  - Impact of satellite anomalies (cloud)
  - August 9th: data from LANDSAT 8 (2nd validation)
- Minimum difference when combining wearable with fixed station data (100% overlap)
- Better correpondence (100% overlap) → more LST data from de satellite + similar land cover fractions + 2nd validation by LANDSAT

- **Accurate LST and ΔQ_s estimates** (CV < 2%), particularly when land cover fractions for satellite image and modeled area are similar → **higher spatial granularity**
- Consistency when using only weather station or weather station + wearable system data as input → valuable **correction tool** for adjusting air temperature daily profiles in locations without nearby fixed stations
- Applications:
  - limited satellite data availability
  - limited weather stations (not in NYC)
  - cloudy days that affect satellite-based LST estimations
  - High surface-thermal variability of urban skins
  - Closer to humans, useful data for human comfort
  - SubSurface Urban Heat Island + Heat Wave Risk Management
- **ΔQ_s – dynamic factor estimation based on dynamic monitoring** → more responsive and tailored mitigation strategies for human centric tackling of urban overheating
- Better building energy performance boundary conditions

Estimating urban thermal persistence at the scale where people walk



Urban storage heat flux · Pedestrian-level monitoring· Land surface temperature

Cerquetelli, et al. Sustainable Cities and Society, 2026

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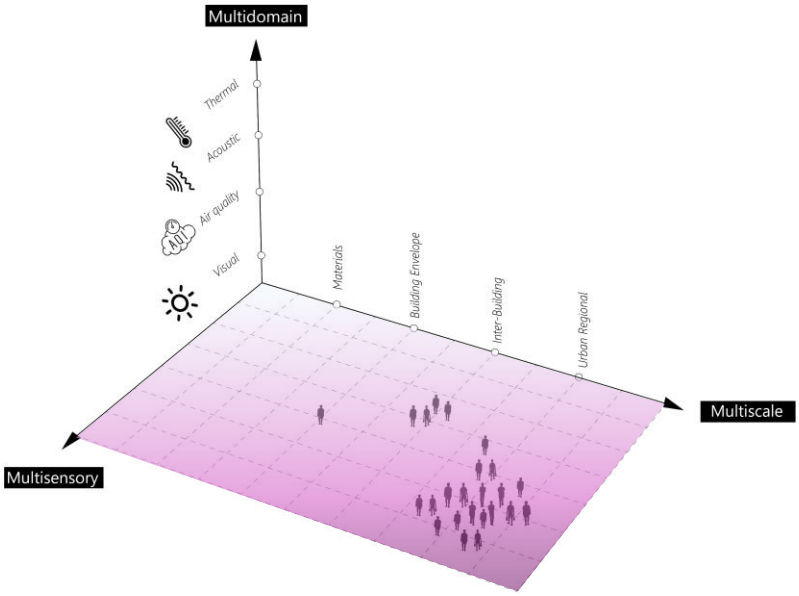
Sensing the Environment



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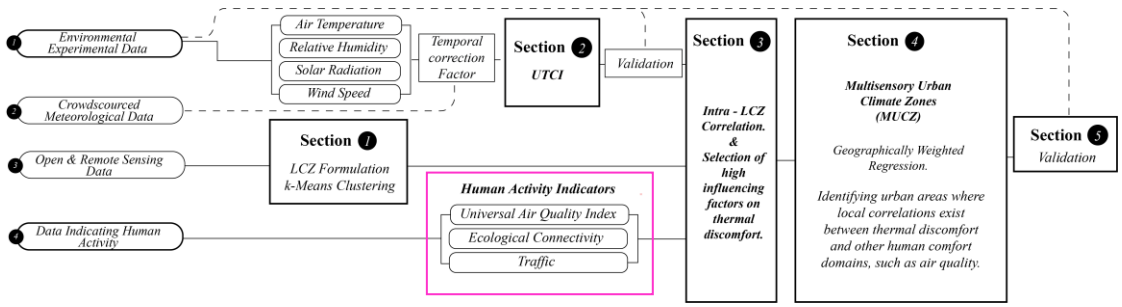
The Gap

Local Climate Zones map static urban morphology — building density, land cover, vegetation. They don't capture anthropogenic heat, air quality, or ecological fragmentation driven by human activity, which can influence comfort as much as form itself.

Our Approach

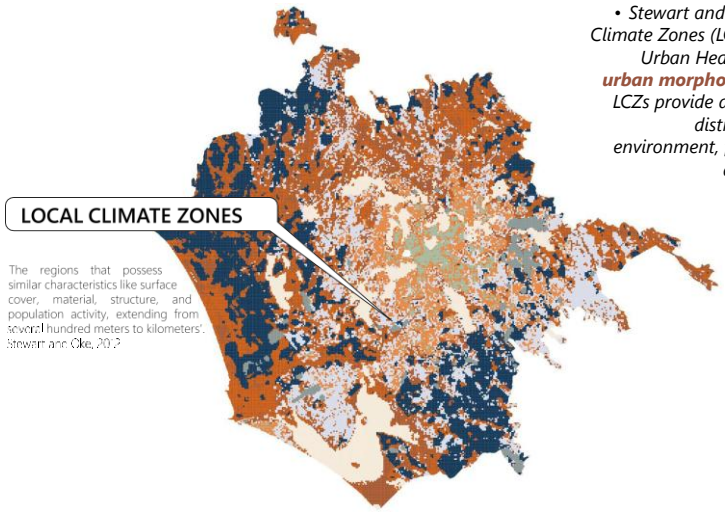
Mobile monitoring transects + crowdsourced weather stations + Google Air Quality API + Circuitscape ecological connectivity → UTCI calculated, then Geographically Weighted Regression maps where thermal stress and air pollution co-occur as Multisensory Urban Climate Zones (MUCZ).

Methodology



Multisensory Urban Climate Zones

Multisensory Urban Climate Zones (MUCZ)



Grapas et., al 2025
Sustainable Cities & Society, Elsevier

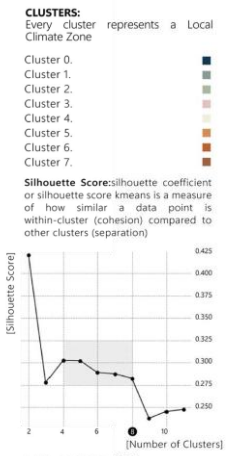
Beyond Urban Morphology

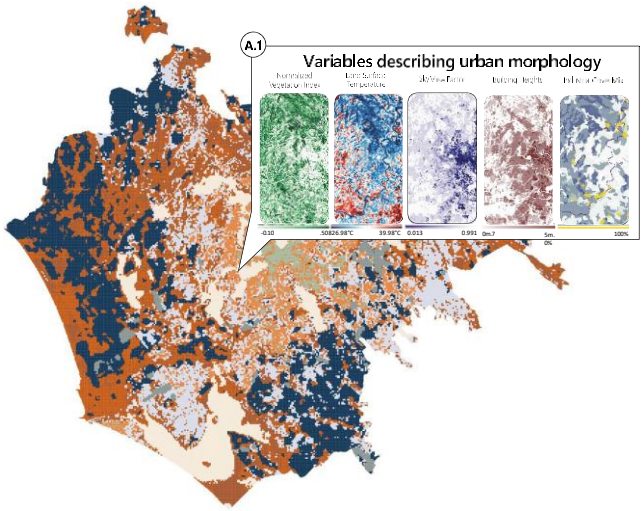
• *Stewart and Oke (2012) proposed a Local Climate Zones (LCZs) classification scheme for Urban Heat Island (UHI) studies, linking* ***urban morphology to thermal properties****. LCZs provide a representation of the spatial distribution of the urban thermal environment, for understanding the factors driving temperature changes.*

Ordinary Kriging · Random Forest · GWR · LISA Spatial Clustering · Circuitscape · UTCI

Multisensory Urban Climate Zones (MUCZ)

Beyond Urban Morphology





- *The study implemented a pixel-level clustering algorithm based on LCZ variables, using LANDSAT 8-9 imagery for NDVI and LST data, building heights from Copernicus, and street networks from OpenStreetMap, with a 200×200m² cell size that balances spatial resolution and practical aggregation.*
- *We employed spatial autocorrelation analysis through, computing spatial lag values using Moran's I to address cluster fragmentation, particularly focusing on LST as a primary variable to handle fragmented zones.*

Grapas et., al 2025
Sustainable Cities & Society, Elsevier

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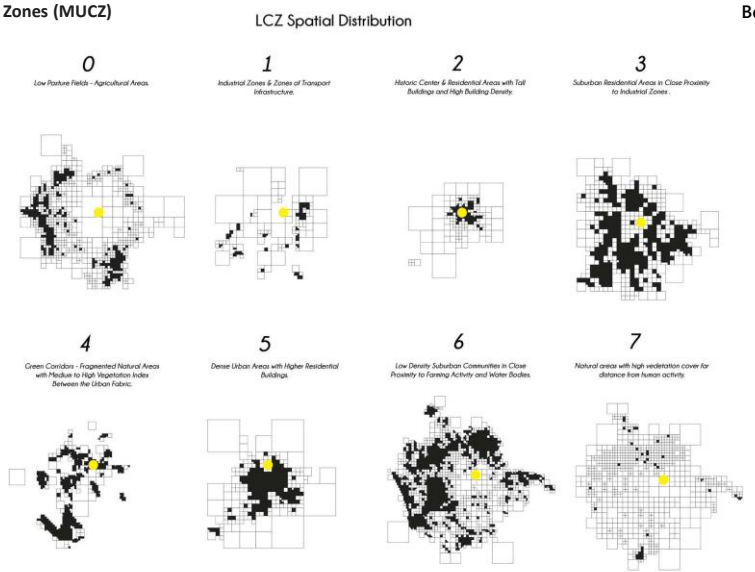
Multisensory Urban Climate Zones (MUCZ)

Beyond Urban Morphology



Grapas et., al 2025
Sustainable Cities & Society, Elsevier

- *8 clusters, exhibiting differences both in terms of spatial distribution*
- *Historic Center*

Ordinary Kriging · Random Forest · GWR · LISA Spatial Clustering · Circuitscape · UTCI

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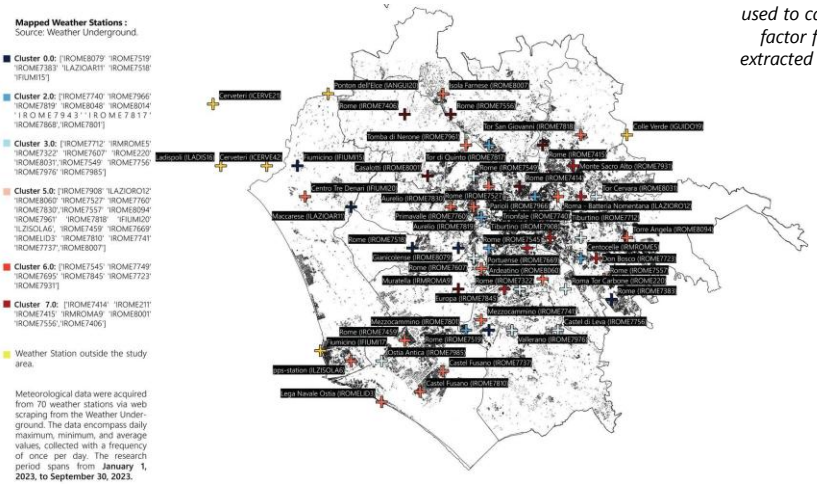
Citizen Science Based Weather Stations
Scraped Meteorological Data

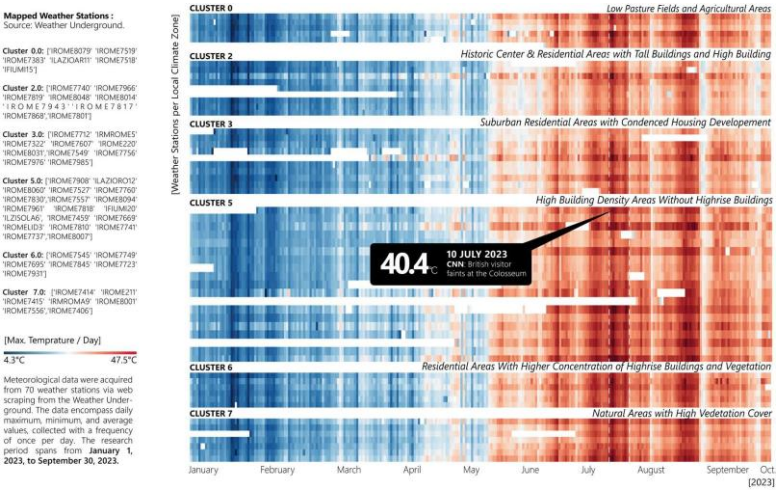


- *Meteorological data from PWS listed on the Weather Underground website were used to calculate a temporal correction factor for the mobile Key parameters extracted included air temperature and relative humidity.*

Ordinary Kriging · Random Forest · GWR · LISA Spatial Clustering · Circuitscape · UTCI

Grapas et., al 2025
Sustainable Cities & Society, Elsevier

Daily Temperature Data / LCZ



- *Notable intra-LCZ Variability in Air Temperature measured by multiple weather stations per each zone.*

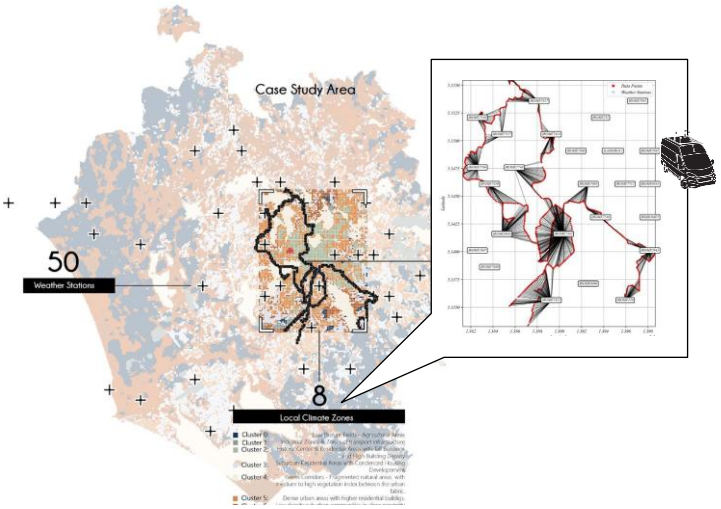
Grapas et., al 2025
Sustainable Cities & Society, Elsevier

Multisensory Urban Climate Zones (MUCZ)

Beyond Urban Morphology

Selecting the Closest Weather Station
(To every monitored data entry)

- *Urban environmental transects were collected during a daily intensive campaign in the summer to assess intra-canyon variability in the urban area. The monitoring equipment consisted of a multi-parametric station mounted on a van. The monitoring route was designed to pass through multiple Local Climate Zones (LCZs) and areas with Personal Weather Stations (PWS), providing a temporal reference for environmental parameters.*



Grapas et., al 2025
Sustainable Cities & Society, Elsevier

Ordinary Kriging · Random Forest · GWR · LISA Spatial Clustering · Circuitscape · UTCI

Multisensory Urban Climate Zones (MUCZ)

Beyond Urban Morphology

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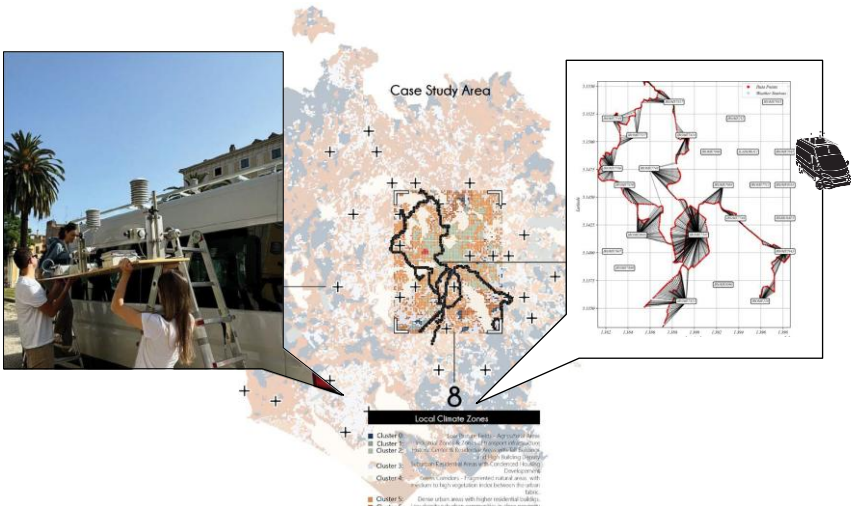


Grapas et., al 2025
Sustainable Cities & Society, Elsevier

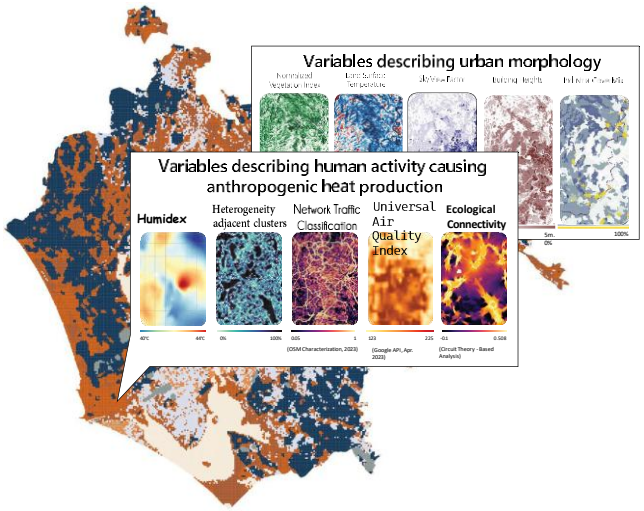
Ordinary Kriging · Random Forest · GWR · LISA Spatial Clustering · Circuitscape · UTCI

Local Climate & Human Activity

Indicators of Human Activity indicating anthropogenic Heat Production

Non-static parameters analysis essential to fully capture dynamic thermal discomfort factors.

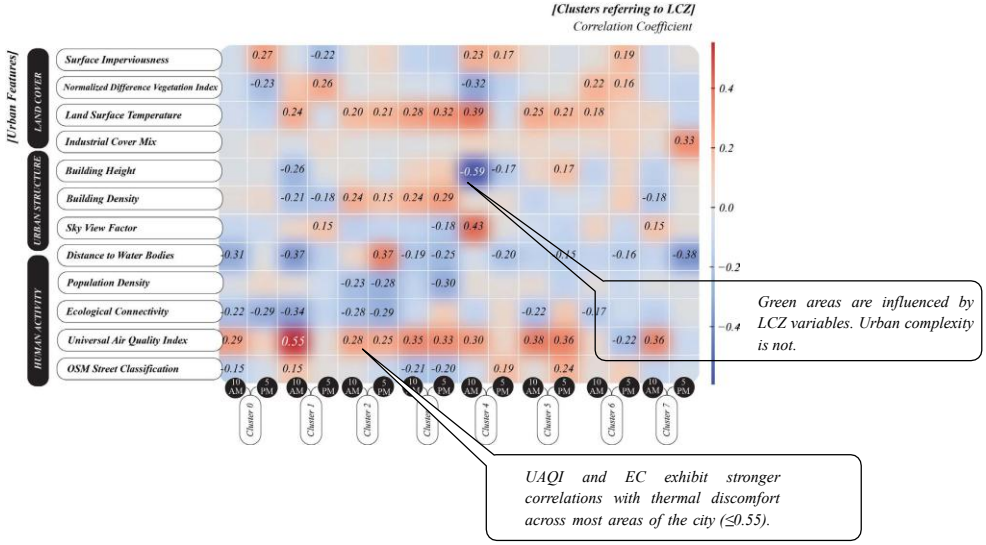
Additional datasets included Universal Air Quality Index (using Google API for pollutants like NO2, PM10, O3, and PM2.5) and OSM street network classifications as indicators of sound pollution.



Grapas et., al 2025
Sustainable Cities & Society, Elsevier

LCZ-Based Correlation Analysis

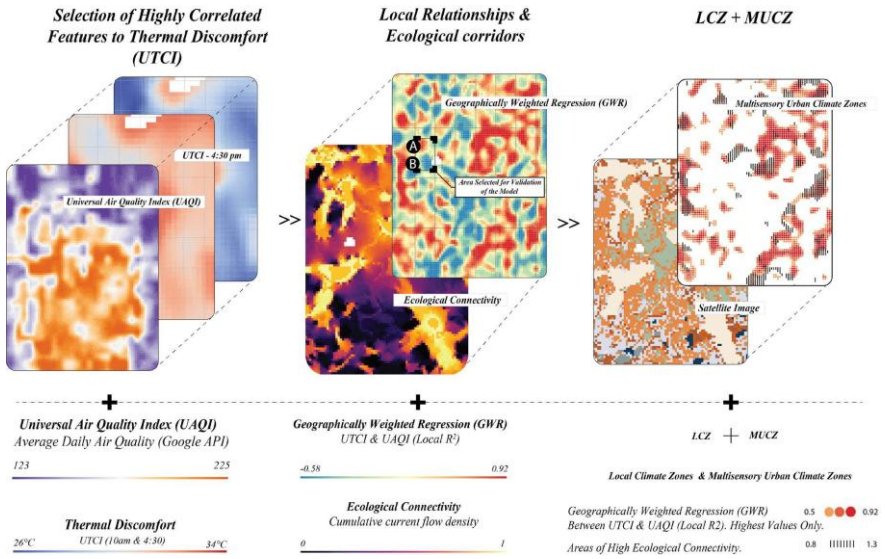
- *Human activity significantly impacts thermal discomfort across Rome, with air quality (UAQI) consistently showing strong positive **correlations with UTCI values**.*
- *Natural features like water bodies and vegetation (NDVI) seem to mitigate thermal stress, though their effectiveness varies by zone.*
- *Ecological connectivity exhibits promising negative correlations to thermal discomfort in dense urban areas but has less*



Grapas et., al 2025
Sustainable Cities & Society, Elsevier

Multisensory Urban Climate Zones (MUCZ)

Beyond Urban Morphology



From LCZ to Multisensory Urban Climate Zones

↓

Identification of human-centric climatopes to promptly plan

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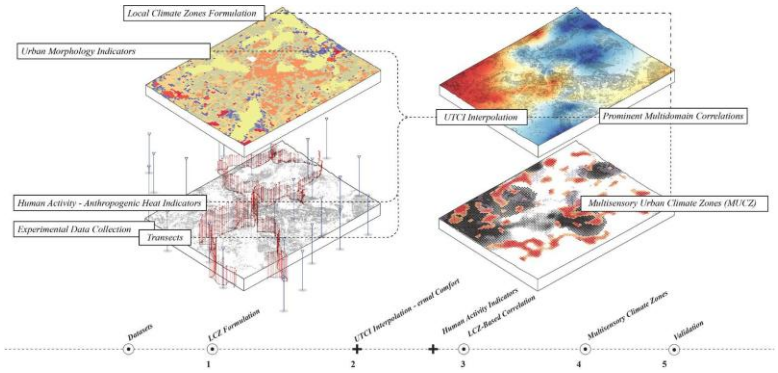
Multisensory Urban Climate Zones (MUCZ)

Beyond Urban Morphology



- **Strong correlations exist between UTCI, UAQI, and Ecological Connectivity, highlighting the need for integrated approaches to urban environmental assessment.**
- **While city structure is difficult to change, human activity is adaptable, suggesting that dynamic, behavior-sensitive interventions offer practical pathways for improving urban comfort.**
- **Identification of human-centric climatopes to promptly plan**
- **Risk and vulnerability mitigation actions**
- **Building energy dynamic boundaries – overheating resilience**

Grapas et., al 2025
Sustainable Cities & Society, Elsevier

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Urban Chronotypes

As human perception evolves over time, microclimate evaluation must be equally dynamic.

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Urban Chronotypes

Sensing the environment is not the same as responding to it

The Behavioural Gap

Sensing the environment is not the same as responding to it. Even when people physiologically detect thermal stress, they may not take protective action. What blocks the translation from sensing to behaviour?

Our Approach

Random Forest and Granger causality map the full stimulus → physiology → behaviour pathway, revealing that perceived safety (not thermal exposure) determines whether sensing becomes action.

Random Forest · Granger Causality · Wearable Sensors · Urban Chronotypes

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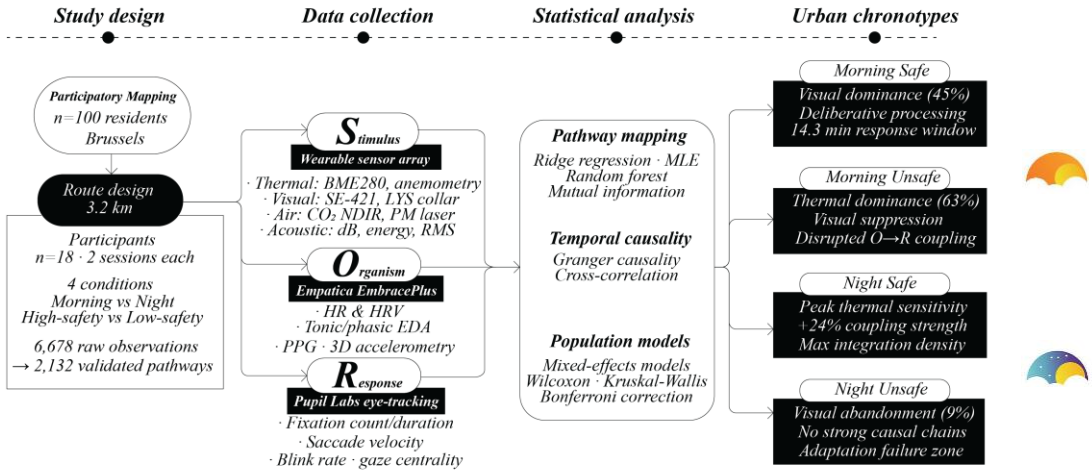
Urban Chronotypes

Sensing the environment is not the same as responding to it

Methods



Grapas et., al 2026
Urban Climate, Elsevier

Random Forest · Granger Causality · Wearable Sensors · Urban Chronotypes

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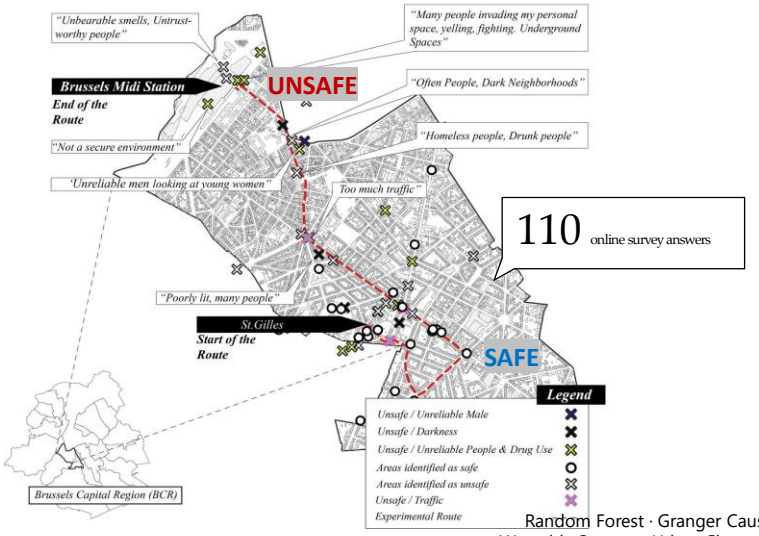
Phase I - Experimental Route Design

We asked **110 residents** of the case study area **to pinpoint where they feel unsafe** in their neighborhood. Based on their answer **we designed our experimental data collection route spanning from safe to unsafe areas in Brussels.**



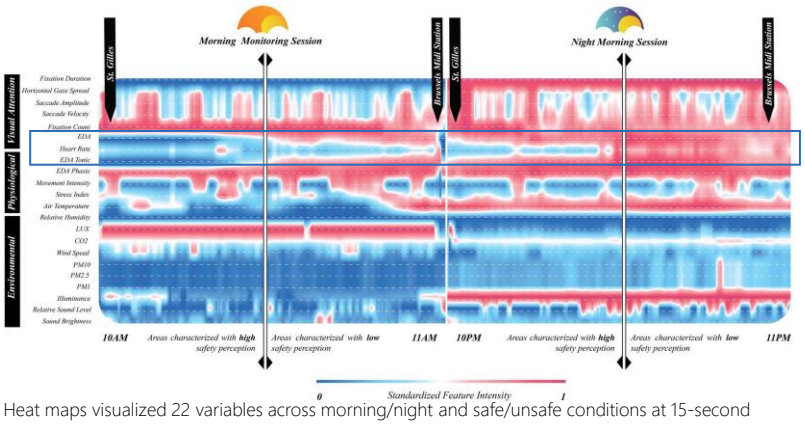
SOR Framework

In the **SOR (Stimulus-Organism-Response) system**, *the organism response refers to the internal state of an individual, which is influenced by external stimuli and, in turn, triggers an external behavioral response*

S	O	R
Stimuli	***Organism***	***Response***
Environmental Inputs	*Physiological Processing*	*Behavioural Output*
• *Audio levels* • *Temperature* • *Light intensity* • *Light Color* • *CO_2 levels* • *PM Concentration* •*Sound Level* • *Sound frequencies*	• *Heart rate* • *EDA (tonic/phasic)*	• *Eye movements* • *Gaze patterns* • *Fixation duration* • *Attention shifts*

Grapas et., al 2026 Urban Climate, Elsevier

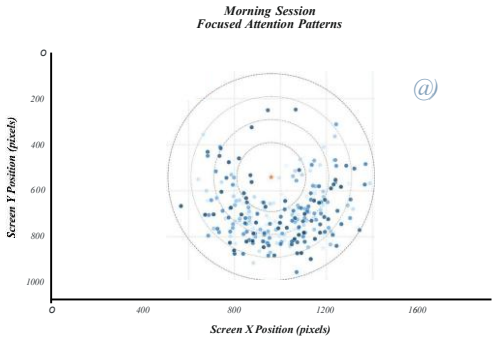
Monitoring - Multi-sensory Experience



- Heat maps visualized 22 variables across morning/night and safe/unsafe conditions at 15-second resolution, revealing marked diurnal shifts: CO_2 exposure increased substantially at night (0.27→0.78, 0.33→0.71), visual engagement dropped (fixation 0.95→0.41), while phasic arousal decreased (EDA 0.88→0.48).

Grapas et., al 2026
Urban Climate, Elsevier

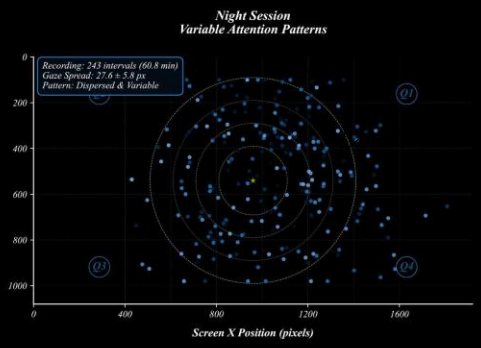
During the day:



Grapas et., al 2026
Urban Climate, Elsevier

Random Forest · Granger Causality · Wearable Sensors · Urban Chronotypes

During the night:



Saccade velocity increases by 15.4% (faster eye movements). Gaze becomes more dispersed.

Statistical Analysis - Proving Causations

Stimuli ⟶ **O**rganism ⟶ **R**esponse

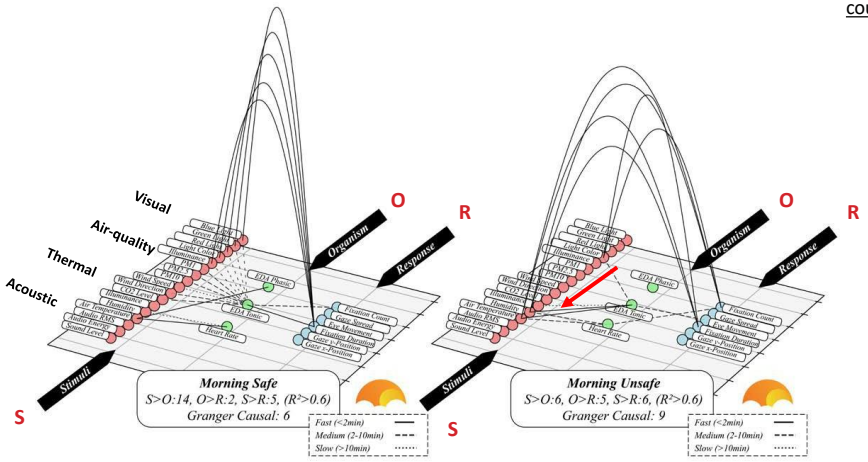
Step 1 - Map the Pathways	**Step 2 - Validate Pathway Strength**	**Step 3 – Account for Individual Differences**	**Step 4 - Correct for Multiple Comparisons**
Ridge Regression & **Granger Causality Tests**	Bootstrap Resampling & Random Forest	Mixed-Effects Models & non-parametric tests (Kruskal-Wallis, Wilcoxon)	False Discovery Rate (FDR)

We retained 2.132 complete causal chains. Each one confirming a sequence where environment predicts physiology and physiology predicts behavior.

Grapas et., al 2026
Urban Climate, Elsevier

Morning Safe
-<u>Visual processing dominates</u> (45% of pathways)
-Strong environmental sensitivity.

Morning Unsafe
-Sensory reorganization: thermal pathways surge to 63% (vs. 45% visual in safe contexts)
-Environmental sensitivity remains strong, but <u>behavioral coupling deteriorates</u>



Grapas et., al 2026
Urban Climate, Elsevier

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Urban Chronotypes

Sensing the environment is not the same as responding to it

Unsafe contexts shift perception to thermal dominance (63% of pathways) **yet block behavioral** adaptation (O→R coupling: +0.189 safe vs. -0.037 unsafe, p=0.025)**.**

Installing cooling infrastructure in unsafe spaces, will simply create abandoned infrastructure. But for sure these are the places where we must put it.

Grapas et., al 2026
Urban Climate, Elsevier

Random Forest · Granger Causality · Wearable Sensors · Urban Chronotypes

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Unmanned Crowdscourced Data

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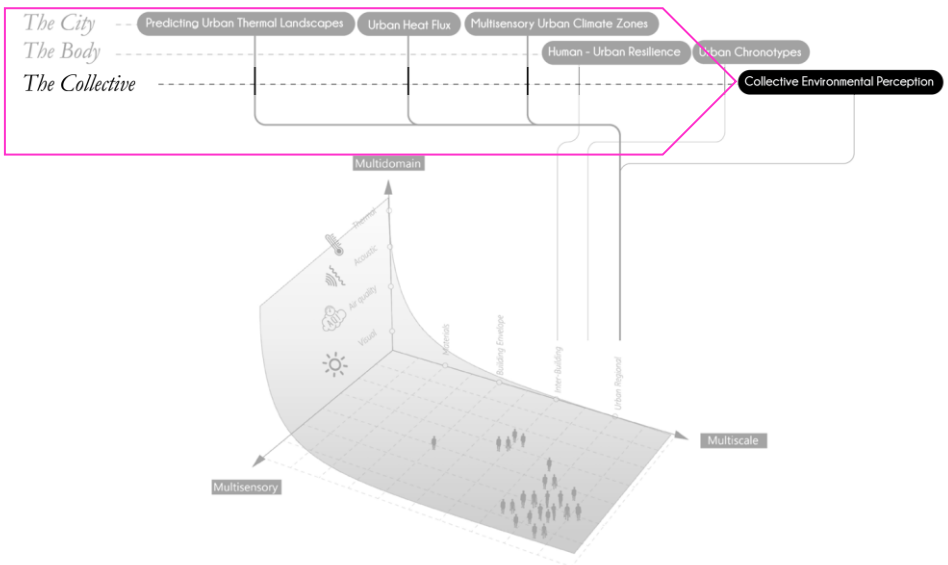
Human Dynamics Observatory.



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The Gap

Traditional comfort surveys require significant resources and tend to target homogeneous samples. Environmental monitoring captures physical conditions but cannot capture authentic community perception — what people actually notice, value, and feel in outdoor spaces.

Our Approach

Social networks comments - Maps reviews from 12 NYC parks (9,558 comments) analyzed via text mining, word frequency, and Afinn sentiment scoring. Lexicons for thermal, acoustic, visual, and air quality domains filter environmental perception comments. Wearable PET monitoring provides complementary objective data and validates community-perceived conditions.

Crowdsourced reviews · Lexicon· Multi-domain Comfort · Afinn sentiment scoring

MULTI-DOMAIN COMFORT OUTDOORS
CROWDSOURCED DATA TO ASSESS HUMAN COMFORT

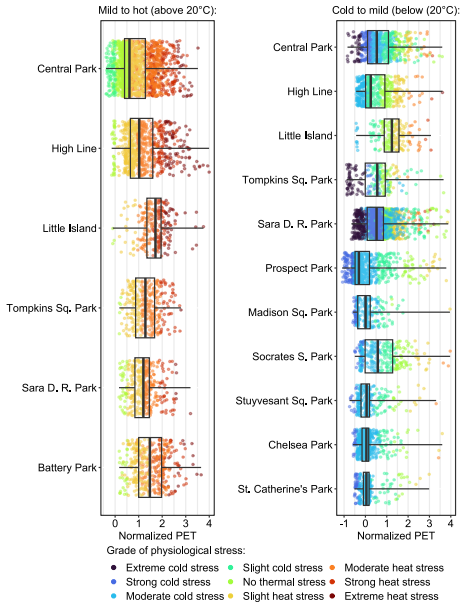
Motivation:
Is crowdsourced data informative regarding people's environmental perception?
What are the environmental factors people care/perceive most?

Crowdsourced reviews: Foster community engagement.
Promote a sense of shared responsibility and collective action.

Why Google Maps? Sharing experience. Providing feedback. Expressing opinions.

Specificity of **mitigation potential park by park (12 parks in NYC)** according to urban design and contextual variables

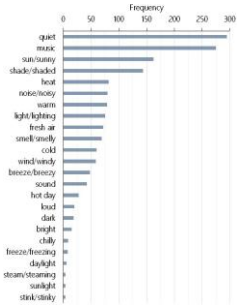
(**environmental data framework**)



Cureau, Bou Zeid, Pigliautile, Pisello, Science of the total environment 2024

MULTI-DOMAIN COMFORT OUTDOORS
CROWDSOURCED DATA TO ASSESS HUMAN COMFORT

***1,358* COMMENTS RELATED TO ENVIRONMENTAL QUALITY – 14% of total dealing with environmental impressions, 3% with wellbeing**

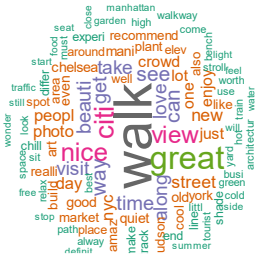


1.ACOUSTICS: quiet, music
Overall positive ratings.

2. THERMAL: sun/sunny, shade/shaded, heat, warm
Likely well-perceived: parks are more attended in the hot periods, and people recognize shading from greenery as a positive aspect.

VISUAL and AIR QUALITY domains are less mentioned. Neutral awareness regarding the visual domain, varied perceptions about air quality (e.g., fresh air and smell/smelly have the same frequency).

Tompkins Park

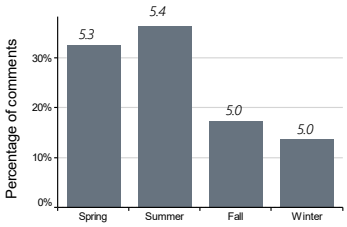


The High Line

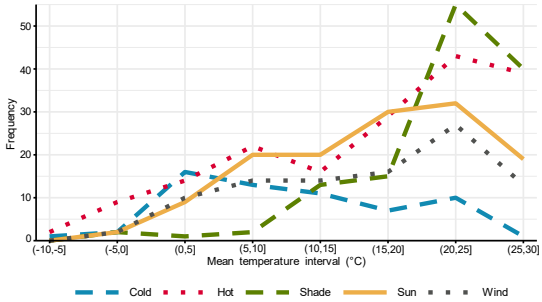
Crowdsourced reviews · Lexicon· Multi-domain Comfort · Afinn sentiment scoring

MULTI-DOMAIN COMFORT OUTDOORS
CROWDSOURCED DATA TO ASSESS HUMAN COMFORT

COMMENTS RELATED TO ENVIRONMENTAL QUALITY – FREQUENCY OF THERMAL-RELATED TERMS x DAILY AVERAGE TEMPERATURE WHEN THE COMMENT WAS WRITTEN



SENTIMENT ANALYSIS (AFINN METHOD)



- **Hot:** hot day, heat, warm, scorch, muggy
- **Cold:** cold, chilly, freeze, freezing
- **Wind:** wind, windy, breeze, breezy

Since AR5, the value of **cross-sectoral collaboration** to advance sustainable development has been more widely recognised, but despite acknowledgement of the importance of health adaptation as a key component, action has been slow (high confidence). IPCC 6th AR

Data

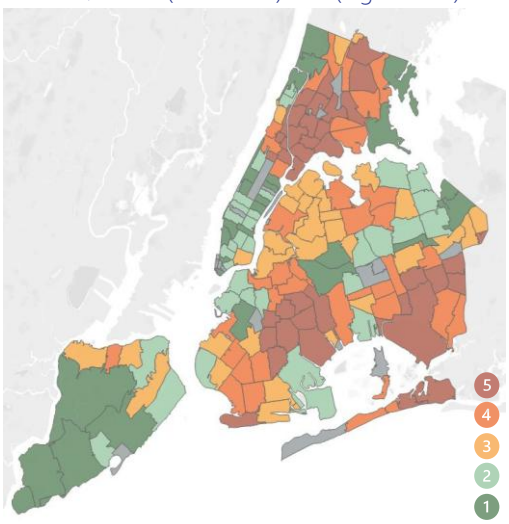
NYC OpenData

NYC Parks

Open data + Official website:

- Number of public cooling features: **spray showers, drinking fountains, outdoor pools**
- Number of **trees**
- **Heat vulnerability index (HVI):** surface temperature, household income, percentage of vegetative cover, access to home air conditioning, and percentage of residents who are Non-Hispanic Black.
- n = **968 parks**

HVI: from 1 (lowest risk) to 5 (highest risk)



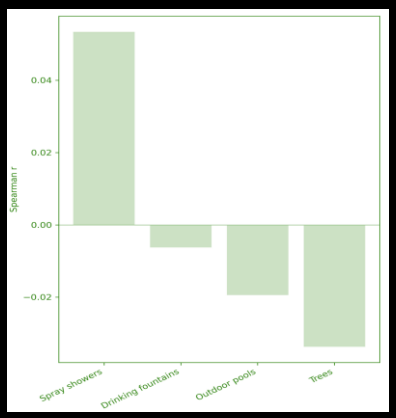
Crowdsourced reviews · Lexicon· Multi-domain Comfort · Afinn sentiment scoring

Crowdsourced Data

Collective Environmental Perception

Number of features vs. HVI

- HVI by ZIP code is too broad → need for identifying hyperlocal vulnerabilities
- Spearman's r [-1;+1] is very close to zero for all features: very weak or no relationship between number of features and HVI → weak mitigation effect
- Features are not located in areas more vulnerable to heat: urban design needs to be consistent with needs and inequalities
- Increasing the number of features is correlated with more positive comments.



Sentiment	Compound	0.12	0.43*	0.17*	0.50*
	Positive	0.10	0.42*	0.13	0.52*
	Neutral	0.10	0.33*	0.12	0.45*
	Negative	0.07	0.09	0.01	0.11
		Spray showers	Drinking fountains	Outdoor pools	Trees
	Number of features (how many features)				

Crowdsourced reviews · Lexicon· Multi-domain Comfort · Afinn sentiment scoring

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From Urgent to Timely Actions through Transformative Approaches (IPCC Sixth Assessment Report, AR6)

From materials to urban scales, with human perception as a driver for vulnerability assessment in the short and long term (cumulative exposure risks).

Humans and/within buildings knowledge to exploit in building-to-urban design for overheating resilience.

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Identification of multidomain well-being as a key for understanding and enhancing adaptation and mitigation to urban overheating and other stressors.

A participatory path: from awareness to engagement, toward the **salutogenic city** — one that actively promotes health, resilience, and shared environmental responsibility.

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