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Mobility, Public Space and Spatial Justice

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Living and walking in cities: Mobility, Public Space and Spatial Justice

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Walking in the heat. A pedestrian-centric heat exposure modeling framework

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Abstract
Climate change is increasing the frequency and intensity of extreme heat events in cities, creating health risks and mobility issues while navigating urban areas outdoors. To identify where and when pedestrians face the highest heat exposure levels, we developed a Heat Exposure Index (HEI) that combines high-resolution microclimate modeling with pedestrian activity along sidewalks. HEI is based on two components, namely heat hazard, calculated using the Universal Thermal Climate Index (UTCI), and pedestrian exposure, estimated through a probabilistic routing model that simulates walking trips between selected origin and destination points. Pedestrian volumes are calibrated using observed data and examined for three time periods, i.e., morning peak, midday, and evening peak. The method is applied in central Los Angeles during a heatwave, revealing significant spatial and temporal differences in sidewalk-level heat exposure. Higher exposure is observed near transit stations and commercial destinations, where elevated UTCI values overlap with high pedestrian activity, disproportionately affecting transit-dependent populations. By combining microclimate conditions with pedestrian mobility patterns, the HEI allows fine-grained analysis of heat exposure. Ultimately, this research offers significant insights for heat-resilient planning strategies that aim to protect pedestrians outdoors and mitigate uneven heat risks in cities.

Keywords
Urban heat exposure; Pedestrian mobility; Climate-resilient cities

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1. Introduction

Climate change and global warming are increasing the frequency and severity of extreme heat events, with cities facing particularly high risks due to the Urban Heat Island (UHI) phenomenon triggered by high amount of heat-absorbing surfaces, such as impervious pavements, and a lack of greenery, which together can raise urban temperatures much higher than in surrounding rural and natural areas (Oke et al., 2017). This effect does more than just raise temperatures; it also exacerbates air pollution (Sarrat et al., 2006) and increases heat-related health risks (Heaviside et al., 2017). Indeed, the UHI phenomenon has increasingly been recognized as a spatial planning challenge, with a growing body of research systematically examining how land-use configurations and ecosystem services can contribute to local climate regulation in urban areas (Isola et al., 2023).

Heatwaves are no longer just rare anomalies but have become recurring events that represent a major environmental challenge (Papa et al., 2015), directly linked to higher mortality rates and heatstroke, and they often worsen chronic health conditions for vulnerable groups like the elderly, children, and low-income communities (Amorim-Maia et al., 2022; Åström et al., 2011; Ebi et al., 2021; Heaviside et al., 2017; Hsu et al., 2021). Extreme heat is also reshaping how people move around the city. It often discourages walking and cycling, essential modes for sustainable mobility, as many people may choose to use air-conditioned vehicles during heatwaves (Gebhart K & Noland, 2014; Wu & Liao, 2020). This shift is concerning because it may perpetuate a dependency on private cars, thereby further exacerbating the climate crisis. For pedestrians, in particular, health risks are significant as they are directly exposed to the heat while navigating the outdoor urban environment. For those without access to a private car, walking is often a necessity rather than a choice, which can turn a daily commute into a health hazard during extreme heat events. However, urban planning and transport policies have historically focused more on vehicle mobility than on pedestrians, which has left many routes thermally uncomfortable and poorly connected (Karner et al., 2015; Sevtsuk et al., 2021). Recent contributions have begun to address this gap by integrating walkability assessment with climate adaptation goals, evaluating how urban interventions can reshape pedestrian accessibility under a people-and-climate oriented perspective (Carra et al., 2022).

Our work builds on the IPCC's risk framework (Pachauri, 2016) to explore an accurate method for estimating heat exposure for people walking in the city. But, instead of relying on general temperature and humidity data, we use the Universal Thermal Climate Index (UTCI), an index much more effective for pedestrian studies because it accounts for the actual microclimate conditions and feeling, as it considers solar radiation, shade, and urban geometry (Harlan et al., 2006; Melnikov et al., 2022).

On the other hand, we incorporate human mobility patterns to identify the specific times of the day and locations where pedestrians are most exposed to heat. In this regard, we improved the resolution of people exposure in two main ways. We model pedestrian trips between specific building locations based on a probabilistic routing model, calibrated with real-world observation data, which captures how people actually choose their paths, rather than assuming they take the shortest route (Sevtsuk & Kalvo, 2024). We also moved away from standard road centerlines, using a network based on actual sidewalks and crosswalks to capture micro-scale differences (e.g., shading, vegetation) between street sides (Basu & Sevtsuk, 2022; Colaninno et al., 2024; Sevtsuk et al., 2021).

Finally, we calculated both the heat hazard (UTCI) and pedestrian volumes (exposure) for three different times of the day, i.e., morning, midday, and evening, acknowledging diurnal variations in microclimates and mobility. We then applied the framework in central Los Angeles to produce a sidewalk-level heat exposure map identifying high-exposure corridors where intense pedestrian activity coincides with elevated UTCI. These corridors represent priority locations for targeted interventions such as shade structures and street trees. More broadly, we argue that integrating mobility and microclimate data gives planners a practical basis for prioritizing climate adaptation where pedestrians face the greatest heat risk.

2. Materials and methods

The designed method quantifies heat exposure levels specifically at the sidewalk scale. To illustrate our method, we first introduce the case study, the datasets, and tools used for analysis. Hence, we explain the steps taken to turn high-resolution microclimate data into the UTCI, which serves as our measure for heat hazard, and the approach used to model the pedestrian exposure, which relies on a probabilistic routing model calibrated against real volume counts at three different times of the day. These elements come together in the Heat Exposure Index (HEI), which combines hazard (UTCI) with pedestrian flows (exposure) to provide a detailed, time-sensitive measure of heat exposure across the study area.

2.1 Study area

The analysis focuses on an area of 6.6 km × 6.6 km in central Los Angeles, California, placed around Exposition Boulevard and Vermont Street (Fig.1), including downtown, South-Central LA, and Skid Row. To avoid edge effects in calculations, we applied an 800-meter walking buffer, which narrowed the final results to a 5 km × 5 km core area. The study area is characterized by a mix of residential and commercial uses, public parks, the University of Southern California campus, and the site for the future 2028 Olympic Village. There are significant socioeconomic differences across the neighborhoods in the area, but they all share a common mobility challenge: even with new transit investments, such as the Expo Line and Downtown Connector, the low-density urban layout implies that people still must walk long distances to reach a transit station, causing urban heat to be a critical concern for public transit users. We examined a 7-day heatwave occurred between September 3rd and 9th, 2022, with daily maximum temperatures higher than 90% of historical values recorded between 1980 and 2022. The prolonged heat event provided a perfect case study to examine how heat risk impacts a city transitioning away from car dependency toward more sustainable walking and transit options.

Fig.1 Visualization of the Los Angeles study area (Expo neighborhood) with a high-resolution close-up depicting sidewalk-scale heat hazard (Source: Colaninno et al., 2024)

2.2 Employed data

The study integrates diverse datasets to model UTCI and pedestrian mobility. The ERA5 high-resolution climate dataset (Copernicus Climate Change Service/ECMWF) combines observational and modeled data at hourly resolution (Hersbach et al., 2020; Jiao et al., 2021; McNicholl et al., 2021). A LiDAR-derived Digital Surface Model (DSM), 2016 Land Use Land Cover (LULC) data, and meteorological inputs were used to calculate mean radiant temperature (T_{mrt}) using the SOLWEIG model, and UTCI (Fiala et al., 2012).

Pedestrian mobility modeling employed a pedestrian network generated using sidewalk polygons in combination with the Tile2Net framework (Hosseini et al. 2023), replacing conventional street centerline networks. This approach accounts for actual pedestrian infrastructure, including sidewalks and crosswalks. Origin and destination points were derived from the Los Angeles GeoHub and GTFS data. The 2020 U.S. Census block-group population counts were spatially disaggregated to residential buildings based on proportional building volumes.

Pedestrian volumes were calibrated using StreetLight data (Streetlight, 2025a, 2025b), which estimates daily walking activity across three periods: morning peak (6:00-10:00 A.M.), midday (10:00 A.M.-3:00 P.M.), and evening peak (3:00-7:00 P.M.).

2.3 Heat hazard: the universal thermal climate index

Conventional temperature and humidity metrics fail to adequately capture heat hazards in urban environments. In this study, we employ UTCI, a bioclimatic measure integrating air temperature, wind speed, humidity, and mean radiant temperature to assess physiological thermal stress (Fiala et al., 2012; Jendritzky et al., 2012). Mean radiant temperature, in particular, is widely recognized to be vital as it accounts for solar short- and long-wave radiation. Studies show that when T_{mrt} exceeds 58.8°C, mortality risks increase by 5% for middle-aged adults and up to 10% for those over 80 (Thorsson et al., 2014). For this reason, we use UTCI, a more informative metric than other standard heat indicators, which categorizes thermal stress across a broad spectrum, from extreme heat (above +46°C) to extreme cold (below -40°C), with neutral conditions typically falling between +9°C and +26°C (Di Napoli et al., 2021).

To get a detailed picture of the microclimate, we calculated the UTCI at a 1-meter spatial resolution. For this purpose, we first estimated the T_{mrt} using the SOLWEIG model via the UMEP plugin in QGIS, a widely recognized tool that accurately captures the effects of urban geometry, surface materials, and trees on radiation (Lindberg et al., 2008; Thorsson et al., 2017). Hence, we used a sixth-order polynomial regression in Python to calculate the final UTCI figures, a standard and efficient method for approximating full UTCI outputs. Hourly UTCI maps were generated during daylight hours (6:00 A.M.- 7:00 P.M.) for a 7-day heatwave in Los Angeles (September 3-9, 2022) and grouped into three time periods, i.e., the morning peak (6:00–10:00 A.M.), midday (10:00 A.M.- 3:00 P.M.), and the evening peak (3:00-7:00 P.M.). For each time slot, we calculated mean and 95th percentile UTCI to characterize typical and extreme heat conditions, then normalized both to a 0-1 scale and multiplied them to produce hazard maps (Colaninno et al., 2024).

2.4 Heat exposure: pedestrian volume and models calibration

Heat exposure occurs when individuals, pedestrians in our case, encounter extreme temperatures that pose a threat to their health and comfort while outdoors. In order to account for the pedestrians' exposure, we modeled walking trips originating from home as origin points to selected key destinations, including parks, workplaces, schools, transit stops, and local amenities. We contend that such locations are vital services that people need to reach safely on foot, hence, focusing on these points supports a key shift in urban planning from simply encouraging movement to ensuring that essential services are actually accessible. Walking trips were modeled using the Urban Network Analysis (UNA) framework through the Madina Python library

(Alhassan & Sevtsuk, 2024; Sevtsuk & Mekonnen, 2012), while we utilize specific address-level points for origins and destinations, rather than aggregated data. Additionally, the model relies on a detailed pedestrian network of actual sidewalks and crosswalks, a level of detail necessary to capture the small-scale differences in the urban environment that significantly influence walking experience. To estimate walking volumes, the model assigns weights to each origin point (homes) based on census-derived resident counts for each building. Trips are then routed to destinations within 800 meters distance using a probabilistic approach that also accounts for behavioral considerations, including detours (up to 20% longer than the shortest path) and a gravity model to reflect the decline in walking as distance increases. Hence, the algorithm estimates pedestrian volumes for each sidewalk segment across the entire network. To improve model accuracy and account for changes over time, we have calibrated the estimated pedestrian volumes using StreetLight data as a proxy for observed counts, leveraging its pedestrian activity index across different time periods. For calibration, we used a multiple linear regression (MLR) model in which the StreetLight index is the dependent variable and the previously computed expected volumes for all origin-destination (O-D) pairs on each network segment are the explanatory variables. Calibration is performed for three weekday periods, i.e., morning peak (AM), midday (mDAY), and evening peak (PM), directly aligned with the heat hazard maps. The outputs enable a detailed spatiotemporal assessment of the actual heat exposure pedestrians face as they move between key destinations. The models' results, as presented in Tab.1, indicate that not all trips are statistically significant in relation to observed pedestrian volumes, suggesting these trips are likely to occur less frequently or contribute minimally to total volumes. Additionally, some O-D pairs resulted in negative coefficients, which were discarded, as they denote counterintuitive effects on pedestrian activity. The table summarizes MLR results with coefficients and standard errors for pedestrian volumes across the three time periods, i.e., AM, mDAY, and PM.

	Morning Peak - AM 6 A.M.–10 A.M.		**Midday - mDAY** 10 A.M.–3 P.M.		**Evening Peak - PM** 3 P.M.–7 P.M.	
O-D	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**
Intercept	129.52	4.93	199.41	8.16	192.90	8.26
Home to Amenities	0.05	0.06	0.03	0.12	0.11	0.12
Home to Jobs	-0.05	0.03	-0.04	0.05	-0.10	0.06
Home to Park	-0.01	0.04	-0.01	0.07	0.01	0.07
Home to School	-0.07**	0.03	-0.07	0.04	-0.07	0.05
Home to Bus	**0.20****	0.06	**0.22****	0.10	**0.35****	0.10
Home to Subway	**0.37****	0.08	**0.44****	0.14	**0.42****	0.15
Jobs to Home	-0.16	0.08	-0.11	0.16	-0.08	0.19
Jobs to Amenities	-0.26**	0.09	-0.49**	0.17	-0.43**	0.15
Jobs to Park	-0.02	0.09	-0.06	0.13	-0.08	0.14
Jobs to Bus	**0.58****	0.13	**0.80****	0.22	**0.71****	0.21
Jobs to Subway	-0.15	0.27	0.01	0.49	-0.09	0.47
Amenities to Home	-0.25**	0.10	-0.30	0.17	-0.20	0.18
Amenities to Amenities	0.09	0.12	0.14	0.20	0.08	0.21
Amenities to Bus	**0.45****	0.16	**1.02****	0.28	**0.94****	0.28
Amenities to Subway	**0.48****	0.22	**0.89****	0.39	**1.01****	0.44
School to Home	0.02	0.06	0.02	0.11	-0.07	0.11
School to Bus	0.17	0.09	0.19	0.13	0.26	0.14
School to Subway	-0.34	0.17	-0.42	0.26	-0.45	0.28
Sample Size	2248		2232		2239	
Adj. R-squared	0.207		0.236		0.244	

** Denotes statistical significance at 95% confidence level ($p < .05$)

Standard Errors are heteroscedastic robust (HC3)

Tab.1 Calibration performance of the pedestrian volume model across three diurnal periods

Only O-D trips with positive and statistically significant model coefficients ($p < 0.05$) were retained and used to adjust the expected pedestrian volumes across the network, resulting in calibrated, time-specific volume estimates corresponding to the three heat exposure periods considered.
Walking trips to bus stops and subway stations consistently show positive and significant effects regardless of the time of day, while the impact of trips to parks, schools, and local amenities is generally weaker, negative, or statistically non-significant. Ultimately, results outline actual daily variations in pedestrian activity patterns while emphasizing the role of transit-related destinations as primary drivers of pedestrian mobility in this area.

2.5 Heat exposure index - HEI

To outline sidewalk segments where high pedestrian activity overlaps with hazardous thermal conditions, we developed the Heat Exposure Index (HEI), which combines segment-level heat hazard with pedestrian exposure. The resulting index provides fine-grained, sidewalk-scale information that can support planners and policymakers in prioritizing targeted heat-adaptation interventions.
Heat hazard (H) was defined as the average UTCI for each sidewalk segment (edge). We buffered each segment and overlaid the buffer with the 1 m UTCI raster, then computed the mean UTCI of the intersecting pixels and attributed it to the segment. Pedestrian exposure (E) is characterized by the calibrated pedestrian volumes derived from the three time-specific MLR models for morning, midday, and evening peak periods (see section 2.4). Consistent with the calibration results discussed earlier, only trips exhibiting positive and statistically significant relationships with observed pedestrian activity were included in the exposure estimates. To ensure comparability between components, segment-level heat hazard and pedestrian exposure were normalized to a continuous scale of 0 to 1 before being integrated into the HEI. The HEI was then computed for each segment according to Eq. (1):

$$HEI_s = \sqrt{H_s^i * E_s^i} \quad (1)$$

where:
HEI_s = Heat Exposure Index for segment *s*,
H^i_s = normalized heat hazard for segment *s*,
E^i_s = normalized pedestrian exposure for segment *s*.

The HEI ranges from 0 to 1, with higher values indicating greater pedestrian heat exposure and highlighting sidewalk segments where elevated thermal conditions overlap with higher pedestrian activity. Because both components are normalized between 0 and 1, the index is computed as the geometric mean of heat hazard (H) and pedestrian exposure (E), expressed as the square root of the product of these two values, since direct multiplication would compress values toward zero, producing a highly skewed distribution. The use of geometric means mitigates such occurrence, preserving the interpretability of the index within the 0-1 range while maintaining sensitivity to variation in both components. Higher HEI values (closer to 1) indicate sidewalk segments with greater combined levels of heat hazard and pedestrian exposure, highlighting locations where interventions such as shading or other cooling strategies may be most urgent.

3. Results: mapping high-exposure sidewalks

As a segment-level measure, the HEI captures the heat conditions pedestrians experience in outdoor urban spaces and helps direct interventions, such as expanding tree canopy, adding shade structures, and siting cooling or first-aid stations along heavily used routes. Prioritizing the places and times with the greatest exposure improves pedestrian comfort and helps cities cope with extreme heat.

Figure 2 shows the HEI for pedestrians traveling between key origin-destination pairs, illustrating how heat exposure across the sidewalk network changes over the course of a typical heatwave weekday.

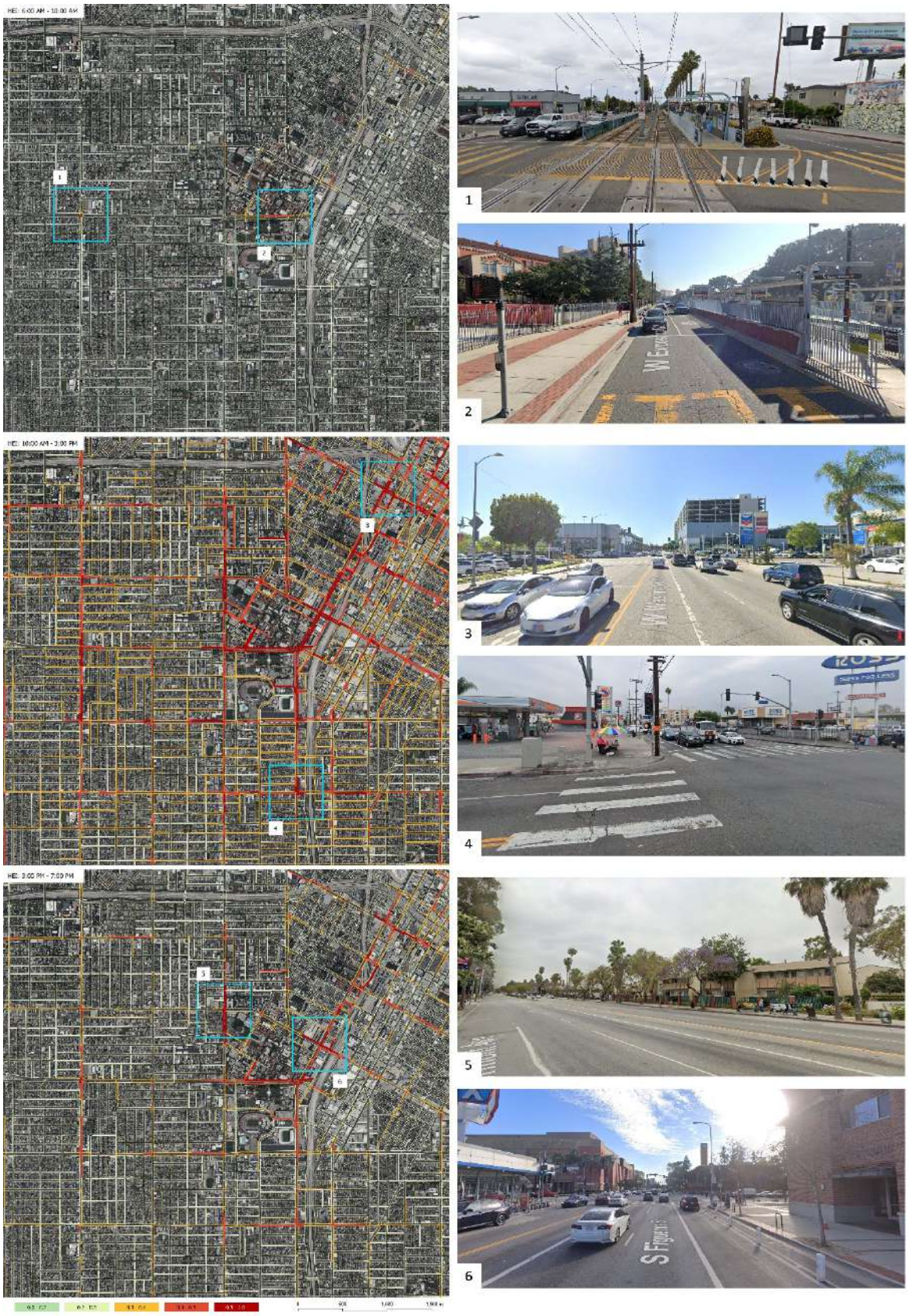

Fig.2 Sidewalk-level HEI: morning (6-10 A.M., top panel), midday (10 A.M.-3 P.M., middle panel), and evening (3-7 P.M., bottom panel), with corresponding street-view insets (1-6) showing how urban features shape pedestrian heat exposure

We point out that thermal exposure peaks during the midday period (10:00 A.M.-3:00 P.M.) and remains elevated into the late afternoon (3:00 P.M.-7:00 P.M.), when conditions along the sidewalk network are most critical for pedestrians. At this time, mapping the HEI at the sidewalk-segment scale reveals pronounced spatial contrasts in exposure, including cases where opposite sides of the same street experience substantially different thermal conditions that can be primarily attributed to uneven shading patterns and/or variations in pedestrian volumes across the street network.

In particular, Figure 2 shows that in the early morning (6:00-10:00 A.M.), most sidewalk segments register low to moderate HEI, depicted in shades of green and yellow, reflecting cooler UTCI values and lower pedestrian flows. However, approaching some transit hubs, such as Expo/Western Station (street-level view 1, Fig.2) and Expo Park Station (street-level view 2, Fig.2), shows higher HEI during the morning too (6:00 A.M.-10:00 A.M.), due to concentrated foot traffic, even though overall heat levels aren't extreme.

As the clock advances into the midday period (10:00 A.M.-3:00 P.M.), HEI values surge into the yellow-through-red range, marking the day's peak in thermal stress. This intensification owes equally to heightened UTCI readings and the influx of people walking to transit stop destinations. Along the major arterial passing beside the Ortho Institute Station (street-level view 3, Fig.2), barren sidewalks bake under unmitigated sun. Here, as we can observe in the street view image, scattered, isolated trees are insufficient to counteract the heat generated by wide, paved, and heavily trafficked roads, especially in an urban fabric where buildings are not arranged compactly, resulting in fragmented shade and the absence of continuous urban canyons.

At a busy crossroads with multiple bus stops (street-level view 4, Fig.2), where HEI peak values are observed, a street vendor shields themselves beneath a portable umbrella cart to escape the intense heat. In other cases (street-level view 5, Fig.2), the placement of trees may not adequately provide shade for benches along sidewalks, or the selected tree species may not offer sufficient canopy coverage.

Although afternoon temperatures begin to decline after 3:00 P.M., HEI remains elevated along many corridors through early evening (3:00-7:00 P.M.), especially on routes to transit hubs, such as the downtown link in street-level view 6, as shown in Fig.2. This persistence reflects the delayed release of heat associated with limited shading, extensive paved surfaces, and surrounding buildings, which sustain higher thermal conditions later in the day. For example, along downtown S. Figueroa Street near Jefferson/USC Station (street-level view 6, Fig.2), higher expected pedestrian volumes toward transit, combined with residual surface heat, result in high levels of heat exposure persisting into the evening.

4. Discussion

4.1 From high-resolution heat exposure mapping to actionable interventions

As extreme heat events become more frequent and intense, understanding exposure at the scale of everyday mobility is increasingly important for urban planning. The heat exposure index developed in this research provides a fine-grained view of when and where pedestrians are most at risk. The sidewalk-segment resolution of the HEI makes it possible to identify specific locations where exposure accumulates, rather than treating corridors or neighborhoods as homogeneous units, and better reflects conditions along actual walking routes.

The HEI maps and street-level views in Fig.2 reveal that pedestrian heat exposure is highly uneven across space and time. Exposure peaks during the midday period and often stays elevated into the late afternoon and early evening, with the highest levels clustering around transit hubs and major arterial corridors. Exposure can also differ markedly between opposite sides of the same street, reflecting differences in shade continuity, street orientation, and pedestrian volumes. Such patterns have direct implications for the design and placement of heat-mitigation measures. In fact, rather than treating large areas as uniform, the results point to the need to target specific sidewalk segments and times of day where HEI is highest. Along these routes, expanding continuous tree canopy, installing permanent or seasonal shade structures, and improving shading

at transit stops can reduce exposure during the hours when pedestrian activity and thermal stress overlap. The street-level examples in Fig.2 further illustrate that isolated or poorly positioned trees often fail to provide effective relief, whereas continuous shade along walking paths is more likely to improve experienced conditions.

We also emphasize the importance of first- and last-mile links from residential areas to transit hubs and major destinations, since they are often unavoidable for transit-dependent travelers and often coincide with peak heat exposure in many of the mapped corridors. Complementary measures, including shaded seating, drinking water, and first-aid or cooling stations, can further support pedestrian comfort and safety during heatwaves along these routes.

Finally, we contend that heat exposure, associated with walking and cycling, raises important equity considerations. Lower-income households, zero-vehicle households, and transit-dependent populations are more likely to rely on active mobility and public transport and therefore face greater exposure to outdoor heat during daily travel (Karner et al., 2015). This concern is particularly acute for the elderly, for whom pedestrian accessibility to essential urban services is not only a matter of convenience but a determinant of quality of life (Gaglione et al., 2019). Paradoxically, the urban environmental quality that most effectively reduces heat exposure, including tree canopy continuity, vegetation cover, and adequate shading along pedestrian routes, tends to be concentrated in wealthier neighborhoods (McDonald et al., 2021), where residents are also more likely to avoid outdoor exposure through private vehicle use or access to air-conditioned environments.

In this context, targeted heat-mitigation interventions along common pedestrian routes in cities have the potential to deliver vital benefits to socially disadvantaged groups, provided they are implemented with explicit attention to equity (Sheikh & van Ameijde, 2022). Ensuring sustained investment in corridors serving transit-dependent and lower-income communities is therefore critical.

The sidewalk-level approach adopted here links microclimate conditions with pedestrian volumes, keeping adaptation planning anchored to everyday travel. Indeed, looking at both together shifts the focus from "hot neighborhoods" in general to the specific segments where people are exposed on the way to transit or key destinations. As cities confront climate change and continued urban growth, this level of detail can inform heat-adaptation policies that are both effective and grounded in how people move through and experience urban space.

4.2 Limitations and pathways for future exploration

It is worth pointing out that, at this stage, the proposed framework is subject to some limitations that affect its representativeness and precision. First, the analysis was conducted within a spatial subset of the city, initially defined as a 6.6 × 6.6 km area and subsequently reduced to a 5 × 5 km core after applying an 800-meter walking buffer to mitigate edge effects. While this adjustment improves alignment with pedestrian accessibility, the limited spatial extent may further constrain the ability to capture broader urban dynamics and the full diversity of citywide conditions.

Second, StreetLight provides pedestrian person-count estimates referenced to street centerlines rather than sidewalk segments, so we reallocated the counts to sidewalk segments based on segment length before using them to calibrate pedestrian flows modeled on the sidewalk network with the UNA Toolbox for the origin–destination pairs considered. Although key behavioral factors were incorporated in the pedestrian flow modeling, including detour ratios and a gravity-based distance decay formulation, the resulting flows remain an approximation. In particular, behavioral responses such as pedestrians switching sides of the street in response to shading conditions are not explicitly captured.

Then, the relatively low adjusted R^2 values across the three models (AM = 0.207, mDAY = 0.236, and PM = 0.244) indicate that pedestrian flows are likely underestimated due to unmodeled trip types. The absence of alighting data at transit stations, for instance, limits the representation of trips originating from transit and

continuing to jobs, amenities, or home. Likewise, pedestrian movements to and from parked vehicles along streets or parking lots were excluded from calibration. Together, these omissions, primarily caused by a lack of data, likely resulted in missing key origin-destination pairs and underrepresentation of pedestrian volumes along important corridors.

Additional uncertainty arises from temporal aggregation as both pedestrian volumes and UTCI values were aggregated over three broad time windows (e.g., 10:00 A.M. - 3:00 P.M.), potentially smoothing short-term peaks in thermal stress or foot traffic that may shape heat exposure more acutely during specific hours.

We contend that, in its current form, the designed framework offers a coherent and operational approach for integrating fine-grained bioclimatic data with pedestrian mobility to identify locations with elevated heat exposure. However, further precision could be achieved by incorporating detailed transit egress data, for instance, utilizing higher-temporal-resolution mobility and climate inputs, and integrating additional evidence on pedestrian behavior, particularly shade-seeking patterns.

Finally, future research would benefit from considering pedestrian heat exposure within a broader social context. Examining how travel behavior and heat resilience vary across population groups, including factors such as age, income, and access to green space, for instance, can effectively help reveal how heat exposure is unevenly distributed across the city. Taking into consideration this perspective is crucial for developing heat-mitigation strategies that are tailored to varying levels of vulnerability and need.

5. Conclusions

With this research, we have advanced urban heat exposure assessment by designing a pedestrian-centric framework that integrates high-resolution microclimate modeling with mobility patterns, with emphasis on walking to selected daily destinations. The approach bridges a critical gap between climate science and urban planning, emphasizing that granular, equity-focused heat mitigation is indispensable for building adaptive cities in an era of escalating thermal extremes.

The HEI quantifies sidewalk-level thermal stress by synthesizing UTCI-derived heat hazard and pedestrian activity in different time periods along the day, with a replicable tool for identifying high-risk pathways.

We have applied this method to central Los Angeles during a heatwave, where the analysis reveals pronounced spatiotemporal disparities. Exposure peaks during midday (10:00 A.M.-3:00 P.M.) and remains elevated near transit hubs and commercial corridors through the evening (3:00 P.M.-7:00 P.M.), disproportionately impacting transit-dependent populations. Findings support the relevance of high-resolution spatial and temporal analysis in heat adaptation planning, as exposure significantly varies across diurnal cycles and different urban areas and services. The proposed framework equips planners to prioritize hyperlocal interventions, such as shade structures, cooling pavements, urban greening, and emergency measures where pedestrian activity overlaps with extreme thermal conditions. By aligning heat mitigation strategies with pedestrian mobility patterns, cities can safeguard the most vulnerable populations, including non-motorized or transit-dependent people, while fostering climate-resilient infrastructure under an equity lens.

However, some limitations need to be mentioned, with particular attention to the spatial scope, pedestrian behavior assumptions, and temporal resolution that together highlight avenues for refinement. In particular, future work should explore the integration of sociodemographic variables to consider other aspects of heat vulnerability, transit egress data to include further key pedestrian flows, and shade-seeking strategies to better be aware of how people adapt to extreme heat while navigating the city. Such improvements will strengthen our understanding of systemic inequities and adaptive capacity.

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Image Sources

Fig.1: Colaninno, et al., 2024;

Fig.2: Elaboration by the authors.

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