Pedestrian-Scale Radiative Balance in the City: Enrichment of a Labeled Dataset and Machine Learning to Explain the Link to Urban Form

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Contacts :
T. Leduc (thomas.leduc@crenau.archi.fr)
A. Rodler (auline.rodler@cerema.fr)
M. Servières (myriam.servieres@crenau.archi.fr)

Subject description

It is now well established that we are witnessing an increase in the intensity, frequency, and duration of extreme weather events (IPCC 2022). This increase, combined with the specific microclimatic response of our built environments, which can locally amplify certain overheating phenomena, alters or sometimes hinders the daily practices of residents. This vulnerability to heatwave hazards is a source of increased morbidity and even mortality, which justifies public policies aimed at climate adaptation in cities (Ruefenacht and Acero 2017). The present thesis is part of this context. The hypothesis suggests that integrating the analysis of urban forms and urban microclimates will offer key strategies for action and design support for planners at different scales, potentially yielding precise outcomes.

The trajectory of the sun in the apparent sky of urban environments is well known, as is the assessment of the incident radiative fluxes that contribute to the heating of outdoor spaces. Simulation models and tools have been developed to assess the radiative balance at any point in an urban scene. In addition to these "physics-based" approaches, other studies have aimed to identify the factors that determine the specific microclimatic response of cities, such as morphology, human activities, or land use. These typology-based approaches have contributed to defining the concept of local climate zones (LCZs), as discussed by (Stewart and Oke 2012, Rodler and Leduc 2019).

The aim of this thesis is to identify the morphological determinants of the specific microclimatic response of the built environment, not at the scale of a few hectometers as LCZs can do, but at the level of the pedestrian and their immediate environment, i.e., at an infra-decametric level. The aim here is to characterize the influence of the distribution of immediately surrounding built volumes on the radiation balance of a pedestrian at any point in open space. This radiation balance is crucial in calculating the average radiant temperature, which is a key variable in assessing the thermal comfort of pedestrians in outdoor spaces (Grosdemouge 2020).

To conduct this research at the intersection of urban form and urban microclimate (specifically its radiative component), we suggest using an inductive approach to extract knowledge from a synthetic labeled dataset. After reviewing the state of the art to understand the analysis of urban forms, the physical phenomena involved, and the main learning techniques[1], the PhD student will proceed to reuse and complete the synthetic labeled dataset (Leduc and Cui 2024). Subsequently, he/she will extract

1 Even if the objective here is to infer knowledge from a synthetic labeled dataset through supervised learning, other unsupervised learning techniques, especially classification, can also be beneficially utilized.

knowledge from it, focusing on co-occurrences between the morphological and radiative signatures of places. His/her work will thus be part of a line of research conducted within AAU as well as CEREMA's BPE team aimed at informing the bioclimatic design of urban open spaces based on the bioclimatic analysis register of forms (Merville, forthcoming; Belgacem 2019; Bernard 2017).

Figure 1 depicts the dimensionality reduction method that has been implemented and utilized within AAU to generate the 27+ million labeled entries of the synthetic dataset mentioned above (Leduc and Cui 2024). The aim of this thesis work is to correlate the morphological signature of places, as shown in Figure 1a, which is the outcome of the overall configuration integrating the arrangement of volumes, orientation, depth of openings, etc., with its radiative signature as depicted in Figure 2a. - and its radiative signature presented in Figure 1c. This signature includes direct and diffuse irradiation rates without the need for the intermediate simulation step shown in Figure 1b. The aim of this research is to train a model to replicate the results of radiative simulation in an urban environment. The underlying assumption is that a model derived from the observation of massive data will yield more immediately exploitable results to explain the link between morphology and the radiative balance.

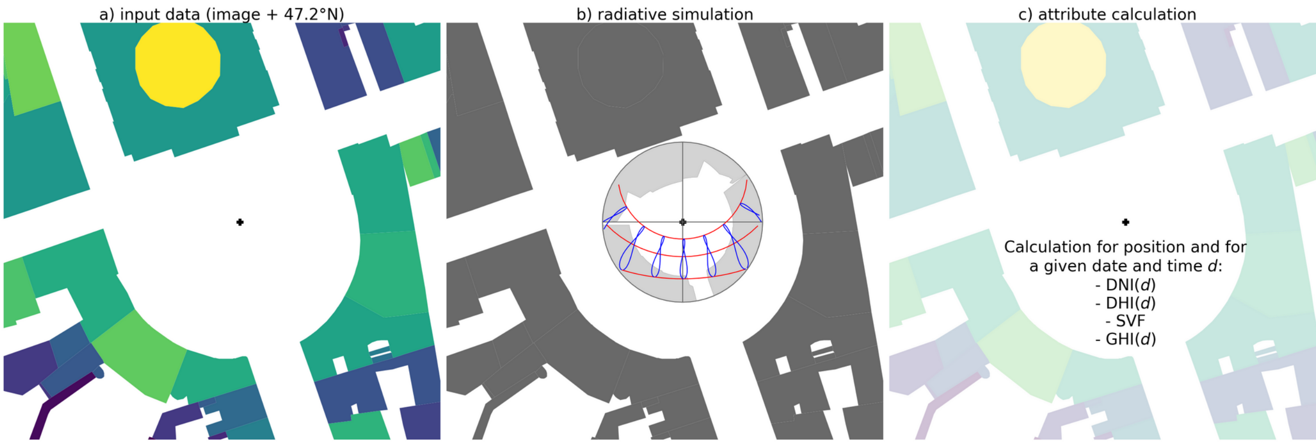

Figure 1: a) the central point to be characterized in the sense of a radiative balance is surrounded by buildings - straight prisms - whose color is a function of the height attribute, and is assigned a position (lat/lon); b) the radiative simulation tools developed in the AAU laboratory transform a 3D+t problem (the sun's path in the sky is a function of time, and its contribution to the central point's radiative balance is a function of the masks built around it) into a plane geometry problem ; c) the aim of the thesis work is to quantify (specifying the level of reliability of the forecast), for a given date, the direct and diffuse solar gains at the central point, using only the input data described in figure 1a, without going through intermediary 1b.

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