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Design and Evaluation of a 3D Cartographic Prototype for Visualizing Urban Thermal Stress at City-Block Scale

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Abstract:

Extreme urban heat has become an urgent global challenge, with the United Nations estimating that 1.6 billion urban residents will be exposed to extreme heat by 2050 (UNEP, 2021). This phenomenon, driven by the Urban Heat Island (UHI) effect, results in significant thermal stress on the human body. At the same time, the growing availability of 3D geospatial data and the development of digital twins offer new opportunities to model and visualize urban microclimates. 3D digital environments provide a more intuitive way for spatially representing and understanding complex geometries and offer an immersive perspective for exploring multidimensional datasets. However, 3D visualization tends to demand higher cognitive load than 2D, as the 3D dimension often introduces issues such as visual clutter, occlusion, and dense, overlapping data displays (Beran et al., 2022; Miranda et al., 2024). Consequently, the ability to balance thermal stress data between visual complexity and communicative clarity within 3D environments is important.

As part of the ClimaSens project, this study aims to design and evaluate a 3D cartographic prototype for the general public that facilitates interpretation of the driving factors behind thermal stress at the city-block level. The prototype will visualize one of the thermal stress indicators, Universal Thermal Climate Index (UTCI), in four simulated scenarios - extreme heat and cold days, each modelled both with and without trees. The prototype will investigate multiple visual encodings including 3D point clouds, vertical planes, and 3D isopleths (see Figure 1). To effectively support the exploration of spatiotemporal 3D urban data, interaction techniques such as time sliders and linked views are implemented, as shown in Figure 2. (Mota et al., 2022)

Managing inherent 3D challenges is essential for maintaining communicative clarity. Occlusion issues can be handled through adaptive cutaways for neighboring buildings and gradual fade-outs for trees that would otherwise block the view. (Rauer-Zechmeister et al., 2024) Finally, the cognitive load of geographic information can be reduced by filtering unnecessary detail and segmenting data into smaller thematic units. (Bunch & Lloyd, 2006)

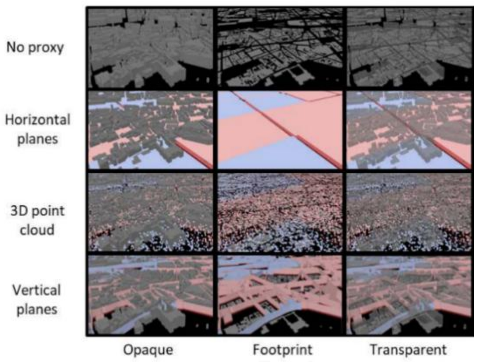

Figure 1. Representation of air temperature spatial patterns using horizontal planes, road-based vertical planes, and 3D point clouds (Gautier et al., 2020).

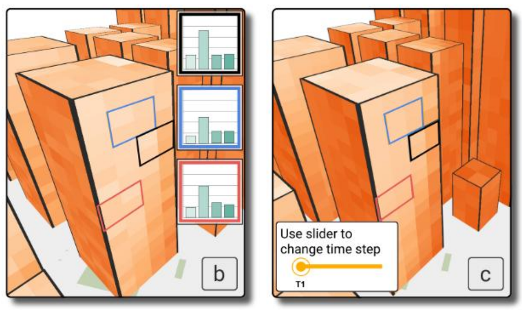

Figure 2. Spatiotemporal visualization strategies with Linked View (left) and Time Slider (right) (Mota et al., 2022).

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The prototype is implemented using Unity 6000.4.1f1, as depicted in Figure 3. It will be evaluated through a task-based usability study comparing decision-making in interactive 3D visualization environments. The expected result will be a 3D cartographic paradigm for urban climate communication, providing insights into how 3D visualization can bridge the gap between complex urban climate data and public understanding. The novelty of this research lies in the empirical evaluation of specific 3D cartographic methods within the context of urban thermal stress.

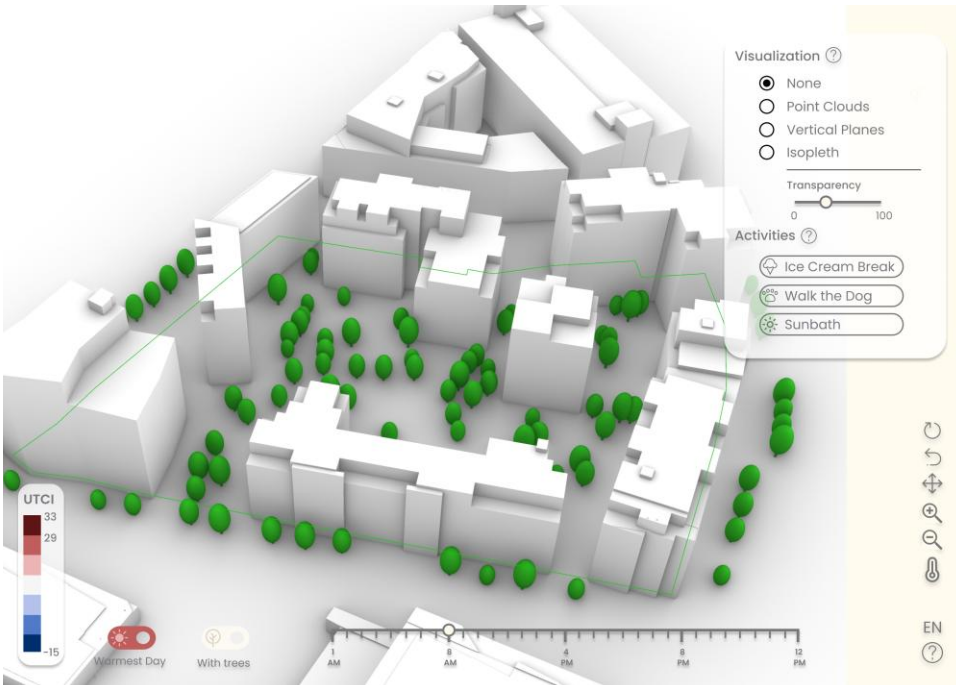

Figure 3. Mock-up of the main screen of the prototype.

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