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Modelling and visualisation of land surface temperature in urban areas represented by 3D city models

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Abstract:

Land surface temperature (LST) in urban areas is traditionally considered a reliable indicator of the urban heat island phenomenon. It is usually observed by thermal satellite or airborne sensors. Unfortunately, such data are often at low spatial and temporal resolutions and their usability can be further reduced by cloudiness. Moreover, the data represent the top of built-up area, i.e., mostly roofs, streets and open spaces. However, the built-up areas exhibit a complex morphology including urban greenery and vertical surfaces such as facades. Therefore, the comprehensive approach requires the use of sophisticated geospatial tools and various data representing urban environment.

In this study, we present a novel approach based on geospatial modelling of LST in geographic information system (GIS) and 3D data represented by 3D city models. The presented approach is based on physical principles using Stephan-Boltzmann Law, 2D and 3D solar radiation tools implemented in GRASS GIS and Python scripting. The LST modelling in GRASS GIS uses input parameters such as solar irradiance, albedo or convection heat transfer coefficient for urban surfaces (Hofierka et al., 2020). The key component of the methodology is solar radiation modelling applied to a 3D city model accurately representing complex urban morphology and thermal properties of urban surfaces.

The methodology was applied to the small study area in the city of Košice, Slovakia consisting of 3261 objects and 73,614 polygons representing mostly administrative and residential buildings. The vector-based 3D city model for this area was derived from photogrammetric and airborne laser scanning data (Hofierka, 2022). The 3D city model was derived at a level of detail 2 (LoD2), which means that the model contains information about the basic geometry of buildings including roof shapes. Other input data, such as albedo and convection heat transfer coefficient were derived from satellite, airborne and other reference data for standard construction materials.

The solar irradiance was calculated using the r.sun and v.sun solar radiation tools in GRASS GIS for 3 time horizons (7:00, 12:00, 17:00 local solar time) on 30 June. These time horizons demonstrate diurnal changes in available solar irradiance with clear-sky (no clouds) atmospheric conditions that occured on 30 June 2016. The clear-sky situation is evidenced by a meteorological ground station as well as Landsat 8 and Sentinel 2 satellite data (Hofierka et al., 2020). Since the r.sun and v.sun modules uses the same ESRA solar radiation methodology (Hofierka and Zlocha, 2012), they can be used to evaluate particular segments of the territory represented by a raster-based digital surface model as well as a vector-based 3D city model. The LST model was calculated for these representations of the urban area and selected time horizons and specific atmospheric and thermal properties of urban surfaces. The results showed that urban morphology has a strong impact on spatial distribution of solar radiation as well as land surface temperature during the daylight hours. At low solar altitudes (mornings, evenings), facades receive more solar radiation and consequently heat up these surfaces, while high solar altitudes heat up horizontal urban surfaces such as roofs (Figure 1).

Urban areas with complex 3D features require an interactive 3D visualisation to fully understand a spatial distribution of the phenomenon. While standard 3D visualisation tools such as ArcGIS Pro Scene can be used for this task, we can also use less traditional visualisation techniques based on Tangible Landscape concept (Petrasova et al., 2020). The concept is based on a combination of geospatial software, Azure Kinect 3D sensor, projector and scanning, and projection and interaction area with physical features representing the study area (Figure 2). The LST values modelled in GRASS GIS can be effectively visualised using Tangible Landscape and a physical 3D city model printed out by a 3D printer to better understand the importance of urban morphology and diurnal dynamics of the phenomenon.

Such complex 3D analysis is useful for identification specific urban surfaces contributing to the urban heat island phenomenon within the city and for detailed planning of mitigation measures. The accuracy of the model can be further

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increased by a higher spatial resolution and higher a level of detail of the urban area representation including urban greenery features as well as a better parameterisation of thermal properties of urban surfaces. The results of this study can be used in urban planning, optimisation of energy use in buildings or mitigation of urban heat island effects.

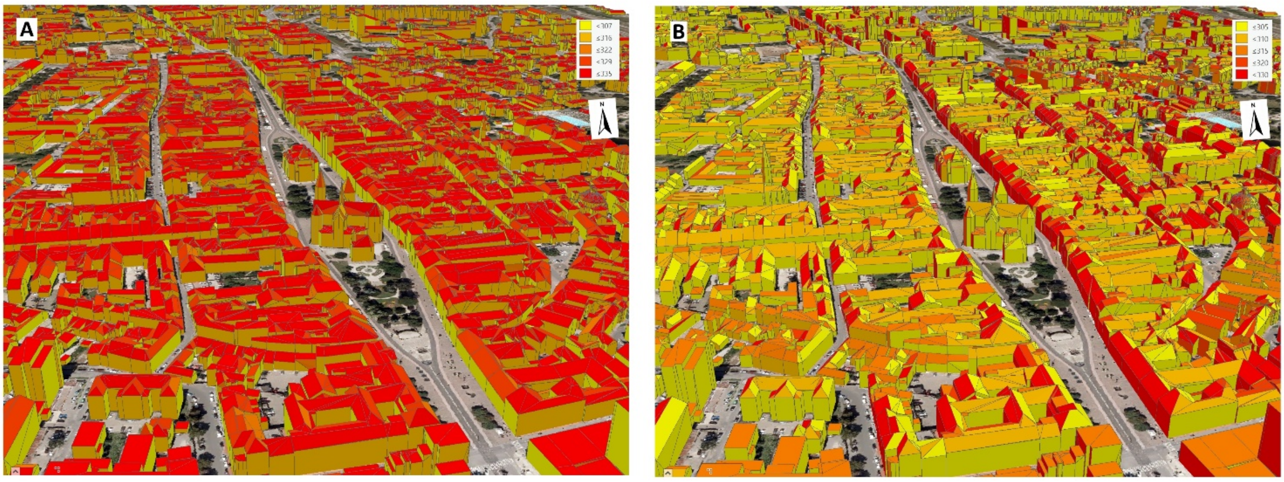

Figure 1. Modelled land surface temperature (in Kelvins) on 30 June, A: 12:00, B: 17:00 local time.

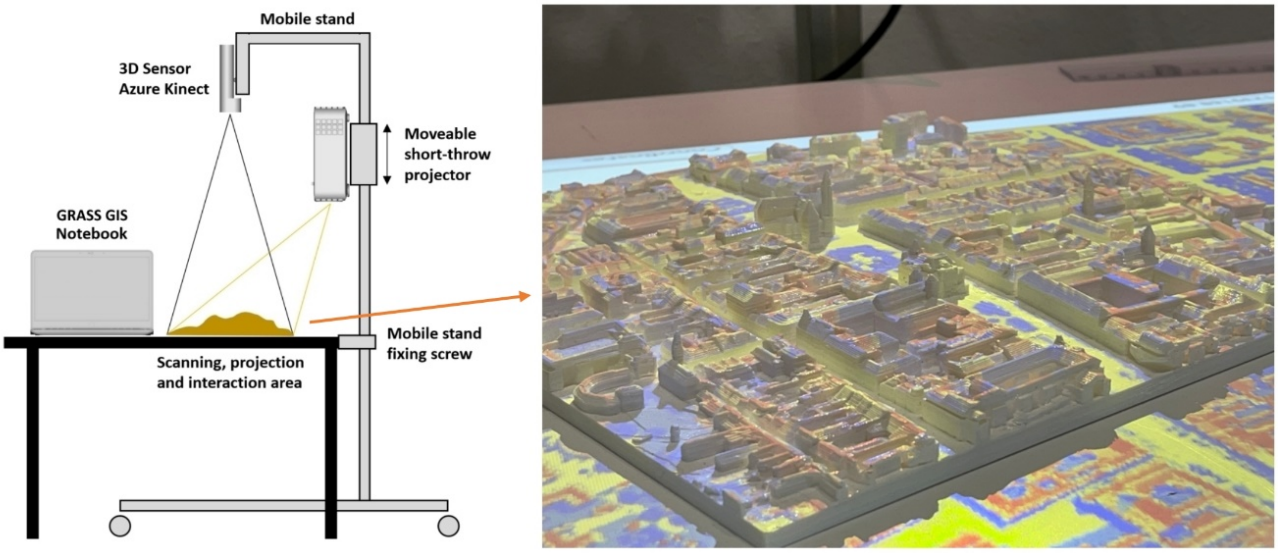

Figure 2. Land surface temperature visualisation using Tangible Landscape.

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