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A new 3D visible space index for evaluating urban openness

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Abstract:

Visibility represents the extent of space that people visually perceive, playing a crucial role in urban management, urban planning and design. Most of traditional studies focus on the two-dimensional morphological feature, neglecting the vertical characteristics of the city. Although some current methods have contributed significantly to representing 3D urban openness, the limitations that they cannot measure real and complex three-dimensional 3D built environment with a high level of integrity and accuracy remain exists. On the one hand, some approaches ignore the space below the viewpoint, so it does not provide visibility analysis (for example 3D isovist) when the viewpoint is at a higher position. On the other hand, some methods require pre-modification of the urban model before visibility can be calculated (for example SOI metric). More importantly, the geometric scenario where the line of sights is obscured by buildings in 3D environment is simplified. This is the reason why an approach to assess real 3D urban space have not been fully conducted yet. Recently, Yi Zhao (2020) evaluated the visibility of a 3D space using mobile point-cloud data. However, the significant cost of LiDAR technology limits the large-scale expansion of the method. Also, point cloud data is mostly used in the street, it is hard to achieve visibility calculations at any location. Accordingly, this study proposes a three-dimensional (3D) openness algorithm based on a geometric subdivision and formula derivation (Figure 1). First, a visual sphere is constructed with the viewpoint as the center. Then, the visual sphere is uniformly subdivided by multiple lines of sight at certain horizontal and vertical angle intervals, yielding multiple discrete visual difference elements (VDEs). Finally, the visible volumes in each VDE are calculated separately to accumulate visible volume of the visual sphere.

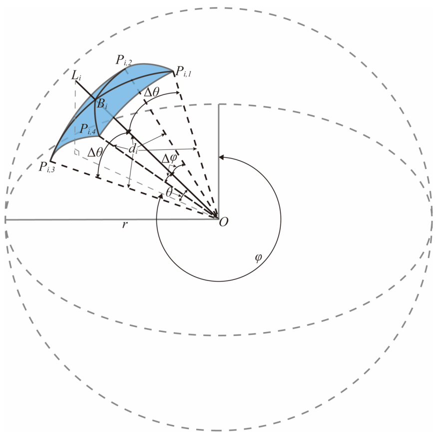

Figure 1. Schematic diagram of a visual differential element

Theoretically, the observer of the line of sight to any surrounding direction is not restricted. In this situation, the visual space is abstracted as a sphere with the viewpoint as the center and a specific radius. This radius is named the visible distance. Generally, the terrain and overlying objects, such as buildings, structures and trees, can block the line of sight. Correspondingly, the visual sphere is separated into visible and occluded parts. Based on this principle, 3D openness metric called visible space index (VSI) is defined by the volume ratio of all visible space to the volume of the visual sphere in this paper.

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The openness model in this paper includes four parameters: visible distance in the sphere (r), horizontal angle interval (Δφ), vertical angle interval (Δθ), and interpolation distance (D) corresponding to the line of sight. The proposed method is validated in simulated urban environment (Figure 2). When the visible distance is fixed, the other three parameters influence the accuracy of the VSI and the efficiency of the modelling. Therefore, we offset the interpolation distance (D), horizontal angle interval (Δφ) and vertical angle interval (Δθ) to different values to calculate the VSIs of the viewpoint. Overall, a total of 1190 parameter value combinations were explored.

Notably, the computational time is significantly reduced with increasing interpolation distance, horizontal angle interval and vertical angle interval. In general, the differences in VSI values with different parameters are all within 0.01 (Table 1). The above results suggest that the conceptual model and the characteristic indicators established in this paper are reasonable and practical.

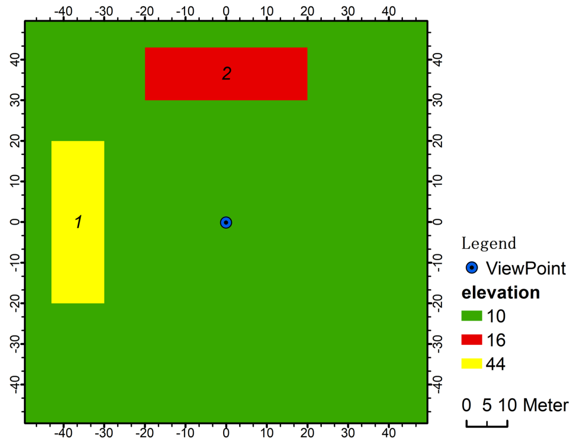

Figure 2. Simulated urban model

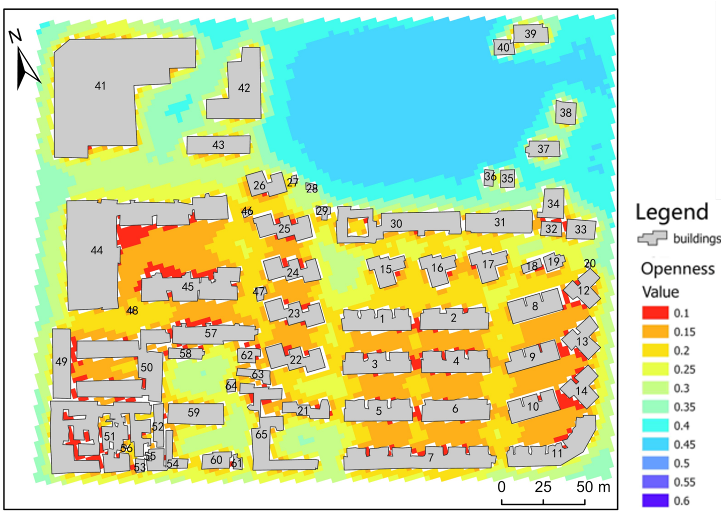

Figure 3. VSI distribution with realistic urban model (0 m)

The result of realistic urban model shows that the proposed method can effectively indicate 3D visual-spatial differentiation characteristics of openness, whilst being more sensitive to the height change of viewpoints (Figure 3)

Hence, it has been demonstrated through experiments that the proposed approach can be effectively used to evaluate openness at any viewpoint in urban areas. This study is expected to provide support for regional planning decisions and the design of more sustainable built environments.

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