Voxel modelling for large 3D urban areas

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SUMMARY

Spatial Digital Twins have emerged as key platforms for local governments and stakeholders to provide and represent 3D spatial data. This data is typically organized into standardized themes such as terrain, transport, and vegetation or as ad hoc data products like buildings, represented in either 2D or 3D. Most of this data is structured as vector datasets, and integrating them into a cohesive 3D model poses challenges in terms of accuracy, resolution, and representation. Variations in sensors, data collection procedures and algorithms often lead to inconsistencies. Furthermore, most existing spatial Digital Twins lack advanced 3D spatial analysis capabilities, such as volume computation and 3D intersections.□□To address these challenges, we are developing a novel approach for integrating and analysing 3D data using voxels - a representation analogous to pixels in 2D raster images. Voxels form a regular grid or 3D array, where each object is composed of a set of voxels, effectively representing it as a solid. This voxel-based representation offers several advantages, including a unified data structure, robust neighbourhood and morphological operations, and the ability to perform analyses across the entire voxelised space, including "air" space.□□Fine-resolution voxels are essential for achieving high accuracy, but their use leads to third power increase in the size of the 3D raster, which severely limits the ability to process large city models. To address this limitation, efficient data structures are required to enable voxel storage and analysis on disk. Octrees, a commonly used data structure, are effective for maintaining 3D regular grids, particularly when voxels form homogeneous regions. Octrees grow only quadratically with increasing resolution and inherently support multiresolution object management.□□Our developments focus on an optimized octree data structure that reduces the memory footprint further, enabling the processing of large urban datasets. This data structure is implemented in SQLite, and we have developed ESRI Add-ins to access the data, execute 3D analyses, and generate LAS or NetCDF files. These outputs can then be visualised as voxel or point cloud layers in ArcGIS Pro.□□We demonstrate the capabilities of our custom data structure through various spatial

operations on datasets with differing complexities and layer types. Using our developed Add-ins, we illustrate voxelisation, querying, and visualisation of voxel models in ArcGIS Pro on datasets from Australia and Germany. By leveraging voxels, our approach enables efficient and accurate 3D data processing at scale, unlocking new opportunities for advanced 3D analytics within Spatial Digital Twins.