10. Volumetric Urban Growth Modelling in Sub-Saharan Africa: An Integrated Statistical and Deep Learning Pipeline for Nairobi Metropolitan Region (2016–2030)

Emmanuel Okello Otieno1,2 and Piero Boccardo2

1 Department of Civil, Building and Environmental Engineering (DICEA), Sapienza Università di Roma, Via Eudossiana 18, 00184 Roma, Italy emmanuelokello.otieno@uniroma1.it 2 SDG11Lab, Interuniversity Department of Regional and Urban Studies and Planning (DIST), Politecnico di Torino, Viale Mattioli 39, 10125 Torino, Italy

Rapid urbanisation in Sub-Saharan Africa is increasingly expressed through vertical densification, yet geospatial monitoring frameworks remain anchored to two-dimensional footprint metrics, limiting quantification of built-environment change and infrastructure demand. The Nairobi Metropolitan Region, with 26 administrative subcounties spanning 5,114 km2, exemplifies heterogeneous growth trajectories that aggregate indicators obscure. This study develops a reproducible threedimensional volumetric monitoring pipeline quantifying annual building volume at subcounty level from 2016 to 2023, with planning-oriented business-as-usual (BAU) scenario projections to 2030. Annual 4 m resolution building height rasters from the Google Earth Engine Open Buildings collection were aggregated to volumetric grids intersected with subcounty boundaries; per-subcounty Ordinary Least Squares regression with significance gating and 90% prediction intervals constitutes the projection core, with ConvLSTM spatial validation confirming that the underlying densification patterns are spatially coherent and learnable (r = 0.937, SSIM = 0.995). Metro-level volume grew from 0.795 to 1.113 km3 (+40.0%, 2016–2023); 19 of 26 subcounties exhibit statistically significant upward trends, yielding a 2030 BAU projection of 1.352 km3 (90% PI: 1.140–1.564 km3). Floor Space Index analysis identifies Kamukunji as the sole subcounty exceeding the high-density threshold by 2023, with Makadara and Starehe projected to cross it within the 2030 horizon, providing 4–7 years of advance warning for infrastructure capacity planning. The reproducible pipeline, transferable across continental Africa via the same data infrastructure, delivers subcounty volumetric projections that complement SDG 11.3.1 monitoring by quantifying insitu vertical densification alongside horizontal land consumption. 2 E. O. Otieno and P. Boccardo