# Abstract

Rapid urbanization in developing nations has intensified pressures on urban infrastructure, mobility systems, and environmental quality. As cities expand, conventional approaches for mapping-built environments, analysing traffic dynamics, and estimating vehicular emissions increasingly fail to deliver timely, accurate, and spatially explicit information. These limitations constrain evidence-based urban planning, policy formulation, and sustainability assessments.

To address these challenges, this thesis develops a suite of integrated methodologies for urban analytics by combining multi-sensor remote sensing, deep learning–based computer vision, and data-driven vehicular emissions modelling. The research is grounded in real-world datasets acquired from controlled and complex urban settings, including the IIT Kharagpur campus and Newtown, Kolkata, ensuring practical relevance and transferability. Collectively, the thesis proposes scalable computational frameworks that link urban form, mobility behaviour, and vehicular emissions within a unified analytical ecosystem.

The first objective focuses on characterizing the urban built environment using high-resolution remote sensing data and deep learning–based computer vision techniques. The study integrates high-resolution optical satellite imagery and UAV-derived orthophotos to demonstrate multi-platform flexibility. Building footprints are extracted and classified into residential and non-residential categories using state-of-the-art object detection models, such as YOLOv8, complemented by advanced segmentation frameworks, including SAM-2, for precise delineation. The resulting datasets provide detailed insights into class-wise building density, spatial distribution, and urban form complexity. These built-environment indicators support urban morphology analysis and serve as critical inputs for subsequent mobility and emissions modelling, establishing a robust foundation for scalable urban analytics.

The second objective is to develop a comprehensive urban mobility modelling framework based on traffic video analytics. Traditional mobility models rely heavily on manual surveys, sparse traffic counts, and assumption-driven behavioural approximations, leading to significant uncertainty. This research addresses these limitations by deploying a computer vision–based traffic analytics pipeline that extracts fine-grained, real-time traffic dynamics. Video feeds from key intersections and traffic analysis zones (TAZs), derived using the built-environment framework, are processed using a YOLOv8-based detection model optimized for heterogeneous Indian traffic conditions, including both motorized and non-motorized modes. Multi-object tracking is achieved using ByteTrack, integrated with OSNet-based appearance embeddings, ensuring robust tracking under occlusions, variable illumination, and dense traffic.

This framework enables the extraction of detailed traffic attributes, including vehicle trajectories, densities, queue lengths, and mode composition across cars, two-wheelers, buses, auto-rickshaws, cycles, and pedestrians. These attributes are aggregated to generate corridor-level performance indicators and city-scale mobility patterns. Built-environment characteristics such as land-use mix, building density, institutional clusters, and activity zones are further incorporated to contextualize mobility behaviour, enhancing trip generation

estimates and supporting evidence-based interventions for parking management, pedestrian safety, modal prioritization, and congestion mitigation. The objective demonstrates a replicable and data-efficient approach to urban mobility modelling that significantly improves spatial and temporal resolution while minimizing manual data collection.

The third objective formulates a novel cascaded vehicular emissions estimation framework that integrates outputs from the built-environment and mobility analytics. Conventional emission inventories often suffer from coarse spatial resolution, generalized emission factors, outdated fleet representations, and limited sensitivity to real-world operating conditions. To address these gaps, the thesis develops a high-granularity, machine-learning–driven emissions pipeline using Random Forest regression, structured as a multi-stage cascade to enhance predictive robustness.

The framework sequentially models intrinsic vehicle attributes, including vehicle age, lambda or HSU opacity, and combustion characteristics, using features derived from traffic video analytics such as vehicle type, speed, acceleration, and operating mode. These intermediate predictions inform subsequent pollutant-specific models estimating emissions of $CO_2$, CO, VOCs, $PM_{2.5}$, $NO_x$, and $SO_2$, ensuring physical consistency and operational realism. The approach explicitly accommodates heterogeneous and informal vehicle fleets, particularly two-wheelers and intermediate public transport, which are inadequately represented in existing models. Spatial integration of emissions outputs with building clusters, road networks, land-use zones, and activity centres reveals localized emission hotspots and enables targeted mitigation strategies.

Overall, this thesis establishes a unified methodological framework linking urban form, mobility behaviour, and environmental impact. The proposed models can operate independently or as interconnected modules within a holistic urban intelligence system. The research demonstrates that systematic integration of machine learning and deep learning with multi-source remote sensing and traffic data can generate actionable insights for sustainable urban planning, emissions mitigation, and data-driven policymaking. The proposed methodologies are generalizable across Indian cities and comparable global urban contexts, offering a robust foundation for developing resilient, low-carbon, and intelligent urban systems.

# Developing Deep Learning Based Methods for Enhanced Integration of Land Use and Transportation model