Enhancing urban functional regions classification by integrating multi-source data with a heterogeneous graph neural network

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Abstract:

Effective urban functional area classification underpins many aspects of urban management, including infrastructure development, environmental monitoring, and public service delivery. While prior research has employed multi-source data to achieve this classification, these efforts have predominantly focused on capturing the morphological and socioeconomic attributes of urban environments (Xing and Meng (2018), Zhao et al. (2023)). However, such approaches often overlook the dynamic patterns of population movements that reflect the fluid nature of urban life. Information on mobility can significantly disclose the interrelations among urban zones and the dynamics of human activities, shedding light on often overlooked behavioral patterns that are instrumental in revealing the functional classifications of these regions (Zhang et al. (2021), Sun et al. (2022)). This enhanced understanding is critical for adjusting urban policy to better accommodate the needs of a vibrant city population. Nevertheless, the inherent heterogeneity and spatio-temporal characteristics of these features pose significant challenges for traditional methods to effectively merge them for precise classification of urban functional areas.

To bridge this gap, our research integrates data on metro passenger flows, which encapsulates features of human mobility, along with Points of Interest (POIs) and vector-based building data. We introduce an innovative framework that employs a Heterogeneous Graph Neural Network (HGNN) to merge features from these diverse sources. In our methodology, urban blocks and metro stations are treated as graph nodes, which are linked based on spatial proximity to form a heterogeneous graph. Features pertaining to the morphology and socioeconomic characteristics derived from the building and POI data, alongside mobility features from the metro data, serve as attributes for these nodes. An HGNN model is then applied to process this graph data and classify the urban blocks into functional types through a semi-supervised learning approach. Figure 1 demonstrates the overall framework of the proposed approach.

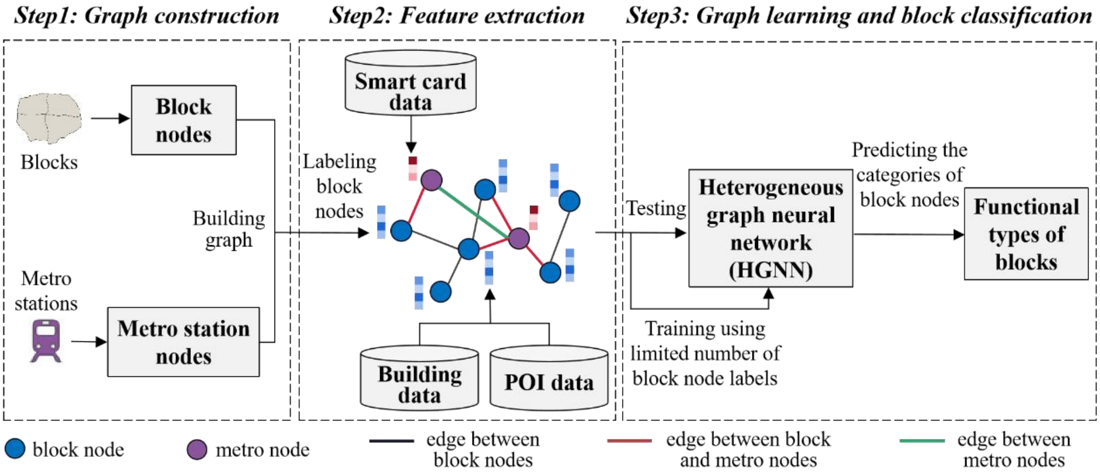

Figure 1. Overall Framework of the proposed approach.

Contrary to conventional homogeneous graph neural networks, which are typically constrained by their capacity to process only one type of nodes and edges, the Heterogeneous Graph Neural Network (HGNN) model is adept at handling diverse node and edge types. This capability allows it to explore the intricate relationships among varied data sources. Leveraging the heterogeneous graph learning framework, HGNN effectively integrates the characteristics of urban blocks with the mobility data from metro stations. This integration enhances the ability of the model to classify

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urban functional regions more accurately, capitalizing on the rich interplay of data attributes to provide deeper insights into urban dynamics.

Experimental results from applying our model to data from Beijing demonstrate that the HGNN method attains superior classification accuracy and macro F1 scores, significantly outperforming existing methods like the random forest and the GraphSAmple and aggregate approaches. Moreover, our ablation study confirms that incorporating metro passenger flow data substantially enhances classification accuracy by 6.87%. These findings underscore the importance of integrating mobility data to deduce functional areas and validate the efficacy of the HGNN in amalgamating data from heterogeneous sources.

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