MEASURING MIXED-USE INTENSITY IN VOLUMETRIC CITIES: DENSITY AND INTERACTION

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ABSTRACT

One of the most common measures used to describe the morphology of cities around the world is built density. However, density is an insufficient measure for capturing the complexity of interaction in cities in the 21st century. Instead, this paper argues that the structure of complex cities is better understood through spatial interaction measures of urban intensity. To that end, the paper proposes a new approach that works from the foundational elements of cities (land uses, density, networks, and flows) and utilizes network interaction methods from quantitative geography to capture urban intensity. The focus here is on the development of an accessibility-based approach to capturing built form, its spatial configuration, and potential to facilitate spatial interaction between different mixes of urban functions. This framework is applied to a case study of Hong Kong, a city which features a highly compact urban form, a layered multi-modal transportation network, and topographically-rich terrain. Results reveal how different configurations of the built environment are distributed over space and highlight the spatial pattern of interaction intensity across the central area of the city.

Keywords: urban volumetrics, network analysis, density, mixed-use, spatial interaction

INTRODUCTION

While measures of urban density are widely used in many disciplines, these measures have been criticized in several important ways. First, with many different methods proposed to capture various aspects of built intensity per land area (Boyko & Cooper, 2011), density has criticized for being a complex and confusing concept in practice (Churchman, 1999). Second, research has shown that measured densities are often independent from the spatial or morphological properties of an area (Alexander, 1993; Berghauser Pont & Haupt, 2010; Forsyth, 2003). Third, because they rely on administrative or arbitrary boundaries in the denominator, density measures reflect areal averages and may suffer from statistical bias and a lack of comparability associated with the modifiable areal unit problem (Openshaw, 1984). Fourth, density measures may not capture the actual use intensity of an area associated with temporality. Population densities derived from Census data typically reflect nighttime populations associated with where people live and such measures are often dramatically different from where people are located throughout the day (Schmitt, 1956). Fifth, objective or conceived measures of density have been criticized for their disconnection from individual subjective evaluations of density and crowding (Cheng, 2010). Sixth, density has been criticized for its limited incorporation of the third spatial dimension (Batty, 2009).

Moreover, urban geographic scholarship in general has been criticized for an over-reliance on a 2D 'planar gaze' that has limited our ability to understand the world's increasingly complex volumetric cities (Batty, 2000; Hewitt & Graham, 2014). In response, McNeill (2019) proposes a new ontology for conceptualizing volumetric urbanism while Bruyns et al. (2020) expand on this work to propose 'urban volumetrics' as a new approach for capturing the morphological complexity of contemporary cities through density, functional mix, compaction and compression, networks, and interaction intensity.

The present research builds on this foundation to demonstrate a new method for modelling volumetric interaction intensity in cities though a focus on accessibility to functional mix. First, built volume and amenity counts are utilized as proxies for the density and intensity of development. Second, the networks of the city are used to capture volumetric densities and their spatial configuration using spatial interaction methods. Third, to provide insight into how these configurations of built volume are used, we employ functional mix as a measure of potential interaction intensity. In this case, we posit that a high mixing of live, work, and visit functions within a high-density volumetric built form represents a morphological context that is high in interaction intensity. This intensity arises as people utilize these built volumes to carry out a variety of functional activities.

METHODOLOGY

Researchers have sought to overcome the issues associated with density in a number of ways and this study draws from three interrelated methodological approaches. The first concerns research that has linked measures of density to human perception. For example, Pafka (2020) employs a multi-scalar approach to measuring density that ranges from 100m^2 based on individual perception to 50km^2 based on regional commuting patterns. The second strand of research concerns network-based approaches to capturing urban density. For example, Berghauser Pont and Marcus (2014) approach human perception from a network perspective, calculating densities for buildings based on a select number of axial steps in Space Syntax (Hillier & Hanson, 1984) and up to 500 metres walking distance on the street network. In this case, the authors argue that the adoption of location-based densities stand to offer greater insight into perceived rather than conceived areal densities.

Third, several authors have utilized 3D data to model built volume as an indicator of urban form to study the morphology of individual buildings (Hamaina, Leduc, & Moreau, 2014), neighbourhoods (Lai, et al., 2018) and entire city regions (Krehl, 2015; Krehl et al., 2016) as well as the spatial distribution of volumetric density in a city over time (Koomen, Rietveld, & Bacao, 2009). Fourth, researchers have used spatial interaction methods to capture the spatial configuration of density in cities, such as Hamaina et al.'s (2014) analysis of volumetric density profiles based on topological interaction and Sevtsuk and Mekonnen's (2012) network-based volumetric interaction. Fifth, we draw upon the Mixed-Use Index (MXI) proposed by Hoek (2010) to conceptualize functional mix in line with previous work that has used the MXI to capture urban intensity (Dovey & Pafka, 2017). Sixth, our research operationalizes the urban volumetrics framework proposed by Bruyns et al. (2020) that sets out an agenda for measuring the morphological complexity of volumetric cities.

The core of our analysis is network accessibility to volumetric and amenity opportunities reachable on the city's transportation network. Volumetric accessibility to functional mix is a function of access potential to complementary uses and is calculated according to Equation 1:

$$A_{i,total} = \sum V_{j,live} f(t_{ij,live}) + \sum V_{j,work} f(t_{ij,work}) + \sum W_{k,visit} f(t_{ik,visit}) \quad (1)$$

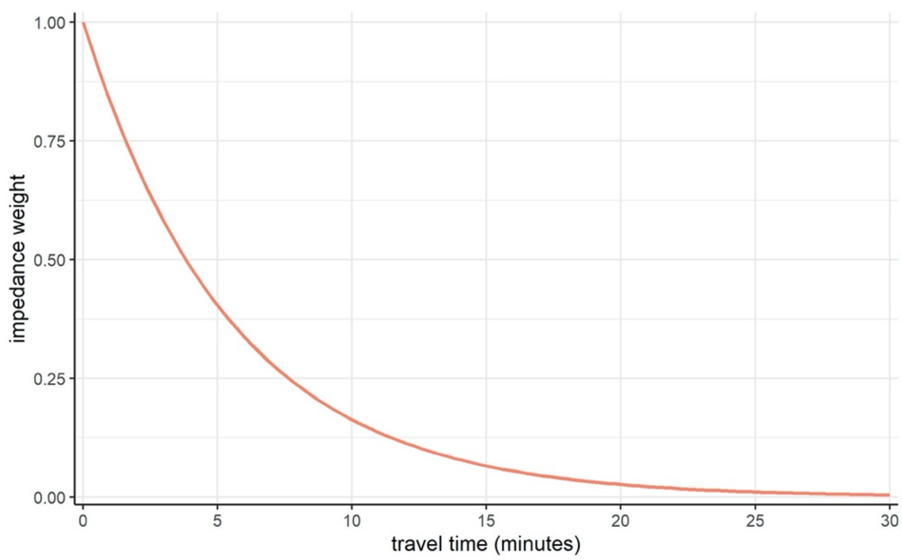
where total access for a given building i is the sum of volumetric opportunities available at other buildings j of type $live$ and $work$ weighted by some function of the travel time on the network between them. Access to amenities is calculated to all POIs k of type $visit$. In this case each POI has an opportunity value $W = 1$ which is then weighted by the travel time required to reach them. In this sense, volume captures the magnitude of live and work development while the amenity count reflects the richness of amenities available within walking distance in a neighbourhood. To make the results for each use category comparable, we rescale the results of the live, work, and visit accessibilities between 0-1. This results in three separate measures of functional accessibility for each building in the data. Finally, the input into the MXI for an individual building is each measure's proportion of the total of these rescaled values for the building.

In this case, we utilize walking as the primary mode of transportation and consider all opportunities reachable within a 25-minute walk. To weight opportunities, we adopt the negative exponential decay function based on Handy and Niemeier's (1997) research into walking access to commercial functions in California:

$$f(t_{ij}) = e^{(-0.1813 t_{ij})} \quad (2)$$

With this function, the weight of destination opportunities continuously declines as travel time from the origin increases. At a 25-minute walk, the weight declines to approximately 0.01 (Figure 1).

Figure 1. Travel Time Impedance Function



HONG KONG CASE STUDY

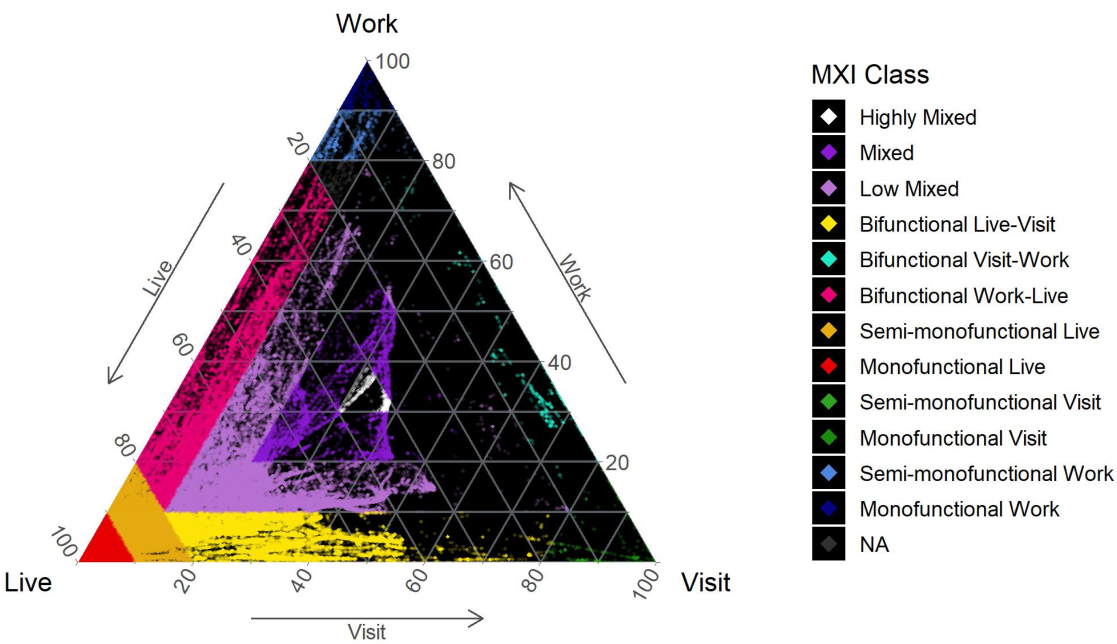
Data for the Hong Kong case study consist of building footprints for the year 2014 obtained from the Hong Kong Government's Lands Department. The buildings are extruded based on their roof height and minimum height on a digital elevation model. This creation of topologically-closed solids results in a measure of built volume for each building that is used as an input to measuring volumetric accessibility. These volumes are then associated with land use data in raster format (at 10m spatial resolution) from the Planning Department to derive an estimate of use-volume for each building based on the dominant land use within the footprint. The classification is complemented with Point-of-Interest (POI) data corresponding to geocoded restaurant licence and hotel databases from the Hong Kong Government as well as a general POI dataset from OpenStreetMap. To model walking accessibility, this research uses a 3D pedestrian network from Higgins (2019a) that interpolates the slope of pedestrian links from the underlying elevation model and calculates their walking time based on Tobler's (1993) hiking function. Many other links such as major underground passageways and skybridges are also captured in this network. Volumetric accessibility is estimated using the accessibility toolbox for ArcGIS Pro from Higgins (2019b).

To capture the intensity of use mix accessible on the network, the land use data are organized into three categories: live, work, and visit. Live functions consist of public and private residential land uses, rural housing, and hotels. The work classification consists of industrial land, business and office development, and government and institutional uses. Finally, visit functions consist of restaurant POIs based on the licence data and retail, cultural (e.g. place of worship, community centre, museum), education (e.g. school, kindergarten), healthcare (e.g. clinic, doctor's office, hospital), and service (e.g. bank, post office) POIs from OpenStreetMap.

RESULTS

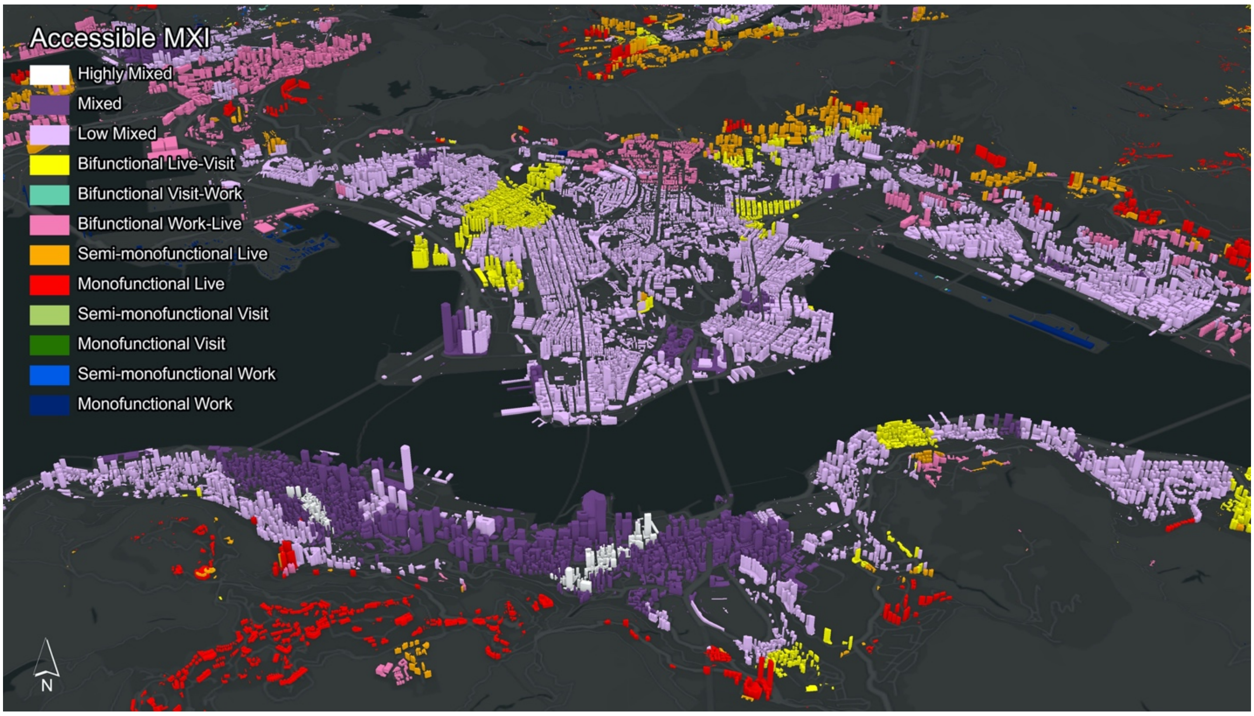
Results of the analysis are presented across two figures. First, Figure 2 plots the distribution of individual buildings within a ternary graph whose axes correspond to the live-work-visit categories of the MXI. Here it can be seen that the mix of uses skews towards the live dimension with much of the city's buildings exhibiting high access to residential land uses plus some mixing of work and visit functions. The centre of the graph highlights areas that are increasingly balanced in their intensity of accessible functional mix.

Figure 2. MXI Building Classification



To visualize the spatial locations of buildings within this classification, Figure 3 shows a map of Hong Kong Island and the Kowloon Peninsula that reveals the spatial pattern of mixed-use intensity. In general, the central area of the city features high levels of use mixing. The northern band of Hong Kong Island exhibits large areas of intermediate mixing that centre on the Central and Admiralty neighbourhoods that make up the city's Central Business District. Two of the city's highly-mixed neighbourhoods can also be seen to the east and west of this main downtown core that have high access to intensive development across all three use-mix categories. The southern Kowloon peninsula is generally more "low mixed" in its categorization. As distance from this central area increases, the use-mix begins to change. Sections of the outlying New Towns visible in the north of Figure 3 tend to have central areas that feature some mixing of uses over all three categories, but are generally more bi-functional and mono-functional in character. Monofunctional residential neighbourhoods tend to be located up the peaks of the city's mountainous terrain. In this case, high slopes generally impede walking access on the pedestrian network and isolate these buildings from the work and visit functions contained within the lower parts of the city.

Figure 3. Accessible MXI Classification of Buildings in Hong Kong



CONCLUSIONS

With a built form that features high population, employment, and amenity densities and pedestrian-oriented design, many neighbourhoods in the central part of Hong Kong exhibit high mixed-use interaction intensity. More outlying neighbourhoods and those located on the city's less pedestrian-friendly slopes are comparatively less intensely developed and exhibit a lower degree of mixing. The resulting accessibility index captures characteristics of the city's live, work, and visit opportunities, including their magnitude, and combines this information with network-based spatial interaction methods to offer an intuitive classification of mixed-use intensity. When captured at the walkable scale, this index reflects human-scale perceived intensity. While our focus here is on mixing of the physical attributes of the city's morphology, these indicators suggest highly mixed neighbourhoods may exhibit social dynamism and propinquity. This research into spatial interaction could be extended further to examine the link between the physical environment and social interaction and urban vibrancy. Enabled by new sources of data and computing power, we suggest this method presents an important new tool for benchmarking the form and function of complex cities in the 21st century.

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