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Check-in behaviour and spatio-temporal vibrancy: An exploratory analysis in Shenzhen, China

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ABSTRACT

Urban vibrancy describes the attraction, diversity and accessibility of a place and exhibits spatio-temporal variability. The relationships between urban vibrancy and land-use configurations are significant for governments, planners and residents. To date, it is challenging for traditional census datasets to support real-time analysis with detailed spatial and temporal granularity. This article takes advantage of emerging crowdsourcing data and adopts social media check-ins over a 24-h period as a proxy for urban vibrancy. A framework that incorporates kernel density estimation (KDE), geographically and temporally weighted regression (GTWR) and the Herfindahl-Hirschman index (HHI) is proposed to explore the spatio-temporal distribution characteristics of vibrancy and the spatio-temporal relationships with the influential factors. The results show that the evolution of vibrancy is influenced by various factors that are heterogeneous over space and time. With a new perspective and deeper understanding of the varying spatio-temporal relationships between vibrancy and point of interest (POI)-based configurations, this study can offers meaningful implications for policy makers and planners regarding the improvement of resource utilization and the rational design of neighbourhoods.

1. Introduction

Urban vibrancy describes the attraction, diversity and accessibility of a place. It can also reflect human activities and their interactions with spatial entities, which exhibits spatio-temporal variability. Vibrancy is an essential element for achieving urban quality of life, originating from good urban form, well-developed urban functions and sufficient urban activities (Jin et al., 2017). Therefore, scholars are keenly interested in urban vibrancy, a concept first described by Jacobs as follows: "liveliness and variety attract more liveliness; deadness and monotony repel life" (Jacobs, 1961, 1969). Lynch (1984) added that vibrancy has three main components: urban morphology, urban function and urban society. Then, March et al. (2012) noted that measuring vibrancy should consider the range of experiences required for a healthy life, including privacy, rest and contemplation.

Although the definitions and measurements of vibrancy differ slightly, most scholars and theories have stated that urban vitality is closely intertwined with land-use configurations and is defined as the recognized human use of land in a city (Coupland, 1997; Li et al., 2016). Many existing studies have attempted to prove that reasonable planning and mixed land-use configurations can increase urban functionality, prolong activity intensities and improve vibrancy at a city scale. Therefore, the increasing interest in improving vibrancy requires a deeper understanding of land-use configurations. While land-use configurations are important to vibrancy, there are also difficulties in measuring vibrancy due to a lack of appropriate data and effective means. Moreover, the question of how to allocate the land use and facilities to promote urban vibrancy has still not been answered articulately. Briefly, there are two main issues in studying urban vibrancy. On the one hand, it is important to find a suitable proxy to precisely measure vibrancy; on the other hand, how to explore the quantitative relationships between vibrancy and land-use configurations is vital.

Fortunately, the rapid development of information and communication technologies (ICTs) has transformed the focus of GIScience towards the spatial, temporal, and dynamic relationships of human behaviours and the environment while also filling many of the gaps of traditional statistical datasets (Shaw, Tsou, & Ye, 2016). As one of the most popular types of geo-tagged data, the spatio-temporal patterns of

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social media check-in data from different locations in a city indicate population distribution, mobility and preference. Check-in data have great potential to provide significant information regarding people's daily activities at different locations and times, and these data have been widely used to analyse patterns of human mobility (Wu, Zhi et al., 2014; Jurdak et al., 2015) and urban structure (Liu et al., 2016; Wu et al., 2016; Zhi et al., 2016). Therefore, this study uses social media check-in data during all hours of a day as a proxy for vibrancy according to the definition of vibrancy (Jacobs, 1961, 1969). Moreover, this study focuses on exploring the quantitative relationships between vibrancy and land-use configurations.

Methodologically, a multitude of models devoted to revealing the relationships between variables have been developed, including multiple linear regression, geographically weighted regression (Fotheringham, Brunsdon, & Charlton, 2003) and spatial filtering model (Griffith, 2004). Notably, human mobility and aggregation show high degrees of temporal and spatial regularity because people often travel to places with certain intentions (Schafer, 2000; Wu, Zhi et al., 2014; Li et al., 2016). For example, many people work from sunrise to sundown. Thus, people are often at their workplaces during daytime hours and resting at their residences during the night. Check-in data that record users' locations over time reflect one dimension of urban vibrancy and dynamics. Thus, location and time are important determinants of urban vibrancy. A popular local regression technique called geographically and temporally weighted regression (GTWR) is adopted in this article to assess heterogeneous relationships over space and time (Huang, Wu, & Barry, 2010). GTWR examines local parameters, rather than global, thereby providing a method for studying the effects of local geography on the relationships between urban vibrancy and its influential factors considering spatial and temporal non-stationarity.

Therefore, this article aims to (1) verify the applicability of the potential data source as a proxy of urban vibrancy, (2) explore the relationship between vibrancy and land-use configurations, and (3) effectively visualize the estimated coefficients representing quantitative relationships between vibrancy and land use. Specifically, this research proposes a framework that integrates kernel density estimation (KDE), geographically and temporally weighted regression (GTWR) and the Herfindahl-Hirschman index (HHI) to characterize the dynamic vibrancy that is related to land-use configurations and other location-specific variables. KDE is applied to measure the spatio-temporal density variation of human behaviour and mobility and verify the validity of check-in data to represent urban dynamics. The results of KDE capture the structure of vibrancy and reflect the less evenly distributed vibrancy over space and time. The influential factors of city vibrancy have been a continuing topic in related research fields, and a thorough understanding of these significant factors is crucial for promoting vibrancy. Considering the fine spatial and temporal granularity of urban vibrancy, GTWR provides excellent advantages in addressing spatial-temporal heterogeneity and is chosen to model the relationships between vibrancy and influencing variables in this article. Although GTWR can address spatial-temporal varying relationships well, the results are difficult to visualize, and the positive and negative effects of variables may offset each other ineluctably if only averages are used to explore spatio-temporal variations. Therefore, HHI is applied to decompose the spatio-temporal varying relationships between vibrancy and factors.

This article introduces social media data to study urban vibrancy. The proposed framework is applied to Shenzhen, China. The results shed light on urban vibrancy in relation to land-use configurations. In principle, this framework can be popularized and transferred to any other study area. Our study can provide useful information to city governments, local organizations, planners, residents, visitors, and anyone seeking to learn more about a city. The remainder of this paper is organized as follows. Section 2 reviews related research on urban vibrancy, land-use/POI-based configurations and GTWR. Section 3 describes the study area and data, including check-in data and POI data. Section 4 describes the framework and corresponding methods in detail. Section 5 discusses the spatial and temporal variations in vibrancy and its spatio-temporal relationships. Section 6 concludes the paper and describes our future work.

2. Literature review

2.1. The measurements of vibrancy

The concept of vibrancy is closely associated with activity intensity and is an important characteristic of public spaces, particularly at the scale of streets and neighbourhoods. Jacobs (1961, 1969) claimed that urban vitality is street life over a 24-h period. Montgomery (1995, 1998) described urban vibrancy as the number of people in and around streets or neighbourhoods (i.e., pedestrian flow) at different times of day and night. With increasing interest in measuring vibrancy, different factors, such as housing/land prices (Nicodemus, 2013; Wu et al., 2016), cultural clusters (Stern & Seifert, 2010), night-time light data (Mellander et al., 2015), built-environment attributes (Winters et al., 2010), population census data, employment rates (Harvey, 2001), and accessibility and connectivity (Braun & Malizia, 2015), are being used to evaluate urban vibrancy. However, these previous studies have all neglected an important issue: One of the most striking features of urban vibrancy is the varying number of people in a location over time (Jacobs, 1961; Montgomery, 1998). Although traditional data collection methods, such as surveying and interviewing, provide detailed and authentic user profiles that include gender, age, and work, those indicators are costly and static and hardly represent population dynamics.

Geo-tagged data, such as social media data, global positioning system (GPS) data from taxis, bus smart-card data (SCD) and cell phone signal data, provide significant advantages that facilitate people to capture the diverse profiles of the urban structure from the perspective of social sensing (Liu et al., 2015). Compared with other location-based data (LBS) and traditional datasets, social media check-in data offer two prominent advantages: (1) Check-in data are spatial footprints of people's activities that can reflect individual travel demands and connect to POI types, and (2) check-in data are relatively easy to obtain through corresponding application program interfaces (APIs) without encountering privacy issues or data qualification. A number of novel studies have used check-in data to analyse a population's mobility (Lin & Cromley, 2015), reflect urban functional structures (Zhen et al., 2017; Zhi et al., 2016) or explore the effects on other urban geographical and economic elements (Shen & Karimi, 2016; Wu et al., 2016).In addition, a number of studies have attempted to correlate check-in data with population density information and DMSP/OLS night-time light image data (census data and remote sensing data, respectively) to assess urban vibrancy (Duggan & Brenner, 2013; Li, Goodchild, & Xu, 2013; Lin & Cromley, 2015; Jendryke et al., 2017). The aforementioned studies have confirmed that check-in data contain precise spatial and temporal information and can reveal activity patterns beyond the night-time residential geographies of conventional and static statistical data sources (Longley et al., 2015). However, these studies have mainly concentrated on using check-in data alone to reflect certain structures and lack analyses and discussions of internal mechanisms. Few studies have taken full advantage of social media check-in data to study urban vibrancy and explore its significant influencing factors.

2.2. Vibrancy and land use

The effect of land use on vibrancy is not a new area of inquiry. The earliest exploration of this topic can be traced back to Howard (1898) and Geddes (1915), who studied living-condition improvements through the optimization of land-use distribution. Before these studies, no clear definition of vitality was available. Jacobs (1961, 1969) was the first to describe vibrancy and implied a correlation between mixed