https://doi.org/10.1016/j.habitatint.2020.102238

This is the Pre-Published Version.

Understanding livable dense urban form for social activities in transit-oriented development through human-scale measurements

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A B S T R A C T

Transit-oriented development (TOD) has been one of the critical concerns for developing dense urban form. Capturing the human-scaled effects of dense urban form in TOD remains poorly explored. This study aims to devise human-scaled measurements to investigate the areas around metro stations in TOD, focusing on the interaction between the physical environment and residents' activities. We employed Urban Network Analysis (UNA) in GIS at the building level with five metrics—*Reach, Betweenness, Gravity, Closeness, and Straightness*—to delineate the spatial configurations of TOD areas; compiled Facebook check-in and points of interest (POIs) data to capture residents' social activities; and synthesized urban form attributes and social activities with a spatial lag model to explore spatial correlations. Urban forms within an 800-m TOD radius have significant impacts on the spatial distribution of POIs and social activities. Traditional neighborhoods are characterized by high *Reach* *Gravity*, and *Betweenness values*, equipped with spatially evenly distributed and rich urban functions of facilities, services, and social activities, whereas integrated development neighborhoods are associated with high *Closeness values* and are equipped with agglomerated facilities, services, and social activities. Furthermore, the residents' social activities vary by time and generally happen in high *Betweenness* and *Gravity* areas during leisure hours. Strengthening urban form through dense road networks, small blocks, side streets, and direct linkages will encourage social activities and enhance residents' accessibility to facilities and services. Urban form follows neighborhood functions that determine a good street life of services, facilities, and social activities.

Keywords:
Urban form
Social activities
Function
Liveability
Human-scale measurements
Urban network analysis (UNA)

1. Introduction

Urban development has sought a dense urban form to combat outward urbanized expansion as the population has grown rapidly and concentrated in cities alongside land constraints. Land use constraints form the cornerstone of Hong Kong's ability to develop a dense urban form and rely on public transport. Historically, as Hong Kong has grown and developed, the Mass Transit Railway (MTR) system has also expanded, providing a crucial artery of connection for residents' everyday lives within transit-oriented development (TOD) areas. Hong Kong's TOD's current state provides a lifestyle and development prototype for global densely populated cities (Cervero & Murakami, 2009; Loo, Cheng, & Nichols, 2017).

The Hong Kong government adopts a TOD approach as a key strategy for its long-term planning and development of advancing a livable dense urban form. As the population continues to increase, Hong Kong will undoubtedly expand the high-standard metro system—the MTR. As one of the most efficient and most massive volumes public transit systems in the world, the MTR was used by 43.8% (more than 5.5 million) of Hong Kong passengers for their daily commutes in 2016 (commute [HK Transport Department, 2017a]). Furthermore, The Hong Kong government and the Mass Transit Railway Corporation (MTRC) have encouraged the development of a "rail + property" mode in exchange for the efficient use of land by enhancing building complexes on top of the land around MTR stations (Hui, Dong, Jia, & Lam, 2017; Hui, Zhong, & Yu, 2016). In return, this initiated development has forged a highly dense building environment in the immediate surroundings of MTR stations, which attracts numerous commercial establishments, activities for people, and economic benefits. MTR stations, thus, become the lifeblood of local neighborhoods in various shapes and sizes, which ultimately serve the social, environmental, and economic needs of residents.

TOD is considered a development model for enhancing land use and transit operations' efficiency (Cervero & Kockelman, 1997; Lin & Li, 2008). Numerous studies have extensively examined the effects of urban form on travel behavior under the context of TOD (e.g., Andrew & Fan, 2016; Cervero, 2004; Kamruzzaman et al., 2014; Lang, Chen, Chan, Yung, & Lee, 2019; Li et al., 2019; Lyu, Bertolini, & Pfeffer, 2016; Ma, Chen, Li, Ding, & Wang, 2018; Wey, Zhang, & Chang, 2016). Dense and mixed-use transit nodes support the clustering of functions and activities (Ozbil, Peponis, & Bafna, 2009; Peponis, Bafna, & Zhang, 2008). People move to live closer to MTR stations, which increases the need to develop a livable dense urban form that substantially increases residents' quality of life (QOL) (Cervero & Murakami, 2009; Loo, Chen, & Chan, 2010). An increased amount of pedestrian activity is likely to happen in the well-designed mixed-use centers with street crossings, sidewalks, etc. (Hess, Moudon, Snyder, & Stanilov, 1999). Images of the city are durable and evolving as the city itself endures and transforms in form and function (Duany & Talen, 2002; Lang, Chen, & Li, 2016). However, the unique areas of transit nodes should recognize the specific urban form and its users' characteristics. Therefore, we pose a question, "Do TOD characteristics differ systematically based on how station-built environment affect residents' daily lives and their spatial and temporal preferences?"

It is perplexing to model TOD planning because there are multiple objectives, it is nonlinear, and it involves complex integer programming. Existing research on possible quantitative ways to model TOD planning remains deficient despite manifold studies with qualitative explorations on TOD planning's basic principles and strategies (Ma, Liu, Wang, Wen, & Wu, 2017). Furthermore, due to data limitations, most previous studies use travel and urban form information to analyze census tracts, ZIP code areas, and transportation analysis zones. However, it is difficult to use these units to identify how the neighborhood-scale aspects are related to human activities. Moreover, few studies have integrated street networks into their network TOD models. Otherwise, studies have ignored several

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important factors, such as the station's accessibility and the relationship between the station-based neighborhood's specific form and its functionality (Levinson & Krizek, 2005). The inclusion of these factors is crucial to adequately investigate the interaction between urban form and travel behavior and the subsequent TOD outcomes (Krizek, 2003).

This study investigated human activity distributions around TOD in relation to all establishments within an 800-m radius on road networks. The presence of human activity constitutes an essential aspect of high- density cities' livable and walkable neighborhoods. Initially, we comprehensively examined urban form through an Urban Network Analysis (UNA) in a high-density city of Hong Kong. Subsequently, we analyzed the distribution of human activities using social media data via *Facebook* within the TOD range. We used a spatial lag model (SLM) to investigate how physically built environments affected pedestrian accessibility and residents' activities. The results can provide future urban planning recommendations to improve existing TOD and develop new TOD (in Hong Kong and abroad) to enhance pedestrian accessibility and livability.

The remaining paper is structured as follows: Section 2 conducts a critical review regarding the interaction between urban form and TOD. Section 3 presents the study area, data, and methods. Section 4 outlines the TOD urban form's characteristics with UNA and each TOD street activity's results using *Facebook* check-in data. Section 5 discusses the relationship between urban form and human activities in selected MTR transit node areas and provides planning recommendations. Section 6 concludes the paper.

2. Literature review

2.1. Association between urban form and TOD

A TOD is usually defined by an area that has an 800-m distance surrounding a transit station, which is tantamount to a maximum 10- min walking distance from a transit station for an average person. Developing a walkable environment with metro stations—an essential element of TOD planning—may provide a healthy lifestyle for residents (Ewing & Cervero, 2010), and it has the potential to improve livability, social lives, and other activities (Loo et al., 2010). Furthermore, TOD areas are identified as a collection of distinct places that encourage compact development. Connecting services, recreational activities, living areas, workplaces, and metro stations are crucial for promoting vitality in a successful TOD (Chen, Hui, Lang, & Tao, 2016; Sun, Zacharias, Ma, & Oreskovic, 2016). Metro stations have been described as the focal points of multiscale city districts that serve as catalysts for revitalizing population and space flow (Vale, 2015). However, not all station catchment areas are the same, and the heterogeneity among station area contexts are associated with various TOD outcomes.

Urban form is defined in this paper as the size and composition of the neighborhoods and communities around stations, which differ for each location. Numerous works have examined urban form's impact on human activity patterns and travel behavior; the association between urban form and TOD encourages high levels of walking accessibility to transit modes (Duncan, 2011; Frank & Engelke, 2001; Handy, 1996a; Huang & Wong, 2016). Compact land use in high-density cities encourages walking and improves overall public transit services (Cervero & Kockelman, 1997; Krizek, 2003; Lang, Long, & Chen, 2018). Developing the transit node environment becomes vital for the success of any given TOD in a livable dense urban form (Belzer & Autler, 2002; Chen, Hui, Wu, Lang, & Li, 2019; Kim, Park, & Lee, 2014). Therefore, a good walkable urban form at the neighborhood scale is a crucial indicator of the walkability of the TOD environment (Schlossberg & Brown, 2004).

2.2. Effects of street configuration on individual travel choice

Empirical TOD research that addresses how the built environment (various forms of street and building patterns) influences travel behavior is framed around three environmental elements: density, land use, and street configuration (Ewing et al., 2011; Higgins & Kanaroglou, 2016; Sung & Oh, 2011). This existing research specifically focuses on the creation of a pedestrian-friendly environment near transit nodes with local street connectivity, road segments, block sizes, building design patterns, density, and intersection patterns (Boarnet & Crane, 2001; Cervero & Kockelman, 1997). Differences in transit ridership across varying neighborhood typologies (e.g., traditional neighborhoods versus standard neighborhoods) are attributed to the differences in street network configurations and walkability levels (Frank & Engelke, 2001). The streetscape and distribution of urban space within a given area impact daily pedestrian activities and walking travels (Ozbil et al., 2009).

However, the literature does not account which factors on a human- scaled dimension intervene in the relationship between urban form and TOD (Calthorpe, 1993; Ratner & Goetz, 2013; Sun et al., 2016); furthermore, this research uses building information and social media data. In contrast to the focus on density and land use, relatively little attention has been paid to the importance of the layout of streets and buildings' placement and design. This is due to the absence of fine-scaled measures that can capture how urban form and individuals intersect (Handy, 1996b) and the weakness of the available urban spatial data and tracked individual trajectories (Liu, Sui, Kang, & Gao, 2014; Shen & Karimi, 2016).

With increasing social media check-in data, which create geo-tagged information and have sharing abilities, we can demonstrate individual mobility patterns at different spatial and temporal scales (Hasan & Ukkusuri, 2014). Moreover, we can use this data to share individual location preferences in urban spaces (Wyly, 2014). Furthermore, a new type of fine-scale data that contains detailed information, including building blocks and points of interest (POIs), can identify and model human mobility patterns and investigate the impacts of the built environment on the spatial interaction between users and real urban spaces (Huang & Wong, 2016; Liu, Wang, Wen, & Wu, 2017; Long, Gu, & Han, 2012; Long, Zhai, Shen, & Ye, 2018; Luo, Cao, Mulligan, & Li, 2016). The availability of spatiotemporally tagged big data helps to understand TOD implications and explore how human-scale urban form impacts pedestrians, human activities, and performances within given TOD areas.

A geographic information system (GIS) offers a rich set of tools to analyze spatial data, and network analyses in the spatial analysis of cities have long been applied in land use planning, transportation planning, and urban geography (Porta, Crucitti, & Latora, 2005). Sevtsuk (2014) used UNA tools to analyze location patterns of retail and food establishment in dense urban environment. Comber, Brunsdon, and Green (2008) applied a GIS-based network analysis to quantify the differences in urban green space accessibility for different ethnic and religious groups. Lang et al. (2019) investigated the distribution of community facilities based on pedestrian street patterns through a network analysis. Buildings accommodate most social activities and act as the key nodes of an urban environment. The UNA approach, as compared with previous spatial network studies, has added buildings (or event locations: e.g., land parcels, transit stations, and POIs) to the network representation of urban settings. This approach can capture the edges and nodes of the urban street network and the flows between buildings, which allows us to account for individual travel behavior, building density, land use patterns, and planning decisions. *2.3. Inhered association among accessibility, urban form, and TOD*

Urban form refers to spatial patterns of buildings, spaces, and streets (Munshi, 2016). Conversely, buildings, streets, and human activities introduce a combined effect that characterizes the physical configurations of a human-scaled urban space (Day, Alfonzo, Chen, Guo, & Lee, 2013). Urban form measurements are interrelated with activity patterns (Handy, 1996b). Research discloses the complicated interactions among urban form, accessibility, and walkability (Ewing & Cervero, 2010; Frank et al., 2006; Smith, Nelischer, & Perkins, 1997). Identifying the composition of individual buildings around the station is vital for defining the overall development.

TOD's primary objectives include creating walkable communities with diverse activities for engendering livability and improving public health. Pedestrian accessibility along the actual street paths is fundamental in TOD planning, and the linkages and connections that pedestrian accessibility brings are important in compact cities. People living in more walkable neighborhoods (characterized by mixed-use buildings, functional street connectivity, high density, and pedestrian-oriented environments) walk more than people living in less walkable communities (Frank et al., 2006). Furthermore, residents' movements are related to social interaction because they interact in offices, shops, residences, entertainment spaces, and parks.

Beneficial urban form characteristics are relied upon to create vibrant neighborhoods that attract human activities and integrate occupants and passersby with supporting neighborhood services and amenities (Hui, Dong, & Jia, 2018; Loo et al., 2017; Luederitz, Lang, & Von Wehrden, 2013). A thriving community makes people feel safe while walking in the streets and encourages pedestrian spaces (Jacobs, 1961). Few studies have specifically assessed TOD neighborhood environments to identify their effects on densely populated cities. The literature is also unclear regarding buildings and street networks' effects on pedestrian activities in the context of metro stations.

3. Methodology

3.1. Study area

Hong Kong, the Specialized Administrative Region of the People's Republic of China, has a total area of 1100 km2, and more than 7 million people inhabit approximately 24% of its entire built-up area. The metro system was developed in the 1970s; the Hong Kong government links TOD by incentivizing the MTRC to develop properties above or around stations in heavily populated urban areas. The metro is residents' primary means of traveling (Cervero & Murakami, 2009). As of 2017, Hong Kong MTR had 187 km of metro lines and 93 stations (see Fig. 1); the average distance was 2 km per station (HK Transport Department, 2017b). One out of every five households live within a 200-m influence zone of a TOD (Cervero & Murakami, 2009).

Transit node areas vary in size, structure, and surrounding environment (e.g., different residential areas, shopping centers, green areas, street life, and pedestrian connections). It is necessary to classify TOD into a typology to improve the characterization of transit node neighborhoods. Certain studies have described station types to differentiate the relationships between walking and TOD (Atkinson-Palombo & Kuby, 2011; Cervero & Murakami, 2009; Zhao & Deng, 2013). In this study, we defined different TOD approaches according to their functions, development backgrounds, and spatial features in three-step categories to classify them: (1) Through (=), Transfer (*), Terminus (#); (2) Local node (L), District center (D), Regional center (R); and (3) Integrated development (ID), Traditional neighborhood (TN), Targeted function (TF) (see Table 1). The TOD areas of Hong Kong Island, Kowloon, and The New Territories were chosen for this study. The 12 selected cases were (see Table 2) Airport, Austin, Causeway Bay, Central, Disneyland Resort, East Tsim Sha Tsui, Jordan, Mong Kok, Tsim Sha Tsui, Tsuen Wan, Wan Chai, and Whampoa. These cases represent the categorized types of transit node areas. Fig. 1a depicts the chosen location's map; Fig. 1b illustrates the Hong Kong MTRC route map.

3.2. Data

Hong Kong government's spatial data (i.e., from the Planning Department and Lands Department, Esri China (HK), and Hong Kong MTRC) were used. Individual-level data include building-related information (size and location), street networks, and MTR station attributes. Social media data were collected from Facebook online check-in records using Python programming on the Graph API (https://developers. facebook.com/docs/graph-api).

Facebook page activity records data were obtained using geographical information at specific time slots (9:00–10:00, 12:00–13:00, 15:00–16:00, 18:00–19:00, and 21:00–22:00) on Monday, Thursday, and Saturday in the same week (sampled on July 6, 8, and 10, 2017). Measuring social media records in the streets estimates the volume of human activities and reflects TOD's spatial characteristics.

POIs are neccessary metadata that helps us understand the interaction between urban form and daily human life (e.g., agglomeration of activities, mobility, and communication). In the entire Hong Kong region, 53,103 POIs are recognized with 33,333 TOD areas (that people have checked into via Facebook). The survey reports *The State of Social Media Usage in Hong Kong* (Stacey Rudolph, 2015) states that 70% of Hong Kong's population (i.e., 5 million Internet users) increasingly favors social media, *Facebook*, for maintaining social relationships. *Facebook* is Hong Kongers' most influential social media—approximately 79% of 2.6 million Facebook users use its "Like" feature, while 72% use it for personal communication. *Facebook* online check-ins were counted five times a day, 1 h each time to ensure that individual activity records were counted at different times on different days in one week. The records were also spatially mapped with POIs in TOD areas at various times. When the count was complete, we prepared a final classification with corrections for each record. The counts were used to measure how

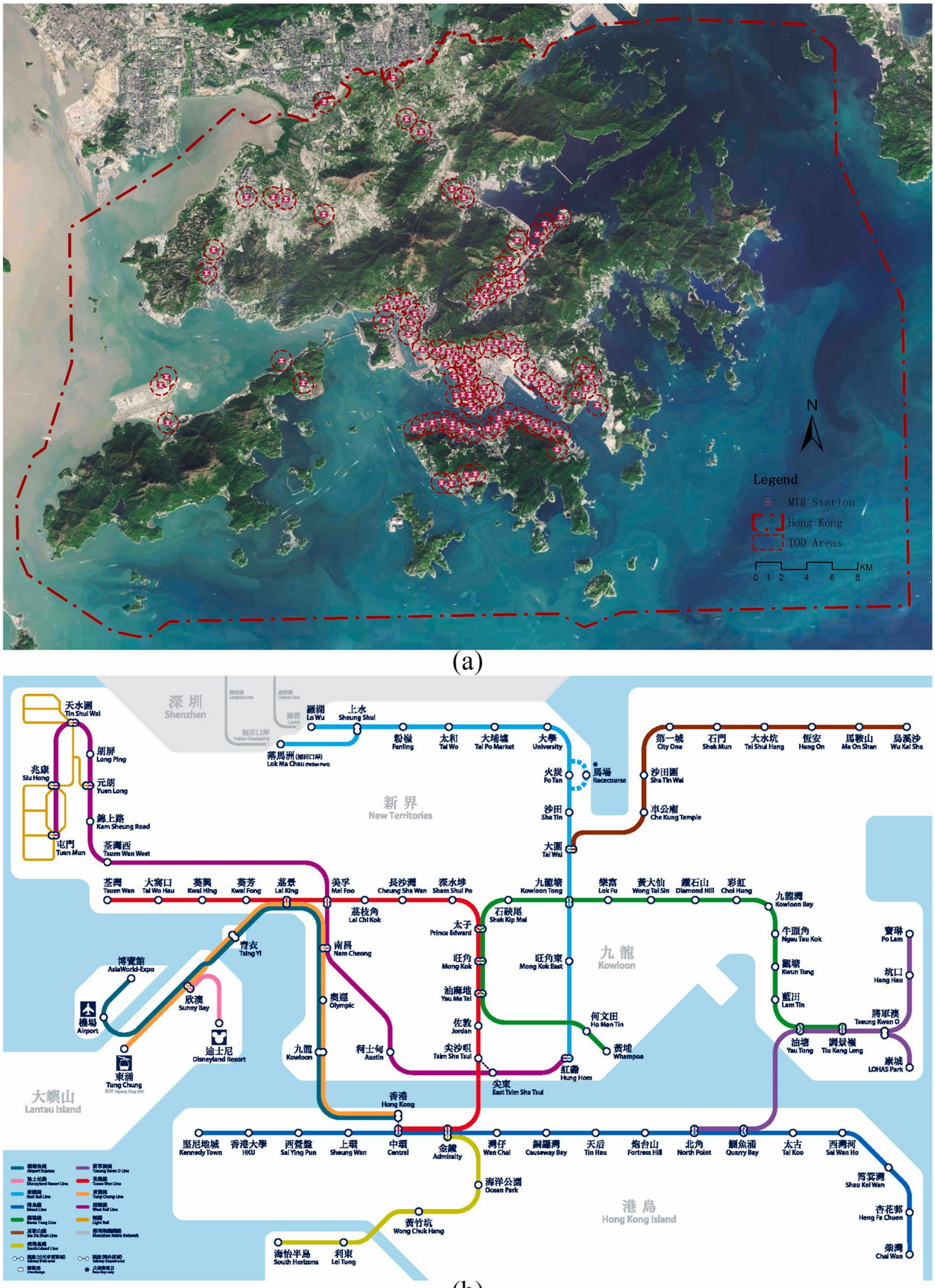

Fig. 1. Map of Hong Kong and its MTR metro system. Fig.1a. illustrates the Hong Kong MTR metro system overlaid on the city map. The red MTR symbol denotes the MTR station, and the black circles show areas within 10 min walking distance from MTR stations. Fig.1b. shows the transit system of 93 metro stations. Adopted from Hong Kong MTR website. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Classifications of Hong Kong MTR stations and TODS, 2017

Admiralty	*	D	ID	Jordan	=	L	TN	Ngau Tau Kok	=	L	TN	Tai Shui Hang	=	L	TN
Airport	=	R	TF	Kam Sheung Road	=	L	TN	North Point	*	D	TN	Tai Wai	*	L	TN
AisaWorld-Expo	#	L	TF	Kennedy Town	#	L	TN	Ocean Park	=	L	TF	Tai Wo	=	L	ID
Austin	=	L	ID	Kowloon	*	D	ID	Olympic	=	L	ID	Tai Wo Hau	=	L	TN
Causeway Bay	=	D	ID	Kowloon Bay	=	L	TN	Po Lam	#	L	ID	Tin Hau	=	L	TN
Central	*	D	ID	Kowloon Tong	*	D	ID	Prince Edward	*	L	TN	Tin Shui Wai	*	D	TN
Chai Wan	#	D	ID	Kwai Fong	=	L	ID	Quarry Bay	*	D	TN	Tiu Keng Leng	*	L	TN
Che Kung Temple	=	L	TN	Kwai Hing	=	L	TN	Racecourse	=	L	TF	Tseung Kwan O	*	D	ID
Cheung Sha Wan	=	L	ID	Kwun Tong	=	D	ID	Sai Wan Ho	=	L	TN	Tsim Sha Tsui	*	D	ID
Choi Hung	=	L	TN	Lai Chi Kok	=	L	TN	Sai Ying Pun	=	L	TN	Tsing Yi	*	D	ID
City One	=	L	TN	Lai King	*	L	TN	Sha Tin	=	D	ID	Tsuen Wan	#	D	ID
Diamond Hill	=	L	ID	Lam Tin	=	L	TN	Sha Tin Wai	=	L	TN	Tsuen Wan West	=	L	TN
Disneyland Resort	#	L	TF	Lei Tung	=	L	TN	Sham Shui Po	=	D	TN	Tuen Mun	*	D	ID
East Tsim Sha Tsui	*	L	ID	Lo Wu	#	R	TF	Shau Kei Wan	=	L	TN	Tung Chung	#	D	ID
Fanling	=	D	ID	LOHAS Park	#	L	ID	Shek Kip Mei	=	L	ID	University	=	L	TF
Fo Tan	=	L	TN	Lok Fu	=	L	ID	Shek Mun	=	L	TN	Wan Chai	=	D	TN
Fortress Hill	=	L	TN	Lok Ma Chau	#	R	TF	Sheung Shui	*	D	ID	Whampoa	#	L	TN
Hang Hau	=	L	ID	Long Ping	=	L	TN	Sheung Wan	=	L	TN	Wong Chuk Hang	=	D	TN
Heng Fa Chuen	=	L	ID	Ma On Shan	=	L	ID	Siu Hong	*	L	TN	Wong Tai Sin	=	L	ID
Heng On	=	L	TN	Mei Foo	*	L	TN	South Horizons	#	L	TN	Wu Kai Sha	#	L	TN
HKU	=	L	TN	Mong Kok	*	D	TN	Sunny Bay	*	L	TF	Yau Ma Tei	*	D	TN
Ho Man Tin	=	L	TN	Mong Kok East	*	L	ID	Tai Koo	=	L	ID	Yau Tong	*	L	TN
Hong Kong	*	D	ID	Nam Cheong	*	L	TN	Tai Po Market	=	D	ID	Yuen Long	*	D	ID
Hung Hom	*	D	ID												

Notes: Stations classified as: Through (=), Transfer (*), Terminus (#); Local node (L), District center (D), Regional center (R); Integrated development (ID), Traditional neighborhood (TN), Targeted function (TF).

Table 2
The 12 selected TODs areas of MTR transit nodes.

Name	Type	Name	Type	Name	Type
Central	*DID	East Tsim Sha Tsui	*LID	Whampoa	#LTN
Tsim Sha Tsui	*DID	Tsuen Wan	#DID	Causeway Bay	= DID
Mong Kok	*DTN	Disneyland Resort	#LTF	Wan Chai	= DTN
Austin	= LID	Jordan	= LTN	Airport	= RTF

Notes: Stations classified as: Through (=), Transfer (*), Terminus (#); Local node (L), District center (D), Regional center (R); Integrated development (ID), Traditional neighborhood (TN), Targeted function (TF).

the residents and visitors traverse the TOD station areas. Consequently, we compared workdays and weekends in the morning, noon, afternoon, evening, and night sections for all TOD types.

3.3. Methods

We employed human-scaled measurements to observe TOD urban form using UNA, and we compared TOD street activities using tracked *Facebook* online check-in data within TOD areas. This study investigated the TOD areas typically traversed by residents in all directions and at a constant pace. We considered a TOD area to be the 10-min walkable area around each station. First, we used UNA to assess how the TOD area's built environment layout impacts pedestrian accessibility. The analysis focused on foot travel to neighborhood destinations to determine pedestrian access from various origins (e.g., residences, workplaces, and leisure facilities). In the analysis, travel paths are represented by all walkable routes in a city (i.e., street networks with sidewalks). Highways and tunnels are included as roads if these paths have sidewalks and are connected to the street network. Second, we computed personal check-in data that was aggregated hourly at the building level, and we mapped its spatial distribution with respect to MTR station data and the urban form analysis. Third, we used an SLM to measure the spatial relationship of the dense urban form's performance and human activities.

Cities are complex systems; computer-aided spatial analysis models can depict urban street patterns by realistically illustrating diverse participants' general decisions (Banai & Rapino, 2009; Porta et al., 2005). An increased interest in network analyses of complicated urban street patterns has led to the development of new indices of centrality. To capture the neighborhoods' fine-scale spatial characteristics, this study presents five measurements of urban form by applying the Urban Network Analysis toolbox in ArcGIS (Sevtsuk, 2014; Sevtsuk & Mekonnen, 2012): *Reach, Betweenness, Gravity, Closeness,* and *Straightness*. The analysis focuses on one travel mode, walking along with street networks, which allows us to understand spatial relationships between buildings, pedestrian flow on urban streets, and distribution of services in urban environments. In this study, UNA measures buildings (total = 319, 432) and street networks (total = 3288 km [in length]) by calculating the radial buffers of TOD within an 800-m radius around each MTR station, which represents about a 10-min walking area (Fig. 1a). The five types of centrality metrics are shown in detail below.

3.3.1. Reach

Reach centrality $Reach^r[i]$measures building *i* reaches within a walking distance radius along with the road networks in graph G, which indicates the number of surrounding buildings that can be reached from building *i* taking the closest route of distance *r*. This measure is defined by the following:

$$\sum$$

$$Reach^r[i] = \sum_{j \in G-\{i\}, d[i,j] \leq r} W[j] \quad (1)$$

where $d[i,j]$ is the closest route distance between buildings *i* and *j*. $W[j]$ is the weight of the node of building *j*, which illustrates building volume by floor area and height. A buffer area of a limited radius is calculated from building *i* in all directions along with the street network until distance *r* is reached. This index illustrates the number of buildings (by volume) reachable from each building within a 500-m walking distance in all directions along the street network. In high *Reach* value areas, large and densely spaced buildings and street networks are dense.

3.3.2. Gravity

Within a given "search radius" weighted by building attributes, the *Gravity* index measures the spatial accessibility constrained by spatial impedance for traveling to the destinations. The *Gravity* measure, first developed by Hansen (1959), assumes that the accessibility of building *i* is proportional to the weight of destination building *j* but inversely proportional to the distance between buildings *i* and *j*:

$$Gravity^r[i] = \sum_{j \in G-\{i\}, d[i,j] \leq r} \frac{W[j]}{e^{\beta \cdot d[i,j]}} \quad (2)$$

where *Gravity* measures building *i* within graph *G* within search radius *r* by weighting travel destination *j* - $W[j]$, $d[i, j]$is the geodesic distance between buildings *i* and *j*, and exponent *β* adjusts distance decay effects. In high *Gravity* value areas, building volumes are large, road networks are dense, and buildings are located close to one another.

3.3.3. Betweenness

Betweenness characterizes the number of trip frequencies from graph theory, and each connection is passed along the closest routes from origin to destination (Freeman, 1977). Furthermore, *Betweenness* is defined as the fraction of all shortest routes between pairs of other buildings along the street network passing through building *i*. *Betweenness* refers to those facilities between others, which can be used randomly with minimal plans or purposes. The *Betweenness* measure is defined as follows:

$$Betweenness^r[i] = \sum_{j,k \in G-\{i\}, d[i,j] \leq r; d[i,k] \leq r} \frac{n_{jk}[i]}{n_{jk}} \cdot W[j] \quad (3)$$

where $Betweenness^r[i]$measures building *i* within search radius *r* and $n_{jk}[i]$accumulates the total number of trips from building *j* to building *k* passing through building *i* along with the shortest routes. *Betweenness* for building *i* is computed by considering all pairs of buildings *j* and *k* within radius *r* from each other. This measure is computed by considering the pairs of buildings *j* and *k* within distance *r* from *i* and when the shortest path from *j* to *k* (or *k* to *j*), which passes by building *i*, is within *r*.

3.3.4. Closeness

The *Closeness* measure demonstrates the inverse of cumulative travel distance from one building to all other buildings within search radius *r* along with the street network on the shortest paths (Sabidussi, 1966). The *Closeness* measure indicates a building's proximity to all other surrounding buildings within a given distance threshold. Further, the *closeness* measure is denoted as follows:

$$Closeness^r[i] = \frac{1}{\sum_{j \in G-\{i\}, d[i,j] \leq r} (d[i,j] \cdot W[j])} \quad (4)$$

where $Closeness^r[i]$measures building *i* within search radius *r*, $d[i, j]$defines the shortest travel distance between nodes *i* and *j*, and $W[j]$is the weight of path destination building *j*.

3.4. Straightness

The *Straightness* measure indicates the extent of the total distance of the shortest paths from one place to all other places in the neighborhood against the total distance of straight Euclidean paths (Vragovic, Louis, & Diaz-Guilera, 2005). The *Straightness* measure is formally expressed as follows:

$$Straightness[i]^r = \sum_{j \in G-\{i\}, d[i,j] \leq r} \frac{\delta[i,j]}{d[i,j]} \cdot W[j] \quad (5)$$

where $Straightness[i]^r$measures building *i* within search radius *r*, $\delta[i, j]$is the distance of the Euclidean straight line between buildings *i* and *j*, and $d[i, j]$is the travel distance of the shortest paths between the same buildings. The *Straightness* index essentially indicates the length of the shortest path connecting all buildings to surrounding node *j* in comparison with the as-the-crow-flies distance.

3.4.1. Spatial lag model

SLM is used for estimating locational factors' spatial dependence. Social activity is the dependent variable, while spatial metrics form independent variables. Each listed index was run 15 times (five times each day for three sample dates) based on time slots. SLM's general model is provided as follows:

$$y = \rho W_y + X\beta + \varepsilon, \quad (6)$$

where W_y is the dependent variable of an N x 1 vector of spatial lags, *ρ*(Rho) is the spatially autoregressive coefficient of the dependent variable, *X* is the independent variable, $X\beta$is an N x K matrix of observations multiplied by a K x 1 vector of regression coefficients*β* for each *X*, and *ε*is a N x 1 vector of the spatial random error terms.

The SLM was computed with a spatial regression in *GeoDaSpace*, and it appropriately inferred the spatial dependence effect. Similar to the selected values shown in Table 4 for the five metrics, some of the spatial autoregressive parameter (Rho) values were also selected, each of which corresponds to a running result. The significance of Rho is represented by the sampled values of the five metrics with asterisks. *ρ*Rho reflects inherent spatial dependence. P-value with an asterisk demonstrates a significant relationship between the attributes and the probability in the model, resulting in significant spatial dependence. R-squared, Log likelihood, and Akaike info Criterion (AIC) indicate the model fit. A weights matrix was created in the variable selection box in *GeoDaSpace* by setting dependent and independent variables, including the check weight files, browsing to locate the weights matrix (social activities versus five spatial metrics) file, and running the model. Due to the graphic presentation's limited space, we chose 12 stations to be the focus study samples. Moreover, the selection criteria were based on the five metrics' performances and the high-volume flow of social activities. These selected station areas had at least one value ranked at the forefront (Table 3).

4. Results and findings

4.1. Pedestrian access along streets in TOD walkable areas

In the UNA analysis, the various TOD approaches exhibit different performances, and the selected cases represent different TOD classifications. For a helpful illustration of the verified results of the UNA index, as well as the reasons that led to the peculiar distributions of POIs and human-scaled social activities, 12 different types of transit nodes and their TOD areas are interpreted in detail: (a) Airport (=RTF), (b) Austin (=LID), (c) Causeway Bay (=DID), (d) Central (*DID), (e) Disneyland Resort (#LTF), (f) East Tsim Sha Tsui (*LID), (g) Jordan (=LTN), (h) Mong Kok (*DTN), (i) Tsim Sha Tsui (*DID), (j) Tsuen Wan (#DID), (k) Wan Chai (=DTN), and (l) Whampoa (#LTN). Residents are assumed to access their destinations along the pedestrian pathways in all directions within TOD areas. An 800-m TOD area is circled in grey for each selected MTR station in the analysis graphics. Figs. 2–6 depict *Facebook* check-in POIs as dark grey dots; colored buildings in these figures display results for five UNA indices with low to high values (appearing as green and red, respectively).

Table 3
Performance list of top-12 UNA Index and social media activities in selected TODs areas of MTR transit nodes.

No.	Reach	Gravity	Betweenness	Closeness	Straightness	Mon 12–13	Mon 21–22	Thu 12-13	Thu 21-22	Sat 12-13	Sat 15-16	Sat 18-19	Sat 21-22
1	Mong Kok	Mong Kok	Mong Kok	Sha Tin	Sheung Wan	Wan Chai	Wan Chai	Causeway Bay	Wan Chai	Wan Chai	Wan Chai	Wan Chai	Wan Chai
2	Prince Edward	Mong Kok East	Prince Edward	Tai Shui Hang	Sai Ying Pun	Causeway Bay	Causeway Bay	Wan Chai	Causeway Bay	Causeway Bay	Causeway Bay	Causeway Bay	Causeway Bay
3	Sheung Wan	Yau Ma Tei	Mong Kok East	Che Kung Temple	Mong Kok	Disneyland Resort	Tsim Sha Tsui	Airport	Tsim Sha Tsui	Airport	Tsim Sha Tsui	Tsim Sha Tsui	Tsim Sha Tsui
4	Mong Kok East	Sai Ying Pun	Sham Shui Po	Fanling	Central	Airport	East Tsim Sha Tsui	Tsim Sha Tsui	East Tsim Sha Tsui	Tsim Sha Tsui	East Tsim Sha Tsui	East Tsim Sha Tsui	East Tsim Sha Tsui
5	Sai Ying Pun	Prince Edward	Yau Ma Tei	Shek Mun	Mong Kok East	Tsim Sha Tsui	Airport	East Tsim Sha Tsui	Airport	East Tsim Sha Tsui	Airport	Airport	Mong Kok
6	Sham Shui Po	Sheung Wan	Shek Kip Mei	Fo Tan	Prince Edward	Sheung Wan	Jordan	Disneyland Resort	Jordan	Hong Kong	Hong Kong	Jordan	Jordan
7	Central	HKU	Sai Ying Pun	Tai Wo	Hong Kong	East Tsim Sha Tsui	Disneyland Resort	Hong Kong	Hong Kong	Central	Central	Central	Mong Kok East
8	Yau Ma Tei	Olympic	Sheung Wan	Racecourse	Yau Ma Tei	Hong Kong	Hong Kong	Central	Mong Kok	Sheung Wan	Sheung Wan	Hong Kong	Central
9	Shek Kip Mei	Central	Cheung Sha Wan	Tai Po Market	HKU	Central	Central	Sheung Wan	Central	Disneyland Resort	Jordan	Sheung Wan	Hong Kong
10	Hong Kong	Hong Kong	Olympic	Tsuen Wan	Causeway Bay	Mong Kok	Mong Kok	Jordan	Sheung Wan	Jordan	Admiralty	Tin Hau	Airport
11	Wan Chai	Ngau Tau Kok	Jordan	Yuen Long	Tin Hau	Yau Ma Tei	Sheung Wan	Mong Kok	Mong Kok East	Mong Kok	Disneyland Resort	Hung Hom	Yau Ma Tei
12	Causeway Bay	Kwun Tong	Hung Hom	Tuen Mun	Wan Chai	Jordan	Mong Kok East	Sha Tin	Prince Edward	Mong Kok East	Mong Kok	Mong Kok	Sheung Wan

Fig. 2 shows the UNA result of *Reach* in the 12 selected TOD areas. Generally, a TOD range covers a large part of a neighborhood's living environment and contains a majority of urban area check-in POIs in Hong Kong. Most TOD areas present high *Reach*, especially around transit nodes, where a vast quantity of check-in POIs and a high frequency of human activities occur. Large volumes of buildings are accessible in an 800-m walking distance along with a street network within a TOD radius. We observed the pattern in two of the three MTR classifications (i.e., “Traditional neighborhood,” “Integrated development,” and “Targeted function.” We found that integrated development areas around transit nodes have mostly concentrated POIs and individual check-ins, whereas traditional neighborhood areas have spatially scattered POIs and check-ins.

The neighborhoods in the Airport (Fig. 2a), Austin (Fig. 2b), and the Disneyland Resort (Fig. 2e) are distinguishable from others because they serve particular functions. For example, the Austin neighborhood has a large site under construction for a future high-speed train hub and the development of the West Kowloon Cultural District. Compared to other “normal” transit node areas, the Airport and Disneyland Resort neighborhoods have fewer concentrated POIs but higher check-in frequencies. These two special MTR node areas are island models with few adjacent developments, thus producing low *Reach* value.

Fig. 3 shows the UNA index *Gravity* and illustrates red-colored high- value areas clustered around transit nodes, with exceptions given to the Airport (Fig. 3a), the Disneyland Resort (Fig. 3e), Central (Fig. 3d), and Tsim Sha Tsui (Fig. 3i). The first two spatially segregated transit node areas (the Airport and the Disneyland Resort) provide particular services, whereas the latter two neighborhoods (Central and Tsim Sha Tsui) have large buildings in red-colored areas due to their locational advantages and urban functions. Additional traditional neighborhood areas clearly manifest concentric *Gravity* with POIs and check-ins clustered in their transit nodes (e.g., Jordan [Fig. 3g], Mong Kok [Fig. 3h], and Whampoa [Fig. 3l]).

Fig. 4 shows UNA index *Betweenness* and has red-colored high-value areas clustered around transit nodes for the traditional development neighborhoods: Jordan (Fig. 4g), Mong Kok (Fig. 4h), and Whampoa (Fig. 4l). Alternatively, high-value areas are gathered in certain ad hoc places competing with transit nodes: Austin (Fig. 4b), East Tsim Sha Tsui (Fig. 4f), Tsim Sha Tsui (Fig. 4i), and Tsuen Wan (Fig. 4j).

Fig. 5 shows the UNA index *Closeness* where red-colored high-value areas appear to be a clustered distribution not only around transit nodes—Causeway Bay (Fig. 5c) and East Tsim Sha Tsui (Fig. 5f)—but also in certain neighborhood focal places—Central (Fig. 5d) and Whampoa (Fig. 5l). Those high *Closeness* areas contain rich POIs and check-ins. In Mong Kok (Fig. 5h), dense side streets and small-sized street blocks characterize its high *Closeness*, which is distributed around the transit node center, largely covering the whole neighborhood.

Fig. 6 shows the UNA index *straightness*. In Hong Kong, geographical constraints and topography impacts have caused a few neighborhoods to develop into grid blocks. Limited topo-land parcels are built in square grid form, where areas are associated with the high value of *Straightness*—Tsuen Wan (Fig. 6j) and Whampoa (Fig. 6l). Mong Kok (Fig. 6h) is one of the few neighborhoods characterized by a grid street form with high *Straightness,* even though Fig. 6h does not depict a large area of red- colored buildings. Several extremely high *Straightness* values exist in the middle of Mong Kok (colored red), which caused remaining neighborhood quantiles to be relatively green colored even though they have high values compared to other neighborhoods.

Table 3 lists 12 top ranking neighborhoods in the Hong Kong MTR system and reflects quantitative results for selected TOD areas in Figs. 2–6. Generally, Mong Kok, Central, Wan Chai, and Causeway Bay demonstrated the high *Reach* and *Straightness* values; Mong Kok and Central showed high *Gravity* values; and Mong Kok and Jordan exhibited high *Betweenness* values. Wan Chai, Causeway Bay, the Disneyland Resort, the Airport, and Tsim Sha Tsui presented high social activity levels on Monday between 12:00–13:00; Wan Chai, Causeway Bay, Tsim Sha Tsui, East Tsim Sha Tsui, and the Airport expressed high social activity levels on Monday between 21:00–22:00; Causeway Bay, Wan Chai, the Airport, Tsim Sha Tsui, and East Tsim Sha Tsui displayed high social activity levels on Thursday between 12:00–13:00; Wan Chai, Causeway Bay, Tsim Sha Tsui, East Tsim Sha Tsui, and the Airport depicted high social activity levels on Thursday between 21:00–22:00; Wan Chai, Causeway Bay, the Airport, Tsim Sha Tsui, and East Tsim Sha Tsui exhibited high social activity levels on Saturday between 12:00–13:00; and Wan Chai, Causeway Bay, Tsim Sha Tsui, East Tsim Sha Tsui, and Mong Kok embodied high social activity levels on Saturday between 21:00–22:00.

Table 4

Spatial lag model for maximum likelihood estimation of UNA index and social media activities in various Hong Kong TODs areas.

Variables	Time	All MTR nodes areas (observations no. = 93)		Selected MTR node areas of different types (observations no. = 12)	
		Coefficient	Prob.	Coefficient	Prob.
Reach	Mon 9–10	0.0318	0.0677*		
	Mon 21–22	0.0678	0.0697*		
	Thu 15-16	0.0789	0.0737*		
	Thu 18-19	0.0158	0.0765*		
	Sat 9-10	0.0236	0.0645*		
	Sat 15-16	0.0732	0.0263**		
Gravity	Mon 9–10	2.44502e-008	0.0046***		
	Mon 12–13	1.71222e-008	0.0932*		
	Mon 18–19	1.55571e-008	0.0376**		
	Thu 21-22			− 2.25423e-007	0.0598*
	Sat 18-19	− 2.91955e-008	0.0952*	− 2.48765e-007	0.0225**
	Sat 21-22			− 2.70319e-007	0.0863*
Betweenness	Mon 9–10	− 0.0246	0.0829*		
	Mon 21–22	2.59507e-011	0.0543*		
	Thu 21-22	4.14278e-011	0.0023***		

	Sat 18-19	2.68463e-011	0.0823*		
	Sat 21-22	4.02937e-011	0.0416**		
Closeness	Mon 9–10			− 17675.3	0.0778*
	Mon 12–13			− 18560.23	0.0614*
	Thu 09-10			− 16684.76	0.0582*
Straightness	Mon 9–10	− 6.37187e-013	0.0594*		
	Mon 18–19	− 4.83101e-013	0.1000*		
AIC	Mon 9–10	1054.07		159.70	
	Mon 12–13	1068.75		157.92	
	Mon 15–16	1067.16		158.57	
	Mon 18–19	1087.52		162.12	
	Mon 21–22	1166.21		173.05	
	Thu 09-10	1039.94		157.04	
	Thu 12-13	1109.47		165.73	
	Thu 15-16	1055.13		156.96	
	Thu 18-19	1076.84		159.21	
	Thu 21-22	1153.45		169.34	
	Sat 9-10	1103.46		166.62	
	Sat 12-13	1125.49		166.81	
	Sat 15-16	1126.68		165.78	
	Sat 18-19	1150.50		166.83	
	Sat 21-22	1153.45		175.15	

Note: Maximum likelihood spatial lag modeling in GeoDaSpace program. Significance level at *p < 0.1, **p < 0.05, ***p < 0.01.

4.2. Connection between TOD, urban form, and human activities

Based on individual check-in records in selected time periods, all the transit node areas in the entire Hong Kong MTR system were structured by a changing spatial pattern, and a temporal pattern as each TOD area experienced variations in social activities (Fig. 7a). Generally, peak social activity hours were between 21:00–22:00 (nighttime) for weekdays and weekends. The second most common social activity time was noon 12:00–13:00 for weekdays and weekends, and the third most common social activity time was evenings 18:00–19:00 for weekdays and weekends. For weekends, another high-performance social time was afternoons (close to evenings) between 15:00–16:00. The overall intensity of social activities among the TOD areas varies widely from dozens per hour to thousands per hour. The top five ranking areas are Wan Chai, Causeway Bay, Tsim Sha Tsui, East Tsim Sha Tsui, and the Airport, standing out of the remaining more-than-double-average social activity records. The former four neighborhoods, which are commercialized TOD areas, share the same temporal pattern of social activities with high check-in records around noon and at nighttime with peak check-ins occurring during weekend nights. Meanwhile, the Airport shows an opposite trend with more check-ins during the day and fewer at night. This trend can be explained by the fact that the Airport is a target service function and is therefore different from the other MTR neighborhoods.

Fig. 7 corresponds to Table 2 and illustrates an entire distribution of the UNA index and social activities in all TOD areas. Fig. 7b shows that, from Mong Kok to Fo Tan, *Reach*, *Betweenness*, *Straightness*, and *Gravity* generally have similar tendencies. However, Sheung Shui, Hang Hau, Tai Wo, Che Kung Temple, Tin Shui Wai, Tiu Keng Leng have a higher value of *Closeness* but the simultaneous low value of *Reach*, *Betweenness*, *Straightness*, and *Gravity*.

Table 4 is useful to explore the relationship between urban form and social activities as it summarizes the SLM results of the significant factors for the entire MTR system and the selected study cases. Notably, *Reach* is closely linked with social activities occurring on Monday mornings 9:00–10:00, nights 21:00–22:00, Thursday afternoons 15:00–16:00, evenings 18:00–190:00, Saturday mornings 9:00–10:00, and afternoons 15:00–16:00 for all MTR TOD areas. *Gravity* is strongly correlated with social activities occurring on Monday mornings 9:00–10:00, noon 12:00–13:00, evenings 18:00–19:00, and Saturday evenings 18:00–19:00 for all MTR TOD areas and on Thursday nights 21:00–22:00, Saturday evenings 18:00–19:00, and Saturday nights 21:00–22:00 for the selected 12 study cases. *Betweenness* is significantly related to social activities occurring on Monday mornings 9:00–10:00, nights 21:00–22:00, Thursday nights 21:00–22:00, Saturday evenings 18:00–19:00, and nights 21:00–22:00 for all MTR stations. *Closeness* has evident connections with social activities occurring on Monday mornings 9:00–

10:00, Mondays at noon 12:00–13:00, and Thursday mornings 9:00–10:00 for the selected 12 study cases. *Straightness* has strong links with social activities occurring on Monday mornings 9:00–10:00 and evenings 18:00–19:00. The next section presents detailed results,

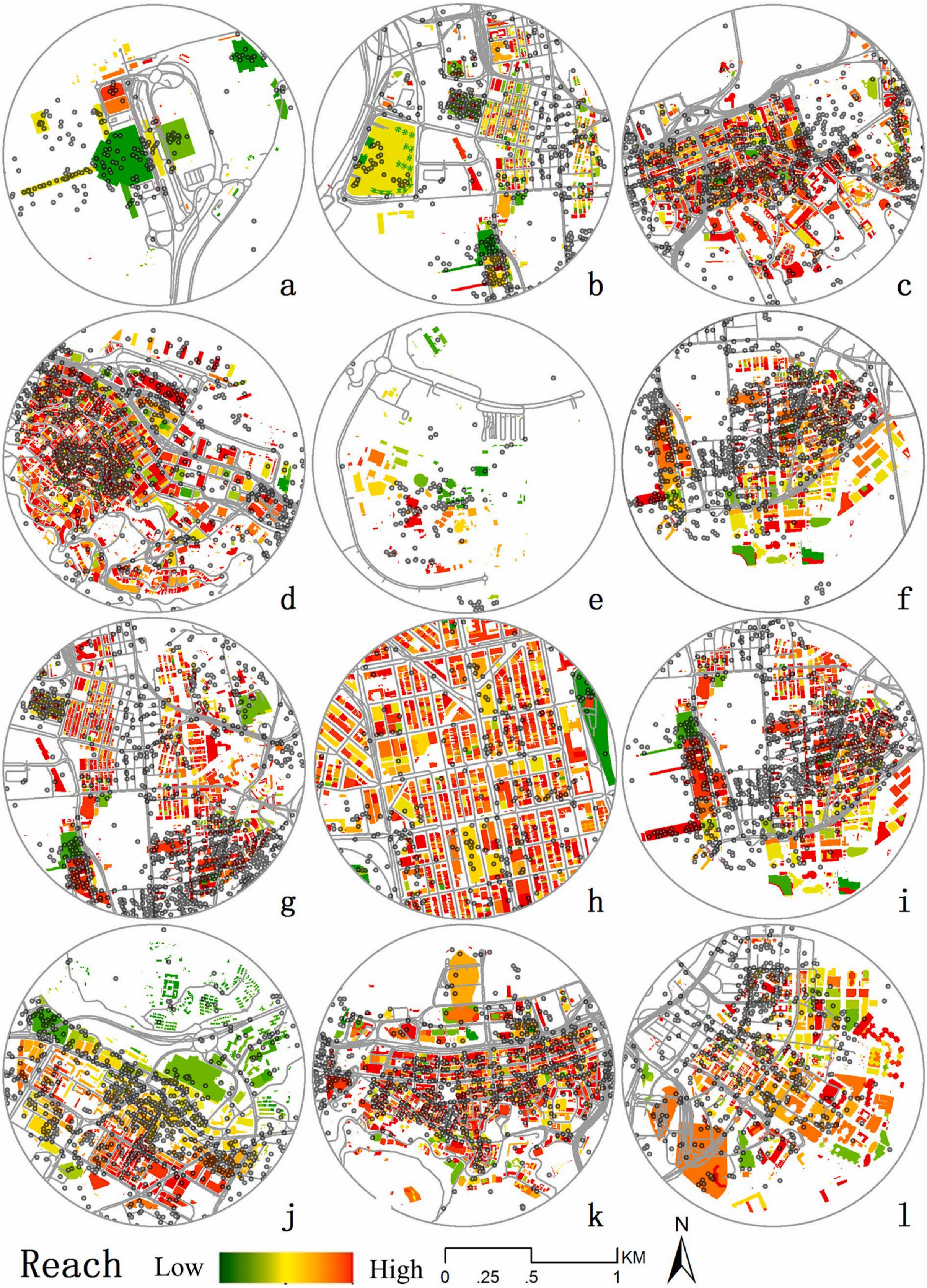

Fig. 2. Reach and Facebook check-in POIs for selected TODs. Grey circle is the MTR station centroid to an 800m TOD range. (a) Airport, (b) Austin, (c) Causeway Bay, (d) Central, (e) Disneyland Resort, (f) East Tsim Sha Tsui, (g) Jordan, (h) Mong Kok, (i) Tsim Sha Tsui, (j) Tsuen Wan, (k) Wan Chai, (l) Whampoa.

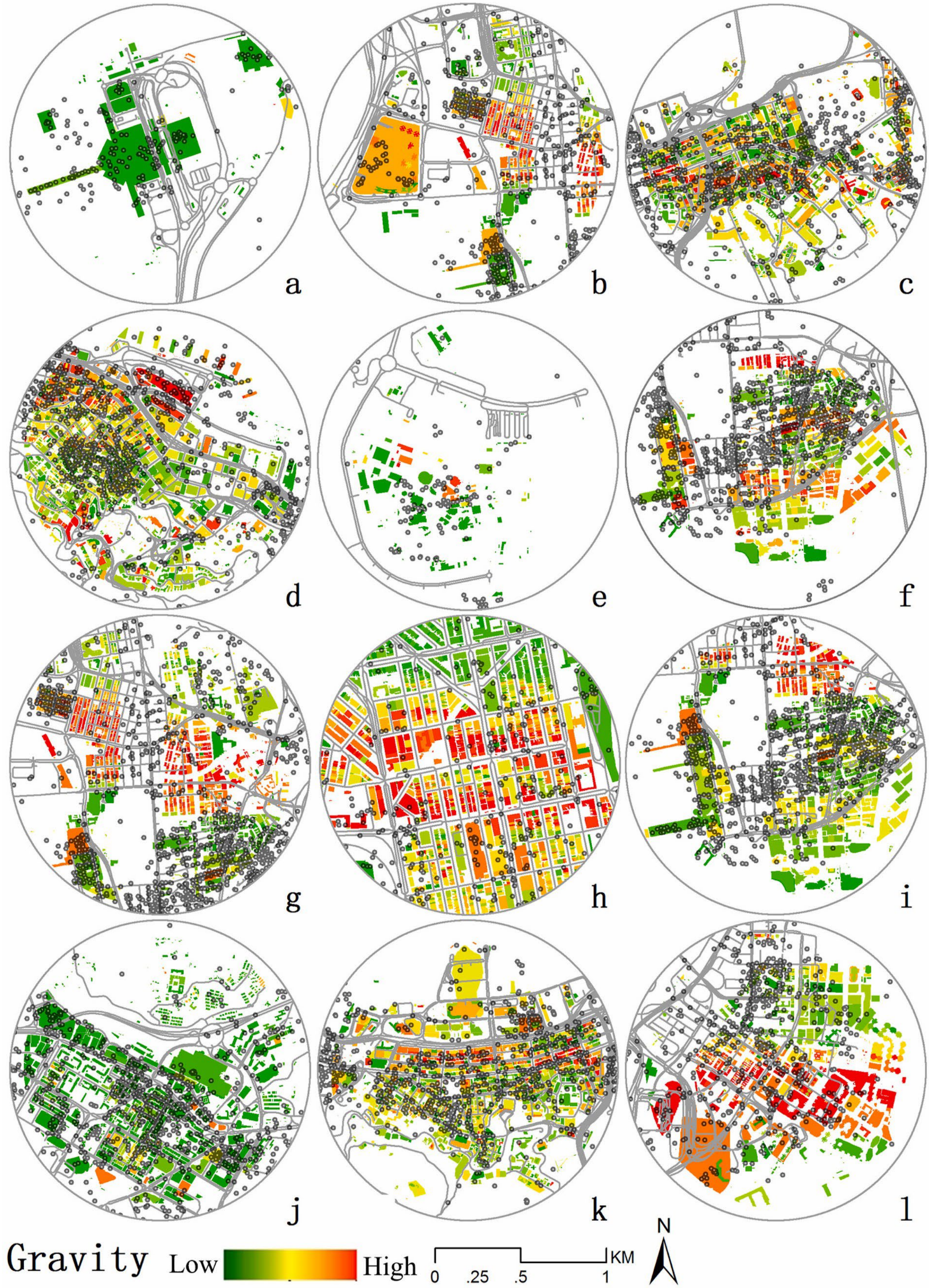

Fig. 3. Gravity and Facebook check-in POIs for selected TODs. Grey circle is the MTR station centroid to an 800m TOD range. (a) Airport, (b) Austin, (c) Causeway Bay, (d) Central, (e) Disneyland Resort, (f) East Tsim Sha Tsui, (g) Jordan, (h) Mong Kok, (i) Tsim Sha Tsui, (j) Tsuen Wan, (k) Wan Chai, (l) Whampoa.

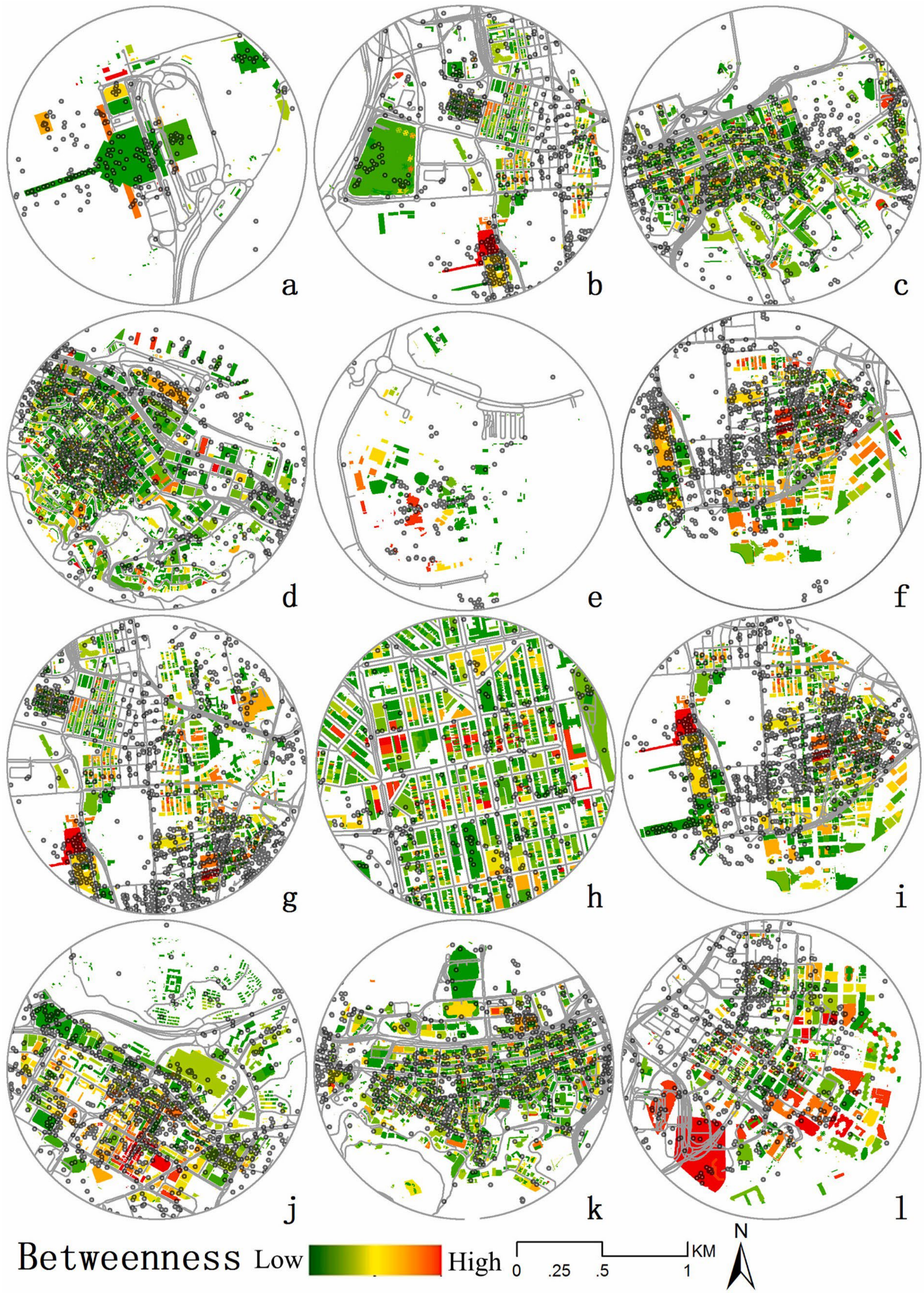

Fig. 4. Betweenness and Facebook check-in POIs for selected TODs. Grey circle is the MTR station centroid to an 800m TOD range. (a) Airport, (b) Austin, (c) Causeway Bay, (d) Central, (e) Disneyland Resort, (f) East Tsim Sha Tsui, (g) Jordan, (h) Mong Kok, (i) Tsim Sha Tsui, (j) Tsuen Wan, (k) Wan Chai, (l) Whampoa.

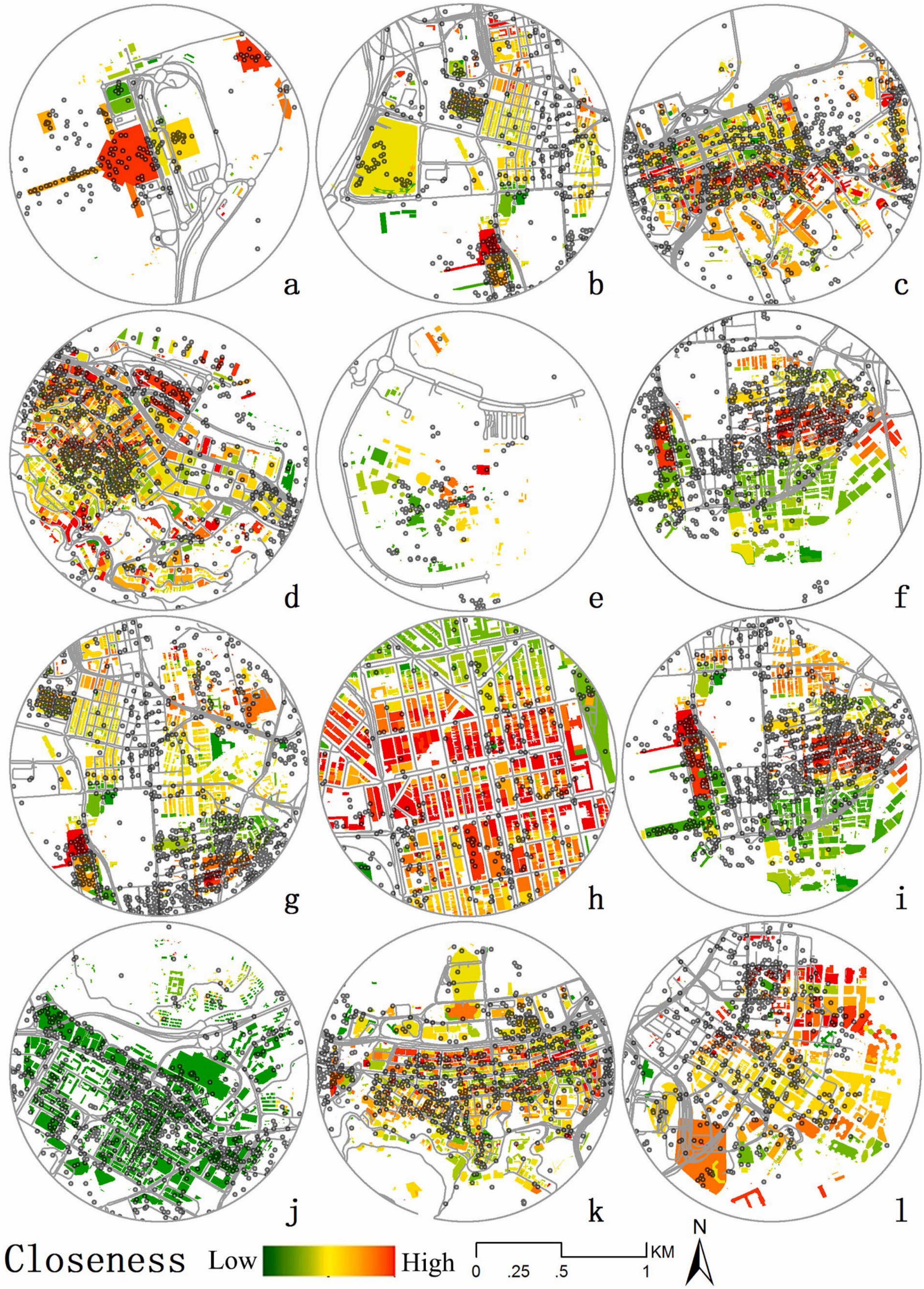

Fig. 5. Closeness and Facebook check-in POIs for selected TODs. Grey circle is the MTR station centroid to an 800m TOD range. (a) Airport, (b) Austin, (c) Causeway Bay, (d) Central, (e) Disneyland Resort, (f) East Tsim Sha Tsui, (g) Jordan, (h) Mong Kok, (i) Tsim Sha Tsui, (j) Tsuen Wan, (k) Wan Chai, (l) Whampoa.

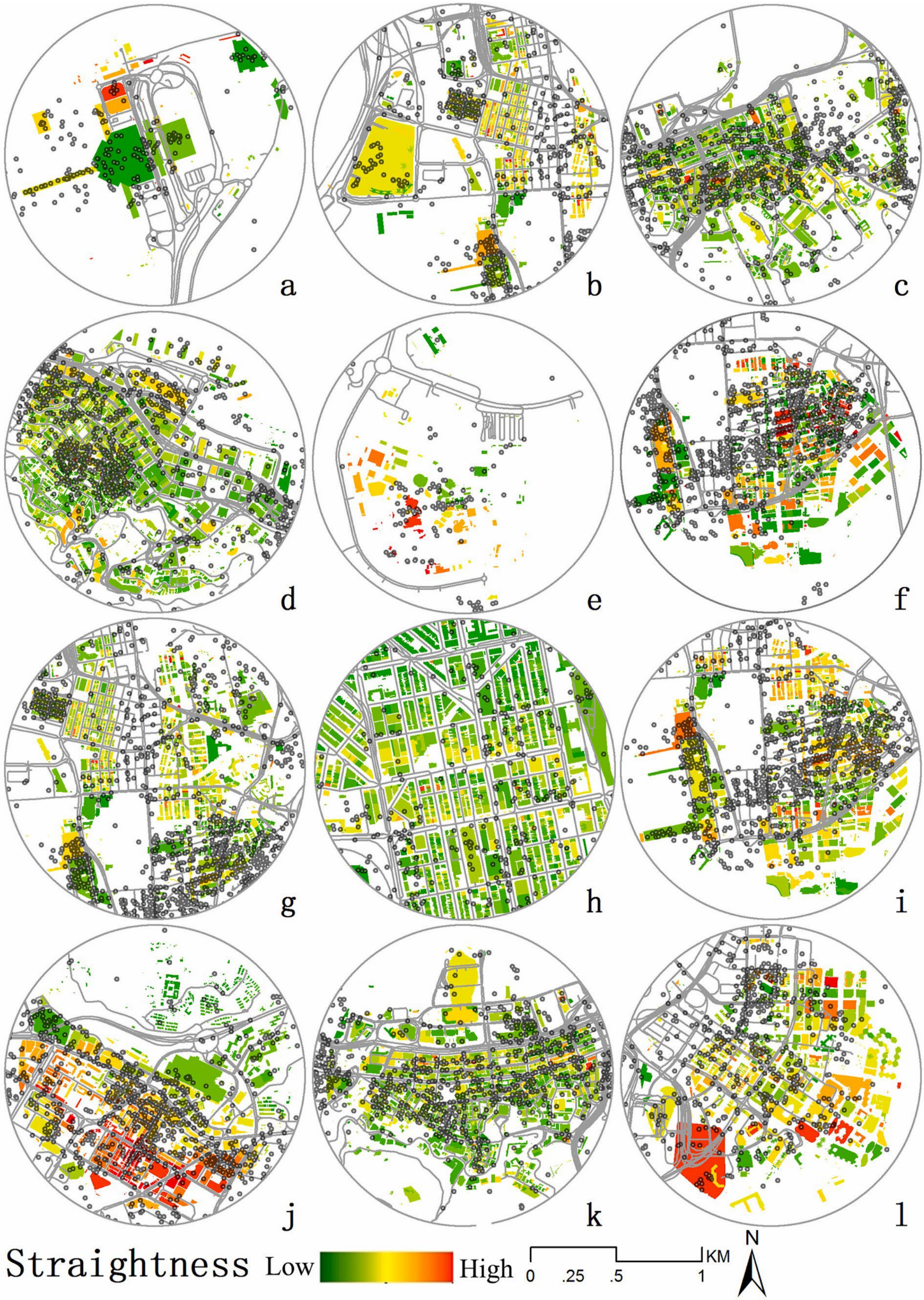

Fig. 6. Straightness and Facebook check-in POIs for selected TODs. Grey circle is the MTR station centroid to an 800m TOD range. (a) Airport, (b) Austin, (c) Causeway Bay, (d) Central, (e) Disneyland Resort, (f) East Tsim Sha Tsui, (g) Jordan, (h) Mong Kok, (i) Tsim Sha Tsui, (j) Tsuen Wan, (k) Wan Chai, (l) Whampoa.

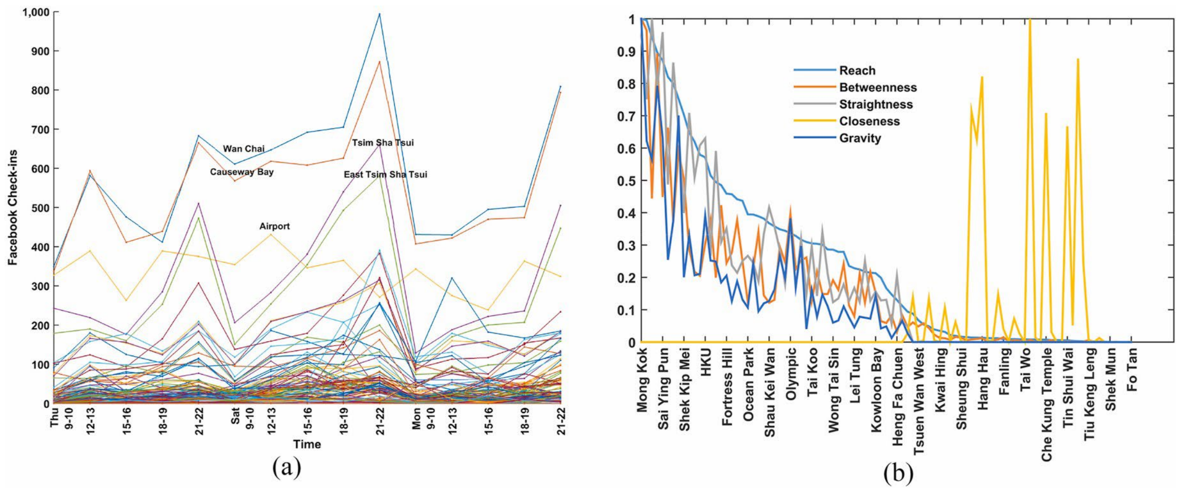

Fig. 7. Dynamic social activities and variations of urban form in different TODs. (a) Facebook online check-ins at various time. (b) Urban form performance in all MTR areas.

interpretation, and discussion.

5. Discussions and implications

5.1. Form follows function: livable human-scaled neighborhoods

To a large extent, the urban form has determinative impacts on the available facilities, services, and individual social activities in TOD areas. While functions play an important role in deciding facility and service allocation, they influence people's decisions to participate and interact. The rule that "form follows function" (Greenough, 1957; Sullivan, 1924) describes modern compact cities and dense urban form (Batty, Sik Kim, 1992). For example, neighborhoods associated with commercial and financial functions—Central, Causeway Bay, Tsim Sha Tsui, and East Tsim Sha Tsui—concentrate a vast majority of public facilities and services by clustering buildings and thereby induce citywide and regionwide travels to those locations for commodities, shopping, entertainment, and businesses. Nevertheless, Mong Kok and Whampoa have developed relatively "good urban form (Lynch, 1984)" grounded in indirect links, side streets, close neighborhoods, small blocks, open communities, and dense roads, which have attracted many facilities, services, and human activities.

Furthermore, TOD areas in traditional neighborhoods (on average and overall) outperform integrated development neighborhoods. Despite certain integrated development, TOD areas have a few high- value locations that benefit from large-volume building complexes (e.
g., Central and the Airport). Traditional neighborhood TOD areas have more evenly distributed space with high values on the UNA index, which allows them to have evenly spaced human-interest areas with neighborhood streets and attractive places on small blocks. For example, certain TOD areas located in traditional street orientations (e.g., Mong Kok and Whampoa) have a well-performed urban form with more POIs and high check-in frequencies for social activities dispersed throughout the neighborhoods. Mong Kok, in particular, has a favorable pedestrian environment with short distances, dense pathways, and direct connections, which gives it a high UNA index value and a mass of activities (e. g., coffee shops, stores, and restaurants).

Certain existing TOD approaches developed over time into integrated development neighborhoods that link large building complexes and contain many services and facilities. TOD approaches with highly commercial and financial functions are well suited for nodes and concentrated places. For example, as major transit nodes, Central and Causeway Bay neighborhoods are associated with large-scale commercial buildings, and these neighborhoods incorporate MTR stations into building complexes in integrated development. Check-in data results indicate that numerous POIs and social activities are highly clustered near transit nodes, and data also show focal places around key functional buildings (e.g., the International Finance Center and The Landmark).

5.2. Livable dense urban form for encouraging human interactions

Urban form at the street level had positive and strong relationships with social activities within TOD areas. Figs. 2–6 depict POI distribution associated with *Reach*, *Closeness*, and *Gravity* and individual check-ins associated with *Betweenness*. Most POIs are concentrated near key building complexes in integrated development TOD areas and have limited tension impacts from transit nodes. While POIs are dispersed throughout traditional neighborhoods, it is favorable to locate facilities in clustered places that can be easily accessed. Evidently, achieving pedestrian access to destinations for daily services and facilities in local neighborhoods is dependent on how easily and spatially residents reach their destinations (e.g., shopping centers, retail stores, and grocery stores).

Facilities are spatially static locations characterized by specific features, whereas individuals' social interactions are dynamic and highly spatiotemporal. From mornings to evenings, people participate in activities influenced by accumulations of places in high-*Gravity* areas during weekdays. During these time periods, people go to offices, schools, and civic service buildings. The opposite trend is true for weekend evenings as people disperse throughout the city for dinners, entertainment, and social interactions during weekend nights. People avoid large and central business areas, including office building areas, during weekend evening hours. That is consistent with the findings of Mehta (2007).

Results also confirmed that social activities generally happen in places with high *Betweenness* values, especially during weekday and weekend nights. People prefer to concentrate on the destinations among other destinations during leisure time (e.g., mixed-use areas in traditional neighborhoods or multifunctional building complex). Other aspects, like *Closeness* and *Straightness,* are negatively associated with social interactions on weekdays; this negative connection does not imply that people do not like *Straight* or *Close* urban form places, but instead indicates that people are less likely to stop or stay in such areas during their working hours. During working hours, people are willing to walk directly to the destinations that meet their needs, either for work or civic services.

5.3. Supportive planning and design for boosting transit-oriented development and neighborhood vibrancy

The aforementioned findings corroborate the argument that TOD areas will increase neighborhood vibrancy if the TOD locations can be revitalized. Following *A Theory of Good City Form* (Lynch, 1984), a series of generalized recommendations should be followed to develop and plan well-fitted future TOD approaches, improve existing ones, and develop TOD beyond Hong Kong. First, creating a livable urban form that encourages pedestrian access to functional destinations is possibly a focal point of a densely populated neighborhood. Moreover, synthetically considering urban built environment's legibility (Lynch, 1960) and street life's vitality (Jacobs, 1961), we affirm the key concern of a supportive urban form—reinforcing the design and space of streets, blocks, buildings, and open spaces through infill and mixed redevelopment improvements for promoting safety, livability, and vitality. Furthermore, existing traditional neighborhood development should be enhanced, development-wise, by fostering integrated development neighborhoods for spatial balance and distribution within TOD zones.

Second, TOD's prevalence of entertainment and leisure facilities reflects the place-making roles of transit nodes and their influenced areas. Transit node areas, as focal points of public gathering places, provide not only transit services but also walkable environments that allow services and human activities to occur within direct, dense, and continuous pathways, where MTR stations incorporate quality layout of TOD for human activities. Accordingly, the aspirations for a good TOD neighborhood in a high-density city are not only to advance the TOD and increase public transit choices but also to enliven social life and places for activities.

Third, transit-supportive TOD strategies allow all people to be entertained and also allow them to walk from various origins to multiple destinations easily. A set of TOD approaches is identified in a human- scaled dimension. Jacobs (1961) elucidated the diversity and "organized complexity" of the city; hence, a range of activities and pedestrian amenities in transit node areas, including commercial centers, offices, restaurants, shops, stores, and community facilities, should be strengthened to encourage activities in retail, recreational facilities, and cultural places, as well as other daily life activities. Well-planned cities form walkable, diverse, and multifunctional landscapes that create a desirable quality of life (Hui, Liang, & Yip, 2018; Lynch, 1984). Therefore, connecting functional spaces and facilities for pedestrian and public circulation in a direct manner (e.g., with overhead walkways and green walkways) is essential.

6. Conclusion

This study offers considerable useful information and facilitates a meaningful comparison between TOD living environments in Hong Kong. We conducted a comprehensive analysis of how local urban forms around MTR stations impact individuals' accessibility and social activities. We employed UNA in GIS to delineate the spatial configuration of the MTR station areas, compiled *Facebook* check-in and POI data to capture individuals' social activities and synthesized urban form attributes and social activities with the SLM to explore the spatial correlations. This study's first key finding is that urban form is strongly associated with pedestrian access, spatial characteristics, and human activities in TOD areas. High-value *Reach*, *Gravity*, and *Closeness* areas accommodate additional facilities and services, and high-value *Betweenness* areas attract additional individual social activities. Traditional neighborhoods have overall high levels of *Reach*, *Gravity*, *Betweenness*, and *Straightness*, whereas integrated development neighborhoods exhibit high levels of *Closeness*. Street networks with dense and highly direct connections are associated with a high proportion of destination-rich areas and human activities.

The second key finding shows that individuals' social activities are strongly associated with facilities and services with significant impacts from specific urban form, neighborhood development mode, time variation, and function. Traditional neighborhoods show spatially evenly distributed patterns of facilities, services, and social activities, whereas integrated development neighborhoods have more commercially oriented large building complexes concentrated in specific focal locations. Individuals' activities vary based on their timing, with people having more access to high *Betweenness* areas during leisure hours and to high *Gravity* areas with key functional building clusters during business hours. Functional streets and buildings also determine the type of social interactions by individuals in the dense urban form.

Overall, the results and findings presented here confirm the hypothesis that the livable dense urban form of Hong Kong includes easy access to a well-developed public transport network, and has geographical and historical factors that contribute to high levels of livability while also allowing people who walk for travel to access their destinations easily. However, our results verify that the traditional considerations of only transit service-related features do not consider fine-scaled urban form and social activities. Supportive strategies that encourage dense urban form are essential to allow frequent users to have easy access to active street-level services, promote the vibrant TOD areas in the high levels of pedestrian activity, and encourage walking. We assert that designing dense road networks, small blocks, side streets, and direct linkages will contribute to a good city form, leading to a favorable environment with allocable services and embraceable social activity. Furthermore, planning mixed function and infilled function streets will supplement a good city form to revitalize traditional neighborhoods and foster integrated development neighborhoods to boost the livable and compact development of high-density cities, particularly in mainland China.

This study confirms that TOD can be an alternative to future compact urban development with supportive zoning, urban design, public-sector leveraging, and pro-active planning. Remarkably, the results presented here also underscore the significance of urban form for future efforts to develop dense and livable transit-oriented urban settings. This study's evidence confirmed that TODs are significantly influenced by configurations of urban form and functions. The good urban form ensures high- quality pedestrian environments, while TOD approaches significantly shape dense urban form in rapidly developing cities. Accordingly, this study's conclusions may help improve residents' livability in Hong Kong and abroad through urban planning and design efforts.

Author statement

The authors declare that this research was conducted in the absence of any relationships that could be construed as a potential conflict of interest in this manuscript. This manuscript has not been published or presented elsewhere in part or in entirety and is not under consideration by another journal. All study participants provided informed consent. All authors have agreed with this submission. Xun Li contributes to research study design, conception, theory; Wei Lang contributes to literature review, figures, and draft writing; Eddie C.M. Hui contributes to interpretation and analysis; Tingting Chen contributes to writing, editing, and etc.

Acknowledgements

This research was funded by a grant from National Natural Science Foundation of China (No. 41801161, 41801163), Natural Science Foundation of Guangdong Province, China (No. 2018A030310263, 2018A030313221), and PolyU Internal Research Accounts (G-SB0D, P0006252). The authors would like to thank Mr. Haoran

Wang, Miss Jiemin Wu, and Dr. Ying Long, who participated in this research, contributing their valuable time to give comments and support. The authors are also grateful for the advice from MIT Professor Emeritus Tunney Lee.

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