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SLOPE, LAYERS, AND WALKABILITY: ESTIMATING THE LINK BETWEEN PEDESTRIAN ACCESSIBILITY AND LAND VALUES IN THE MORPHOLOGY OF HIGH DENSITY CITIES

Abstract: *Traditional urban economic models of the city postulate that the price and development intensity of land is a function of its accessibility. Traditionally, this accessibility has been measured from both the topographical and topological perspectives. However, the higher-density "volumetric" cities require new methods and techniques for estimating accessibility and its link to urban form. Volumetric cities feature multiple modes of movement and stacked layers of activities above and below ground with a particular emphasis on pedestrian networks. Moreover, variation in the relationship between these layers of activities and the ground presents additional complexity when considering pedestrian connectivity and the ease of movement in cities with varied terrain. As such, there are a number of challenges involved in measuring accessibility to capture the dynamics of high-density, volumetric, and topographically-varied cities. In response, the present paper employs a suite of new hybrid topographical-topological accessibility measures to capture the built and natural environments. Using the case of the western district on Hong Kong Island, the present paper associates volumetric accessibility with property values. Our spatio-temporal models find that accessibility is positively capitalized into the price: homeowners are willing to pay to live at certain locations. As such, accessibility to amenities and opportunities in the compact city appears to be broadly valued in the study area. These results form a foundation on which further explorations of the link between urban context, accessibility, and value will be built.*
Keywords: *accessibility, walkability, land value, volumetric.*

Introduction

Traditional urban economic models of the city postulate that the price and development intensity of land is a function of its accessibility (Alonso, 1964; Mills, 1972; Muth, 1969). Although the spatial equilibrium foundations of these urban economic models are viewed as inconsistent with the more modern conceptualization of cities as complex and far-from-equilibrium entities (Batty, 2012), the notion that accessibility is valued remains a key aspect in forming research into various aspects of interactions between humans and the built environment. For example, although findings vary, previous research has found a positive association between accessibility to rapid transit facilities and land prices (Higgins & Kanaroglou, 2016).

In general, this accessibility has been measured empirically in two ways. In the field of economic and transportation geography, the concept of accessibility can be defined as the ease with which one can travel between origins and destinations to reach opportunities of value (Páez, Scott, & Morency, 2012). Under this perspective, more topographic measures of accessibility are employed to capture variations in the relationship between the distribution of locations over space, the opportunities at these locations, and the friction involved in travelling between them.

A second set of more topological accessibility measures comes from the network sciences. According to Batty (2009), in this perspective, opportunities are assumed to be the same over space, and the focus is on the topological distances between network edges and nodes. From this, measures of centrality capture the network accessibility of different locations.

However, the study of accessibility of higher-density "volumetric" cities requires new methods and techniques for estimating accessibility and its link to urban form. Per Shelton et al. (2011), volumetric cities feature multiple modes of movement and stacked layers of activities above and below ground with particular emphasis on pedestrian networks. Moreover, topographical variation in these layers of activities and their relationship with the ground presents additional complexity when considering pedestrian connectivity and the ease of movement. Quite simply, separate topographic and topologic approaches to measuring access do not fully capture the dynamics of high-density, volumetric, and topographically-varied cities.

In response, using a case study of the western district of Hong Kong Island, the present paper proposes a new approach to measuring pedestrian accessibility in volumetric cities, and estimates its link to land prices. In this framework, we capture multiple dimensions of both the natural and built environments, including the construction of a 3D pedestrian network and representation of the study area's urban morphologies. Next, we model the walkable accessibility characteristics associated with this urban context using a suite of new hybrid accessibility measures proposed by Sevtsuk and Mekonnen (2012) that incorporate the foundations of network analysis from the topological perspective with the spatial distribution of opportunities in the volumetric built environment from the topographic perspective. To this end, the remainder of the paper details our methods and data, estimates spatio-temporal hedonic regressions, presents results, and offers a discussion of these findings and future steps.

Data and methodology

Urban Network Analysis

Sevtsuk and Mekonnen (2012) have proposed a new set of hybrid Urban Network Analysis (UNA) accessibility measures that draw from both the topographic and topological perspectives. Specifically, this involves incorporating aspects of the built environment, namely buildings, into the analysis of urban networks, expanding the analytical frame to include streets as network edges, intersections as junctions, and the built environment as opportunities that can be associated with different weight. These opportunities can include characteristics such as the volume of buildings, their land use mix, population, employment, or other aspects of the built environment. From this, five separate accessibility measures are derived that incorporate the weights associated with the opportunities for interaction at particular buildings into more topological measures of centrality based on the characteristics of some underlying network G (Equations 1-5).

$$Reach_i = \sum_{\substack{\forall j \in G \neq i; \\ d_{ij} \leq r}} W_j \tag{1}$$

Reach captures the sum of all weighted opportunities W at buildings j that are within some network distance r of building i. This measure captures the centrality of a particular building to others on the network.

$$Gravity_i = \sum_{\substack{\forall j \in G \neq i; \\ d_{ij} \leq r}} \frac{W_j}{e^{\varphi \cdot d_{ij}}} \tag{2}$$

The *Gravity* measure is similar to *Reach* but applies a distance decay function φ to account for spatial interaction.

$$Closeness_i = \frac{1}{\sum_{\substack{\forall j \in G \neq i; \\ d_{ij} \leq r}} (d_{ij} \cdot W_j)} \quad (3)$$

Closeness is the inverse of the total weighted distance and measures how close a particular building is to all others on the network.

$$Straightness_i = \sum_{\substack{\forall j \in G \neq i; \\ d_{ij} \leq r}} \frac{\delta_{ij}}{d_{ij}} \cdot W_j \quad (4)$$

Straightness captures how closely network distances d_{ij} reflect Euclidean distances δ_{ij}, capturing elements of the urban morphology around particular buildings.

$$Betweenness_i = \sum_{\substack{\forall j,k \in G \neq i; \\ d_{jk} \leq r}} \frac{n_{jk}[i]}{n_{jk}} \cdot W_j \quad (5)$$

Finally, *Betweenness* reflects the number of times building i lies on the network path between buildings j and k weighted by the opportunities at building j.

In terms of applications, the only paper to associate these accessibility measures with land values is the work by Kang (2017). Using home sales data for Seoul, Korea, separate multi-level hedonic models are run for each of the five accessibility measures. Results show that residents value access to commercial, residential, and office space as measured in building volume, but that industrial use is a disamenity. The present paper continues this approach, estimating spatio-temporal models to examine whether the volume of the built environment is capitalized into home values in Hong Kong.

Capturing the Volumetric City

Hong Kong is a very three-dimensional city and capturing the accessibility dynamics of this context requires taking into account the characteristics of both the natural and built environments. The underlying natural environment is varied from a hilly to mountainous topography. Compared to flat cities, this topography has a profound effect on the travel characteristics and structure of the underlying transportation network. To account for this, the present research works from the methods previously proposed in Higgins (2018) to construct a 3D, slope-aware representation of the pedestrian network in the study area. This includes deriving Z-coordinates for network edges and intersections from a 2m resolution digital elevation model from the Hong Kong Government's Lands Department, calculating the slope of individual links, and employing Tobler's (1993) Hiking Function to estimate the velocity of pedestrian travel based on the gradient of network links.

Next, a database of 3D buildings from the Lands Department is used to represent the voluminous nature of Hong Kong's built environment. Volume is estimated based on a building's height and the area of its building footprint. It should be noted that the simplicity of these building polygons means that volume will be over-estimated for buildings with tapered or other designs that deviate from the shape of their ground-level footprint. Nevertheless, this approach gives some indication of the high-density, high-volume character of the volumetric city described by Shelton et al. (2011).

Together, this 3D pedestrian network and building volumes are combined to calculate Sevtsuk and Mekonnen's (2012) five UNA hybrid accessibility measures. For the purposes of this research, the study area is limited to the western part of Hong Kong Island. This study area aligns with real estate transactions collected by the team members, the details of which are discussed in the next section. The maximum travel time r from any building is set to a walking time of 10 minutes. For the *Gravity* calculation, φ is set to 0.1813 per Handy and Niemeier (1997). An example of the results of the *Gravity* calculation for buildings in the study area is displayed in Figure 1.

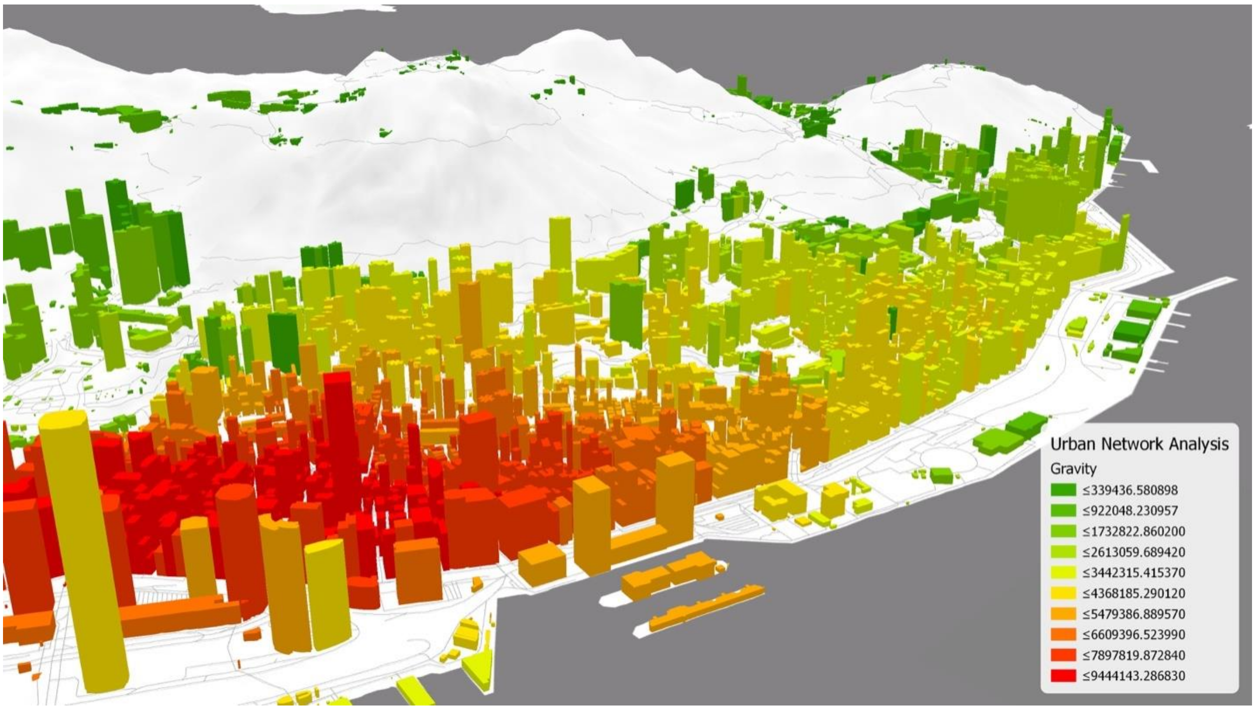


Figure 1. Gravity Measure of Built Volume

The correlation matrix for each of the five measures is also displayed in Table 1. Here, it can be seen that Reach, Gravity, Closeness, and Straightness are all very highly correlated with one another. The one exception is Betweenness, which appears to capture a different aspect of accessibility than the other measures.

Table 1

Hybrid Accessibility Measure Correlations

	(ln)Reach	(ln)Gravity	(ln)Closeness	(ln)Straightness	(ln)Betweenness
(ln)Reach	1.000				
(ln)Gravity	0.955	1.000			
(ln)Closeness	-0.982	-0.885	1.000		
(ln)Straightness	0.933	0.978	-0.862	1.000	
(ln)Betweenness	0.213	0.283	-0.160	0.300	1.000

Spatio-Temporal Hedonic Regression Model

To estimate whether and how accessibility is capitalized into home values in Hong Kong, this paper utilizes a spatio-temporal hedonic model based on the two-stage least squares approach proposed by Kelejian and Prucha (1998; 1999; 2010). The model takes the form:

$$y = \alpha + \rho W y + \beta N + \gamma H + \theta L + \tau Q + \varepsilon \quad (6)$$

$$\varepsilon = \lambda W \varepsilon + \mu \quad (7)$$

Where y is a vector of log-transformed sale prices, measured as the price in Hong Kong Dollars (HKD) per square foot of net living area, α is a constant term; ρ and λ are scalar autoregressive parameters; W is the spatio-temporal weights matrix; Wy is the spatially- and temporally-lagged dependent variable; N is a vector of variables reflecting the accessibility characteristics of the building in which the home is located; H is a vector of the characteristics of the home; L is a vector of additional locational characteristics such as the median household income of a home's neighbourhood; Q is a vector of quarterly dummies corresponding to the time of sale; β, γ, θ, and τ are parameters to be estimated; ε is the spatio-temporal autoregressive error term; $W\varepsilon$ is the spatially- and temporally-lagged error term; and μ is the independent and heteroskedastically-distributed error term.

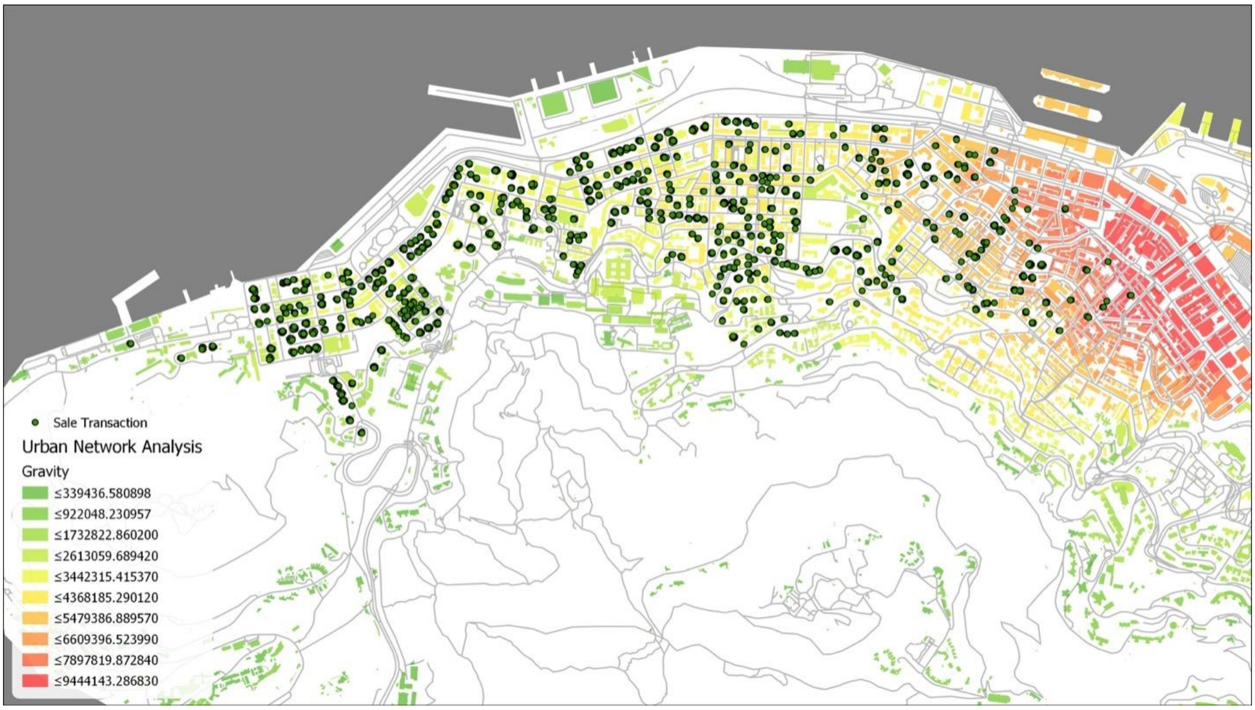
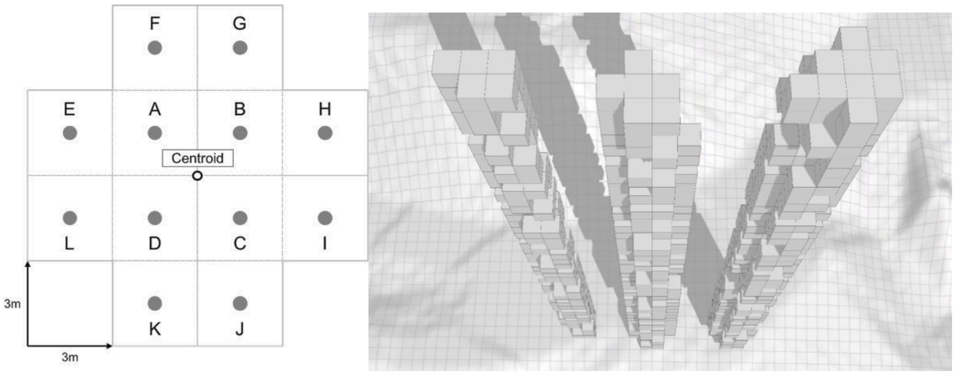


Figure 2. Sample Sales Distribution

The real estate transactions are collected from EPRC Limited, which records any sale transactions for flats from the Hong Kong Government's Land Registry. The sample consists of any transactions that occurred within a 10-minte walk of the Sheung Wan, Sai Ying Pun, Hong Kong University, and Kennedy Town stations on the Mass Transit Railway (MTR) network between the first quarter of 2015 and the third quarter of 2017. The distribution of real estate sale transactions and buildings used in the calculation of the UNA accessibility measures (with *Gravity* used as an example) is shown in

Figure 2. The spatial distribution of buildings used in the calculation of the accessibility measures is larger than that of the real estate transactions. This ensures that the potential for spatial boundary effects is reduced but has a large number of buildings within a 10-minute walk of others on the network surrounding the sale transactions.

To account for the three-dimensional nature of sale transactions in Hong Kong's volumetric built environment, the "Spherical Distance Weights" technique proposed by Higgins (2018) is used to associate different flats with an estimation of their location in 3D space. Briefly, this involves offsetting transactions from the centroid of the building in which they are located based on their unit number according to the grid displayed in the left panel of Figure 3. Next, these offset units are layered by their floor number (excluding omitted floors where required) based on an assumed building storey height of 3m. The end result resembles the right panel of Figure 3, with transactions represented by individual 3m by 3m cubes for visualization.



Source: Higgins (2018)

Figure 3. Unit-offset Grid (left) and Combined Unit-Floor Offset (right)

Finally, because real estate data exhibit spatio-temporal dependence, relations among properties in time and space are accounted for based on the methods outlined by Higgins (2018). This includes first calculating the inverse 3D distance from each property to all others. The spatial extent of this sphere is limited to a distance of 200m of potential spatial association. Next, the inverse temporal distance measured in months elapsed between transactions is also calculated. In the last step, the Hadamard product of these two distances is taken, and the resulting matrix of spatio-temporal relations among properties in the sample is utilized to control for spatial and temporal dependence in the hedonic models.

Sample Description

Descriptive statistics for the sample of real estate transactions are presented in Table 2. The mean sale price is approximately HKD$9.5 million for properties that average about 500 square feet of net living area for a net price per square foot of about HKD$18,100 over the study period. The remainder of the table describes the volumetric accessibility measures, each property's proximity to their nearest MTR station, its structural characteristics, and the median household income of the neighbourhood based on data from the 2016 census collected at district council constituency area small-level geography.

Table 2

Sample Descriptive Statistics

Variable	*Mean (Prop.)*	*Std. Dev.*	*Min*	*Max.*
Sale Price (HK$, millions)	9.523	8.737	2.000	163.000
Net Area (ft^2)	504.75	319.29	155.00	7,395.00
Sale Price per Sq. ft. (Net, HK$)	18,095.05	5,305.47	8,960.57	46,333.14
Volumetric Accessibility				
(ln)Reach	15.954	0.380	14.863	17.094
(ln)Gravity	14.901	0.341	13.762	16.025
(ln)Closeness	-21.892	0.435	-23.043	-20.870
(ln)Straightness	15.846	0.393	14.585	17.127
(ln)Betweenness	17.642	4.265	0.000	21.430
MTR Proximity				

Walking Time to Station (min)	3.654	1.909	0.217	9.981
Property Characteristics				
Balcony (0-1)	0.099	0.299	0	1
Bay Window (0-1)	0.535	0.499	0	1
Bedrooms (no.)	1.427	1.186	0	5
Building Age (years)	18.442	14.617	0	59
Carpark (0-1)	0.034	0.181	0	1
Club House (0-1)	0.479	0.500	0	1
Direction Facing: North (0-1)	0.129	0.335	0	1
Direction Facing: North-East (0-1)	0.117	0.322	0	1
Direction Facing: North-West (0-1)	0.121	0.326	0	1
Flat Roof (0-1)	0.030	0.172	0	1
Pool (0-1)	0.387	0.487	0	1
Rooftop (0-1)	0.020	0.141	0	1
Terrace (0-1)	0.000	0.022	0	1
Unit Floor Number	18.078	11.740	0	63
Neighbourhood Attributes				
Median Household Income (HK$10,000s)	331.749	141.052	200.000	915.860
Quarter of Sale				
Omitted for Brevity (0-1)				
n				4,214

Results

Given the high correlations among the UNA accessibility measures, five separate spatio-temporal models are estimated, and their results are presented in Table 3. Model fit across each is good, and the variables corresponding to the structural and neighbourhood characteristics of each transaction generally perform as expected. However, for brevity, we focus here on the results of the different accessibility measures. First, proximity to the nearest MTR station is valued, with the variable indicating that sale prices decrease by average 0.5% for every minute farther a property is located from their nearest station entrance on the pedestrian network. In this sense, a property located 10-minutes away is valued about 5% less than one located next to the station.

In terms of the UNA accessibility measures, all return statistically significant results across the five models. Due to the log transformation of both the dependent variable and UNA measures, these coefficients are interpreted as elasticities. For *Reach* for example, a 1% increase in the total built volume located within a 10-minute walk of a property is associated with an increase in sale prices of about 4%, all else being equal. Similar results are found for the *Gravity* measure, where a 1% increase in travel-time weighted building volume is associated with an increase in sale prices of about 3.2%. Increasing *Closeness* is associated with a decrease in sale prices of about 3.9%, but given the inverse nature of this measure, it again suggests that centrality is positively valued. For *Straightness*, a 1% increase in the proportion of building paths that resemble Euclidean distances is associated with a statistically significant increase in property values of about 2.8%. Finally, increasing *Betweenness* is associated with higher property prices, but only marginally. Here, a 1% increase in the number of shortest paths between other buildings on the 3D network is associated with a 0.1% increase in transaction prices, all else being equal.

Table 3

Spatio-Temporal Model Results

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	*Coefficient*		*Coefficient*		*Coefficient*		*Coefficient*		*Coefficient*	
Accessibility										
(ln)Reach	0.03949	***								
(ln)Gravity			0.03193	***						
(ln)Closeness					-0.03882	***				
(ln)Straightness							0.02783	***		
(ln)Betweenness									0.00101	*
Accessibility to MTR										
Walking Time to MTR Station (min)	-0.00541	***	-0.00465	***	-0.00591	***	-0.00498	***	-0.00476	***
Property Characteristics										
Balcony (0-1)	-0.13044	***	-0.13120	***	-0.12930	***	-0.13244	***	-0.13082	***
Bay Window (0-1)	-0.03133	***	-0.03197	***	-0.03104	***	-0.03212	***	-0.03461	***
Bedrooms	0.00731	**	0.00733	**	0.00716	**	0.00738	**	0.00696	**
Building Age (years)	-0.01843	***	-0.01856	***	-0.01844	***	-0.01859	***	-0.01875	***
Building Age^2	0.00015	***	0.00015	***	0.00015	***	0.00015	***	0.00015	***
Carpark (0-1)	0.20663	***	0.20584	***	0.20648	***	0.20642	***	0.20597	***
Club House (0-1)	0.04407	***	0.04208	***	0.04467	***	0.04118	***	0.04249	***
Direction Facing: North (0-1)	0.00914		0.01016		0.00864		0.01047		0.01055	
Direction Facing: North-East (0-1)	0.01774	**	0.01727	**	0.01794	**	0.01691	**	0.01635	*
Direction Facing: North-West (0-1)	0.02997	***	0.02739	***	0.03138	***	0.02671	***	0.02394	***
Flat Roof (0-1)	0.13316	***	0.13309	***	0.13344	***	0.13336	***	0.13390	***

Pool (0-1)	0.02701	***	0.02599	***	0.02651	***	0.02676	***	0.02043	**
Rooftop (0-1)	0.08591	***	0.08548	***	0.08562	***	0.08582	***	0.08182	***
Terrace (0-1)	0.17120	*	0.17150	*	0.17218	*	0.17219	*	0.17705	*
Unit Floor Number	0.00527	***	0.00520	***	0.00532	***	0.00519	***	0.00517	***
Neighbourhood Attributes										
Median Household Income (HK$10,000s)	0.00017	***	0.00017	***	0.00016	***	0.00018	***	0.00018	***
Quarter of Sale										
2015 Quarter 1					(*reference*)					
2015 Quarter 2	0.00214		0.00208		0.00224		0.00252		0.00290	
2015 Quarter 3	0.03699	***	0.03712	***	0.03682	***	0.03740	***	0.03744	***
2015 Quarter 4	-0.02210	*	-0.02295	*	-0.02167	*	-0.02269	*	-0.02407	*
2016 Quarter 1	-0.02451	*	-0.02601	*	-0.02365	*	-0.02603	*	-0.02792	*
2016 Quarter 2	-0.05281	***	-0.05362	***	-0.05234	***	-0.05336	***	-0.05422	***
2016 Quarter 3	-0.01370		-0.01416		-0.01348		-0.01406		-0.01474	
2016 Quarter 4	0.03472	***	0.03501	***	0.03454	***	0.03514	***	0.03554	***
2017 Quarter 1	0.06572	***	0.06570	***	0.06567	***	0.06592	***	0.06615	***
2017 Quarter 2	0.11987	***	0.12033	***	0.11942	***	0.12043	***	0.12025	***
2017 Quarter 3	0.11812	***	0.11889	***	0.11758	***	0.11902	***	0.11990	***
α	9.20070	***	9.35627	***	8.98248	***	9.39072	***	9.82306	***
ρ	0.00472	***	0.00477	***	0.00458	***	0.00481	***	0.00420	***
λ	1.27904	***	1.27912	***	1.27912	***	1.27896	***	1.27955	***
n	4,214		4,214		4,214		4,214		4,214	
Pseudo-R^2	0.811		0.810		0.812		0.810		0.810	

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Discussion and Conclusions

Compared to the more traditional topographic measures of access to opportunities and topological measures of centrality as accessibility, the hybrid measures employed by UNA offer a new way to capture the complex characteristics of the built and natural environments of complex cities. Combined with Hong Kong's varied terrain, this combination of a topographically-rich and high-density volumetric urban context provides an interesting case to study the dynamics of urban morphologies and the urban spatial structure.

Taken together, the results of our preliminary analysis reveal that volumetric accessibility is broadly valued in the high-density Hong Kong real estate market. This suggests that when homeowners buy and sell property, they are implicitly paying a premium for higher accessibility. Such a finding is in line with the expectations of traditional urban economic models and offers evidence to support the idea that the compact city offers a high level of accessibility to amenities and opportunities that homeowners are willing to pay for.

However, these results can only offer a snapshot of the market in aggregate. Future research by the team will seek to extend this analysis to a more disaggregate level of study to identify whether and how different typologies of urban neighbourhood morphologies affect these relationships and differ from the aggregate findings. As in previous research by Tang and Yiu (2010), it may be that although volumetric accessibility is valued, this relationship may only hold to a certain point, after which the increasing density of an ever-more compact city becomes a disamenity.

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