Spatial distribution of high-rise buildings and its relationship to public transit development in Shanghai

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\textbf{ABSTRACT}

The relationship between dense urban development, often represented by high-rise buildings, and its location vis-à-vis metro stations reflects the connection between transportation infrastructure and land use intensity. Existing literature on high-rise buildings has focused either on developed countries or on cities where urban and public transit developments have occurred in an uncoordinated manner. This paper examines the following questions: What is the spatial proximity and spatial correlation between high-rise buildings and metro stations in different stages of development in various parts of the city? What were some of the factors that resulted in the observed patterns? The results suggest that buildings constructed after 2000 and buildings within the urban core/Shanghai Proper districts had a greater spatial proximity to the metro stations. However, the spatial correlation, measured by the number of high-rise buildings within a 500-m buffer from the nearest metro stations and the time-distance to these stations, is stronger in the outer districts than in the urban core. These differences can be accounted for by Shanghai's stages of urban development, the existence of metro infrastructure when high-rise development was undertaken, and the city's land use policies. This case study sheds light on the relationship between high-density developments and metro systems in other large cities in China and other developing countries where rapid urban development coincides with the establishment of a comprehensive public transit system.

1. Introduction

High density developments are often represented by constructions of high-rise buildings in major cities across the world (Yuen and Yeh, 2011; Ng, 2011). The multi-story invention accommodates thousands of people in a very small footprint to preserve lands in urban centers with greater developmental pressures (Yuen and Yeh, 2011). At present, most high-rise buildings are being constructed in developing countries (Rove et al., 2016). However, existing literature on high-rise buildings has focused either on developed countries or on cities where urban and public transit developments have occurred in an uncoordinated manner (Broitman and Czamanski, 2012; Al-Kodmany, 2016). Little is understood of the coordinated development of high-rise buildings and metro systems in developing countries. If we can better understand how the underlying factors (i) the development stage, from the initial growth and stabilization stage to the post-urbanization decline, and (ii) the existence of metro infrastructure shape the growth of cities, we can better coordinate land use and transportation policies. This research fills the gap by providing a spatial evaluation of Shanghai, a rapidly growing city entering an early stage of urban stabilization. It has seen increasing numbers of new developments and urban retrofitting projects intended to intensify development in areas around metro stations. The paper seeks to address the following questions: What is the spatial proximity and spatial correlation between high-rise buildings and metro stations in different stages of development in various parts of the city? What were some of the factors that resulted in the observed patterns?

The paper's analysis spans between 1994 and 2010. These bookends were selected because the former represents the operational beginnings of Shanghai’s Metro system and the resumption of high-rise construction during a period of rapid economic growth, while the latter marks the end of a period of rapid metro expansion. The high-rise buildings were calculated at the district level, using the nineteen original administrative districts. Instead of using the most common measure of density, the paper was also intentional in using the number of high-rise buildings as a proxy for high density construction. This is because the
number of high-rise buildings is often set as a policy target in China's urban development (Rowe et al., 2016).

The paper begins by reviewing the existing literature on land use and transportation, before describing the study area, the data collection process, and the types of spatial analyses undertaken using GIS. It then presents the findings and discusses the various urban development forces underpinning the observed patterns: the differences in spatial proximity and spatial correlation between high-rise buildings and metro stations are associated with the stages of urban development, the existence of metro infrastructure at the time of the high-rise development, and land use policies. Findings from this paper can shed light on the relationship between high-density developments and metro systems in other large Chinese cities that are planning to expand or construct new metro systems as well as in other developing countries where rapid urban development coincides with the construction of a comprehensive public transit system.

2. Literature review

Existing literature on the spatial distribution of high-rise buildings and its relationship to public transit has been advanced in urban economics, planning, and geography (Bertaud, 2015; Zhou et al., 2015; Al-Kodmany, 2016). Across these disciplines, three interrelated approaches have been used to analyze the relationship. The first emphasizes the temporal dimension of development processes (Briotman and Czamanski, 2011; Czamanski and Roth, 2011; Al-Kodmany, 2016). The second relates the spatial dynamics of location theories to high-density development in urban areas (Zhou et al., 2015). The third focuses on how changing land use policies and public transit service influence the outcome of high-density spatial forms (Yue and Yeh, 2011; Bertaud, 2015). In China and other developing countries, urban development policies have been increasingly important in locating high-density development and public transit. The resultant patterns are far more complex than what is suggested in the simple distance-decay model put forward by conventional urban economic theories developed in the Western literature.

2.1. Temporal dimension: stages of urban development

The rapid development of high-rise buildings in conjunction with the expansion of metro systems result in spatial patterns that are different from those observed in early stage urban developments. It is important to examine the construction of high-rise buildings with respect to the developmental stage of the city (Frenkel, 2007) because urban growth patterns are often shaped by the public transit infrastructure, accessibility, and investment at the time of development (Giuliano et al., 2012; Hu and Giuliano, 2011). Hall (1971) first introduced the stage model based on his empirical observations. The model suggests that a city or a metropolitan region has a development cycle from growth to stability and then to decline. During the growth stage, the population moves from the periphery to the city center. This is followed by a population de-concentration after a period of stabilization. The stage model of urban development was both supported and criticized (Champion, 2001). One criticism focused on the model's completeness, claiming that there is a fourth stage of re-concentration after a city or metropolitan region's decline (Berg et al., 1982; Klaassen et al., 1981). The fourth stage can also be understood as the beginning of the next development cycle (Frenkel, 2007). Examples include urban regeneration and redevelopment principles such as promoting low carbon travel and increasing urban density and interconnectivity.

In China's coastal cities, urban growth coincided with a new period of industrialization and modernization since the post-reform era in the late 1980s (Rowe et al., 2016). In Shanghai, the stage of growth (early 1990s - early 2010s) has ushered in an early phase of stabilization (early 2010s to today). Krieger (2009) further suggested that the urban re-concentration is occurring in tandem with urban growth in Shanghai. Rowe et al. (2016) attributed the high-density development and re-development to high building obsolescence as a part of urban re-generation. In Shanghai's outer districts, the rapid construction of high-rise buildings occurred with the expansion of the metro system (Shanghai Metro, 2012). In the urban core, however, the peak in high-rise construction predates the operation of the metro system.

2.2. Locational theories of high-density development

Urban economists suggest that the 'Density-Distance' curve best explains the drop of land values, and correspondingly the development density, from a city's center to its periphery (Alonso, 1964; Bertaud, 2015; Mills, 1967; Wheaton, 1998, 1998). According to this proposition, if development adheres to the distance-decay model, the number of the high-rise buildings will decrease the further away from the urban core where land values are high. The model itself is based on the United States where density is strongly associated with private automobile dependency. Despite the persistent belief that most travel destinations are still in the CBD, some empirical studies have revealed that jobs are moving away from city centers in America and elsewhere (Angel and Blei, 2016). In more recent years, high-rise development that incorporates mass transit has claimed to offer a more sustainable way to accommodate future growth. Thus, where density is concerned, the focus has shifted away from city centers to understanding the relationship between high-rise development and public transit (Nasri and Zhang, 2014).

In North America, the Tall Building and Transit Oriented Development (TB-TOD) model has been proposed to as a solution for efficient suburban growth (Al-Kodmany, 2016). In East Asia, many large cities such as Tokyo and Shanghai have also adopted such a transit-oriented model in suburban development (Cervero and Day, 2008; Guan and Rowe, 2016, 2018). Under these conditions, density is no longer a simple function of the distance from the city center. Instead, it is a more refined outcome of public transit-oriented development interacting with travel distance. Further, studies have shown that high-density urban development is discontinuous in space (Benguigui et al., 2006), as observed in the seemingly random distribution of high-rise buildings (Benguigui et al., 2004). In China, this “leapfrogging” phenomenon is evident in the suburban districts (Rowe et al., 2016). In urban districts, however, the densely distributed high-rises and metro stations may render the distance-decay model irrelevant (Briotman and Czamanski, 2012). Development rights for high-rise constructions may not always be obtainable adjacent to metro stations. In addition, separation of high density development from the most congested areas may even be an amenity. Differences in the locations of high-rise buildings at the urban center versus those at the urban edge deserve further investigation considering the costs and benefits of spatial variations (Briotman and Czamanski, 2012).

2.3. Public transit, high-density development, and urban development policies

There have been extensive studies on how high-density land use may affect public transit (Zhou et al., 2015). The effects of public transit, especially the metro system, on the location of high-density development, however, have been much less studied (Cervero and Day, 1997; Huang, 1996; Zhou et al., 2015). Depending on accessibility improvements, the effects of metro transit on high-density development may vary from city to city (Smith, 1986). In this regard, existing studies have tended to ignore the characteristics of the implementation agencies and the locational conditions (Briotman and Czamanski, 2012). In American cities where employment centers are dispersed beyond the CBD, transit-induced, high-density residential developments close to these employment centers can reduce the reliance on private automobiles (Angelo and Blei, 2016; Chen et al., 2018). In countries where rapid high-density developments prevail, constructing a metro transit
system can be more effective in implementing public transportation and land use policies (Bertaud, 2015; Angelo and Blei, 2016). Both metro transit systems and high-density developments have the potential to steer the urban spatial development and land use policy (von Klemperer, 2015). Nevertheless, much as they can be complementary, having one does not necessarily guarantee the occurrence of the other in proximate location (Smith, 1984).

Urban development policies can likewise influence the location of high-rise buildings vis-à-vis metro transit. In China, land use regulations may undercut profit maximization possibilities in high-rise developments. As such, it is necessary to take into consideration policy interventions when understanding the spatial proximity of and spatial correlation between high-rises and metro stations.

3. Methodology

3.1. Study area

Shanghai is a city of 23 million residents located at the mouth of the Yangtze River Delta (China Population Census, 2010). As of 2010, Shanghai has nineteen county-level divisions comprising eighteen districts and one county1 (Shanghai Municipal Government, 2011). Nine districts on the western banks of the Huangpu River are collectively referred to as ‘Shanghai Proper’ or the urban core, as shown in Fig. 1. These include Changning, Huangpu, Hongkou, Jing'an, Luwan (which was subsumed under Huangpu District in 2011), Putuo, Xuhui, Yangpu, and Zhaobei. This area is also known as Puxi. On the eastern banks of the Huangpu River is Pudong district. Since it underwent rapid economic development beginning from the early 1990s, Pudong has also been classified as part of ‘Shanghai Proper’. Beyond this urban core are four suburban districts, four of which are served by the Shanghai Metro: Baoshan, Jiading, Minhang, and Songjiang.

3.2. Data collection

3.2.1. High-rise buildings

High-rise buildings are defined architecturally as buildings which are at least 20 stories in height and have a height-to-least-width ratio exceeding five. In this research, high-rise buildings that were above 20 stories were included in the inventory. Shanghai saw its first skyscrapers appear in the 1920s. After a long hiatus during the Second World War and the first four decades of the People’s Republic, high-rise building construction resumed in 1994. Since then, an average of more than 300 high-rise buildings have been added to the city annually (Shanghai Statistical Bureau, 1994-2011). This was driven by strong economic growth and a political ambition to develop a special economic zone in the Pudong New Area that essentially altered Shanghai’s skyline from the 1990s through 2000s (Appendix 1).

Statistical data on the number of high-rise buildings in each district were first collected from the Shanghai Statistical Yearbook of 2011. As of 2010, Shanghai had 3610 high-rise buildings (847 buildings over 30 stories and 2763 over 20 stories). Pudong district had the largest stock of high-rise buildings. Table 1 shows the distribution of high-rise buildings in the nineteen districts.

The graph in Fig. 2 shows that the districts had varying degrees of high-rise developments and that the construction of high-rise buildings reached a steady state between 2008 and 2010. Some of the sixteen to nineteen-story buildings were included in this study. This was because some of the residential neighborhoods were complexes with buildings ranging from sixteen to above 20 stories. These developments were then treated as a whole and the buildings less than 20 stories were also included, on the precondition that the average building height in these complexes was at least 20 stories. This brought the final count of the high-rise buildings used in this study from 3610 to 4376.

High-rise buildings were also manually located using Bing Map 2010. The georeferenced locations of the buildings were checked against an Open Street Map and Baidu Map to ensure their locational accuracy.2 Then, information on the building type and when it was completed were compiled via multiple sources such as the Shanghai Atlas (2011), Global Cities & Building, East View Geospatial, and Shanghai Skyscraper Page.3 In cases where multiple high-rise buildings were located at the center of a community or neighborhood, additional visual inspections were undertaken to improve the locational accuracy (Hackeloeer et al., 2014).

3.2.2. Metro lines and stations

Coinciding with the surge in high-rise development was the establishment of Shanghai’s Metro system. Construction first started in 1986, and it was only in 1993 that the Shanghai Metro began operating, with Line 1 connecting the Shanghai South Rail Station to Xujiahui (Shanghai Metro, 2012). Over the subsequent decades, the Shanghai Metro continued to expand, particularly in conjunction with the 2010 Shanghai World Expo (Shanghai Metro, 2012). By then, the system had eleven lines in operation, covering a total length of 420 km, and serving 279 stations, as shown in Fig. 1 (Railway Gazette, 2010). Information on the transit networks was extracted from data made available by Harvard University’s Center for Geographic Analysis, research done by the East-West Cultural Development Center, and from atlases and maps available at the Harvard University Yenching Library.

3.3. Types of analysis

To carry out the analyses, a database was first constructed in ArcGIS to compile four layers of information: metro lines, metro stations, geographical features, and high-rise buildings. All data, including the transit network were georeferenced into ArcGIS using the Xi’an 1980 GK Zone 19 coordinate system.

To determine the spatial proximity between high-rise buildings and metro stations, the number of the high-rise buildings located within walking distance of a metro station was calculated. A 500-m walking radius was used in this research even though studies have shown that the maximum walkable distance is approximately 300 m4 (Dittmar and Ohland 2004). This is because urban residents are supposedly willing to walk slightly longer distances of up to 500 m to get to the nearest transit station in a pleasant but not weather-protected area during periods of inclement weather (which is a close approximation for the conditions in Shanghai) (Dittmar and Ohland, 2004). Then, the Geospatial Modeling Environment (GME) analyst was used to calculate the number of high-rise buildings within the 500-m radius.

To calculate the spatial correlation between the location of high-rise buildings and metro stations, an accessibility or time-distance analysis was conducted to understand how the accessibility of high-rise buildings around metro stations varied by location. The time-distance analysis model calculated the time spent (tₜ) traveling from trip origins (high-rise buildings, tₒ) to trip destinations (the closest metro stations, tₛ). The study area was divided into 50-m by 50-m grid cells as the unit of analysis. The time-distance formula was adopted from the ArcGIS’s spatial analyst tool function, and is shown as follows:

\[ t = \frac{d}{v} \]

where \( d \) is the walking distance and \( v \) is the walking speed.

4 Assuming an average pedestrian walking speed of 3 km per hour, and a comfortable or preferred maximum walking time of six to 7 min, the maximum walkable distance calculated was 300 m (Dittmar, 2004).
where, \( t_d \) is the trip destination(s), \( t_s \) is the travel speed, \( m_i \) is the maximum distance, \( m_j \) is the mode of travel, \( s_c \) is the start value of the time travelled, \( R_k \) is the resistance rate, this is used to model the fatigue of the travellers, \( C \) is the travel capacity.

The time-distance analysis results were compared with travel time computed by Baidu Map to eliminate modeling mistakes and to improve the accuracy of the time-distance analysis since traffic and transit conditions are more complex in reality. The results were then classified.

Fig. 3. Time-distance in minutes from each grid cell to the nearest metro station and city center by metro after adjusting for traffic conditions.
into seven time-distance zones as shown in Fig. 3.

Finally, a Pearson’s correlation test was carried out in Stata using the number of high-rise buildings in a given grid cell and the time-distance value calculated in ArcGIS.

Where \( r \) is the Pearson’s correlation coefficient, \( x_i \) is the number of high-rise buildings in each grid cell zone, \( y_i \) is the travel time from the center of the grid cell to the closest city centers, \( n \) is the number of grid cell zones under study, and \( x \) and \( y \) are sample means. The value of correlation can range from \(-1\) to \(+1\). \(-1\) means that the variables under study are in a perfect negative linear relationship. On the other hand, \(+1\) represents a perfect positive linear relationship. A correlation value of zero means that the two variables are randomly distributed with no obvious correlation. The Pearson test was calculated for each of the nineteen districts under study.

### 4. Observations and discussion

#### 4.1. Spatial proximity of high-rise buildings around metro stations

**4.1.1. Closer proximity of buildings to stations constructed after 2000**

The GME results show that most of the high-rise buildings constructed after 2000 were located within the 500-m buffer around the metro stations whereas those built before 2000 tended to be located further away. Among the 1643 high-rise buildings built before 2000, 804 (about 49%) were located within the 500-m buffer as compared to 1967 (about 72%) of the 2733 high-rise buildings built between 2000 and 2010. This is not only because of land use regulations such as those promoting compact development, but also influenced in part by when the metro stations were constructed. Prior to 2000, many of the high-rise buildings were completed before the metro stations and lines were laid and when market forces came into play. With the near completion of the metro system in 2000, improved accessibility and higher land values attracted buildings of higher densities and higher FARs to be located closer to the metro stations.

There are three explanations accounting for this observation: First, the urban core districts were developed earlier than the outer ones (see Table 1 for inner versus outer districts) in the late-nineteenth and early-twentieth centuries. These were then part of the French Concession and International Settlements, and the center of commerce when Shanghai was a treaty port. Some of the high-rises here were built in the mid-1980s before the metro stations and lines were laid and when market forces came into play. Second, the higher land values in the Waitan-Lujiazui CBD led to a natural clustering of high-rise buildings, regardless of the relative location and accessibility to a metro station. This has been the case since the adoption of a more radical market approach in the 1990s that led to higher property prices in Shanghai’s inner districts (Wu, 2014). Third, land use planning and transportation projects were better coordinated after 2000 than before, with lessons learnt from the earlier stage of rapid growth. For instance, high-rise developments in

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**Table 2**

Correlation between density and distance, represented by the number of high-rise buildings in the 500-m buffers and the cost distance value of each of the metro stations.

<table>
<thead>
<tr>
<th>District</th>
<th>No. of High-rises Counted</th>
<th>No. of High-rises in the 500-meter Buffer</th>
<th>Percentage of High-rises in the Buffer</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai Proper</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huangpu</td>
<td>336</td>
<td>333</td>
<td>99%</td>
<td>0.2772</td>
</tr>
<tr>
<td>Yangpu</td>
<td>165</td>
<td>51</td>
<td>31%</td>
<td>0.2761</td>
</tr>
<tr>
<td>Luwan</td>
<td>242</td>
<td>237</td>
<td>98%</td>
<td>0.1060</td>
</tr>
<tr>
<td>Jing’an</td>
<td>193</td>
<td>99</td>
<td>51%</td>
<td>0.0512</td>
</tr>
<tr>
<td>Hongkou</td>
<td>414</td>
<td>285</td>
<td>69%</td>
<td>-0.0596</td>
</tr>
<tr>
<td>Xuhui</td>
<td>939</td>
<td>746</td>
<td>79%</td>
<td>-0.1531</td>
</tr>
<tr>
<td>Zhabei</td>
<td>124</td>
<td>118</td>
<td>95%</td>
<td>-0.2687</td>
</tr>
<tr>
<td>Changning</td>
<td>646</td>
<td>620</td>
<td>96%</td>
<td>-0.2915</td>
</tr>
<tr>
<td>Putuo</td>
<td>624</td>
<td>441</td>
<td>71%</td>
<td>-0.2955</td>
</tr>
<tr>
<td>Pudong</td>
<td>545</td>
<td>236</td>
<td>43%</td>
<td>-0.3776</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suburban Districts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baoshan</td>
<td>19</td>
<td>2</td>
<td>8%</td>
<td>0.2449</td>
</tr>
<tr>
<td>Jiading</td>
<td>21</td>
<td>7</td>
<td>35%</td>
<td>0.0221</td>
</tr>
<tr>
<td>Minhang</td>
<td>95</td>
<td>18</td>
<td>19%</td>
<td>-0.4848</td>
</tr>
<tr>
<td>Songjiang</td>
<td>13</td>
<td>2</td>
<td>19%</td>
<td>-0.6239</td>
</tr>
<tr>
<td>Chongming</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fengxian</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jinshan</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nanhui</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Qingpu</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>4,376</td>
<td>3,195</td>
<td>73%</td>
<td>-0.2599</td>
</tr>
</tbody>
</table>
the outer districts such as Pudong, Putuo, and Changning coincided with the expansion of the Shanghai Metro and the real estate market boom in the early 2000s.

These three factors effectively reinforced a pattern of spatial organization where urban planners stipulate detailed control plans that required but also incentivized developers to build high density projects around the metro stations. With a well-networked, high-capacity metro system in place and planned for the foreseeable future, the incentives to

Fig. 4. Density-distance relationship by districts. The x-axis refers to the travel time to metro stations in minutes while y-axis refers to the number of high-rises. Most districts exhibit a decay function except for Huangpu, Luwan, Jing’an and Yangpu.
produce a more compact spatial pattern remain high.

4.1.2. Closer proximity of buildings to stations in the urban core/Shanghai Proper

The GME calculation also revealed that most districts within the urban core had more than half of their high-rise buildings located in the 500-m buffer around the metro stations (see Table 2). The exceptions were Pudong and Yangpu, which only had at 43 percent and 31 percent respectively. This was because Pudong is larger in land area and includes places that were not served by the metro. For Yangpu, this was because the area was essentially a suburban district in the pre-reform era and historically dominated by heavy industries. Much as Yangpu is now part of Shanghai Proper, it still has a suburban land use configuration. Recently, economic transition and historical preservation programs in Yangpu district have driven land developments in a manner that is more responsive to market forces. In comparison, the outer districts had a smaller proportion or even none of their high-rise buildings included in the 500-m buffer around the metro stations. Jiading, for instance, had the highest rate at 35 percent, while Chongming, Fengxian, Jinshan, Nanhui, and Qingpu had none.

The high-density land use and transportation development that is observed in the urban core/Shanghai Proper is absent in the outer suburban districts. A twofold explanation is that these suburban districts are more car-oriented and the land use patterns there adhere more to the classic density-distance curve where building density is lower the further away from the urban center.

4.2. Spatial correlation of high-rise buildings around metro stations

The correlation results (Table 2 & Fig. 5) revealed a dichotomy between the inner core and the outer districts of Shanghai Proper, where the former did not conform to the density-distance decay model unlike the latter. Within Shanghai Proper, the inner core districts had positive correlation scores, such as Huangpu, Luwan, and Jing’an of 0.2772, 0.1060, and 0.0512 respectively. The outer districts had negative correlation scores, such as Pudong, Putuo, and Changning of −0.3776, −0.2955, and −0.2915 respectively. Pudong had the lowest correlation score of −0.3776 while Huangpu had the highest correlation score of 0.2772. What is notable is that Pudong, which is classified administratively as part of Shanghai Proper because of the Lujiazui Financial Center, has an overall spatial pattern of development that is more suburban in nature. The high correlation score reconfirmed that the density distribution patterns in Pudong resembled those in the outer districts of Shanghai Proper. The exception was Yangpu, an outer district that had a high correlation score.

Fig. 4 shows the density-distance relationship in the various districts, where the x-axis is the distance to metro stations and the y-axis is the number of high-rises. The travel distance to metro stations for Huangpu, Luwan, and Jing’an districts levelled off at around four to 5 min. They clearly do not exhibit a distance-decay function. Several explanations may account for this. First, it may not always be possible to develop right by a metro station. Second, it may be beneficial to separate the high-rise buildings from the most congested areas. Third, the densely distributed metro stations in these districts provide convenient pedestrian access no matter where the buildings are constructed.

The urban form and spatial patterns of the suburban districts reflected the Transit-Oriented Development (TOD) approach where the transit infrastructure was planned first and then determined the land uses available for lease (Rowe et al., 2016), thereby giving rise to the clustering of high-rise, high-density developments in closer proximity to areas of greater accessibility in and around the metro stations. Moreover, in Pudong, Yangpu, and Minhang, most of the high-rise buildings that were located outside of the 500-m buffers are residential.
whereas commercial and office high-rises tended to be closer to the metro stations. Further, the prevalence of automobile usage in these less congested districts allowed for some office buildings to be built further away from the metro stations.

The correlation results for the respective districts were mapped in Fig. 5. Districts with positive correlations were symbolized in green while districts with negative correlations were symbolized in yellow. The various shades of each represent the correlation strength, with darker shades indicating stronger correlations and lighter shades for weaker correlations. Districts without any correlation values were symbolized in white. Five districts had no high-rise buildings within the 500-m buffers around the metro stations; these included Chongming, Fengxian, Jiashan, Nanhu, and Qingpu. The map again revealed a pattern where there was a positive correlation observed in the inner core districts while the surrounding and suburban districts mostly had negative correlations between the number of high-rise buildings above 20 stories within walking distances to metro stations and the time-distance to the nearest station.

In summary, urban development policy is increasingly important in locating density, and simple distance-decay models are not applicable to large cities in China. The underlying drivers for the differences of spatial proximity and spatial correlation between high-rise buildings and metro stations are associated with the stages of urban development, the existence of metro infrastructure at the time of the high-rise development, and land use policies.

5. Conclusions

Understanding the complex spatial proximity and spatial correlation between high-rise buildings and metro stations matters in accounting for the urban growth patterns and land use configurations in different contexts. In Shanghai’s case, the results in this study demonstrate that the differences between inner districts and outer districts of the locations of high-rise buildings and metro stations are associated with the stages of urban development, the existence of metro infrastructure at the time of the high-rise development, and land use policies.

The study has also shown that high-rise buildings as a proxy for land rent can be useful to understand the relationship between land use and the proximity to metro transit. This is especially true in China where planning and policy goals are often determined by an absolute number of high-rise buildings to be constructed within a specified period. Moreover, the methodology adopted in this paper could also be used to examine the relationship between land use and metro development elsewhere in China and other East Asian countries where rapid urban development coincided with the creation of a comprehensive public transit system.

Finally, the research here has focused on understanding the spatial patterns of urban development in Shanghai from 1994 to 2010. It could be extended to trace the rate of changes in the building density-transit access relationship, which will offer a more dynamic picture of the spatial patterns in the city’s urban formation. Further research could also be undertaken to examine how high-rises of different uses and high-rise residences of various types vary in their relationships to transit access, and to understand the kinds of policies and agents driving these relationships.

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Appendix 1

Lujiazui, Pudong in the 1980s (left) and early 2010s (right) from across the Huangpu River over the Bund in the historic International Settlement area of central Shanghai. Source: Bricole urbanism.

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