Do compact cities provide a solution for sustainable urbanization?

Compact cities are often associated with higher residential densities and public transit–oriented urban growth, such as many Western European cities that have been considered more compact than many in the United States and China. Some post-war North American cities, on the other hand, have come to epitomize urban sprawl with their low-density suburbs and car-oriented urban infrastructure. The scale of the case study cities discussed in this chapter differs drastically from what is often proposed as compact in the United States, for example; thus, the use of the term “compact cities” in this chapter is associated with the East Asia circumstances and large metropolitan cities in China. Although divergent interpretations exist among scholars, compactness, which is seen to be advantageous over sprawl, has been advocated as one of the key strategies to establish sustainable cities. Traditionally, compactness is measured by criteria such as Moran’s index and the Shape index. These indices were originally developed by statisticians and applied in biology and ecology. Since the 1970s, they have become popular tools to measure urban forms and spatial patterns of human activities in the disciplines of planning and urban geography. The focus, though, was on how to improve productivity and lower energy consumption per capita. However, these conventional measures of compactness did not reflect the virtues of a well-performing compact city and potentials for its sustainable development.

Without addressing the environment and the ecological systems, even cities with compact forms can be detrimental. Urban compactness created by densification, for instance, tends to cause the elimination of green space. Furthermore, an urban area with large continuous hard surfaces can cause severe storm water runoff. Densely developed urban centers, lacking well-distributed green space, can destroy animal habitats by eliminating these connections from their ecosystem. Artificially created urban edges with straight lines can constrain the range of activities for certain domestic insects. The shortcomings of a human-centered compact city can cause discomforts for urban dwellers as well. For example, clustered high-rise towers can limit the view sheds for pedestrians while gated...
communities in high-density neighborhoods can deny public access to interior green spaces. Last but not least, closely clustered residential towers can also block sunlight. This violates a critical dimension of social life in some East Asian cultures, especially in the Chinese circumstance, which is to have direct solar access.

Relevance of compact cities in contemporary Chinese urbanization

East Asian megacities that have emerged since the 1950s, such as Tokyo and Seoul, can be characterized by their higher densities and more compact urban forms, unlike their Western counterparts. In China, rapid urbanization has likewise created multiple megacities and urban clusters with intensive development since the turn of the twenty-first century. Rapid economic development brought about by industrialization and modernization has often occurred at the expense of the environment. China’s post-reform period of urban development beginning in the 1990s was accompanied by the urban environment degradation. With the implementation of the 11th Five Year Plan of the Chinese central government released by the National Congress in 2006, understanding the different types of compact cities has become a central research issue. The subsequent guidelines of the plan touched upon multiple aspects of planning including the urban street grid, neighborhood diversification, multicentered city layout, and so forth. As urban pollution, overcrowding, and environmental degradation worsens in Chinese cities, it is necessary to develop a more comprehensive measure of compact cities. Urban pollution is often associated with transportation-related air pollution and greenhouse gas emissions. The rising level of vehicle miles traveled (VMT) has been claimed to be the primary cause of many urban environmental problems. In China, strict policies have been adopted to encourage compact cities and finer-grained urban blocks and accessible communities, which may address these issues. On the other hand, the potential socioeconomic consequences of overcrowding and congestion may outweigh the benefits of policies favoring high compactness. No doubt that an appropriate balance between urban functional structure and environmental quality is more desirable.

Methodology

An urban form that incorporates comprehensive aspects of compact cities can be more sustainable and may accommodate higher densities of urban dwellers while preserving the integrity of their urban ecological systems. Going beyond the measurement of urban spatial arrangements than Moran’s index alone, this chapter suggests other aspects of compact cities that should be evaluated. This study assesses these aspects using two categories of spatial metrics: the arrangement of urban built space and the dimensions of urban open space. Of these
two categories, the former includes compactness, porosity, and diversity, while the latter includes edge density, patch type, and parcel density. In particular, the dimensions of urban open space build upon the diverse selection of surface metrics from the growing field of surface metrology. Largely unknown to urban planners and urban geographers, structural and molecular physicists have developed the field of surface metrology to quantify surface patterns and gradients. These surface metrics were modified and then applied to quantify urban landscape gradients and urban open space. A geographic information system (GIS), a system designed to analyze spatial data, was also used to store and analyze the spatial metrics data. A base map that contains the layer files of variables was first generated. Then a number of GIS operations were applied to process and consolidate data collected. The results of the spatial metrics measures were compiled into a single composition score to evaluate the spatial conditions of compact cities.

**Spatial metrics of urban built space**

The spatial metrics of urban built space were measured by the three respective spatial indices: Moran’s index, porosity index, and a combination of Shannon’s index, Simpson’s index, and modified Simpson’s index. Together, they provide an evaluation of the spatial conditions of urban built space. Compactness, as distinct from spread and sprawl, is one of the attributes that describes urban form. It is a property based on the assumption of a closed Euclidean space. The conventional measures of compactness include spatial indices that describe the value distribution in the sub-areas such as Moran’s index. Porosity describes the penetration of open space in urban conditions. It is one of the metrics deployed by landscape ecologists to describe the conditions of land surfaces and their coverage. While compactness measures the condition of urban parcels, porosity describes the presence of open space within built-up urban areas.

Open space, in this chapter, includes parks, plazas, playgrounds, and other recreational areas and excludes vacant lots and unused land. For example, porosity can evaluate urban parks and public plazas that enhance the quality of urban ecological conditions and abandonment of public amenities. The measure of diversity was performed by applying three methods: Shannon’s index, Simpson’s index and the modified Simpson’s index. The mean of the three methods was used as the diversity score. Shannon’s diversity index was originally developed as a mathematical measure of species diversity in a community. It was later adopted by the field of urban studies in order to measure land use diversity. Simpson’s index was developed by Edward H. Simpson in 1949. It measures the degree of concentration when individuals are classified into types. Simpson’s index is less sensitive than Shannon’s index in the presence of rare classes. The modified Simpson’s index was developed by Pielou in 1975. It was transformed into a general class of diversity indices in the 1980s.
Moran’s index can be expressed by the following equation:

$$I = \frac{N}{\sum i \sum j w_{ij}} \frac{\sum i \sum j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum i (X_i - \bar{X})^2}$$

Where

- $X_i$ population or value in sub area $i$
- $X_j$ population or value in sub area $j$
- $\bar{X}$ mean of population or value
- $N$ number of sub area
- $w_{ij}$ weighting between sub areas $i$ and $j$.

A higher Moran’s index corresponds to a monocentric form, represented by concentrated developments at one or multiple areas of a city; a lower result corresponds to a decentralized form, represented by more evenly distributed patterns. The weighting coefficient that defines neighborhood conditions is $w_{ij}$. The weighting matrix behind $w_{ij}$ utilizes the inverse distance spatial relationship to allow nearby features to have a larger influence. $N$ is the number of sub-areas in each city. $X_i$ and $Y_i$ values reflect the conditions of the land parcels such as density, land coverage ratio, or other proxies. In this research, resident population figures from the 2010 Population Census, which was published by the National Bureau of Statistics of China, were used.

Porosity

The porosity index of an urban area is the ratio of open space or non-urban area to the total area. This measure displays the overall size of the open space within the study area, and it does not take into account of each individual size and its spatial distribution. The formula to calculate porosity is:

$$P = \frac{\sum_{i=1}^{n} O_i}{\sum_{j=1}^{m} A_j}$$

Where

- $O_i$ open space in area $i$
- $A_j$ urban space in area $j$
- $n$ number of sub-areas of open space
- $m$ number of sub-areas of urban space.

A higher porosity means the presence of more open space. $O_i$ is the size of open space in area $i$. $A_j$ is the size of urban space in area $j$. The number of sub-areas of
open space in each city studied is $n$, while $m$ is the number of sub-areas of urban space in each city studied.

**Diversity**

Shannon’s diversity index is calculated as follows:

$$H = -\sum_{i=1}^{R} p_i \ln p_i$$

Where

- $p_i$ proportion of land parcels belonging to the type selected in the dataset of interest
- $R$ number of land classifications.

In this research, the value of Simpson’s index represents the probability that any two types of land selected at random would be different types. Simpson’s index is expressed as follows:

$$S = \sum_{i=1}^{n} p_i^2$$

Where

- $p_i$ proportional abundance of the type of land
- $n$ number of land classifications.

The modified Simpson’s index is expressed as follows:

$$S_r = \frac{-\ln \sum_{i=1}^{n} p_i^2}{\ln n}$$

**Spatial metrics of urban open space**

Spatial metrics of urban open space here describe the physical characteristics of the open space and its relationship with the surrounding urban space. These shape metrics were developed in the field of landscape ecology.\(^{18}\) Edge density, patch type, and parcel density were used as indicators of land parcel shapes.

An edge refers to the border between two different classes of spaces.\(^{19}\) As transition zones, edges are often particularly rich in species.\(^{20}\) The geomorphological diversity by landscape change and factors of human influences had a significant impact on the types of habitat that each individual patch supports. Edge conditions can be measured by the edge density or what is also known as the Perimeter Area Ratio (PAR). Edge density can be expressed as the length of all borders between different open space patch types or classes in a reference area divided by the total
area of the reference unit (in this case, 500 m by 500 m). Edge density takes into account the shape and the complexity of non-urban areas. It is a measure of the complexity of the shapes of land parcels and is an expression of the spatial heterogeneity of a landscape mosaic. The Interspersion and Juxtaposition Index (IJI) explicitly takes into account the spatial configuration of patch types. This index considers the neighborhood relations between open space patches and other types of urban spaces. Each type of land use is analyzed for adjacency with all other land use types, and the index measures the extent to which types are interspersed, that is the degree to which each type shares an equal border with other land use types.

Parcel density is developed from the concept of patch density. It is a fundamental aspect of land pattern because it provides guidance as to where development has occurred or is likely occurring. When measured by itself, it produces limited interpretive value; however, it is especially useful for comparative analyses across different study areas. Parcel density analyzes what is actually on the ground, versus modeling land use from satellite and other remote sensing techniques.

**Edge density**

The edge density index can be calculated as follows:

$$E = \frac{\sum_{i=1}^{n} P_i}{\sum_{j=1}^{m} A_j}$$

Where

- $P_i$ perimeter of area $i$
- $A_j$ size of area $j$
- $n$ number of sub-areas of open space
- $m$ number of sub-area reference units.

Edge density is a function of the size of the mapping unit defined, or grain size, which was set at 500 m by 500 m in this research. The smaller the mapping unit, the better the spatial delineation, resulting in an increase of the edge length. The more regulated shape the land patch, the shorter the total edge length. For example, a round shape has the most regulated shape, which provides the least edge length for a certain size.

**Patch type**

Patch type of urban open space is measured by the IJI index. It is calculated as:

$$IJI = \frac{-\sum_{i=1}^{m} \sum_{k=1}^{m}[E_{ik} \ln(E_{ik})]}{\ln\left[\frac{m(m-1)}{2}\right]}$$

Where

- $E_{ik}$ edge length of type $i$ in sub-area $k$.

This index considers the neighborhood relations between open space patches and other types of urban spaces. Each type of land use is analyzed for adjacency with all other land use types, and the index measures the extent to which types are interspersed, that is the degree to which each type shares an equal border with other land use types.
Spatial metrics of urban form

Where

\( IJI \)  interspersion and juxtaposition coefficient

\( m \)  number of classes

\( E_{ik} \)  length of edge between class \( i \) and class \( k \).

The IJI is a relative index that represents the observed level of interspersion as a percentage of the maximum possible given the total number of patch types. Low values suggest that the land parcel types are distributed disproportionately, where classes are bordering only a few other classes. High values result from land distributions in which the parcel types are almost equally adjacent to each other where each class has a common border with all others.\(^{24}\) The IJI value approaches zero when the distribution of adjacencies among unique patch types becomes increasingly uneven and approaches 100 when all patch types are equally adjacent to all other patch types. The minimum number of land types is three, which is required in an IJI evaluation.

\[ Pd = \frac{n}{\sum_{i=1}^{n} A_i} \]

Where

\( n \)  number of land parcels in the area

\( A_i \)  total land area.

**Composite score**

The purpose of applying the composite score was to disclose the balanced of spatial form in general without emphasizing one metric over the others.\(^ {25} \) The composite scores in this study are derived by the sum of all six compact city variables based on the following equation:

\[ CS_i = W_i \sum_{j=1}^{n} \ln \left( \frac{X_j - \bar{X}_j}{\bar{X}_j} + 1 \right) \]

Where

\( W_i = 1 \)

\( CS_i \)  composite score of city \( i \)

\( X_j \)  shape metrics, diversity and compactness of city \( i \)

\( \bar{X}_j \)  mean of variables.
Study areas

Beijing, Shanghai, and Shenzhen are the top three most developed cities in China and were selected as comparative cases for this research. Beijing in the north is the capital city and the political center of the nation. Shanghai, which is almost midway between Beijing and Shenzhen, is an economic center with the highest gross domestic product for several consecutive years in China and also a directly-controlled municipality or a provincial city. Shenzhen in the south is the flagship city for the post-reform era, taking advantage of being near Hong Kong. All three cities are regarded as tier one cities by virtue of their economic performance and population, and less so their respective administrative statuses. They are also located within the largest metropolitan regions: Beijing in the Bohai rim region, Shanghai in the Yangtze River delta region, and Shenzhen in the Pearl River delta region. Environmental issues and ecological degradation are also the most severe among these large Chinese cities.

The study area in each city was defined by an area measuring 65 km east-west by 45 km north-south, centered on the inner city district(s). A 2 km buffer zone was included in each study area to reduce the edge effect. Land parcels within the 63 km by 43 km zone were used for the analysis of spatial metrics. These areas covered most of the urban built-up extents of the three cities. The land parcels were then categorized into three functions: urban, open space, and others, such as farmland and forest land. Table 14.1 lists the number of land parcels, their total area, and perimeter for Beijing, Shanghai, and Shenzhen, respectively.

<table>
<thead>
<tr>
<th>Land Parcel</th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Shenzhen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>5,897</td>
<td>10,636</td>
<td>3,449</td>
</tr>
<tr>
<td>Open</td>
<td>311</td>
<td>310</td>
<td>120</td>
</tr>
<tr>
<td>Other</td>
<td>3,981</td>
<td>24</td>
<td>313</td>
</tr>
<tr>
<td>Total (n)</td>
<td>10,189</td>
<td>10,970</td>
<td>3,882</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land Area</th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Shenzhen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>908</td>
<td>1,338</td>
<td>588</td>
</tr>
<tr>
<td>Open</td>
<td>219</td>
<td>89</td>
<td>62</td>
</tr>
<tr>
<td>Other</td>
<td>802</td>
<td>388</td>
<td>567</td>
</tr>
<tr>
<td>Total (km²)</td>
<td>1,929</td>
<td>1,814</td>
<td>1,217</td>
</tr>
<tr>
<td>% of Urban</td>
<td>47.04%</td>
<td>73.75%</td>
<td>48.28%</td>
</tr>
<tr>
<td>% of Open</td>
<td>11.37%</td>
<td>4.90%</td>
<td>5.12%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parcel Geometry (Total Perimeter)</th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Shenzhen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>8,317</td>
<td>11,029</td>
<td>4,105</td>
</tr>
<tr>
<td>Open</td>
<td>1,106</td>
<td>635</td>
<td>367</td>
</tr>
<tr>
<td>Other</td>
<td>3,634</td>
<td>564</td>
<td>602</td>
</tr>
<tr>
<td>Total (km)</td>
<td>13,057</td>
<td>12,228</td>
<td>5,075</td>
</tr>
</tbody>
</table>
Figure 14.1 The distribution of urban and open spaces in Beijing (top), Shanghai (middle), and Shenzhen (bottom)
Data for the three study areas were collected from multiple sources, including the GIS data from the Harvard Geospatial Library, China GIS layers from the Beijing City Lab, and the Open Street Map (OSM). The China GIS layers were generated from OSM and its Points of Interest (POI) database. Information on the urban function, density, and land use mix for each parcel was stored in the layers. The data for each parcel was cross-validated by selecting sample locations in each city from the respective map sources to check for consistencies. Then the dataset was projected to the same coordinate system in GIS using the UTM WGS1984 Zone50N, which is defined by the UTM grid zones and is the most commonly used projection system in coastal China. Information on the urban space parcels was obtained from different sources. There were occasions when the same piece of land was identified as both urban and open space in the inner city area. Thus, the parcel function was cross-checked using multiple satellite images including Baidu Map, Google Earth, and the World Imagery Basemap from the US Geological Survey and the National Aeronautics and Space Administration. The land parcel data were then possessed by preserving only features within the extent of the study areas, which were transformed to a vector format in GIS by converting them from the input raster format. During this process, the “maximum area method” was used for the land parcel assignment as it allowed the single feature with the largest area within the area to yield the attribute to be assigned to the land parcel.

**Results**

Moran’s index test was executed in ArcGIS using the spatial autocorrelation function. The analysis process applied chordal distances in meters and the threshold distance was first set to 2,000 m. This distance incorporated at least five spatial lags of urban blocks, as the maximum length of a standard super block is 400 m in the study areas. The results revealed that there were only five land parcels with no neighbours in both Beijing and Shenzhen, and nine for Shanghai. However, the test also generated twenty-four land parcels with neighbors that exceeded 1,000 for Shanghai. This outcome made it necessary to re-conceptualize the spatial relationships and reset the threshold distance to avoid potential overreach of the neighboring parcels.

A second run the threshold distance was reduced to 1,000 m, which effectively eliminated the problem of overreaching. However, it generated fifty-one and ninety-three land parcels with no neighbours for Shenzhen and Shanghai, respectively. Compared with the number of the total land parcels, these accounted for almost 2 percent of Shenzhen’s and 1 percent of Shanghai’s total land parcels. A third run was designed to reduce the number of land parcels with no neighbours, and so the threshold radius was set to 1,500 m. It turned out to be the most appropriate model as the results showed that no parcel had more than 1,000 neighbours and the number of parcels with no neighbours was also reduced. Based on this third run, Moran’s index was 0.0216 for Beijing, 0.0456 for Shanghai, and 0.0042 for Shenzhen (See Table 14.2). One indicator from the results was the
<table>
<thead>
<tr>
<th></th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Shenzhen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Threshold distance</strong></td>
<td>2,000</td>
<td>1,500</td>
<td>1,000</td>
</tr>
<tr>
<td>Parcel with no neighbors</td>
<td>5</td>
<td>12</td>
<td>53</td>
</tr>
<tr>
<td>Parcels with neighbors exceeding 1,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Expected index</strong></td>
<td>(0.000170)</td>
<td>(0.000170)</td>
<td>(0.000170)</td>
</tr>
<tr>
<td><strong>Variance</strong></td>
<td>0.000004</td>
<td>0.000007</td>
<td>0.000013</td>
</tr>
<tr>
<td><strong>p-value</strong></td>
<td>0.0165</td>
<td>0.0216</td>
<td>0.0324</td>
</tr>
<tr>
<td><strong>Moran’s index</strong></td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td><strong>Explanation</strong></td>
<td>less than 1% likelihood of random chance</td>
<td>less than 1% likelihood of random chance</td>
<td>less than 1% likelihood of random chance</td>
</tr>
</tbody>
</table>
z-score, it showed how many standard deviations the parcel distribution pattern was from the mean. Based on the z-scores of the third run, there was less than 1 percent likelihood that the clustered patterns were the results of random chances for all three cities. In addition, Shanghai and Shenzhen, to different extents, all showed relatively compact urban development patterns. Moran’s index would be close to +1 for a perfectly compact pattern and close to −1 for a perfectly dispersed pattern. Based on this standard, Shanghai performed the best in terms of compactness.

The results of the porosity test are shown in Table 14.3, where Beijing had a coefficient of 0.1330, Shanghai 0.0576, and Shenzhen 0.0895. As mentioned earlier, a higher porosity value implies the presence of a larger open space area. Apparently, within the study areas, Beijing dominated in both the absolute open space area and the open space to urban space ratio. Shenzhen, on the other hand, had the smallest amount of open space area. However, Shenzhen ranked higher than Shanghai in terms of its porosity because the total urban area was also smaller for Shenzhen.

The measure of diversity is determined by the dynamics of land uses. For the purpose of this research, the land uses in study areas were classified into eight categories: (1) civic, (2) commercial and service, (3) education, (4) industrial, (5) open space and recreation, (6) residential and mix use, (7) transportation, and (8) other uses. This land classification was based on both the Chinese and the US systems. Among the categories, with the exception of open space and recreation and other use, all the others belonged to the “urban or built-up land” parent category. Agricultural land was classified under “other uses.” The results for the Shannon’s entropy, Simpson’s diversity, and modified Simpson indices are shown in Table 14.3. In terms of land use diversity, Beijing had the greatest diversity across all three measures while Shenzhen had the lowest. The reason to have multiple tests was to examine the consistency across these different measures. The consistent outcomes ruled out any potential calculation biases in the indices, and the mean of the results from the three tests was used to calculate the final composite scores: Beijing 0.0725, Shanghai 0.0624, and Shenzhen 0.6152.

The landscape metrics were calculated in FRAGSTATS (Version 4), a software developed by McGarigal at the University of Massachusetts, Amherst. Based on the analysis, Shanghai had the highest edge density score of 7.1495, followed by Shenzhen with 5.8946, and Beijing with 5.0430. Shanghai also had the highest IJI score of 39.1151, followed by Beijing at 37.6741, and Shenzhen at 34.8384. Again, Shanghai had the highest parcel density score of 0.1709, followed by Beijing at 0.1612, and Shenzhen at 0.0986. The raw data for each of the variables were then normalized by subtracting the means from the raw data and then dividing by the means. Before the composite scores were calculated, the normalized data were scaled to a range between −1 and +1.
Table 14.3 Combined spatial metrics of Beijing, Shanghai, and Shenzhen

<table>
<thead>
<tr>
<th>Metric</th>
<th>Center</th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Shenzhen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
<td>Normalized</td>
<td>Final</td>
<td>Raw</td>
</tr>
<tr>
<td>Compactness</td>
<td>Moran’s Index</td>
<td>0.0216 (0.0935)</td>
<td>(0.0164)</td>
<td>0.0456</td>
</tr>
<tr>
<td>Porosity</td>
<td>Green to Urban Ratio</td>
<td>0.1330 0.4248 (0.3832)</td>
<td>0.0590</td>
<td>0.0576</td>
</tr>
<tr>
<td>Diversity</td>
<td>Shannon’s Diversity</td>
<td>1.4368 0.5642 (0.3832)</td>
<td>0.0746</td>
<td>1.3189</td>
</tr>
<tr>
<td></td>
<td>Simpson’s Diversity</td>
<td>0.7016 0.5249 (0.3832)</td>
<td>0.0703</td>
<td>0.6787</td>
</tr>
<tr>
<td></td>
<td>Modified Simpson</td>
<td>1.2093 0.5472 (0.3832)</td>
<td>0.0727</td>
<td>1.1355</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1.1159 0.5454 (0.3832)</td>
<td>0.0725</td>
<td>1.0444</td>
</tr>
<tr>
<td>Landscape</td>
<td>Edge Density</td>
<td>5.0430 0.1635 (0.0223)</td>
<td>(0.0298)</td>
<td>7.1495</td>
</tr>
<tr>
<td>Metrics</td>
<td>Interspersion and Juxtaposition</td>
<td>37.6741 0.3806 (0.0223)</td>
<td>0.0538</td>
<td>39.1151</td>
</tr>
<tr>
<td></td>
<td>Parcel Density</td>
<td>0.1612 0.1229 (0.0223)</td>
<td>0.0193</td>
<td>0.1709</td>
</tr>
<tr>
<td>Performance</td>
<td>Composite Score</td>
<td>44.0157 0.7919 (0.0223)</td>
<td>0.1585</td>
<td>47.5254</td>
</tr>
</tbody>
</table>
Figure 14.2 Land use classification in Beijing (top), Shanghai (middle), and Shenzhen (bottom)
The impact coefficients showed how variables were weighted in the composite scores. They were calculated by dividing the standard deviations by the means. The variances of compactness were the largest, that is, making it the most influential variable, followed by porosity, land use diversity, parcel density, edge density, and finally the IJI. Details of the impact coefficient are shown in Table 14.4. However, for purposes of this research, an even-weighted distribution was found to be more reasonable with equal emphasis placed on each variable. The impact coefficients were then adjusted by weight according to the following process: first, the scores were adjusted to the standard deviations and means; second, the ranges of scores were calculated; third, the scores were adjusted to the same range across all six variables. The outcome coefficients became 1.0000 (see Table 14.5).

### Table 14.4 Impact coefficient of the spatial metrics that measure compact cities

<table>
<thead>
<tr>
<th>metric</th>
<th>Beijing</th>
<th>Shanghai</th>
<th>Shenzhen</th>
<th>Variance</th>
<th>SD</th>
<th>Mean</th>
<th>Impact Co.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compactness</td>
<td>(0.0164)</td>
<td>0.1085</td>
<td>(0.2892)</td>
<td>0.0276</td>
<td>0.0208</td>
<td>0.0238</td>
<td>0.8741</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.0590</td>
<td>(0.0805)</td>
<td>(0.0071)</td>
<td>0.0032</td>
<td>0.0379</td>
<td>0.0934</td>
<td>0.4056</td>
</tr>
<tr>
<td>Diversity</td>
<td>0.0725</td>
<td>0.0624</td>
<td>(0.0278)</td>
<td>0.0020</td>
<td>0.2708</td>
<td>0.9252</td>
<td>0.2927</td>
</tr>
<tr>
<td>Edge Density</td>
<td>(0.0298)</td>
<td>0.0284</td>
<td>(0.0038)</td>
<td>0.0006</td>
<td>1.0596</td>
<td>6.0290</td>
<td>0.1758</td>
</tr>
<tr>
<td>IJI</td>
<td>0.0538</td>
<td>0.0600</td>
<td>0.0407</td>
<td>0.0001</td>
<td>2.1759</td>
<td>37.2092</td>
<td>0.0585</td>
</tr>
<tr>
<td>Parcel Density</td>
<td>0.0193</td>
<td>0.0290</td>
<td>(0.0626)</td>
<td>0.0017</td>
<td>0.0392</td>
<td>0.1436</td>
<td>0.2733</td>
</tr>
<tr>
<td>Total</td>
<td>0.1585</td>
<td>0.2078</td>
<td>(0.3497)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 14.5 Adjusted composite scores of Beijing, Shanghai, and Shenzhen

<table>
<thead>
<tr>
<th></th>
<th>Adjusted by SD and Mean</th>
<th>Adjusted to the same weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beijing</td>
<td>Shanghai</td>
</tr>
<tr>
<td>Compactness</td>
<td>(0.0187)</td>
<td>0.1241</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.1455</td>
<td>0.1986</td>
</tr>
<tr>
<td>Diversity</td>
<td>0.2478</td>
<td>0.2133</td>
</tr>
<tr>
<td>Edge Density</td>
<td>(0.1693)</td>
<td>0.1616</td>
</tr>
<tr>
<td>IJI</td>
<td>0.9192</td>
<td>1.0262</td>
</tr>
<tr>
<td>Parcel Density</td>
<td>0.0707</td>
<td>0.1062</td>
</tr>
<tr>
<td>Total</td>
<td>1.1952</td>
<td>1.4329</td>
</tr>
</tbody>
</table>
Conclusions

What are the spatial characteristics of a compact city?

Based on the composite scores, Shanghai is the most compact city, followed by Beijing and then Shenzhen. This ranking was focused on the overall performance of all six spatial metrics selected in the study. No one city outperformed others in
all aspects. For example, Shanghai performed better with regard to compactness, edge density, IJI, and parcel density, but performed poorly on porosity. Beijing performed better in terms of diversity and porosity but performed poorly on edge density. Shenzhen ranked the last in four measures: parcel density, IJI, diversity, and compactness. Shenzhen only outperformed Beijing in terms of edge density and Shanghai in terms of porosity. The radar chart in Figure 14.4 summarized the composite scores of three cities on six spatial metrics.

The compactness of Shanghai reflects the multicentered layout of the city. The centers are clusters of commercial, office, and residential mix-uses. Currently, there are nine such city centers. The high density areas are supported by an extensive public transit system, with the 588 km Shanghai Metro and more than 1,000 formal bus services. Beijing also has a large subway network for public transit. Where Beijing falls short is in the number of city centers. The central business district, or Guomao as referred to by locals, to the east and the Financial Street to the west are the only two identifiable high density mixed-use city centers. With the further development of the Economic and Technological Development Area, better known as Yizhuang, the Olympic Center Zone, and Zhongguancun, an innovation hub to the north, Beijing could potentially become more compact. The reasons that Shenzhen did not perform well on compactness are twofold. First, Shenzhen’s original linear form developed along the Shenzhen-Hong Kong borderline in order

![Radar chart of composite scores in summary for Beijing, Shanghai, and Shenzhen](image-url)
to embrace trading opportunities through Hong Kong. One of the consequences is the separation of an inner zone, better known as “Guannei,” from an outer zone or “Guanwai.” In urban terms, this resulted in a developmental lag in the outer zone. Even though Shenzhen possesses at least four centers – Luohu, Futian, Nanshan, and Yantian – in each of its original Special Economic Zone (SEZ) districts, the spatial distribution of the four centers follows the linear shape of the city. Further development in the outer zone districts such as Longgang and Longhua and expansion of their district centers can help build up Shenzhen’s compactness.

Beijing performed best in terms of open space parcel porosity. The abundant open space along the Fifth Ring Road is the most significant contributing factor. However, the low edge density reveals that the configurations of Beijing’s open space are mainly large land parcels with linear edges and rectangular shapes. This means that even though Beijing possessed large open areas, these are not necessarily well-functioning spaces. Shanghai, on the other hand, did not score high on porosity but did well on edge density. The existing open space is parcelized into smaller ones due to the finer-grained layout of the city’s infrastructure and street network.

Diversity scores of Shanghai and Beijing were both relatively high, whereas Shenzhen had a low score as a result of a planned city following policies that encouraged coarse-grained, large functional zones. When rapid development and growth were prioritized, Shenzhen did not have the luxury to put effort into more fine-grained, block-level planning. It did not take long before the city found itself in a monotonous cityscape where mixed uses of land became necessary. The results of the IJI metric also revealed the lack of adjacency of different land uses.

Parcel density can be explained by each city’s road network and urban block configuration. Shanghai’s finer grained street hierarchy, at least in the Puxi area west of the Huangpu River, compensated for a higher overall parcel density. On the other side of the Huangpu River, the Pudong area was planned with larger urban blocks that lowered the parcel density. Areas outside of Beijing’s Fourth and Fifth Ring Roads and the outer zone of Shenzhen are populated with the so-called megablocks, which significantly lowered the parcel densities.

**How to build a more compact city**

The ranking of the composite scores reflects the relative performance of each compact city. It is by no means a one-size-fits-all standard. The method does allow the research to be expanded to a larger pool of cities and towns, and the relative ranking system provides flexibility to adjust for more or fewer independent variables. Out of the six selected variables for this research, two of them – porosity and edge density – were specifically concerned with open space. It emphasizes the idea that compact cities should not only be valued for economic growth and transit efficiency, but also for access to open space, that is, the urban “nature” and the ecological network that run parallel to the urban network.

One potential improvement for Shanghai is to enhance its open space porosity. A feasible approach is to convert brownfields and post-industrial sites into green open space, such as the historical industrial zone in Yangpu District along occupied
14.2 km$^2$ of land, including 2.6 km$^2$ of storage space. With certain brownfield remediation and proper control of developing sequence, the city can provide more open space through cost-effective ways.

The most recognizable deficiency for Beijing is its low edge density. Obviously, it is not easy to increase the perimeters from the existing rectangular blocks in the middle of a big city. A potential solution may lie within the configuration of the megablocks. Currently, a high percentage of the megablocks in Beijing, either for residential use, or former work units, are gated and inaccessible to the public. The recently publicized “Key Suggestions to Further Reinforce the Management of Urban Planning and Construction” by the State Council of China called for the opening up of these closed communities. This policy also introduced opportunities to create more open space to the public realm while subdividing large urban blocks. Retrofitting megablocks and increasing the number of thoroughfares at the city level can also benefit parcel density and IJI.

Between Shanghai and Beijing, the former performed better in almost all aspects. This had to do with Shanghai’s historical urban spatial context and the preservation of its overall street network, the traditional housing and cultural heritage. To further improve Shanghai as a compact city, perhaps a striking plan that attracts people’s attention with conspicuous scheme such as an “emerald necklace” kind of green open space network will do. The breakthrough point for Beijing is the reconfiguration of megablocks, and the consequences can be more than just the improvement of a compact city.

Enhancing Shenzhen’s performance as a compact city can be undertaken in numerous ways. The first would be to increase the city’s compactness in the outer zone. The city has expanded to the Dapeng Peninsula to the east and to the upper reaches of the Pearl River estuary as a result of the relocation of its port facilities northwards, thus stretching out its urban boundaries. Further development of the outer zone and the construction of new centers in the outer zone districts can help to release developmental pressures on the inner zone and along the coast. In addition, the new city center of Qianhai currently under development to the northwest can also improve the compactness of Nanshan District, while concentrated development in the border between the inner and outer zones in Longhua and Longgang can improve Shenzhen’s overall compactness. Shenzhen is relatively new compared to Beijing and Shanghai, which have longer histories. The pro-growth urban planning policies in Shenzhen was proposed at a time when economic growth was prioritized. The policies that may satisfy a fast growing city’s requirements are not sustainable in the long term. Now that China is transitioning to a period of slower growth, it is timely to contemplate what the form and qualities of more rational compact cities should be.

**Spatial metrics on compact cities in China**

Compactness alone in terms of urban spatial arrangements does not promise the efficient performance of compact cities. In this research, additional spatial metrics such as porosity, diversity, edge density, patch type, and parcel density were introduced to collectively provide a more refined understanding of efficient compact
cities. The compactness of Moran’s index emphasizes the density and spatial distribution of an urban settlement. Porosity and edge density, as mentioned earlier, seek to address the qualities of open space. It draws attention to the importance of open space in a city and its benefits to urban dwellers. Another immediate advantage of having open space is to provide places for daily physical exercise and recreation, both of which are increasingly relevant to the creation of healthy cities. To evaluate vegetation cover of the open space and the availability of facilities for social and individual activities, additional spatial metrics became necessary for future studies. Diversity and patch density both concerned the functional distribution of land parcels. Leaving aside the local city government’s intention to maximize fiscal revenues and to minimize the costs and challenges of infrastructure improvements, land parcelization and street layout should be finer-grained. In some cases, where mixed-use areas prevail, the two metrics of diversity and patch density should incorporate the variations in use in the land parcels instead of adopting the conventional Boolean logic of true or false. By so doing, mixed-use parcels can be better represented. The research can be refined subsequently using this degree of truth logic to conduct more in-depth analysis of compact cities. A well-balanced urban form in terms of compactness and other metrics can satisfy the needs of both urban productivity and ecological well-being. The study of these spatial metrics as shown here will be of relevance to Chinese cities and towns in their plans to achieve more adaptive and optimal urban forms.

Notes


3 Moran’s index is a measure of spatial autocorrelation developed by Patrick Alfred Pierce Moran. Spatial autocorrelation helps understand the degree to which one object is similar to other nearby objects. Shlomo Angel, Jason Parent, and Daniel Civco, “Ten Compactness Properties of Circles: Measuring Shape in Geography,” *The Canadian Geographer / Le Géographe canadien* 54, no. 4 (2010), 441–461.


5 Ibid.; see also ChengHe Guan, “Quantifying the Landscape Sensitivity of the Wildland-Urban Interface in the Appalachian Trail region,” Working paper.


The landscape gradients, developed from the concept of Forman’s land mosaic model, describe land surface with a continuous multidimensional gradient. More recently, surface metrics have been applied to urban analysis on ecological conditions and the quantification of landscape structure.


Eiden, Kayajanian, and Vidal, “Capturing Landscape Structures.”

McGarigal and Marks, “Spatial Pattern Analysis Program for Quantifying Landscape Structure.”


McGarigal and Marks, “Spatial Pattern Analysis Program for Quantifying Landscape Structure.”


These numbers are quoted from the official website of Shanghai Municipal People’s Government, 2016.

Rowe and Guan, “Striking Balances between China’s Urban Communities, Blocks and Their Layouts.”

Shanghai Yangpu Government, Urban development and planning of the Yangpu District, the Thirteenth Five Year Plan for Economic and Social Development, 2016.