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Introducing Third Dimension on Space Syntax: Application on the Historical Istanbul

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INTRODUCING THIRD DIMENSION ON SPACE SYNTAX: APPLICATION ON THE HISTORICAL ISTANBUL[1]

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ABSTRACT

The historically developed area of Istanbul will be analyzed with conventional space syntax approach and its extended version. The topography of the study area is rich in height variation. To analyze urban forms on a three-dimensional surface, space syntactic idea is extended in two aspects. The notion of axial lines is extended to incorporate the height change by introducing "extended axial lines". Moreover, a weighting function is introduced to represent the overlapping nature of inter-visible areas between two neighboring axial lines. Space syntactic indices related to local centeredness are calculated and compared to indices representing actual urban activities. The results indicate that space syntactic indices extended to three-dimensional space capture well the concept of the amount of buildings and commercial activities along roads, whilst they fail to capture the concept of experts' indication of local centers. The space syntax approach emphasizes the mutual visibility, which may not be the principal factor in forming traditional cities, such as Islamic cities. This result, therefore, suggests that another principal factor should be sought in building of a powerful analyzing tool for such traditional cities. Compared to the extension to three-dimensional space, the introduction of the weighting function for intersecting angles of extended axial lines does not contribute significantly to the improvement of this analysis.

Keywords: space syntax, three-dimensional surface, extended axial line, angle of intersections, Istanbul

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1. INTRODUCTION

Space syntax originated by Hillier has been a powerful tool to analyze urban forms, as a number of empirical works have already established[6]. A typical approach in space syntax is to construct an axial map for public space based on the city map by drawing a set of axial lines, which represent minimum number of visible lines that cover all the space in question.

Since the axial lines are drawn based on a two-dimensional map, axial lines fail to express three-dimensional changes in the space, namely height. In the conventional application of space-syntax, a single axial line can express a straight road, whilst a curved road may need more axial lines to represent it. Space syntax thus captures the curvature of roads. Maybe a road is curved because it is naturally generated in this way, or because the topography does not allow a straight road due to the drastic change in height. This aspect is very important to distinguish, in particular, when we want to apply space syntax to vernacular cities, such as traditional Islamic cities. Here there is an urgent need for developing a new method that can capture the curvature of surface, i.e., the change in height.

To develop such a method, we propose extended version of axial lines, called "extended axial curves" in this paper. To develop this idea, imagine the space to be analyzed is a road network in a city; by standing up on the road, the surface of the road is visible up to certain point, beyond which some portion is invisible because the road curves enough to conceal some portion of the road by buildings along the road, or because the road changes its surface height from the sea level enough to conceal some further portion. By approximating this situation, an extended axial curve is defined as a representation of the space in question, such that all the points are visible by standing on any location on the extended axial curve.

Moreover, incorporating the change in the direction of extended axial curves makes another extension of this concept. If two consecutive extended axial curves have similar directions, then two spaces represented by these extended axial lines tend to have a large amount of mutually visible areas. Two spaces are then judged not so discernible than the case that two extended axial curves have drastic change in direction. This factor will be taken into account by introducing weights determined by the intersecting angles of two line segments connecting the end points of extended axial curves.

To proceed these extensions, the usage of GIS (Geographic Information System) is indispensable. GIS can easily handle elevation data to derive extended axial curves. The method is detailed in Section 2.

The concepts developed above are applied to the analysis of road network in the historical part of Istanbul. The results show that extended version of space syntactic indices well capture the local centeredness in Istanbul, when it comes to the modern nature of local centers,

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6 See Asami, Kubat and Istek (2001), Brown (1999), Hanson (1989), Hillier (1999), Hillier, *et al*. (1993), Kubat (1997, 1999, 2001), Penn, Hillier, Bannister and Xu (1998), Peponis, *et al.* (1989), Peponis, Ross and Rashid (1997), and Read (1999), for example.

such as amount of buildings and commercial activities along the road. Another feature of local centeredness that seems well rooted from the historical and cultural background is not, however, well captured by the method. This result is suggested by the low correlation coefficients between experts' indication of local centers and space syntactic indices. In Islamic cities, the straightness of roads is not a fundamental factor in forming cities. Nonetheless, the symbolic buildings, such as mosques, stand out in traditional Islamic cities by constructing such facilities taking the topographic factors into account. This may imply that a notion of visibility other than that along public space should be developed to analyze such feature in the urban form. The results also show that the introduction of weighting function for angles of directions of neighboring extended axial lines does not contribute significantly in improving the analysis, while the extension to three-dimensional space does.

2. EXTENDED AXIAL CURVES AND EXTENDED AXIAL LINES

An axial line in the conventional space syntax is a representation of the space in question to signify a unit of space in which any two points in the space are mutually "visible". The definition of "axial line" is a little ambiguous, however, due to the ambiguity of "visibility". Judged from common practice of axial lines, two points on a road in the space is defined visible, if two points projected to the axial line are mutually visible.

Roads seldom lie on a completely flat land. The land surface has ups and downs, and so have roads. Usual axial lines are drawn based on a two-dimensional map, not taking into account the height change of roads. But as described in the introduction, the distinction between the road curves due to topography and the road curves on flat land is a critical factor in analyzing vernacular cities, such as traditional Islamic cities. To remedy this situation, the notion of axial line is extended here.

A natural extension of space syntax to the three-dimensional surface is to utilize the visibility idea again. But if the visibility of a point on a surface from another point on a surface is analyzed, we can easily get into a difficult situation that a road consists of (continuum) infinite number of axial "lines" which are virtually all points, for example, when the road forms a hill-shape with negative second derivative of height with respect to the horizontal distance. To avoid such a case, a practical extension is to introduce an eye-level view. That is, we will judge a point on a surface visible, if we can see from an eye-level above the surface. In our study, the eye-level is set to be 1.5m high above the road surface.

An extended version of axial line is then defined by a portion of the surface of the road, the projection of which onto the flat plane (a sea level surface, for practical example) is a line segment, so that any point on the portion is visible from an eye-level of any point on the portion. Since this extended version of axial line is typically a curve along the road surface, it will be called "*extended axial curve*" hereafter. As the conventional axial line is the case, a point on a road is regarded visible if the representative point on the extended axial curve, at which the line segment between the point in question and the representative point is perpendicular to the extended axial curve and visible from all the points at eye-level on the extended axial curve.

Since it is very difficult to derive extended axial curves by precisely minimizing the number of extended axial curves so that they cover the entire road network, a heuristic approach is taken here. To do so, first a usual axial lines are drawn based on the two-dimensional map, and then a projection of each axial line onto the road surface is checked with respect to visibility on the three-dimensional surface. This is partitioned into several extended axial curves so that visibility condition in the sense above is met. This procedure does not necessarily yield the exactly minimum number of extended axial curves, but the resulting extended axial curves can be thought of as an approximation to it. The heuristic "extended axial curves" derived by this procedure are called simply "extended axial curves", and the extended axial curves in the strict sense will be called "strict extended axial curves" hereafter.

For each extended axial curve, a line segment is defined by that connecting straightly between two end points of the extended axial curve. Since this line segment is straight by definition, it is termed "*extended axial lines*" hereafter. This will ease the definition of weighting function for angles in directional change in the following.

3. WEIGHTED EXTENDED AXIAL LINES

It is worth noting that neighboring extended axial lines meets at a point so that the angle formed by two consecutive extended axial lines can be easily measured. This angle can be regarded as the change in direction from one extended axial curve to the other extended axial curve. If the change in direction is small, then two extended axial curves are similar in the sense that most of the curves can be mutually visible even though not entirely. If not on the other hand, then two spaces represented by the curves are hardly connected visually. From the visibility point of view, if the angle formed by two extended axial lines is larger (i.e., close to 180 degrees), then two lines should have more common visibility.

In the usual space syntax, no distinction is made for axial lines intersecting with different angles. If the two consecutive axial lines have more common views, then it is natural to weight a small number in measuring the "(graph-theoretical) distance" between the end points. Similarly, in our extended framework, it is natural to weight a small number in measuring the "(graph-theoretical) distance" between the end points of consecutive extended axial lines.

To put this casual idea into a rigorous framework, it is necessary to consider the appropriate weighting factor for each angle. To do so, consider L-shaped road represented by two axial lines (Figure 1). Let q be the angle of change in direction of two axial lines in the unit of radian.

Dalton (2001) is the first to introduce the idea to assign weights for differently intersecting axial lines. He used w(min{q, $\pi - q$}) for the weighting function and applied it to usual two-dimensional axial lines. As is described in Section 4, however, this function cannot distinguish the acute angles and obtuse angles. If the angle is acute (i.e., q is greater than $\pi/2$), then common visible area between the neighboring extended axial lines is large, whereas if the angle is obtuse (i.e., q is less than $\pi/2$), then common visible area between the neighboring extended axial lines is small. From the visibility point of view, this distinction is essential. For this reason, other weighting methods are introduced. A simple method to weight according to the angle is to utilize directly this angle, q. Let w(q) be the weighting function, then is can be defined by:

$$w(q) = 2q/\pi$$

This weight is 1 when q is a right angle, and this value can be thought of the number of turns in the unit of right angle. This weighting function is designated as "simple" weighting function hereafter.

Another method to weight is to utilize the vector difference. Make directed vectors for two consecutive axial lines, and change each vector in scale such that the length of the directed vectors is one. The vector difference of two directed vectors can be defined as in Figure 2. A new notion of weighting function can be defined by:

$$w(q) = \text{the length of this vector difference}$$
$$= (2\text{-}2\cos q)^{1/2}$$

This weight is 0 when q is 0; 1 when q is $\pi/3$; and 2 when q is π. This function is more sensitive to smaller values of q. This weighting function is designated as "vector" weighting function hereafter.

4. EXTENDED SPACE-SYNTACTIC INDICES

Many of the axial indices frequently used are derived from looking at the relations of a space with its adjacent spaces either in the global or local context. Global indices are given by taking into account all the spaces that are in the area concerned, while local indices are given by limiting the scope to the finite number of "steps" (in the conventional axial analysis, this means the number of changes of direction). The actual calculation is done by treating the axial map as a graph representation in such a way that each axial line is represented by a vertex and the intersection point of two axial lines becomes an edge connecting two vertices (Figure 3).

For the conventional axial lines, the following indices have been computed: *connectivity*, *control*, *mean depth*, *integration*, *maximum depth*, *local mean depth*, *local spaces* (*K*), and clustering coefficient (*G1*, *G2*).

(1) Connectivity is the number of immediate neighbors of the axial line. This is equivalent of what is called the degree of vertex in graph theory.

(2) Control can be thought of as a measure of relative strength of the axial line in "pulling"

the potential from its immediate neighbors. When an axial line *lx* has *n* neighbors and the connectivity of each neighbor, l_i (i = 1, 2, ..., n) is represented by C(l_i), the control value of the axial line *lx* is given by:

$$\text{Control} = \sum_{i=1}^{n} \frac{1}{C(l_i)}$$

(3) Mean depth (designated as *MD*) is the mean distance of all the axial lines from an axial line. Integration is derived from mean depth, and it was invented in an attempt to compare values between systems with different number of axial lines. Suppose that an axial line has mean depth *MD* in a system with *k* lines. The mean depth can be transformed so that it takes a value between 0 and 1 as:

$$\text{RA} = \frac{2\,(\text{MD} - 1)}{\text{k} - 2}$$

This value (*RA*) is then relativized by dividing with the *RA* of the "diamond-shaped" graph with the same number of vertices (axial lines) in which the vertices are ordered so that there are m (>1) vertices whose distance from the root space is the mean depth of the system, m/2 vertices at the distance minus 1, and so on (Figure 4). Integration is a reciprocal of this value, which is given by the formula:

$$\text{Integration} = \frac{\text{D}_\text{k}}{\text{RA}}$$

where

$$\text{D}_\text{k} = \frac{2\left(\text{k}\left(\log_2\left(\frac{\text{k}+2}{3}\right)-1\right)+1\right)}{(\text{k}-1)(\text{k}-2)}$$

Discussions on this method of relativization can be found in Hillier and Hanson (1984), and Krüger (1989).

(4) Maximum depth (designated as *MaxD*) is the maximum distance of the axial line found in the system.

(5) Local mean depth (designated as *MDi*) is the mean distance of axial lines within the number of steps *i* (in this paper, *i* = 3, 4, ..., 10) from the root space, and local spaces (designated as *Ki*) is the number of axial lines included in such a local system. A local system within step 1 consists of only the root space itself, and a local system within steps 2 includes the root space and the axial lines that are adjacent to the root space.

(6) Clustering coefficient (designated as *Gi*, with *i*=1,2) is based on the definition by Watts and Strogatz (1998), and it measures the "cliquishness" (Watts, 1999) of the neighborhood of the root space. It takes the ratio of the actual number of connections (edges) to the number of connections of the complete graph with the same number of axial lines (vertices). *G1* includes the local system within steps 2 (*i.e.*, the root space plus all the axial lines one step away), and *G2* includes the local system within steps 3 (Turner, *et al.*,

2001).

The computation of extended axial curves is similar to that of conventional axial lines. The same set of indices is used. The computation of (weighted) extended axial lines is more complicated, since it takes the angle of incident formed by two axial lines into account. The idea that the angle of incident is used for the weighting factor in calculating mean depth has been first suggested and implemented by Dalton (2001). This implementation assumes that the angle of incident between two lines is always equal to or smaller than p/2. When two lines share a single point but do not meet at a right angle, the smaller value of two possible representations of the angle is always chosen. In other words, let w(q) be the weighting function, and the distance of two adjacent axial lines d(l_1, l_2) can be defined by:

$$\mathrm{d}(l_1, l_2) = \begin{cases} \mathrm{w}(q) & \left(0 \leq q \leq \frac{p}{2}\right) \\ \mathrm{w}(p - q) & \left(\frac{p}{2} \leq q \leq p\right) \end{cases}$$

It is possible to argue that this choice of implementation can reduce the computational complexity of the model because the distance of two adjacent extended axial lines can be uniquely determined without any additional information under this model. The resulting axial model is essentially the same as the conventional axial model, with fractional distances between axial lines instead of applying a constant unit throughout the system.

However, if the purpose of introducing weighting factor is to better represent the degree of change in direction and thus the degree of visibility, such properties are treated inconsistently in this model. Consider the four-element conventional axial map in Figure 5 (a). Suppose that the distances to two parallel axial lines, in each of which either point **a**, or point **b** is included, are to be calculated when the axial line which includes point **S** is a root space. A graph representation of the axial map is shown in Figure 5 (b). Since the model makes no distinction between the angle θ and π−θ, the distance to the line with point **a** and the distance to the line with point **b** must be the same. However, Figure 5 (a) clearly shows that, if the trip starts at the point **S** and takes either route $1 \rightarrow 2$ or $1 \rightarrow 3$ to reach the point **a** or **b**, respectively, the route $1 \rightarrow 3$ naturally should have a greater visibility since the change of direction is smaller at the junction point than it is when the route $1 \rightarrow 2$ is taken. Overall, the trip from point **S** to **b** should be visually more "connected", and therefore shallower than the trip from point **S** to **a**. This means that the assumption made by Dalton's model should be discarded.

This consequence means that the two sides of the junction point in the same axial line may not carry the same property any more. For example, the axial line with point **a** will be shallower if the distance is measured from the opposite end of the axial line than from the side where point **S** exists. A similar distinction can be made to the destination, as the area opposite to the side of point **a**, for example, would be more visually connected from the root space.

In order to address the issues described above, the extended axial lines have been further broken up into smaller segments (called *extended axial segments*, hereafter), as shown in Figure 6 (a). Here, the computation is based on line segments whose end points are defined by either junction points or the end points of the axial lines to which they originally belong. By definition, no extended line segments share points with other extended line segments except end points, which could make a significant difference from conventional axial lines in the local spatial characteristics.

A graph representation of this model is shown in Figure 6 (b). The weighted distance is properly assigned to each edge. Notice that there are many edges whose weight is zero. This indicates that the vertices (representing extended axial segments) that are connected by such an edge are in the same extended axial line.

The following indices have been computed using three different weights (simple, vector, and constant - which assigns a constant value of 1 to each edge except for the ones that connect vertices in the same axial line): mean depth (*MD*), maximum depth (*MaxD*), local mean depth (*MDi*), and local spaces (*Ki*).

For the purpose of comparison to other models, the indices of the axial segments have been summarized by extended axial line, and mean, minimum and maximum values of each index for axial segments have been calculated, along with local values specific to the axial lines such as: *connectivity, control*, *G1*, and *G2*.

5. LOCAL CENTERS IN ISTANBUL

Local centers are generally represented by local integration values in space syntax literature (Asami, Kubat and Istek, 2001; and Kubat, 1997, 2001). The effectiveness of the methods developed above can be tested by comparing the resulting space syntactic indices for usual axial lines and those for extend axial lines to actual data derived from the study area of Istanbul. For example, local integration is supposed to represent the extent of local centeredness. Correlation coefficients between the values of local integration and actual amount of traffic on the road may reveal which approach can produce more appropriate notion of local centeredness.

To find the actual local centers in historical part of Istanbul, three approaches are taken here: (a) local centers identified based on the amount of taxi bays; (b) local centers identified based on the average number of stories of buildings along the extended axial lines; and (c) local centers identified based on the city planners' view points.

5.1. Amount of taxi bays

There are several taxi bays in the historical part of Istanbul. Since the city is not fully equipped with railway facilities, taxis and sharing taxis are common traffic mode. Taxi bays are regarded as center of such traffic mode, and therefore we can expect that their locations may indicate local centers in the city to some extent. There are 53 taxi bays that are currently used in 1999, and there are 55 taxi bays that are currently planned to equip by the Municipality of Metropolitan Istanbul in 1999 (Municipality of Metropolitan Istanbul, General Director of Transportation, Transportation Planning Department, 1999). A dummy variable, *taxi*, is constructed based on this information. The variable, *taxi*, takes one if the extended axial line includes an existing taxi bay or a planned taxi bay, and zero otherwise. Since the number of existing taxi bays is small, the existing taxi bays and planned taxi bays are both counted together.

5.2. Average number of stories of buildings

Limited number of survey points for taxi bays may prevent us from inferring any decisive conclusion on the effectiveness of several methods. To overcome this shortcoming, we sought for a proxy variable to indicate the local centeredness. Fortunately, there is a spatial data for GIS (Geographic Information System) for the study area. The number of stories of buildings along each extended axial lines can be computed.

To compute the average building stories, we first created buffering zone for each extended axial line[7]. Then, all the buildings are scanned included in the buffering zone, and then the average number of stories of the buildings is calculated. This value will be designated as *"building height"*.

Figure 7 shows the *building height* along extended axial lines. Areas with higher stories are marked in black. Eminonu, Aksaray, Beyazit, Fatih, *etc.* are shown to be local centers in the sense that there are higher-story buildings along the roads.

5.3. Experts' notion of local centers in Istanbul

Indices based on some physical phenomena are useful, for it is objective, but they tend to be defective because they can only indicate a very limited aspect of local centeredness. In fact, the notion of local center is very difficult to describe by a single physical index. To complement our analysis, it is also useful to identify the local centers by experts from their experience as city planners in Istanbul. This identification, of course, is subjective, but it can represent a more comprehensive notion of local centers.

Twenty academicians (or urban planners) majoring city planning or architecture in the Faculty of Architecture, Istanbul Technical University were asked to indicate on a map of Istanbul what they think are local centers in the historical part of Istanbul. To do so, no definition of local centers was provided, for we did not want to confine the scope of "local

[7] The buffering is made with 41.5 meters. This value is given by the area of total study region divided by the total length of roads, and hence this value can be regarded as the average maximum distance from the road to points in the blocks.

centers" in this process[8]. With this information, the whole area is classified into four zones: namely 0-zone, 1-zone, 2-zone and 3-zone. 0-zone is the zone where no one indicated that the area is local center. 1-zone and 2-zone are the zone where one and two urban planners (or academicians) indicated that the area is local center, respectively. 3-zone is the zone where three or more urban planners (or academicians) indicated that the area is local center. The three dummy variables and one discrete variable are constructed based on this information. The variable, *expertj*, is defined as a dummy variable taking 1 if the extended axial line is included in a area where *j* or more professors indicate as local center, and 0 otherwise, for j=1,2,3. The variable, *expert*, takes *k*, if the extended axial line is included in *k*-zone. See Figure 8 for these results.

5.4. Commercial areas in Istanbul

Local centers often consist of aggregation of commercial facilities. With this reason, a dummy variable, designated as "*commercial*", signifying whether an extended axial line included in commercial areas or not, can express the degree of local center to some extent. To do so, the land use map (Yildiz Technical University, City & Regional Planning Department, 1996) is scanned and the commercial areas are digitized. A dummy variable, *commercial*, is defined to be 1 if the extended axial line is included in the commercial area, and 0 otherwise. See Figure 9, in which commercial area is marked in gray.

6. RELATIONSHIP BETWEEN THE SPACE-SYNTACTIC INDICIES AND INDICES REPRESENTING ACTIVITIES OF LOCAL CENTERS

The space syntactic indices are calculated for the historical part of Istanbul (Figure 9). There are 1,546 (conventional) axial lines. Taking into account the three-dimensional land surface change, they are partitioned into 7,785 extended axial lines. Moreover, by following the method explained in Section 4, they are further partitioned into 14,694 extended axial segments. To make meaningful comparison, extended space syntactic indices that can be calculated for all the extended axial segments are assigned to extended axial lines by assigning maximum, mean or minimum value of extended axial segments to extended axial lines. To distinguish the assignment methods, "max", "mean" or "min" are attached in the last part of variable names. Basically results are not considerably different among these assignment methods.

The correlation coefficients between the space-syntactic indices (introduced in Section 4)

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and indices representing activities of local centers (introduced in Section 5) are calculated. Table 1 reports the results for conventional space syntactic analysis, which does not take three-dimensional surface change into account. Clustering coefficient, *G2*, within steps 3 has high negative correlation coefficient with *building height* and *commercial*. Clustering coefficients have low value for networks close to complete dual graph. In other words, the coefficients are small for networks with many intersections among axial lines. Local centers often are located at the core of city, where many roads are gathering, which is more similar to the tree graph. Thus it is natural to have negative correlation coefficients with indices representing urban activities for local centers. High value (in absolute value) of correlation coefficient may indicate that the index, *G2*, based on conventional space syntax approach can capture the feature of local centeredness rendered by *building height* and *commercial*. Moreover, the correlation coefficient with *G2* under the conventional space syntax approach is found to be the highest in absolute value, partly because the axial lines under the conventional space syntax approach tend to be longer than extended axial lines under the extended approach. The network, therefore, extends the largest area under the conventional approach, and each axial line has more intersections with other axial lines, and therefore the tree-graph like feature is most emphasized under the conventional approach. The conventional approach can be concluded to perform fairly well to indicate feature of local centers represented by by *building height* and *commercial*.

Ki (*i*=3,…,10) is the number of axial lines accessible within *i* steps. Local centers should be accessible from many local spaces, and therefore these indices are expected to have positively correlated with indices of urban activities. The maximum correlation is attained for *building height* with *K5*, for *taxi*, *experti*'s, *expert* with *K3*, and for *commercial* with *K4*. This may suggest that local centers are influential within three to five steps from the center.

Local mean depth, *MDi*, indicates relative closeness to the center within the area in *i* steps. This index has positive correlation coefficients for low steps and negative coefficients for high steps with all the activity-based indices. This means that the local center is very accessible for neighbors but not for farther areas.

Tables 2,3,4 and 5 report correlation coefficients for extended axial lines, and hence taking into account the three-dimensional change in height. Table 2 reports the results for extended axial lines with unitary weight for extended axial <u>lines</u>. Table 3 reports the results for extended axial lines with unitary weight for extended axial <u>segments</u>. *G2* still exhibits the high negative correlation coefficients with *building height* and *commercial*, but lower values than those under the conventional space syntactic analysis. The conventional method performs relatively well, even though it fails to take three-dimensional aspects into account.

It is remarkable that correlation coefficient between *K10* and *building height* is very high (0.539 in Table 2) under the method of unitary weight for extended axial lines. Actually this value is the highest correlation coefficient in absolute value among all the correlation coefficients calculated in the paper. Moreover, the value is still increasing with respect to step, local spaces (*Ki*) in limited steps are potentially the most powerful descriptor of local centeredness represented by *building height*. Similarly, the highest correlation coefficient with *commercial* is attained by K10 under the method of unitary weight for extended axial lines. With these results, we may conclude that local spaces (*Ki*) with appropriate number of step well explains the feature of local centers represented by *building height* and *commercial*.

When the extended axial lines are introduced, the correlation coefficient between *building height* and *Ki* is high. Since the average length of extended axial lines is smaller than that of conventional axial lines, the topological distance based on extended axial lines tend to resemble metric distance. This observation suggests that introduction of metric distance within the analytical framework may improve the prediction power of local centers.

Introduction of weighting function for angles of neighboring extended axial lines does not improve the results, for the correlation coefficients in Tables 4 and 5 are not higher than those in Table 2. Compared to the extension to three-dimensional space, introduction of weighting function for intersecting angles of extended axial lines does not contribute significantly to the improvement of the analysis. Again, if the metric distance is introduced, the introduction of weighting functions may contribute more.

Taxi bay index fails to exhibit large correlation coefficients with space syntactic indices. This is partly because taxi bay is not located necessarily at the highest central areas due to the lack of space and competitive character with other more intensive land use. Since the number of taxi bays is very small, this may also cause low values.

Experts' notion of local centers (*expert1*, *expert2*, *expert3* and *expert*) does not have very large correlation coefficients with space-syntactic indices. It is of interest to observe that building heights and existence of commercial activities are well captured by space syntactic indices, while experts' notion is not. Since space-syntactic indices are based on the visibility relations, which is rather a modern city planning tends to emphasize. In other words, the concept itself is suited to the analysis of modern cities. Istanbul is a very traditional city with much influence of non-European cultures (Kubat, 1999). In fact, the local centers suggested by experts are in many cases local centers developed from old ages. These local centers are not based on the modern notion of city planning. This may suggest that a different aspect than the visibility should be the fundamental factor characterizing such local centers. In other words, conventional space syntax approach is not an effective device to analyze traditional city forms inheriting other than Byzantium, Roman or modern city formation.

7. CONCLUSION

The present paper extends the conventional space syntactic approach in two ways: extension of the notion of axial lines into three-dimensional space, and introduction of the weighting function by the intersecting angles of extended axial lines. Such extension necessitates improvement in the calculation of indices, and this is described in Section 4. For comparison purposes, several indices are measured to represent actual urban activities in Istanbul. It is found that average building height and commercial dummy variable have high correlation coefficients with space-syntactic indices. This suggests that building height and existence of commercial activities are well captured by space-syntactic method. In particular, clustering coefficient, *G2*, within 3 steps under the conventional space syntactic method explains well the feature of local centers represented by *building height* and *commercial*. The best descriptor of local centers appears to be the local spaces (*Ki*) with an appropriate number of steps under the method of unitary weight for extended axial lines. In this connection, the extension of space syntactic idea to three-dimensional surface improves the explanatory power well. Moreover, the results may suggest that introduction of metric distance within the analytical framework may improve more.

Space syntactic indices under any methods, however, fail to capture experts' notion of local centers. This may be because the conventional space syntax heavily depends on the visibility aspect, which is not an overwhelming factor in formation of traditional Islamic cities. A principle other than visibility appears necessary as a principal device of spatial analysis for such cities. Such an extension will complement space syntax approach and open up a new field of urban morphology, potentially with a help of GIS technique.

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Table 1. Correlation coefficients for axial lines (conventional method).

2D	*building height*	*taxi*	*expert1*	*expert2*	*expert3*	*expert*	*commer-cial*
Connectivity	0.216	0.239	0.147	0.154	0.155	0.173	0.262
Control	0.043	0.185	0.107	0.112	0.117	0.127	0.123
G1	-0.227	-0.147	-0.112	-0.116	-0.127	-0.134	-0.281
G2	-0.504	-0.087	-0.086	-0.070	-0.065	-0.085	-0.360
Integration	0.382	0.198	0.063	0.113	0.113	0.107	0.329
K3	0.354	0.291	0.145	0.169	0.161	0.179	0.353
K4	0.396	0.281	0.122	0.154	0.142	0.158	0.351
K5	0.412	0.250	0.103	0.138	0.129	0.139	0.332
K6	0.408	0.222	0.077	0.121	0.116	0.118	0.316
K7	0.389	0.198	0.053	0.106	0.105	0.098	0.308
K8	0.365	0.178	0.029	0.091	0.095	0.078	0.308
K9	0.348	0.159	0.018	0.080	0.091	0.068	0.310
K10	0.339	0.144	0.014	0.073	0.087	0.063	0.311
MD	-0.366	-0.156	-0.023	-0.079	-0.087	-0.069	-0.324
MD3	0.339	0.104	0.017	0.071	0.041	0.048	0.272
MD4	0.340	0.085	-0.020	0.017	0.001	-0.002	0.191
MD5	0.245	0.017	-0.064	-0.021	-0.006	-0.037	0.074
MD6	0.099	-0.040	-0.112	-0.052	-0.020	-0.074	-0.024
MD7	-0.110	-0.114	-0.124	-0.088	-0.054	-0.104	-0.116
MD8	-0.302	-0.175	-0.113	-0.111	-0.083	-0.118	-0.197
MD9	-0.386	-0.207	-0.072	-0.109	-0.094	-0.103	-0.252
MD10	-0.405	-0.214	-0.047	-0.103	-0.100	-0.092	-0.291
MaxD	-0.339	-0.144	0.031	-0.030	-0.041	-0.012	-0.290

Table 2. Correlation coefficients for extended axial lines (unitary weight for line).

line_trad	*building height*	*taxi*	*expert1*	*expert2*	*expert3*	*expert*	*commer-cial*
Connectivity	0.158	0.044	0.054	0.060	0.050	0.064	0.164
Control	0.020	0.024	0.021	0.019	0.012	0.021	0.063
G1	-0.124	-0.048	-0.044	-0.049	-0.034	-0.050	-0.125
G2	-0.351	-0.035	-0.075	-0.084	-0.067	-0.087	-0.218
Integration	0.473	0.056	0.177	0.225	0.182	0.224	0.285
K3	0.265	0.052	0.071	0.082	0.071	0.086	0.227
K4	0.347	0.049	0.088	0.096	0.083	0.103	0.271
K5	0.405	0.054	0.095	0.110	0.092	0.114	0.301
K6	0.449	0.057	0.094	0.123	0.100	0.122	0.325
K7	0.483	0.061	0.097	0.137	0.108	0.131	0.343
K8	0.507	0.062	0.097	0.149	0.115	0.137	0.355
K9	0.525	0.065	0.097	0.158	0.123	0.143	0.362
K10	0.539	0.066	0.097	0.165	0.129	0.148	0.368
MD	-0.491	-0.052	-0.180	-0.210	-0.172	-0.217	-0.296
MD3	0.276	0.013	0.048	0.066	0.058	0.065	0.157
MD4	0.359	0.003	0.057	0.083	0.067	0.079	0.194
MD5	0.399	0.018	0.058	0.099	0.076	0.088	0.212
MD6	0.411	0.025	0.049	0.108	0.078	0.088	0.215
MD7	0.403	0.026	0.049	0.114	0.079	0.091	0.205
MD8	0.381	0.023	0.046	0.112	0.078	0.088	0.189
MD9	0.356	0.024	0.044	0.108	0.080	0.086	0.170
MD10	0.332	0.023	0.044	0.100	0.078	0.083	0.150
MaxD	-0.446	-0.045	-0.288	-0.280	-0.225	-0.310	-0.285

Table 3. Correlation coefficients for extended axial lines (unitary weight for segment).

line_const	*building height*	*taxi*	*expert1*	*expert2*	*expert3*	*expert*	*commer-cial*
Connectivity	0.158	0.044	0.054	0.060	0.050	0.064	0.164
Control	0.020	0.024	0.021	0.019	0.012	0.021	0.063
G1	-0.124	-0.048	-0.044	-0.049	-0.034	-0.050	-0.125
G2	-0.351	-0.035	-0.075	-0.084	-0.067	-0.087	-0.218
K3mean	0.190	0.041	0.054	0.060	0.051	0.064	0.181
K4mean	0.304	0.043	0.079	0.087	0.073	0.092	0.253
K5mean	0.379	0.051	0.091	0.102	0.084	0.107	0.289
K6mean	0.431	0.054	0.092	0.118	0.096	0.117	0.317
K7mean	0.470	0.059	0.095	0.133	0.104	0.127	0.337
K8mean	0.497	0.059	0.097	0.145	0.111	0.134	0.350
K9mean	0.517	0.062	0.097	0.154	0.118	0.140	0.359
K10mean	0.532	0.064	0.096	0.161	0.125	0.144	0.365
MD3mean	-0.028	-0.008	-0.019	-0.026	-0.029	-0.028	-0.062
MD4mean	0.139	-0.006	0.019	0.024	0.012	0.022	0.054
MD5mean	0.230	0.014	0.034	0.056	0.041	0.050	0.107
MD6mean	0.271	0.013	0.033	0.070	0.045	0.056	0.132
MD7mean	0.273	0.019	0.035	0.074	0.042	0.058	0.130
MD8mean	0.255	0.013	0.030	0.071	0.039	0.053	0.119
MD9mean	0.230	0.014	0.027	0.065	0.041	0.050	0.102
MD10mean	0.205	0.014	0.025	0.057	0.039	0.045	0.081
MDmax	-0.498	-0.053	-0.186	-0.220	-0.180	-0.226	-0.306
MDmean	-0.498	-0.053	-0.186	-0.220	-0.180	-0.226	-0.306
MDmin	-0.498	-0.053	-0.186	-0.220	-0.180	-0.226	-0.306
MaxD	-0.446	-0.045	-0.288	-0.280	-0.225	-0.310	-0.285
RAmax	-0.498	-0.053	-0.186	-0.220	-0.180	-0.226	-0.306
RAmean	-0.498	-0.053	-0.186	-0.220	-0.180	-0.226	-0.306
RAmin	-0.498	-0.053	-0.186	-0.220	-0.180	-0.226	-0.306

Table 4. Correlation coefficients for extended axial lines (simple weight for segment).

line_simple	*building height*	*taxi*	*expert1*	*expert2*	*expert3*	*expert*	*commer-cial*
Connectivity	0.158	0.044	0.054	0.060	0.050	0.064	0.164
Control	0.020	0.024	0.021	0.019	0.012	0.021	0.063
G1	-0.124	-0.048	-0.044	-0.049	-0.034	-0.050	-0.125
G2	-0.351	-0.035	-0.075	-0.084	-0.067	-0.087	-0.218
K3mean	0.188	0.042	0.052	0.058	0.049	0.062	0.179
K4mean	0.300	0.047	0.073	0.083	0.071	0.087	0.254
K5mean	0.371	0.052	0.087	0.098	0.082	0.103	0.290
K6mean	0.420	0.055	0.091	0.114	0.092	0.114	0.313
K7mean	0.458	0.058	0.097	0.129	0.100	0.125	0.332
K8mean	0.484	0.060	0.099	0.140	0.106	0.133	0.345
K9mean	0.503	0.063	0.100	0.149	0.112	0.138	0.354
K10mean	0.516	0.064	0.100	0.157	0.118	0.143	0.360
MD3mean	0.296	0.009	0.070	0.102	0.089	0.099	0.208
MD4mean	0.343	0.002	0.073	0.108	0.092	0.104	0.225
MD5mean	0.370	0.005	0.079	0.117	0.099	0.112	0.221
MD6mean	0.376	0.003	0.081	0.124	0.104	0.117	0.209
MD7mean	0.367	-0.001	0.085	0.126	0.104	0.120	0.190
MD8mean	0.349	-0.005	0.089	0.126	0.103	0.121	0.170
MD9mean	0.325	-0.010	0.093	0.124	0.103	0.122	0.151
MD10mean	0.301	-0.016	0.094	0.119	0.100	0.120	0.132
Mdmax	-0.289	-0.064	0.010	-0.079	-0.077	-0.049	-0.217
MDmean	-0.292	-0.065	0.009	-0.080	-0.080	-0.051	-0.224
Mdmin	-0.293	-0.066	0.009	-0.082	-0.081	-0.052	-0.228
MaxDmax	-0.290	-0.063	-0.006	-0.110	-0.101	-0.075	-0.259
MaxDmean	-0.293	-0.063	-0.007	-0.111	-0.103	-0.077	-0.266
MaxDmin	-0.295	-0.064	-0.007	-0.113	-0.105	-0.078	-0.271
Ramax	-0.289	-0.064	0.010	-0.079	-0.077	-0.049	-0.217
Ramean	-0.292	-0.065	0.009	-0.080	-0.080	-0.051	-0.224
Ramin	-0.293	-0.066	0.009	-0.082	-0.081	-0.052	-0.228

Table 5. Correlation coefficients for extended axial lines (vector weight for segment).

line_vector	*building height*	*taxi*	*expert1*	*expert2*	*expert3*	*expert*	*commer-cial*
Connectivity	0.158	0.044	0.054	0.060	0.050	0.064	0.164
Control	0.020	0.024	0.021	0.019	0.012	0.021	0.063
G1	-0.124	-0.048	-0.044	-0.049	-0.034	-0.050	-0.125
G2	-0.351	-0.035	-0.075	-0.084	-0.067	-0.087	-0.218
K3mean	0.189	0.042	0.053	0.058	0.049	0.062	0.179
K4mean	0.300	0.046	0.073	0.084	0.071	0.088	0.255
K5mean	0.372	0.052	0.087	0.099	0.082	0.104	0.291
K6mean	0.421	0.056	0.091	0.116	0.093	0.115	0.317
K7mean	0.460	0.059	0.096	0.130	0.100	0.125	0.336
K8mean	0.486	0.060	0.098	0.140	0.105	0.132	0.351
K9mean	0.505	0.064	0.099	0.149	0.111	0.137	0.360
K10mean	0.518	0.065	0.099	0.157	0.117	0.142	0.366
MD3mean	0.303	0.007	0.071	0.103	0.088	0.099	0.210
MD4mean	0.349	0.000	0.075	0.108	0.090	0.104	0.227
MD5mean	0.375	0.004	0.080	0.118	0.098	0.113	0.224
MD6mean	0.383	0.003	0.084	0.125	0.103	0.118	0.215
MD7mean	0.375	0.000	0.088	0.126	0.103	0.121	0.198
MD8mean	0.358	-0.004	0.092	0.126	0.102	0.122	0.179
MD9mean	0.336	-0.009	0.096	0.124	0.102	0.123	0.160
MD10mean	0.311	-0.015	0.098	0.120	0.099	0.122	0.141
MDmax	-0.297	-0.064	0.009	-0.081	-0.080	-0.051	-0.222
MDmean	-0.299	-0.065	0.008	-0.083	-0.081	-0.053	-0.226
MDmin	-0.300	-0.065	0.008	-0.084	-0.083	-0.053	-0.230
MaxDmax	-0.293	-0.062	0.010	-0.097	-0.091	-0.060	-0.253
MaxDmean	-0.296	-0.062	0.010	-0.098	-0.093	-0.061	-0.258
MaxDmin	-0.297	-0.063	0.009	-0.099	-0.094	-0.062	-0.262
RAmax	-0.297	-0.064	0.009	-0.081	-0.080	-0.051	-0.222
RAmean	-0.299	-0.065	0.008	-0.083	-0.081	-0.053	-0.226
RAmin	-0.300	-0.065	0.008	-0.084	-0.083	-0.053	-0.230

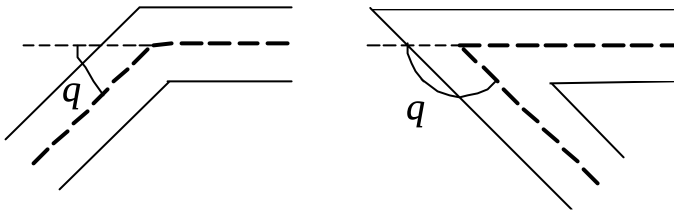

Figure 1. L-shaped roads and the angles of change in direction.

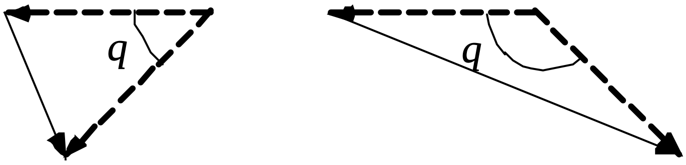

Figure 2. The vectors indicating the differences of vectors in direction for two cases in Figure 1.

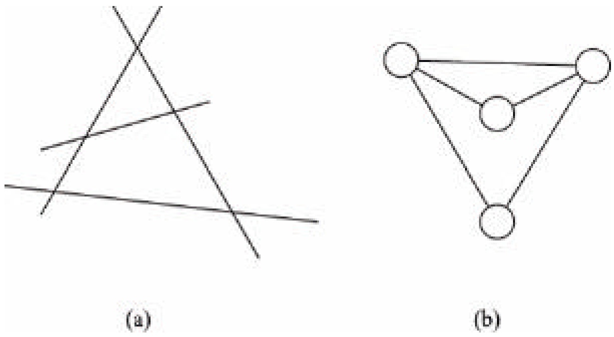

Figure 3. Axial map (a) and its graph representation (b).

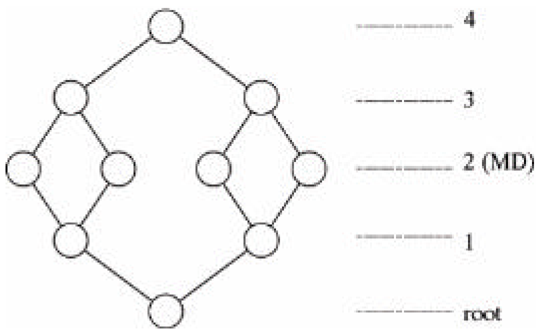

Figure 4. Diamond-shaped graph.

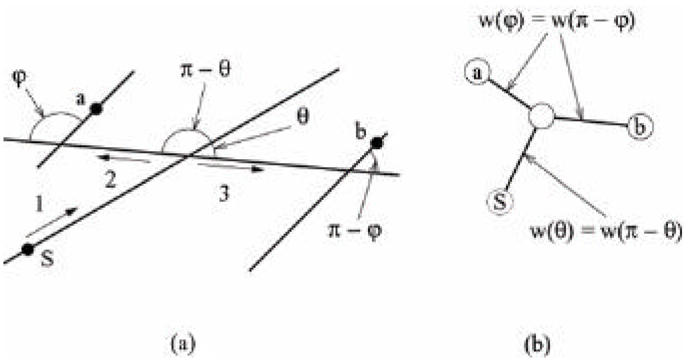

Figure 5. Four-element conventional axial map (a) and its graph representation (b).

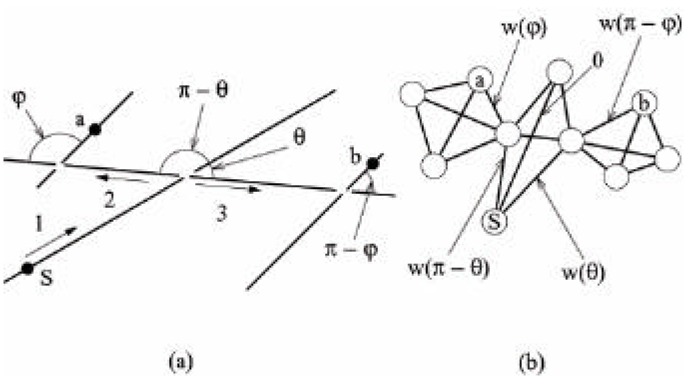

Figure 6. Extended axial segments (a) and its graph representation (b).

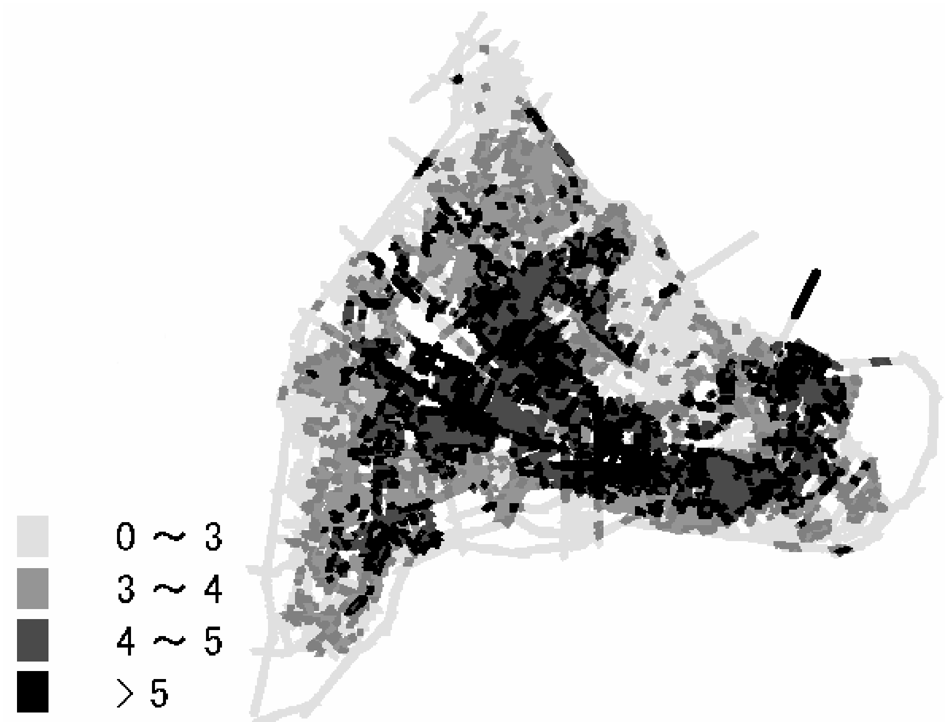

Figure 7. Average stories of buildings along extended axial lines.

(Average stories are marked by gray tone.)

Figure 8. Experts' notion of local centers in Istanbul.

(*k*-zone is indicated by light gray for k=1, gray for k=2, and deep gray for $k \geq 3$.

0-zone is other areas than gray toned.)

Figure 9. Land use map of Istanbul.

(Commercial areas in gray)