

Classification of areas through quantifiable spatial attributes

Abstract

This paper presents a comparative analysis of three areas within London based on measurable attributes of each city block, to assess the degree to which characteristic differences between the neighborhoods are evident and quantifiable. Both morphological measures of buildings and Space Syntax measures of streets are used. Results indicate that neighbourhoods are clearly distinguishable, however, the types of measures which best capture that distinction vary depending on the distinction being made. In the cases studied, building morphology alone distinguishes the residential neighbourhoods from mixed use, but the distinction between two residential neighbourhoods requires a combination of building and street measures.

1. Introduction

Differences between neighbourhoods are often non-discursive, in that they are difficult to make explicit. Quantifiable spatial attributes, as they are represented in plans of city blocks, show fundamentally important ways with which to perceive and reason about the world. The present research examines to what extent the comparison of quantifiable spatial attributes between neighborhoods of a city can provide information that lead to the distinction of the neighborhoods within the same city, in correlation to existing conventional methods of town planning and space syntax methods, such as integration and choice.

An important contribution of Space Syntax is to demonstrate that these distinctions are real, and to demonstrably quantify them. Primarily, Syntax is a method that identifies structures within a spatial configuration, by investigating spatial complexes. The method is based upon the theory that the form-function relation in buildings and cities passes through the structural properties of its configuration (Hillier, 1998). "*Space syntax allows us to understand and describe built space as a field of potential movement and co-presence.*" (Peponis, 1997, p.34.3).

Distinctions between neighbourhoods have also been shown to be quantifiable at the scale of building morphology using measurable attributes other than those of Space Syntax (Laskari, 2007). Differentiation, in terms of morphology, examines the uniqueness of the layout of the built environment.

We compare a set of three neighbourhoods in London to determine the degree to which distinctions are measurable. The goal of this research is to highlight those attributes that clearly express the possible distinctions, by comparing and combining topological and morphological measurements.

1.1 Studied regions

London is a collection of villages that were planned as villages but have no reference to the adjoining villages. After the 17th century, town planners engaged into imposing rational patterns of development. Outside the City, land was divided to estates that were of private ownership. Despite the great changes that took place in London's life in general over the centuries up until the 19th century, the town planning methods as well as the city itself changed little. The development was not continuous or steady, but instead waves of constructions emerged between eras of inactivity (Olsen, 1964). Before the construction of the railroad, London's development was mostly linear, along the river Thames. The introduction of the commuter train helped determine patterns of suburban development; towns grew up around the suburban stations; also made possible north-south development and ended the Thames' role as the determinant of the direction of urban development. But by the end of the 19th century, the Underground was complete resulting to the inhabitation of the city's periphery, away from the Center (Brown, 2004). Two types of urban design policies were followed at the time. First was the traditional village plan of curving streets. Second was the neo-classical type that was more orthonormal as a rectilinear grid (Olsen, 1964). These two types are still reflected in today's London, sometimes within the same neighborhood.

For the present study three areas were selected that either belong to one of the above types of plan representations or have both within; the City of London, Pimlico and East Dulwich. Defining distinct neighbourhoods can be questionable. In a social approach, Suttles refined neighbourhoods as local communities that have their identity and boundaries imposed on them by outsiders (Sampson, 2002). Past studies (Dalton e.a, 2007) have shown that spatial design appears to have ground impact on the shaping of neighbourhoods. In the present study, the boundaries that are selected are the ones defined by the local government as administrative boundaries (in London, boroughs and wards). The reason behind that choice is the fact that there was a need for a metric distance reference in the measurements that follow (section 2.2). Furthermore, since there is no explicit way of describing a neighbourhood, these boundaries were viewed as the only recorded area delimitation.

The City of London is one of the ceremonial counties within London. As a region, it has its origin from the Roman London. The great fire of London in 1666 as well as bombings during the WWII left only few notable historic structures and altered the urban identity of the area. In the beginning of the 1860s the depopulation of the City started and its architecture changed with great office blocks, which constitute the highest percentage of land use until today (Brown, 2004).

Pimlico is a neighbourhood within the City of Westminster, an inner London borough, which became the political capital of England, Scotland, Wales, and Ireland in the 19th century (Brown, 2004). The area is delimited by Vauxhall Bridge at the east, the River Thames at the south and the railway to Victoria station at the West side. By the 1890s Pimlico had declined to such an extent that the sociologist Charles Booth could describe it as being perhaps the most deplorable middle-class neighbourhood in London (PIMLICO DESIGN GUIDE, p.4). In the mid-1930s a great wave of development around the edges resulted to modern housing estates but leaving most of the original 19th century core of Pimlico intact, which is now protected by conservation area status (Brown, 2004). Furthermore, the area survived the war with its essential character unscathed. The land uses of the area are mainly residential.

East Dulwich is a region within Central London and more specifically, located at the south-east part of central London. It was developed during the 19th century but suffered extend damage during World War II. It was chosen as a region that was developed away from the Thames axis and hosts land uses mainly residential.



Figure 1: Map of the City of London



Figure 2&3: Maps of the city blocks of Pimlico and East Dulwich respectively.

2. Methodology

2.1. Morphological approach

2.2.1 City block

A city block is the basic element of urban planning and urban design. For this analysis adjoining buildings were considered as one built unit and the space around them (roads, gardens etc.) as a general open space.

2.2.2 Fractal dimension

The fractal dimension of an object is a measure of how similar the object is to itself at different scales. Two dimensional fractals are structures that can be measured from 2-D data, such as flat or slightly curved images. If an image is strictly flat, any extracted structure can have a fractal dimension with a value between 0 and 2. Essentially, solid blobs appearing in an image have a Euclidean dimension of $D = 2$, curvilinear structures a dimension near $D = 1$, and dots a dimension near $D = 0$ (<http://geza.kzoo.edu/~erdi/>). One method of fractal dimension computing is the box counting method, implemented for the present thesis. This method computes the “*number of cells required to entirely cover an object, with grids of cells of varying size. Practically, this is performed by superimposing regular grids over an object and by counting the number of occupied cells*” (Morency, 2003, p.30). The method is affected by the resolution of the digitized representations of the plans as well as the orientation of the grid and its initial placement (Morency, 2003). The code

used for the present thesis estimates the fractal dimension of a city block through the box counting method. The input of the code is a black and white image plotted from plan drawing files at a scale of 1:250. The code is written in Processing based on the code written by A. Laskari.

2.2.3 Conventional methods of plan analysis

For every city block of each area the following measurements were extracted:

- **Total area** in square meters, extracted via AutoCAD with the AREA tool.
- **Perimeter** in meters, extracted as above.
- **Built area** in square meters, extracted as above.
- **Built ratio**, calculated from the above values: built area / total area.
- **Number of buildings**, counted via AutoCAD.

The plans of the city blocks, used for the above calculations, originated from Digimaps¹ and extracted via the AutoCad Map 3D software.

2.2. Topological approach

For the purposes of the present research, an axial map of radius that contains the plans of the three areas under study was accessed. As a second step, a segment angular analysis was implemented via the DepthMapX software, after the map was turned into a segment map to extract values regarding choice and integration measurements weighted by segment length. The units of this analysis are street segments and the 'distance' relation between them is the amount of angular change from one segment to the other. For example

¹ City :Integrated Transport Network (ITN) [GML2 geospatial data], Scale 1:1250, Tiles: GB, Updated: 9 December 2013, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <<http://digimap.edina.ac.uk>>, Downloaded: Fri Jul 25 21:28:39 BST 2014
Topography [GML2 geospatial data], Scale 1:1250, Tiles: GB, Updated: 9 December 2013, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <<http://digimap.edina.ac.uk>>, Downloaded: Fri Jul 25 21:28:39 BST 2014

Pimlico : Integrated Transport Network (ITN) [GML2 geospatial data], Scale 1:1250, Tiles: GB, Updated: 9 December 2013, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <<http://digimap.edina.ac.uk>>, Downloaded: Fri Jul 25 21:27:22 BST 2014
Topography [GML2 geospatial data], Scale 1:1250, Tiles: GB, Updated: 9 December 2013, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <<http://digimap.edina.ac.uk>>, Downloaded: Fri Jul 25 21:27:22 BST 2014

East Dulwich: Integrated Transport Network (ITN) [GML2 geospatial data], Scale 1:1250, Tiles: GB, Updated: 9 December 2013, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <<http://digimap.edina.ac.uk>>, Downloaded: Fri Jul 25 21:29:25 BST 2014
Topography [GML2 geospatial data], Scale 1:1250, Tiles: GB, Updated: 9 December 2013, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <<http://digimap.edina.ac.uk>>, Downloaded: Fri Jul 25 21:29:25 BST 2014

a straight line has a 0 degree connection. To perform the segment analysis a metric distance must be used as a radius for the measure. The radius used to analyze the map was 500m, as the smallest distance between boundaries within the regions under study. Depth in space syntax is a term that describes the direct connections between nodes in a graph. The depth value divided by the number of nodes involved minus one leads to a mean depth value (MD) (Jiang, 2008).

Integration or mathematical closeness calculates how close each segment is to all others within the specified radius of study, using the least angle measure of distance(Klarqvist, 1993). Therefore, it is a measure of how accessible each segment is from all the others, and how much potential it has as a destination for movement. It could be said that integration measures the destination potential for a segment at that radius.

Choice or mathematical betweenness, in contrast, is a measure of the degree to which each segment lies on least angle routes between all other pairs of segments within the radius, so it measures the through-movement potential of each segment within that radius, in contrast to the to-movement potential measured by integration (Klarqvist, 1993).

3. Comparison of measurements

For the comparison of the above measurements, Principal Components Analysis (PCA) was implemented. PCA is a useful statistical technique that has found application in fields such as face recognition and image compression, and is a common technique for finding patterns in data of high dimension. It is a dimensionality reduction method that “*seeks a projection that best represents the data in a least-squares sense*” (Duda, 2000, p.114). Linear methods such as the PCA are preferred since they are simple to compute and analyze. For the present study, PCA is used to find the most useful components of the above analysis, to better represent and compare the data in a lower dimension. With the above method the data are expressed in terms of the patterns between them, where the patterns are the lines that most closely describe the relationships between the data (Smith, 2002). The PCA code for the present study is written in MatLab.

4. Results

4.1 PCA of the morphological measurements

In this section a Principal Components Analysis was conducted for the results of all areas. This method combines all the morphological measurements, in an effort to discover the components that give the greatest variation in the

results. The observations were normalised before the analysis in order to have comparable values. The table below labeled as *explained* shows the percentage of influence of each component to the data set. The results are displayed as scores plots that show samples grouping of the data and contain the greatest amount of variability in the data set .

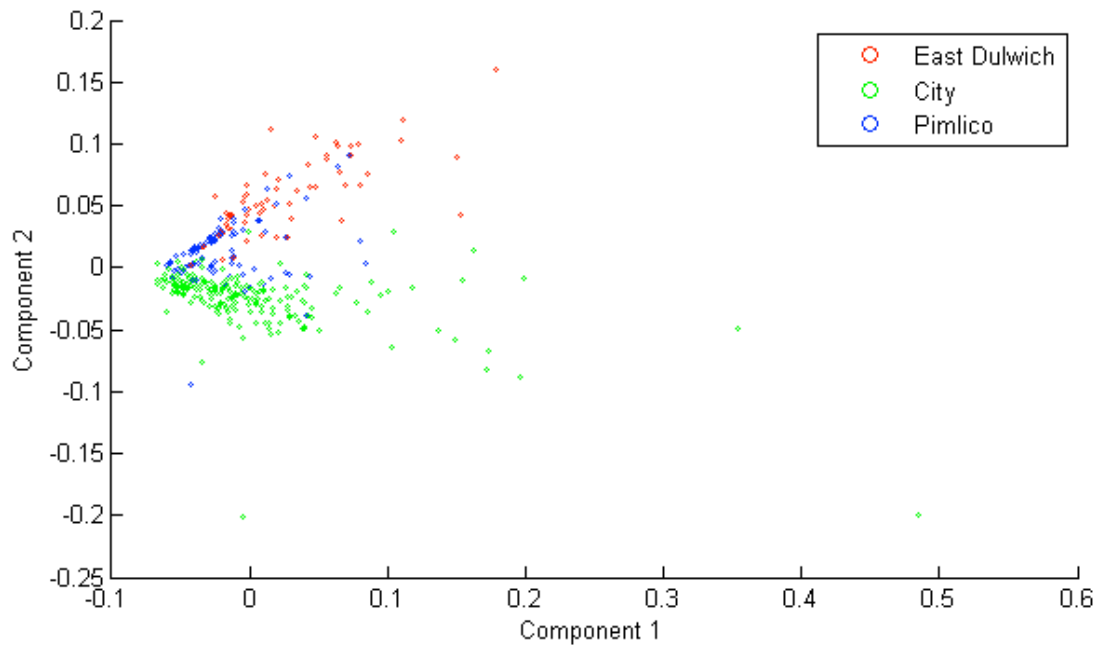


Figure 4: PCA Scatter plot of the first components

coefficients	PC1	PC2	PC3	PC4	PC5	PC6
X1 (Fractal dim.)	0,035707	0,051353	0,035725	-0,0505	-0,05465	0,994623
X2 (total area)	0,638364	-0,10627	-0,22447	0,294386	0,66511	0,042127
X3 (perimeter)	0,350803	0,016448	-0,00182	0,68576	-0,63735	-0,01358
X4 (built ratio)	-0,03748	-0,4143	0,870363	0,195489	0,176297	0,011088
X5 (Buildings)	0,347818	0,807887	0,434892	-0,17501	0,024394	-0,07736
X6 (built area)	0,588023	-0,40184	0,040848	-0,60965	-0,34169	-0,05156

Table 1: Coefficients matrix of principal components in relation to variables under study. The cells highlighted represent variables of great variance.

explained	PC1	PC2	PC3	PC4	PC5	PC6
%	55,20058	26,36573	14,28721	2,514157	2,514157	0,246019

Table 2: a vector containing the percentage of the total variance explained by each principal component.

As it is presented in the graph above a clustering of the areas may be observed, between the City and the two residential areas of Pimlico and East Dulwich. With only a few outliers, particularly in the Pimlico group, this is a nearly linear separation given entirely by the second principle component through the mean of the data set. In the coefficients table, each column contains coefficients for one principal component, and the columns are in descending order of component variance. The x axis is the first component. We can observe from the coefficients matrix that variables X2 and X6 are the ones that give the greatest variance for the 1st component. The important part is in axis y that we have the second component and the variables X4, X5, and X6 are the ones that result to the clear clustering of the regions. More specifically, these variables represent the built ratio, number of buildings and total built area of each block, respectively. Pimlico and Dulwich are mainly residential areas. Their values for the 2nd component are mainly above 0 while City's values are mainly below 0. This leads to the conclusion that, as it can be deduced from the coefficients table, it is the result of the variables mentioned above that represent total area and built area. Pimlico is the area that its nodes are overlapping with both City and East Dulwich, which may be a result of the morphology of the space configuration in the area. As mentioned in the beginning of the present thesis, Pimlico is an area that has maintained its character and is the result of re-designing but with traces of the old character. In contrast, East Dulwich is an area that is the effect of a particular design and City is a "patchwork" of reconstruction phases. With these observations one might characterize the similarities between Pimlico and the rest two areas of the analysis reasonable.

Furthermore, the graph illustrates differences between the clusters that are formed. East Dulwich presents a low positive correlation between the two components, even though there is no observable strong relationship. On the other hand, for the cluster that is formed by Pimlico's nodes, the graph is scattered in a way that it does not approximate a line. Therefore, there is no observable correlation between the two components. There is a group of nodes around 0,0 that presents a strong, positive correlation, but they cannot be regarded as representative samples of the cluster, since they belong to a small portion of the nodes. Finally, City presents a stronger correlation than the two other clusters that are formed, with a slight negative slope. As in Pimlico, City's cluster has a stronger correlation around 0.0 that tends to spread, especially as the values of the 1st component rise.

It should be noted that there are some nodes in the graph that have great variation compared to the cluster they belong to and were, thus, examined

individually. Furthermore, there are observable overlapping nodes in the graph that were also compared as groups of data.

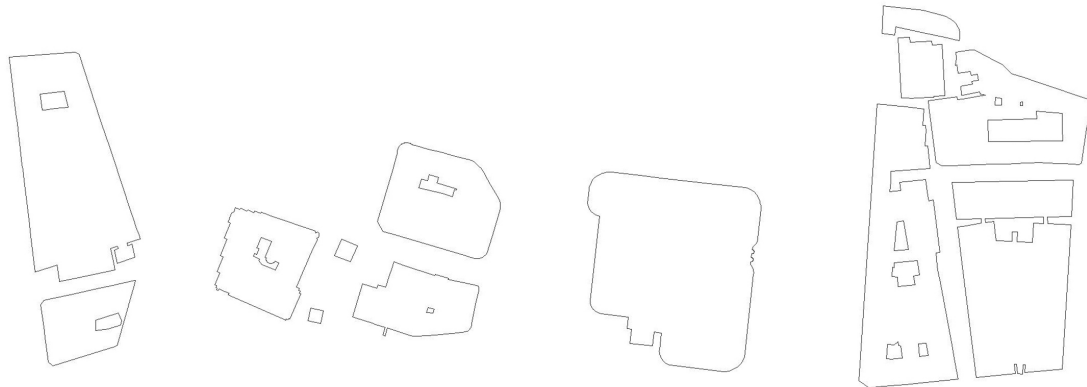


Figure 5: blocks A047, A027, A151 and A159 respectively

block No	Fractal dim.	total area (m ²)	perimeter (m)	built ratio	Buildings	built area
A047	1,41590	11511,19300	435,41800	15,87603	9	1827,52000
A027	1,21834	9855,32820	369,85800	56,84100	1	5601,86670
A151	1,29579	8504,12340	428,35200	58,75632	8	4996,71030
A159	1,36972	9652,22840	429,71300	50,25977	12	4851,18750

Table3: measurements of blocks

The table above presents the blocks that belong to the City region and have the greatest difference from the rest of the nodes of the cluster. Block A47 has the lowest value for the 2nd component but also the greater value for the 1st component. Block A27 has both values low, with a notable difference from the rest of the blocks of the region. The blocks with the highest component values in the City is A151 and A159.

In Pimlico, the block with the lowest values in both components is B086. The block with the highest value for the 2nd component is B006 and the one with the highest for the 1st component is B094.

Finally, in East Dulwich the block with the highest values in both components is C026. Since, as mentioned before, there is a weak relationship between the two components for the cluster of East Dulwich, there are not other blocks

that present a significant differentiation from the rest of the nodes in the graph.

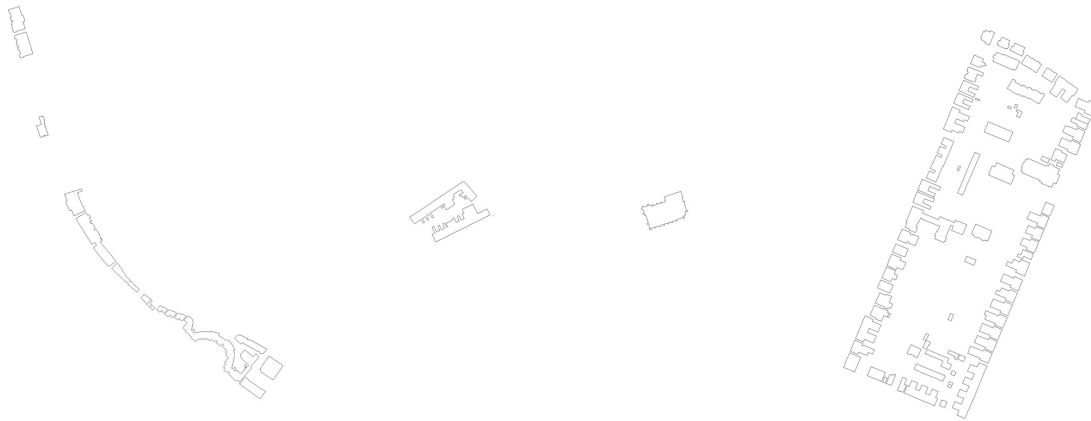


Figure 6: Blocks B006,B086 and B094 and Block C026 respectively

block No	Fractal dim.	total area (m²)	perimeter (m)	built ratio %	Buildings	Built area
B006	1,41106	2131,521	210,909	26,73063	12	5697,69
B086	1,19084	18506,756	777,490	4,29719	2	795,27
B094	1,23399	29747,507	1701,460	26,03845	28	7745,79
C 026	1,56543	50035,746	976,207	21,35505	17,5	1068,516

Table4: measurements of blocks

From the figures above, the differences of the blocks that had extreme values on the graph are also visually understandable from the plan representations. As it is shown in the maps of the regions, there are not distinct similarities in neither the plans of these blocks with the rest of the blocks of the same region nor the plans of blocks of the other regions. The same conclusion can be drawn from the values of the variables that were studied, that are presented in the tables above.

As mentioned above there some nodes in the graph that overlap. These nodes are mainly nodes from Pimlico that overlap with nodes of the rest areas. A sample of both was selected, based on the score chart that was extracted from the PCA and they were compared through their overall results. Through the comparison, it was found that the two factors that are similar for the above blocks are the total built area of each block and the number of buildings that this area is divided to. In a former discussion (section 3.1.3.) it was pointed out that the proportion of number buildings to area covered by buildings may lead to the characterization of the architectural typology that is

represented by the buildings in each block. The third key factor is the built ratio, i.e. the proportion of open to built space. As a measurement, it describes the typology of the entire block. The result of this PCA may be a clustering of regions based on this architectural typology. More specifically, it is observed that there is a type of block similar in both Pimlico and East Dulwich, where many, small building units constitute the built space of the block. On the contrary, nodes that overlap between Pimlico and City represent blocks that contain large building units. Pimlico is a heterogenous area, in terms of architectural typology, while the rest present a degree of homogeneity.

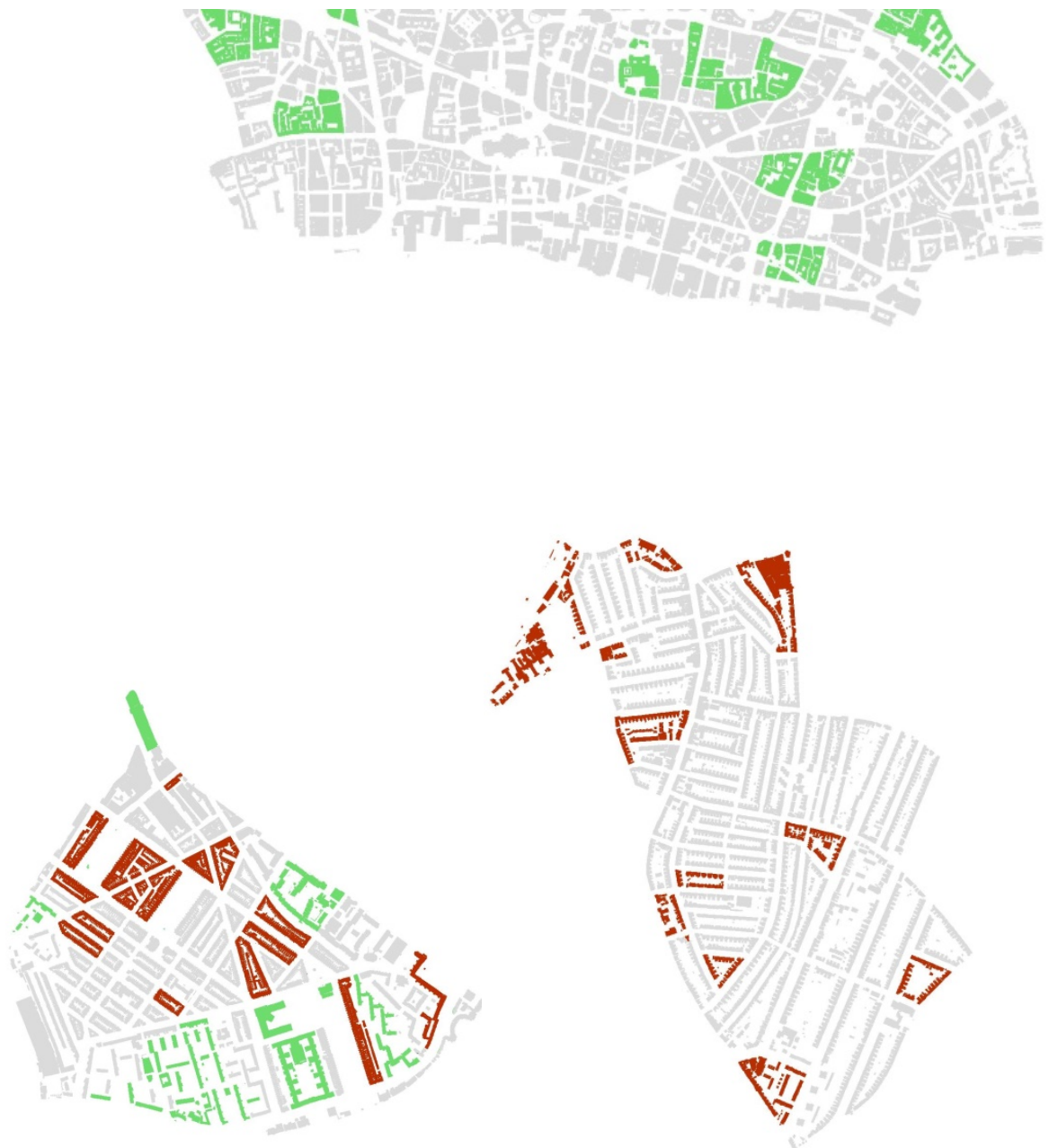


Figure 7: Maps of the 3 areas(not in scale). Top is City, bottom - right is East Dulwich and at the bottom - left is Pimlico. The blocks are paired with red those that had similar scores after

the PCA between Pimlico and East Dulwich and green is the same correlation but between Pimlico and City.

4.2 PCA of the two methods

This section is a description of the results of the analysis described in section 4.1 with an addition of two extra variables that derive from street segment analysis. The values of choice and integration, weighted by segment length, were calculated using Depthmap software for the street segments that surround each city block under study. Both default measures were weighted by segment length in this case due to large differences in segment lengths between the City and the other regions. The mean value of these segments was used as the measure for the block.

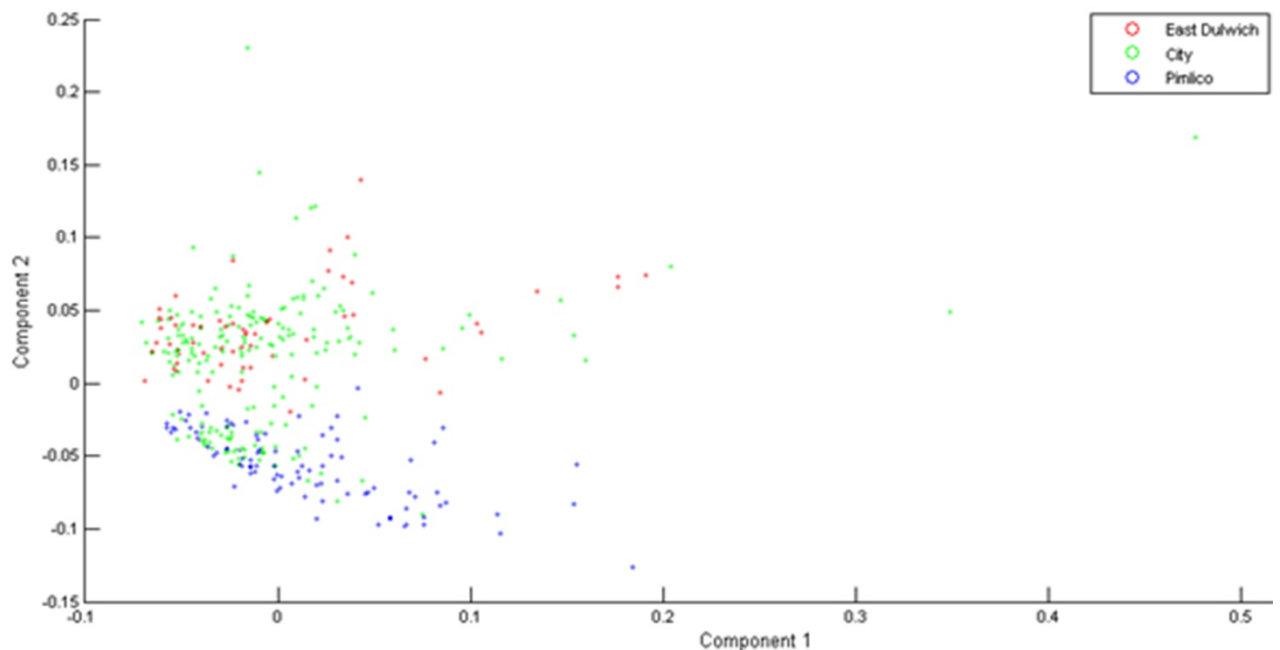


Figure 8: PCA Scatter plot of the first components

Coefficients	PC1	PC2	PC3	PC4	PC5	PC6	PC7
X1(Fractal dim.)	0,037241	-0,03842	0,023351	0,038942	-0,00097	-0,05006	-0,05398
X2(total area)	0,633192	0,084518	-0,09431	-0,23272	-0,05676	0,287719	0,664196
X3(perimeter)	0,349446	-0,00994	-0,04177	-0,02287	0,026425	0,683145	-0,63875
X4(built ratio)	-0,0385	0,267874	-0,16919	0,858931	-0,30097	0,207058	0,16406

X5(Buildings)	0,363734	-0,52491	0,286844	0,451433	0,527311	-0,15124	0,03348
X6(built area)	0,577382	0,29258	-0,18315	0,041601	-0,20503	-0,61717	-0,34567
X7(mean integration)	-0,07035	0,602051	-0,22635	0,022144	0,760864	0,021305	0,019801
X8(mean choice)	0,058861	0,442633	0,89058	0,005224	-0,08055	0,030367	-0,00388

Table 6: Coefficients matrix of principal components in relation to variables under study. The cells highlighted represent variables of great variance.

explained	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
%	37,60606	29,52066	14,12502	9,147601	6,829862	1,635287	0,978872	0,156639

Table 7: a vector containing the percentage of the total variance explained by each principal component.

We are particularly interested in the relationship between the two residential areas, which were not previously distinguishable based on building morphology alone. The addition of the two street measures to the previous morphological variables significantly changed the clustering result of the PCA. The first important observation is that Pimlico and East Dulwich now form clusters that are clearly, almost linearly separated. As in the previous analysis this line of separation is very near the overall set mean (0 coordinate) of the second component. The variables that most greatly influence the result are the total area of the city block, the number of buildings of each block and the average integration value of the street segments that surround the blocks (table 6). Based on this result, it may be suggested that the two residential areas, Pimlico and East Dulwich have characteristic differences between them that are quantifiable.

Due to the heavy weighting of the crucial second component by the two added street measures, however, it is not clear whether this distinction results from these measures alone, or as a combination of both the morphology of the spatial layout and the topology of the street network combined. A plot of the two measures of mean integration and choice, in isolation, easily resolves this. It is clear (figure 9) that the two street measures do not differentiate between the three areas. The observation above therefore indicates that a combination of both street and building morphological measures is required to characterise the residential neighbourhoods.

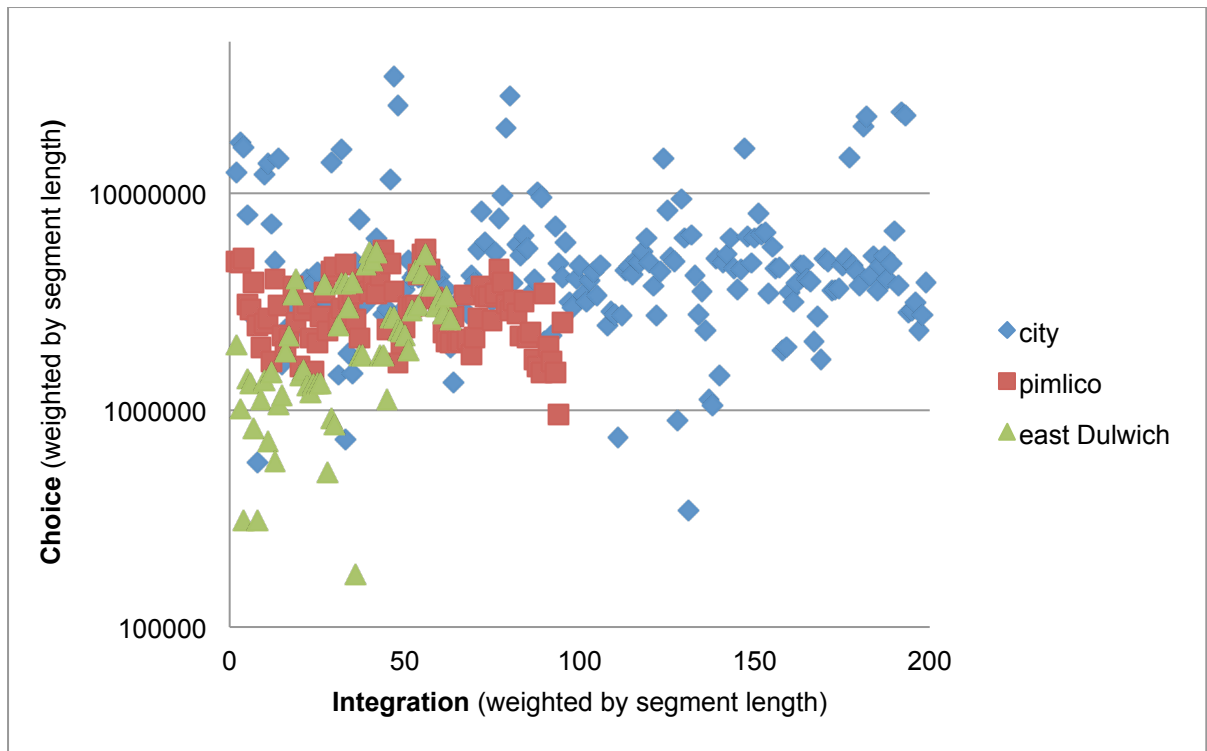


Figure 9: Integration and Choice alone do not separate the three areas.

Through the scores of the principal components analysis of the last section, an average value for the second component was calculated. As discussed above, the classification of the areas was a result mainly based on the specific component. In an effort to discover a characteristic type of city block, for each area a block was selected that had the closest score to the average value.

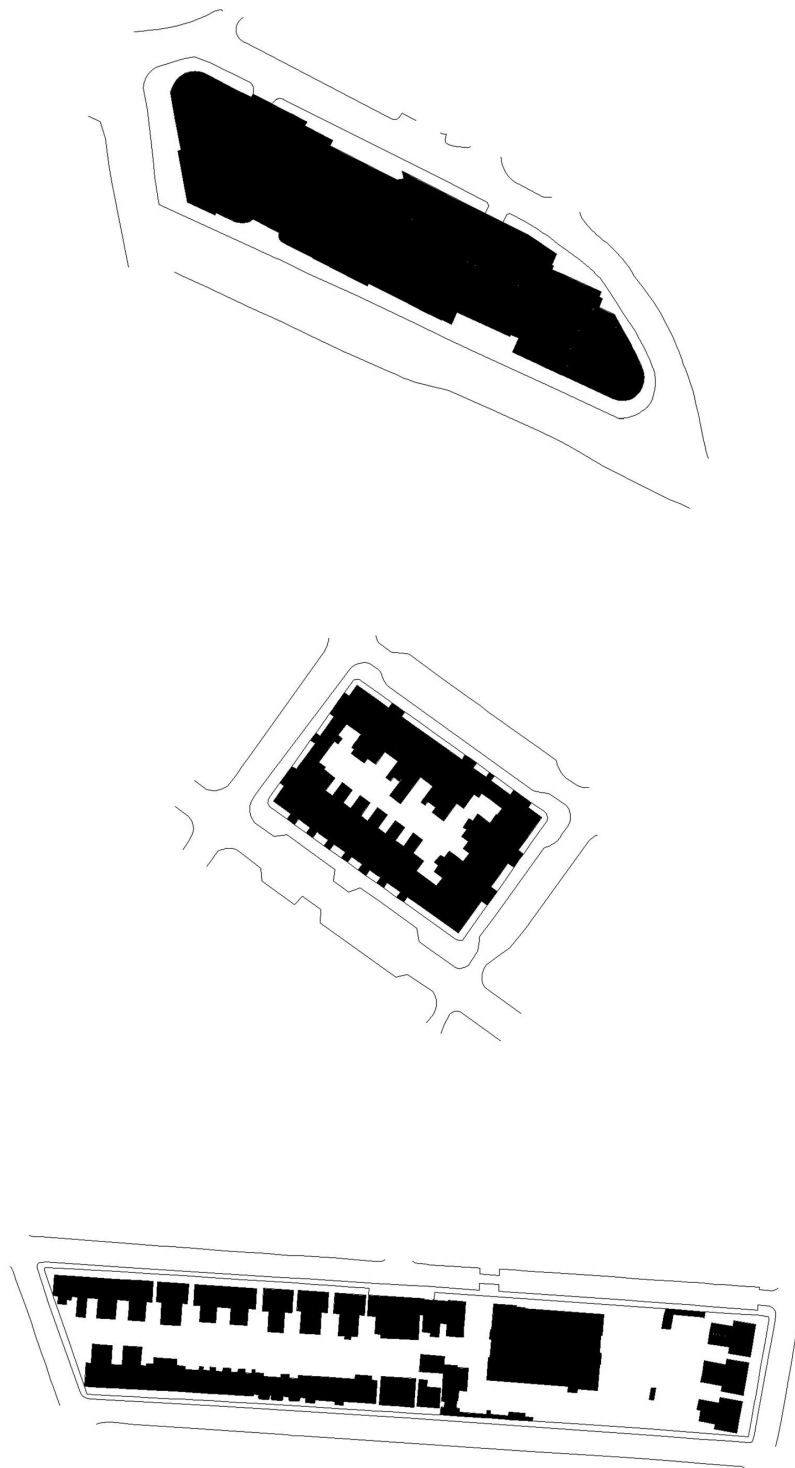


Figure 10: Blocks A035(above), B051(middle) and C049(below) (City, Pimlico and East Dulwich). Interruptions of the road lines indicate intersections with other street segments.

It is observed from the figure above (figure 10) that there is a characteristic distinction between the types of city blocks between the areas. The first block that belongs to City is a highly built up block with a very small percentage of open space. The surrounding streets are non-orthogonal with many intersections. On the contrary, Pimlico's block presents a balance of built to open space. The roads around it form a rectangular shape and intersect only at the corners of the block. Finally, in East Dulwich, the characteristic block has large, uninterrupted open spaces. The streets may not be orthogonal but there is a tendency for parallel segments that have intersection at the corners but also somewhere in between. These observations describe the regions as a whole, based on the results of the present analysis. Therefore, it may be valid to conclude that these three types of blocks presented above are the characteristic types for each region.

5. Discussion

Different methods of spatial analysis were combined in an attempt to discover patterns of interrelation between space layouts, through quantifiable spatial attributes. These methods represented related but distinct examinations of spatial layouts, regarding morphological and topological attributes.

The results of the methods showed that there can be distinction of areas within the same city, based entirely on quantifiable spatial attributes. After the implementation of the PCA, there was a dimensionality reduction that made the differences more clear in graph representations. However, there was no pattern observed between the methods as all measurements resulted to different results, with no observable relation between them.

In the first method, morphological attributes alone show a strong distinction between the residential neighbourhoods and the city. These are dominated by #buildings, built area and built perimeter. These do not differentiate the two residential neighbourhoods. A possible interpretation of this observation may be that the typology of the architecture in an area is more important when comparing regions than the complexity of the outline of the geometries (buildings and blocks).

In the second method, Syntax measures of streets (alone) do not make clear distinctions, but a combination of street and building measures do distinguish Pimlico from both East Dulwich and the City (which overlap). The factors that led to the separation are the number of buildings in each city block and the integration and choice measurements.

5. Conclusion

Each of the three neighbourhoods can be reliably distinguished using quantifiable spatial attributes. The two morphological factors that highlighted the variations between the squares of each area are the built up area and the number of buildings, factors characterizing architectural typology's properties.

But different attributes distinguish different neighbourhoods; a combination of both Syntax and morphology is necessary. Through the Syntax method the two main differentiating factors were revealed, integration and choice. As measurements, these reveal information on the areas related to accessibility, network traffic, and possibly lead to assumptions about the use of land in areas, based on the values they have. The results vary, as there was no correlation between them.

Overall, the conclusion of the study is that residential is distinguished from mixed use by morphological attributes, but residential neighbourhoods are distinguished from one another by their Syntax measures.

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