

# **Urban identity through quantifiable spatial attributes**

Coherence and dispersion of local identity through the comparative analysis  
of building block plans

**Anna Laskari**

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Bartlett School of Graduate Studies  
University College London

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## **Abstract**

The present analysis investigates whether and to what degree quantifiable spatial attributes, as expressed in plan representations, can capture elements related to the experience of spatial identity.

Spatial identity is viewed as a constantly rearranging system of relations between discrete singularities. It is proposed that the structure of this system is perceived, inter alia, through its reflection in patterns of variable associations amongst constant spatial features. The examination of such patterns could thus reveal aspects of spatial identity in terms of degrees of differentiation and identification between discrete spatial unities.

By combining different methods of shape and spatial analysis it is attempted to quantify spatial attributes, predominantly derived from plans, in order to illustrate patterns of interrelations between spaces through an objective automated process.

Variability of methods aims at multileveled spatial descriptions, based on features related to scalar, geometrical and topological attributes of plans.

The analysis focuses on the scale of the urban block as the basic modular unit for the formation of urban configurations and the issue of spatial identity is perceived through consistency and differentiation within and amongst urban neighbourhoods. The abstract representation of spatial units enables the investigation of the structure of relations, from which urban identity emerges, based on generic spatial attributes, detached from specific expressions of architectural style.

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## **1. Introduction**

The notion of urban identity is examined by analysing patterns of relations amongst quantifiable spatial attributes as they are expressed in plan representations of building blocks.

The main objective of the analysis is to investigate if and to what extent quantifiable attributes of spatial representations can provide information about spatial qualities that are non-discursive (Hillier, 1996) but essential to the experience of spatial identity.

### **1.1. Analytical decomposition: the city through the urban block**

Focusing on the scale of the urban block as the module of urban agglomerations, the analysis attempts to reveal the degree and nature of relation between quantifiable scalar, geometrical and topological spatial attributes, as they are expressed through plans, with the identity of the corresponding spaces, experienced from the point of view of the dweller and the passer-by.

The urban block is viewed, through its plan, as a configuration of built and open spaces whose geometrical shape and topological interrelations determine to a great extent the visual perception of urban environments, influencing spatial experience and defining local particularities related to spatial identity.

The observation of the urban system through the modular element of the building block serves merely analytical purposes and does not imply the reduction of the whole to a single category of modules, since “a coherent system cannot be completely decomposed into constituent parts. There exist many inequivalent decompositions based on different types of units” (Salingaros, 2000).

### **1.2. Analytical recomposition: urban identity as a system of relations between singularities**

“A city is a network of paths, which are topologically deformable” (Salingaros, 1998).

According to this observation, the city is viewed as a continuous, heterogeneous and indivisible system (Deleuze, 2005) whose identity emerges constantly from the rearrangement of interrelations between discernible singularities.



This system of interrelations could be abstractly described as a structure of bifurcating, converging or diverging series of variations, in analogy to Leibniz's model of the world's structure (Deleuze, 2005). According to this model, forces of identification and differentiation, attraction and repulsion, within and amongst spatial unities are expressed through the law of the series, defining the range and patterns of variation (texture) of the singular blocks and the degrees of conversion or diversion between series.

Attractions within the series, related to the consistency of the neighbourhood, are associated to spatial relations based on physical contiguity and continuity. Attractions amongst series, expressed by their conversion (compossibility), are related to transpatial relations (Hillier and Hanson, 1984) that act beyond spatial discontinuities.

### **1.3. The dataset: a set of selected singularities**

The specific dataset analysed here consists of selected actualised instances of the virtually infinite and constantly fluctuating series of potential singularities representing each neighbourhood (Cache, 1995). The groups of blocks under consideration only as a sample represent the areas they belong to, since these do not constitute uniquely defined finite sets of urban blocks, but temporary territories of identification and differentiation.

However, the law of the series is inherent in each singularity and thus could be derived from a confined subset of the infinite series of variations.

The attempt to classify blocks according to a partial description of their attributes reflects the intention to discern between compossible and impossible series (Deleuze, 2005) in the view to potentially extract and reconstruct the law governing them and through it to reveal attributes of the series and its singularities that could not be directly derived from the initial knowledge of the dataset. Ambiguities in the classification could indicate locations of possible bifurcations, where converging series meet.

In this framework, the attempted classification of the block plans would illustrate an abstract synchronous view of the structure of relations from which urban identity emerges.

It is not the measured attributes per se that reveal elements of spatial identity, but the belief that they are governed by and reflect patterns in a structure of relations from which identity emerges, renders these attributes partial indexes of degrees of differentiation and identification between spatial unities.

However, the efficiency of these indexes is limited and their interpretation ambiguous, since major issues concerning the formation and perception of spatial identity are not spatial or

describable in spatial terms. Spatial identity is actualised and materialised through construction but not fully described by it (Laskari, 2006). Every act of construction, mental or material, actualises a new fold of the virtual characteristics of the locus, but does not capture it in a static, structural way.

In this framework, the present analysis is based on a series of reductions and concessions regarding the relation between urban identity and quantifiable attributes of spatial representations. Despite these limitations, it is believed that such attributes do account for the way in which the city is perceived and its identity experienced, reproduced and propagated through space and time.

#### **1.4. Structure of the thesis**

The relation between quantifiable spatial attributes, inherent in plan representations, with the experience of space and spatial identity, has been in the centre of focus of a wide range of theoretical and practical investigations. A brief review of a confined selection of research directions within the field summarises the main theoretical and methodological references of the present analysis. These can be generally distinguished into spatial investigations concerning the potential connection between patterns of human behaviour and patterns of spatial constants within plan configurations and researches regarding the categorisation of spaces based on comparisons between quantified features of the corresponding plans. According to this distinction, both directions are related to the characterisation of differentiated spatial identities according to quantifiable features of plan representations. Specific methods and related implementations within an architectural context are further analysed and discussed in the framework of the presentation of the methodology that was followed in the present analysis.

A selection of plans representing urban building blocks belonging to different areas of Athens and London have been analysed and compared at different levels, through established and experimental methods of feature measurement.

Finally, the results from these measurements and comparisons were interpreted and discussed in the view to investigate the potentials of the implemented methodology in terms of possible connections between the quantification of plan attributes and issues of spatial identity.

## 2. A brief overview of the field

### 2.1. Quantifiable plan attributes and spatial experience

The relation between the experience of spatial identity and quantifiable spatial attributes has been in the centre of interest of different fields of spatial analysis. Very extensive research in the field is being effected in space syntax. According to Psarra and Grajewski (2001) the description of spatial experience is the main focus of “space syntax”, a theory and a method for measuring spatial properties and relating them to patterns of movement and social function. Layouts are described as permeability patterns held amongst “convex spaces” and “axial lines”. “The major thrust of space syntax has been to describe space and movement as a dimension of social copresence” (Peponis et al, 1997, p.764). The initial aim of space syntax was to “show how order in space originates in social life, and therefore to pinpoint the ways in which society already pervades those patterns of space that need to be described and analysed” (Hillier and Hanson, 1984, p.8). Space syntax has developed several methods for the analysis and quantification of configurational attributes in relation to spatial experience, the most prevalent of which are related to the representation of plans through axial lines, defined as the longest lines that pass through convex spaces without intersecting spatial boundaries (Hillier and Hanson, 1984, Peponis et al, 1997). These lines are related to spatial experience, since they “correspond more closely to our intuition of space as a field of movement” (Peponis et al, 1997, p.763). Space is considered through its syntactic characteristics rather than the attributes of its shape (Figure 1).



*Figure 1.* Different mapping representations of town of G in France

(Hillier and Hanson, 1984, pp. 90, 91, 92, 100, 104)

a. conventional map, b. axial map, c. convex map, d.y-map, e. interface map

The way in which the structure of space and movement affect our exposure to the elements of shape has been investigated through methods closely related to those implemented by space syntax (Peponis et al, 1997, Peponis, 1997). Peponis et al have introduced a series of methods regarding the quantification of plans in terms of informational stability and change in relation to the moving subject (Figure 2). Spatial experience is thus directly linked to specific characteristics of shape “bridging the gap between the changing nature of a spatial environment and the constant nature of its shape” (Psarra and Grajewski, 2001, p.2).

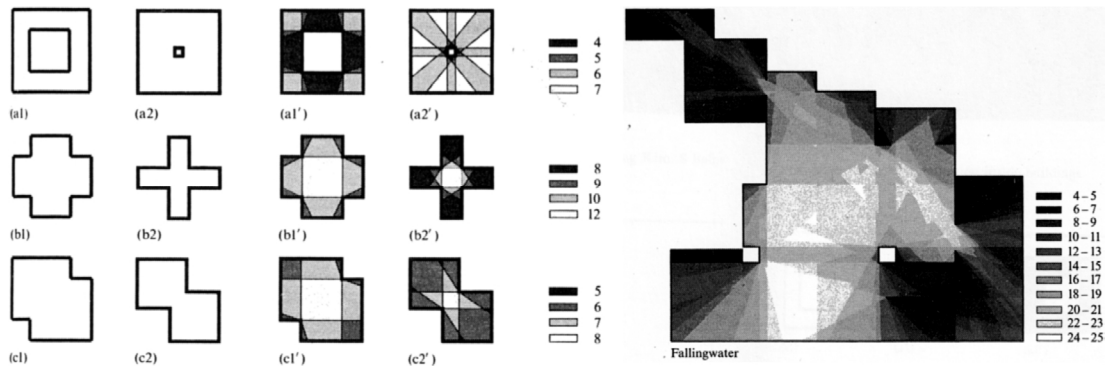


Figure 2. E-spaces (Peponis et al, 1997, pp.774, 775)

Plans shaded according to the number of visible discontinuities from e-spaces: three pairs of theoretical plans (left) and a simplified plan of Fallingwater by Frank Lloyd Wright (right).

Implementing elements from both directions described above, Psarra and Grajewski have introduced a method for describing shape and shape complexity using local properties (Psarra and Grajewski, 2001, Psarra, 2003). This method, which is analysed in detail further, describes space through the attributes of the perimeter of its shape, as seen in plan, in terms of connectivity. Spatial experience is related to the degree and rate of changes in visibility from sequential locations along the perimeter (Figure 3).

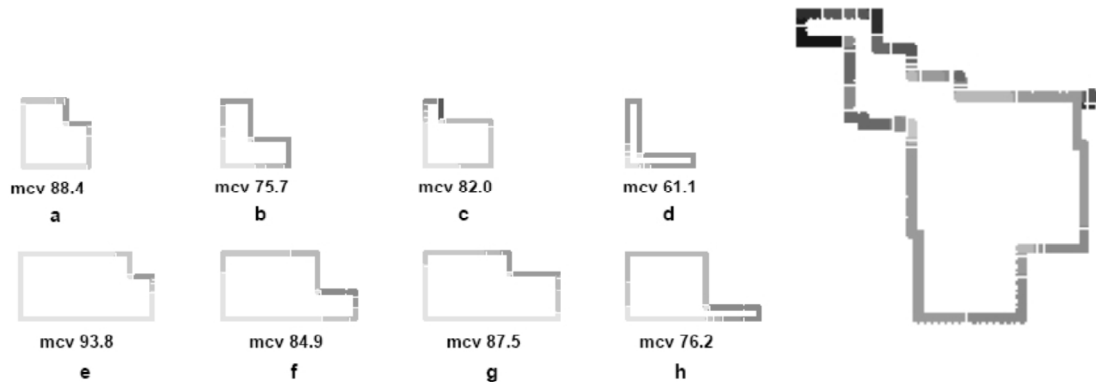


Figure 3. Connectivity values (Psarra and Grajewski, 2001, pp. 4, 12)

Plans shaded according to the distribution of connectivity values along the perimeter and mean connectivity value: theoretical plans (left) and a simplified plan of Fallingwater by Frank Lloyd Wright (right).

## 2.2. Quantifiable plan attributes and categorisation of spaces

The description of plan representations through syntactic attributes of the perimeter of shapes has also been proposed by Gero and Park (1997, Park and Gero, 2000) and later Gero and Jupp (2003, Jupp and Gero, 2003). According to Gero and Park (1997), this

method moves away from numerical to symbolic descriptions that represent qualities rather than quantities, describing “with classes of shapes as opposed to quantitative modelling which describes individual shapes” (Gero and Park, 1997, p.829). According to this method, shapes are represented and analysed through encoding the characteristics of intersections of arcs (edges) at the vertices, combining semantics (Gero and Park, 1997) and graph theory (Gero and Jupp, 2003). This method is not directly structured according to the embodied experience of spaces represented by the shapes described, but it can be associated to spatial perception through its relation to intuitive understanding of shape semantics. These qualitative shape representations, called Q-codes (Figure 4), have been used for the categorisation of plans, based on degrees of similarities between their codified features and defined shape categories (Park and Gero, 2000). According to this method, the quantification of qualitative, semantic features of shapes enables the classification of building plans within a relative system of comparisons.



Figure 4. Q-code semantics and semantic graphs (Gero and Jupp, 2003, p.8, Jupp and Gero, 2003, p.4)  
Q-code semantics for primitive shapes (left), original drawing (centre) and semantic graph representation of Farnsworth House (right).

Relative methods of classification of building plans according to the quantification of spatial features have been implemented by Hanna both in an analytic and in a generative framework (Figure 5). Measurements deriving from axial and boundary maps were used for the representation and comparison of plans in high-dimensional space. Degrees of similarity and differentiation have been measured either directly in high-dimensional space, through the comparison between graph spectra corresponding to plans (Hanna, 2007a, b), or in two dimensions, by reducing dimensionality through principal component analysis (Hanna, 2006, 2007c). Details about these methods are discussed in the section of methodology.

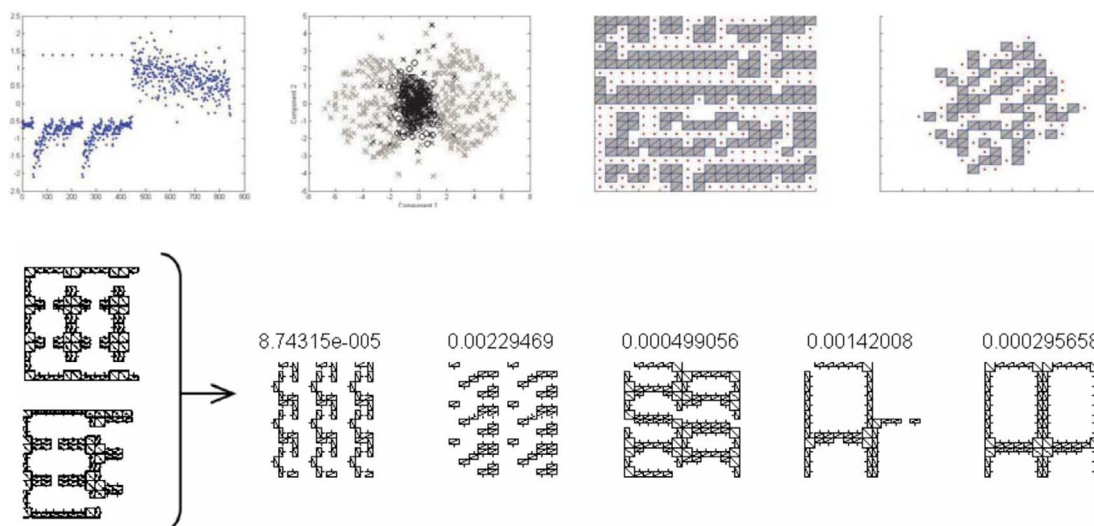


Figure 5. Generation of spatial configurations according to learned configurational types  
(Hanna 2006, p. 15, 2007b, p. 2018)

Supervised learning for the generation of two different types of abstract configurations:  
linear and random (top) and different desk layouts produced by a Genetic Algorithm (bottom).

The approaches described above derive from various fields of spatial research and respond to different questions concerning space analysis and generation. However, they share the stand that the quantification of spatial attributes, as they are manifested in plan representations, can be related to embodied spatial experience or to perceptive categorisations of spatial character. In this sense, all approaches account for the perception of spatial identity, as it is reflected in configurational characteristics of plans.

Most implementations of these methods investigate spatial unities either at the scale of individual spaces and buildings or at urban scale. The consideration of the intermediate scale of the urban building block, attempted here, examines the potential of generalisation of such methods in a continuous range of scales of spatial organisation.

### **3. Methodology**

#### **3.1. Definitions and specifications**

##### **3.1.1. The urban block**

Since urban layouts are usually heterogeneous and complex, the boundaries of distinct urban blocks can be ambiguous. In order to overcome this ambiguity, the block was considered as the body of built and open spaces, surrounded by freely accessible public passages and whose boundaries coincide with materialised or insinuated designations of property limits.

Since the analysis focuses on the configuration of private open spaces and their relation to public space and to surrounding buildings in terms of visibility and permeability, partitions were omitted and adjacent built or open spaces were viewed as continuous. Since possible boundaries between open spaces are much lower and lighter than the built volumes defining the overall contour, buildings were considered as solid volumes and open spaces as their negative void.

##### **3.1.2. The study case**

###### **a. Selection criteria**

The city of Athens, Greece, was selected as the main study case. Athens' metropolitan character and long turbulent history are reflected in an urban environment characterised by a recognisable, unified and continuous identity that emerges from a multiplicity of heterogeneous singularities and local particularities. It offers thus the framework for a multi-levelled analysis, with the possibility to spread on different scales of spatial identifications and differentiations.

In order to restrict and define further the specific framework of study, it was decided to focus on the city centre, as it was considered to offer great diversity in terms of historical depth and thus construction phases, social structuring and land uses.

Four different areas in the centre of Athens were selected according to the differentiation amongst them and to their internal consistency, in order to enable the examination of the possibility of relation between quantifiable spatial attributes and local identity. Internal consistency refers to the perceptive character of each area rather than to homogeneity of building block features, since the centre of Athens is characterised by great mixture of buildings from various historical periods and architectural styles.

The selection of the neighbourhoods was mainly based on the general belief that, during the building boom of the late fifties and early sixties (Philippidis, 1990, Aravantinos, 1997), the

character of the Athenian urban environment shifted dramatically. Public opinion was considered as an index of how spatial identity is experienced. Making the assumption that the distribution and fluctuations of land values are at some degree a quantifiable expression of public appreciation, the initial criteria for the selection of the areas were their distribution on both sides of the historical threshold of the reconstruction period and the differentiation in land values (Figure 6).

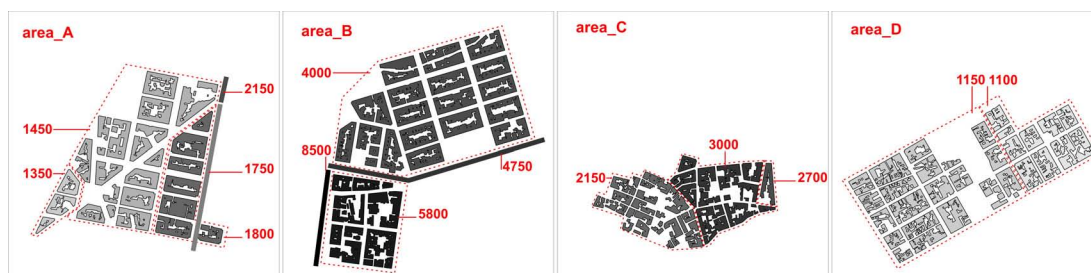


Figure 6. Distribution of land values in the four selected areas of Athens  
(source: Tables of Objective Values, published by the Greek Ministry of Economy and Economics)

## b. Selected areas

According to these criteria, the selected areas were *Mouseio*, *Kolonaki*, *Plaka* and *Metaksourgeio* (Figures 7, 8).

Mouseio, labelled as area A, is a highly integrated area, adjacent to the central and very busy Omonoia square, highly mixed in terms of national and social composition and characterised by predominantly modern constructions (Figure 7a).

Kolonaki, registered as area B, is a less integrated neighbourhood on the banks of mount Lycabettus, also characterised by modern constructions. It is considered to be the traditional bourgeois area of central Athens (Figure 7b).

Plaka, or area C, is part of the historical core of Athens, at the feet of the Acropolis. It is a protected area of cultural heritage, characterised by many archaeological sites and low rising buildings, prevailingly constructed before the beginnings of the twentieth century (Figure 7c).

Finally Metaksourgeio, labelled as area D, is an early-industrial area, situated along Peiraos avenue, the main connection between Athens and the port of Piraeus. It was developed in the nineteenth century in direct relation to the silk factory (“metaksourgeio” means silk factory in Greek) that was functioning in the area. The neighbourhood has been scarcely reconstructed (Figure 7d).

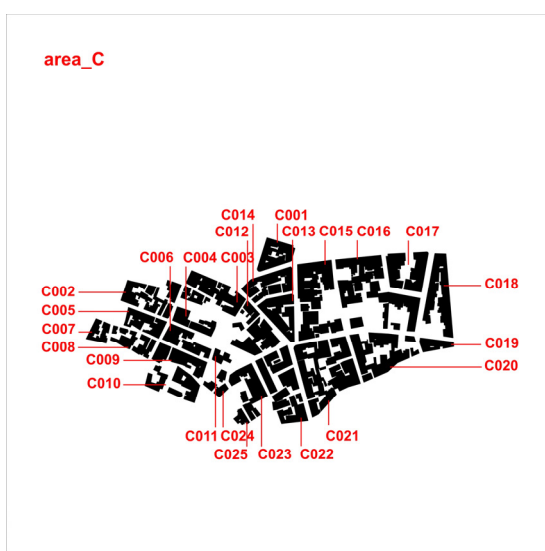
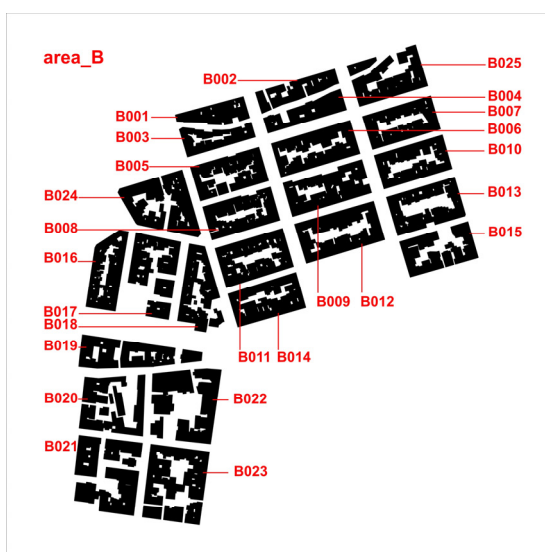
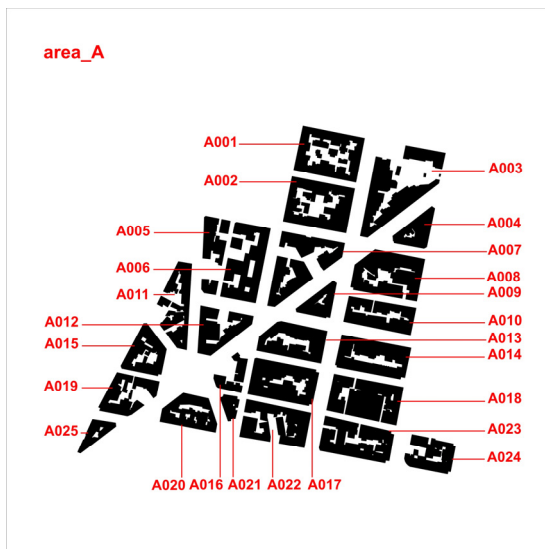




Figure 7. Characteristic snapshots of the selected areas

Although Athens is the central focus of study, an area of London complements the dataset in order to amplify the comparative possibilities of the analysis beyond the potentially restrictive characteristics of a single city. With the intention to validate the measurements through the comparison between areas with correspondent characteristics, it was decided to select an area in central London with mixed land uses and variable construction phases. According to these criteria, the area of Bloomsbury and Fitzrovia was considered suitable for the requirements of the study. The selected area was labelled area L (Figures 7e, 8). The dataset consists of twenty-five building blocks from each area (Figure 8).







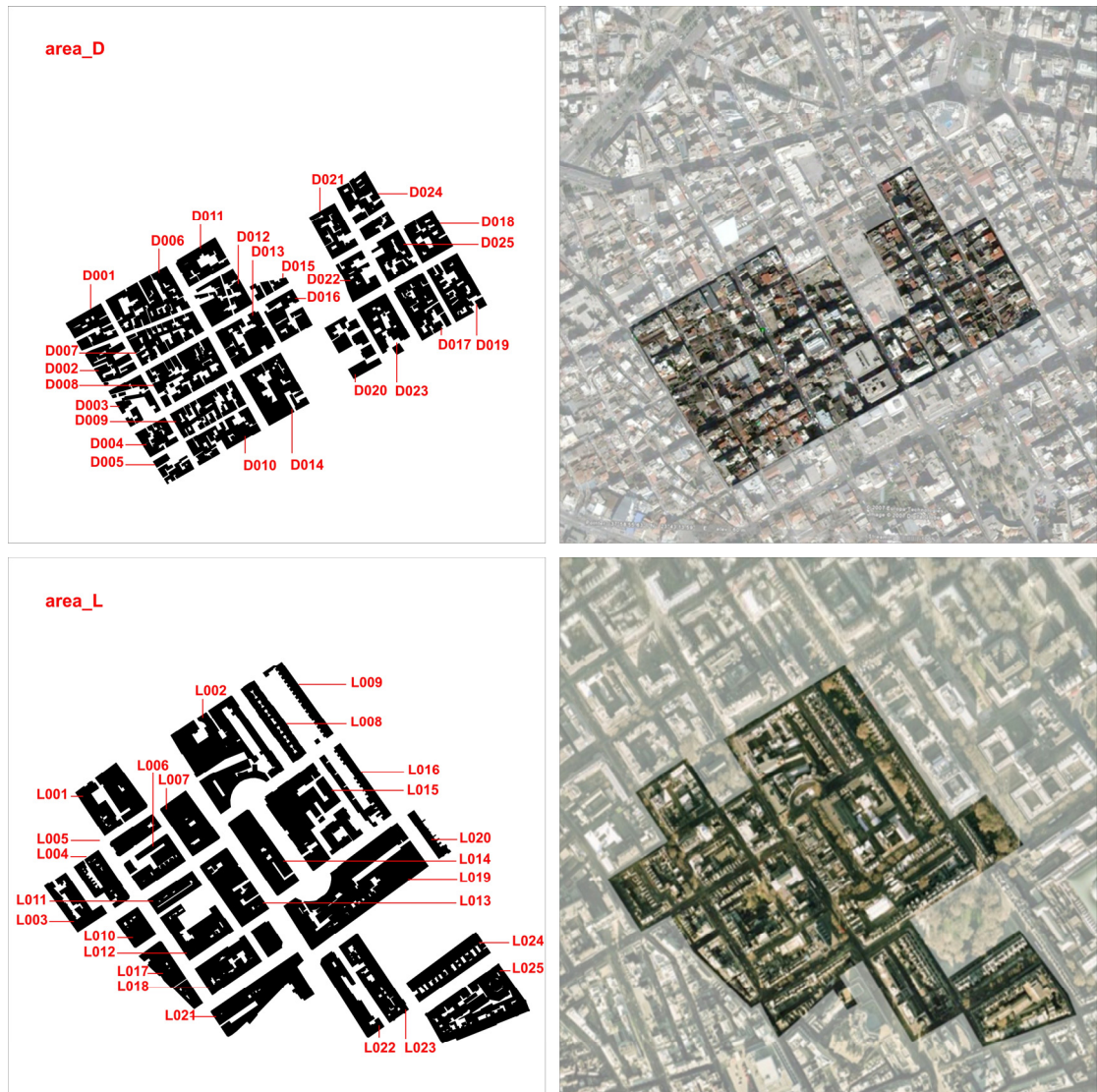


Figure 8. The study case: five urban areas.

General urban context (top), numbered building blocks (left) and aerial view (right)  
 (source of aerial photographs: Google Earth)

### 3.2. Measurement methods and previous implementations

#### 3.2.1. Selection and measurement of plan features

In order to reinforce the validity of the results it was considered essential that more than one methods of spatial analysis be implemented and their outcomes compared. In this framework, methods used in distinct fields of spatial studies for the analysis of different features were implemented in order to extract variable data about the blocks under examination.

A short overview of these methods accompanied by previous implementations is given in this section whereas further details and specifications about the present application are available in Appendix I.

### 3.2.2. Conventional methods of Urbanism

Established methods of measurement and representation used in urban studies have been largely implemented for the comparison between plans and the illustration of results.

The plans of the building blocks, forming the basis for all measurements, originated from conventional topographical maps, detailed at the scale of 1:500.

A first set of measurements were derived from typical urban analysis maps. These can be distinguished into quantities that refer to attributes accounting for building regulations and measures that represent the existing situation (Figure 9).

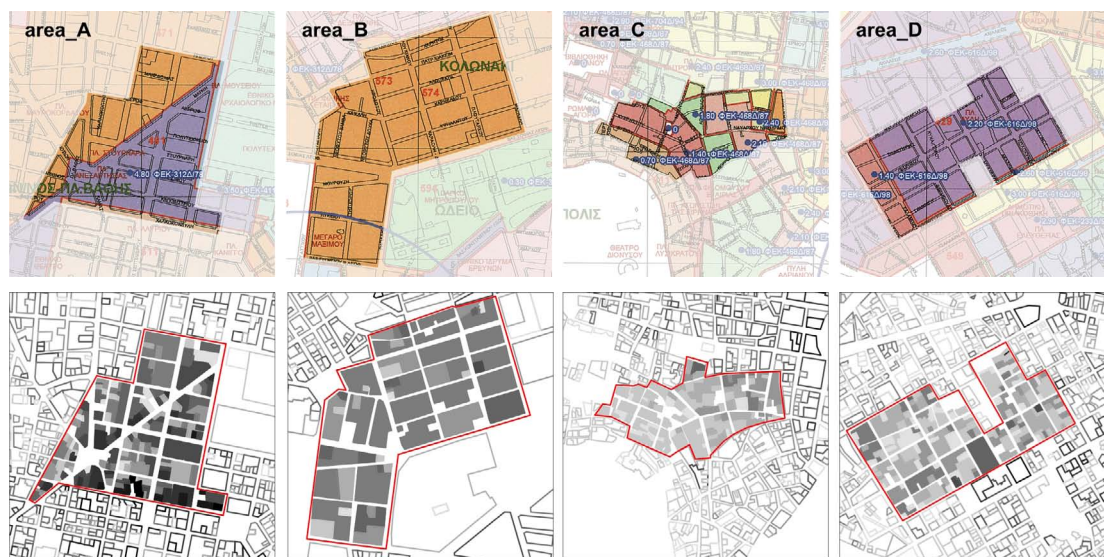


Figure 9. Regulations and existing situation.

Top: distribution of floor area factor

(source: Department of Urban Planning of the Municipality of Athens),

Bottom: existing building heights per plot

(source: Laboratory of Geographical Systems of Information of the Department of Urban and Regional Planning of the School of Architecture at the National Technical University of Athens)

### 3.2.3. Classification by principal components analysis using axial graph spectra

Spatial representation and analysis through axial maps is used by space syntax in order to illustrate and quantify connectivity relations in continuous spaces, in terms of unobstructed sight lines.

An axial map is defined as the least set of straight lines which passes through each convex space and makes all axial links (Hillier and Hanson, 1984, p.92).

Properties of axial maps have been shown to be related to spatial perception and therefore to the experience of spatial identity. Their ability to represent both topological and geometrical attributes of space contributes to their success in capturing multiple configurational qualities.

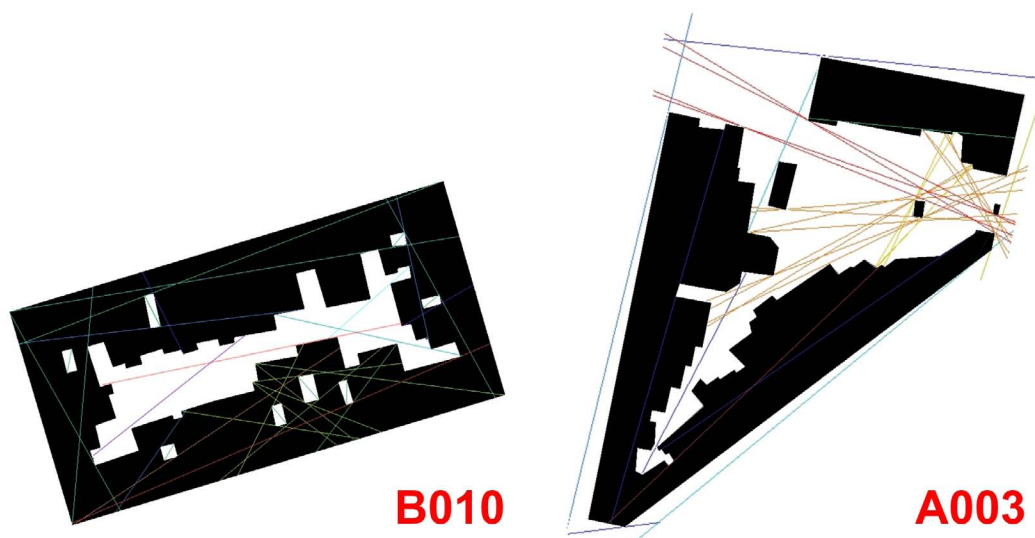


Figure 10. Axial maps of two sample plans.

Reduced axial maps were generated for both open and built spaces, including a zone of public open space around permeable blocks.

A method for mapping axial map representations of plans into high-dimensional feature space was used in order to classify building block plans from different areas. The use of axial graph spectra, or ordered set of eigenvalues, for the representation and generation of plans (Figure 11) is discussed in details by Hanna (2007a,b). According to Hanna, “the spectra of various graphs have been shown to be an effective representation of spaces, which can be used to measure similarity of both global and local spatial structure” (Hanna, 2007a, p.12).



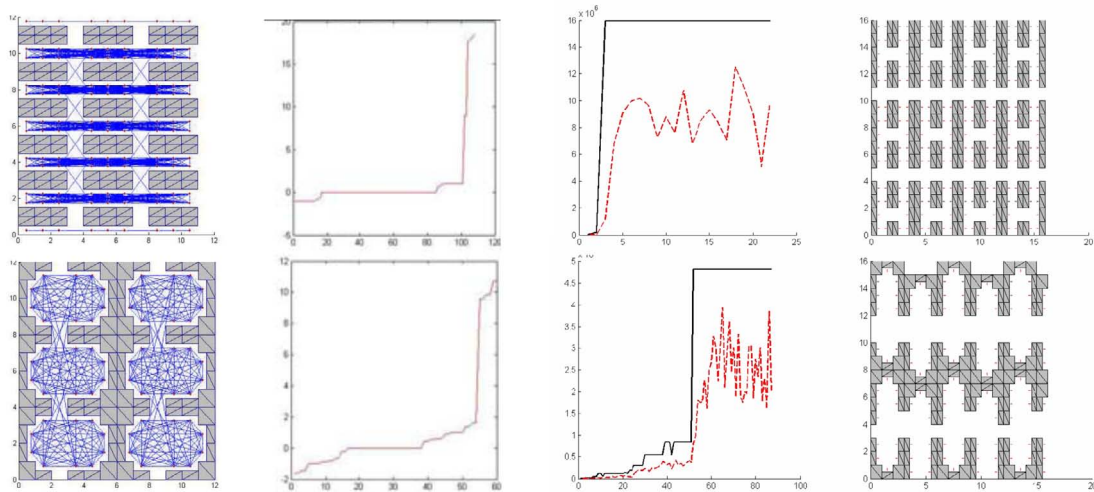
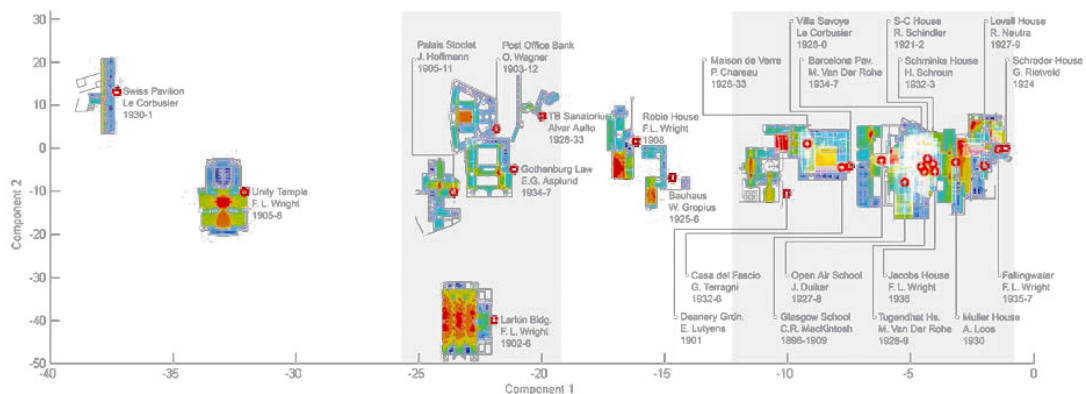


Figure 11. Axial map spectra (Hanna 2007a, p.6, 2007b, p.216)

Axial maps, related spectra for different types of desk configurations (left) and corresponding GA generated layouts with spectra (right)

As the comparison between high-dimensional data can be complicated, principal component analysis (PCA) was implemented in order to reduce dimensionality and highlight differentiations within the dataset. Principal component analysis is “an unsupervised approach to finding the “right” features from the data. (...) It projects d-dimensional data onto a lower dimensional subspace” ( Duda et al, 2001, p.568).

The method of classification of axial graph spectra through PCA has been used for the description of different architectural styles through the definition of feature space archetypes as well as for the classification of plans of different building types (Hanna 2006, 2007c) (Figure 12).



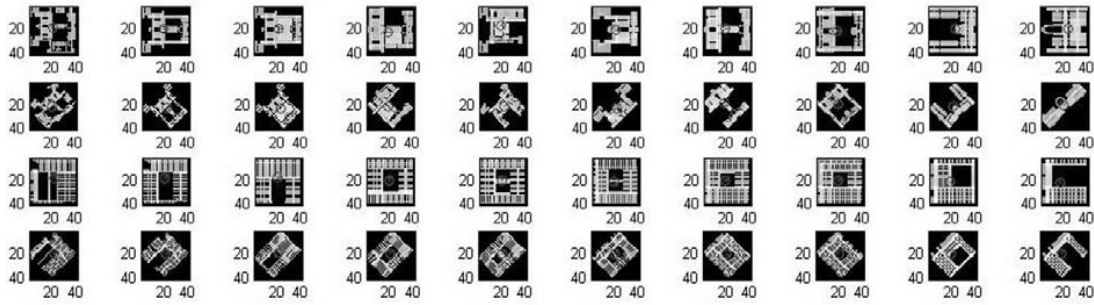


Figure 12. Classification of building plans through principal components analysis, using axial map spectra (Hanna, 2007c, pp. 10, 11)

Example buildings plotted in feature space (previous page) and classification of building types: the upper 20 plans represent museums and the lower 20 offices (this page)

It has been shown to be a method that enables the automated representation of plans within a uniform feature space in a way that depicts degrees of differentiation without requiring explicit description of the attributes compared. In this framework it was applied for the classification of the building block plans (Figure 13).

The implementation was based on an algorithm written by Sean Hanna in Matlab.

The axial maps were generated using Depthmap software.

PCA was also used independently from the axial graph spectra, for the classification of the plans according to all measured attributes. For this analysis, JMP software was used.

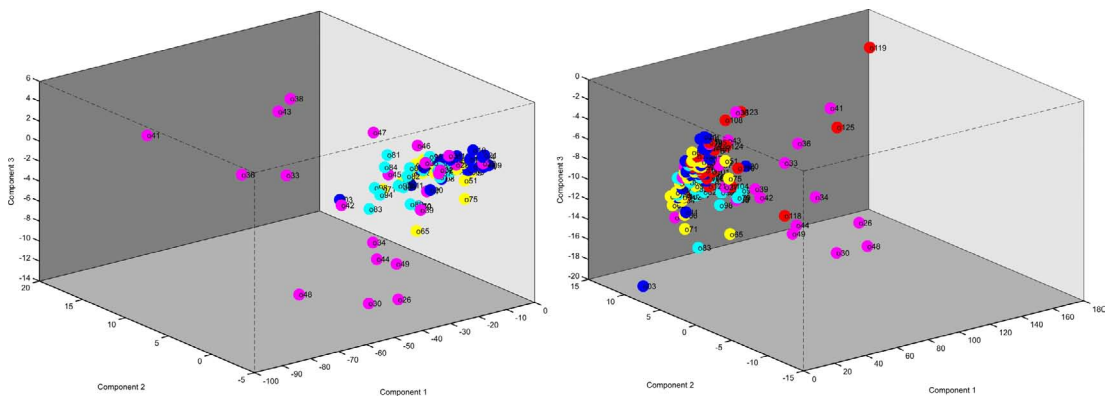


Figure 13. Plots of the sample's axial graph spectra against the three first principal components. Blocks from Athens (left) and from both Athens and London (right)

### 3.2.4. Fractal dimension measurement through box-counting method

#### a. Fractal dimension in architecture

Fractal dimension is a measure of dimensionality of fractal structures. It accounts for the rate of growth of the length of a fractal curve from one generation stage to the next (Bovill, 1996), expressing the degree to which a fractal fills space as the scale of observation decreases.

There are many definitions and ways for calculating fractal dimension, all related to mathematical fractals and thus referring to theoretical, infinitely self-similar structures. However, architectural structures and their representations often have fractal properties that can be approached through their estimated fractal dimensions.

The main characteristic of architectural structures that can be considered as a fractal property is self-similarity. In this view, fractals have been used in architectural context in different scales, for analytic or synthetic purposes.

At an urban scale, the analogy of fractal self-similarity has been used for the analysis and simulation of urban configurations and growth (Figure 14), since “in terms of spatial structure, cities distribute their resources in space in such a way that their networks of distribution fill space efficiently, moving goods and people along dendritic networks which fill space the most economically. These networks exist in the same form with the same space filling properties at different scales and through different times in terms of city growth” (Batty, 2007, p.14). The fractal city has a structure that manifests itself in the same morphology at different scales (Batty and Longley, 1994).

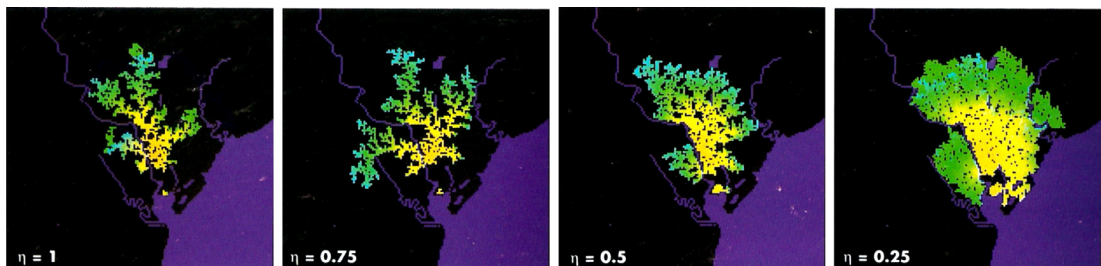


Figure 14. Fractal simulation of the urban growth of Cardiff (Batty and Longley, 1994)

At the building scale, fractal geometry has been used as a design tool (Bovill, 1996, 2000) as well as an analytical means for the approach of architectural analogies and rhythms (Figure 15). Fractal dimension in particular has been viewed as an indicator of complexity of building plans and elevations (Lorenz, 2002, Bovill, 1996, 2000) (Figure 15).



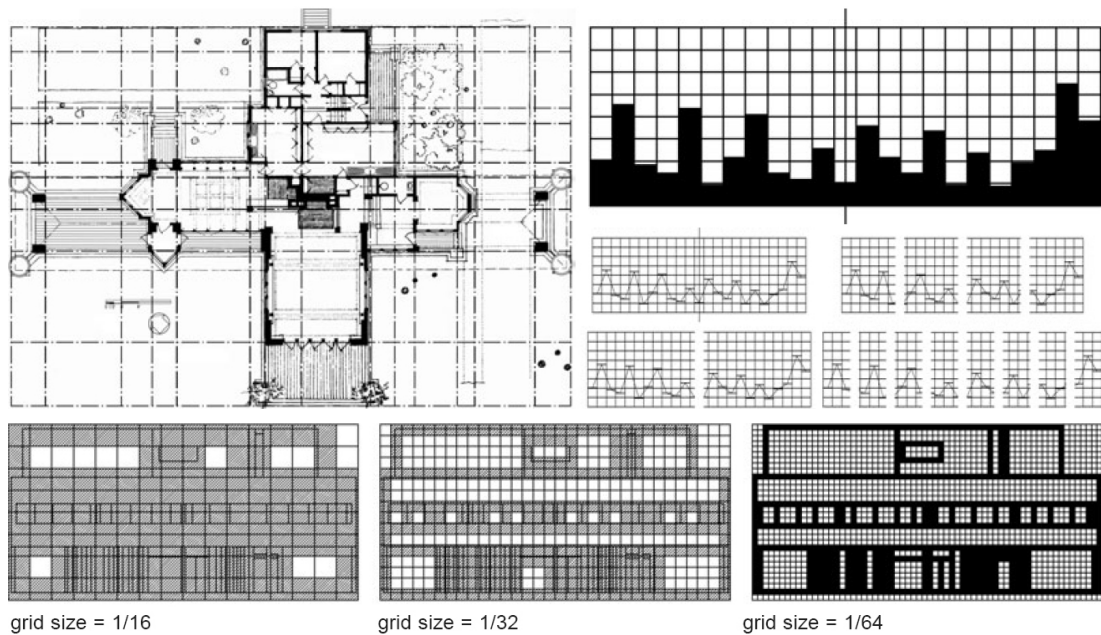


Figure 15. Fractal rhythm and fractal dimension in architectural analysis (Bovill, 1996)

Analysis of the plan of Willits House by Frank Lloyd Wright based on fractal rhythm (top) and box counting dimension of the elevation of Villa Savoye by Le Corbusier (bottom)

In the specific case of the building block plans, fractal dimension was used as an index of complexity and self similarity of the contours of open and built spaces. The amount and scale of meandering of the spaces constituting the blocks affect the visual permeability of open spaces and the way they are perceived from the street or through the windows of adjacent buildings in terms of visual depth and layering.

## b. Box-counting

The method used for the calculation of fractal dimension of the plans counts the Minkowski-Bouligand dimension, more commonly referred to as box-counting dimension. This method can be used for calculating the fractal dimension of images rather than of single fractal curves. It enables thus the measurement of composite objects that are constituted by a multitude of disconnected fractal structures. In this way, it was possible to measure the dimension of each plan as a whole instead of measuring each contour separately. Of course, the resulting measurements correspond to the image of the plan and not to the building block itself.

For the measurement of fractal dimension in the framework of the present analysis, an algorithm was written in Processing (Appendix III), based on the description of the box-counting method.

Practically, the box counting method is based on a repetitive process of laying a grid of constantly decreasing scale over the image under measurement. At each grid scale, the number of cells that contain parts of the structure is counted and the fractal dimension is given by the comparison between scales (Figure 16, Table III)

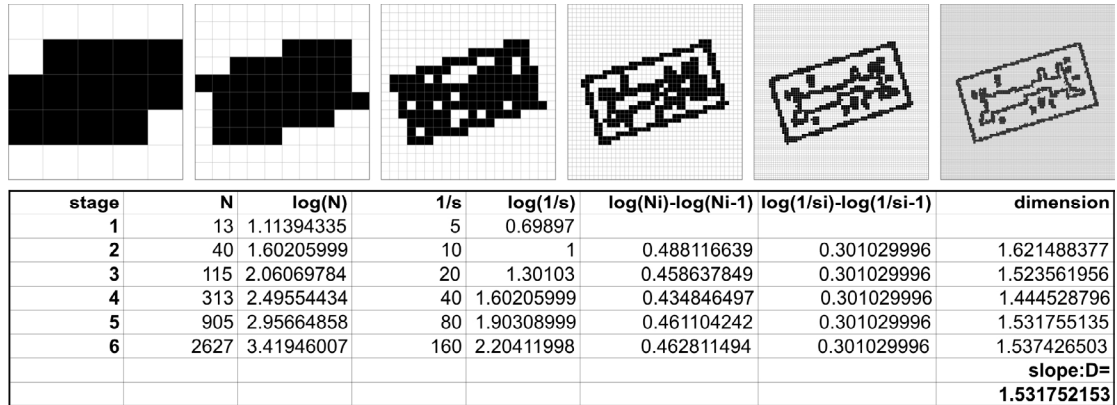


Figure 16. Box-counting in Processing

Example of fractal dimension measurement for block plan B010

### 3.2.5. Connectivity as a local shape property

The experience of open spaces within the building blocks is directly related to the way they are gradually revealed to visual perception. As aforementioned, there are several methods for measuring and analysing visual properties of space, based on the assumption that the received visual information and spatial experience changes according to the observer's position in space (Psarra and Grajewski, 2001). Some methods analyse this sequential nature of spatial experience and others combine separate visual instances into a synchronous view.

The method implemented here, introduced and developed by Psarra and Grajewski (2001), offers a combination of local and global, sequential and synchronous approaches of visual experience, and is based on the description of syntactic properties of shape perimeter (Figure 17, Table IV).

Approaching shape from its perimeter, this method was considered to be suitable for the specific analysis, since the open spaces within the building blocks are initially and often uniquely experienced through their perimeter, either from the edges adjacent to streets or through the windows of the facades of the surrounding buildings.

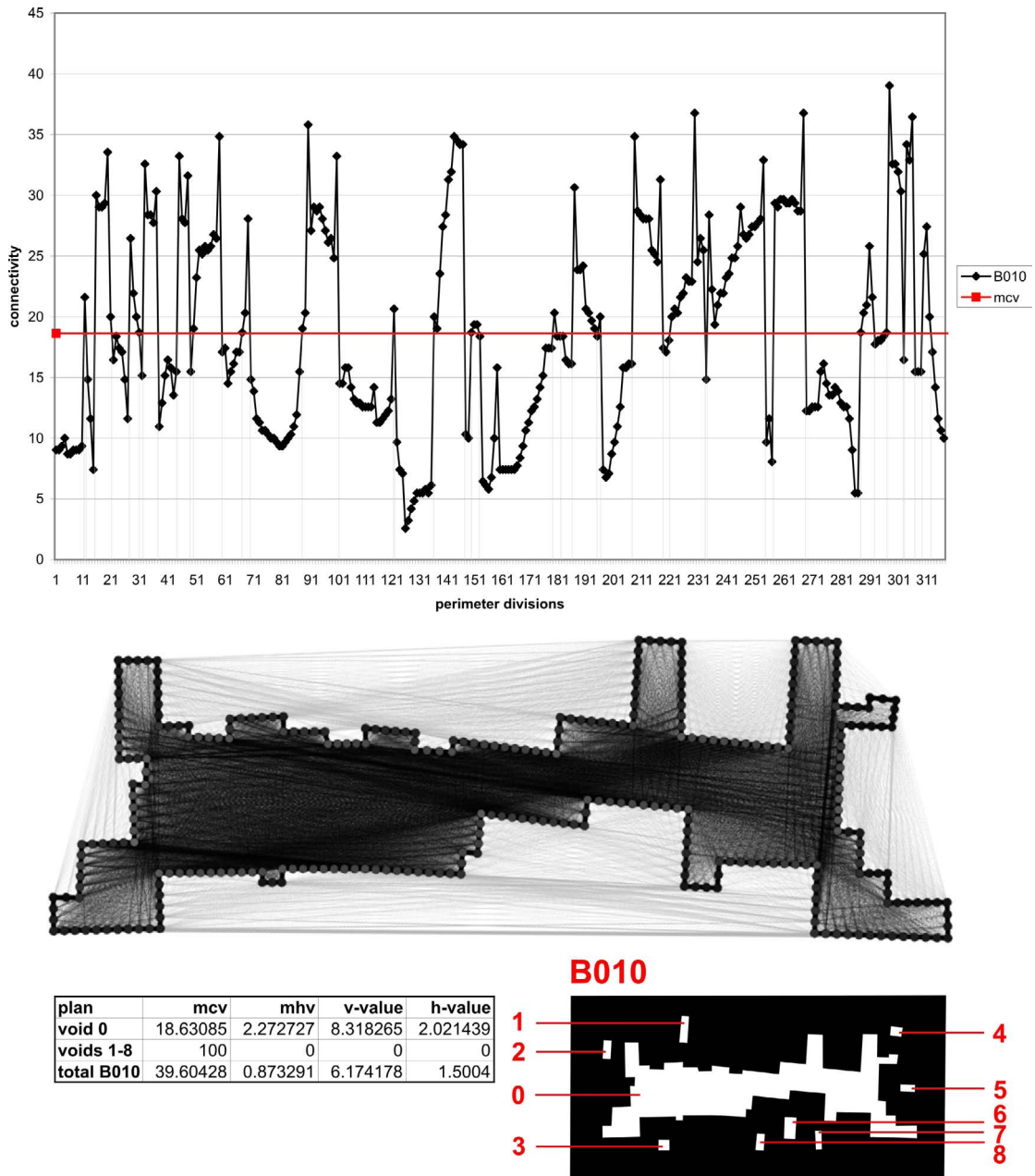


Figure 17. Connectivity measurements in Processing

Example of measurements for block plan B010. Calculation of convex lines (centre) and graph of local properties for the central open space (top) and total measurements for the whole plan (bottom)

## Measurement

According to Psarra and Grajewski, this method explores ways of comparing shapes of different geometry without relying on traditional notions of geometrical order, by quantifying their convexity in terms of distribution of connectivity along the perimeter.

Originally, it has been implemented using a GIS based computer programme. For the present implementation, an algorithm was written in Processing, based on the description of the method (Appendix III).

In order to calculate connectivity, the perimeter of the shape is subdivided into segments of equal length. From the subdivisions a complete graph is derived for the shape, where all points subdividing the perimeter are connected to each other. The number of connections that lie completely within the perimeter is calculated for each point. The ratio of such connections from each subdivision to their total number represents the mean connectivity value for each location on the perimeter of the shape.

## a. Global properties

### a.1. Mean connectivity value (mcv)

The average of connectivity values for all perimeter segments gives the mean connectivity value (mcv) for the shape as a whole.

This quantity is an index of the convexity of the shape, meaning that higher values suggest a more convex shape, consisting prevalingly of areas that expand along two axes. Experimental observations support the assumption that mcv captures global configurational characteristics of the shape, related to its degree of occlusion and to the relations of the parts to the whole in terms of symmetry and regularity (Figure 18).

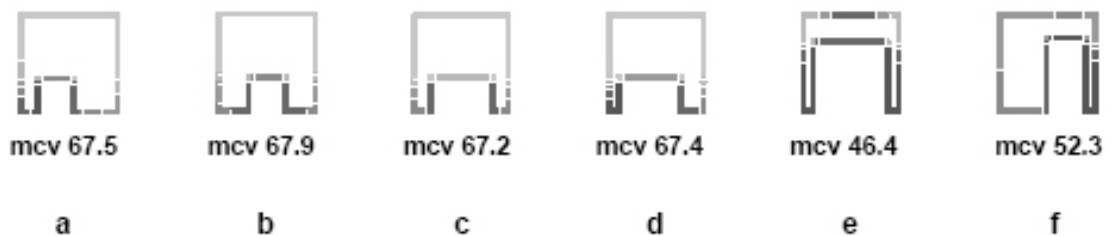


Figure 18. Distribution of connectivity along the perimeter and mean connectivity for different degrees of occlusion and symmetry (Psarra and Grajewski, 2001, p.4)

## b. Local properties

The measurement of mean connectivity value for each location along the perimeter enables the contemplation of the shape's behaviour in terms of stability and change at a local scale, by plotting connectivity values on a graph (Figure 17). "The x-axis corresponds to the number of cells (subdivisions) and hence captures perimeter length. The y-axis maps connectivity values" (Psarra and Grajewski, 2001, p.6). Two quantities, v-value and h-value, are extracted from the graph, corresponding to changes along the two axes. These are

calculated using standard deviation, a measure that indicates how much on average a set of values differs from a mean.

#### **b.1. v-value: vertical standard deviation**

V-value represents the level of differentiation in connectivity amongst perimeter locations and is calculated as the standard deviation of all connectivity values from mean connectivity.

High v-values suggest high degrees of dispersion or differentiation amongst perimeter locations, produced by the combination of convex and non convex shapes of different sizes.

Low v-values suggest stability of connectivity values along the perimeter. This can be caused either by simple, symmetrical convex shapes with high connectivity values all along the perimeter or by very meandering shapes with equally distributed low connectivity.

#### **b.2. h-value: horizontal standard deviation**

H-value reflects the level of differentiation in the rate of transformation of connectivity values along subsequent perimeter sections and is measured as the standard deviation of all distances between subsequent nodes, defined by the points of intersection of the graph with the horizontal line representing mean connectivity.

High h-values account for variable rates of differentiation of connectivity that characterise uneven, asymmetrical shapes.

Low h-values correspond to even rates of differentiation that can be related either to symmetrical, rhythmic shapes or to very meandering contours where distances between rises and falls of connectivity are similarly short.

#### **b.3. Mean horizontal value (mhv)**

Besides these two quantities, v-value and h-value, the use of which is proposed by Psarra and Grajewski, it was considered useful to take into account one more measure, the average distance between subsequent points of mean connectivity value. Mean differentiation along the x axis (mhv) accounts for the pace of connectivity changes.

High mean distances along the x axis correspond to low rates of differentiation, accounting for shapes that are characterised by smooth changes or long perimeter segments with stable visibility.

Low mean distances reflect high rates of change due to frequent and large variations in connectivity.

### **3.3. Combination of methods**

#### **3.3.1. Categories of measurements**

Each of the methods described produces measurements that capture different attributes of spatial configurations. The final output from all methods is expressed through scalar quantities, but these often derive from processes that take into account geometrical and topological attributes of the plans under analysis and thus at some degree reflect these features. According to the focus of each process, the quantities measured for the analysis of the blocks could be distinguished into scalar, geometrical and topological.

##### **a. Scalar quantities**

The quantities involved in traditional urban analysis can be considered as scalar, since they don't describe geometrical or topological characteristics of the plans, but relations between quantities.

##### **b. Geometrical measures**

The measurement of fractal dimension accounts for geometrical attributes of the plans, as it refers to self-similarity and metric proportions of the parts in relation to the whole. It has been noticed that topologically identical objects can have different fractal dimensions (Lorenz, 2002, p.31).

##### **c. Syntactic-topological measures**

The other methods, connectivity measurements and spectral analysis of axial graphs, focus on syntactic properties of the plans. The results of these methods are affected both by the geometry and topology of the configurations under measurement, but what is measured is essentially the relations between locations of the plans, both at a local and at a global level. In this sense, these methods can be considered as prevalingly topological.

#### **3.3.2. Combinatorial analysis**

This distinction shows that each method can only partially describe the plans. The comparative combination of measurements deriving from different methods enables a more spherical contemplation of the dataset and at the same time allows the examination of the suitability of the selected methods.

## **Scales of analysis**

In order to arrive to conclusions about relations between plans, neighbourhoods and possibly the two cities, but also about the suitability of the methods, the data was examined both at the level of individual building blocks and at the level of the local area, through the analysis of patterns occurring within each single measurement, by combinations of measurements in pairs and by the simultaneous consideration of the whole set of measurements.

### **a. Single quantities**

At the scale of individual blocks, for each measurement, plans from all areas with unusual values, either high or low, were pointed out. This was a way for validating and comparing the methods, since the extreme cases are indicative of the nature of captured features. The convergence of extreme values towards the same plan illustrates high differentiation of the specific block.

Furthermore, plans from all areas that have visual similarities were compared in order to confirm whether their similarity is reflected in the measurements.

At the scale of the neighbourhood, comparisons were attempted according to the patterns of distribution, range, variation, mean and extreme values for each quantity.

Measurements were also illustrated in maps with different shadings for different ranges of values in order to distinguish possible patterns of distribution in space.

### **b. Pairs of quantities**

The different quantities were combined into pairs and the corresponding measurements plotted in scatter graphs.

At the level of individual blocks, extreme outliers and their behaviour in relation to other quantities were noted, similarly to the analysis of single measurements.

At the scale of the neighbourhood, the patterns of distribution as they appear in the scatter graphs were examined. It was attempted to distinguish general tendencies within the same area and to compare with trends in other areas in order to reveal relations of identification and differentiation between neighbourhoods.

### **c. Set of quantities**

Finally, the patterns produced by the distribution of values in all quantities were investigated by combining all measurements through principal components analysis.

The simultaneous view of the dataset enabled the comparison of relations within and between neighbourhoods over all measured attributes.

### 3.4. Limitations of methodology

The main issue that this analysis attempts to approach is whether and to what degree quantifiable attributes of spatial representations, and specifically plans, can capture elements related to the experience of spatial identity. There are important limitations inherent in the question itself, as major issues concerning the formation and perception of spatial identity are not even spatial, let alone be captured in a plan. However, it has been proved that some aspects of spatial experience are indeed related to spatial layout, being influenced by it and reflected in it. The focus might thus be shifted to the validity of objective measurement of these aspects, since they are usually related to non-discursive spatial attributes.

Another level of limitations is imposed by the dataset under analysis. First of all it cannot be proved if possible conclusions are generalisable or if they correspond uniquely to the specific dataset. Nevertheless, the selection of highly heterogeneous areas and the relatively large number of data reduce the risk of specificity. Besides, the existence of universal limits for values of building features, deriving from universal constraints (Steadman, 1998), supports the possibly generalisable character of such measures.

The dataset itself is not equidistributed, since the samples from Athens are more complete than those from London in terms of number of areas, amount of information and personal experience. Some measurements, regarding building regulations, land values and building heights were available only in the case of Athens.

Furthermore, in the case of Athens, different data were extracted from maps of different periods, resulting to certain inconsistencies.

Further limitations are entailed by the methods of measurement per se. Principal component analysis produces results that cannot be explicitly interpreted, since the "components" don't correspond to distinct measures. It is thus impossible to evaluate the importance of information that has been discarded through the process of dimensionality reduction. Additionally, the method of PCA might not be the most suitable for classifying the data, since it aims at the greatest differentiation within the whole dataset. "Although PCA finds components that are useful for representing data, there is no reason to assume that these components must be useful for discriminating between data of different classes. If we pool all of the samples, the directions that are discarded by PCA might be exactly the directions that are needed for distinguishing between classes" (Duda et al, 2001, p.117). This means that PCA might be ideal for illustrating differentiation between all individual plans, but in order to classify the different areas, other methods of unsupervised learning could have been implemented. Multiple discriminant analysis (MDA) could have been more suitable, since it seeks a projection that best separates the data (Duda et al, 2001). The implementation of supervised techniques was not considered, since the aim was to illustrate in the simplest way innate, unmediated relations between unlabelled plans.



Fractal dimension measurement through box-counting is very sensitive to the properties of the image, but limitations deriving from this fact were minimised as much as possible through the thorough preparation of the plans.

Connectivity measurements can produce ambiguous results, since the values are not linearly related to convexity and complexity. Low values account for both very simple and very complex shapes.

Lastly, the set of specific selected methods is not necessarily the most suitable for the description of the dataset.

An additional measurement that would capture visual permeability of the blocks from the street by measuring mean connectivity of edges adjacent to public space (Figure 19), was not finally implemented for the whole dataset, due to time restrictions. This and other quantities would possibly contribute to a more complete representation of the dataset. However the fact that the selected set of methods covers different categories of spatial attributes, and the observation of occasional information overlap between certain measurements, enforces its adequacy.

Considering these limitations, it could be claimed that the selected methods are not individually sufficient for the purpose of the analysis. However, their combination and the size of the dataset might balance out possible mistakes and insufficiencies to some degree.

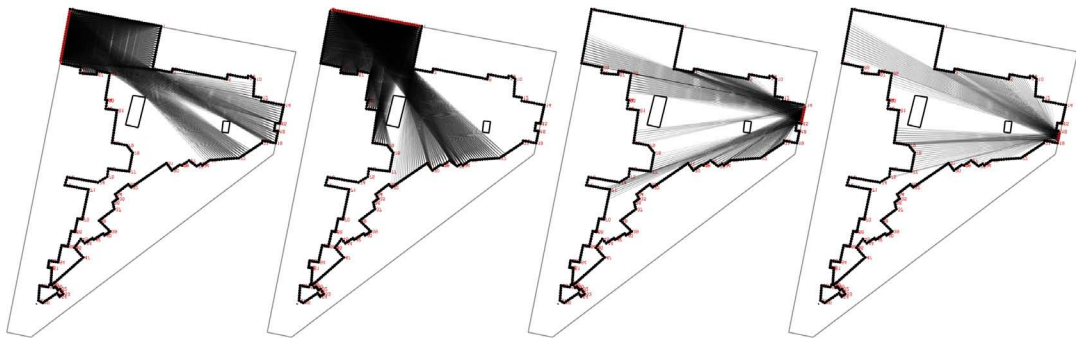


Figure 19. Visual permeability from the street.

Example of measurement for block plan A003. Total mcv=18.347, street mcv=19.124.

## 4. Results and possible interpretations

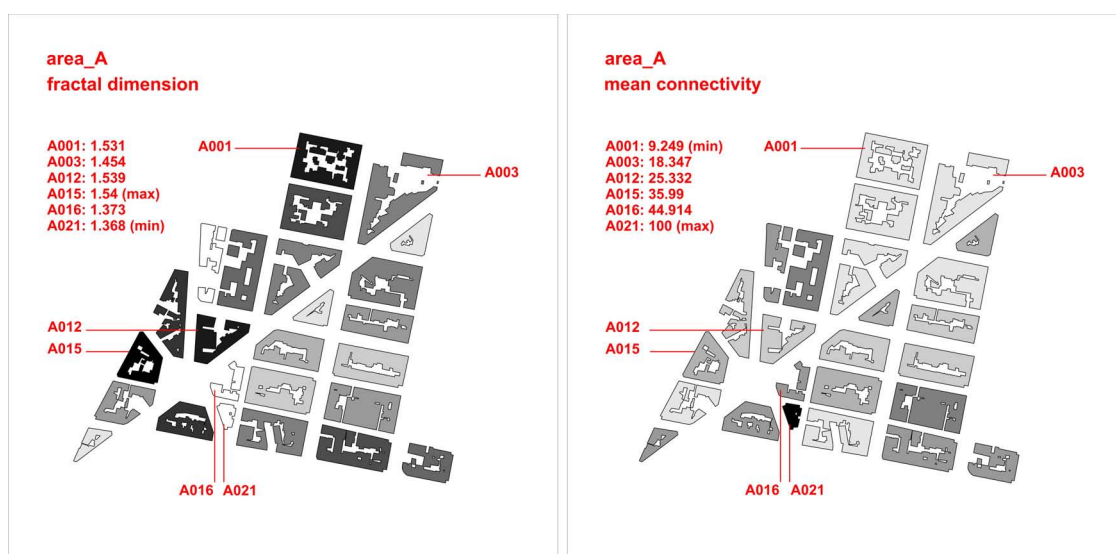
A brief overview of the results and possible interpretations is presented in this section. Detailed descriptions of the most representative graphs and further findings and interpretations are given in Appendix II.

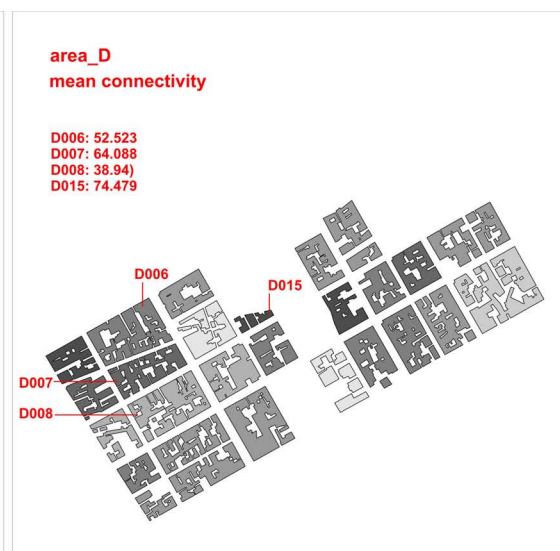
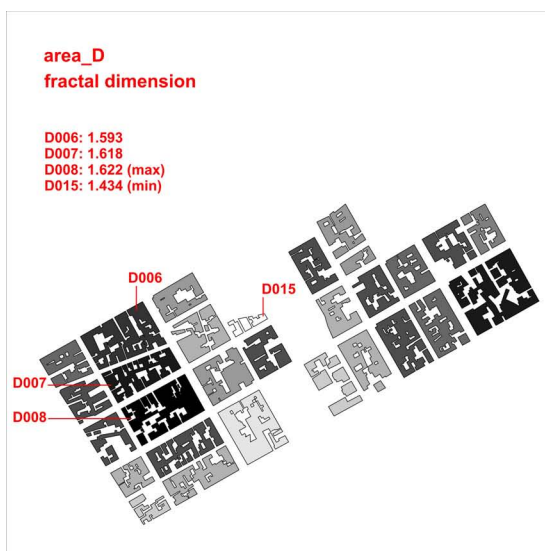
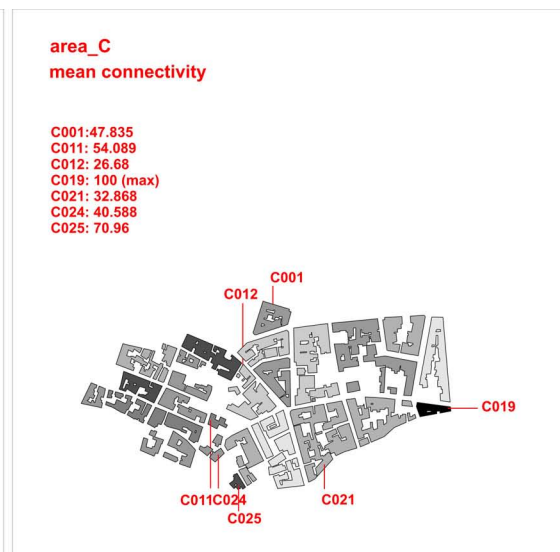
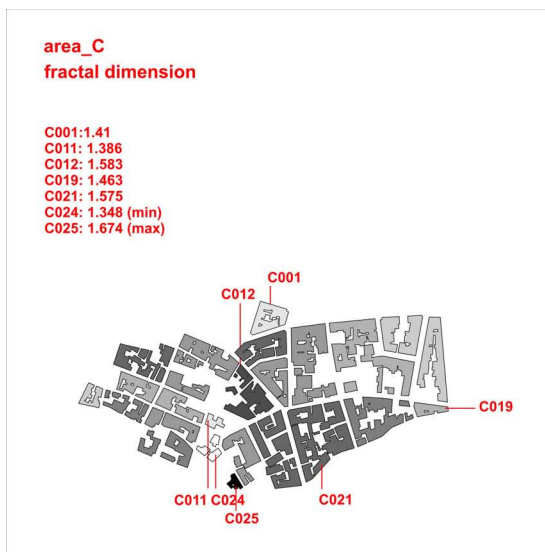
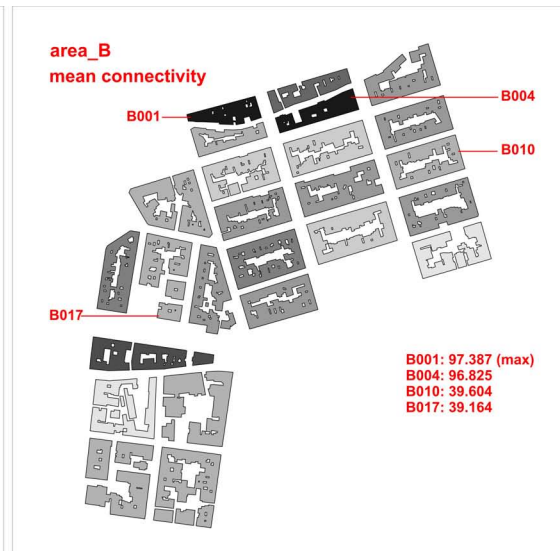
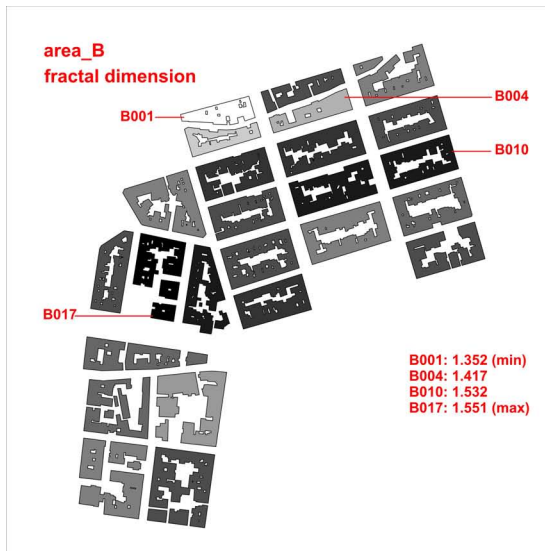
### 4.1. Single quantities

#### 4.1.1. Individual plan scale

Looking at the highest and lowest values in each neighbourhood and for each quantity, certain correspondences between measurements were revealed. An interpretation of the plans was attempted through the combination between corresponding values.

From the observation of the most intensively differentiated plans it was made clear that there is some correspondence between the measurements deriving from the different methods. Their relative magnitudes are not related in a constant way, since in some cases different quantities correlated whereas in others they exhibited opposite trends, but their extreme values repetitively converged towards the same plans. From the examination of the specific examples, it can be claimed that fractal dimension is strongly related to connectivity values, which is a logical result since both measures reflect attributes related to differentiation, repetition and complexity. However their relation is variable, as different combinations of maximum and minimum values were noticed (Figure 20).





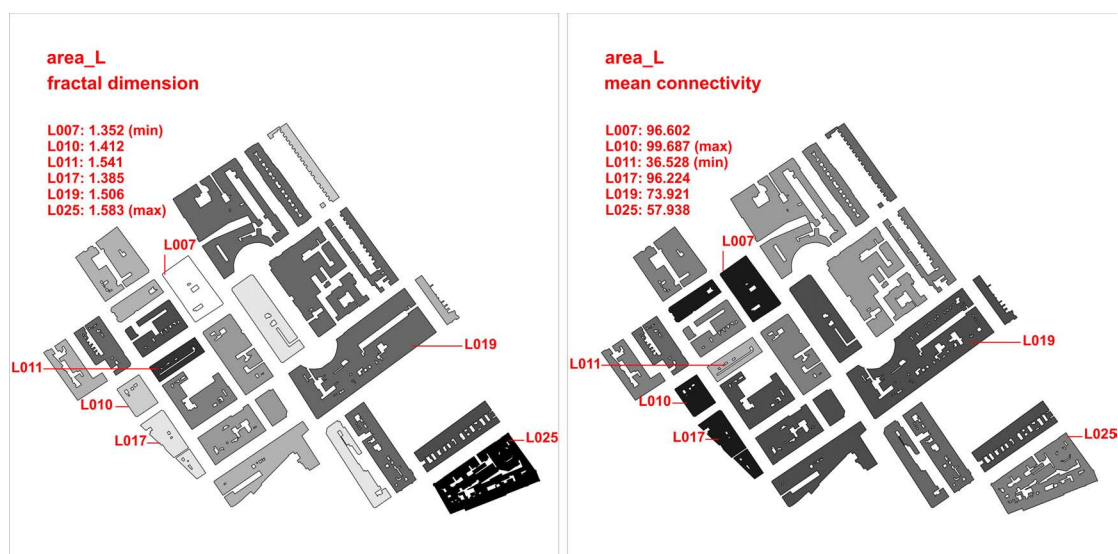


Figure 20. Comparison between fractal dimension and mean connectivity values within each area.  
Extreme values (numbered blocks) often coincide in variable relations.

Some relation of these quantities with scalar measures referring to total area, ratio of built space, number and total perimeter of open spaces was observed. In many cases a combination of low fractal dimension, high connectivity, high ratio of built space and low total area and perimeter of voids appeared. However, this might derive from the limitations imposed by small building plots rather than reveal an intrinsic relation between these quantities, since small plots only allow for few and small regularly shaped openings in order to maximise exploitable built area.

The PCA classification of the axial graph spectra was shown to distinguish as highly differentiated plans with high values of total area, perimeter and number of open spaces. High correlation was noticed between the principal components and measurements regarding numbers of built and open spaces (Figure 21). These measures are all scalar, related to the size and geometry of space rather than topological relations. This might derive from the fact that larger plans, incorporating greater numbers of distinct elements, have the possibility of more diverse configurations than smaller ones (Steadman, 1998), exhibiting thus a wider range of differentiation, or it might just mean that the spectra of the axial graphs are more affected by global metric transformation than local topological relations.

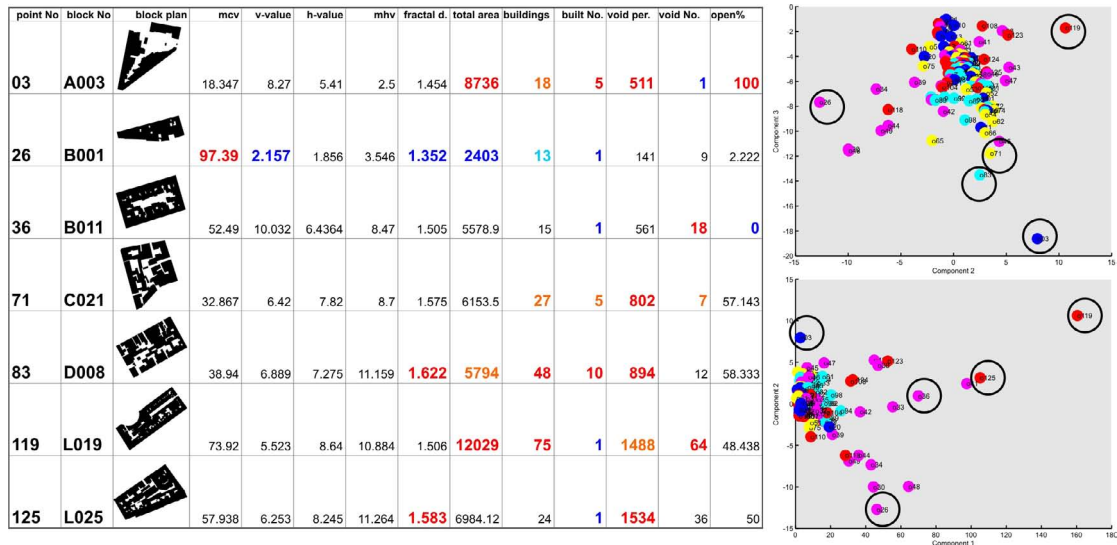


Figure 21. Spectral analysis and scalar attributes.

Outliers in the plots deriving from the principal component analysis of axial graph spectra (circled, right) present repetitively extreme values in scalar attributes (left).

The consistency of the measurements was also validated by comparing the values corresponding to plans that present visual similarities (Figure 22).

A number of comparisons demonstrated that similar plans have analogous values in most of the quantities, observation that supports the consistency of the methods implemented for the measurements.

block No	block plan	mcv	v-value	h-value	mhv	fractal d.	total area	built ratio
A003		18.35	8.275	5.405	2.5	1.454	8735.56	0.59
A007		16.77	8.137	5.848	4.5454	1.447	5983.55	0.71
C018		28.4455	10.77	4.91	2.943	1.427	3478.17	0.69
A004		33.47	12.2	9.295	8.333	1.378	1833.6	0.93
A009		33.38	12.5	4.165	3.846	1.381	1468.15	0.938
A025		46.91	12.05	7.534	10.837	1.375	1020.78	0.917

Figure 22. Similar values for visually similar plans

#### 4.1.2. Neighbourhood scale

For each quantity measured, the values of the blocks from different areas were compared amongst them. In all cases the ranges of values corresponding to the various neighbourhoods overlapped. This showed that the distinct character of each area cannot be directly connected to single measurements. However, differences in the distribution and range of values could reflect some general characteristics. In this framework, the values of each area were sorted from low to high and plotted into graphs.

**a. Fractal dimension**

In the case of fractal dimension, the ordered graphs distinguished clearly between neighbourhoods (Figure 23).

The differences might be too small to categorise the neighbourhoods, however the general ranking correlates with the visual impression from the local maps.

The relatively lower general ranking and limit of complexity in the modern areas might be related to their limited historical span, to their massive construction during the building boom of the '50-'60 and to consistency in building regulations and techniques from the time of their construction up to now. On the other hand, the higher limit of complexity in the older areas could be reflecting the gradual and perpetual processes that forged them throughout the centuries. Especially area C, in the core of the historic centre of Athens, presents not only the highest maximum value of fractal dimension, but also the widest range of variations. This is possibly due to the copresence of elements from all historical phases, from early antiquity until now, and to the intensively deformed street grid that leads to more variable block shapes (Steadman, 1998), both characteristics deriving from the historical depth of the area.

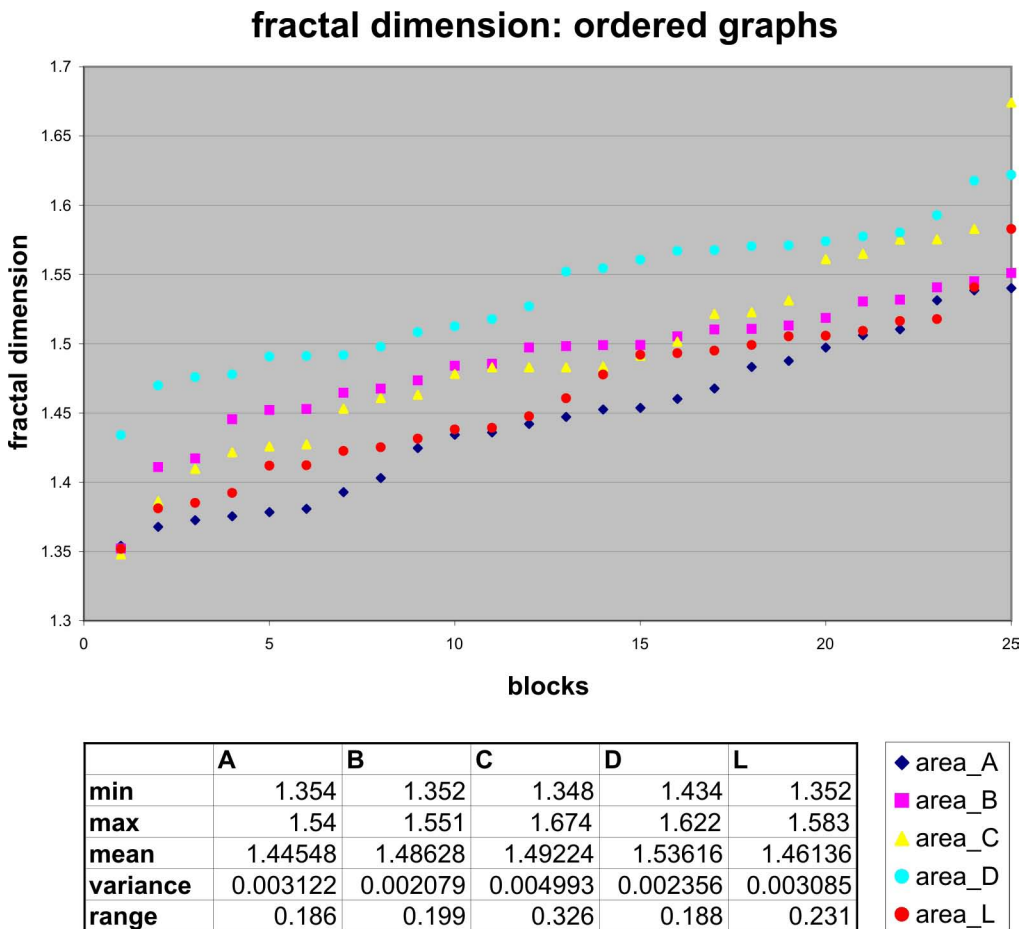


Figure 23. Fractal dimension: ordered graphs and total values for each area



## b. Connectivity

The ordered graphs of mean connectivity values (m<sub>cv</sub>) show exactly the same overall ranking as fractal dimension for the areas within Athens (Figure 24). London has clearly higher connectivity than all the areas of Athens, reflecting greater regularity in the shapes of open spaces, deriving possibly from a more organised, all-encompassing design and building process.

Mean horizontal differentiation (m<sub>hv</sub>), v-value and h-value produced a different ranking (Figure 24), possibly related to higher degrees of differentiation (high v- and h-values) combined with smooth changes in visibility (high m<sub>hv</sub>) for the older areas of Athens in contrast to more repetitive and regular configurations in the modern neighbourhoods.

According to these observations, it could be said that fractal dimension and mean connectivity converge towards ranking the different areas in terms of global complexity and fragmentation, whereas m<sub>hv</sub>, v-value and h-value converge towards distinguishing between areas according to local differentiation and rhythm.

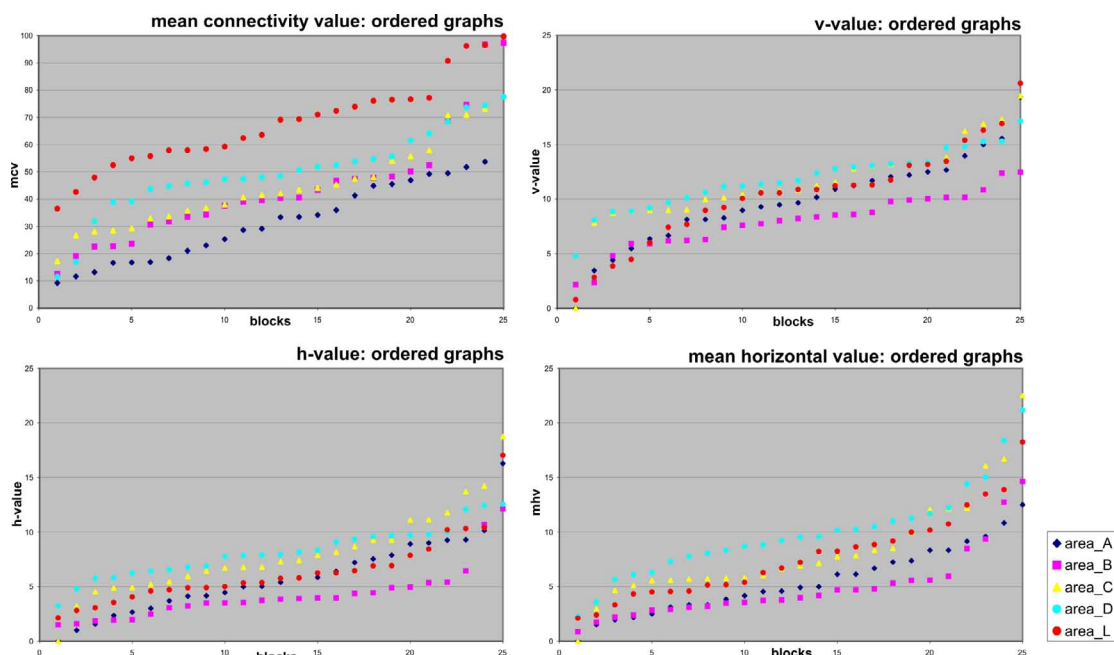


Figure 24. Connectivity: ordered graphs of the various connectivity values for each area

## c. Scalar attributes of open spaces

Values concerning the characteristics of open spaces reveal that, in Athens, although the older areas have few open spaces, they actually exhibit a more open character, allowing their yards to be visible from public space (Figure 25). On the contrary, the two modern areas have isolated openings, mainly serving the purpose of light-wells. Large open spaces in area A correspond to empty sites rather than courtyards. These differences reflect

historical changes in the social role of open space, namely the shift from open space as a locus for social encounters to open space as building infrastructure. The London area reflects a different lifestyle, having many small open spaces, divided almost equally into enclosed yards and street-facing openings, mainly light-shafts.

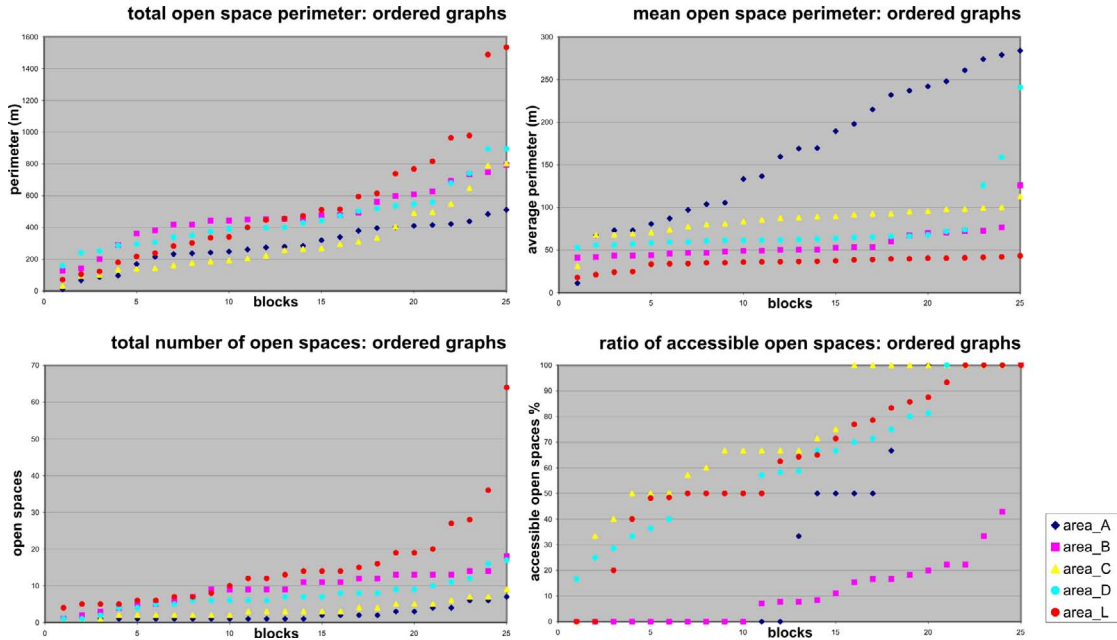


Figure 25. Attributes of open spaces

Ordered graphs of various measurements regarding open spaces of the building blocks for each area (top)

Typical open spaces (bottom):

area A: central residual void, area B: the balcony is the only private open space visible from the street, area C: visible courtyards, area D: occasionally visible courtyards, area L: typical “cours anglaise”



The above observations show that, although each single measurement is not sufficient for differentiating between the neighbourhoods or comparing blocks, the relative distribution of values was shown to have captured particularities of the areas that are usually not considered as directly related to spatial attributes, such as historical depth and social practices.

## **4.2. Pairs of quantities**

Quantities corresponding to different categories of attributes (scalar, geometric, topological) were combined in pairs in order to illustrate complementary features inherent in the plans. Additionally, quantities that in the previous level of analysis were shown to be related to each other were also paired up.

These pairs of quantities were plotted together in scatter graphs, through which both the relation between the quantities themselves and general tendencies within different neighbourhoods were investigated. In most cases the overall impression was rather mixed, with groups of points corresponding to plans from different areas overlapping. However, when considering each area as a unity, differences in the slopes of the regression lines that best describe the points of each neighbourhood revealed differences in the overall behaviour of the distinct sets.

### **4.2.1. Individual plan scale**

The relation between different values in the case of individual blocks derived from the analysis of extreme values in individual quantities that was discussed above.

### **4.2.2. Neighbourhood scale**

#### **a. Connectivity graphs**

As observed through the ordered graphs, mcv exhibits a similar overall distribution to that of fractal dimension and different from that of mhv, v- and h-values.

By plotting mean connectivity against v-values, h-values and mhv respectively, an interesting pattern emerged through positive correlation of values in all areas of Athens and negative for London, showing opposite trends for the two cities at a global scale (Figure 26).

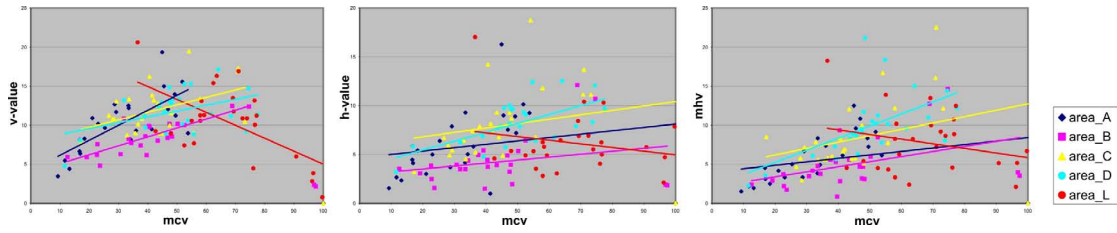


Figure 26. Connectivity scatter-plots: Opposite tendencies between Athens and London

This fundamental difference might reflect the different processes that have prevailed in the formation of the two cities.

In Athens, urban construction has been mobilised locally and is characterised by bottom-up processes. The building blocks have not been designed as a whole but are the result of independent, uncoordinated local actions. Open spaces as they appear in the plans were formed from the aggregation of residual areas (Philippidis, 1990) and thus their overall shapes are differentiated and unequally distributed.

In London, the equal distribution of similar open spaces is often the result of global processes. Many blocks were designed and built as a whole, showing consistency in their layout.

Although the consistent behaviour of the areas of Athens shows some homogeneity, when each neighbourhood was observed individually, some different trends were captured, revealing fluctuations in the degree of correlation between the measured attributes according to local particularities.

Mhv, v- and h-values correlate well amongst them in all cases (Figure 27), showing that in all areas, highly differentiated open spaces present arrhythmic, smooth changes in connectivity. This high correlation might signify that the descriptions given by the three quantities possibly overlap, making the consideration of all redundant for the representation of the plans.

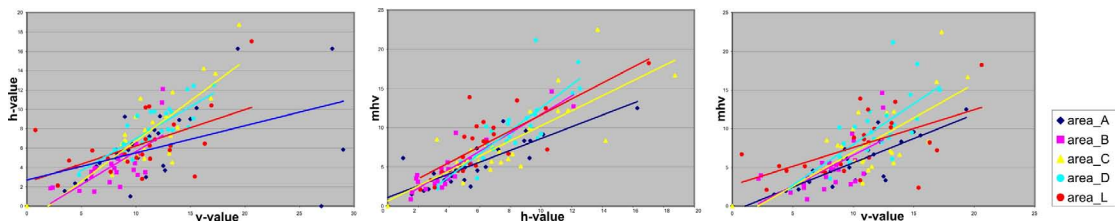


Figure 27. Correlation between h-, v- and mh- connectivity values.

H- v- values correlation=0.76, h- mh- values correlation=0.82 and v- mh- values correlation=0.7

**b. Geometrical - topological quantities**  
**Fractal dimension - connectivity graphs**

The ordered graphs revealed similar overall distributions for fractal dimension and mean connectivity values. However, by plotting these quantities together, it was observed that they exhibit slightly opposite trends of development (Figure 28, top left). In most cases, higher fractal dimension corresponded to lower connectivity values and vice versa, since both quantities are associated to fragmentation but in an inversed proportional relation.

The plots of fractal dimension against v-, h- and mh- values revealed some diversions (Figure 28, top right, bottom), reflecting local particularities regarding differentiations in the relation between rhythm, scale and topological associations of subshapes.

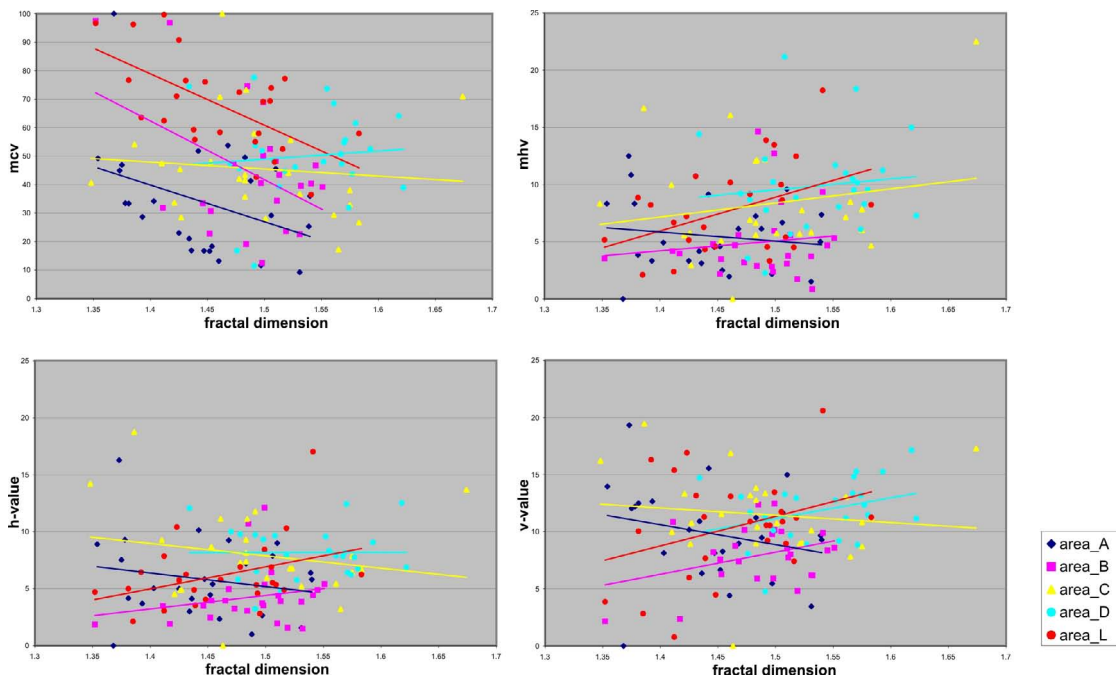


Figure 28. Relation between fractal dimension and the various connectivity values

**c. Geometrical-scalar quantities**  
**Fractal dimension - normalised height variance graph**

The relation of differentiation in the horizontal and vertical plane, reflected in the plan and elevations respectively, was illustrated through the comparison between fractal dimension and height variance (Figure 29 left).

Fractal dimension accounts for the fluctuations of the overall contour, as seen in plan, and height variance reflects oscillations along the skyline. By plotting these quantities together, various relations were revealed, prevailingly related to the proportion of low, older building

within higher, modern constructions. These concern only the areas within Athens, since, as aforementioned, information regarding building heights was not made available in the case of London.

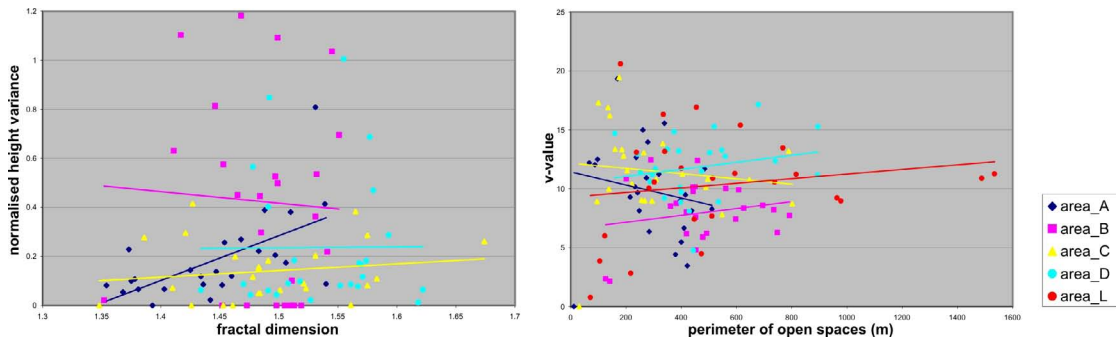


Figure 29.

#### d. Scalar-topological quantities

##### Number and perimeter of open spaces - connectivity values

The graphs representing the relation between the number and perimeter of open spaces against connectivity values  $m_{cv}$ ,  $m_{hv}$ ,  $v$ - and  $h$ - values all exhibit an overall triangular distribution (Figure 29 right, Table II). This shows that in cases with fewer openings, and thus generally shorter total perimeter, the range of variation in all connectivity values is greater. As more open spaces aggregate in the same block, connectivity values converge towards the mean. It could be claimed that as a general trend, higher numbers and total perimeters of openings have a stabilising effect on visibility and its rates of change both at a global and at a local scale.

Between the areas of Athens different trends account again for local characteristics, such as connected courtyards in the older areas in contrast to isolated light-wells in the modern blocks.

These and similar observations, deriving from the various measurements and their relational comparison, revealed that the combination of different quantities in pairs might not be sufficient for the distinction between neighbourhoods or for the description of their particular character, but general trends that reflect specific relations between spatial attributes can be studied. These relations characterise each area as a heterogeneous but indiscernible whole and represent intrinsic tendencies associated with abstract expressions of spatial identity.

This level of analysis, where each area is uniquely defined through the specific set of blocks constituting it, does not allow the classification of unlabelled examples. It reckons each area

through a complete, finite set of given elements and attempts to reveal if and to what degree quantifiable attributes of specific singularities reflect the law that governs the whole set, the whole series of variations (Deleuze, 2005) that constitutes the neighbourhood, or the city.

The system of identifications and differentiations that was structured through the comparative analysis of single or pairs of quantifiable spatial attributes is totally self-referential and relational. All observations are meaningful within the specific context of given singularities and their finite interrelations and any generalisations can only be based on the assumption of universality of specific attributes (Steadman, 1998).

In order to view this system of relations within a wider context, a more global structure should be formed, within which the character of each singularity, as reflected in the values given by the measurements, and its location within the system would be uniquely related. In this system, unlabeled singularities would be identified according to their absolute location within the structure.

### **4.3. Set of quantities**

#### **Principal component analysis**

In this framework, it was attempted to combine all measured attributes of the blocks in a high-dimensional structure, where each block would be represented as a uniquely defined point. The representation of such a structure was made possible through the implementation of principal component analysis. It should be noted that even though in the high-dimensional structure each block is uniquely represented, independently from the other blocks, in the reduced feature space the location of each point depends on the composition of the set.

Since the data provided for Athens was more complete than in the case of London, it was decided to analyse both Athens independently, based on the complete set of measures, and in combination with London, using reduced data.

By plotting all measurements regarding the four areas of Athens and projecting them on the two principal components, a clear distinction between areas was observed (Figure 30). Apart from some exceptions, there was a division between older and modern areas.

Although the points corresponding to areas C and D were scattered upon one half of the plot, areas A and B were separated into two clusters. Points that might appear misclassified correspond in almost all cases to blocks ambiguously located at the boundaries of their neighbourhood (Figure 30, bottom).

Particularly, in the case of blocks from area C that appear to cluster clearly with area A, it was noted that they are subject to building regulations standing for modern areas (Figure 30, top right). This might signify that the PCA classified correctly blocks that were erroneously considered as belonging to a specific neighbourhood.

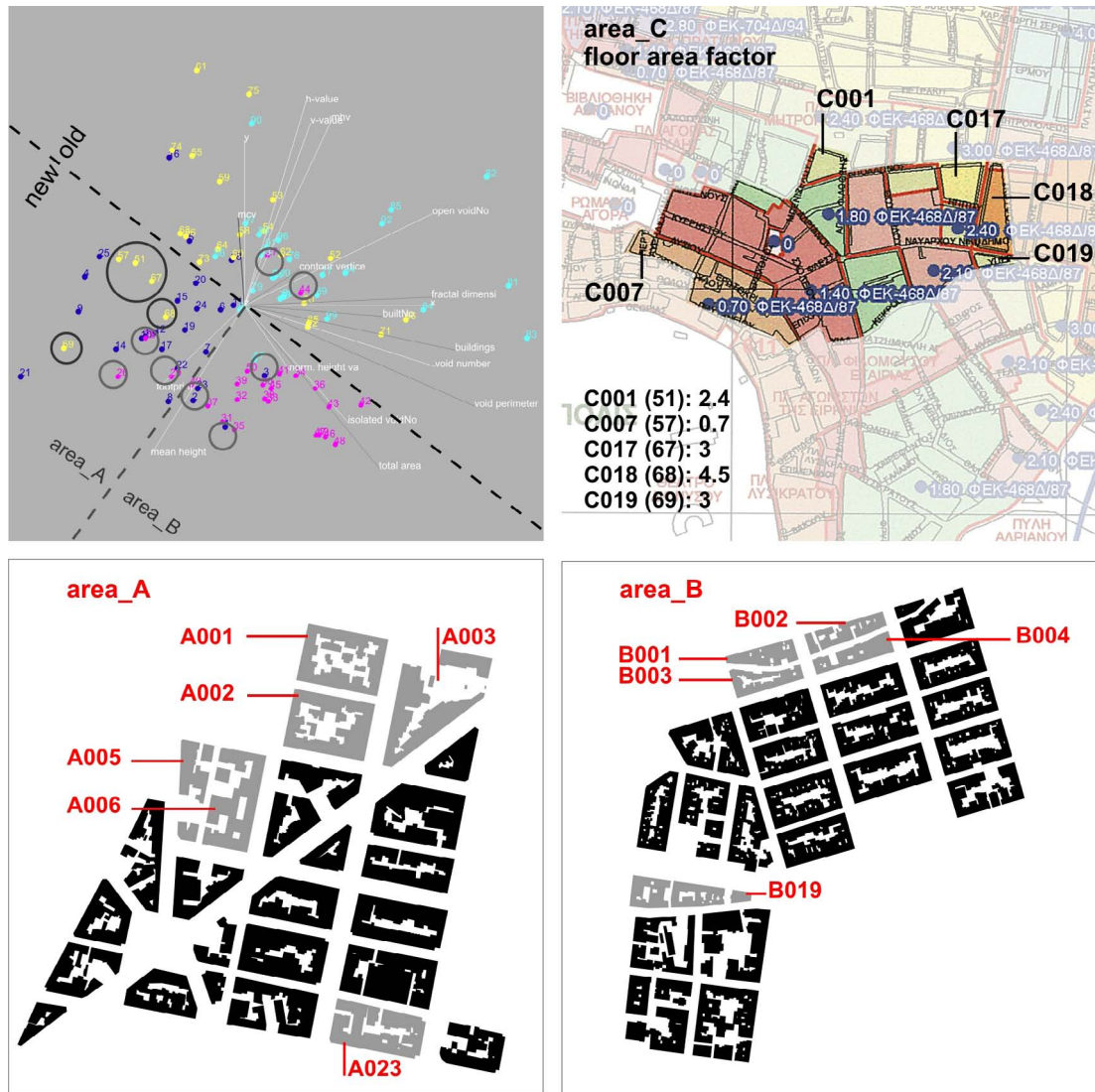


Figure 30. PCA classification for the areas of Athens.  
Clustering of different neighbourhoods (top left) and misclassified blocks (numbered).

However, the introduction of the data regarding the area of London altered the interrelations within the system, resulting to a redistribution of the points representing the blocks (Figure 31). When plotting the system against three principal components, this redistribution led to the formation of two composite clusters with some overlap between them. The first cluster incorporated areas A, C and D, whereas the second cluster consisted of areas B and L. The introduction of London simultaneously intensified the differentiation of area B and the internal attractive forces within the rest of Athens, reflecting the comparative nature of relations. The new distribution indicates that, on one hand, differences between areas A, C and D were weaker than the overall differentiation from London and on the other hand similarities between area B and London were more intense than similarities within the city of Athens.

The formation of two clusters might reflect the different processes that generated the areas in each. Of course these processes are specific to the unique circumstances characterising each locus, but they could be very generally distinguished into prevalingly global or mainly local. In this framework, the cluster consisting of areas B and L could be claimed to be characterised by global forces of formation whereas the cluster including the rest of the areas could be related to local actions.

It is true that neighbourhood B is the most thoroughly designed area of the Athenian sample, having been a privileged bourgeois location since the nineteenth century. This top-down process of formation might abstractly relate area B to London, where global decisions seem to have prevailed over local actions of spatial administration and control.

On the contrary, the other three areas were grown out of local actions and initiatives, through the conflict and equilibration of personal interests and small scale revendications. Even in the case of area A, which was massively rebuilt during the construction boom, the forces of schematisation were largely localised, with the main driving force of construction being private investment (Philippidis, 1990, Karydis, 2006).

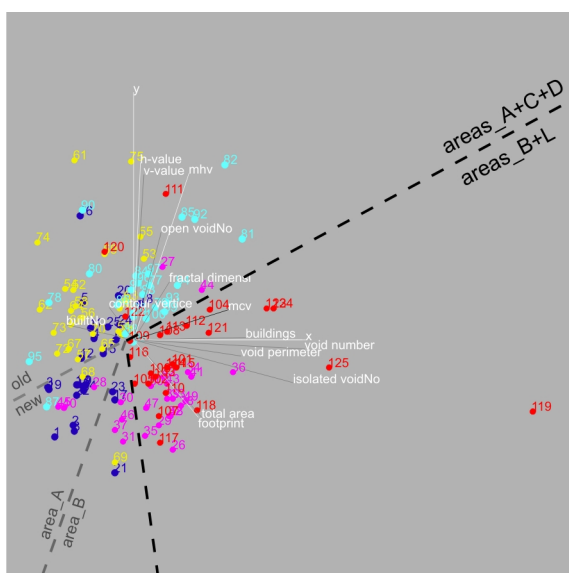


Figure 31. PCA classification of the whole dataset

Because of the alteration of interrelations between the blocks according to the composition of the dataset and considering the unequal proportion of data concerning the two cities, the area of London was compared with each area of Athens separately. In accordance to the overall plot, area B presented the least differentiation. However, despite the overlap, a general tendency of the blocks belonging to the same area to cluster was observed (Figure 32b). The distinction between clusters was clearer in the plots of the rest of the Athenian neighbourhoods against the London sample and consistency was noticed in the misclassified blocks from London (Figure 32a, c, d). The repetitive misclassification of the same blocks might indicate that, given the particularities of the specific sample and the



measurements used, these blocks presented more differentiation from the rest of the sample they belong to than from each of the other samples. It is indicative that these blocks don't belong to the misclassified cases in the comparison between areas B and L.

Based on these observations, it could be claimed that, given wide enough amounts and variance of information on quantifiable spatial attributes, it is possible to distinguish between spatial unities based on their degrees of identification and differentiation. The relative distances between points representing blocks account for the degree of variability, with similar blocks naturally falling closer together and highly differentiated cases being plotted far apart.

From the quantitative description of disconnected singularities, patterns of attraction and repulsion emerged that reflect both the unity and continuity of local identity, as it is formed through locally contiguous heterogeneous particularities, and the translocal relations between spatially discontinuous elements.

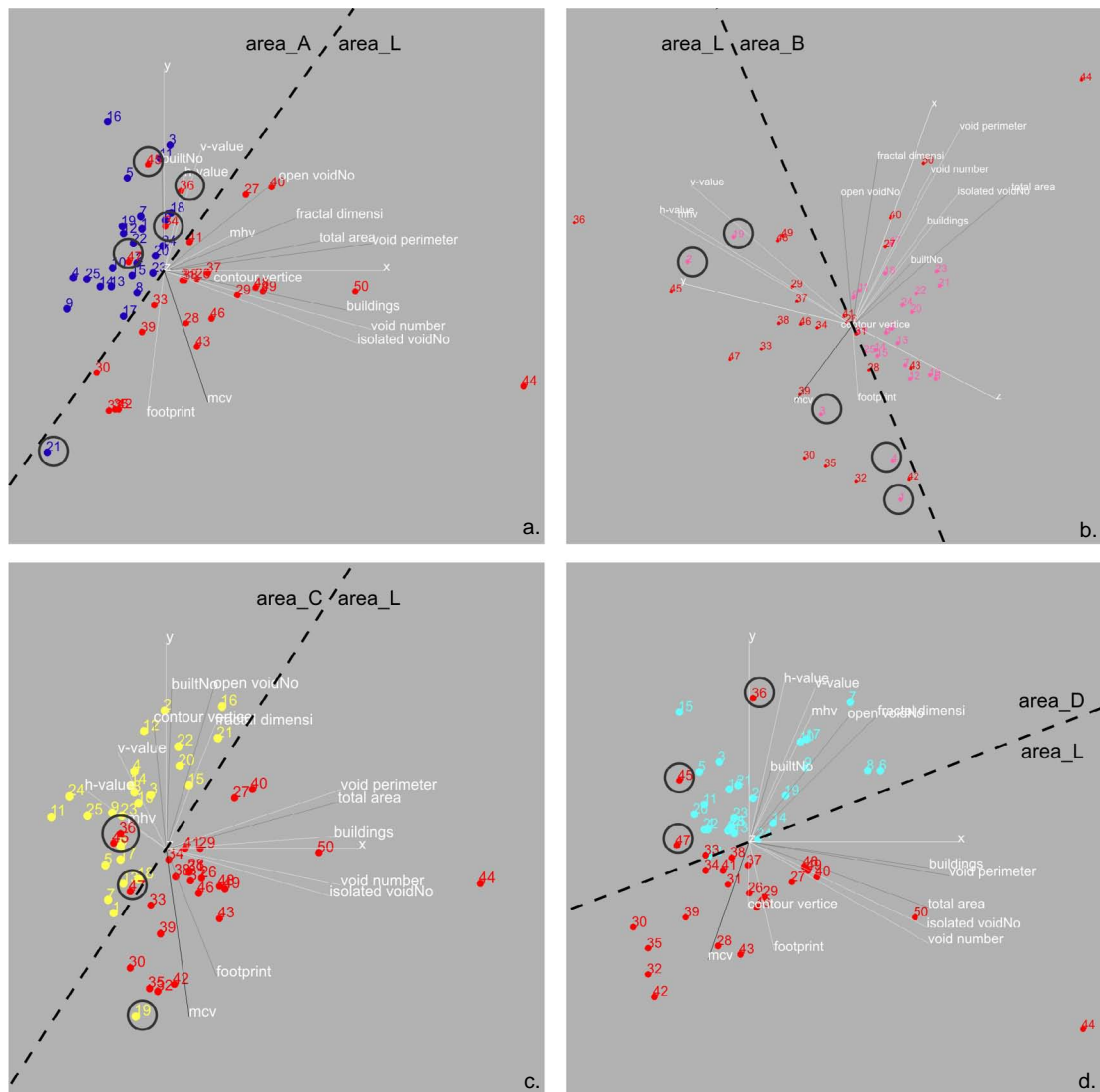


Figure 32. PCA of the area in London and each of the areas in Athens



## 5. Discussion

Through the combination of different methods of shape and spatial analysis it was attempted to examine patterns of distribution and interrelation between various quantifiable attributes inherent in spatial representations, in order to illustrate complex relations of identification and differentiation between spatial unities.

These methods were selected based on their different approaches to processes of spatial experience and were shown to complement each other in the description of spatial configurations and their interrelations, since they reflect related but distinct aspects of layouts, regarding scalar, geometrical and topological attributes. However, constant high correlation between specific quantities might reflect some redundancy in the measurements.

The examination of each quantity individually, led to the conclusion that even though a single measurement might be insufficient for the description of space and spatial interrelations, when applied to a labelled population, the range and distribution of values can reveal general relations between sets of spatial unities. It also revealed relations and correspondences between the quantities themselves, indicating the convergence of results deriving from different methods.

These interrelations were examined in more detail through the scatter graphs of pairs of quantities. The overall degree of correlation between the quantities represented by the two axes indicated the general character of their association. The examination of patterns produced by the clustering or dispersal of points corresponding to block plans belonging to the same neighbourhood and of differences in the slopes of the regression lines best describing these points, revealed comparable general tendencies within each neighbourhood, illustrating degrees of differentiation or accordance.

The overall structure of these convergences and divergences between different areas, based on degrees of identification and differentiation between individual blocks along all measured quantities, was approached through the three-dimensional representation of the high-dimensional plotting of all measurements.

All three different scales of analysis have shown that the measurement of quantifiable spatial attributes, as they are expressed through plan representations, might lead to the detection of degrees of differentiation between spatial unities that account for local particularities not directly related to the specific quantity. Such particularities regard the historical layering of construction periods coexisting in each area, elements connected to social practices such as the role of private open space as a locus for social interaction, the particular social, historical and political circumstances that formulated processes of construction, leading to the prevalence of global or local forces or the local and translocal propagation of spatial models related to social identity.

It could thus be claimed that configurational features manifest in plan representations, that by their own only partially reflect elements relevant to spatial identity, when used for the quantification and comparison between a population of plans, they can be used as indexes of relations that expand over the confined significance of the feature per se. It is not the measured attributes that reveal elements of spatial identity, but the way in which this identity has shaped and is reflected in the specific spatial configurations exhibiting the features under measurement.

However, the comparison between plans according to quantifiable spatial attributes can only account for relative degrees of differentiation in an abstract, quantitative manner and further interpretation of these relations requires specific domain knowledge.

According to this observation, the analysis of a population of plans according to quantifiable spatial attributes would result to an abstract illustration of the structure of attractive and repulsive forces between individual plans, in terms of degrees of identification and differentiation.

At the first two levels of analysis, where quantities were examined individually or in pairs, the plans were labelled. In this case, general tendencies within the neighbourhoods were viewed as resultants of the internal forces within predefined sets of plans and relations between these resultants illustrated the relations amongst the corresponding neighbourhoods. At this level, local forces prevailed over translocal relations as each area was defined as a discrete unity and as such compared to other unities.

At the third level of analysis, where all quantities were considered simultaneously, the blocks were unlabelled and the structure of the field of forces emerged from the innate relations of every plan with every other. The fact that plans corresponding to the same areas naturally clustered together indicated that, as a general trend, local forces of identification indeed prevailed over transpatial (Hillier and Hanson, 1984) attractions. However, the effect of transpatial relations was also manifest, driving individual plans to cluster with blocks from different physical locations. The presence of transpatial relations was intensified with the introduction of the plans from London in the system that shifted the whole relational structure in an unpredictable way, fortifying simultaneously local attractions within three areas of Athens and transpatial attractions between the fourth area of Athens and London.

This reveals the relative nature of the system, proving that it is highly self-referential and thus accounts as an index of degrees of differentiation between a specific set of plans rather than an objective general measure. Any generalisation of conclusions might thus be disputable.

## **6. Conclusion**

The combination between different methods of shape and spatial analysis enabled the quantification of a range of spatial attributes regarding scalar, geometrical and topological features inherent in plans of urban blocks. The analysis of the resulting values at different levels of observation led to the gradual structuration of a system of forces reflecting spatial and transpatial relations according to degrees of identification and differentiation between spatial unities.

This system, accounting for the distribution of non-discursive spatial characteristics related to the perception of space, could be viewed as an abstract map of intensities through which spatial identity is experienced. Spatial identity cannot be explicitly described through quantifiable spatial attributes as represented in plans, but its continuity, indivisibility and heterogeneity can be abstractly perceived through the field of forces constantly rearranging the singularities from which it emerges.

The investigation of the correspondence between closely related groups of plans and the relevant values and distributions in specific measures could possibly lead to the extraction of general rules that could inform design processes in the direction of reproducing elements of spatial identity independently from the repetition of specific morphological, configurational and technical characteristics. Spatial identity could thus be preserved through space and time detached from the replication of established configurations and architectural styles.

## **Appendix I**

### **1. Sources**

Various data about the building blocks was collected from different sources. It was sought that all data sources be associated to official institutions.

#### **a. Athens**

Maps regarding building regulations, available only for the sample from Athens, were obtained by the Department of Urban Planning of the Municipality of Athens (Διεύθυνση Πολεοδομίας Δήμου Αθηναίων).

Maps illustrating the existing situation in Athens were granted from the archive of the Laboratory of Geographical Systems of Information (Εργαστήριο Γεωγραφικών Συστημάτων Πληροφοριών) of the Department of Urban and Regional Planning of the School of Architecture at the National Technical University of Athens.

Land values of the blocks, used for the selection of the areas, were extracted from “Tables of objective Values” for defined urban zones (Πίνακες Τιμών Αντικειμενικών Αξιών), published by the Ministry of Economy and Economics of Greece (Υπουργείο Οικονομίας και Οικονομικών, Γενική Διεύθυνση Δημόσιας Περιουσίας και Εθνικών Κληροδοτημάτων, Διεύθυνση Τεχνικών Υπηρεσιών και Στέγασης, Τμήμα Αντικειμενικού Προσδιορισμού Φορολογητέας Αξίας Ακινήτων).

#### **b. London**

All data concerning London was extracted by maps available through EDINA, the JISC (Joint Information System Committee) national academic data centre, based at the University of Edinburgh.

Aerial photographs of both cities were captured using Google Earth.

## 2. Details about methods of measurements and specifications for the present implementation

In this section, further details about the methods of measurement implemented in the present analysis and resulting quantities are given, together with specifications regarding adjustments and developments that were carried out in order to address the particular requirements of the specific implementation.

### 2.1. Conventional methods of Urbanism

A first set of measurements were derived from typical urban analysis maps. These can be distinguished into quantities that refer to attributes accounting for building regulations and measures that represent the existing situation.

#### 2.1.a. Quantities related to building regulations

The quantities that describe building regulations are the following:

- Limit of maximum height, given in meters and number of stories.
- Limit of maximum ratio of built and open area given as a percentage to the surface of the building plot. This ratio, in the case of Athens, is set to 70% for all areas, but 100% is not rare for constructions preceding chronologically the application of the specific regulation.
- Limit of maximum total floor area factor given as the ratio of total floor area to site area.

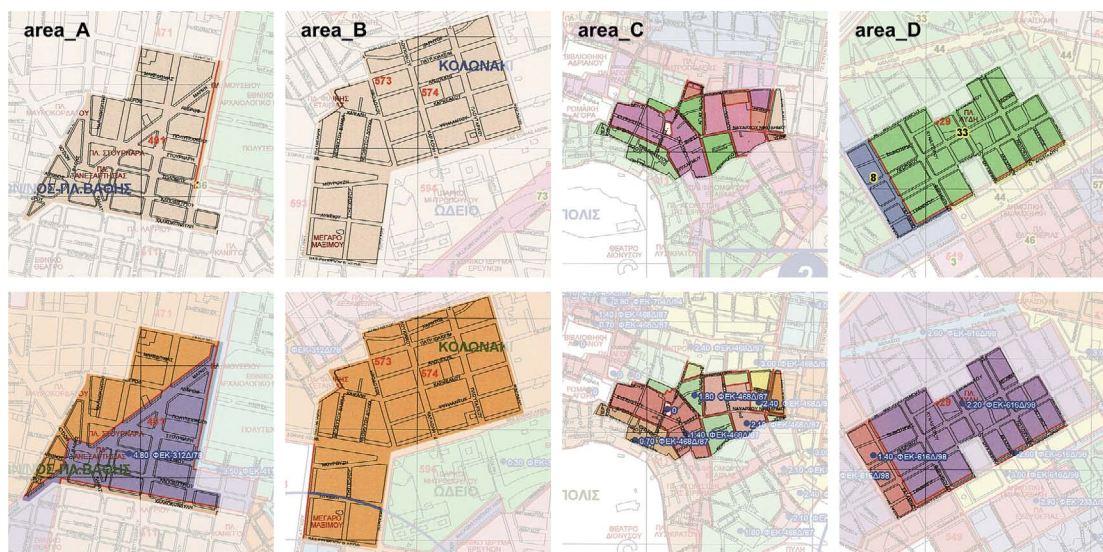


Figure 33. Regulations in the areas of Athens (source: Department of Urban Planning of the Municipality of Athens)  
Maximum heights (top) and maximum floor area factor (bottom)

The values related to building regulations are not necessarily informative about the existing situation, since in most areas the majority of buildings were built before the implementation of the latest updated regulations ('73, '80), but at some extent they reveal the official view of or desirable perspective for the particular areas, being thus an indicator of their perceived character and intended future transformations.

Nevertheless, in the case of the protected area C, building regulations in general correspond to the existing situation, as they were formulated based on it and in the view of preserving it.

### 2.1.b. Quantities describing the existing situation

A second category of measurements, widely used in established urban analysis methods, describes the existing situation and regards quantitative attributes of the blocks.

- Existing heights (only for Athens) were given for every plot in storey numbers. From these, mean storey number and height variance were measured for each block.
- Total area and actual ratio of built and open area were derived from the topographical map. The map also provided evidence about the shapes and general layout of the blocks.



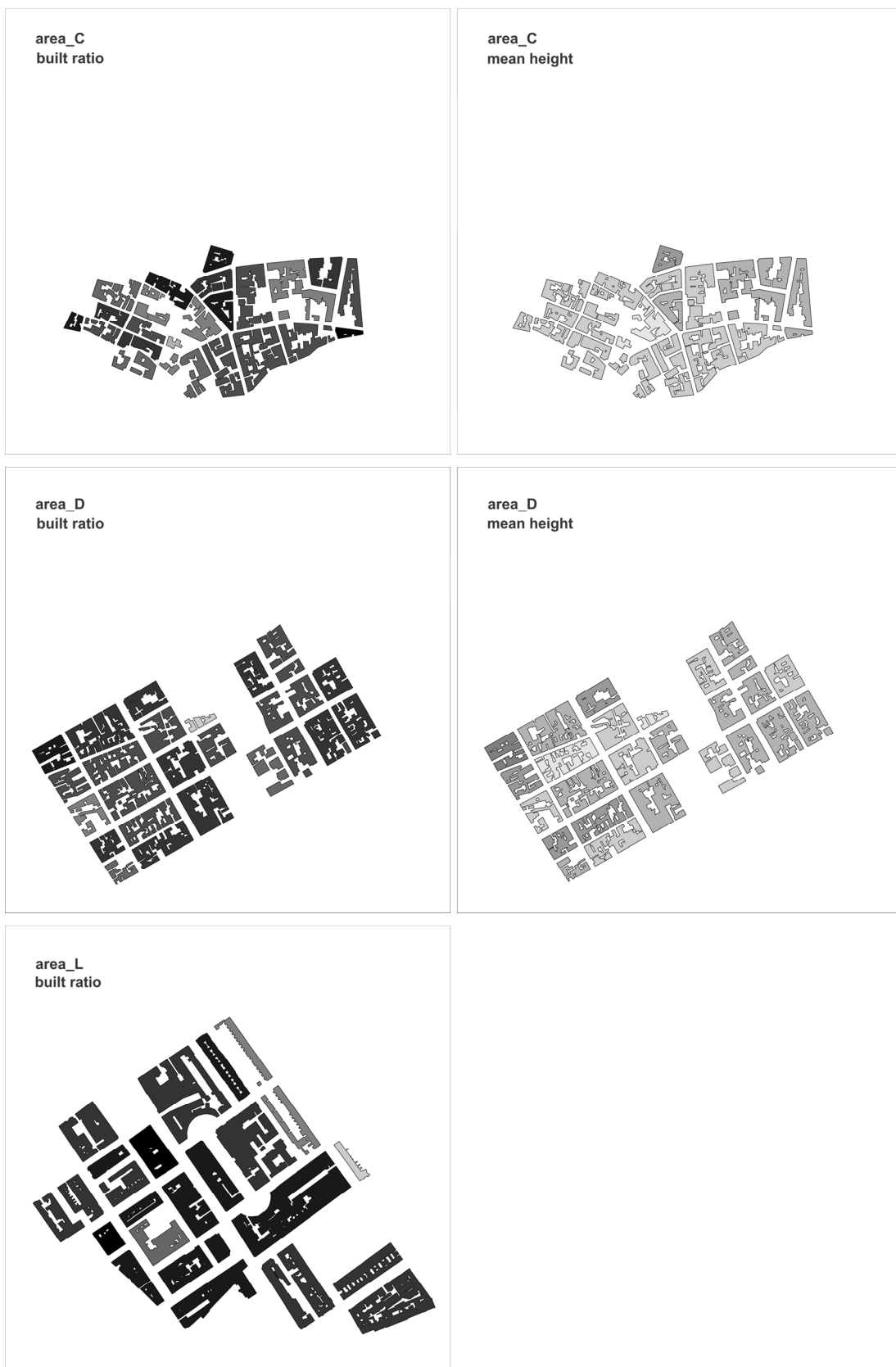


Figure 34. Existing situation  
Ratio of built surface (left) and mean height in numbers of levels (right)

## 2.2. Classification by principal components analysis using axial graph spectra

Axial maps were generated for all spaces constituting each block, both built and open, using Depthmap software. A zone of open space around the outer contour of the blocks was considered as belonging to them, in order to capture differences between blocks with totally built perimeter and blocks whose open spaces are visible from the street (Figure 10). First “all-line maps” were generated, including all lines that may be drawn through the open space of the plan by connecting two convex corners, one convex and one reflex corner such that the line can be extended through open space past the reflex corner, or two reflex corners such that the line can be extended through open space past both of them (Turner, 2004). These were then reduced into “fewest line maps (subsets)” by keeping the minimum number of lines that complete all topological loops and fully observe the whole system (Turner, 2004). For each reduced axial map a connectivity matrix was produced, depicting intersections between all couples of lines in the axial map. In other words, the axial maps were transcribed into graphs (Hillier and Hanson, 1984, p.93) and those into connectivity matrices. According to Hanna “for any graph with a set of nodes  $V$  and a set of edges  $E$ , the most straightforward way of representing the graph in matrix form is to use the adjacency matrix  $A$ , a  $|V| \times |V|$  matrix defined by  $A(i,j) = 1$  if  $(i,j) \in E$  or 0 otherwise” (Hanna, 2007a, p.4).

In the framework of the specific implementation, lines of the axial map were considered to intersect themselves, or nodes of the axial graph to be self-connected, since, according to Hanna (2007a), the assumption of not self-connected nodes, that is  $diag(A) = 0$  for the adjacency matrix, would effectively remove nodes which have no other connections from the graph entirely.

The matrices corresponding to different spaces constituting each block were combined into a single matrix, accounting for the connectivity of the whole block. These matrices were used for the generation of the spectrum, or ordered set of eigenvalues, of the graphs representing each block. “This spectrum is useful as a representation of the graph because it is invariant under all permutations of the original matrix, and therefore identical for all isomorphic graphs” (Hanna, 2007a, p.4).

In this way, a high dimensional feature vector was produced, that enabled the plotting of each block as a single point in high dimensional space with each value in the spectrum on a different axis.

According to Hanna (2007a), the spectra of axial graphs were seen to capture both local and global patterns of spatial arrangement, since local changes of configurational patterns affect both the values in the spectrum and their distribution. Furthermore, the spectra of various graphs “constitute a reliable metric of plans, in that similar plans have spectral vectors that fall close together in a high dimensional space, while very different plans fall farther apart” (Hanna, 2007a, p.12).



After the spectra of all block plans were calculated, principal component analysis (PCA) depicted the three dimensions in which the whole data set was more likely to vary. These dimensions, the principal components, correspond to the eigenvectors with the highest eigenvalues and were used for the plotting of the data set in a three dimensional space. The process by which PCA determined the principal components can be understood geometrically "if we picture the data points  $x_1, x_2, \dots, x_n$  as forming a  $d$ -dimensional, hyperellipsoidally shaped cloud. Then the eigenvectors of the scatter matrix are the principal axes of that hyperellipsoid. PCA reduces the dimensionality of feature space by restricting attention to those directions along which the scatter of the cloud is greatest" (Duda et al, 2001, p.117).

Thus, reduction of dimensionality was succeeded, preserving the most essential features of the data set. According to Hanna, "the dimensions of this new feature space are strictly computational, and are meaningful only in a statistical sense, rather than in the sense that they could be easily described" (Hanna, 2006, p.8).

Nevertheless, the relative distance between the plotted data points in the reduced feature space is an index of similarity and differentiation. In this view, this method was implemented in the case of the building block plans in order to capture intensities of relations rather than compare explicitly specified spatial attributes.

## **2.3. Fractal dimension measurement through box-counting method**

### **2.3.1. Range of fractal dimension**

In the case of fractals that extend in two dimensions, the fractal dimension is a float between one, the Euclidian dimension of the line, and two, the Euclidian dimension of the surface.

### **2.3.2. Self-similarity and self-affinity**

As mentioned, the most significant fractal characteristic of architectural structures is self-similarity.

The term *self-similarity*, when referring to architectural or other non-mathematical fractal structures, signifies *self-affinity*, since self-similarity induces precise regularity in scalar transformations. “Any structure is self-similar if it has undergone a transformation in which the proportions of the structure have all been modified by the same scaling factor. (...) If a transformation reduces an object unequally in one or another way, then the transformation is referred to as a self-affine transformation. (...) Self affinity is called statistical self-similarity” (Lorenz, 2002, p.10).

### **2.3.3. The meaning of fractal dimension in an architectural context**

Fractal dimension was used as an indicator of complexity, fragmentation and coexistence of different scales within the plans of the building blocks.

According to Lorenz, “visually the fractal dimension is the expression of the degree of roughness, which means how much texture an object has” (Lorenz, 2002, p.23).

These attributes are directly connected to spatial perception, since they affect the experience of repetition and differentiation. “Fractal geometry is able to describe complex forms, finding out their underlying order and regularity.(...) The fractal dimension is a measurable characteristic of order, with low dimensions near one, and surprise, with higher dimensions up to two” (Lorenz, 2002, pp.55, 50).

### **2.3.4. Box-counting dimension – The algorithm**

The method used in the present analysis for the calculation of fractal dimension counts the Minkowski-Bouligand dimension or packing dimension, more commonly referred to as box-counting dimension.

The box-counting method calculates the changes of the number of boxes of a grid that are needed to cover the structure under measurement as the size of the boxes decreases (Appendix III).

If  $N(\epsilon)$  is the number of boxes of side length  $\epsilon$  required to cover the structure, the box-counting dimension is defined as

$$D_b = \lim_{\epsilon \rightarrow 0} (\log N(\epsilon) / \log (1/\epsilon))$$

Graphically, the box-counting dimension is measured by representing the resulting relation between the cells that contain the structure against the whole grid at each scale through a log-log graph. The gradient of the line represents the fractal dimension of the image.

A simplest calculation, given the fact that the graph is often not linear, takes as total fractal dimension of an image the average of the distinct dimensions given by the comparison between scales. The formula for the calculation of the fractal dimension between two scales is the following:

$$D_b = [\log(N_i) - \log(N_{i-1})] / [\log(1/s_i) - \log(1/s_{i-1})]$$

Where  $N_i$  is the number of boxes in iteration  $i$  that contain part of the structure and  $1/s_i$  is the number of boxes in each row or column of the grid in iteration  $i$  (Figure 16).

### 2.3.5. Restrictions

The implementation of this method entails certain restrictions and difficulties that are related mainly to the facts that the structure under measurement is not fractal in a mathematical sense and that the analysed object is the image of the structure and not the structure itself. Both facts are related to issues of scale and to the amount of detail that can be taken into account. Another series of problems derive from the nature of the method, as the structure is analysed through its relation to a distinct element, the grid.

#### a. Scale

Fractal dimension is scale independent. "If we analyse the structure on different scales, we will always find the same basic elements. Fractal dimension also expresses the connection between these different scales" (Lorenz, 2002, p.23).

However, this is true only for mathematical fractals. Non mathematical fractals can exhibit self-similar characteristics down to a certain scale of detail. Beyond this range of scale the structure is reduced to straight lines and its fractal dimension decreases to one. This threshold sets the lowest limit above which fractal dimension measurement is meaningful. This is true for all methods of measurement. In the case of box counting, this threshold can be easily defined since the image of the fractal structure has a predefined scale that expresses the amount of detail it includes. In other words, the scale of the plan or image

defines the limits within which the measurement can provide information about the fractal dimension of the real object.

This sensitivity to scale renders the method of box-counting affected by the quality and display characteristics of the image, meaning that different linewidths, shadings and positionings can lead to different measurements. The results for the same object vary according to its representation. For example, measuring the same plan we got a value of  $D_b=1,548$  for an image of the contour and a value of  $D_b=1,802$  for a shaded, solid plan (Figure 35).

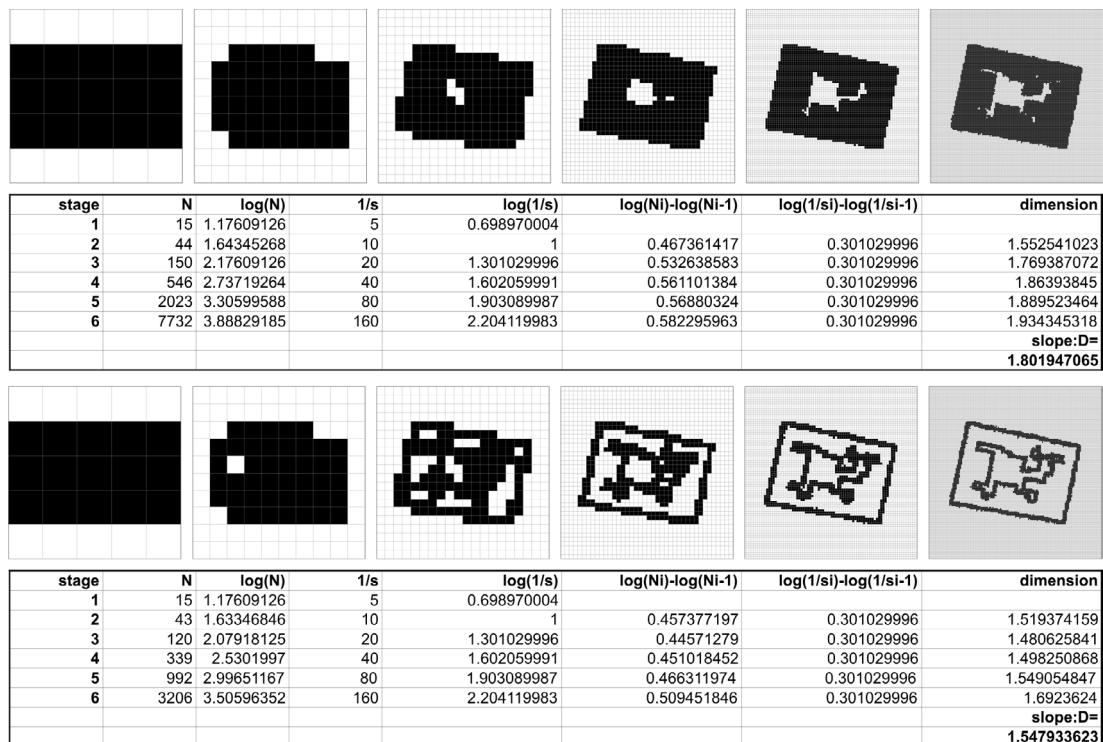


Figure 35. Effect of different rendering of the plan on fractal dimension

In order to have consistency in the measurements throughout the data set, it was sought that all plans be at the same scale, independently from their relative sizes. For each of the two cities, block plans were extracted from the same map in order to assure consistency in the amount of detail, since different maps of the same scale may differ in this aspect. Unfortunately, it was impossible to get exactly the same map for Athens and London, but using maps of the same scale (1:500) at least minimised differentiations in the overall range of values.

All plans were plotted with the same line weight and rendered into images of the same resolution. Because the sizes of the plans varied considerably, two canvas sizes were

selected, of 800\*800 and 1280\*1280 pixels respectively, without altering the scale of the plans. This was managed by increasing or decreasing the area around the plan as required.

Even though the images were carefully prepared, there were cases where pixels of the background were mistaken by the algorithm for parts of the plan and were included in the measurement (e.g. block A019, Table III). Nevertheless, because of the size of the data set and the scarcity of similar errors it is believed that such cases didn't affect the results.

#### **b. Range of box sizes**

The fact that box-counting method is scale dependent is directly related to the comparison between different grid sizes. The selection of the grid scales depends directly on the scale of the image and the detail included in it. There is thus a lowest and upper limit of grid sizes within the range of which measurements are consistent.

"In general too small box-sizes would mean that every difference caused by the preparation for the computer is also taken into consideration. In consequence the thickness of a line of the image should represent the absolute lowest limit size for the box-counting method". If the line is thicker than the finest box scale, "the dimension of this line on the lower scale increases approaching two, though a line is one dimensional in Euclidian sense. This and the fact that below this scale no more detail can be picked up, are the reasons why the lowest box-size should be bigger than the thickness of the lines" (Lorenz, 2002, p.63).

On the other hand, the largest box-size can be as large as the image itself. But this extreme can be eliminated, because the result would always be one.

Usually the largest scale is set to one fourth of the width or height of the image and the size decreases by the factor of two from scale to scale, so that the outer boundary of the grid and the relative position of the boxes remain constant throughout the process.

The box sizes that were selected for the specific implementation derived from the above suggestions and from the preset size of the images, as the divisions, representing numbers of pixels, had to be integers. "If the relative position of the boxes and their size do not change, the number of boxes at the basis is not important, that means that the "white" area around the image can be small or big-the results are the same"(Lorenz, 2002, p.119). In other words, since all plans had the same scale and image resolution, it was the boxes' size that affected the results and not their number.

According to these restrictions the frame of the grid was divided sequentially in boxes of 160, 80, 40, 20, 10 and 5 pixels side-length. These sizes defined the number of boxes in each case. For the smaller blocks, represented in images of 800\*800 pixels, the numbers of subdivisions of the grid in the different iterations were 5, 10,20,40,80 and 160, whereas for

the large plans of 1280\*1280 pixels they were 8,16,32,64,128 and 256. In both cases the grid decreases by the factor of two between iterations (e.g. blocks L018 and L019, Table III).

**c. Starting points and orientation**

Since all images were of the same scale and resolution, if the relative position of the image did not change throughout the different scales, the position and rotation of the plan didn't affect the results considerably. For the same block plan the fractal dimension was measured  $D_b=1,548$  for the actual orientation of the plan and  $D_b=1,558$  for a rotation of the plan so that its main axes be parallel to the grid axes (Figure 36). Even though the values were very similar, it was considered more suitable to keep the real orientation of the plans, as given in the overall city maps.

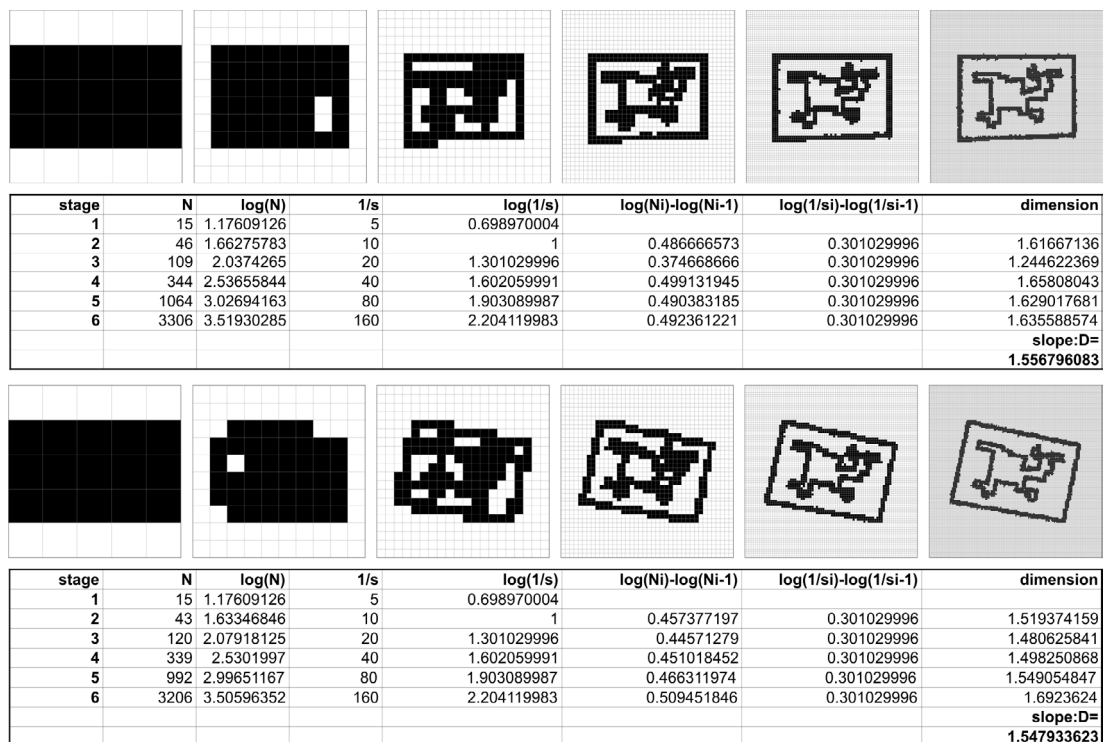


Figure 36. Effect of plan orientation on fractal dimension

## **2.4. Connectivity as a local shape property**

There are several methods for measuring connectivity of spaces, mostly based on visual attributes of space.

Apart from axial maps, that reflect patterns of visual connections within space through the representation of unobstructed sight lines between plan vertices, space syntax also uses isovists and visibility graphs for the examination of spatial properties in relation to visual perception. Isovists, first described by Benedict, are defined as polygon shapes visible from a vantage point in space (Benedict, 1979). Related to these, the visibility graphs display the unobstructed sight lines between points of a grid laid over the plan, capturing thus a synchronous view of visual perception from different locations.

Other methods are based on the calculation of the amount and distribution of visual information available at each point within space, relating visual information to spatial elements regarding corners, edges and surfaces (Peponis et al, 1997) (Figure 2).

As aforementioned, the method used in the framework of the present analysis, introduced and developed by Psarra and Grajewski (2001), measures local characteristics of shape perimeter. The description of shape is thus based purely on the syntactic properties of its perimeter (Psarra and Grajewski, 2001, Psarra, 2003). These local properties refer to the number of connections of each perimeter location to every other, accounting thus for the convexity of space. "By measuring local properties of shapes expressed as a structure of connectivity connections we may begin to understand how simple configurations behave. Furthermore, if we consider shapes as enclosing space, it is interesting to know how local properties of perimeter articulation can account for spatial experience as a sequential process" (Psarra and Grajewski, 2001, p.2).

In other words, this method quantifies the convexity of shapes in terms of distribution of connectivity along the perimeter.

### **2.4.1. Convexity**

The formal mathematical definition of convexity is that no tangent drawn on the perimeter passes through the space at any point (Hillier and Hanson, 1984, p.97). This means that in a convex shape any two points along the perimeter can be joined together by lines that belong entirely to its area, without crossing its boundaries or being outside the shape.

The lines that lie completely within the shape are thus considered as indicators of convexity.

### 2.4.2. The algorithm

Originally, this method has been implemented using a GIS based computer programme. For the present implementation, an algorithm was written in Processing, based on the description of the method (Appendix III).

In order to calculate connectivity, the perimeter of the shape is subdivided into segments of theoretically equal length. In most implemented examples though, the segments are of approximately equal length as the different lengths of edges would only allow exact subdivisions defined by their least common multiple. The user defines the length of the desired subdivision and the algorithm calculates the closest possible subdivision for each edge.

From the subdivisions a complete graph is derived for the shape, where all points subdividing the perimeter are connected to each other. In order to calculate the number of lines that lie within the shape, first the lines that intersect at least one of the edges of the perimeter are depicted by detecting line to line intersection. The total number of connections for a perimeter subdivided by  $n$  points is  $n*(n-1)/2$ . If the number of intersecting lines is subtracted from this total of connections, the remaining lines are the ones that lie completely within or outside the shape. The calculation of the number of lines outside the perimeter is based on the assumption that in order to define the location of a non intersecting line in relation to the shape it is sufficient to determine whether one point on the line lies within or outside the perimeter. The location of a point in relation to a planar shape, indicating whether the point lies within or outside the shape, can be defined by calculating the number of intersections of the perimeter by a projection of the point on the shape. Practically, an infinite line starts at the point under consideration and if the number of its intersections with the perimeter is even, then the point lies outside the perimeter; if it is odd, then the point belongs to the shape. Finally, the number of lines that lie outside the perimeter are subtracted from the non-intersecting lines and the percentage of this new number against the number of total connections is calculated. This quota represents the mean connectivity value for each location on the perimeter of the shape. The average of connectivity values for all perimeter segments gives the mean connectivity value (mcv) for the shape as a whole.

In the case of connections between points belonging to the same edge, these are considered as lines within the shape, since straight edges materialised in space are experienced as continuous elements and don't produce changes in visibility in the way that corners do. Of course, continuous boundaries do affect the way space is perceived, but considering them as obstacles and thus counting them as not laying within the perimeter would result in the impossibility of existence of absolutely convex shapes, expressed by 100% connectivity.



This method has been initially used for the analysis of simple shapes that presented no discontinuities such as wholes or internal sub-shapes and the measurements referred to a single continuous perimeter line (Psarra and Grajewski, 2001). In the first implementation of the method for the measurement of building plans by Psarra and Grajewski, internal separations were omitted in order to simplify the problem. Later, more complex shapes were analysed, including limited discontinuities representing spatial partitions, but combinations of separate shapes haven't been attempted (Figure 37). According to Psarra, "in more complex shapes the quantification of these concepts is not yet properly addressed" (Psarra, 2003, p.1).

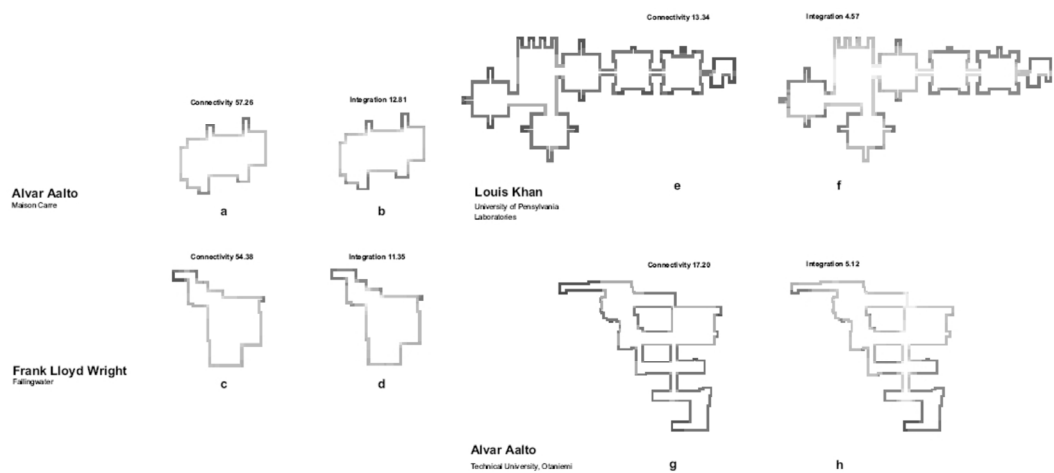


Figure 37. Connectivity measurements of single plans without internal partitions (Psarra, 2003, p.10)

In the case of the building block plans analysed here, each block consists of more than one shapes that might additionally contain secondary shapes within their perimeter and the method had to be expanded in order to encompass the particularities of the shapes under consideration.

The problem of combined measurement of multiple shapes was dealt with by processing each individual perimeter separately and calculating its contribution to the overall configuration based on the relative length of the given perimeter in comparison to the total perimeter length of the shapes constituting the block plan. This method led to a single value for each block and allowed the comparison between blocks as consistent entities.

In the case of composite shapes, where the perimeter under consideration enclosed secondary shapes, the latter were considered as visual obstacles that occlude parts of the perimeter as viewed from certain locations. In this case, the obstructing shape was not measured as part of the perimeter of the surrounding shape, but the connectivity lines that intersected it were considered discontinuous and thus measured as intersecting, non convex lines (Figure 38).

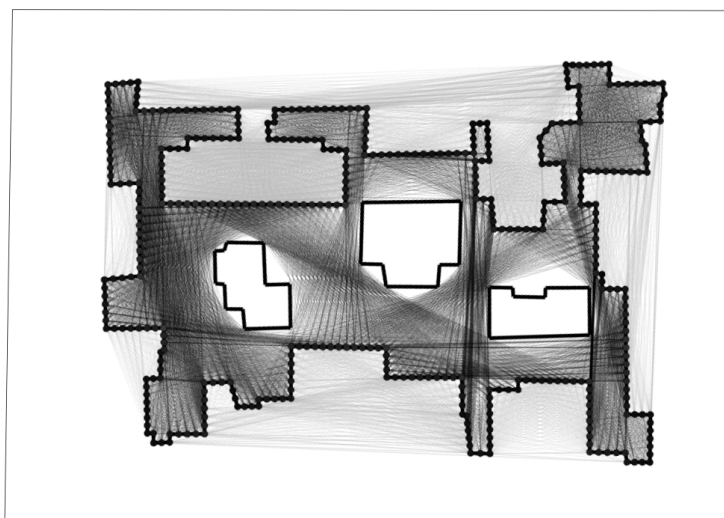


Figure 38. Connectivity of perimeter with internal obstacles  
Example of measurements for block A001

### 2.4.3. Measures

#### a. Global properties

##### a.1. Mean connectivity value (mcv)

The main suggestion is that “each perimeter location has a mean connectivity value (mcv) defined as the percentage of locations it is connected to without crossing a boundary or falling outside the area of the shape” (Psarra and Grajewski, 2001, p.3).

As aforementioned, the calculation of mean connectivity value for the shape as a whole reflects how convex the shape is. Experiments with transformations of simple shapes have shown that metric changes in the proportions of shapes and symmetry seem fundamental as they determine the configurational properties of shapes. It has also been noted that there is a slight increase in the values from symmetric to asymmetric arrangements (Psarra and Grajewski, 2001, pp.4,5) (Figure 18).

These experimental observations support the assumption that mcv is a measure that captures global configurational characteristics of the shape, related to its degree of occlusion and to the relations of the parts to the whole in terms of symmetry and irregularity.

#### b. Local properties

The graphical representation of connectivity values corresponding to each perimeter segment is the basis for further quantifying patterns of information stability and change (Figure 17). These patterns can be studied both in relation to the perimeter as a whole and to the succession of segments along its course.

**b.1. v-value: vertical standard deviation**

The level of differentiation amongst values on the y axis is calculated using standard deviation, a measure that indicates how much on average a set of values differ from the mean value (mcv). Vertical standard deviation, referred to as v-value, stands for the degree of differentiation amongst perimeter locations of a perimeter as a whole. "As the levels of occlusion, generated by reflex angles are strengthened, shapes move away from undifferentiated configurations [and causes v-value to rise]. However, further increase of occlusion creates a large number of locations with much lower and equally distributed connectivity values [causing v-value to decrease]" (Psarra and Grajewski, 2001, p.8).

**b.2. h-value: horizontal standard deviation**

The level of differentiation in the rate of transformation of connectivity values along subsequent perimeter sections is measured by calculating the standard deviation of all distances between subsequent nodes, defined by the points of intersection of the graph curve with the horizontal line of the mean connectivity value. To overcome metric distances in perimeter length we relativise by dividing nodal distances with the total number of perimeter cells (Psarra and Grajewski, 2001, p.8).

H-value captures the rates of change of connectivity values. The smaller the difference amongst all nodal distances is, the more identical the rates of change between subsequent locations of high and lower connectivity values.

The above three measures, proposed by Psarra and Grajewski, "can capture three characteristics in shapes. Mean connectivity value can account for the level of occlusion or break up in a configuration. The higher this value the less occluded the space is. V-value expresses the balance between the parts and the whole. High values represent a configuration in which a dominant shape is balanced against subsidiary shapes attached to it. Finally, h-value stands for the level of repetition or rhythm characterising the linear progression along individual sides. The higher the h-value the less repetitive a pattern is" (Psarra and Grajewski, 2001, p.13).

Two more measurements deriving from this method were proposed in the framework of the present implementation, one regarding the rate of changes in connectivity and the other accounting from permeability of the block from the street.

**c. Mean differentiation rate (mhv)**

This quantity is the analogous of mean connectivity for the other axis and reflects the rate of differentiation for the perimeter as a whole. If h-value represents the differentiation of rates of connectivity changes along the perimeter, mean differentiation along the x axis (mhv) accounts for the pace of these changes.

#### d. Visibility from the street

As aforementioned, this method has been previously used for the analysis of cohesive, continuous spaces in which all edges of the perimeter can be considered to contribute equally to the way they are perceived. In these cases the attributes of the perimeter are relevant to spatial experience because of its property to enclose space. However, in the case of the building blocks, all edges are not equivalent in their influence upon visual perception, since some of them are formed by surfaces of adjacent buildings and others are open to the public realm of the street. It is obvious that edges along the street are more likely to be offered as vantage locations for visual contemplation of these spaces. It was thus attempted to quantify visual accessibility to open spaces of each building block as a whole through the measurement of mean connectivity value for the edges that are open towards the street (Figures 19, 39). This measurement could capture the visual permeability of each block, a feature that was experientially considered as a very important element of differentiation between neighbourhoods in the example of Athens.

Unfortunately, due to time limitations, this quantity was only measured for a part of the dataset and thus couldn't be used for the comparison between the whole set of plans.

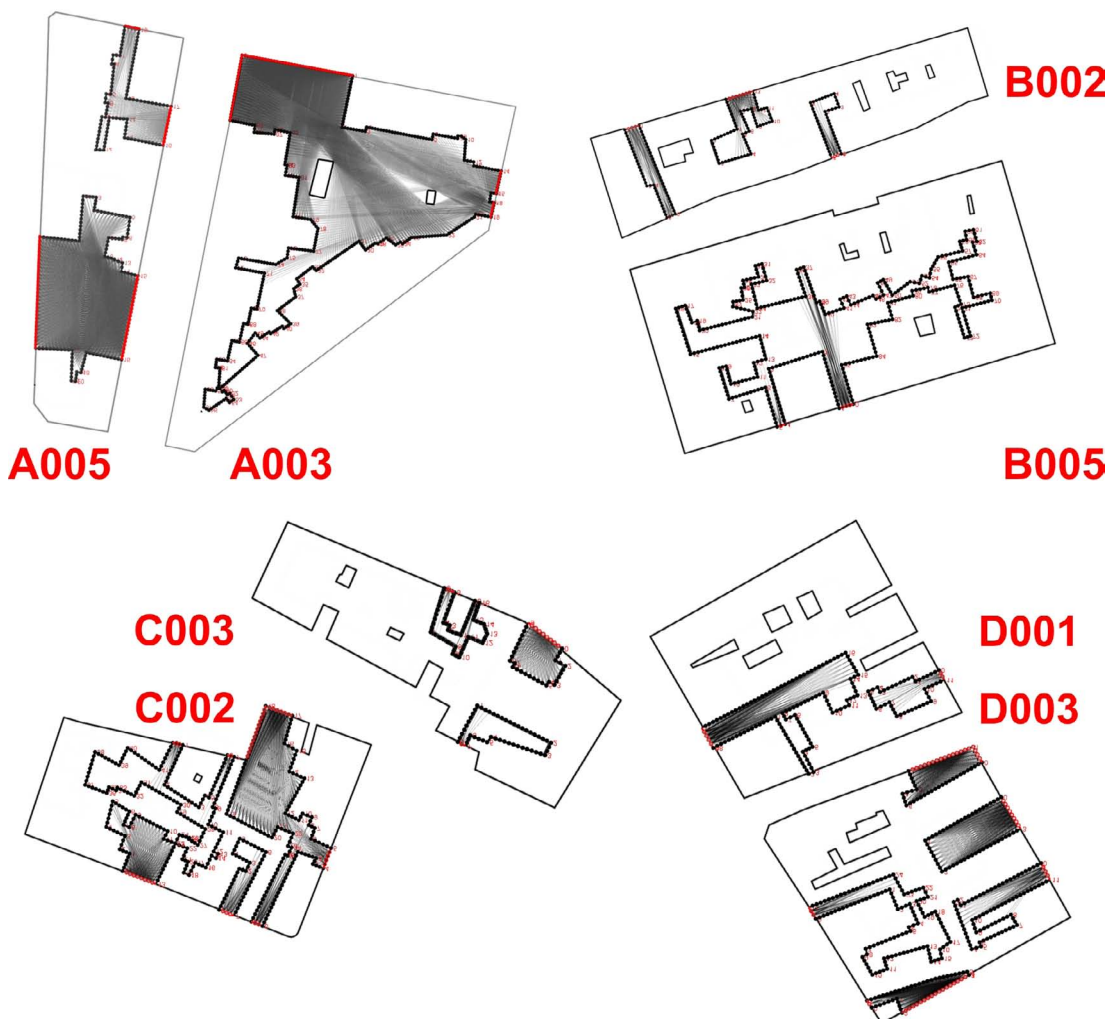


Figure 39. Connectivity in terms of visibility from the street

## Appendix II

### 1. Results

In this section detailed descriptions of the most representative results are given, accompanied by possible interpretations.

#### 1.1. Single quantities

##### 1.1.1. Individual plan scale

###### a. Extreme values

Looking at the highest and lowest values in each neighbourhood and for each quantity, certain correspondences between measurements were revealed. An interpretation of the plans was attempted through the combination between corresponding values.

The following observations can be confirmed through Table I, presenting all measurements for all blocks and significant values for each area.

In area A, blocks A016 and A021 have fractal dimensions that approximate the lowest value for the area, reflecting low self-similarity and low fragmentation. They are constituted by large areas of built and void spaces, distributed without apparent rhythm. These characteristics are captured in their connectivity values, with A021 being totally convex ( $m_{cv}=100$ ,  $v\text{-value}=0$ ,  $h\text{-value}=0$ ) and A016 exhibiting the maximum  $v$ -value and mean differentiation rate ( $m_{hv}$ ) in the area as well as relatively high  $m_{cv}$  and  $h$ -value. The extremely high  $v$ -value accounts for the asymmetric, non rhythmic distribution of sub-areas within the plan and the maximal  $m_{hv}$  reflects stability in connectivity and low fragmentation, all of which were captured by the fractal dimension. A004 appears to also have the highest ratio of built area combined with the smallest total area and the shortest perimeter of open space.

Blocks A001, A012 and A015 have the highest fractal dimensions in the area with A001 being very fragmented, a characteristic which is also reflected in the fact that it has the lowest mean connectivity value, and A012 and A015 exhibiting self-similarity in terms of different scales of meandering. In the case of A001 fragmentation is present in the vertical dimension as well, as it is the block with the highest height variance.

A003, the block with the largest total area and perimeter of open space is an extreme outlier in the PCA classification.

Blocks B001 and B004 combine the lowest fractal dimensions and v-values with the highest mc- values. These values are caused by the random perforation of large built areas by small convex shapes. High mcv is produced by the combination of these small voids, while low fd and v-value reveal stability and lack of rhythm in the plan. B001 combines these characteristics with the highest ratio of built area and the smallest total area, whereas B004 presents the shortest perimeter of open space.

B017 has the highest fd, combined with the lowest ratio of built space, reflecting the fragmentation of built area in the specific block. B010, which also has very high fd, presents the lowest h-value and mhv, due to the high degree of equally distributed meandering of the contour.

C001, C011 and C024 are the blocks with the lowest fd in area C. C011 and C024 are simple configurations of single buildings laid out in a courtyard in an asymmetric, highly differentiated plan, resulting to high v- and h-values. C011 combines the maximum v- and h-values with the lowest ratio of built space. C001 presents the highest mean height, being at the boundary of the protected historic area.

The maximum fd belongs to C012 and C025, two very different configurations. C012 is a fragmented layout with many different scales of meandering, viewed as levels of self-similarity, and minimum mean height. C025 is expressed through a single self-similar contour of built space that defines highly convex, differentiated areas, combined with the smallest total area. These properties are reflected in high mc-, v- and h- values and maximum mhv, caused by high and stable convexity. This combination of high h-value and mhv shows that frequent changes in visibility are not necessarily large or sudden.

C019 is another extreme in the neighbourhood, having a totally convex open space with the shortest perimeter, combined with the maximum ratio of built space. The small area of the plot only allowed for minimum openings of rectangular shapes.

C016 and C021, outliers in the PCA classification, are characterised by maximum number of openings and total area for C016 and maximum perimeter of open spaces for C021.

In area D, the block with the lowest overall measurements is D015, a juxtaposition of buildings along one side of a public square. The simplicity of the building layout in combination with the existence of the square result in the lowest fd, private open space perimeter, ratio of built space and mean height.

On the other hand, D006, D007 and D008 form a group of blocks, clustered in space, that are characterised by high fd, due to their complex self-similar contour. Although these blocks exhibit fragmentation, this is produced almost by a simple meandering contour. D007 has the highest v- and h-values, due to its intense differentiation, combined with minimum height variance. D006 has the maximum total area and number of open spaces whereas D008, also picked by the PCA, has the longest perimeter of open spaces.

L007 and L017, blocks characterised by compact built areas perforated by small convex openings, have the low fd combined with high mcv as a result of the aggregation of partial convex open spaces asymmetrically scattered within robust built spaces. L010, although similar to L007 and L017, presenting the highest mcv, v-value, built ratio and minimum perimeter of open spaces, has a higher fractal dimension, probably due to the more rhythmic configuration of its voids.

L011 exhibits the minimum mean connectivity together with maximum v- and h-values and a high fd, as a result of the unique proportions of its central void. L025, an outlier in the PCA classification, has the maximum fd and perimeter length of open spaces, reflecting the high fragmentation due to many differentiated openings. Another block distinguished by the PCA, L019, combines the maximum total area and number of open spaces.

**b. Axial map spectra**

The analysis based on the axial map spectra of the plans was carried out both for Athens alone and for Athens and London in combination and was compared to each of the other measurements (Figure 40).

In both cases, the first principal component showed high negative correlation with the number of isolated open spaces (-0.847 for Athens and -0.9 for both cities) and total number open spaces (-0.714 for Athens and -0.779 for both cities). The second component in the case of Athens and the third for both cities correlated in opposite ways with the number of built spaces (0.62 and -0.667 respectively).

These correlations agree with the observations based on extreme values (Figures 21, 41) and converge towards the conclusion that the axial graph spectra reflect mostly scalar attributes of spatial configurations.

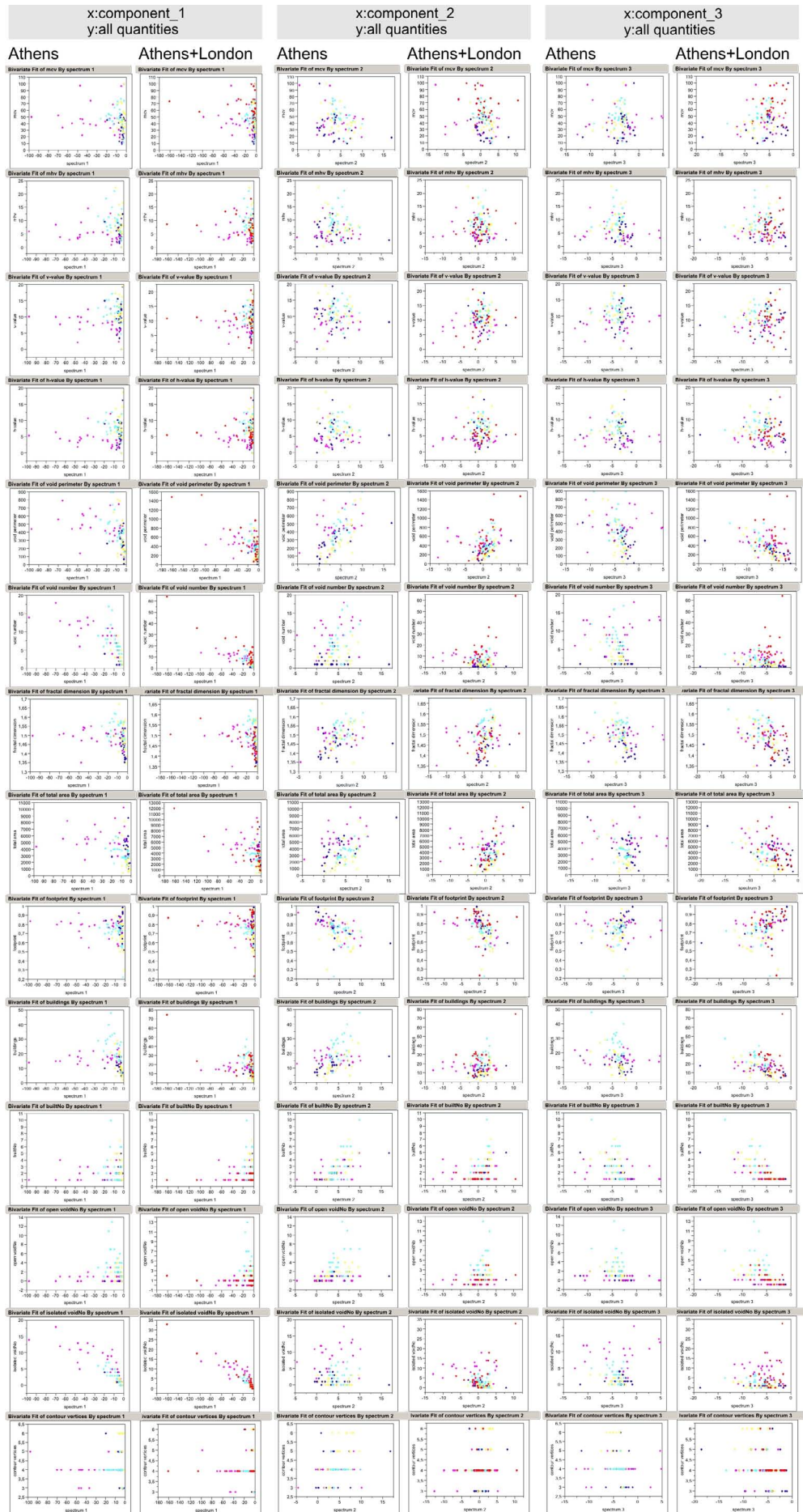
Athens Correlations				Athens+London Correlations			
	spectrum 1	spectrum 2	spectrum 3		spectrum 1	spectrum 2	spectrum 3
mcv	-0,1266	-0,3078	0,0482	mcv	-0,1405	-0,2306	0,2872
mhv	0,0419	-0,0529	-0,0736	mhv	-0,0457	-0,0074	0,0388
v-value	0,1128	0,0613	0,0668	v-value	0,0462	0,1659	0,0523
h-value	0,1385	0,0529	-0,0682	h-value	0,0828	0,0607	-0,0218
void perimeter	-0,3736	0,5321	-0,2771	void perimeter	-0,5809	0,3116	-0,3585
void number	<b>-0,7174</b>	0,1603	-0,0435	void number	<b>-0,7794</b>	0,1614	0,0375
fractal dimension	-0,1490	0,3370	-0,1713	fractal dimension	-0,2001	0,1686	-0,3607
total area	-0,3528	0,4046	-0,2099	total area	-0,4572	0,2060	-0,3976
footprint	-0,1794	-0,4929	0,0884	footprint	-0,1741	-0,3425	0,2945
buildings	-0,1420	0,3739	-0,2557	buildings	-0,3851	0,1889	-0,2523
builtNo	0,0975	<b>0,6232</b>	-0,3930	builtNo	0,1228	0,3057	<b>-0,6674</b>
open voidNo	0,1200	0,3238	-0,1638	open voidNo	0,0829	0,2288	-0,3518
isolated voidNo	<b>-0,8472</b>	-0,0081	0,0447	isolated voidNo	<b>-0,9011</b>	-0,0082	0,0361
contour vertices	0,0669	0,3319	-0,0995	contour vertices	0,0640	0,2012	-0,2449
mean height	-0,2002	-0,2864	0,1360				
norm. height variance	-0,1810	0,0732	0,0080				
land value	-0,4767	-0,0092	-0,0701				
floor area factor	-0,2405	-0,2407	0,1351				

Figure 40. Correlations of the three principal components of the spectral analysis with all quantities

Above: Table of correlation values

Next page: Comparative scatter-graphs of the three principal components of the spectral analysis against all quantities







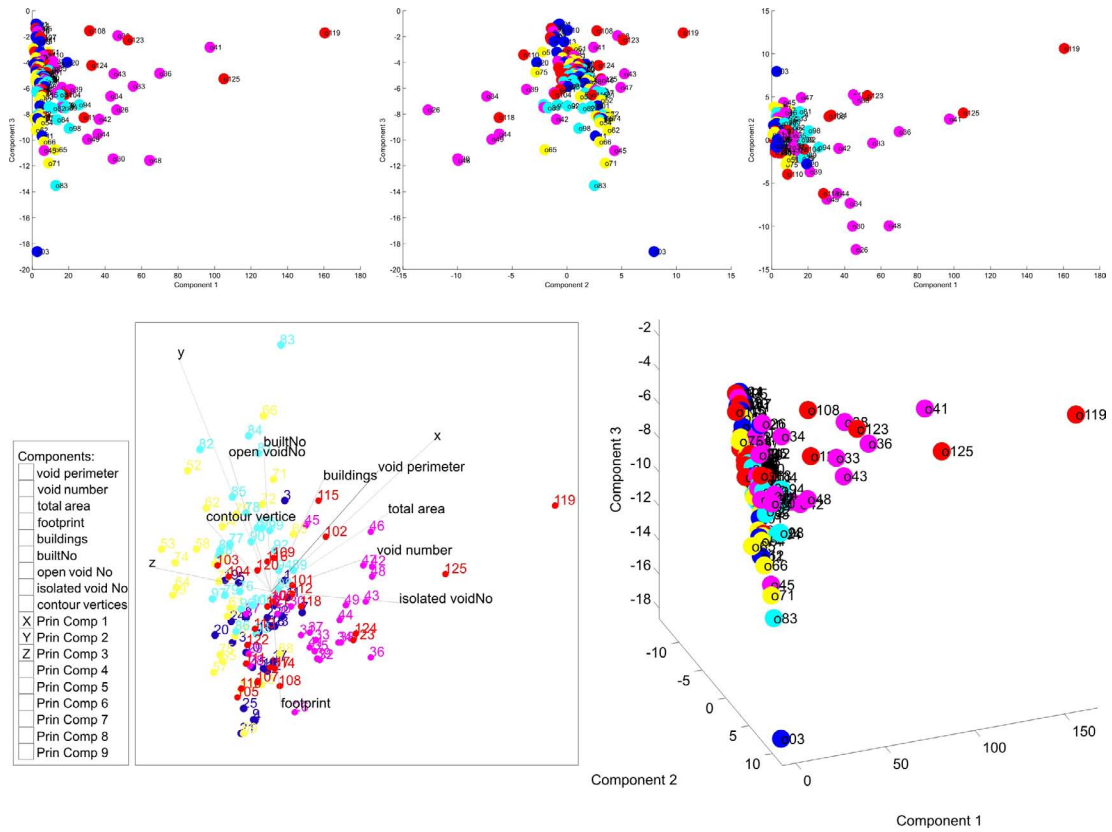


Figure 41. Similarities between spectral analysis (top, bottom right) and principal component analysis of scalar quantities (bottom left)

### c. Correspondence of values of visually similar blocks

The consistency of the measurements was also validated by comparing the values corresponding to plans that present visual similarities (Figures 22, 42).

block No	block plan	mcv	v-value	h-value	mhv	fractal d.	total area	built ratio
A003		18.35	8.275	5.405	2.5	1.454	8735.56	0.59
A007		16.77	8.137	5.848	4.5454	1.447	5983.55	0.71
C018		28.4455	10.77	4.91	2.943	1.427	3478.17	0.69
A004		33.47	12.2	9.295	8.333	1.378	1833.6	0.93
A009		33.38	12.5	4.165	3.846	1.381	1468.15	0.938
A025		46.91	12.05	7.534	10.837	1.375	1020.78	0.917
C017		33.608	13.32	4.52	5.556	1.421	2593.8	0.757
L001		59.28	11.29	4.9	6.28	1.438	4510.36	0.8
A024		49.52	11.23	7.205	7.24	1.483	2882.42	0.768
L012		72.4	10.88	6.918	9.17	1.478	3467.97	0.635
A021		100	0	0	0	1.368	613.45	0.987
C019		100	0	0	0	1.463	590.08	0.967

Figure 42. Similar values for similar plans

### 1.1.2. Neighbourhood scale

#### a. Fractal dimension

The overall change of fractal dimension within all areas is smooth, with only exception the sudden rise towards the maximum value of area C (Figure 23). This general distribution agrees with the ranking given by mean values, according to which area A has the lowest overall value (mean  $fd=1.45$ ), followed by areas B and C (1.49), whereas area D has the highest dimension (1.54). The area of London lies between areas A and B (1.46). The differences might be too small to categorise the neighbourhoods, however the general ranking correlates with the visual impression of the local maps. Area A is expressed through simple layouts and incorporates less variability than the other areas. On the other extreme, area D is the most fragmented and complex area, exhibiting layouts that are often unintelligible for the passer-by.

In terms of extreme values, all areas have very similar bottom limit of fractal dimension (1.35 for areas A, B, C, L and 1.43 for area D), making it a universal measure for the dataset. On the other hand, maximum values vary considerably, with lower values for the two modern areas A and B (1.54, 1.55 respectively), higher values for the older areas C and D (1.67, 1.62) and the area of London in between (1.58).

#### b. Connectivity

The ordered graphs of mean connectivity values (m<sub>cv</sub>) show exactly the same overall ranking for the areas within Athens apart from a sudden rise at the higher extreme for areas B and C (Figure 24). London has clearly higher connectivity than all the areas of Athens. Mean horizontal differentiation (m<sub>hv</sub>), v-value and h-value produced a different ranking, with area B exhibiting the lowest overall values, followed by areas A, C and finally D and London fluctuating between A and C.

#### c. Scalar attributes of open spaces

Mean values concerning the characteristics of open spaces (Figure 25) reveal that, the number and total perimeter of open spaces within each block agree on low values for area A, followed by area C. Higher values correspond to areas D and B. London has considerably higher values in both quantities, possibly due to the numerous and very characteristic “cours anglaises” (typical light-shafts along the façades). However, this ranking does not reflect the openness of the neighbourhoods, since mean values of the ratio of openings accessible from the street show a clear difference between the old and the modern areas, with London closer to area D.

**d. Scalar attributes of blocks**

The examination of building heights and total footprints (Figure 43) reveals low density in the older and high density in the modern neighbourhoods, with lowest values for the historical centre and higher for area A. It should be noted that in areas A and B, footprints exceed the regulations, due to the fact that more buildings were constructed before the juridical decrease of permissible footprint in '73. London exhibits high ratios of built area, identical to area A.

Area C presents the largest variation in terms of total area and more irregular block shapes, due to the distortion of the street grid in the historical centre, whereas area B has the largest blocks and D the most regular ones. London is second highest both in total area and regularity of shapes, fact that could be related to top-down processes of design and construction. It was also observed that in areas D and L sizes were not equally distributed within the corresponding range, but some sizes were repeated, producing groups of equal sizes, corresponding to different preset spans of the street grid.

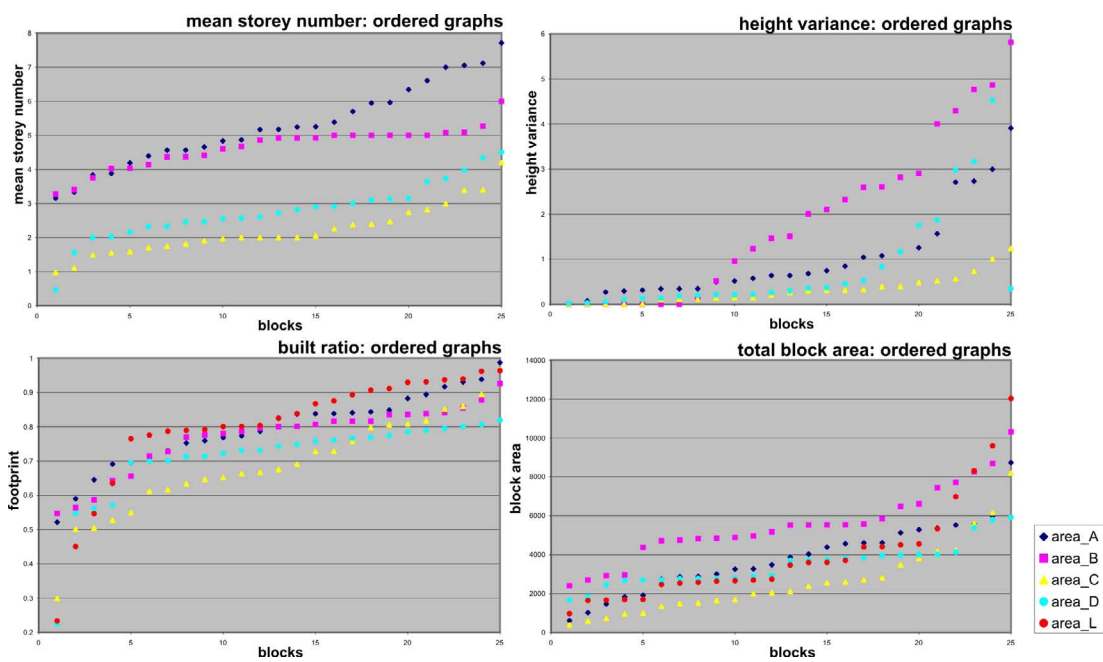


Figure 43. Ordered graphs of metric attributes of blocks

## 1.2. Pairs of quantities

The following observations can be confirmed through Table II, presenting scatter plots and correlation values for all pairs of measurements.

### 1.2.1. Neighbourhood scale

#### a. Connectivity graphs

In all areas of Athens mcv correlated with v-, h- and mh- values (Figure 26), with connectivity rising in parallel with the other values, whereas in London higher mcv values corresponded to lower v-, h- and mh- values. This means that, as a general trend, in Athens, as the open spaces within the blocks become more convex, their connectivity changes smoothly and they exhibit more differentiation by incorporating secondary yards of different sizes and shapes. In London, as voids become more convex, they get more regular or similar to each other.

The main cluster of area A is distributed along a steep regression line, reflecting more intense differentiations in shape combinations as the open spaces get more convex. In area B there is still correlation, but as convexity increases, slightly lower v-values account for the stabilising effect produced by the aggregation of smaller regular voids. Areas C and D exhibit higher v-values, almost independently from changes in connectivity, revealing higher differentiation in all scales of complexity and size.

Mhv, v- and h-values correlate well amongst them in all cases (Figure 27). The overall correlation between v- and h-value is 0.76, between mhv and v-value it is 0.7 and between mhv and h-value correlation is 0.82 (Table II).

#### b. Geometrical-topological quantities

##### Fractal dimension-connectivity graphs

In most cases, higher fractal dimension corresponded to lower connectivity values and vice versa, since both quantities are associated to fragmentation but in a reversed relation (Figure 28). The only exception is the case of area D, where slight rises in fractal dimension were related to more convex spaces. This might reflect the particular configurational characteristic of this area that was already mentioned, regarding the formation of the blocks by the meandering of almost a single contour line. This line might exhibit high self-similarity and simultaneously surround convex open spaces, producing the slight but unusual correlation between the two quantities.

The plots of fractal dimension against v-, h- and mh- values revealed some interesting diversions, reflecting local particularities regarding differentiations in the relation between rhythm, scale and topological relations of subshapes (Figure 28, Table II). For most

neighbourhoods the general trend is identical in the three graphs, with the exception of area C that changes behaviour in the case of mhv.

Areas B, C and L present proportional distribution along both axes, showing positive correlation between fractal dimension and  $v$ -,  $h$ - and  $mh$  values. This means that in these areas, self similarity is connected to differentiation in terms of rhythm, scale and topological relations of subshapes.

Area B exhibits a constant opposite trend, with self similarity being associated to the equalising effect of intense meandering.

Area C flips from positive correlation between fractal dimension and mean differentiation to negative correlation in the other two graphs, reflecting the fact that meandering can lead to frequent but small alterations in visibility without crossing the line of mean connectivity and thus without reducing mhv proportionally to the other measures.

### **c. Geometrical-scalar quantities**

#### **Fractal dimension- normalised height variance graph**

Height variance was calculated as the ratio of different storey numbers distributed within the total area of the block and normalised by dividing by mean storey height.

Area A exhibits correlation between the two measures, reflecting configurations characterised by proportional variations along the horizontal and vertical plane (Figure 29, Table II).

In the plots of areas C and D, regression lines almost parallel to the x axis show independence of the two quantities, as in the older neighbourhoods, low heights entail consistently low height variance and high variation in plan layouts produces large ranges of fractal dimension values.

Area B on the other hand, presents a very slight inversed correlation within very dispersed results. Great dispersion along the axis representing height variance might correspond to the copresence of very homogeneous blocks, consisting of modern buildings with identical heights, and mixed blocks incorporating buildings from different periods. Negative correlation might reflect the fact that blocks consisting of uniquely modern constructions present high fractal dimensions, because of self similarity of the contour of the central residual voids and the perforation of the built body by light-wells, combined with homogeneity in heights which results to low, often zero, height variances.

#### **Number and perimeter of open spaces - fractal dimension**

It was observed that the number and total perimeter of open spaces correlated well ( $c=0.72$ ) (Table II), showing that longer perimeters are due to greater numbers of average sized openings rather than to single large openings. This relation is especially intense in the case of London, probably because of the number of "cours anglaises".

By plotting fractal dimension against these two related quantities (Table II), an expected slight correlation was observed, since all measures are related to fragmentation. This proportional relation was clear in the case of London, with fractal dimension increasing because of further perforation of the built body. However, in Athens this phenomenon was found to be weaker, since fractal dimension here, as shown before, seems to relate more to self-similarity of single contours than to fragmentation.

**d. Scalar-topological quantities**

**Number and perimeter of open spaces - connectivity values**

The graphs representing the relation between the number and perimeter of open spaces against connectivity values  $m_{cv}$ ,  $m_{hv}$ ,  $v$ - and  $h$ - values all exhibit an overall triangular distribution (Figure 29, Table II).

In most of these graphs, the points representing the area of London are largely scattered and usually the boundaries of the triangle are formed prevalingly by this area. This distribution reveals high variation in the degrees of differentiation and regularity in blocks with few openings as opposed to the equalising effect of greater numbers of voids.

### **1.3. Set of quantities**

#### **Principal component analysis**

##### **1.3.1. PCA of all block plans**

###### **a. Athens**

By plotting all measurements regarding the four areas of Athens and projecting them on the two principal components, a clear distinction between areas was observed (Figure 30). Apart from some exceptions, there was a division between older and modern areas, with areas C and D occupying the upper right half of the plot and areas A and B on the lower left half.

Points that might appear misclassified correspond in almost all cases to blocks ambiguously located at the boundaries of their neighbourhood.

Blocks C001, C007, C017, C018 and C019, that appear to cluster clearly with area A, all belong to the boundaries of area C as it was defined. Interestingly, it was noted that all these blocks, apart from C007, are subject to building regulations standing for modern areas. This might signify that the PCA classified correctly blocks that were erroneously considered as belonging to a specific neighbourhood.

Blocks from area B that have been plotted within other areas (B001, B003, B004 and B019 are within the cluster of area A whereas B002 has crossed the line between old and modern areas) also belong to the boundaries of the neighbourhood and are characterised by being adjacent to the only two irregular street-lines of the area.

Finally, blocks A001, A002 and A003 that have been plotted within area B again were shown to belong to the boundaries of area A.

###### **b. Athens and London**

The introduction of the data regarding the area of London altered the interrelations within the system without however altering dramatically the principal components (Figure 44).

Specifically, in the PCA representing only the sample from Athens, from the positions of the vectors of the different quantities it can be observed that the first principal component correlated well with geometrical and scalar quantities, namely fractal dimension, the number of buildings in each block, the perimeter and number of open spaces and the number of accessible open spaces, whereas the second and third components were related to connectivity values. Specifically, the second component correlated with mhv, v- and h – values and the third with mcv.

With the incorporation of the London data in the system, the first component correlated with scalar attributes regarding again the number of buildings and open spaces and the total perimeter of open spaces and the second and third component stayed related to connectivity values in the same manner as in the case of Athens.

This might signify that differentiations both within Athens and between the two cities depend more on geometrical and scalar rather than topological variations. However, the different positioning of the main clusters in the two plots reflects differences in the significance of the various quantities. In the case of the two cities, the fact that the two main clusters are separated along the x-axis demonstrates the prevalence of the first component, and thus of scalar quantities, not only in the differentiation of the whole dataset but also in the clustering of different areas. In the case of Athens, although the same quantities are the most significant in the differentiation of the whole, the almost horizontal separation of the two major clusters and the gap separating area B from the old neighbourhoods demonstrate the importance of the second component in the clustering of the blocks in areas.

This difference between the two plots might suggest that differentiations between areas within Athens are mostly due to topological variations, whereas the differences between the two cities depend predominantly on scalar characteristics of spatial configurations.

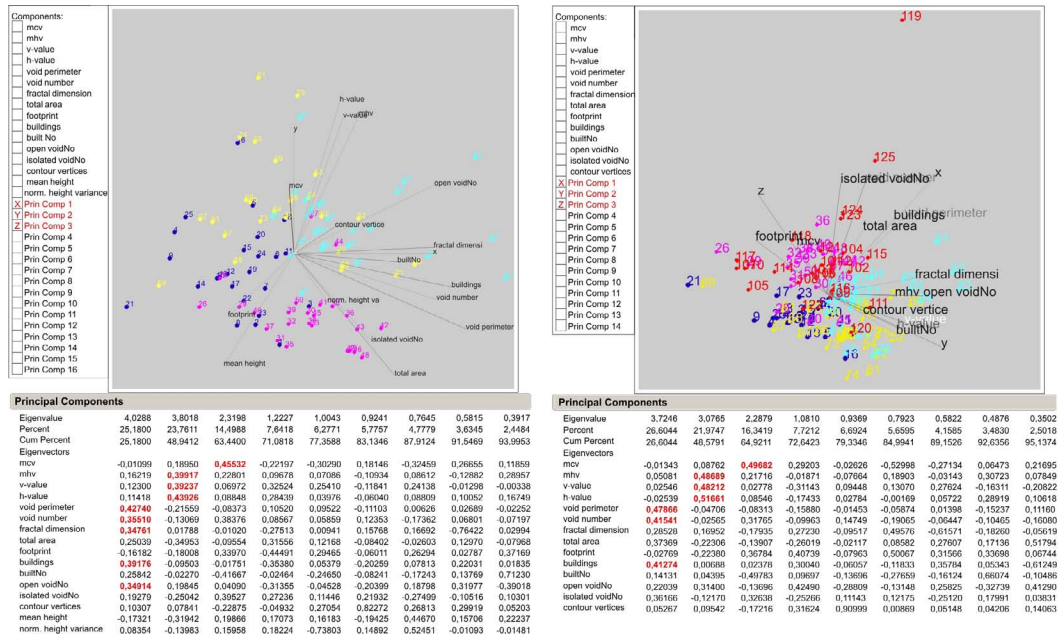


Figure 44. Principal components. Athens (left), Athens and London (right).



### 1.3.2. Neighbourhood scale Comparison between the two cities

When area B was plotted with the sample from London, blocks B001, B002, B003, B004 and B019 were misclassified again, verifying their intense differentiation from the rest of the sample from area B (Figure 32b).

Area A was better distinguished from area L when plotted against principal components 1 and 3 rather than 1 and 2 (Figure 45), showing that in the specific case, the attributes along which the blocks of the two neighbourhoods are better distributed are not the most significant in distinguishing between them. In all other cases these attributes coincided, reflecting the intensity of intrinsic attractions within each area.

In the comparison between the London sample and areas A, C and D (Figure 32a, c, d) blocks L011, L020 and L022 were repetitively misclassified, reflecting possibly the intense differentiation of these blocks from the rest of the London area and their constant attraction to Athens. Blocks A021 and C019, both detected as extreme cases in previous levels of analysis, were misclassified, supporting the convergence between different methods of measurement.

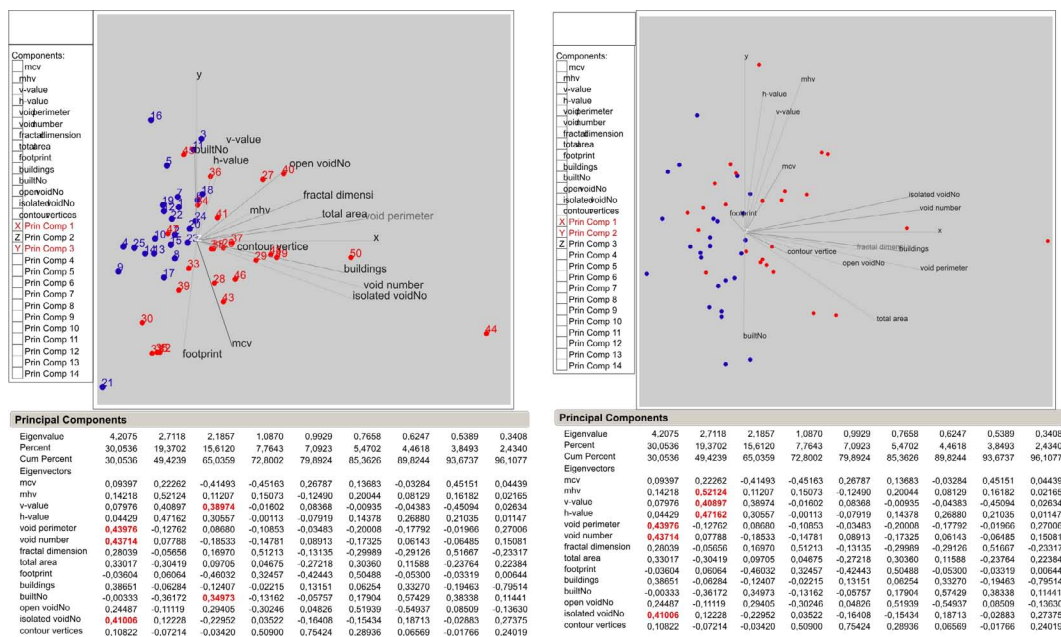


Figure 45. Classification of areas A and L.  
Plot against components 1 and 3 (left) and 1 and 2 (right)

## **2. Tables**

This section includes tables presenting the results from various measurements.

### **Table I**

Values for all quantities and all block plans and overall values for each area (minimum, maximum, average, range and variance of values for each quantity)

### **Table II**

Scatter plots and correlation values for all pairs of quantities for the whole dataset

### **Table III**

Fractal dimension measurement for the whole dataset, Processing











### **Table IV**
















Connectivity measurements for a sample of plans from each area, Processing











### **Table V**
















Photographic snapshots of the areas under analysis











Block No.	plan	mcv	mhv	v-value	h-value	fractal dim.	void perim. (m)	void No.	total area	footprint	buildings	built No.	open voids%	vertices	mean height	norm. height	variance	land value	floor area factor
A001		9.249023	1.51515	3.45853	1.56236	1.531	422	1	5523.627	0.73021	19	4	0	4	4.63705	0.808239113	1450	4.2	
A002		11.65038	2.17391	5.47035	2.66207	1.497	400	1	5570.052	0.75953	18	2	0	4	5.25359	0.20491226	1450	4.2	
A003		18.34696	2.5	8.27467	5.40507	1.454	511	1	8735.561	0.59995	18	5	100	5	4.568026	0.256269776	1800	4.5	
A004		33.46902	8.33333	12.1994	9.29491	1.378	67	1	1833.6	0.93058	5	1	0	3	5.965016	0.108884541	1775	4.8	
A005		49.21307	8.33333	13.9646	8.90288	1.354	279	2	3006.393	0.6453	14	3	100	4	3.838438	0.081750702	1450	4.2	
A006		53.74486	6.13636	8.97735	9.25026	1.468	396	4	5288.533	0.75266	11	2	50	4	4.660393	0.269165068	1450	4.2	
A007		16.76541	4.54545	8.13674	5.84811	1.447	438	1	5983.549	0.70987	18	2	100	3	4.190992	0.137585803	1450	4.5	
A008		13.19122	1.96078	4.41192	2.34872	1.46	379	1	5366.35	0.83684	14	1	0	5	5.700929	0.119538412	1775	4.8	
A009		33.37629	3.84615	12.4981	4.16475	1.381	97	1	1468.148	0.98844	7	1	0	3	5.243467	0.065805697	1450	4.8	
A010		21.03954	4.16667	10.9176	3.00676	1.434	274	1	3480.247	0.84107	11	1	100	4	5.389201	0.118229585	1775	4.8	
A011		29.17371	6.68044	11.668	7.8929	1.506	484	3	4032.377	0.69092	12	3	66.667	3	4.869445	0.173772576	1450	4.2	
A012		25.33178	5	9.66577	6.39243	1.539	242	1	3274.875	0.7869	8	1	100	3	6.607827	0.413523689	1450	4.5	
A013		23.01836	3.33333	10.1742	4.99526	1.425	232	1	3871.038	0.83831	13	1	0	5	5.177011	0.143886888	1450	4.8	
A014		28.66695	3.33333	12.664	3.69751	1.393	237	1	4388.921	0.84863	9	1	0	4	7	0	1775	4.8	
A015		35.99304	7.36434	9.29848	5.81042	1.54	215	2	2745.129	0.82622	13	1	0	4	3.880691	0.097950831	1350	4.5	

	44.91406	12.5	15.3363	16.2804	1.373	169	1	1913.811	0.52171	7	2	100	3	4.565925	0.228283207	1450	4.8
	34.19331	4.92884	8.13937	5.03286	1.403	248	3	4607.914	0.83279	18	1	0	4	4.396979	0.066592313	1450	4.8
	51.81039	9.14864	15.5582	10.14	1.442	339	6	5130.522	0.89414	12	2	50	4	3.333169	0.02210449	1775	4.8
	16.89146	3.125	6.36163	4.1211	1.436	284	1	3257.908	0.69532	15	3	0	5	3.154915	0.08565936	1350	4.5
	45.5252	9.5977	14.9898	9.00583	1.51	261	4	2865.153	0.84375	10	1	0	6	7.119598	0.380500978	1450	5.1
	100	0	0	0	1.368	11	1	614.4523	0.98749	7	1	0	3	6.345448	0.054109339	1450	4.8
	16.65234	4.58769	6.6555	4.45619	1.452	410	2	4604.549	0.7735	12	2	50	4	5.949171	0.083214283	1450	5.1
	41.33146	6.13026	9.48262	1	1.488	415	7	4566.956	0.83845	12	2	85.71	4	7.714161	0.388472058	1775	5.1
	49.52111	7.24379	11.2292	7.20485	1.483	319	6	2882.418	0.76845	8	1	33.333	5	7.055275	0.221942873	1775	5.1
	46.91424	10.8374	12.0474	7.53385	1.375	87	2	1020.782	0.917	6	1	50	3	5.171516	0.099720856	1350	4.5
<b>Amin</b>	9.249023	0	0	0	1.354	11	1	614.4523	0.52171	5	1	0	3	3.154915	0	1350	4.2
<b>Amax</b>	100	12.5	15.3363	16.2804	1.54	511	7	8735.561	0.98749	19	5	100	6	7.714161	0.808239113	1800	5.1
<b>Amean</b>	33.99833	5.49288	9.82399	5.8399	1.44548	288.64	2.2	3841.315	0.79392	11.88	1.8	39.4284	3.96	5.27952932	0.184724588	1543	4.656
<b>Arange</b>	90.75098	12.5	15.3363	16.2804	0.186	500	6	8121.109	0.46577	14	4	100	3	4.559246	0.808239113	450	0.9
<b>Avar</b>	364.353	9.31754	16.6515	11.9861	0.00312161	17122.8704	3.2	3151464	0.01192	16.7456	1.12	1761.472549	0.6784	1.42086249	0.028347115	27026	0.087264
















block No.	plan	mcv	mhv	v-value	h-value	fractal dim.	void perim. (m)	void No.	total area	footprint	buildings built	No. open voids%	vertices	mean height	norm. height	variance	land value	floor area factor
B001		97.38708	3.5461	2.15725	1.85611	1.352	141	9	2403.28	0.92634	13	1	2.222	3	4.864111	0.021419556	4000	4.2
B002		68.87549	12.734	12.4645	12.119	1.499	290	7	2952.971	0.85481	17	2	42.857	4	4.36752	1.09188006	4000	4.2
B003		31.81376	4.18363	10.8539	3.48875	1.411	201	2	2689.098	0.8362	15	1	0	4	4.601966	0.633901228	4000	4.2
B004		96.8254	3.96825	2.35702	1.91769	1.417	126	5	2921.259	0.87871	24	1	20	4	4.411917	1.102979272	4000	4.2
B005		22.59734	3.72967	6.20832	3.85486	1.531	492	6	4842.767	0.80066	22	2	16.667	4	3.40729	0.362216884	4000	4.2
B006		23.64272	1.74393	4.81077	1.58137	1.519	453	5	5534.669	0.81602	23	1	0	4	5	0	4000	4.2
B007		48.28168	3.09527	8.53854	1.96568	1.51	361	11	4757.516	0.8163	17	1	0	4	5	0	4000	4.2
B008		40.54867	2.8376	9.78648	3.74084	1.497	443	12	4716.949	0.81592	19	1	8.333	4	4.928733	0.526193851	4000	4.2
B009		40.40872	9.35631	9.90535	4.44102	1.541	608	11	5533.189	0.80701	17	1	0	4	4.372272	0.218575377	4000	4.2
B010		39.60428	0.87329	6.17418	1.5004	1.532	419	9	4823.08	0.78673	16	1	0	4	5.273665	0.534554053	4000	4.2
B011		52.49072	8.46899	10.0315	6.43639	1.505	561	18	5578.901	0.80168	15	1	0	4	5	0	4000	4.2
B012		22.76042	2.19132	7.58546	2.47451	1.452	452	4	6479.002	0.77627	19	1	0	4	5	0	4000	4.2
B013		47.44943	3.19925	10.1549	3.23928	1.473	460	13	5524.615	0.72743	18	1	0	4	5	0	4000	4.2
B014		43.38419	5.58313	8.01771	3.90313	1.513	419	9	4889.543	0.8418	16	1	0	4	5	0	4375	4.2
B015		12.5295	2.38095	5.91078	3.53716	1.498	478	1	5176.662	0.71472	13	2	100	4	6	0	4375	4.2











	50.20252	5.95588	10.1587	5.36067	1.499	442	14	4376.061	0.83846	14	1	0	5	4.025648	0.498102417	4375	4.2
	39.1642	5.32614	8.59241	5.41442	1.551	695	14	7717.695	0.54753	12	3	7.143	4	3.750118	0.69501893	4375	4.2
	46.75258	4.69249	8.36474	4.9015	1.545	626	13	5845.225	0.65579	15	3	15.385	3	4.143524	1.035681293	4375	4.2
	74.61112	14.6351	12.3836	10.6946	1.485	459	12	5528.215	0.78053	12	3	16.667	3	5.076581	0.297382825	6625	4.2
	19.11717	2.89618	5.903	3.06716	1.484	478	3	7440.986	0.56409	18	5	33.333	4	3.279573	0.446193758	7150	4.2
	30.70301	3.47445	6.29216	3.95537	1.453	748	9	10316.11	0.5864	15	4	22.222	4	4.033891	0.575298886	7150	4.2
	33.45229	4.79106	8.21608	3.49982	1.446	735	11	8686.748	0.64282	14	3	18.182	4	4.924778	0.81340763	5800	4.2
	34.33901	3.77763	7.73962	4.37925	1.511	792	13	8266.218	0.83508	15	4	7.69	4	5.087273	0.101387521	5800	4.2
	37.54732	5.59376	7.41522	4.96259	1.468	597	13	6615.518	0.79634	22	2	7.69	4	4.92422	1.18105304	4000	4.2
	47.83486	4.70113	8.77568	3.95235	1.465	382	9	4971.337	0.76967	18	1	1.111	5	4.678991	0.449663489	4000	4.2
<b>Bmin</b>	12.5295	0.87329	2.15725	1.5004	1.352	126	1	2403.28	0.54753	12	1	0	3	3.279573	0	4000	4.2
<b>Bmax</b>	97.38708	14.6351	12.4845	12.119	1.551	792	18	10316.11	0.92634	24	5	100	5	6	1.18105304	7150	4.2
<b>Bmean</b>	44.09294	4.94946	7.95191	4.24976	1.48628	473.92	9.32	5543.904	0.75869	16.76	1.83	12.78008	3.96	4.64608284	0.423285202	4576	4.2
<b>Brange</b>	84.85759	13.7618	10.3072	10.6186	0.199	666	17	7912.829	0.37881	12	4	100	2	2.720427	1.18105304	3150	0
<b>Bvar</b>	437.2797	10.1271	6.55464	6.03256	0.00207916	29145.9136	17.6576	3464725	0.00929	10.6624	1.3856	445.0453509	0.1984	0.36273429	0.15045281	1024974	3.15544E-30
















Block No.	plan	mcv	mhv	v-value	h-value	fractal dim.	void perim. (m)	void No.	total area	footprint	buildings built	No. open voids%	vertices	mean height	norm. height	variance	land value	floor area factor
C001		47.45414	9.96377	9.96666	9.25691	1.41	138	3	1485.686	0.89418	10	1	0	4	4.204396	0.070973096	3000	2.4
C002		37.9753	6.01226	10.8207	7.8617	1.575	496	6	2808.111	0.64666	19	5	100	6	1.813111	0.286652119	2150	1.4
C003		73.2033	12.1267	10.4137	11.1051	1.484	221	7	2111.885	0.8511	20	2	71.429	6	1.960133	0.049409402	2150	1.6
C004		41.47869	6.62329	13.8226	8.14037	1.483	333	4	2701.386	0.50427	15	4	75	5	1.740634	0.149660392	2150	1.4
C005		70.75037	16.0494	16.8805	11.1243	1.461	135	4	1342.127	0.81765	7	1	50	4	2	0	2150	1.4
C006		48.02139	5.08578	11.5313	8.67302	1.453	204	3	1682.473	0.67554	10	2	66.667	4	2	0	2150	1.4
C007		45.31514	5.75439	8.91238	4.8682	1.426	95	2	723.3651	0.7973	6	1	100	4	2	0	2150	0.7
C008		55.67492	7.73112	9.0238	6.77654	1.523	256	5	1517.384	0.68252	10	4	100	5	1.551384	0.068956493	2150	0.7
C009		57.87454	12.1875	13.355	11.773	1.491	160	3	1643.909	0.80826	11	2	66.667	6	1.705071	0.182353697	2150	0.7
C010		44.09162	5.68594	8.96219	6.76576	1.521	294	3	2381.507	0.61208	12	3	66.667	5	1.583839	0.089213032	2150	0.7
C011		54.08867	16.6667	19.4522	18.743	1.386	175	1	995.7422	0.29933	2	1	100	4	1.107644	0.278911174	2150	1.4
C012		26.67925	4.64404	11.2351	6.69421	1.583	404	2	3790.196	0.52726	11	4	100	6	0.976208	0.108783169	2150	1.4
C013		43.39804	12.0544	12.7706	9.28887	1.483	191	3	1984.959	0.85948	12	1	33.333	3	2.742208	0.049534171	3000	1.8
C014		29.25709	7.14286	13.0516	5.42862	1.561	264	2	2043.62	0.80596	10	2	100	6	2.374643	0.001692044	3000	1.8
C015		28.00615	5.72888	10.749	5.93399	1.501	647	5	5604.178	0.65123	21	4	40	4	2.258812	0.062592982	3000	2.1











	42.0154	6.90506	13.1841	7.27498	1.478	789	9	8198.59	0.54926	29	5	66.667	6	3.387112	0.115699156	3000	2.25
	33.60752	5.55556	13.3223	4.52391	1.421	185	1	2593.803	0.75705	9	2	100	4	3.401571	0.294944013	3000	3
	28.44549	2.94296	10.7657	4.90972	1.427	309	2	3478.168	0.69099	10	1	50	3	2.988914	0.414035332	2700	4.2
	100	0	0	0	1.463	31	2	590.0775	0.95689	4	1	50	3	2.821382	0.198133043	3000	3
	36.66506	5.81413	10.1199	5.21034	1.531	489	5	4173.322	0.66671	22	4	60	5	2.393134	0.202584979	3000	2.1
	32.86761	7.82419	8.7039	6.42049	1.575	802	7	6153.503	0.72763	27	5	57.143	5	2.47166	0.081024089	3000	1.8
	17.19871	8.48084	7.80486	3.20471	1.565	548	2	4234.528	0.72818	21	7	100	4	1.902044	0.382599456	2150	1.4
	35.74419	5.59457	8.98392	7.38406	1.483	267	2	2561.266	0.61597	8	3	100	5	2.047586	0.156573643	2150	1.4
	40.58764	8.33333	16.2097	14.2108	1.348	141	1	942.7178	0.50089	5	3	100	6	2	0	2150	0.7
	70.96025	22.5	17.292	13.6882	1.674	100	3	389.6513	0.63328	5	1	66.667	4	1.488991	0.260652348	2150	0.7
<b>Cmin</b>	17.19871	0	0	0	1.348	31	1	389.6513	0.29933	2	1	0	3	0.976208	0	2150	0.7
<b>Cmax</b>	100	22.5	18.4522	18.743	1.674	802	9	8198.59	0.95689	29	7	100	6	4.204396	0.414035332	3000	4.2
<b>Cmean</b>	45.65442	8.29622	11.4833	7.97055	1.49224	306.96	3.48	2645.287	0.68999	12.64	2.76	72.8096	4.68	2.19669908	0.140079113	2478	1.658
<b>Crange</b>	82.80129	22.5	18.4522	18.743	0.326	771	8	7808.939	0.65756	27	6	100	3	3.228188	0.414035332	850	3.5
<b>Cvar</b>	318.7672	22.0991	14.1329	14.7567	0.00499282	42849.2384	4.1696	3393140	0.02098	50.3104	2.7424	699.8004608	1.0176	0.529980444	0.014371111	164616	0.698336



Block No.	plan	mcv	mhv	v-value	h-value	fractal dim.	void perim. (m)	void No.	total area	footprint	buildings	built No.	open voids%	vertices	mean height	norm. height	variance	land value	floor area factor
D001		73.70671	8.06293	9.21136	6.32315	1.555	339	8	2709.567	0.79527	18	2	50	4	4.503564	1.006202324	1150	1.4	
D002		61.5202	9.56799	11.4878	6.7714	1.58	474	7	2673.857	0.6992	27	2	71.489	4	3.98228	0.469170174	1150	1.4	
D003		31.87742	6.09109	13.2095	6.22584	1.574	391	2	2931.851	0.54697	18	6	100	4	2.031915	0.182236462	1150	1.4	
D004		53.77042	7.77474	10.61	6.53754	1.492	287	7	1842.784	0.8006	19	2	57.143	4	3.735053	0.847536032	1150	1.4	
D005		45.71087	8.68736	11.7009	9.78302	1.478	306	5	1665.37	0.5617	16	3	80	4	3.106335	0.565194997	1150	1.4	
D006		52.52268	11.2458	15.2688	9.07351	1.593	895	17	5918.75	0.75062	40	1	58.824	4	2.913274	0.286671971	1150	1.8	
D007		64.08787	15.0151	17.1493	12.5352	1.618	679	16	3948.139	0.7483	33	1	81.25	4	1.561827	0.012591023	1150	1.8	
D008		38.9402	7.27515	11.1588	6.88318	1.622	894	12	5793.544	0.72288	48	10	58.333	4	2.821694	0.064218516	1150	1.8	
D009		43.7384	8.30918	12.3575	7.76028	1.577	740	10	4016.328	0.69557	32	6	70	4	4.340785	0.686719107	1150	1.8	
D010		48.45041	21.1693	13.2862	9.66483	1.508	547	9	3832.634	0.75801	34	3	66.667	4	2.332455	0.090632402	1150	1.8	
D011		44.80143	8.83472	12.9419	7.93849	1.518	241	4	2765.288	0.78954	16	1	75	4	3.644023	0.098734284	1150	2.2	
D012		11.55614	2.27273	4.77107	3.23314	1.491	444	1	3701.879	0.73197	28	6	100	4	2.158803	0.060653056	1150	2.2	
D013		39.23075	5.6553	9.699	4.78619	1.513	400	6	3828.968	0.77418	26	1	100	4	2.47066	0.183458266	1150	2.2	
D014		47.43598	9.2172	13.0648	10.0125	1.47	503	8	5384.976	0.80658	29	3	25	4	3.010046	0.086664789	1150	1.8	
D015		74.47917	14.4025	14.7171	12.0658	1.434	159	4	2779.16	0.22487	7	3	100	3	0.468263	0.062857838	1150	2.2	

	50.7138	10.496	13.3548	7.85133	1.567	350	5	2883.555	0.73107	17	2	40	4	2.573929	0.077757001	1150	2.2
	54.76374	18.3729	15.2905	12.4288	1.57	519	11	3874.502	0.76935	27	3	36.364	4	3.15462	0.165590784	1100	2.4
	68.49154	11	11.1845	7.89079	1.561	295	7	2796.719	0.81907	19	1	28.571	4	2.457656	0.085634035	1100	2.2
	48.0038	11.6913	12.7605	9.59138	1.552	559	9	4126.574	0.76727	29	2	33.333	4	2.728328	0.08110755	1100	2.4
	16.86382	3.57143	8.07923	5.82752	1.476	429	1	3732.069	0.57176	15	6	100	4	2.326753	0.043242665	1150	2.4
	47.35861	9.52063	14.8339	8.14767	1.568	374	6	2775.774	0.78498	20	1	66.667	4	1.998535	0.172404787	1150	2.2
	77.56632	12.2222	11.3625	9.72343	1.491	252	6	2458.803	0.74337	15	1	50	5	2.906233	0.401884845	1150	2.2
	51.90754	10.2273	10.1208	9.32542	1.498	396	6	3761.455	0.77091	22	3	16.667	4	3.138403	0.043972046	1150	2.4
	46.14132	6.31509	8.88399	5.75711	1.527	535	8	4010.595	0.71257	30	4	50	4	2.605792	0.021851706	1100	2.2
	55.67987	10.1591	8.85029	6.41989	1.571	398	6	2711.684	0.71348	24	1	50	4	2.554516	0.116774371	1100	2.2
<b>Dmin</b>	11.55614	2.27273	4.77107	3.23314	1.434	159	1	1665.37	0.22487	7	1	16.667	3	0.468263	0.012591023	1100	1.4
<b>Dmax</b>	77.56632	21.1693	17.1493	12.5352	1.622	895	17	5918.75	0.81907	48	10	100	5	4.503564	1.005202324	1150	2.4
<b>Dmean</b>	49.97276	9.88628	11.8142	8.18261	1.53616	456.24	7.24	3480.992	0.7092	24.36	2.96	62.61232	4	2.78102968	0.236510441	1140	1.976
<b>Drange</b>	66.01018	18.8965	12.3783	9.30202	0.188	736	16	4253.38	0.5942	41	9	83.333	2	4.035301	0.892611301	50	1
<b>Dvar</b>	237.4416	16.8645	7.12736	5.11381	0.00235637	33858.4224	14.7424	1131557	0.01486	78.7104	4.9184	615.9798653	0.08	0.723616393	0.071377298	400	0.122624

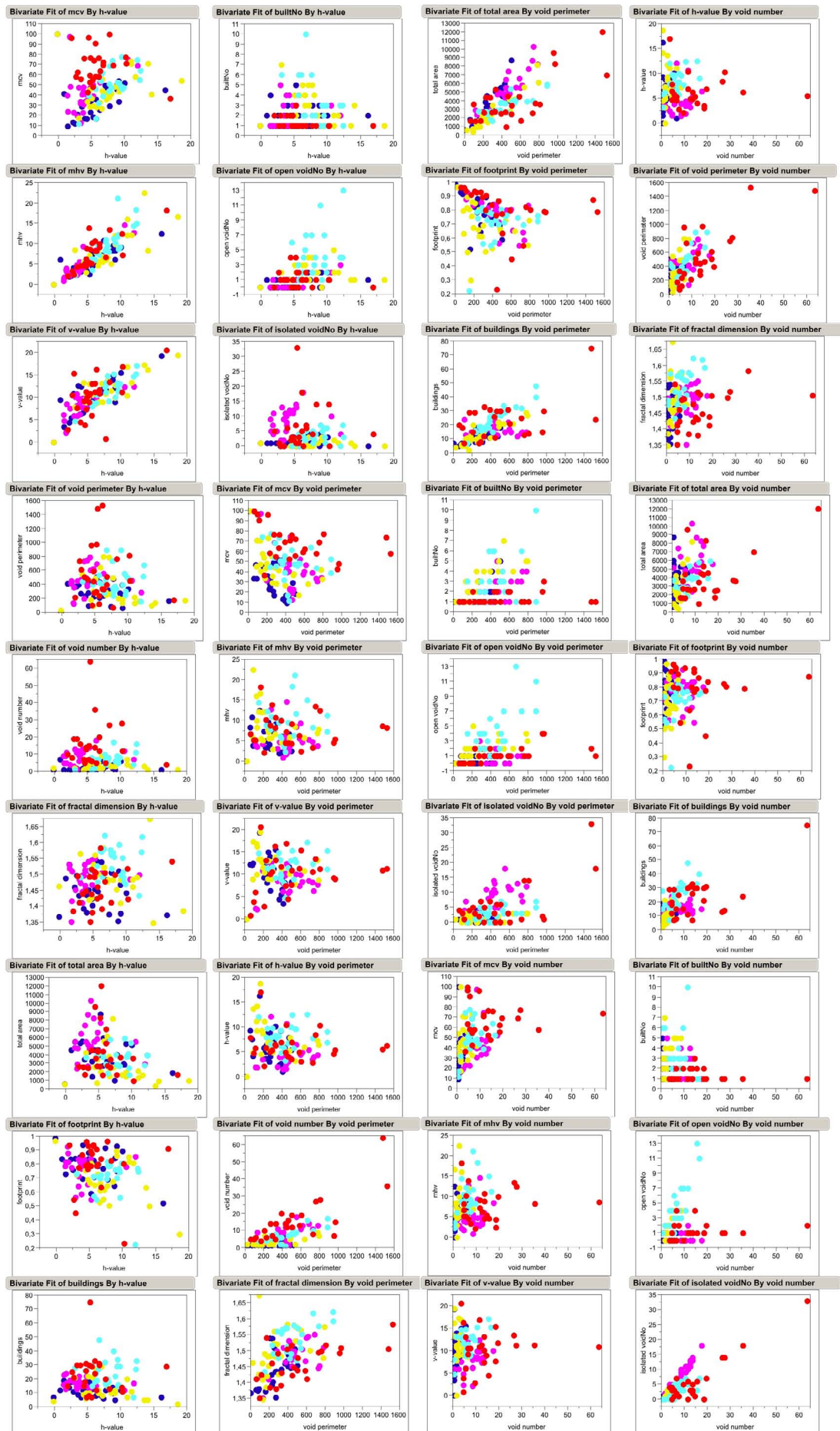
block No.	plan	mcv	mhv	v-value	h-value	fractal dim.	void perim. (m)	void No.	total area	footprint buildings	built No.	open voids%	vertices
L001		59.28025	6.27525	11.2975	4.90118	1.438	594	13	4510.364	0.80069	31	2	76.923
L002		42.63879	4.54514	9.22854	4.5909	1.493	964	7	9599.56	0.79166	15	2	71.429
L003		55.79918	4.32975	7.67989	3.54457	1.439	511	19	2466.862	0.77558	30	1	100
L004		69.35426	9.99333	11.748	6.90106	1.505	400	20	2539.287	0.83848	31	1	65
L005		90.77126	5.14905	5.99349	5.75052	1.425	123	6	1646.643	0.93955	7	1	83.333
L006		52.4917	4.51342	7.41765	4.90705	1.516	447	14	2694.298	0.76505	26	2	78.571
L007		96.60232	5.17007	3.86546	4.71048	1.352	105	5	3606.848	0.96182	18	1	40
L008		55.01744	13.8799	10.5706	5.33596	1.492	302	7	2665.274	0.89357	8	1	0
L009		62.41669	2.39259	15.395	3.05993	1.412	614	19	1699.451	0.45072	21	2	100
L010		99.68701	6.69014	0.77461	7.86228	1.412	71	5	1666.671	0.96381	20	1	20
L011		36.52852	18.2407	20.6067	17.031	1.541	180	4	1687.914	0.91166	29	1	0
L012		72.40213	9.17315	10.8841	6.91844	1.478	514	12	3467.969	0.63504	30	1	50
L013		58.37213	10.1821	13.0979	5.79526	1.461	238	6	4411.329	0.92954	29	1	50
L014		76.65708	8.84865	10.051	4.99501	1.381	283	14	4390.05	0.93114	7	1	85.714
L015		47.93569	5.39494	8.96374	5.3583	1.509	978	15	8305.731	0.78721	30	3	93.333

	57.95851	3.32899	10.565	2.81131	1.495	738	8	2582.905	0.54657	25	1	87.5	4
	96.22417	2.10665	2.82913	2.12792	1.385	217	10	2640.293	0.93591	15	2	50	4
	76.08452	4.57751	4.47886	4.04929	1.448	473	16	4553.67	0.86728	30	2	62.5	4
	73.92127	8.64067	10.8845	5.52283	1.506	1488	64	12028.57	0.87554	75	1	48.438	4
	71.0358	7.21612	16.9168	10.4076	1.423	455	12	973.2055	0.23356	11	1	100	4
	76.51348	10.7353	13.1647	6.24453	1.431	340	14	5336.537	0.90593	33	1	64.286	5
	63.58249	8.22317	16.3094	6.45879	1.392	335	5	2743.576	0.80118	12	1	100	4
	69.13002	13.4769	13.4678	8.43378	1.499	768	27	3710.9	0.82465	13	1	48.148	4
	77.21049	12.4716	11.2205	10.3139	1.518	816	28	3597.239	0.80379	14	1	50	4
	57.9383	8.24513	11.2642	6.25327	1.583	1534	36	6984.117	0.78933	24	1	50	4
<b>Lmin</b>	36.52852	2.10665	0.77461	2.12792	1.352	71	4	973.2055	0.23356	7	1	0	4
<b>Lmax</b>	99.88701	18.2407	20.6067	17.031	1.583	1534	64	12028.57	0.96381	75	3	100	6
<b>Lmean</b>	67.82215	7.75201	10.347	6.17141	1.46136	539.52	15.44	4020.45	0.79845	23.36	1.32	63.007	4.2
<b>Lrange</b>	63.15849	16.1341	19.8321	14.9031	0.231	1463	60	11055.36	0.73024	68	2	100	2
<b>Lvar</b>	260.6601	14.8893	20.0937	8.89004	0.00308543	143540.6496	160.726	6831483	0.02826	182.3904	0.2976	801.3035162	0.32

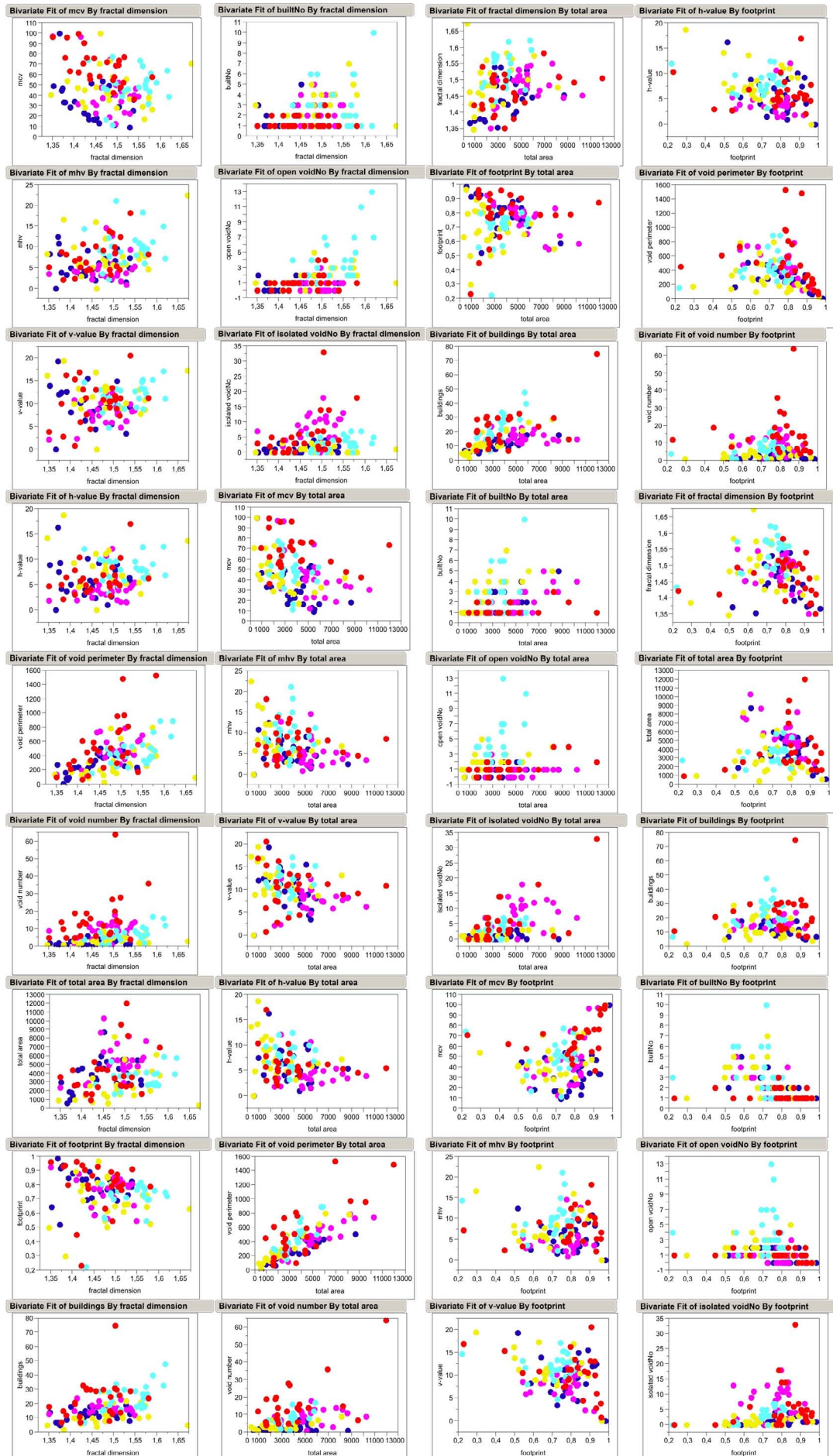
**Table I**

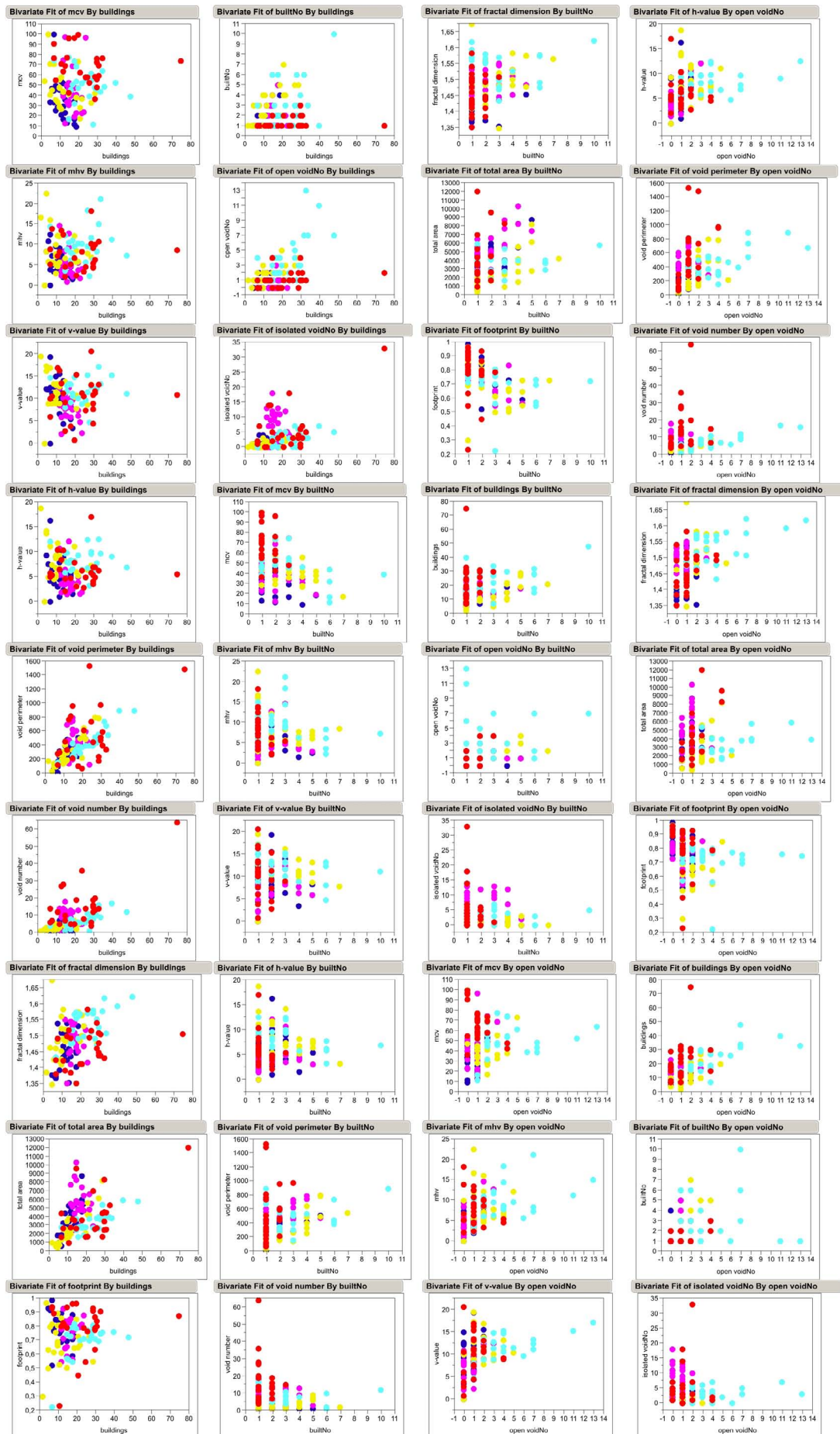
Measurement results: Values for all quantities and all block plans and overall values for each area (minimum, maximum, average, range and variance of values for each quantity)



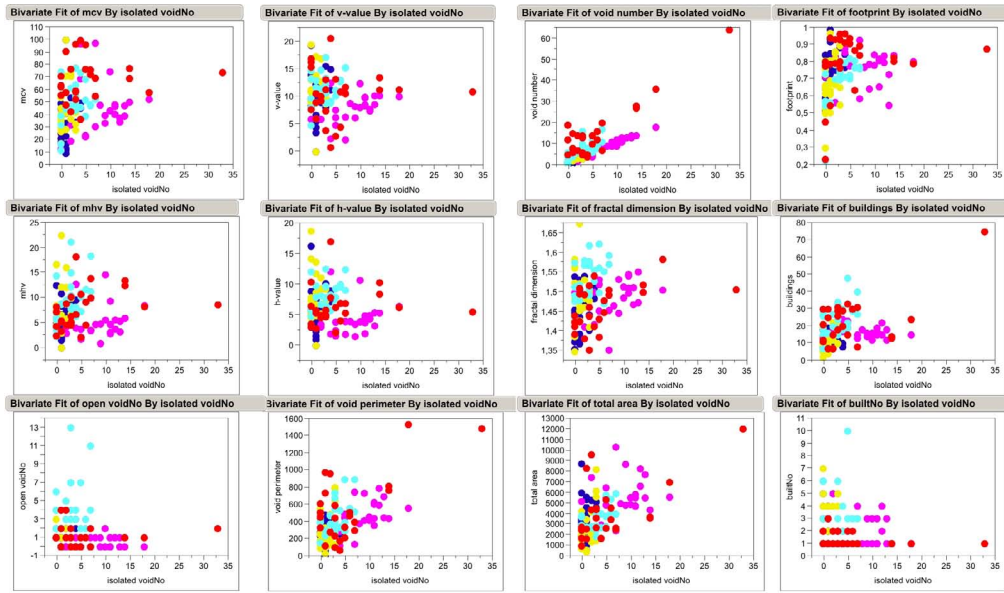












Correlations													
	mcv	mhv	v-value	h-value	void perimeter	void number	fractal dimension	total area	footprint	buildings	builtNo	open voidNo	isolated voidNo
mcv	1,0000	0,3084	-0,0292	0,1773	-0,1496	0,3546	-0,1880	-0,3259	0,2482	0,0611	-0,3726	0,0699	0,2119
mhv	0,3084	1,0000	0,6979	0,8194	-0,0401	0,1387	0,2695	-0,2646	-0,0629	0,0785	-0,1058	0,3788	0,0718
v-value	-0,0292	0,6979	1,0000	0,7620	0,0282	0,0642	0,1440	-0,2179	-0,3514	-0,0029	-0,0568	0,3349	-0,0739
h-value	0,1773	0,8194	0,7620	1,0000	-0,1225	-0,0229	0,1120	-0,3190	-0,3057	-0,0643	-0,0031	0,3406	-0,0927
void perimeter	-0,1496	-0,0401	0,0282	-0,1225	1,0000	0,7222	0,4508	0,7476	-0,1672	0,6330	0,2956	0,3325	0,5777
void number	0,3546	0,1387	0,0642	-0,0229	0,7222	1,0000	0,2070	0,4337	0,1024	0,6159	-0,1338	0,1462	0,8144
fractal dimension	-0,1880	0,2695	0,1440	0,1120	0,4508	0,2070	1,0000	0,1940	-0,1212	0,3706	0,3032	0,4661	0,2084
total area	-0,3259	-0,2646	-0,2179	-0,3190	0,7476	0,4337	0,1940	1,0000	-0,0150	0,4568	0,2685	0,0741	0,5212
footprint	0,2482	-0,0629	-0,3514	-0,3057	-0,1672	0,1024	-0,1212	-0,0150	1,0000	0,0875	-0,4159	-0,1904	0,2242
buildings	0,0611	0,0785	-0,0029	-0,0643	0,6330	0,6159	0,3706	0,4568	0,0875	1,0000	0,2271	0,4464	0,4173
builtNo	-0,3726	-0,1058	-0,0568	-0,0031	0,2956	-0,1338	0,3032	0,2685	-0,4159	0,2271	1,0000	0,2944	-0,1776
open voidNo	0,0699	0,3788	0,3349	0,3406	0,3325	0,1462	0,4661	0,0741	-0,1904	0,4464	0,2944	1,0000	-0,0973
isolated voidNo	0,2119	0,0718	-0,0739	-0,0927	0,5777	0,8144	0,2084	0,5212	0,2242	0,4173	-0,1776	-0,0973	1,0000

Table II


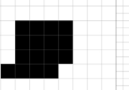
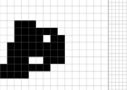



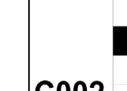

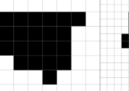
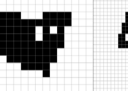



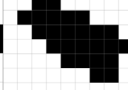
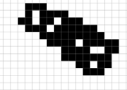



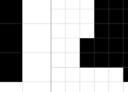





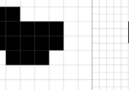
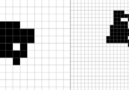



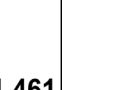
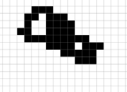



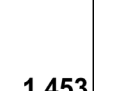




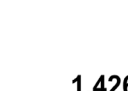


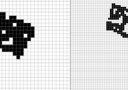


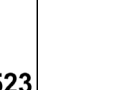



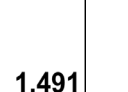


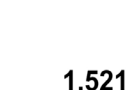



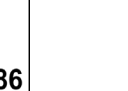

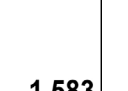

Scatter plots and correlation values for all pairs of quantities for the whole dataset

block	stage_1	stage_2	stage_3	stage_4	stage_5	stage_6	fractal dimension
A001							1.531
A002							1.497
A003							1.454
A004							1.378
A005							1.354
A006							1.468
A007							1.447
A008							1.46
A009							1.381
A010							1.434
A011							1.506
A012							1.539

A013							1.425
A014							1.393
A015							1.54
A016							1.373
A017							1.403
A018							1.442
A019							1.436
A020							1.51
A021							1.368
A022							1.452
A023							1.488
A024							1.483
A025							1.375

block	stage_1	stage_2	stage_3	stage_4	stage_5	stage_6	fractal dimension
B001							1.352
B002							1.499
B003							1.411
B004							1.417
B005							1.531
B006							1.519
B007							1.51
B008							1.497
B009							1.541
B010							1.532
B011							1.505
B012							1.452

B013							1.473
B014							1.513
B015							1.498
B016							1.499
B017							1.551
B018							1.545
B019							1.485
B020							1.484
B021							1.453
B022							1.446
B023							1.511
B024							1.468
B025							1.465

block	stage_1	stage_2	stage_3	stage_4	stage_5	stage_6	fractal dimension
C001							1.41
C002							1.575
C003							1.484
C004							1.483
C005							1.461
C006							1.453
C007							1.426
C008							1.523
C009							1.491
C010							1.521
C011							1.386
C012							1.583

C013							1.483
C014							1.561
C015							1.501
C016							1.478
C017							1.421
C018							1.427
C019							1.463
C020							1.531
C021							1.575
C022							1.565
C023							1.483
C024							1.348
C025							1.674



block	stage_1	stage_2	stage_3	stage_4	stage_5	stage_6	fractal dimension
D001							1.555
D002							1.58
D003							1.574
D004							1.492
D005							1.478
D006							1.593
D007							1.618
D008							1.622
D009							1.577
D010							1.508
D011							1.518
D012							1.491



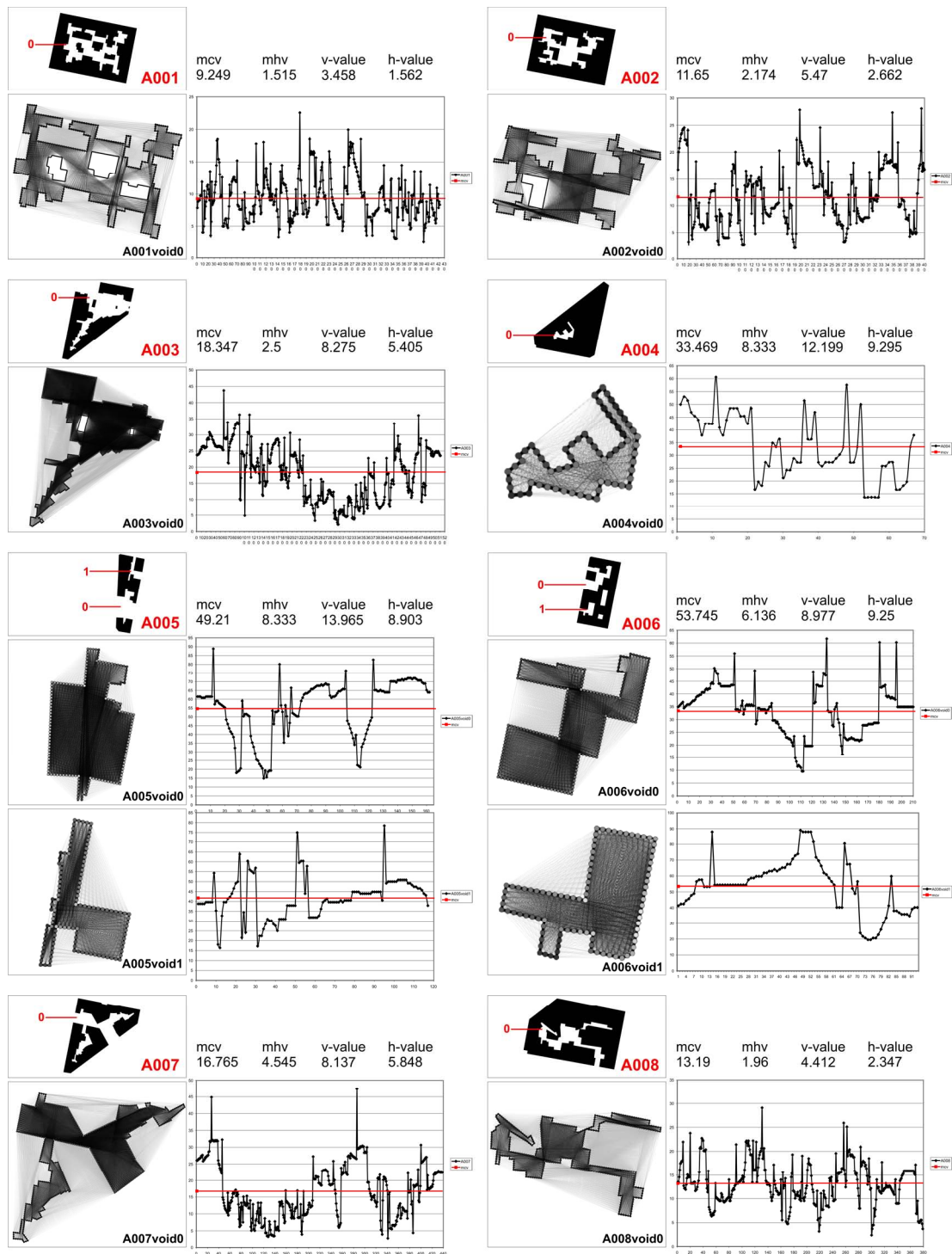
D013							1.513
D014							1.47
D015							1.434
D016							1.567
D017							1.57
D018							1.561
D019							1.552
D020							1.476
D021							1.568
D022							1.491
D023							1.498
D024							1.527
D025							1.571

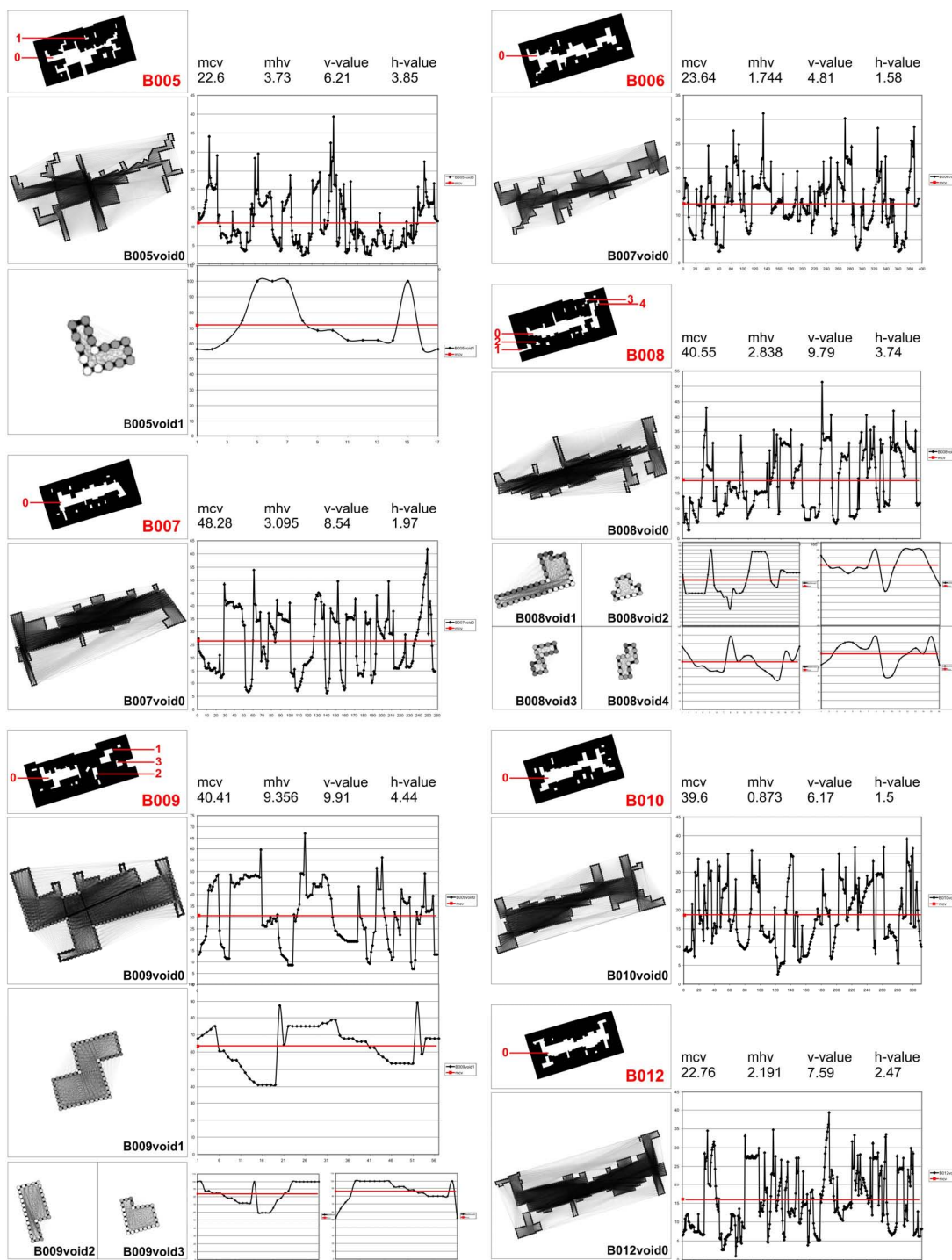
block	stage_1	stage_2	stage_3	stage_4	stage_5	stage_6	fractal dimension
L001							1.438
L002							1.493
L003							1.439
L004							1.505
L005							1.425
L006							1.516
L007							1.352
L008							1.492
L009							1.412
L010							1.412
L011							1.541
L012							1.478

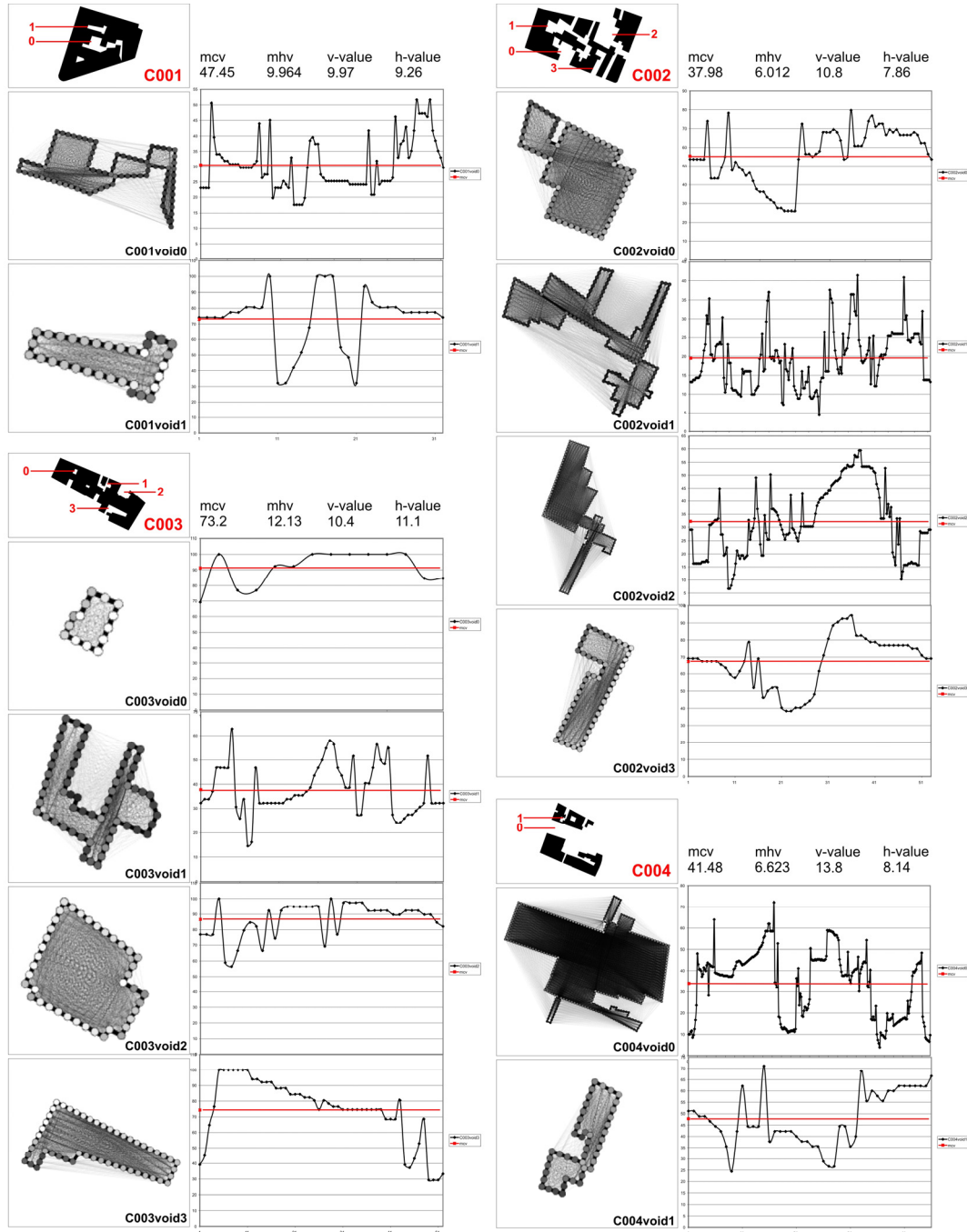
L013								1.461
L014								1.381
L015								1.509
L016								1.495
L017								1.385
L018								1.448
L019								1.506
L020								1.423
L021								1.431
L022								1.392
L023								1.499
L024								1.518
L025								1.583

Table III

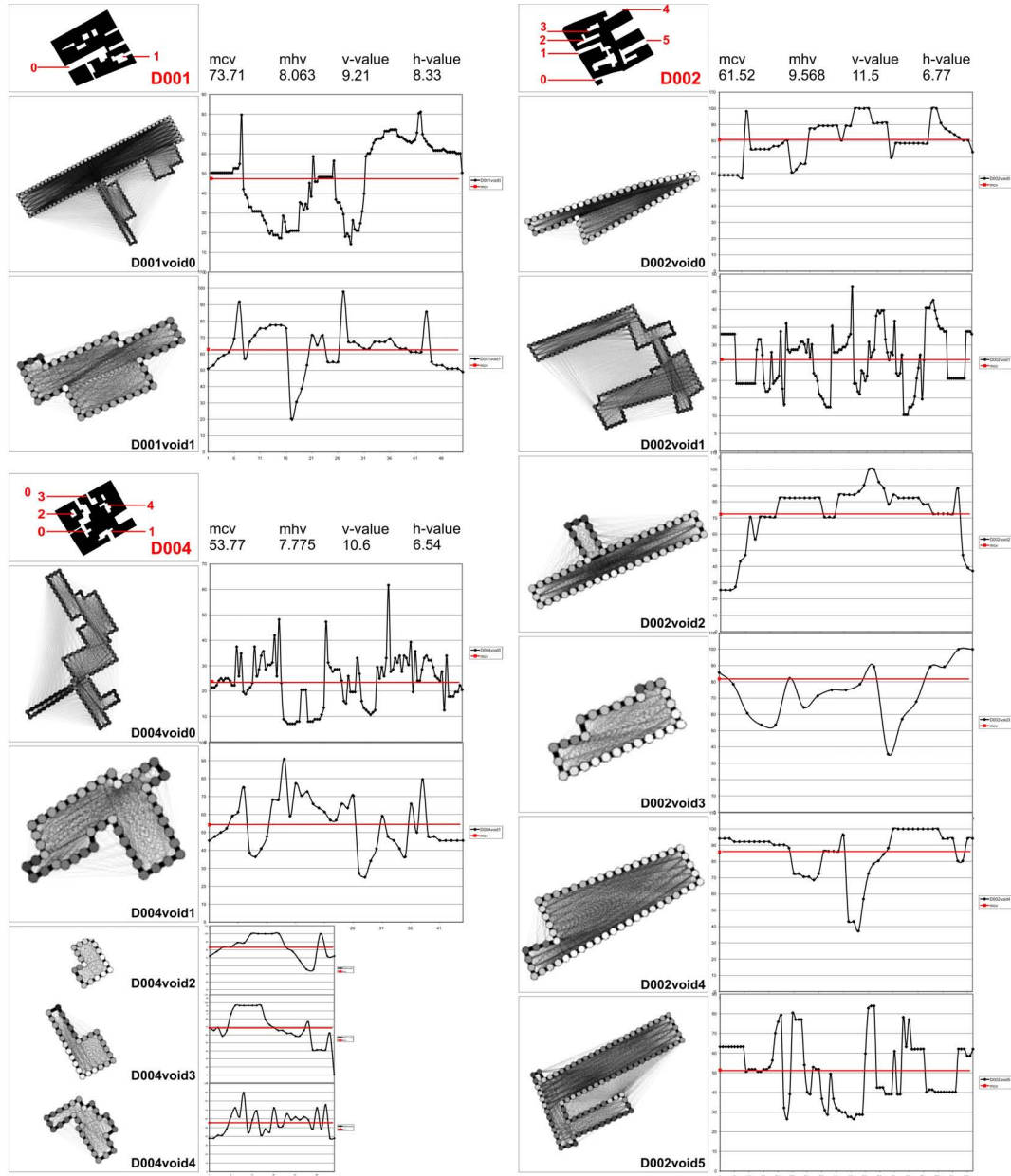
Fractal dimension measurement from Processing

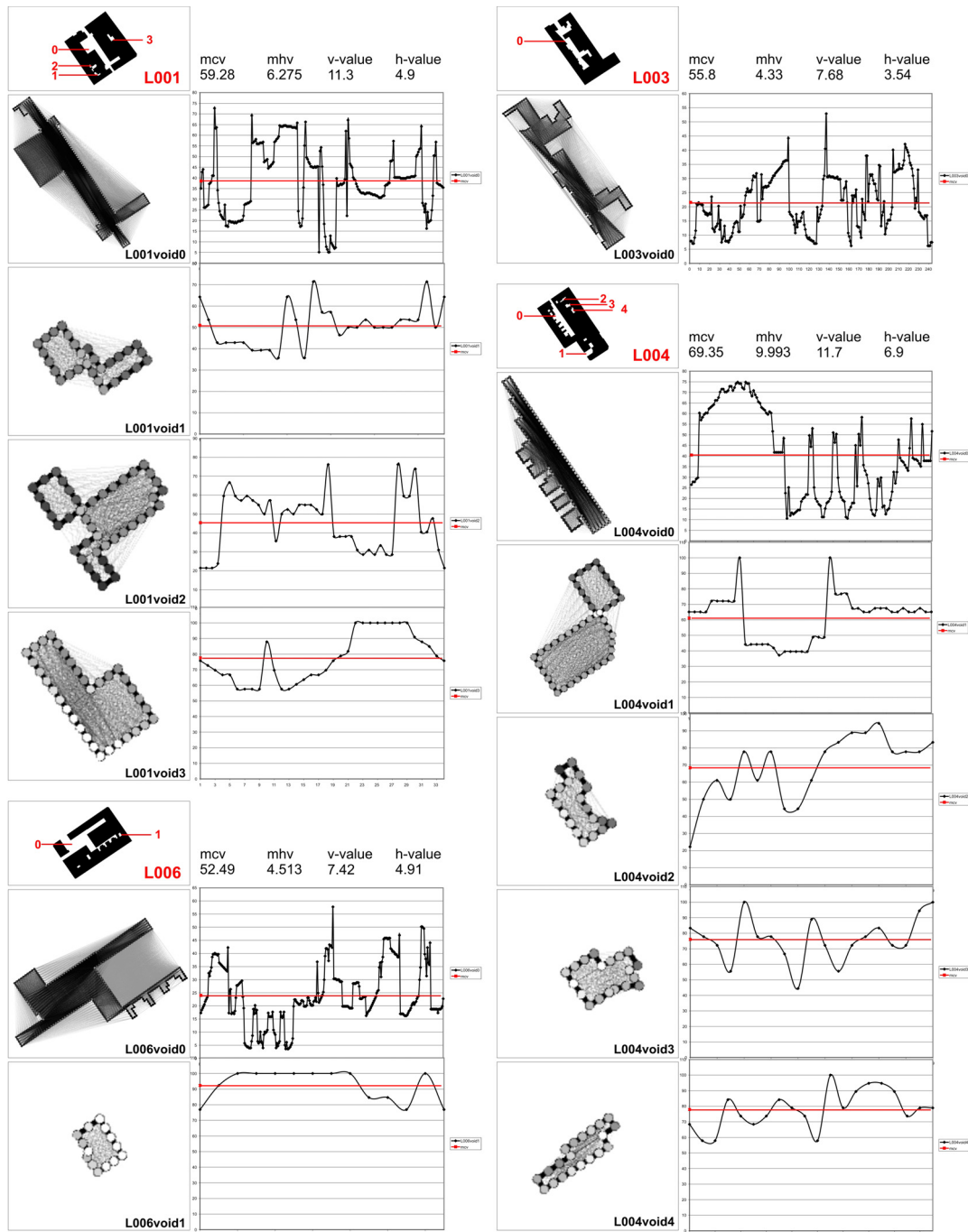












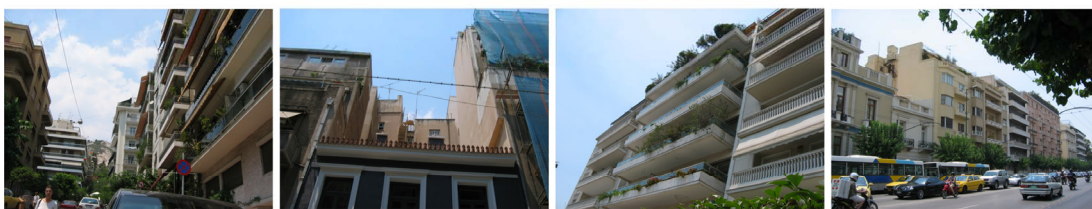
**Table IV**

Connectivity measurements from Processing for a sample of plans from each area





area\_A: Mouseio



area\_B: Kolonaki



area\_C: Plaka



area\_D: Metaxourgeio



area\_L: Bloomsbury-Fitzrovia

**Table V**

Photographic snapshots of the areas under analysis

## Appendix III

### Code snaps

This section includes details of the programs written in Processing for the measurement of fractal dimension and connectivity values, accompanied by brief explanations.

#### 1. Box-counting dimension

The plan is imported into Processing as a black and white .jpg image. In order to count the grid boxes that contain parts of the structure, the algorithm looks at the brightness of each pixel in each grid cell. If a pixel that is not white is found (brightness not 255) then the corresponding cell is counted as containing part of the structure and the search continues to the next cell. This process is repeated at each iteration, for different grid scales.

```
...
for (int m=0; m<grid.length; m++)
{
  for (int n=0; n<grid.length;n++)
  {
    side=width/d;
    grid[m][n]=new Grid(m*side, n*side, side);
    for (int a=m*side; a<(m+1)*side; a++)
    {
      if (jumper)
      {
        jumper=false;
        break;
      }
      for (int b=n*side; b<(n+1)*side; b++)
      {
        col=buffer.get(a,b);
        br=brightness(col);
        if (br!=255)
        {
          grid[m][n].value=0;
          jumper=true;
          break;
        }
      }
    }
  }
}
```

```

    {
        grid[m][n].value=1;
    }
}
}
if (grid[m][n].value==0)
{
    grid[m][n].colour=0;
    boxcount[i]++;
}
...

```

The decision to detect white instead of black colour was based on the fact that, because of the format of the plan (image, not vector graphics), lines could appear discontinuous at smaller scales.

## 2. Connectivity values

The plan is imported into processing as arrays of coordinates of its vertices, extracted through a text parser from a .dxf file.

### a. \*.dxf parser

```

...
for (int i=0; i<(contents.length)-4; i++)
{
    String trimmed=contents[i].trim();
    String trimmed2=contents[i+4].trim();
    if (trimmed.equals("VERTEX")&& trimmed2.equals("SELECTION"))
    {
        total_vertices++;
    }
}
x = new float [total_vertices];
y = new float [total_vertices];
int count_a=0;
for (int i=0; i<contents.length-4; i++)
{
    String trimmed=contents[i].trim();
    String trimmed2=contents[i+4].trim();
    if (trimmed.equals("VERTEX")&& trimmed2.equals("SELECTION"))
    {
        String thisline_X=contents[i+6].trim();

```

```

    x[count_a] = float(thisline_X.trim());
    String thisline_Y=contents[i+8].trim();
    y[count_a] = float(thisline_Y.trim());
    count_a++;
}
}
...

```

## **b. Subdivision of perimeter edges**

```

...
for (int i=0; i<x.length-1; i++)
{
    side_length[i] = dist(x[i], y[i], x[i+1], y[i+1]);
}

for (int i=0; i<x.length-1; i++)
{
    division[i]=round (side_length[i]/d_length);
}

for (int i=0; i<x.length-1; i++)
{
    for(int j=0; j<division[i]; j++)
    {
        float la=lerp(x[i],x[i+1],j/float(division[i]));
        float lo=lerp(y[i],y[i+1],j/float(division[i]));
        if (a<div)
        {
            x_d[a]=la;
            y_d[a]=lo;
            a++;
        }
    }
}
...

```

**c. Detection of line to line intersection**

```

...
boolean lintersection=false;

void intersection (float x1,float y1,float x2,float y2,float x3,float y3,float x4,float y4)
{

float ua=((x4-x3)*(y1-y3))-((y4-y3)*(x1-x3))/(((y4-y3)*(x2-x1))-((x4-x3)*(y2-y1)));
float ub=((x2-x1)*(y1-y3))-((y2-y1)*(x1-x3))/(((y4-y3)*(x2-x1))-((x4-x3)*(y2-y1)));
lintersection=false;
if( !(((y4-y3)*(x2-x1)-(x4-x3)*(y2-y1))==0) && ua>0 && ua<1 && ub>0 && ub<1)
{
    lintersection=true;
}
}
...

```

**d. Mean connectivity count**

**Step 1:** find the connections that don't intersect the perimeter.

The algorithm looks at each connection in relation to each perimeter edge. If the current connection is found to intersect an edge, the search continues to the next connection.

```

...
for (int j=0; j<div; j++)
{
    if (i!=j)
    {
        for (int k=1; k<x.length; k++)
        {
            intersect=false;

            intersection(x_d[i],y_d[i],x_d[j],y_d[j],x[k-1],y[k-1],x[k],y[k]);
            if (lintersection==true)
            {
                intersections[i]++;
                intersect=true;
                break;
            }
        }
    }
    ...
if (intersect==false)
{
    no_intersect[i]++;
}
...

```

**Step 2:** from the connections that don't intersect the perimeter find those that lie outside the shape.

A line is drawn from the middle of each non-intersecting connection towards the four directions (x, y, -x, -y) and the number of intersections with the perimeter determines whether the point (and thus the connection) is inside or outside the shape.

```

...
    x_mid=((x_d[i]+x_d[j])/2);
    y_mid=((y_d[i]+y_d[j])/2);
    x_midb=x_mid+width;
    y_midb=y_mid;

    ...//similarly for the other directions...

    for (int m=1; m<x.length; m++)
    {
        intersection(x_mid,y_mid,x_midb,y_midb,x[m-1],y[m-1],x[m],y[m]);
        if (!intersection==true)
        {
            counter++;
        }
        ...//similarly for the other directions...
    }
    if (counter%2==0 && counterb%2==0 && counterc%2==0 && counterd%2==0)
    {
        outside[i]++;
    }
...

```

#### e. H-value count

In order to calculate horizontal standard deviation, the points that have mean connectivity value need to be determined:

```

...
    mean=float(total_inside)/float(div);
    la=0;
    for (int i=0; i<div-1; i++)
    {
        if ((inside[i]>=mean && inside [i+1]<=mean)|(inside[i]<=mean && inside [i+1]>=mean))
        {
            if (la<div-1)
            {
                h_point[la]=1+i+((inside[i]-mean)/(inside[i]-inside[i+1]));
                la++;
            }
        }
    }...

```

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## **cd-rom**

The cd-rom includes a .pdf document of the thesis along with two programs in Processing, one for calculating the fractal dimension of .jpg images and one for measuring connectivity values of .dxf drawings.