# Multidimensional Comparative Analysis for the Classification of Residual Urban Voids

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*Spatial configurations can be perceived through a variety of descriptions of their physical form and structure. Each description can offer an autonomous interpretation or be combined with others parathetically, in a logic of multiple distinct layers. However it is asserted that meaningful information can be extracted from a simultaneous view of sets of descriptions within a high-dimensional structure. This paper investigates the possibility of conducting a comparative analysis and classification of non-typical spatial formations based on the synchronous view of multiple quantifiable spatial attributes.Under the hypothesis of a reciprocal definition of spatial structure and occupation practices, it is intended to identify distinct generic spatial types in order to subsequently determine a range of suitable respective generic use types.This investigation supports the formulation of strategies for the reactivation of unused, residual urban voids, currently being addressed by the research programme titled "Strategies to network urban interventions in the Metropolitan Centre of Athens". The programme is carried out by the School of Architecture of the National Technical University of Athens in collaboration with the Region of Attica, under the scientific coordination of Professor Dr. Parmenidis (2013).*

**Keywords:** *multidimensional descriptions, generic spatial types, quantifiable attributes, dimensionality reduction, classification*

## INTRODUCTION

The perception of physical space through multiple descriptions encompasses the conception of multi-leveled interpretations, evaluations, distinctions and categorizations. Different criteria reveal different associations, corresponding to equally valid understandings of interrelations and categories. When dealing with designed artefacts, where ideology and intentions are determinative, descriptions and distinctions can often make use of preconceived 'names' and explicit criteria. However, in many cases of non designed entities the terms need to be invented.

This paper presents a methodology for describing and comparing such undesigned spaces, with non-typical formal and structural characteristics, in order to classify them into distinct types. These are residual, unused or informally used open spaces, whose classification can be described as a "type-2" problem, according to Clark and Thornton's (1997) distinction. In such problems the regularities in the data are not evident, as in "type-1" problems, but require the re-interpretation and recoding of the data in order for the relevant patterns to become visible.

Dealing with what Rittel and Weber (1973) describe as "wicked problems" where there is no definite formulation of the problem and "every specification of the problem is a specification of the direction in which a treatment is considered", there is no way of defining a priori which features are the most relevant to measure and predetermining the classification criteria.

The proposed method for describing non-typical spaces is based on the quantification of multiple spatial attributes of different classes and their comparison in a multidimensional feature space (Laskari et al. 2008). Focusing on configurational characteristics (Hillier and Hanson 1984), the attributes under measurement refer mainly to metric, geometric and topological features of the plans of the respective spaces.

The resulting types are referred to as 'generic' spatial types (Badiou 2005) in the sense that they are not fixed and unambiguous categories directly related to specific and describable architectural attributes such as morphological, typological or technical characteristics. They are considered as open and possibly interchangeable, loose groupings according to abstract degrees of similarity, indefinite and multiply interpretable types related to perceptive qualities of space.

## CONTEXT AND RELEVANCE

The purpose of the classification is to support a strategy for activating large sets of residual urban voids by proposing possible distributions of new functions. The list of uses is open and their correlation to specific spatial types is only indicatory, since there is no unique or correct association between them. However, different uses present variable spatial requirements that can inform the selection criteria. These were specified according to the following aspects:

- Spatial layout of activities (linear, around one or multiple centres).
- Desired degree of connectivity to the street network.
- Duration (permanent, ephemeral, periodic).
- Range of influence (building block, neighbourhood, city).

## CASE STUDY

The proposed method is being tentatively tested in the area of Patissia, a dense neighbourhood of central Athens (figure 1). Patissia was selected as a representative example of the prevalent type of urban development in the 50-80's period that characterises most modern Greek urban settings.


Figure 1
The study case: the area of Patissia, central Athens (left). Location and form of urban voids (middle, in gray). The urban voids are defined as continuous open spaces within the blocks (right, in red).

### *Defining the Urban Voids*

Initially all categories of voids, both public and private, that form the network of open spaces in the urban fabric are taken into account. In the specific area, three distinct hierarchical classes of such unbuilt spaces are detected (figure 5, left):

- Streets (public).
- Passageways (public), defined as parts of the street network, often paved, with limited accessibility and length of up to two blocks.
- Unbuilt spaces within the urban blocks (public and private, accessible or not).

Whereas the first two classes constitute well defined and quite uniform types, the third category encompasses highly differentiated spaces, requiring finer typological subdivision.

This paper focuses on the scale of the urban block by investigating the definition of distinct types within this third class of urban voids.

The urban block is abstractly viewed as a binary configuration of built and open spaces. The elementary component of the analysis is the 'urban void', defined as the largest possible aggregation of continuous open spaces within one block, as viewed in plan, regardless of proprietary limits and other physical boundaries such as fences, level differences, geological, structural or textural discontinuities (figure 1).

The conditions that formed these spaces throughout time comprise repetitive processes of local spatial reconfigurations, aggregations and subdivisions and derived mainly from the implementation of specific building regulations and construction routines that prevailed during the Greek construction boom of the period between 1950 and 1980. Gradually, these formations expand and get even more intricate by incorporating other kinds of unbuilt spaces, such as lightwells, frontages, remnants from relocations of the building line, oddments from expropriations, empty lots, yards, or other undefined and disjoint residual voids.

Consequently, these spaces currently appear as highly heterogeneous, fragmented, arbitrary, not readily describable and yet very characteristic of the typical Athenian urban block. They are mainly undesigned, almost random colligations of residual, disparate spaces that can be defined merely as the negative of built space. Their fragmented and ill-defined identity renders these spaces vague, almost non-describable and intrinsically open to multiple readings.

## METHODOLOGY

The difficulty to describe these urban voids in explicit terms doesn't allow for the designation of unambiguous evaluation criteria for their classification into distinct types. This requires the definition of a descriptive logic that would act on a procedural level. The multiplicity of space is being perceived through a heterogeneous combination of discontinuous and discrete partial definitions, each of which is viewed as a distinct descriptive dimension. It is therefore attempted to capture the physical form and structure of space through these multiple dimensions by gradually identifying, measuring and representing them. This process comprises successive stages and the transition from one to the next involves respective changes in the dimensionality of the representation space of the data.

### *Selection of features: Identification and measurement of quantifiable attributes*

In order to represent physical space through its multiple dimensions, the first step is to identify these dimensions and define ways to quantify and measure them.

At this stage, the analysis focuses on the selection, recording and quantification of spatial attributes that are either related to predefined spatial requirements of the proposed functional types or intuitively regarded as particularly significant for the description of the specific spatial configurations. It is intended that these attributes refer to qualities of space that account for its multiple definitions while being independent from distinct morphological, typological and technical characteristics. These are abstract qualities referring to predicative properties of the unitary component seen as one, relational properties deriving from its description as a compound entity and procedural properties that are formulated through experiential and perceptive processes. Such properties are considered to be associated with fragmentation, complexity, coexistence of multiple scales, relation between parts, self-similarity, convexity, linearity or centrality, connectivity, symmetry and rhythm.

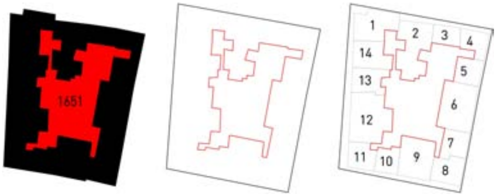



Figure 2
Example of scalar measurements for block 1651: void area 119.73 sq.m., void to built ratio 24%, void perimeter 302.17 m., number of open edges 0, surrounding buildings 14

By combining different methods of shape and spatial analysis, sets of local and global spatial attributes expressing the above spatial qualities are being quantified and measured. The measurements are predominantly derived from plans through non-interpretative, algorithmic measurement methods.

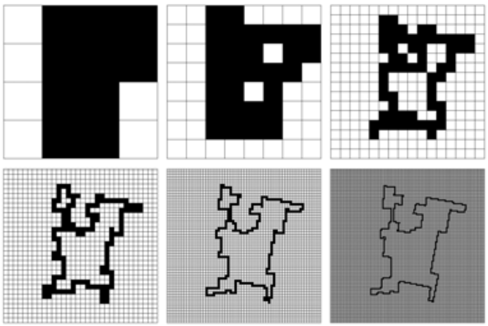


Figure 3
Graphic calculation of box-counting dimension (Minkowski-Bouligand dimension) for block 1651: Fractal Dimension 1.13

**Local attributes.** Local features concerning each spatial unit individually are being measured through quantifiable scalar, geometric and topologic/syntactic attributes.

**Scalar measures.** Scalar attributes comprise arithmetic measures that can be directly derived from plans. These are intended to capture properties referring mainly to issues of size, metric proportions and quantitative expressions of openness or enclosure with regard to the surrounding streets. Such measures are, for example, total area and perimeter length, footprint ratio, number of adjacent and contained buildings, number of openings to the surrounding streets, percentage of accessible perimeter length (figure 2).

**Geometric measures.** Geometric attributes related to the amount of fragmentation, multiplicity of scales, repetition and self-similarity are considered to be adequately expressed by the fractal dimension (Mandelbrot 1982) of the perimeters' shapes. The measurement of fractal dimension has been widely used by Bovill (1996) in the context of various architectural analyses. The method implemented for the calculation of fractal dimension is "Box-Counting", a graphic method based on a repetitive process of laying a grid of constantly decreasing scale over the image under measurement (figure 3). 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.

**Topologic - syntactic measures.** For the measurement of topologic and syntactic attributes, such as spatial connectivity and convexity, a method for the description of properties of shape perimeter is implemented. This method, introduced and developed by Psarra and Grajewski (2000) offers a combination of local and global, sequential and synchronous approaches of visual experience, by quantifying the convexity of shapes in terms of distribution of connectivity along the perimeter.

Following this method, the perimeter of each shape is subdivided into segments of equal length. From the subdivisions a complete graph is derived from which the number of connections that lie entirely within the perimeter is calculated for each point and plotted on a graph (figure 4). From this graph, a set of measurements is derived, corresponding to global and local characteristics of shape, in terms of stability and change, rhythm and repetition (Psarra and Grajewski 2000, Psarra 2003).

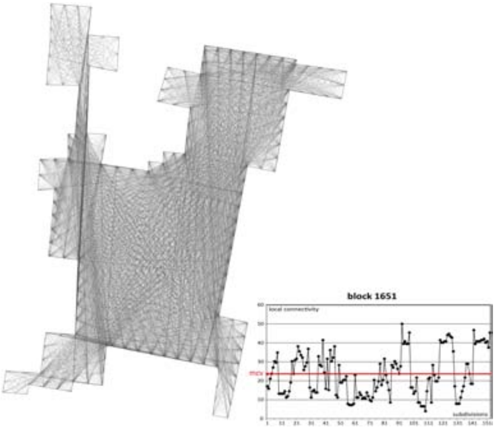



Figure 4
Graphic calculation of connectivity measures for block 1651. Convex lines (left) and distribution of local connectivity along the perimeter (right). Total mean connectivity (mcv - represented by the red line) 23.57, vertical standard deviation (v-value) 11.7, horizontal standard deviation (h-value) 4.09

**Global attributes.** In addition to the local measurements concerning individual voids, their relation with the wider network of open spaces is also taken into consideration.

The distinction of open spaces into hierarchical types mentioned above is used in order to evaluate their spatial connections and create a weighted graph representing the network. The edges are labelled according to the hierarchy class of the respective nodes and the overall connectivity of each individual void is calculated from this graph. This measurement accounts for the accessibility and connectivity of the spaces under analysis on a neighbourhood scale (figure 5).

## *Multidimensional plot: feature space*

The selection and measurement of a set of different types of spatial attributes enables the gradual definition of each void through multiple, independent descriptions. Each spatial unit is perceived as a multidimensional vector, with each of its dimensions corresponding to one of the features under measurement.

By plotting the quantities deriving from the measurements in a high-dimensional feature space, every spatial unit is represented as a uniquely defined point. The concentration or dispersion of points corresponds to a relative degree of association among the represented spaces along all attributes simultaneously (Laskari at al. 2008).

The unified quantification and non-hierarchical organisation of a variety of disparate and disconnected spatial properties allows for the simultaneous incorporation and consideration of attributes of different classes within the same system, encompassing and overcoming the multiplicity, heterogeneity and non-describability of the spaces under analysis and renders them comparable in the framework of an open system of quantified interrelations, without compromising their singularity.

Obviously, it is impossible to reduce space to a complete list of attributes. Only the actual physical spatial object per se supports full dimensionality and exhibits the complete spectrum of possible descriptions. The selection of a specific set of attributes, regardless of how many, is by definition an interpretative action, delimiting the field of possible readings of the represented spaces. In this sense, the representation of spaces through multidimensional vectors constitutes a process of preliminary dimensionality reduction and considerable data abstraction.

## *Dimensionality reduction: point distribution*

The produced multidimensional representation space may be mathematically defined, but it is not a straightforward task to directly visualise it in an intelligible and legible way. However, it is suggested that mapping this high-dimensional space onto a space of lower dimensionality, while maintaining the metric and topological relations between the initial multidimensional vectors, could reveal patterns of interrelations and enable the illustration of degrees of similarity and difference between the represented spaces. According to Hanna (2011), "the use of high-dimensional input has been shown effective in revealing types in artefacts at many levels of scale".

At this stage, three different algorithmic meth-

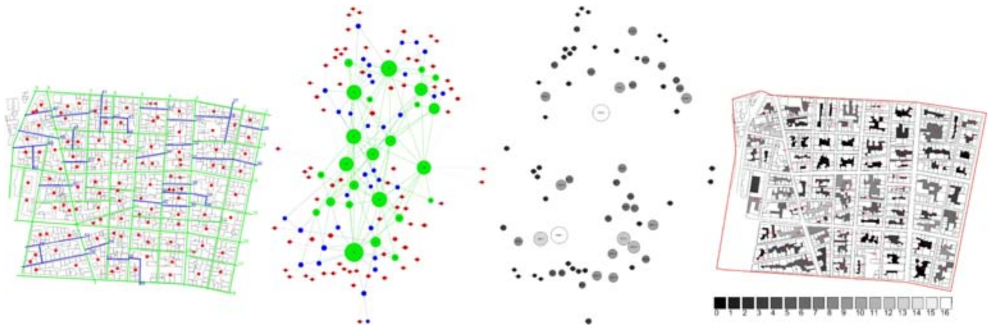


Figure 5
Calculation and visualisation of distribution of weighted connectivity. From left to right: Map of open spaces: streets (green), passageways (blue) and voids within blocks (red). Weighted graph of open spaces. Calculation of weighted connectivity for the voids within blocks. Visualisation of connectivity values on the map.

ods for mapping and visualising multidimensional data are employed and compared. These are implementations of Principal Component Analysis, Kohonen Networks and Particle-Spring Systems simulations.

Since the spaces under analysis are unlabelled, the selected methods are non-supervised. Although they express different approaches, coming from statistic analysis, artificial intelligence and computational physics simulation respectively, they all offer the potential of preserving and revealing 'hidden' structures in the data by producing intelligible and meaningful visualisations of the system of relations within the initial multidimensional dataset.

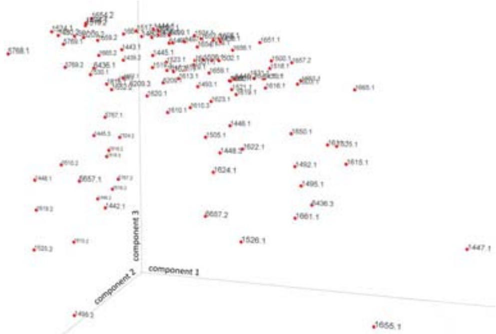



Figure 6
Projection of the high-dimensional feature vectors onto the three Principal Components.

**Principal Component Analysis (PCA).** Principal Component Analysis, a technique of multivariate analysis (Duda et al. 2001), has been previously used for the classification of spaces in various implementations. For example, Hanna has employed it both in an analytic and in a generative framework for the generation and classification of plans according to axial graph spectra (Hanna 2007a, 2007b).

According to Jolliffe (2002) "the central idea of principal component analysis is to reduce the dimensionality of a data set in which there are a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This reduction is achieved by transforming to a new set of variables, the principal components, which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables." These new, fewer variables are artificial and purely computational. They account for most of the variance in the initial variables without representing specific dimensions of the original high-dimensional space.

By plotting all measurements and projecting them on the first three Principal Components, a new, three-dimensional distribution of points is produced, that maintains the structure of relations amongst the initial high-dimensional data (figure 6).

**Kohonen Networks / Self Organising Maps (SOM).** Kohonen Networks are non-supervised Artificial Neural Networks that map multidimensional feature vectors on two dimensions in a self-organising way (Kohonen 1995). This is done through the gradual adaptation of the synaptic vectors of the neurons constituting the map to the input space (Rojas 1996).

Self Organising Maps have been proved to be efficient in mapping high-dimensional spatial attributes in several implementations. For example, a self-organising map was used by Benoudjit (2004) in order to create a space classification map on the base of human perception criteria, while Harding and Derix (2011) have used SOMs to classify spatial layouts generated by a growing neural gas algorithm.

Figure 7
Two-dimensional mapping of the feature space by a Self Organising Map.

In the case of generic spatial types, the use of SOMs was considered to be particularly suitable, since, according to Derix (2006) they "offer the chance to explore relationships between properties of objects that result in general categories of distinctions" and the occurrence of recurring general patterns "would indicate not just differences of feature configurations but also point towards spaces that share non-explicit qualities."

Presenting the measurements of each space as multidimensional feature vectors to the neural network, we gradually get a two-dimensional distribution of points whose distance from each other reflects their proximity in the initial multidimensional space (figure 7).

**Physics simulation of a system of particles and springs.** This is not a dimensionality reduction method per se, but by enabling the spatial expression of dynamic associations among multiple elements it can support the understanding of interrelations within complex data structures.

A Particle-Spring System simulation is employed for the visualisation of the associations of spaces in multiple dimensions, taking into account all measurements simultaneously by treating them as components of physical forces.

Each space is represented as a point-mass particle. All particles are connected to each other in pairs via virtual springs whose rest length is set as the Euclidean multi-dimensional distance between the respective feature vectors of the connected particles. The particles representing the voids are initially located in positions corresponding to their geographic location on the map, but under the exertion of the forces of the springs tending to reach their rest lengths, the system comes to a state of dynamic equilibrium where the relative position of the particles reflects associations among the represented spaces (figure 8).

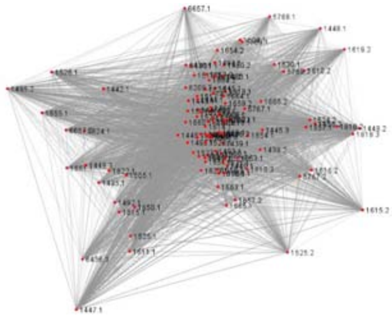
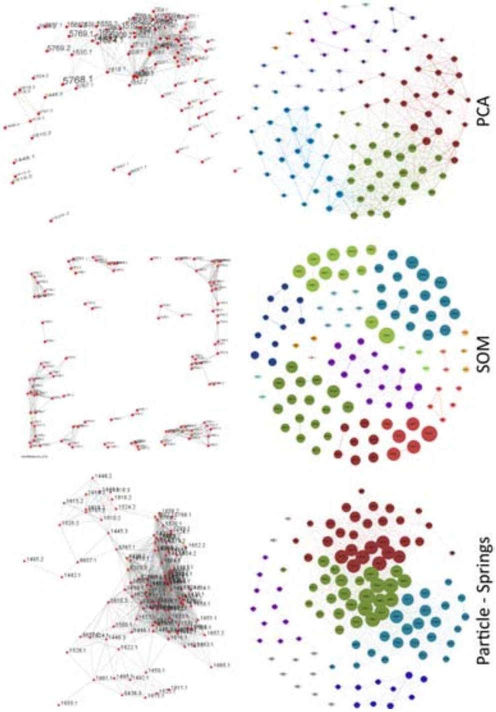


Figure 8
Particle-Spring system simulation. The particles move under the exertion of the springs' tensions until they reach a spate of equilibrium.

## *Classification: typology extraction through clustering*

All three methods used for dimensionality reduction result in two or three-dimensional distributions of points, where closely related spaces are plotted closer together. In this sense, distance accounts for abstract degrees of variance. Although this offers a general visualisation of convergences and divergences along all measurements, there are not yet obvious, well defined groups that would allow for the classification of the spaces into distinct types.

In order for separate clusters to appear, the structure of relations among the points needs to be made visible. The first step in this direction consists in generating a complete graph for each of the three distributions, by connecting all the points to each other. Each connection is assigned a weight according to its length and weaker connections, corresponding to longer distances between points are filtered out. The second step refers to the actual cluster extrapolation. Modularity is calculated for the resulting weighted graphs and each cluster is considered to represent a distinct "generic spatial type" (figure 9).




## COMPARISON OF METHODS

The classification results deriving from the different mapping methods appear to converge, with the same combinations of spaces persistently forming clusters. Most diversions from this pattern seem to occur due to different cluster scales across different methods: larger groups from one method correspond to merged smaller groups from another method and most unclassified points correspond to the same voids in all methods (figure 10, 11).

The graphs deriving from SOM and Particle-Springs produced equal numbers of clusters, with the SOM exhibiting a more even distribution in terms of sizes, whereas the Particle-Springs gave few large clusters and an amount of single, unclassified points. The graph generated from PCA resulted in fewer clusters with a limited number of prevailing large groupings and many smaller clusters and single points (figure 9, 10).

Since the intention was to perceive general and interchangeable generic spatial types and not unambiguous distinct classes, all results can be considered as equally valid. Different groupings could support alternative distributions of generic functions and offer a spectrum of possibilities within the same urban planning strategy.

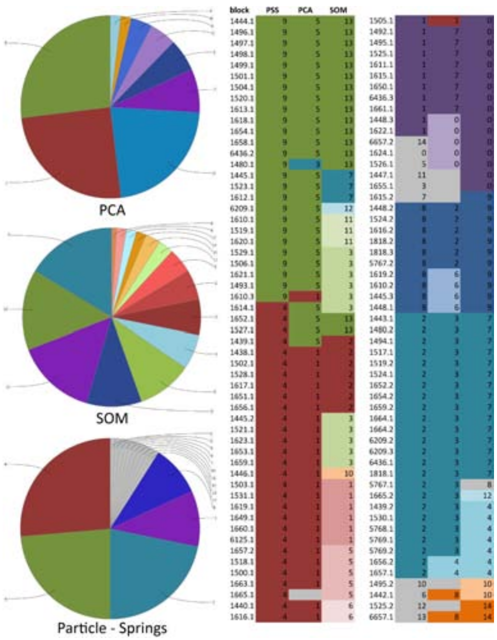



Figure 9
Clustering: weighted connections (left) and graph modularity analysis (right). Results for PCA, SOM and Particle - Springs respectively (from top to bottom).

Figure 10
Cluster distribution and comparison of results deriving from the three mapping methods. Number of clusters and population of each cluster for each method (left). Correspondence of clusters across methods (right).

## PRELIMINARY RESULTS AND CONCLUSIONS

The proposed approach for classifying non-typical urban voids is based on the hypothesis that there are inherent properties of spatial structure which can be measured and that abstract qualities related to spatial perception can be derived from their combination.

Following this hypothesis, the synchronous view of multiple attributes of a set of spatial representations could lead to the appearance of patterns revealing relations among the respective spaces, in terms of abstract degrees of similarity and difference.

The relative position of each spatial unit mapped in reduced dimensionality structures depends on a set of intrinsic relations that cannot be discerned a posteriori and examined as distinct components (Hanna 2007b). These relations are not expressed through specific describable features but rather as degrees of proximity through cohesion or dispersion of points. This system of abstract interrelations does not explicitly reveal elements regarding the nature or cause of the different degrees of conversion or diversion among the initial data.

By graphically mapping and visually examining the resulting types on the area plan (figure 11), there is a sense of accordance between the classification and the perceptive impression of the respective voids in terms of similarity and differentiation. This intuitive validation can be attributed to different allocations of abstract spatial qualities within each type, such as openness, introversion, connectivity, accessibility, convexity, fragmentation, self-similarity, homogeneity, symmetry and scale. These qualitative perceptive features are rooted in the concepts that formed the selection criteria for the specific set of initial attribute types and measurement methods, but they do not unequivocally derive from any one of them in isolation.

Consequently, distinct types do not explicitly correspond to specific morphological, typological or technical spatial characteristics; neither can they be directly linked to any individual measurement.

In Badiou's words "the class of multiples which are connected to the event will not be determined by any of the properties which can be formulated in the language of the situation" (Badiou 2005).

The difficulty of precise verbal expression of perceptive properties of spatial structure refers to non-discursive spatial attributes (Hillier 1996) related to generic features.

In this sense, the resulting types, referred to as generic types, exhibit multiple identities and openness to multiple interpretations, programmatic specifications and uses. Therefore, the assignment of generic functional types to generic spatial types is not a straight forward process. There is no unique or correct correlation but a wide range of equally fit possible suggestions.

For this task, the spatial types need to be interpreted, lose their generic character and be verbally described, acquire names and properties. Even though the initial selection of features according to which the classification is performed is based on criteria regarding the perceptive character of the voids' physical form and structure as well as spatial requirements of the proposed generic functions, the resulting types do not explicitly express them in a one-to-one relation. This means that the spatial types need to be empirically post-evaluated. At a first level, the same criteria can be applied. At a next level, external criteria, not necessarily connected to the physical form of space, need to be taken into account. For example, such criteria could refer to the present functions of the buildings surrounding each void, architectural typology of buildings, the existence or not of adjacent empty buildings that could also be reused, demographic characteristics of the specific block, the possibility of combination with other voids in its proximity, environmental properties, proprietary issues etc.

In this context, the methodology for classifying non-typical spatial formations into generic types, based on multiple descriptions of their physical form and structure, acts as an open and generalisable framework for setting out a strategy for the reacti-


Figure 11
Visualisation of the types resulting from PCA, SOM and Particle - Springs respectively on the area map. Each colour corresponds to a type and unclassified spaces are shown in gray.

vation of urban voids in the metropolitan centre of Athens and other urban settings with similar generic spaces. According to Badiou (2005) "as a general rule, the multiple (and its sub-multiples) fall under numerous determinants" and in this sense, this framework is only meant to depict possibilities and not to set out final and definite land use plans.

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