KYRIAKIDIS CHARALAMPOS
M.Sc. Urban and Transport Planner, c.Ph.D.
National Technical University of Athens, School of Rural and Surveying Engineering
kyriakidisharry@gmail.com

ILIADIS FILIPPOS
M.Sc. Urban and Transport Planner
GAIAOSE S.A.
Iliadis.fil@gmail.com

Compactness evaluation of the Athens metropolitan area

Abstract
In recent decades, the compact city model is considered an ideal model of residential development that can lead to city sustainability. This perception follows the principles of European urban planning, obeying its historical course. The same views are expressed to a large extent in Greek literature regarding the organization of the urban space, which is becoming a reality through the development of the first Sustainable Urban Mobility Plans (SUMPs) in various municipalities in the country. The compact city is the target of modern Greek city planners. However, the question arising is to what extent modern Greek cities are compact. This question is of special interest in the spatial context of the metropolitan complex of Athens, which contains about half of the country's population.
Therefore, the aim of this announcement is to investigate the degree of compactness of the residential areas of the municipalities that constitute the metropolitan complex of the Greek capital. In order to study this issue, a computational indicator based on the literature was proposed. The municipality index was estimated based on open source data was used, while a comparative analysis of the indicator values per municipality was carried out. Another issue that has been studied is the investigation of associations between municipalities in terms of specific compactness parameters.
The results of the survey highlight the fact that Athens is a compact residential area with its municipalities organized in three categories of compactness. Based on these categories, the structural affinity of the municipalities of the Athens urban complex is established, while the degree of influence of the parameters, which determine the compact urban form, is shown. In addition, it has been observed that, in a certain extent, the farther a municipal is from the city centre, the lower its compactness index is. However, besides the conclusions made for Athens, it is important to highlight the potential of this methodology as it can be used in the future for other cities, in order to provide comparative analysis on the organization of cities and to monitor the progress of interventions for sustainable mobility and urban development.
Key words: Compact city, Compactness index, Self-organizing maps (SOM), Athens.

Introduction

The question of the ideal urban form has been a subject of discussion as old as the theory of urban planning (Barbopoulos, et al., 2005). However, recently this debate has arised again, since the recognition of the importance of urban planning and, as a consequence, of urban form in promoting sustainable development (Breheny, 1996).

The two approaches to the theory of ideal urban form are the compact and the diffused urban form (Bakogiannis, et.al., 2014; Corbella and Drach, 2017). The first one conflicts with urban diffusion (Newman, 2005; Kosar, 2014), while the latter systematically supports expansion policy and connectivity with the city centre via a competent highway system (Rodi, 2012).

The above two approaches, although they appear to have purely planning dimensions, are both based on different philosophical concepts and approaches to the development of cities. The diffused city is based on the view of non-intervention, adopting a 'laissez faire' system, with the planning effect being spatially indeterminate and characterized by a low urbanity and reduced sociability (Aesopos, 2006). On the other hand, the approach of the "compact" city is based on the perception of interventionality and adopts a model of full exploitation of the urbanized territory (area) by promoting cohesion in the residential fabric (Lock, 1995 in Portokalidis and Zygouris, 2011), with the result that their inhabitants co-exist with a large number of people, which does not allow them to develop meaningful relationships with everyone (Simmel, 1903).

Today, after several years of scientific quests, research tends to promote consistency and the creation of high-density urban arrangements, as a model that approaches the sustainable city to a satisfactory extent (Barbopoulos, et al., 2005; Portokalidis and Zygouris, 2011; Lim and Kain, 2016; Mouratidis, 2017). For this reason, it is supported and promoted by several leading institutions around the world (Mouratidis, 2017). The European Union, in particular, promotes the compact city model through a series of guidelines, such as the Green Paper on the Urban Environment (1990) and the document entitled 'Thematic Strategy on the Urban Environment' (2004). The question, however, is: How exactly is the compact city defined, or even better, what are the parameters that make a city compact?

Indeed, despite the increased literature concerning compact cities, there is no clearly defined definition (Newman, 2005) and, therefore, there are no clear criteria that make a city compact. Three important criteria that determine the compact city, according to the OECD (2012), are building density, public transport and accessibility to local services and jobs. A similar approach is taken by Clercq and de Vries (2000), who emphasize the importance of accessibility and public transport as important features of compact cities, since population and urban density are identified as an integral part of compact cities. In fact, according to Burton (2002), it is the only decisive element in characterizing a city as compact. In the above parameters, Lee, et al. (2015) and Mouratidis (2017) add mixed land uses. The use of the above parameters is critical for the development of tools for measuring compactness, since there are a few tools and indicators (see in Burton, 2002; Lee, et.al., 2014).

In Greek literature, the use of an indicator to measure the compactness of cities has not been suggested. Nowadays, this is a major drawback, as several Greek cities have already been under Sustainable Urban Mobility Plans (SUMPs), and the absence of such an indicator poses problems in monitoring the development of cities and the results of SUMPs, which aim indirectly to the compact city. The aim of this paper is to formulate a measuring compactness indicator. In this way, it is possible to answer a crucial question: How compact is the metropolitan complex of Athens? The above question could be rephrased as follow: How compact are the municipalities of the metropolitan complex of Athens? Thus, in the context of this paper, using the proposed indicator, the degree of compactness of the municipalities of the metropolitan complex is investigated, and a typology is attempted, regarding the degree of compactness in relation to the distance of the areas from the city centre. The following sections present the methodology followed, as well as the results for the case study of the metropolitan complex of Athens.

Methodology and results

In order for the paper's research question to be investigated, the following methodological steps were taken:

1. *Study area borderline:* The municipalities of the metropolitan complex of Athens were designated as the study area. This spatial reference is very broad and allows the area to be assessed and bordered in different ways. The assessment chosen in the context of this paper is not administrative, but the boundaries were determined on the basis of the urbanity of the regions. This considered to be necessary because the municipalities within the boundaries of the metropolitan complex include large areas within their administrative boundaries that are not inhabited (eg. Mount Imittos), and, therefore, the results will present the specific municipalities as diffused, while their residential areas may be characterized by high densities.

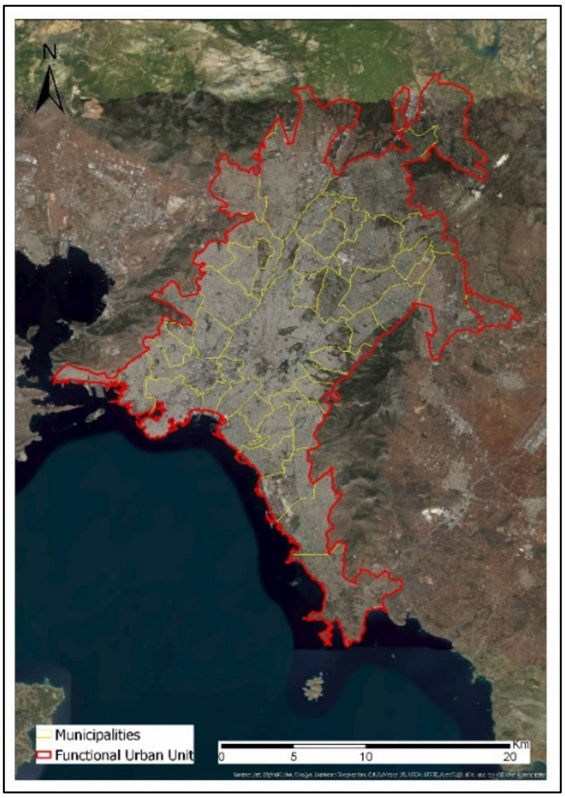


Figure 1. Study Area borderline.

2. *Determination of compactness parameters:* From the literature research, four basic parameters related to the compact city have emerged. These are (Clercq and de Vries, 2000; OECD, 2002; Burton, 2002; Lee, et.al., 2014; Lee, et.al., 2015; Mouratidis, 2017): (a) building and population density, (b) public transport, (c) accessibility and (d) land-use mix. Given the fact that Greek cities are characterized by mixed land-use (SEMPCHPA, 2017), which is reflected also in the General Urban Planning of the

municipalities under consideration, interest has been focused on the other parameters: 1. Population density (pop/km2), 2. Cycle path (%) coverage, 3. Transport sites (%) coverage, 4. Average building height (m) and 5. Public & Green spaces (%) coverage. The variables were constructed based on data derived from the Hellenic Statistical Authority (2011), Open Street Map and Athanasopoulos and Vlastos (2018). Data manipulation was mainly performed through the QGIS 2.18 software.

Variables	Variable construction method
1. Population density (pop/km2)	Each municipality's population from the year 2011 was divided by its total area in km^2.
2. Cycle path (%) coverage	A 300m buffer was applied (polyline data) and its total area was divided by the municipality's total area in km^2.
3. Transport sites (%) coverage	A 300m buffer was applied in transport sites (point data) including subway, train and bus stops. After that the buffer's total area was divided by the municipality's total area in km^2.
4. Average building height (m)	Data about building height were available in a sub municipal level, thus the average building height in meters was calculated.
5. Public & Green spaces (%) coverage	The total area of the public and green spaces of each municipality was divided by the municipality's total area in km^2.

Table 1. Variable Construction and definition.

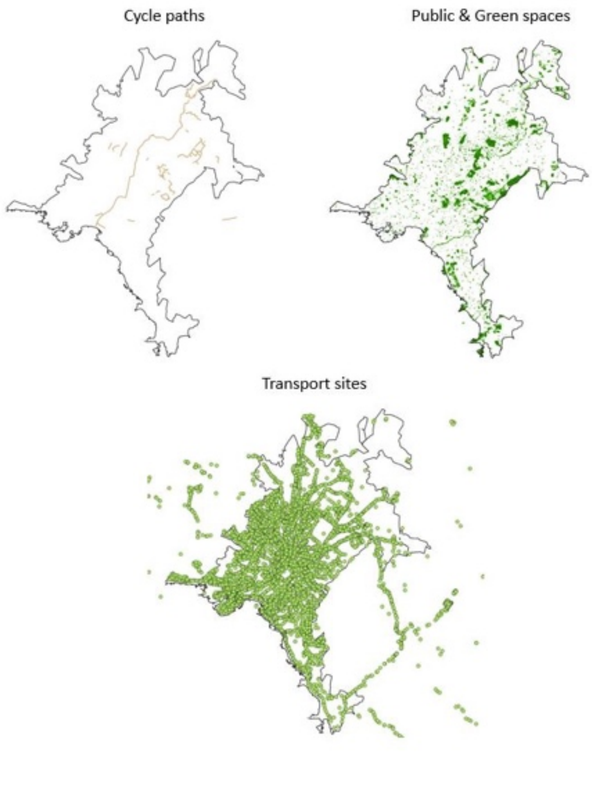


Figure 2. Variable geographical characteristics

3. *Compactness index estimation:* After the variable construction, data were inserted in a table. A normalization method *(Xi = Xi – Xmin / Xmax – Xmin)* was applied in order for the data to range between 0 and 1. Afterwards they have been added up *(Index=V1+V2+V3+V4+V5)* considering that their values have a positive contribution to the final index (Psatha, 2014).

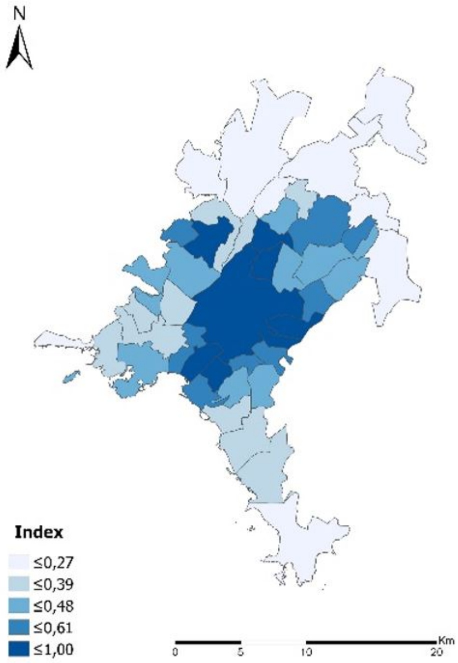


Figure 3. Indexed municipalities.

Municipal	Population density (pop/km2)	Cycle path (%) coverage	Transport sites (%) coverage	Average building height (m)	Public & Green spaces (%) coverage	Ranking Index
ZOGRAFOU	14242,1	46,3	90,8	14,4	28,0	1
KALLITHEAS	21386,2	34,4	91,0	11,9	8,3	2
ATHINAION	17035,4	18,7	94,2	12,3	13,7	3
NEAS SMIRNIS	20860,8	0,0	100,0	13,6	8,4	4
GALATSIOU	14208,3	10,8	76,1	10,9	30,4	5
KAISARIANIS	11276,3	0,0	65,9	11	36,0	6
NEAS IONIAS	15256,5	27,2	97,6	8,7	8,7	7
ILIOU	11289,6	25,2	99,8	7,3	20,1	8
PETROUPOLEOS	15574,5	0,0	96,4	9,2	19,8	9
VIRONOS	16162,3	0,0	85,8	10,2	16,3	10
DAFNIS - IMITOU	13820,3	29,2	99,8	7,9	4,3	11
VRILISSION	8675,2	59,4	48,9	9,1	6,9	12
PALAIOU FALIROU	13367,4	1,6	94,5	12	4,8	13
PAPAGOU - HOLARGOU	8725,0	19,7	57,2	9,8	20,8	14
AMAROUSIOU	5381,2	23,1	62,6	8,9	23,3	15

MOSHATOU - TAUROU	8146,5	30,2	93,0	8,9	2,7	16
AGIAS PARASKEVIS	8425,2	15,9	68,7	9,4	14,8	17
ILIOUPOLEOS	13175,8	0,0	95,5	9,1	7,7	18
PEIRAIOS	14623,6	0,0	90,2	9,9	2,8	19
AGIOY DIMITRIOU	14307,0	0,7	95,5	8,4	5,5	20
CHAIDARIOU	9644,3	0,0	88,1	7,7	16,5	21
FILOTHEIS - PSIHIKOY	4477,3	38,7	48,6	8,2	14,1	22
IRAKLEIOU	10597,6	24,6	67,7	8,6	2,6	23
HALANDRIOU	7229,4	32,1	66,9	8,5	3,5	24
PERISTERIOU	13498,0	0,0	98,8	7,6	3,0	25
AGIAS VARVARAS	12225,9	0,0	79,5	7,2	11,3	26
KORIDALLOU	16716,6	0,0	60,0	8,4	4,6	27
FILADELPHIAS - CHALKIDONOS	994,9	1,7	99,5	8,6	15,0	28
AIGALEO	10893,0	0,0	91,7	7,5	5,2	29
AGION ANARGIRON - KAMATEROU	7996,4	16,0	88,5	6,8	2,7	30
ALIMOY	6972,5	0,0	77,8	9,7	6,0	31
NIKAIAS - AGIOU IOANNI RENTI	10792,9	0,0	81,0	8,1	3,8	32
KERATSINIOU - DRAPETSONAS	12464,8	0,0	64,2	8,2	4,7	33
GLIFADAS	6369,9	0,0	71,5	9,7	6,2	34
ELLHNIKOY - ARGIROUPOLIS	4727,4	0,0	65,0	8,6	15,2	35
LIKOVRISIS - PEUKIS	7551,8	1,7	63,7	8,8	6,9	36
PERAMATOS	7724,9	0,0	81,4	6,9	2,5	37
METAMORFOSEOS	5595,2	0,0	71,5	7,9	2,1	38
VARIS - VOULAS - VOLIAGMENIS	2231,5	0,0	45,2	8	14,2	39
KIFISIAS	2942,8	32,1	23,0	6,8	6,1	40
PENTELIS	4795,9	2,8	30,6	7,3	11,7	41
ACHARNON	2884,5	0,0	45,3	5,9	6,1	42
FILIS	4241,1	0,0	33,5	5,3	3,0	43
DIONISOU	1920,7	0,5	3,3	5,8	9,7	44
PALLINIS	2415,4	4,0	0,6	6,2	4,4	45

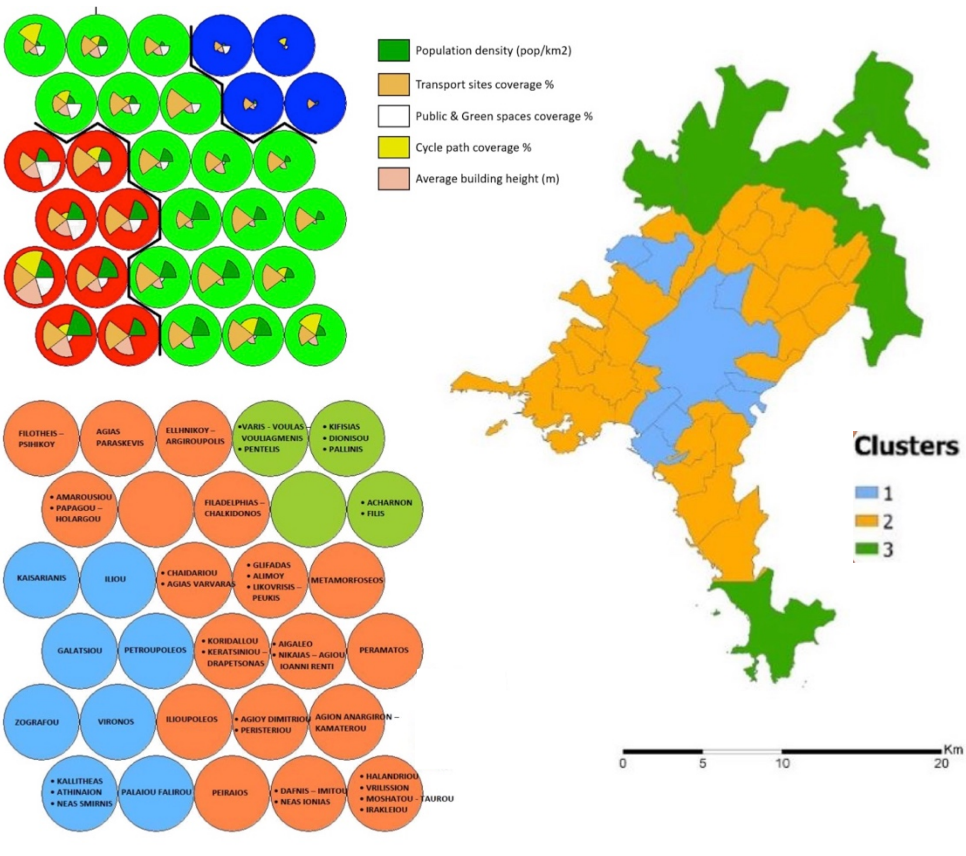
Table 1: Quantitative characteristics of the study area

4. *Clustering:* The self-organizing map approach (SOM), one of the most popular unsupervised neural network learning models (Li and Shanmuganathan, 2007; Roh,

et.al., 2003). SOM is a data visualization technique based on unsupervised artificial neural networks that can transform multi-dimensional data into two-dimensional maps. This technique was first introduced by Teuvo Kohonen in the 1980s. The main idea is the assignment of weights in randomly generated vectors. During the training process weights can be updated according to data characteristics, thus data with similar characteristics would be re-organized to closest nodes.

Analysis was performed via the R statistical package and specifically with the Kohonen library. Clusters were represented in 5 x 6 grid while only two nodes were left blank. The model was trained through 500 iterations (Kohonen, 1982; Xueying et.al, 2012; R project, 2017).

The figures below illustrated some aspects of this clustering algorithm to the study area. In figure 4a, the weights of each node are presented. It can be said that the difference between each cluster is mostly based on the quantitative extent of each variable and no certain typology can be observed. Figure 4b presents the spatial dimension of each cluster, while figure 4c shows, in a more specific way, in which cluster each municipality is assigned, as well as their structural resemblances and differences.



4a 4b 4c

Figure 4. a. Node weights and clusters. b. Study area clustering. c. Municipality clustering

5. *Descending index hypothesis*: The visual results revealed a pattern. It can be observed that Municipalities that tend to be farther from the metropolitan areas' central location (Municipality of Athens) tend to have lower compactness index. Thus, the centroid of each municipality was constructed along with its associative distance from

the Athens municipality centroid. After that, a polynomial regression analysis was fitted as it could better explain the findings.

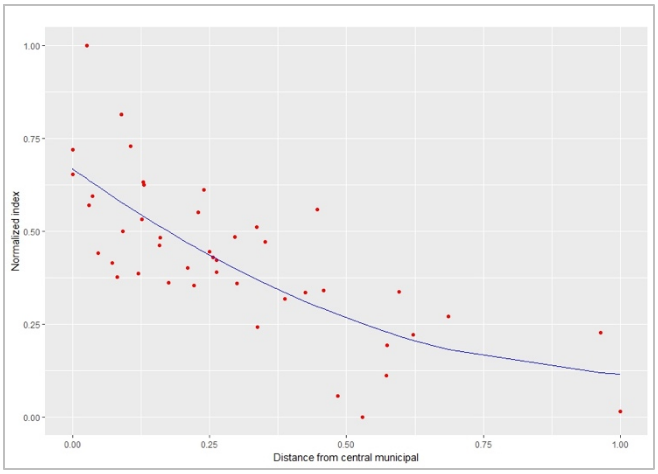


Figure 5. Polynomial OLS correlation diagram (Norm. Index VS Dist. from central municipal).

Dependent variable: Normalized index	**Confidence interval**: 95%	**Formula**: $f(x)= c - bx + ax^2$
	coefficient	**p-value**
const	0.668338	2.32e-018 ***
Norm_dist	−1.05433	0.0001 ***
Norm_dist^2	0.501990	0.0763 *
Adjusted R^2	0.555476	

Table 2: OLS model (Norm. index vs Dist. from central municipal)

The OLS model show that a certain correlation between these two variables may exist, although the Adjusted R2 is relatively small (0,555).

Conclusions

Nowadays, the compact city model is considered as the most sustainable one in comparison to other models. For that reason, various organizations (including European Unions) promote this urban form through different policies and legislation. Although, the international bibliography is sufficient in regard to the positive effects of the compact city, certain methodological approaches have to yet been explored. Under these circumstances, there is not any adequate definitions about the parameters that constitute a compact city, as well as value thresholds that can determine a city's compactness level.

In Greece most cities can be considered as compact ones to a sufficient extent. But as it has been mentioned above, methodological frameworks and studies are missing, even for the Athens metropolitan area which is the biggest urban area in the country.

This paper's goal is to investigate several of these aspects e.g. how compact are the municipalities of the metropolitan area. This research question was approached via some methodological tools like SOM, statistical and geographical analysis.

The final variables were constructed based on various data. These were: Population density (pop/km^2), Cycle path (%) coverage, Transport sites (%) coverage, Average building height (m) and Public & Green spaces (%) coverage. After that, a compactness index was estimated for each municipality. In order, for the variances and the different characteristics of each unit to be better evaluated, a SOM clustering approach was performed. It was observed that the study area was characterized by three clusters. The cluster form seemed to depend on the municipality's distance from the central one (Athens municipality). Thus, a correlation analysis was performed, based on each unit's centroids, and the results tend to validate this hypothesis. So, it could be said that a certain typology could be applied in Athens metropolitan area. The city tends to be more compact in the center but an area's compactness level will decrease the farther this area is from the city center.

References

Aesopos, I. (2006). The diffused city. In: Gospodini, A. and Beriatos, H. (eds). New urban landscapes and the Greek city. Athens: Kritiki Publications, 104-120.

Athanasopoulos, K. and Vlastos, Th. (2018), Mapping the Geography of Cycling Infrastructure in Greece through an Open Participatory Procedure. In; 11th International Conference of the Hellenic Geographical Society (ICHGS-2018): «Innovative Geographies: Understanding and Connecting our World», Laurio, Greece, 12-15 April 2018.

Bakogiannis, E., Kyriakidis, C., Siti, M., Eleftheriou, V. and Siolas, A. (2014) Urban planning VS environment. Re conciliating the conflicts. In: 4th Pan-Hellenic Conference in Rural and Surveying Engineering, Thessaloniki, Greece, September 2014.

Barbopoulos, N., Milakis, D. and Vlastos, Th. (2005) Seeking the form of a sustainable city: A critical approach to the compact urban model. Aeichoros, 4(1), 20-45.

Breheny, M. (1996) Centrists, decentrists and compromisers: views on the future of urban form. In: Jenks, M., Burton, E. and Williams, K. (eds). The compact city. A sustainable urban form? Oxford: Oxford Brookes University, 13-35.

Burton, E. (2002). Measuring urban compactness in UK towns and cities, Environment and Planning B: Planning and Design, 29, 219-250.

Clercq, F. and de Vries, J., 2000. Public transport and the compact city. Transportation Research Record: Journal of the Transportation Research Board, 1735.

Corbella, O. and Drach, P. (2017) Compact cities VS spread cities. In: 33rd PLEA International Conference: Design to Thrive, Edinburgh, UK, January 2017.

Hellenic Statistical Authority (2018) Available online at: www.statistics.gr [Retrived on January 2018]

Kohonen, T. (1982) Self-organized formation of topologically correct feature maps. Biological Cybernetics, 43, 59-69.

Kosar, A.S. (2014). Sustainable compact city concept. Razprave, 41, 145-164.

Lee, J., Kurisu, K., An, K., & Hanaki, K. (2015). Development of the compact city index and its application to Japanese cities. Urban Studies, 52(6), 1054-1070.

Lee, J., Kurisu, K., An, K. and Hanaki, K.(2014). Development of the compact city index and its application to Japaneese cities. Urban Studies, 52(6), 1054-1070.

Li, Y. and Shanmuganthan, S., 2007. Social area analysis using SOM and GIS: A preliminary research. RCAPS Working Paper, No. 07-3. Available online at: http://en.apu.ac.jp/rcaps/uploads/fckeditor/publications/workingPapers/RCAPS_WP07-3.pdf [Retrived on March 2018].

Lim, H. K., & Kain, J. H. (2016). Compact cities are complex, intense and diverse but: can we design such emergent urban properties?. Urban Planning, 1(1).

Mouratidis, K. (2017). Is compact city livable? The impact of compact versus sprawled neighbourhoods on neighbourhood satisfaction, Urban Studies, 1-23.

Newman, M. (2005) Compact City Fallacy. Journal of planning, education and research, 25(1), 11-26.

OECD (2012). Compact city policies: A comparative assessment. OECD Green Growth Studies. OECD Publishing.

OpenStreetMap (2017) Available online at: www.openstreetmap.org [Retrived on January 2018]

Portokalidis , K. and Zygouris, F. (2011). The peculiar "Compact Diffusion" of Greek cities. In: Proceedings of the 9th National Conference of ERSA-GR, Athens, 6-7 May 2011.

Psatha, E. (2014) Quality of life comparative study in Greek middle-sized cities. PhD thesis. University of Thessaly.

Rodi, A. (2012). Urban sprawl or compact city? Overcoming the dilemma through urban planning. In: Proceedings of the 3rd Pan-hellenic Conference on Planning and Regional Development, 1, 679-680.

Roh, T. H., Oh, K. J., & Han, I. (2003). The collaborative filtering recommendation based on SOM cluster-indexing CBR. Expert systems with applications, 25(3), 413-423.

R project (2017) Package “Kohonen”. Available online at: https://cran.r-project.org/web/packages/kohonen/kohonen.pdf [Retrived on January 2018]

Simmel, G. (1903) The metropolis and mental life. In: Brdige, G. and Watson, S. (eds). The Blackwell city reader. Oxford and Malden, MA: Wiley-Blackwell, 2002

UNSPECIFIED (1990) Green Paper on the Urban Environment. COM (90). Available online at: http://aei.pitt.edu/1205/ [Retrived on March 2018].

UNSPECIFIED (2004) Towards a thematic strategy on the urban environment. Communication from the Commision to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. COM (2004) 60. Available online at: http://aei.pitt.edu/38666/ [Retrived on March 2018].

Xueying J., Kean L., Jiegou Y., Wenhui C. (2012) Application of Improved SOM Neural Network in Anomaly Detection. 2012 International Conference on Medical Physics and Biomedical Engineering, 33, 1093 – 1099.