Urban Atlas, land use modelling and spatial metric techniques

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Abstract

This paper is focused on the use of the Urban Atlas dataset that was recently released by the European Environment Agency for analyzing urban environments. The Urban Atlas provides information on land use for all cities in Europe with population of more than 100.000 inhabitants. After providing an overview of the differences between this dataset and the CORINE LC data that have been available for some years, it discusses how the dataset could be used for land use modeling. Finally it presents the estimation of various landscape metric indicators for several cities in Greece. These indicators can be used for comparing the structure and the form of the various cities.

1. Introduction

Availability of consistent datasets on land uses in urban environments for major parts of Europe has been an issue that has severely hampered research in the area of comparing various cities as well as monitoring the way cities grow. The traditional methodology to obtain information has been from various sensors, aerial imaging and/or satellite sensors. Aerial images if available for some cities could provide a higher spatial resolution, but their availability has been always an issue since they were proprietary, land use classes had to be derived if not available though in situ research and not amenable for comparative analysis. High spatial resolution satellite images nowadays available at a relatively low cost for most cities could provide information on land use after significant processing at a resolution of about 30 m (Landsat type), or higher (2.5 m for SPOT 5). The CORINE LC database (EEA 2010a) first developed in 1990 and then again in 2000 covered all of Europe, with the various land uses identified (Büttner et al. 2004). However, the focus being on agricultural, forests and wetlands areas out of the 44 land cover classes there are only two classes related to urban fabric. Of course, with a resolution of 100 meters it would be impossible to obtain more detail in urban areas.

Addressing the issue European Space Agency (ESA) started in 2009 through the Global Monitoring for Environment and Security (GMES) program releasing the Urban Atlas, a dataset on land use for all cities in Europe with a population of more than 100,000 inhabitants. Information on the dataset are available at http://www.eea.europa.eu/data-and-maps/data/urban-atlas (EEA 2010b). The data have been produced from sensors with spatial resolution of 2.5 meters and have a minimum mapping unit of 0.25 ha. There are a total of 20 distinct land use classes. Data for more than 200 cities have been released so far and the process is expected to be completed by the end of 2011. The dataset is produced with uniform standards for all cities thus permitting cross comparisons. Most important to maximize the use of the dataset ESA is making the dataset available for free for either private or business use. Users can download, without even registering, the dataset for any city they might be interested.

The availability of such an extensive and inexpensive dataset will drive research in analyzing urban areas and in conjunction with the upcoming release of the 2011 Census data will result in an environment that would stimulate model application. Land use models (Wegener 1994, Waddell 2002, Torrens and Benenson, 2005) have been used since the mid sixties for forecasting and policy assessment in urban areas. Application of such models has been always faced with the lack of suitable datasets which the Urban Atlas might solve partially.

Using the Urban Atlas there are many different ways for analyzing the structure of a city. Providing simple percentages for different land use classes is one way for accomplishing this. However they hide the morphology of an area. Increasingly in the last ten years spatial metric techniques are used to define indicators for the landscape that could be used for comparing the structure and the form of the various cities. They provide a framework for examining unique spatial components of intra-and inter-city urban structure, as well as, the dynamics of change (Gustafson 1998, Alberti and Waddell 2000, Herold et al. 2002).

This paper consists of four different parts. In the following section there is a discussion about the Urban Atlas dataset and its differences and similarities with the CORINE LC dataset. In the next section the potential application of the dataset for land use modeling is elaborated, whereas in the next section there is a discussion on the estimation of spatial metric indicators for the cities in Greece. Finally the findings of this study are summarized in the Conclusions.

2. Urban Atlas dataset

The Urban Atlas brings together thousands of images from European satellites and provides detailed and cost-effective mapping of larger urban zones, yielding accurate land cover and usage data. As it has been already mentioned, the Urban Atlas dataset can be downloaded from the EEA Urban Atlas website. Additionally, the respective maps can be also seen through a map viewer, which will be gradually improved (EEA 2010b).

The Urban Atlas provides high resolution land use data based on the exact same boundaries as the Urban Audit for all its Larger Urban Zones. The Urban Audit is a collection of statistical data collected by Eurostat in the EU-27 member countries. In future, the analysis of Urban Atlas data will benefit significantly from having access to socio-economic data for the same areas and vice versa the Urban Audit will benefit from having access to reliable and comparable urban land use data and a spatial representation of its information. The implementation of the Urban Atlas project was awarded to the French company SIRS in December 2008. Until September 2010 228 (out of 305 planned) cities (> 100.000 inhabitants) have been mapped using very high resolution (2.5 m) Earth Observation (EO) data (Spot 5, Formosat-2, Kompsat-2 and ALOS data) for the reference year 2006 ± 1 year (EIONET 2011). Until June 2010, the following nine Greek cities have been mapped: Athens, Thessaloniki, Patra, Heraklion, Larissa, Volos, Ioannina, Kavala and Kalamata.

The Urban Atlas cities are mapped using in total 20 classes of which the 17 are urban classes. The urban fabric (CORINE LC classes 1.1.1 and 1.1.2) are differentiated by their degree of imperviousness which is integrated from the Land Monitoring Core Service (LMCS) high resolution soil sealing layer. The production is based on a mix of photo-interpretation and object oriented classification with a 3-step validation involving a project internal quality assessment, independent experts and a technical review by the European Topic Centre Land Use and Spatial Information. So far the quality of products is good, errors have been reprocessed by the contractor and the production is going on quite smoothly, except some problems with the availability of required EO data (EIONET 2011).

The scale of CORINE LC is 1:100.000 and the minimum mapping unit is 25 ha. The scale of Urban atlas is 1:10.000 and the minimum mapping unit is 0.25 ha for the artificial surfaces and 1 ha for the other surfaces.

The complete Urban Atlas nomenclature scheme is shown in Table 1 (Meirich (2008). The CORINE LC nomenclature scheme (EEA 2010a) has been adopted, however especially for artificial surfaces a fourth level is used to distinguish the different subcategories. For example the CORINE LC class 1.1.2 (Discontinuous Urban Fabric) has been broken down into the following sub-classes in Urban Atlas: 1.2.1.1.0 (Discontinuous Dense Urban Fabric: sealing level 50% - 80%), 1.1.2.2.0 (Discontinuous Medium Density Urban Fabric: sealing level 30% - 50%), 1.1.2.3.0 (Discontinuous Low Density Urban Fabric: sealing level 10% - 30%). Future editions of the Urban Atlas are planned every three to five years, communicating on the evolution of cities.

Table 1. *The Urban Atlas nomenclature* (Meirich (2008).

Class code	Nomenclature
11100	Continuous Urban Fabric (Sealing Degree > 80%)
11210	Discontinuous Dense Urban Fabric (Sealing Degree 50% - 80%)
11220	Discontinuous Medium Density Urban Fabric (Sealing Degree 30% - 50%)
11230	Discontinuous Low Density Urban Fabric (Sealing Degree 10% - 30%)
11240	Discontinuous Very Low Density Urban Fabric (Sealing Degree < 10%)
11300	Isolated Structures
12100	Industrial, commercial, public, military and private units
12210	Fast transit roads and associated land
12220	Other roads and associated land
12230	Railways and associated land
12300	Port areas
12400	Airports
13100	Mineral extraction and dump sites
13300	Construction sites
13400	Land without current use
14100	Green urban areas
14200	Sports and leisure facilities
20000	Agricultural + Semi-natural areas + Wetlands
30000	Forests
50000	Water bodies

As explained by Bossard et al. (2000), when defining the minimum mapping unit, we must keep in mind that, in reality, land cover occurs is a combination of surfaces which to a greater, or smaller degree are homogeneous/heterogeneous, whatever the scale used. Furthermore, irrespective of how they have been processed, data acquired by satellite systems do not provide a representation of the actual land cover situation, nor can land cover be mapped in all of its complexity

Therefore, taking into account the note of Lavalle et al. (2002) on the compatibility between CORINE LC and other datasets, it can be stated that the CORINE LC nomenclature is neither always detailed enough nor compatible with that of the Urban Atlas. For example, CORINE states that class 1.1.2 (discontinuous urban fabric) can be distinguished when buildings, roads and other artificially surfaced areas cover between 50% and 80% of the total surface area of the unit. According to both this definition and the scale 1:100.000, CORINE individuates areas corresponding to class 1.1.2 and marks them out as polygons, shown in Figure 1, where the CORINE LC map of the city of Heraklion is shown. However, the same polygons investigated at the scale of Urban Atlas are divided in smaller zones as shown in Figure 2, where the respective Urban Atlas map of the city of Heraklion is shown. The Urban Atlas classification is therefore more detailed (4 Levels). Consequently, the area classified by Urban Atlas would most probably show parts where artificially surfaced areas cover more than 80% of the total surface area of the unit, and for this reason correspond to continuous urban fabric. In this case, the portion of land analyzed would be classified differently according to CORINE or Urban Atlas guidelines. It should be noted that the land cover mapped by CORINE correspond to year 2000, whereas the land cover mapped by Urban

Atlas correspond to the 2008, therefore there are differences between these two maps due to the sprawl of the city.

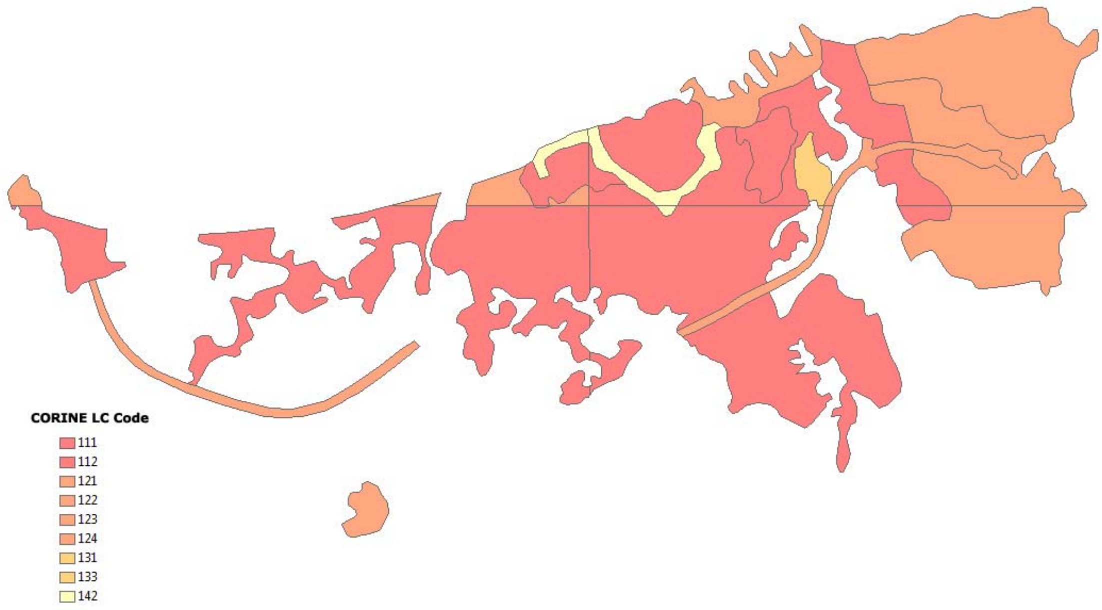

Figure 1. *The artificial surface for the city of Heraklion, as provided in CORINE LC dadaset. Only the artificial surfaces are presented. The codes in the legend are explained in Table 1.*

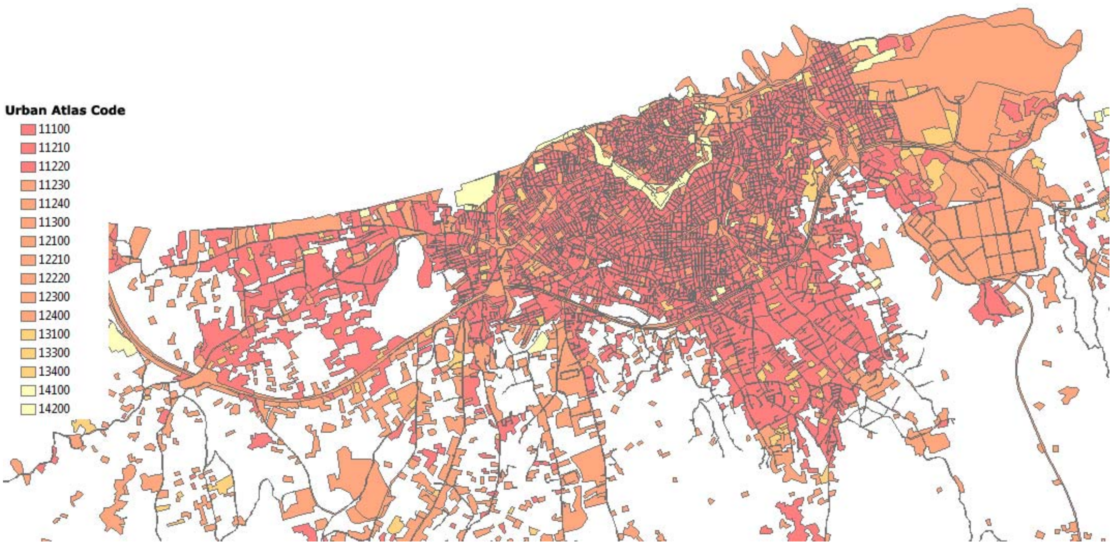

Figure 2. *The artificial surface for Heraklion, as provided in Urban Atlas dataset. Only the artificial surfaces are presented. The codes in the legend are explained in Table 1, however a more detailed classification (Level 4) has been adopted in Urban Atlas (Meirich 2008).*

It is therefore of basic importance to bear in mind that a feature having a certain attribute in CORINE LC might have a different one in Urban Atlas dataset, because the minimum mapping unit is smaller and the mapping scale is more detailed.

3. Urban land use modeling

Urban modeling can be described as the art of expressing in mathematical terms the interaction of people and activities in the urban environment. Cities grow and sometimes contract based on the behavior of many individual stakeholders. Their behavior is not necessarily deterministic and the objectives of each one can be conflicting. The issue in land use modeling is to express in mathematical terms the various relationships thus providing a framework that can be used for simulating the way cities grow and most importantly to estimate the impact of various policies before they are implemented. Given the heterogeneity of the various stakeholders it is an art to be able to select the appropriate framework that will permit a valid representation of the real world, anticipate the changes that will occur in the future as a result of changing socio-economic conditions and technology and accomplish this with parsimony.

Land use modeling has been around since 1964 when Lowry (1964) first presented a model for Pittsburgh. Since then there has been a multitude of models developed for different cities following different methodologies. Until the mid-90's the lack of data forced modelers to use larger traffic analysis zones (TAZ), the lower spatial unit at which the various variables/activities are estimated. With the availability of GIS datasets since 1995, detailed satellite images around 2000 and the increasing power of computers the size of the traffic analysis zone became smaller and nowadays it is not uncommon to use TAZ representing one city block. The availability of data at higher spatial resolution resulted also to the application of a new set of mathematical methodologies for urban modeling. Whereas in the 1990's relationships among the various variable of the models were expressed through statistical-econometric type equations, these, in many instances, were supplanted by techniques of cellular automata, agent modeling and microsimulation. These techniques provide some advantages over the more traditional methodologies since they do not impose the same equations for all TAZs, but often are addressing a limited set of variables. This paper will not discuss the details and the advantages/disadvantages of the various methodologies since this is not its objective. Detailed information on the various urban models can be found in Wegener 1994, Southworth, 1995, Landis and Zhang 1998, Klostermann 1999, Waddell 2002, Parker 2003, Benenson and Torrens 2004, Miller et. al. 2004, Mantelas, L.et. al. 2010, and the various references cited there.

The implementation of all urban models requires at least three ingredients; information on the location of economic and residential activities, data on the transportation network and data on land available for development and the associated zoning constraints. The former two should be available for two time periods thus permitting the calibration of the model parameters. The level of detail on the variables being simulated is an important issue. A model used to simulate just the growth of an urban area without going into the details of the various activities (residential, basic/nonbasic employment or by sector) requires fewer data but could have limited use for operational purposes and simulating the impact of some policies.

Traditionally large operational urban models for various urban agglomerations have been developed using data from the decennial census, surveys on the location of employment activities and elaborate surveys on the travel behavior of individuals. For models with more limited capabilities the CORINE dataset readily available for two time periods for all of Europe has been used. As part of the Murbandy/Moland project (2002) datasets for 25 cities in Europe were produced with a classification of land use classes relative similar to the Urban Atlas. The scale of these datasets is 1:25.000 (versus 1:100.000 and 1:10.00 for CORINE and Urban Atlas respectively) and the minimum mapping unit is 1 ha. (versus 25 ha. and .25 ha for CORINE and Urban Atlas). However, the Murbandy/Moland datasets are proprietary and not readily available.

There is no doubt that the availability of the Urban Atlas will provide a major thrust in the art of modeling. On the other hand it will not provide answers to all the difficulties faced by modelers when trying to implement a model. In the section below, detailed information are provided of how the Urban Atlas dataset might affect urban modeling.

Definition of TAZ/cells:
The minimum mapping unit is .25 ha this means that traffic analysis zones or more correctly cells of dimension 50x50 meters could be defined. However, as stated in the Mapping Guide (page 11) the interpreted area should be interpreted with at least 100m extension to ensure accuracy and continuity of polygons. Thus cells of 100x100 might be on the average a more appropriate minimum cell size. Of course, depending on the type of study (local scope vs metropolitan) larger cell size might be used. Cell size is also affected by the size of the city blocks since going at TAZ smaller than city blocks is unreasonable.

Detail of land use cover:
The land use classes of interest for urban modeling are:

- Continuous urban fabric and the four discontinuous urban fabric areas; these are mainly residential but could also be buildings for office type of employment. Detailed characteristics of the housing type could be obtained by superimposing datasets from the Census. Information on employment by place of work would need additional surveys. In conjunction with zoning constraints datasets the areas of discontinuous urban fabric could provide information on the land available for infill/new development.
- Industrial, commercial, public, military and private units; all of these are separate categories and therefore could be used to identify areas of employment in terms of industrial and office employment; information on employment could be obtained from surveys or company registers. Limited information could be obtained with respect expansion of these activities in these areas.
- Road network; the road network contains 8 types of roads. It is not clear how good and detailed the network provided is and alternative sources such as those available from commercial vendors or Open Street Map (http://www.openstreetmap.org) might provide better source of data. For rapid transit no information is available, hence the location of transit stations and the connectivity of the network should be obtained from other sources.
- Construction sites, land without current use; information on these areas combined with zoning constraints could provide info for areas where new/re development can occur.
- Agricultural, semi-natural, wetland areas; these areas a priori should not be available for development, however, their conversion to urban areas is an issue affected by legislation and its enforcement.

Overall, the detail of land use cover if combined with data from the census could provide a relatively good data source for implementing models addressing macro type of policies.

Availability for multiple time periods
The Urban Atlas datasets have been developed for all cities using EO data from 2006. Comparable datasets for other periods do not exist and it should not be expected that ESA would produce a similar dataset for the next five to ten years. Nonetheless, urban modelers will find ways to overcome this problem. CORINE data could be used for the two urban fabric classes that are similar, although the differences in minimum mapping unit will result in methodologies that do not take advantage the detailed datasets of Urban Atlas. Another way will be to develop datasets of land use classes for previous years by processing EO data readily available such as Landsat (Chrysoulakis et al. 2011).

The lack of exactly similar datasets for another time period will stimulate development of modeling techniques which will be based on calibrating models based on datasets that are not exactly similar and calibration techniques that might be ad-hoc or heuristic. Models based on using the Urban Atlas and assuming patterns of urban growth similar to some other cities or obtained through a Delphi process when used for projecting urban growth will undoubtfully emerge. These procedures should not be discarded on the grounds of scientific excellence, as long as the assumptions they are based on are reasonable.

Modeling frameworks

The availability of a similar dataset for many places will permit the replication of the same modeling framework for different cities. Efforts such as those carried out at TRL in the mid 90's when different models were compared on the same dataset might reemerge. However, the major revolution on modeling frameworks might come by adapting the framework of open source software/open street data. That is making data and models available to use for free or at a minimum cost on the internet. Planners, special interest groups and individuals might be interested to use such a framework. Of course this might create problems if the modeling methodologies are not robust and not based on reasonable assumptions. The same level of freely available simulation packages could become also available under the Google Earth/ Microsoft Bing frameworks.

4. Landscape metrics

Spatial metrics are used to define indicators for the landscape that could be used for comparing the structure and the form of the various cities. In the last ten years there has been an increasing interest in applying spatial metric techniques analysis of urban environments, to examine unique spatial components of intra-and inter-city urban structure, as well as, the dynamics of change (Alberti and Waddell 2000, Herold et al. 2002, Gustafson 1998). Recent efforts have built on the fractal measures previously used to measure form, and have employed a variety of metrics to describe urban form (Herold et al. 2005a,b). The landscape perspective (patch-based representation) assumes abrupt transitions between individual patches that result in distinct edges. These measures provide a link between the detailed spatial structures that result from urban change processes.

The landscape metrics discussed in the literature have concentrated on addressing the issue of urban vs non-urban land use in order to address the issue of the continuous expansion of urban areas in the periphery. In this paper, the problem is slightly different. There are data for only one time period and there are more land use classes. Hence, the various landscape metrics are estimated for each land use separately and the objective is to use the indices to obtain information on the form of the city.

In this paper, the following landscape metrics, as proposed by Herold et al. (2003) were considered:

- Patch Density (PD): The ratio between number of patches and total area.
- Edge Density (ED): The ratio between perimeter of all regions in the area and total area.
- Largest Patch Index (LPI): The area of the largest patch of the corresponding patch type divided by the total area of urban agglomeration.
- Euclidean Nearest-Neighbor Distance (ENN_MN): The distance mean value over all urban patches to the nearest neighbouring urban patch, based on shortest edge-to-edge distance from cell centre to cell centre.
- Area Weighted Mean Patch Fractal Dimension (AWMPFD): The area weighted mean value of the fractal dimension values of all patches of the same class.
- Contagion Index (CONTAG): The overall probability that a cell of a patch type is adjacent to cells of the same type.

The CONTAG index is the only index estimated for all classes, whereas all other indicators are estimated separately for each class. The above landscape metrics indicators were calculated for all cities in Greece for which the Urban Atlas contains data. As shown in Table 2, there are information for 9 urban agglomerations. The term urban agglomerations is more appropriate for some of them since the area covered includes not only the main city of the area but also all neighboring cities.

Table 2. *Greek cities for which information are available in the Urban Atlas*

Urban agglomeration	Population (1991)	Population (2001)	Total area (Urban Atlas)	Total artificial area (Urban Atlas)
Athens Metropolitan area	3.523.407	3.761.810	3.042.235.353	71.065.489
Thessaloniki Metropolitan area	733.005	773.180	1.425.817.472	15.564.938
Patras Metropolitan area	165.947	176.716	512.632.621	5.077.613
Heraklio Metropolitan area	140.034	163.834	604.441.776	4.475.044
Larisa	114.334	126.076	1.549.413.171	12.226.108
Volos Metropolitan area	106.210	114.368	304.256.687	3.517.881
Ioannina	63.725	70.203	1.325.265.942	8.212.613
Kavala	60.187	63.293	351.612.006	1.893.764
Kalamata	50.693	57.620	441.717.334	2.805.237

Since a large portion of the area covered in the urban atlas is agricultural, semi natural, forests and water bodies and our objective was to identify the form of the cities only the area covered by artificial surfaces was considered. Additionally, some of the land use classes were aggregated since for some of them the percentage coverage of the whole area was very small. The following land use classes were considered:

- Main Class 1 (MC1): It contains the Urban Atlas class 1.1.1.0.0 (Continuous Urban Fabric); this is similar to the Class 1.1.1 of CORINE, however, of different resolution as discussed in Section 2 of this paper.
- Main Class 2 (MC2): It contains the Urban Atlas class 1.1.2.1.0 (Discontinuous Dense Urban Fabric); this is similar to the Class 1.1.2 of CORINE, however, of different resolution as discussed in Section 2 of this paper.
- Main Class 3 (MC3): It contains the Urban Atlas classes 1.1.2.2.0 (Discontinuous Medium Density Urban Fabric), 1.1.2.3.0 (Discontinuous Low Density Urban Fabric) and 1.1.3.0.0 (Isolated Structures).
- Main Class 4 (MC4): It contains the Urban Atlas class 1.2.1.0.0 (Industrial, commercial, public, military and private units).
- Main Class 5 (MC5): It contains the Urban Atlas classes 1.2.2.1.0 (Fast Transit Roads and Associated Land), 1.2.2.2.0 (Other Roads and Associated Land) 1.2.2.3.0 (Railways and Associated Land), 1.2.3.0 (Port Areas) and 1.2.4.0 (Airports).
- Main Class 6 (MC6): It contains the Urban Atlas class 1.3 (Mine, Dump and Construction Sites).
- Main Class 7 (MC7): It contains the Urban Atlas class 1.4 (Green areas and sport facilities).

The FRAGSTATS software (McGarigal et al. 2002) was used to estimate the various indicators for each of the 7 Main Classes. It must be pointed out that the various land uses are not uniformly distributed in every urban agglomeration. In Class 6 the area covered by the different land uses in the various urban agglomerations in most cities is less than 3%, whereas in Class 7 the green areas and the recreational areas represent about 2-3% in most urban agglomerations, a percentage that is definitely very low.

The CONTAG index describes the heterogeneity of a landscape by the probabilities that a pixel of patch class a is adjacent to another patch class b. It measures to what extent landscapes are aggregated or clumped. Landscapes consisting of patches of relatively large, contiguous landscape classes are described by a high contagion index. If a landscape is dominated by a relatively greater number of small or highly fragmented patches, the contagion index is low. The more heterogeneous the urbanized area becomes, e.g. resulting from higher fragmentation or more individual urban units, the lower the contagion index (Herold et al. 2003). The estimated values of CONTAG for each of the Greek urban agglomerations analysed are shown in Table 3, whereas the estimated values of the other landscape metrics that were calculated for the different Main Classes are shown in Table 3. The distribution of CONTAG in urban agglomerations is shown in Figure 3. Lower values of CONTAG are observed in bigger and more compact cities as expected.

Table 3. *CONTAG values for each city under study.*

Urban agglomeration	CONTAG
Athens Metropolitan area	20,0429
Thessaloniki Metropolitan area	23,0459
Patras Metropolitan area	22,2434
Heraklio Metropolitan area	30,9903
Larisa	31,3259
Volos Metropolitan area	26,7743
Ioannina	28,8144
Kavala	26,4984
Kalamata	28,8413

The values of CONTAG range from 20 for Athens to 31 for Larisa. The lowest values are for Athens, Patras and Thessaloniki the three largest urban agglomerations in terms of population. It is reasonable that in these areas there is mixed use hence the overall probabilities of adjacency of the various patches is the lowest. Among the other urban agglomerations Volos and Kavala have about the same CONTAG whereas Larisa and Heraklion have the highest.

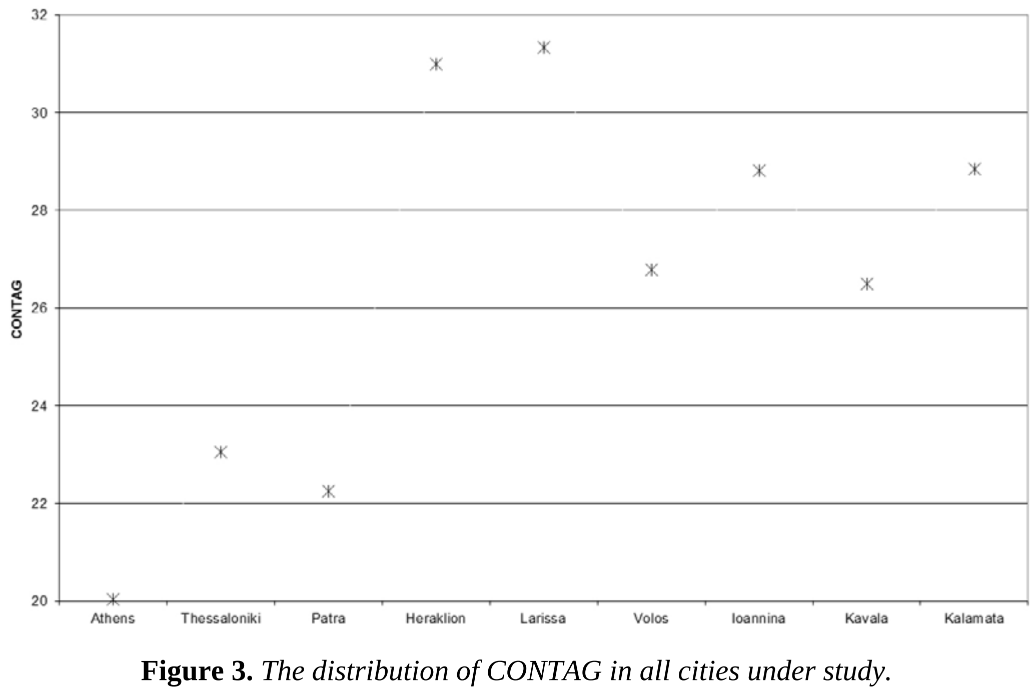

Figure 3. *The distribution of CONTAG in all cities under study.*

Table 4. L*andscape metric indices for the different Main Classes for each city under study.*

Main Class	PD	LPI	ED	FRAC_AM	ENN_MN	PD	LPI	ED	FRAC_AM	ENN_MN
			Athens					**Volos**		
MC1	0,9976	6,3964	23,4608	1,2775	385,1773	1,6338	13,0587	43,3552	1,3102	279,343
MC2	3,0564	0,8399	36,5495	1,1514	314,9302	5,7065	1,4266	48,7539	1,1396	178,744
MC3	4,5834	2,7275	55,054	1,1654	309,3732	13,2126	1,8647	75,4514	1,127	200,596
MC4	3,3229	1,1235	31,4441	1,1178	382,4871	10,4659	8,4887	68,8806	1,1392	272,351
MC5	9,9259	1,3387	63,7623	1,068	288,0983	38,809	0,9235	119,292	1,0693	158,228
MC6	1,0111	0,1895	6,8096	1,0503	654,7055	2,8888	1,9712	18,9428	1,0874	343,502
MC7	1,2164	0,3007	11,3257	1,0861	520,8393	2,0127	0,219	10,8211	1,0631	473,855
			Thessaloniki					**Ioannina**		
MC1	1,0956	5,8583	27,1444	1,2333	649,0041	1,5862	2,4564	15,7977	1,2096	514,97
MC2	4,2395	1,3079	48,8056	1,1161	300,556	5,9614	0,8942	60,9661	1,1531	260,26
MC3	5,4239	0,1481	32,3463	1,0442	367,2405	13,5835	0,2582	70,7332	1,0896	245,203
MC4	6,1396	2,9563	53,9779	1,1267	387,0388	23,5795	1,0166	106,6454	1,0793	226,603
MC5	9,693	2,749	58,395	1,0598	343,2006	57,666	1,485	153,006	1,0472	163,233
MC6	1,5596	0,3652	10,996	1,0564	701,5615	3,4172	1,9055	35,2894	1,1355	393,375
MC7	1,2881	0,153	9,3327	1,0473	636,375	1,1178	0,314	8,2502	1,0859	1043,02
			Patra					**Kavala**		
MC1	2,6564	5,4719	29,7839	1,2645	316,1629	1,8227	8,3011	34,948	1,2459	390,85
MC2	8,8242	0,5003	63,9527	1,1338	207,3259	4,2397	2,8232	51,0946	1,1612	231,064
MC3	16,2838	1,8285	111,1121	1,1441	202,1701	11,8474	1,6543	62,0109	1,1175	291,466
MC4	8,6605	0,7596	52,6905	1,0949	280,6626	7,2511	2,5557	53,2145	1,0936	270,494
MC5	42,5745	0,7551	146,1906	1,0939	151,4223	40,9708	5,2897	133,056	1,0644	162,468
MC6	3,3295	0,796	19,1585	1,0829	334,6809	2,3774	3,1798	20,9212	1,0655	631,13
MC7	5,3127	0,3593	26,7637	1,0774	240,3288	2,2585	0,6637	14,1852	1,0814	431,928
			Heraklion					**Kalamata**		
MC1	1,1619	4,3329	19,6232	1,2616	452,987	2,1614	3,2331	22,5144	1,1976	205,701
MC2	3,0177	3,5462	37,8424	1,171	428,8131	6,4841	0,6844	38,4726	1,1076	247,015
MC3	14,6851	4,2643	121,5476	1,1495	212,9886	21,5418	1,1437	135,6268	1,1255	170,155
MC4	7,4394	2,8604	53,0036	1,1029	284,8007	10,5548	2,0443	63,1484	1,1037	308,595
MC5	38,4556	2,8241	111,849	1,0609	169,1226	58,6816	8,6996	166,1203	1,0577	161,454
MC6	2,1947	0,8513	14,201	1,0582	457,4814	2,8458	0,3332	13,7968	1,058	606,541
MC7	0,8553	0,4478	7,0359	1,0905	1358,7562	2,0893	0,1531	11,2392	1,0573	577,927
			Larissa							
MC1	2,4876	2,3369	31,0602	1,2069	370,0551					
MC2	4,3812	0,8392	50,1216	1,168	186,3163					
MC3	10,9143	0,3099	49,6482	1,0839	327,9803					
MC4	7,9017	1,0738	58,2729	1,0981	309,0127					
MC5	86,9187	3,9014	237,3093	1,0647	173,1029					
MC6	2,2552	0,4734	15,855	1,0781	583,6188					
MC7	1,2395	0,4433	7,325	1,0932	824,8193					

It is difficult and probably not useful to discuss all the spatial metric indicators, hence the discussion is focusing on some of the main issues. The discussion covers mainly the indicators for the 5 first land use classes since it was felt that these are the dominant land uses in the cities examined. Green areas which is of concern in all urban areas, however, the total coverage as discussed earlier in less than 4% in most cities.

PD: *The ratio between number of patches and total area.*
For most cities the value of the PD indicator is the lowest for the continuous urban fabric class with the second lowest being for the discontinuous dense urban fabric. This is reasonable since these two land uses areas are more compact rather than other land uses. The highest values of the indicator are for MC5 (Transport infrastructure) which again is reasonable given the fact that this "land use class" provides connectivity in a city and therefore is dispersed. For all cities the PD indicator for Dump sites and Green areas is low.

Comparing PD indicators in the same city for Athens and Thessaloniki the relative difference between the PDs of the various land use classes is about the same. In Thessaloniki the indicator for industrial activity is higher than in Athens signifying a wider dispersion of commercial activity.

LPI: *The area of the largest patch of the corresponding patch type divided by the total area of urban agglomeration*
This indicator can be considered as a measure of the separation of the urban landscape into smaller individual patches versus a dominant core. The values this indicator takes for continuous urban fabric are somehow similar for the three largest cities, implying that the distribution of this land use is similar in all three cities. These are the cities with the lowest CONTAG. For Volos the value is significantly higher which means that there is a relatively large concentration of continuous urban fabric. To a lesser extent this is also true for Kavalla.

ENN_MN: *The distance mean value over all patches of a certain land use class to the nearest neighboring patch of the same class, based on shortest edge-to-edge distance from cell centre to cell centre.*
In all cities the sequence of the values of this indicator for the various land uses is similar, with the one for Continuous Urban Fabric having the largest value implying that these areas are more segregated, that is they are further apart. This is reasonable since it would be expected that continuous urban fabric areas will be further apart. The largest value appears in Thessaloniki indicating that the continuous urban fabric areas are further apart and probably this being an indication of a defined multicenter city.

ED: *The ratio between perimeter of all patches of a land use class in the area and total area*.
As expected the highest values for this indicator for all the cities is for the transport infrastructure land use class. In all urban areas the ED indicator takes the lowest values for the continuous urban fabric, with higher values for the other two classes of discontinuous urban fabric. This implies that the continuous urban fabric areas have on the average a smaller perimeter. For Athens for patches of class 1, 2 and 3 the average perimeter is respectively 270, 370 and 435 m/ha. For industrial activity the relative similarity of the value of this index for all cities is worth noting and can be again explained by the fact that for this land use there are similarities on both the average area of the patch as well as on the perimeter.

AWMPFD: *The area weighted mean value of the fractal dimension values of all patches of the same class.*
This indicator that can take values between 1 and 2 can be considered a measure of the complexity of the shapes of the various patches of a land use class. A value close to 1 implies simple shapes, whereas values of 2 denote highly convoluted shapes. For all land uses with the exception of continuous and discontinuous urban fabric this index takes values less than 1.1 thus making difficult any valid comparative interpretation. Continuous urban fabric for all

cities has values of 1.2 and only for Volos it reaches a value of 1.3. One issue that might explain the low values for this index is that the minimum mapping unit of 0.25 ha and the image resolution of 2.5 m. result in patches that are not zagged but have a relatively simple shape.

5. Conclusions

There is no doubt that the availability of Urban Atlas will have major impact on the analysis of urban areas. It will provide a dataset that can be immediately used for planning purposes and estimating various indicators particularly if combined with other datasets. Just by comparing percentages of land use classes planners will be able to develop a macro image of the form of the city.

Urban modeling will be affected as well. The level of detail in the dataset will provide datasets that will permit the application of sophisticated or more simple models for monitoring growth and/or estimating the impact of various policies. Modeling frameworks might emerge as open source or as part of the Google Earth/ Bing Maps infrastructure.

For urban metrics the Urban Atlas dataset will permit a comparison of urban areas in different countries and different sizes. Research in the area of the definition of urban metrics might be stimulated since the metric indicators used today have been defined on the basis of datasets that contained fewer land use classes. New landscape indicators might be developed that consider the distribution two or more land use classes simultaneously.

In conclusion the availability of such a massive dataset for almost all urban cities in Europe, developed with the same standards might revolutionize the field of urban studies and research thus leading to a more sustainable future.

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