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THE EFFECT OF URBAN DENSITY, GREEN SPACES AND MOBILITY PATTERNS IN CITIES' ENVIRONMENTAL QUALITY: AN EMPIRICAL STUDY OF THE METROPOLITAN AREA OF THESSALONIKI

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It has been proved that urban development patterns affect in various ways cities' environmental quality. To this purpose, one of the factors that have been examined is the role of urban green spaces, in balancing the effects of human activities in dense urban landscapes. One of the major external costs of dense urban environment is smog and greenhouse gas emissions that are heavily related to existing mobility patterns. High levels of concentration of such emissions along with high urban density are considered to be the main reason for cities' environmental degradation. In this context this paper presents the results of a study investigating how urban green spaces can improve air quality, in major transportation axis within the city of Thessaloniki. In order to do so, urban density along the axis, green space per capita, green space spatial distribution, mobility patterns and transport emissions volumes are being considered. Comparison of these indices among the transportation axis under study indicates that there is a positive relation between building density, urban density and volume of emissions observed, while a dispersed rather than a concentrated pattern of green spaces could better help improve cities' environmental quality.

Key words: **Urban patterns, urban mobility, green spaces, environmental quality.**

THE ISSUE OF URBAN DENSITY AND ENVIRONMENTAL QUALITY

Cities are considered to be as emergent phenomena of interactions among socioeconomic and biophysical forces (Alberti *et al.,* 2003). Thus different urban development patterns reflect the amount and interspersion of built and natural environment within urban fabric. Recently great emphasis has been given on the effect of green spaces in improving cities' air quality through the absorption of various air pollutants, while relevant research has shown that appropriate allocation of urban green spaces, considering air pollution sources and urban density, has significant effect on improving air quality (Bolund and Hunhammar, 1999).

In this context, there have been many studies and empirical research examining the environmental performance of urban patterns at the local, regional and global scale (Alberti, 1999). Furthermore there is an extensive bibliography related to the impact of urban development patterns on landscape, with urban density being one of the major determinants of cities' environmental performance. Specifically to urban density there has been a long lasting and extensive debate about the impacts of dense or sprawl urban patterns on quality of life. Most planning scholars argue that extensive urban sprawl has negative effects on the environmental and social sustainability of our cities (Newman and Kenworthy, 1999; Calthrope, 1993; Cevero and Kockelman, 1997), when several empirical studies have shown that areas with different residential and job density

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or with the same density but with clustered, rather than dispersed, development patterns have different effect on energy consumption, transportation related atmospheric emissions and urban air quality.

On the other hand there have been serious concerns and critics about compact high density development patterns. Opponents to dense urban development approach (Cox, 2003; Crane, 1996) argue that one of the principal reasons that compact city strategies cannot reach its objective of reducing traffic congestion (or its rate of growth) is because of the strong positive relationship between higher population density and higher traffic volumes (Ross and Dunning, 1997). Moreover, as more vehicle miles occur in a confined geographical location, traffic slows down and is subject to more stop-and-go operation, leading to increased time spent in traffic and higher air pollution emissions, since most vehicle created pollutants are emitted at higher rates in lower speeds (Cox, 2003). Also, the presence of high buildings on either side of the road, common in many city centres, creates a 'street canyon', which reduces the dispersion of the emitted pollutants from traffic sources and can lead to significantly higher concentrations locally (EEA, 2012).

The hypothesis that spatial configuration of elements in an urban region, influences ecosystem has been examined in various ways both by environmentalists and urban planners. Alberti (1999) identified four elements that are relevant to the metropolitan scale and can be examined in relation to a broad range of environmental variables. These elements were *form, density, grain* and *connectivity*. More specifically, *form* refers to the degree of centralization/ decentralization of urban structure, *density* is the ratio of population or jobs to the area, *grain* indicates the diversity and heterogeneity of functional land uses and *connectivity* measures the interrelation and mode of circulation of people and goods across the location of fixed activities (Alberti, 2005). Furthermore Alberti (2005) identified four dimensions according to which the interaction between urban landscape and natural ecosystem functions should be considered, one of them being the ability of the environment to act as a an absorbing factor of emissions and waste.

Thinking about urban green spaces as absorbing surfaces within urban environment the question that this paper poses is how green spaces can improve air quality through the absorption of transport emissions. Related bibliography indicates that urban green spaces have important ecological effects (Attwell, 2000; DeRidder *et al.*, 2004), and enhancement of green spaces has the potential to mitigate and adverse effects of urbanization in a sustainable way, making cities more attractive to live in reversing urban sprawl and reducing travel demand. A survey on ecological function on green spaces indicates that vegetation cover in urban parks may filter up to 85% of surrounding urban pollutants (Miller, 1997; Bollund and Hunhammar, 1999; Jim and Chen 2008). Allocation of green space is also quite important in mitigating the negative effects of urbanization since more dispersed forms of green space may be preferred when congestion externalities are present (Wu *et al.*, 2003). In addition, other research showed that suitable allocation of urban green spaces, considering the air pollution sources and urban densities has significant effects on improving air quality and the whole ecosystem balance (Smith, 1990).

In this context this paper investigates how certain factors like urban density, green space per capita, green space spatial distribution and mobility patterns could affect air quality[2]. Different parts of the Metropolitan Area of Thessaloniki (MATh) are being examined in order to evaluate how green space can mitigate the adverse effects of urbanization. Furthermore comparison of indices amongst the transportation axis under study will help on one hand to set planning priorities and formulate recommendations regarding the use of green space as a design tool in urban planning strategies, and on the other hand to consider alterations in existing mobility patterns.

METHODOLOGY

Taking into account the four structural variables (form, density, grain and connectivity) that Alberti identifies as major elements in examining the relation of urban patterns and environmental performance of cities (Alberti, 1999, 2003, 2005), four group of indices were identified:

Building density: The main parameter describing the form of a city is its overall density. Building density refers to the degree of centralization or decentralization of urban structures and to the intensity of development of a city. Many studies have shown that intensity of development in a city has significant effect on the travel distances, modal splits, economic productivity, and lower per capita energy and carbon dioxide emissions (Beatley, 2000).

In order to measure building density *floor area ratio index* (FAR) was used. Floor area ratio is defined as the total square meters of a building divided by the total square meters of the lot the building is located on. Generally, higher FARs tend to indicate more dense urban tissue. On the other hand buildings of varying numbers of stories can have the same FAR, because FAR counts the total floor area of a building, not just the building's footprint. Therefore, in order to avoid any misinterpretations additional data that has to do with the height of the buildings have been used to identify the "intensity" of building structures.

Urban Density: Urban density is referring to *grain*, meaning the diversity and heterogeneity of functional land uses. Mixed land use is considered to be a critical issue in achieving more efficient, equitable and livable cities, since having residential, commercial, recreational and light industry uses in close proximity to one another, creates viable alternatives to driving and increases viability of public transit (http://www.smartgrowth.org/principles/mix_land.php).

Urban density index has been calculated as the sum of square meters that each functional land use occupies to the build surface for each building block, multiplied by a diversity factor. More specifically the function used to calculate urban density index, is as follows:

$$UDIndex = (\Sigma L_i / TL) * (n/n_{max}) * 100$$

[2] It should be mentioned that this paper presents the results of a research conducted solely by the authors. The crude data used in this paper was acquired from other research programs that authors participated in the past.

where,

ΣL_i = sum of functional land uses in the zone (in square meters);

TL = total build surface of building block;

n = number of land uses recorded in the zone (except residential land use);

n_{max} = maximum number of land uses that could be recorded (according to relevant land use legislation, excluding residential land use).

Functional land uses include all sorts of uses like commerce, administration, education, health, recreation etc. and doesn't include residential use. Values of urban density index close to 100 indicate greater mix and heterogeneity of urban functions.

In addition to urban density, population density was also calculated to depict residential concentrations. The index is calculated as the number of residents per hectare for each building block. This index is extensively used in US and Australian cities to depict the imbalance between job and residential location, were center city population densities are very low. European cities have much healthier and balanced central districts with a mix of jobs, services and housing, which in turn have significant effects in mobility patterns (reduced need to travel). Therefore high population densities indicate a more balanced urban environment, more efficient mobility patterns and less transportation emissions. To this end net population density with values from a 100-400 people/ha are considered to be acceptable and appropriate for residential areas. Contrarily in areas with 400-600 people/ha, serious issues of light, air and congestion occurs. Such high densities could be realized in cases were mix density is high enough to ensure a hygiene urban environment (Aravantinos, 1997).

Finally, it should be noted that all crude land use and building data used in this paper to calculate the above mentioned indices was acquired from a research program conducted by the Aristotle University of Thessaloniki in 2007[3].

Green Space: Having set the indices that would help us identify urban landscape, the next step was to find indices that would consider the interaction between urban landscape and natural ecosystem mainly as a way to absorb transportation produced emissions. Green and open space that is integrated into urban fabric is considered to be the best absorbing surfaces for any air pollutants. Related research shows that creation and improvement of urban green spaces are suggested as main policies for mid and long-term environmental improvement in city scale (De Ridder et al, 2004). For the purposes of this research two types of indices were calculated: one related to the size and number of green spaces and one to their distribution. It should be noted that as green spaces both parks and open spaces (public squares) were considered.

As far as the size of green spaces the percentage of green space to the total area of the building block (in square meters) and to the total area of the zone under study was calculated. Furthermore in order to relate green spaces to the population living in the area a second index was calculated, the green space per capita (sqm/person). Despite the fact these two indices enabled us to make inferences about the amount of green space they did not give any information about its spatial distribution. Therefore two more indices showing distribution of green spaces were calculated.

The first spatial distribution index is related to the density of green spaces. Kernel Density method[4] was used to calculate the density of green spaces in a neighbourhood, therefore when two green spaces are close or in short distance then the intensity of the phenomenon under study is higher. Under this notion a series of maps showing Kernel Density, hence the density of green spaces, were created. Furthermore a Nearest Neighbour Analysis was performed in order to determine if the pattern of green spaces is random, regular or clustered. This type of analyses uses the distance between each green space and its closest neighbouring green space to determine the pattern[5]. If Nearest Neighbour Index (NNI) is smaller than one then pattern exhibits clustering, if index is larger than one then pattern is ordered. In order to calculate spatial distribution indices ArcGIS software program was used.

Finally, it should be noted that there are several other indices that could be used in order to evaluate urban green space quality i.e. the Biotope Area Factor (BAF), Greenspace Factor etc. More specifically BAF expresses the area portion of a plot of land that serves as a location for plants or assumes other functions for the ecosystem. Despite the fact that this index could add valuable information in regard to green space quality, data availability was the main factor that defined which indices could be used in the analysis described in this paper.

Mobility patterns, transportation emissions and air quality: Mobility patterns are considered as a major factor in assessing environmental performance of a city. They are strongly related to the use of car and transit, the journey-to-work distances and urban density. Furthermore, it has been proved that different urbans forms produce different mobility patterns (Banister 1997; Cevero and Kockelman, 1997). In this paper mobility patterns are considered to be the major determinant of produced air pollutants volumes (Đukić and Vukmirović, 2012). The major automotive emissions of concern to health are presented in terms CO, NO_x, VOC, PM, NH_3, SO_2 and heavy metals produced by different vehicle categories as well as greenhouse gas emissions (CO_2, N_2O,

[3] The research program was related to the development of a global methodology for the vulnerability assessment and risk management of lifelines, infrastructures and critical facilities, within dense urban areas (SRM-LIFE). An application to the metropolitan area of Thessaloniki was performed where a detail recording of building data and land use was made, in building bock level.

[4] Kernel method is used in statistics as a measure of similarity. In particular, the kernel function k(x,.) defines the distribution of similarities of points around a given point x. In this paper Kernel Density was used to calculate the density of features in a neighbourhood around those features (feature being green space).

[5] The Nearest Neighbour index measures the distance between each feature centroid and its nearest neighbour's centroid location. It then averages all these nearest neighbour distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analyzed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed.

CH_4). Besides, pollutants are influenced by the composition of traffic (HGVs, buses etc.) since different modes of transport use different types of energy, and therefore emit different pollutants. Vehicle composition in urban areas is generally different to the national composition. For example, buses, mopeds and motorcycles make up a higher proportion of vehicle composition in urban areas than they do nationally (EEA, 2012).

More specifically, the calculation of emissions was conducted using COPERT 4 model, a Computer Programme that calculates Emissions from Road Transport.[6] COPERT 4 estimates emissions of all major air pollutants (CO, NO_x, VOC, PM, NH_3, SO_2, heavy metals) produced by different vehicle categories (passenger cars, light commercial vehicles, heavy duty trucks, busses, motorcycles, and mopeds) as well as greenhouse gas emissions (CO_2, N_2O, CH_4). It also provides speciation for NO/NO_2, elemental carbon and organic matter of PM and non-methane VOCs, including PAHs and POPs. The general equation used to calculate emissions and fuel consumption is the following:

Emissions [g] = Emission_Factor [g/km] x Distance_Travelled [km]

were «*Emissions*» denote the emission factors for each vehicle category and «*Distance_Travelled*» is considered equal to the length of each road segment which is deducted from the GIS information system (http://emisia.com.copert).

In order to examine the connection between build environment and environmental quality a descriptive analysis of the above mentioned indices amongst the different study areas was performed. Furthermore, a series of maps were generated depicting their spatial distribution. The distribution and quantity of each index was measured, evaluated and compared for each one of the areas revealing the connection (if any) between urban green spaces and environmental quality.

APPLICATION TO THE METROPOLITAN AREA OF THESSALONIKI

The Metropolitan Area of Thessaloniki

Thessaloniki is the second largest city in Greece (after Athens), the administrative centre of the region of Central Macedonia and a significant industrial and commercial gateway for the Balkans and the wider Eastern Mediterranean region. Metropolitan area of Thessaloniki (MATh) consists of 11 municipalities, extends over an area of 1,455 km^2 and, according to the most recent census (2011), its population reaches approximately a total of 1,000,000 inhabitants. Since the early '80s MATh experienced tremendous changes in terms of its morphological and functional organization. Significant elements of these changes were the continuous urban expansion and the formation of a "new city" that lacked defined boundaries and dominant center(s) (Pozoukidou, 2014).

Key feature in Thessaloniki's urban structure is its high building and population density. Comparing to other European cities, Thessaloniki is considered to have high urban density that in many areas far surpasses the threshold limits set in several European cities[7]. This quite dense urban environment, combined with the non-existence green spaces and the inadequate road network leads to great degradation of city's environment. It is quite important to highlight that Thessaloniki's central business district (CBD) is characterized by a diversity and mix of urban functions with emphasis in businesses, service and commerce. In the areas adjacent to CBD there are smaller sub centers that function supplementary to center city and with the exception of certain transport axis these areas are predominantly residential (AUTH Research Committee, 2007).

Apart from commerce and services, CBD accommodates significant residential activity and a considerable number of archaeological sites and historical monuments. Due to the geomorphological constraints, CBD extends as a strip between the coastal zone and a mountainous area, with a width of approximately 1 kilometer at its most narrow section. Figure 1 shows the general configuration of the city and CBD.

The road network of the city is often congested and delays are presented during peak periods mainly due to commuters' traffic. The findings of the General Transportation study of the Metropolitan Area of Thessaloniki indicates that 25% of approximately 1,600,000 daily trips in the city have as origin and/or destination the CBD, resulting to the degradation of the environment and the quality of life in this area (ORTHE, 2000). Nowadays this figure is more than 1,750,000 trips/day.

Despite the large population of the metropolitan area and the mobility problems city centre experiences due to the private car dependence, Thessaloniki is one of the few European cities of similar urban characteristics that have no fixed route rail transport system (http://library.tee.gr/digital/kma/kma_m1498/kma_m1498_galousis.pdf). The present public transport system of Thessaloniki comprises the public bus system and the number of passengers annually served by the bus fleet is approximately 180,000,000, with an average occupancy of 42% (http://www.oasth.gr). Surveys show that the urban transport problem of the city centre is expected to be alleviated in a considerable degree when the currently under construction metro system will be in operation (Roukouni *et al.,* 2012). As far as the environmental benefits, it is estimated that the operation of Line 1 will decrease the CO_2 and CO emissions approximately by 1.25 Mt and 25 kt respectively up to 2041, mainly due to the diminishment of road volumes and congestion (Gavanas *et al.*, 2012).

As far as the environmental performance of the city it should be pointed out that Thessaloniki, in terms of its air quality, is considered as one of the most polluted cities in the European Union (www.who.int/ceh/publications/11airpollution.pdf). This is mainly due to the fact that existing mobility patterns,

[6] COPERT 4 is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport that has been developed by EMISIA S.A., a spin-off company of Aristotle University of Thessaloniki.

[7] For instance there are areas in the city center were the FAR reaches 8.2, where gross (bruto) and net (netto) density can reach up to 800 persons/ha and 1600 persons/ha respectively.

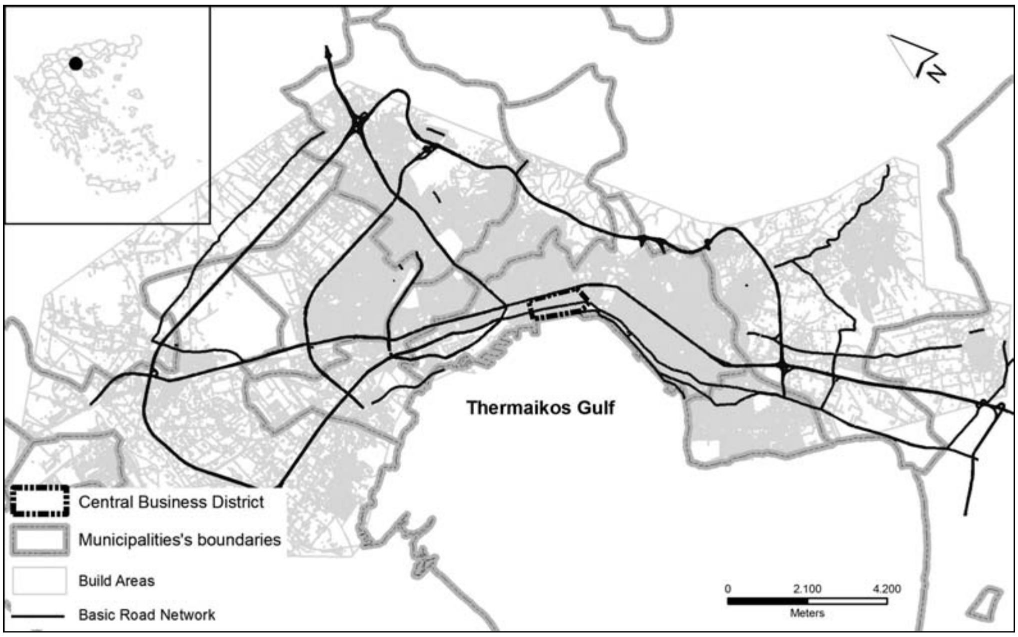

Figure 1. The city of Thessaloniki
(Source: processed by authors)

mediterranean climate, geographic location and topography of the city create favorable conditions for the production and reciprocation movement of air masses and transport of air pollutants (SO_2, particulates, CO, NO, NO_2 and O_3) in the city (Tsitsoni and Zagas, 2001).

Description of the study area

The study area consists of 6 zones extending approximately one block (depending on the geometry and size of city blocks) along six transport axis. The criteria used for choosing these areas were: location within MATh, land use functional characteristics, as well as functional and geometric characteristics of each transport route (Figure 2), (Table 1, 2). Following is a short description of the major characteristics of each study zone.

Zone 1, is located in the Municipality of Thessaloniki, extends along Tsimiski Street and comprises the CBD of Thessaloniki. It is the most central and busiest area of Thessaloniki and an origin-destination for the majority of trips taking place in the metropolitan area of Thessaloniki. Tsimiski Street is a main-one way- artery, with particularly high traffic volumes, serving through traffic in the east-west direction of the city. During peak hours there are serious congestion issues, with extremely low traffic speeds, a problem that is exacerbated by road side illegal parking. Zone 1 is a densely populated area with high FAR and high buildings heights (6-9 floors).

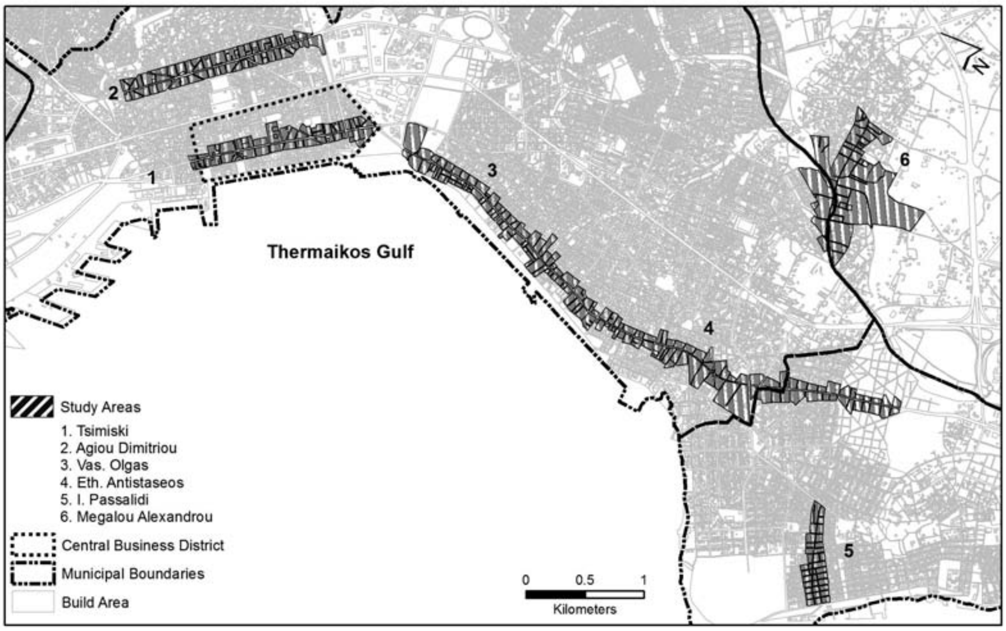

Figure 2. Study Areas
(Source: processed by authors)

The predominant functional use is retail that coexists with uses like service, education, administration, health, culture etc. Despite the dominance of the tertiary sector, residential use is also present, which is concentrated mainly in the east part of the zone. As for green spaces, they are quite limited, while there are some major pedestrian areas that function as open spaces.

Zone 2 is located near CBD and extends along Agiou Dimitriou Street. In terms of it's functionally Agiou Dimitriou is a secondary-one way- artery, with relatively low traffic volumes that serves the west-east direction. The zone has a FAR of 3.3, which is predominantly residential and with especially high population density (454 res/ha). Apart for residential use there are other type of uses related to the tertiary sector, culture, education and health, while in the west part of the area there is concentration of light industry and crafts. As far as green and open spaces, there are two significant open spaces, while there are some smaller urban green islets.

Zone 3, belongs to the municipality of Thessaloniki and extends along Vas. Olgas street. This street is a main -one way- artery, with high traffic volumes that serves through traffic in the direction east - west. The zone is located close to CBD with an average FAR of 3.8. It is a densely populated area with a total population of 16,167 inhabitants. It is a residential area with a mix of other uses such as services, administration and culture. Green spaces are mostly concentrated in the western part of the zone where the Horticultural Park and two other smaller urban parks are located.

Zone 4 is located in southeastern part of the city. It belongs to the municipality of Thessaloniki and Kalamaria and extends along a portion of Eth. Antistaseos Street. In essence this zone is a continuation of Zone 3 to the east, and is also a main -one way- artery with sufficient functional width that serves through traffic in the direction of east-west. Nonetheless it has smaller traffic volumes comparing to zone 3. Zone 4 is primarily a residential zone, with the exception of some uses that are related to services, culture and administration. The area has an average FAR of 2.4, much lower compared to the adjacent Zone 3 due to the fact that a large part of the area belongs to a different municipality where the statutory FAR is lower than those in the Municipality of Thessaloniki. With a population of 7,337 inhabitants and a population density of 210 res/ha this area is characterized by low population density compared to other zones. As for green and open spaces there are two small green spaces along the axis.

Zone 5, belongs entirely to the municipality of Kalamaria located in the east side of the city, and extends along a portion of I. Passalidi. Functionally I. Passalidi Street is a main –one way-collector artery with relatively small traffic volumes, connecting main arteries to the local network in the direction of south - north. It is primarily a residential zone, with the exception of some services and recreation uses. There are no green and open spaces located in the area. FAR is 2.9, while the population of the area is 4,008 inhabitants. It should be noted that Zone 5 is the smallest in terms of area size.

Zone 6 belongs both to municipality of Thessaloniki and municipality of Pilea-Hortiatis. It extends along Megalou Alexandrou Street in the northeast side of the city. Functionally Megalou Alexandrou Street is characterized as a secondary collector street, is bidirectional and serves as a connection between several arteries and local roads. It is a street with relatively low speed and low traffic volumes. This

Table 1. Urban features of study areas

Zones		Building Density (Mean)*	Population Density (Mean) (res/Ha)	Building Height (Mean) (m)**	Number of floors (Mean)	Population	Area (m^2)	Area of green space (m^2)
1.	Tsimiski	5.3	174.48	16.52	5.90	5,857	363,633	8,844
2.	Agiou Dimitriou	3.3	454.21	12.30	4.39	15,592	339,099	41,748
3.	Vas. Olgas	3.8	482.78	14.20	5.07	16,167	409,242	26,056
4.	Eth. Antistaseos	2.4	210.03	9.56	3.41	7,337	429,232	26,041
5.	I. Passalidi	2.9	343.03	11.81	4.22	4,008	113,865	0
6.	Megalou Alexandrou	0.8	76.92	5.74	2.05	1,913	577,579	24,058

Source: processed by authors
* mean Floor Area Ratio (FRA) per Zone
** number of floors x 2,80 m

Table 2. Functional classification/Functional and geometrical attributes of road segments

Road Segments		Functional Classification	Length (km)	Hourly Average Daily Traffic Volume (PCU*)	Average Speed (km/h)	Effective width (m)
1.	Tsimiski	Main Artery	1.6	3283	28	14
2.	Agiou Dimitriou	Secondary Artery	1.7	555	28	12
3.	Vas. Olgas	Main Artery	2.8	1995	34	16
4.	Eth. Antistaseos	Main Artery	2.2	1470	35	16
5.	I. Passalidi	Main Collector	0.9	322	37	7
6.	Megalou Alexandrou	Secondary Collector	1.2	269	26	10

Source: processed by authors
* Passenger car unit

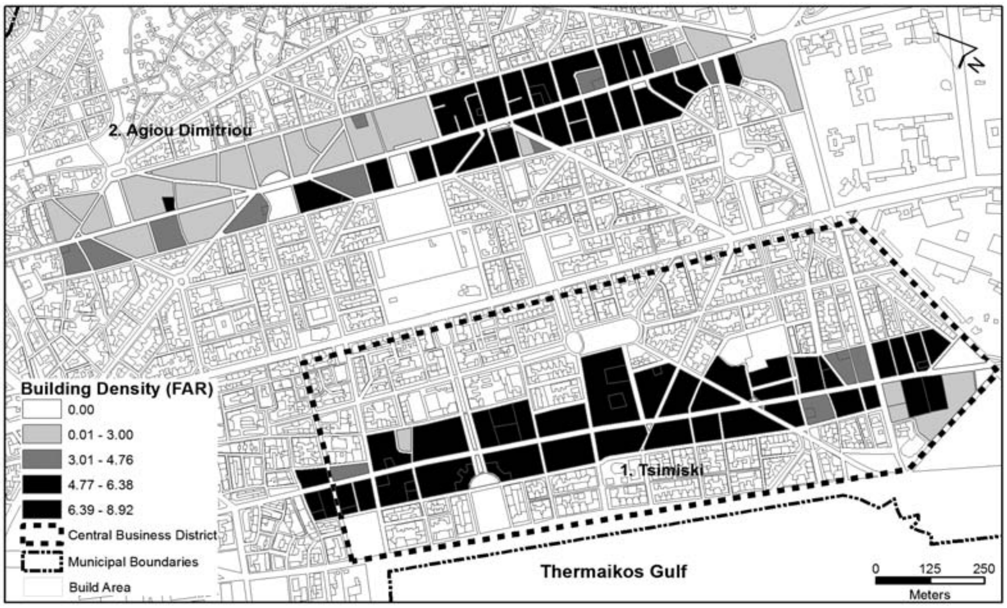

Figure 3. Building density in Zones 1 and 2
(Source: processed by authors)

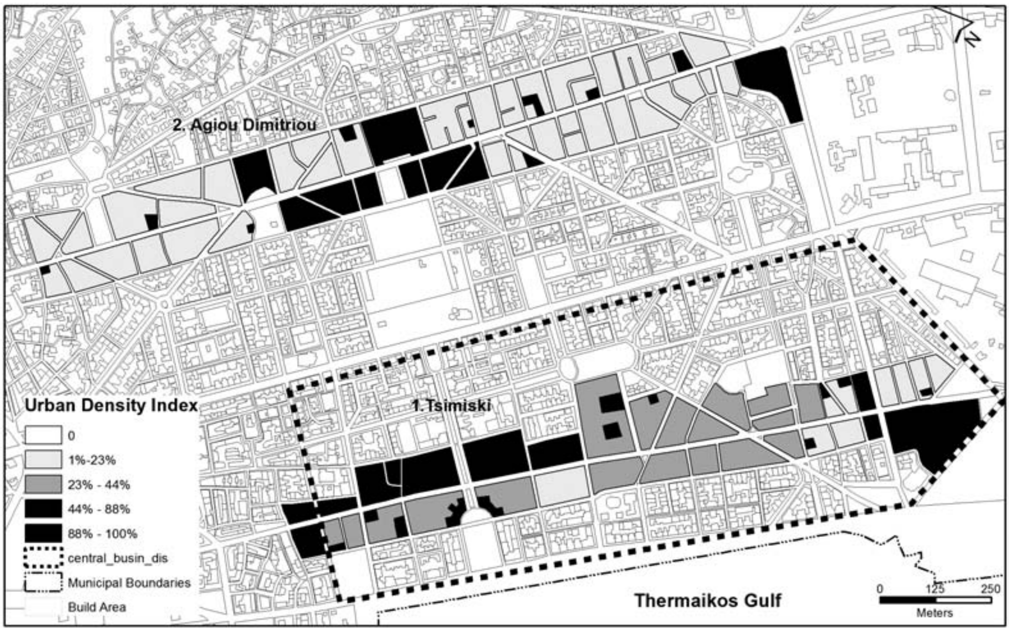

Figure 4. Urban density in Zones 1 and 2
(Source: processed by authors)

zone is characterized by an average FAR of 0.8 and therefore has low building heights. A total 1,913 inhabitants resides in this area. Large and unformed building blocks are particular to this zone due to the fact that in this area there is still a lot of undergoing construction. The prevalent use is residential but other uses like recreation, education and services are recorded. The green and open spaces are confined to small urban green islets.

Results and Discussion

Following is a presentation of the indices calculated for each zone and a comparison amongst the different zones. In the end a synthetic approach is attempted to reveal any relations between urban/build environment and air quality for the city of Thessaloniki.

Building Density

In order to measure urban density FAR index was used. FAR for each building bock and a mean value for each zone was calculated. It should be noted that FAR presented here is the "realized" one, meaning that it is the result of the calculations performed in the context of this paper and represents existing situation. Therefore the realized FAR may vary from the statutory one due to illegal construction.

Building density indicator shows that CBD area (Zone 1 and 2) has very high building densities that in some cases reach the value of 8.5. Specifically, Zone 1 has the highest building density values and Zone 6 the lowest, where only one block has FAR greater than 3. In general building densities tend to become lower towards the east side of the city. As far

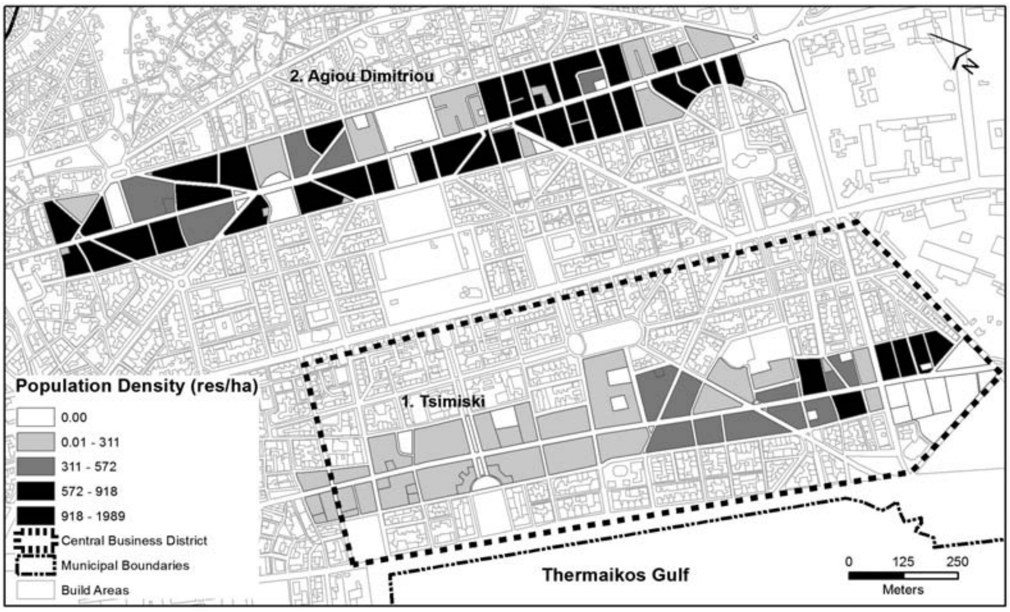

Figure 5. Population density in Zones 1 and 2
(Source: processed by authors)

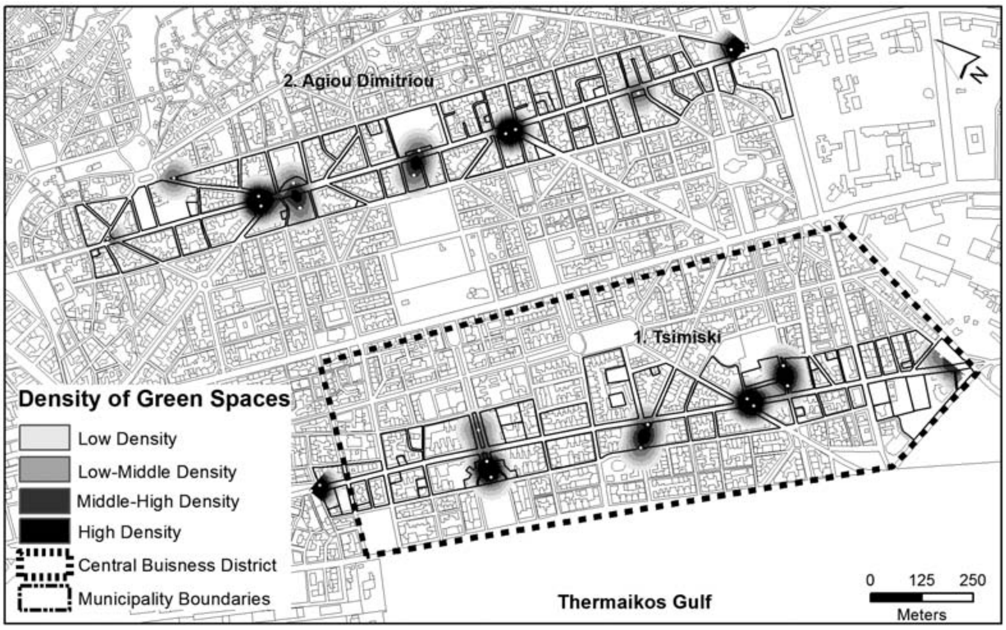

Figure 6. Green Space density in Zones 1 and 2
(Source: processed by authors)

as number of floors and height of the buildings, these are directly related to FAR. Therefore the highest buildings are located in Zone 1 (8-9 floors) and the lowest buildings in Zone 6 (2-3 floors). Figure 3 shows the values for building density in Zone 1 and 2.

Urban Density

Calculation of urban density index indicates that Zone 1and 2 have high values (Figure 4). Zone 3 and 4 present quite high values in certain parts, since these areas accommodates a variety of uses that mostly serve the east part of the city. Zone 5 and 6 seem to have less variety of land uses and are mostly residential areas with a handful of other uses to accommodate local needs.

Population Density

Zone 2 and 3 have the highest values of population density that surpasses 918 res/ha. It is worth noting that in Zone 3 there are building blocks that have population density from 1417 to 1989 res/ha, an extremely high number according to international standards. Zone 1 (Figure 5) has relatively low population density which is increasing towards the east part of the zone. The relatively low values in this zone are due to the fact that this area is primarily occupied by uses such as commercial and services. The lowest population density occurs in Zone 6, which as mentioned earlier is a new area, with low building density and still in construction phase, while Zone 5, which is primarily a residential zone, has a population density that ranges between 311-572 res/ha.

Percentage of green space to the total land area & Green space per capita

According to Table 3 that presents "Percentage of green space per zone" index, the highest values occur in Zones 2, 3 and 4 with very similar percentages, while Zone 5 has no green spaces therefore the value of index is 0. On the other hand the results of "green space per capita" index shows that Zone 2 has the lowest value (2.68 m^2/person) due high population numbers in this area.

Table 3. Green Space Indices

Zones		Percentage of green space pre zone (%)	Green space (m^2/capita)	NNIndex
1.	Tsimiski	2.43	1.51	0.894
2.	Agiou Dimitriou	12.31	2.68	1.28
3.	Vas. Olgas	6.37	1.61	0.970
4.	Eth. Antistaseos	6.07	3.55	2,578
5.	I. Passalidi	0.00	0.00	-
6.	Meg. Alexandrou	4.17	12.58	3,627

Source: processed by authors

Table 4. Emissions per zone

Road Segments		CH_4 (gr)/km	PM_{10} (gr)/km	NO_x (gr)/km	CO_2 (gr)/km	FC (gr)/km
1.	Tsimiski	171.8	149.1	2014.0	686235.2	217007.7
2.	Agi. Dimitriou	24.0	18.0	224.9	118078.3	37347.9
3.	Vas. Olgas	100.0	75.9	906.2	369680.4	116923.1
4.	Eth. Antistaseos	65.1	53.3	730.1	290563.0	91887.4
5.	I. Passalidi	13.9	14.4	245.9	70227.3	22202.5
6.	Meg. Alexandrou	11.3	10.1	146.3	61884.4	19566.9

Source: processed by authors

According to an OECD (2014) report that sets the standards in terms of urban green spaces, the rate of 9 m^2/person is recommended as the low end threshold.[7] Furthermore according to a research conducted by the Aristotle University of Thessaloniki in 2002, the green space per capita in Municipality of Thessaloniki was 2,19 m^2/capita, while in the municipality of Kalamaria, where two of our study areas are located, this index is 7,28 m^2/capita (Ganatsas *et al.*, 2002). Table 3 indicates that only Zone 6 meets the international standards, mainly due to the fact that few people resides in this area and certainly not because of the presence of large green and open spaces. Zone 2 is the only area within the municipality of Thessaloniki that has a rate of green space/ capita greater than the average of the municipality. Zone 1 has just 1.51 m^2/capita of green space when Zone 5 has a value of zero for this index.

In terms of its spatial distribution, Figure 6 shows the density of green spaces in zones 1 and 2. The input distance used to calculate density of green spaces, using the Kernel Density method was 75m. The distance was determined by the size of the block therefore for Zone 6 a larger distance was used due the peculiarity of building blocks in this area. Furthermore calculating NNI for each zone (Table 3), revealed that center city areas are of high density and concentration of green and open spaces, while the pattern is definitely clustered (NNI<1 or close to 1). For zones 3, 4 and 6 distribution of green spaces is somehow ordered and there are no green space concentrations.

Emissions

Table 4 indicates that higher pollutants are observed in Zone 1 and lower in Zone 6. Furthermore it seems that pollutants are proportionate to traffic volumes and inversely proportional to speed.

CONCLUSIVE REMARKS

The initial purpose of this paper was to assess the effect of urban green spaces on air quality accounting for traffic emissions and build environment. Results show that there is a positive relation between building density, urban density and volume of emissions observed in the six zones. This means that the higher urban density is, the higher the emissions/pollutants are and vice versa. The same rationality applies for building density. It should be noted that the positive relation was something that was expected since dense urban development patterns in conjunction with mobility patterns that heavily rely in private vehicles and bus public transit, creates high rates of emissions.

In regard to green spaces the first remark has to do with their quantity, since according to international standards, all six areas have low rate of green space per zone and low green per capita index. At the same time both Green Density Index and NNIndex indicate that the relative dispersion of green spaces is minimal. For instance in Zone 2 where the highest percentage of green space per zone occurs, there is one large open space and several smaller ones. Nevertheless their effectiveness as absorbing surfaces is reduced due to the fact that most of green spaces are concentrated in certain parts of the zone, when according to Wu *et al.* (2003) more dispersed forms of green space are preferred when congestion externalities are present. The same rational applies also for Zone 1, where concentration of green spaces occurs in certain parts of the axis. As far as the rest of zones where NNI indicates a more regular distribution, the size and number of green spaces per se, makes them inadequate to mitigate the negative effects of traffic.

All the above findings have certain planning implications. Ensuring green and open space in Greek cities is performed through General Urban Plans. In these plans there are regulations related to the amount of green space that has to be reserved and is proportional to the population of the area planned. The planning standard is 2.5 m^2/resident, which obviously is not enough so that to play a significant role in improving environmental quality of cities. Therefore it is imperative to increase the rate of green space per capita but also to integrate guidelines in regard to allocation of green spaces. Towards this direction it is also imperative to alter existing mobility patterns in a way that alternative forms of transport is promoted. This includes a turn towards public transit and non-motorized traffic i.e. walking biking etc. as

[7] The same study reports that North American cities such as Edmonton, Des Moines and Madison have the largest share of green area per person which is higher than 5000 m^2/person when in Juares, Bari, Anjo and Athens, recorded the lowest values of this index which was below 9 m^2/person.

well as use of eco-vehicles. In this way it can be ensured that green and open spaces can mitigate the adverse effects of urbanization in a sustainable way, making cities desirable places to live in.

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