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Exploring the urban types of built density, network centrality, and functional mixture in the city of Athens

An open data approach

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ABSTRACT

Patterns and urban typologies have a longstanding tradition as tools for understanding, discussing, and planning the city. However, the last decade advanced spatial analysis is increasingly employed for identifying urban types since it provides a quantitative/analytical approach to describe the patterns of urban form. In this context, we explore the types of urban form in Athens, as identified by an open-data methodological framework. Specifically, we examine the geography and interconnection of the types of buildings, streets and land-uses/functions as quantitatively defined by build density, network centrality, and functional mixture, respectively. What is more, the results of the methodology for Athens, are examined and evaluated by local experts in the fields of urban planning, participatory planning, sustainable mobility, and urbanism in general, during two expert focus groups.

A key element of this research is that it exclusively uses open data sources, and datasets readily available for European urban space, thus, offering the possibility of replicating this methodology in another European city. Another substantial contribution of this paper is the development of urban types for functional mixture -meaning the combination of land uses and economic activities describing the *function* of the city- an important element of urban form, which is currently missing from the relevant literature. The results –as evaluated by the expert focus groups- demonstrate that the applied methodology yields very interesting results for Athens, since the emergent types of build density, network centrality, and functional mixture are successful in describing the diverse character of Athens in city-level or neighbourhood-level.

KEYWORDS

typo-morphology, space syntax, built density, open data, Athens

1 INTRODUCTION

Cities of today has been characterized by complex structures and configurations that limit the ability of citizens and non-experts in general, to get involved in a dialog about their neighborhood, their city and ultimately the place where they live their life. This issue lies in the core of what Lefebvre called "right to the city" and contradicts the ever-growing conversation about participatory planning. The conceptual schema of patterns and urban types have been proposed as a powerful tool for understanding, planning and discussing the city even from the 1960's (e.g. Lynch, 1960/1990; Alexander, et al., 1977; Bandini, 1984). The use of typo-morphology for this process has a long research tradition (Moudon, 1994; Moudon, 1997; Marshall & Caliskan, 2011). However, the traditional typo-morphological approaches for identifying urban types are typically vague, capturing the symbolic dimension rather than the performance (Berghauser Pont, et al., 2019a). On the other hand, spatial analysis provides a quantitative/analytical approach to describe the patterns of urban form especially suitable for contemporary diffused urban forms (Serra, 2013) and applicable to data-driven planning procedures (Ye, et al., 2017).

The core objective of this paper is to map and explore the urban form types of Athens –i.e. the urban types of built density, network centrality and functional mixture[1]-, as identified by an open-data methodological framework that utilizes data available for the European urban space. Therefore, the there are two main research questions:
RQ1: What types of built density, network centrality and functional mixture are identified in a historic Mediterranean city like Athens?
RQ2: What is the geographic distribution and the interplay among different types of urban form?

In the next section, the relevant published research is briefly analysed. The "Datasets and Methods" is comprised by three sub-sections: "Datasets and Software" where the used data and software is documented in detail, "Methodology and Methods" describing our methodological approach and the final subsection titled "Analytical components for defining the types of urban form" where we analyse the variables used to quantitatively define the types of build density, network centrality and functional mixture. In the fourth section we present the results of the implemented methodology in Athens, Greece as well as the evaluation and comparative analysis of the results. In the final section, we summarise the conclusions and discuss directions for future research.

2 LITERATURE REVIEW

Urban space is perceived through various descriptions of its form and configuration, which are organized, grouped and finally categorized into patterns and typologies (Lynch, 1960/1990, p. 2;

[1] In this paper we term/ define "***functional mixture***" as the combination of land-uses as well as economic and human activities that describe the *function* of the spatial unit analysed

Alexander, et al., 1977). This instinctive mental process, is crucial for understanding the city and its various characteristics (Laskari, 2016, p. 11) and as such has been utilized by many researchers even from the 1960's (e.g. Lynch, 1960/1990; Alexander, et al., 1977; Bandini, 1984). Typo-morphology places this concept at the core of its approach, however until recently it focused on qualitative methods to explore urban typologies resulting in symbolic but vague urban types, successful in capturing the *character* of the city but not in describing its performance (Berghauser Pont, et al., 2019a). Nevertheless the last decade, advanced spatial analysis and quantitative analytical methods are increasingly employed for identifying urban types. Typical such examples are the work on the classification of buildings of Berghauser Pont & Haupt, 2009; Colaninno, et al., 2011 and Perez, et al., 2018. The research on classification of urban blocks and street network by Vialard, 2014; Barthelemy, 2015; Gil, et al., 2012; Serra, et al., 2013 and Serra, 2013. The work on exploring the plot types of different European cities done by Bobkova, et al., 2019 and Marcus & Bobkova, 2019, as well as the research by Araldi regarding retail patterns (Araldi and Fusco, 2019; Araldi, 2019). Furthermore, very interesting research has been done by Fleischmann focusing on urban patterns in different cities throughout the world and the development of open source tools and methods for researching urban morphology (Fleischmann et al., 2021; Fleischmann et al., 2020; Fleischmann, 2019).

However, the most relevant –to our research- body of work has been done by Berghauser Pont, et al (Berghauser Pont, et al., 2019a; Berghauser Pont, et al., 2019b). In their publications, they utilize advanced spatial analysis to examine the urban types of buildings, streets and plots for five European cities (Amsterdam, London, Stockholm, Gothenburg and Eskilstuna), while they also link the identified urban types with human activity, and specifically pedestrian movement (Berghauser Pont, et al., 2017; Berghauser Pont, et al., 2019a; Berghauser Pont, et al., 2019b; Stavroulaki, et al., 2019; Bolin, et al., 2021). It is worth mentioning that our paper, also draws inspiration from the relevant work of van Nes, Ye, et al (van Nes, et al., 2012; Ye & van Nes, 2014; Ye & van Nes, 2013). In their research they utilize build density, network centrality and functional diversity to identify combinatorial urban types.

In this paper, particularly, we will focus on exploring the typologies of the three elemental components of urban form in Athens: built density, network centrality and functional mixture. These three features are the analytical pillars of our research, since they considered to be fundamental elements of urban form and have been used extensively in relevant research (e.g Berghauser Pont, et al., 2019a; Ye, et al., 2017; Araldi & Fusco, 2019). Built density is a crucial aspect for describing and planning the city, and a fundamental element of urban form. However, it should be defined as a multi-variable phenomenon in order to relate it effectively with urban form (Van Nes, et al., 2012). Street network is the urban element connecting all urban functions in the city and a key aspect of urban form. It has an architecture, that is a certain geometry, a certain topology and a certain scaling. Network centrality, as defined by space syntax, addresses the inherit property of space to shape human movement and ultimately activity in space (Hillier, et al., 1993; Penn, et al., 1998).

Finally, regarding functional mixture, the economic activities, human activities and land-uses follow their own rules and ultimately form a unique spatial pattern (Shen & Karimi, 2017), describing the *functional* character of a city. The spatial distribution of the functional mixture of the city incorporates information about the socio-economic characteristics of the people living in it (Araldi & Fusco, 2019) and for this reason it has been recognized by many researchers in the field of urban form as a fundamental element of urban form (e.g. Conzen, 1960).

3 DATASETS AND METHODS

3.1 Datasets and Software

At the core of our approach is to develop a replicable and transferable methodological framework for identifying the types of urban form. To this end we exclusively use open data, available (and compatible) for the European urban space, and all data sources are listed in Table 1. The software used for processing the data and implementing the methodology of this paper is the following:

- For data preparation and spatial analysis: ArcGIS Pro 2.7.0,
- For Space Syntax Analysis: QGIS 3.4.14 with the use of the QGIS plugin 'Place Syntax Tool' (version 3.1.3) and the QGIS plugin 'Disconnected Islands' (version 2.0.2)
- For various statistical analysis and other relevant tasks: MS Excel 2013

Table 1: Data sources used per analytical component

Analytical Pillar	Analytical Component	Spatial Unit of Analysis	Data Source | Dataset
Built Density	***Ground Space Index (GSI)***	Urban Block	Urban Atlas | Building Height
	Floor Space Index (FSI)	Urban Block	Urban Atlas | Building Height
Network Centrality	***Angular Choice (250m-10km)***	Street segment	OpenStreetMap | roads (motorized network)
Functional Mixture	***Population Density***	Urban Block	Urban Atlas | Population estimates by Urban Atlas polygon

Functional Density	Urban Block	OpenStreetMap | Points of Interest (pois) OpenStreetMap | Places of Worship (pofw)
Functional Diversity	Urban Block	OpenStreetMap | Points of Interest (pois) OpenStreetMap | Places of Worship (pofw)
Density of Public Open Spaces	Urban Block	Urban Atlas Polygons| Urban Atlas

3.2 Methodology and Methods

The proposed methodology is consisted of four distinct steps as can be seen in the following figure (Figure 1). At the first step the components that shall be used to quantitatively describe the character of the buildings, streets and activities of Athens are selected and calculated. Subsequently, the analytical components of build density, network centrality and functional mixture are classified via multivariate clustering (step 2) and their statistical signatures are studied to identify the types of urban form of Athens (step 3). Finally, the results for Athens are comparatively analysed empirically, but also are evaluated by local experts.

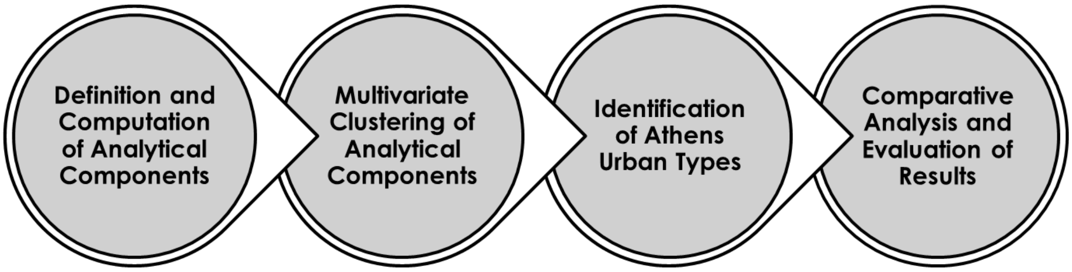

Figure 1: Methodological steps for exploring the types of urban form in Athens

On a technical note, for the multivariate clustering we utilize the machine learning algorithm K-means to identify the "*natural*" clusters of our data (Jain, 2010). The metrics/indicators of our analytical components (described in detail in the next section) constitute the variables for the K-Means unsupervised classification, and visual empirical inspection is utilised for merging classes according to their similarities/dissimilarities. Following the relevant methodology of Maloutas and Spyrellis (2020), we chose this two-step process in order to prevent the classification from being affected by the presence of very small and very particular clusters which the classification algorithm cannot automatically discard and reallocate

3.3 Analytical components for defining the types of urban form

Built density

Built density is a multi-variable phenomenon, decisive for planning the city, and a fundamental element of urban form. Therefore, following relevant literature (Berghauser Pont, et al 2019a; Berghauser Pont, et al 2019b), for quantitatively describing the types of built density we used: Ground Space Index (GSI) and Floor Space Index (FSI).

Ground Space Index (GSI) Reflects the coverage, or compactness, of the development (Rådberg 1996; Berghauser Pont, et al 2019a). It is calculated with the following formula:

$$\boldsymbol{GSI}_i = \frac{Built - up\ surface_i}{Area\ of\ city\ block_i}$$

Floor Space Index (FSI) Describes the total built-up area, by also taking into account the building height or the number of levels (Rådberg 1996; Berghauser Pont, et al 2019a). It is calculated with the following formulas:

$$\boldsymbol{FSI}_i = \frac{Gross\ Floor\ Area_i}{Area\ of\ city\ block_i}$$

$$\text{Or } \boldsymbol{FSI}_i = GSI_i \times AVG\_BuidHeight_i$$

The combination of ***Ground Space Index (GSI)*** and ***Floor Space Index (FSI)*** describes both the built-up coverage and its height while distinguishing the different building typologies, something that each metric individually could not do (Steadman, 2014; Perez, et al., 2018).

Network Centrality

Street network is the urban element connecting all urban functions in the city and a key aspect of urban form. Network centrality, in particular, conceptualizes and quantifies the inherit property of urban grid to shape human movement (Hillier, et al., 1993; Penn, et al., 1998).

Following the latest methodological developments in the field of space syntax, angular choice (also known as angular betweenness) is used in this paper to describe network centrality. Angular choice $(CHO_{(i,r)})$ reflects through-movement potential and it measures the sum of the shortest angular path overlaps (n_{jk}) for a particular street segment (i), between all pairs of origins and destinations (j,k), within a user-defined radius (r) (Shen & Karimi, 2017).

$$\boldsymbol{CHO}_{(i,r)} = \sum_{k=1}^{K} n_{jk}, \{dis_{(i,j)} \leq r;\ dis_{(j,k)} \leq r\}$$

Specifically, following the relevant literature for quantitatively describing the types of network centrality we used: ***Angular choice in multiple radii (low, medium, high)***

Functional Mixture

The combination of land-uses, as well as economic and human activities –which we term as "functional mixture"- encompasses important information about the socio-economic characteristics of a city (Araldi & Fusco, 2019) and for this reason it has been recognized by many researchers as a fundamental element of urban form (e.g. Conzen, 1960). However, to successfully describe the functional form of a city the usual land-use map is not enough. To that end we propose multiple analytical components to quantitatively describe the types of functional mixture: ***Population Density***, ***Functional Density***, ***Functional Diversity***, ***Density of Public Open Spaces.***

Population Density, refers to the population (number of residents) living per square meter and depicts the residential (or non-residential) character of an area.

$$\boldsymbol{Population\ Density_i} = \frac{Population_i}{Area\ of\ city\ block_i}$$

Functional Density, refers to the number of points of interest per square meter and describes the functional centrality of an area meaning the intensity of human activity.

$$\boldsymbol{Functional\ Density_i} = \frac{Points\ of\ Interest_i}{Area\ of\ city\ block_i}$$

Functional Diversity describe the vibrancy, the vitality and ultimately the different dimensions/characters of an area and can be calculated via the entropy index (Cervero & Kockelman, 1997) which quantifies the degree of heterogeneity among the different categories of points of interest.

$$Functional\ Diversity_i(raw) = -\frac{\sum_k (p_k \ln p_k)}{\ln N}$$

$$\boldsymbol{Functional\ Diversity_i} = \frac{Functional\ Diversity_i(raw)}{Area\ of\ city\ block_i}$$

k: the corresponding category; p: proportion of the corresponding category per city block, N: the total number of different categories

Density of Public Open Spaces, refers to the area of public open spaces per square meter.

$$\boldsymbol{Density\ of\ Public\ Open\ Spaces_i} = \frac{Area\ of\ Public\ Open\ Spaces_i}{Area\ of\ city\ block_i}$$

Functional density and ***Functional diversity*** are at the heart of the morphological approaches to analyse human activity and functions in urban space (Cervero & Kockelman, 1997; Song & Knaap, 2007; Steiniger, et al., 2008; Zhong, et al., 2015). As they describe the intensity of the human presence, urban vitality, and finally the character of the individual areas of a city (Jacobs, 1961, pp. 143-147; Hillier, 1999; Hillier, 2002; Hillier, 2003). In addition, **public open spaces**

with free access are the *natural* places where social practices of coexistence and encounter can manifest and as such are extremely important for identifying the typologies of functional mixture. (Jacobs, 1961, pp. 143-147; Alexander, et al., 1977; Hillier, 1999; Pinto & Brandão, 2015).

4 RESULTS

4.1 Area of Interest: Athens Municipality

Athens is a historic Mediterranean city, the capital of Greece and one of the biggest economic centers in southeastern Europe. The Municipality of Athens, in particular, had a population of 664,046 in 2011 census within its official limits, and a land area of approximately 39 sq.km. The administrative division of Athens Municipality contains 7 Municipal Communities[2] that are subdivided into 53 districts/neighborhoods[3], as found in geoadata.gov.gr the official open data catalogue for Greece.

It is both a symbol city and a city of contrasts. It combines the historic city built on the site of Ancient Athens, which retains to this day its timeless character, and the contemporary city, built after the founding of the Greek state. The diverse urban patterns of Athens is the result of the different development processes of the city during the 19th and the 20th century. These processes are associated with important historical circumstances as well as the implemented socio-demographic and economic development choices of the country (Maloutas, 2000). The various time periods in which Athens developed resulted in a diverse urban and social fabric and thus is considered to be an ideal case study with significant research interest that is currently missing from the relevant typo-morphological literature.

4.2 The building types of Athens

As described in Section 3, at the core of our approach is to exclusively use open data (available and compatible for the European urban space) to identify the urban form typologies of Athens. Specifically, for identifying the building types of Athens, we used the urban atlas dataset Building Height 2012 at block-level. After the data have been prepared and Ground Space Index and Floor Space Index have been calculated, K-Means Multivariate clustering is utilized for identifying the build density urban types of Athens. The built density analytical components (i.e. Ground Space Index – GSI and Floor Space Index - FSI) are analyzed to compose the patterns of build density for Athens. The statistical signature of the identified classes can be seen in Figure 2, while its spatial signature can be seen in Figure 3. The following 7 build density types are found for Athens.

[2] https://geodata.gov.gr/en/dataset/op1a-anuot1kwv-ko1votntwv
[3] https://geodata.gov.gr/en/dataset/op1a-re1tov1wv-anuou-a0nvaiwv

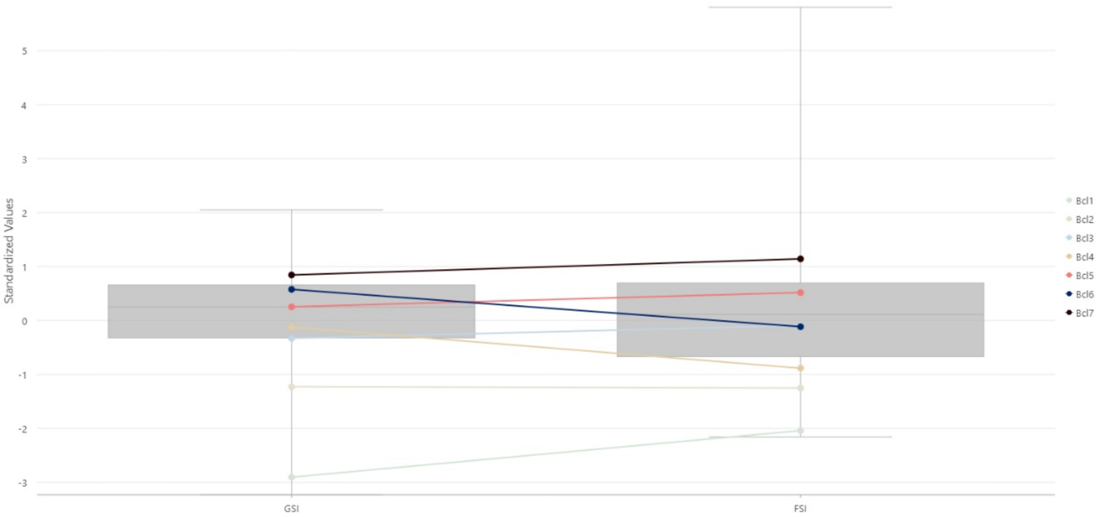

Figure 2: The statistical signature of the identified build types in Athens

Table 2: Statistics of the identified build types in Athens

Cluster Code	Number Of Blocks	Ratio
Bcl1	355	6.06%
Bcl2	551	9.41%
Bcl3	739	12.62%
Bcl4	765	13.06%
Bcl5	1058	18.06%
Bcl6	883	15.07%
Bcl7	1507	25.73%
Grand Total	*5858*	*100.00%*

The Type ***Bcl1.*** is labeled as '*Open Spaces/Isolated structures*', since both Ground Space Index (GSI) and Floor Space Index (FSI) are almost zero (mean GSI and FSI values are approx. 0.1 and 0.5 respectively), which means that both the built-up surface and the total built up volume are very limited. As can be seen on Figure 3, in Athens as Type ***Bcl1*** have been identified the various green spaces -larger or smaller- (e.g. Lycabettus Hill, Acropolis Hill, Zappeion) as well as the various public spaces of the city, such as squares (e.g. Syntagma Square and Omonoia Square), and pedestrian routes (e.g. the pedestrian street of Fokionos Negri).

Build type ***Bcl2***, is labeled as '*Spacious low-rise'* because it has very low values of both Ground Space Index and Floor Space Index (mean GSI and FSI values are approx. 0.4 and 4.2 respectively). Build type ***Bcl2*** can be found in blocks with public buildings/facilities such as hospitals, museums, and universities as well as blocks that neighboring/are adjacent to the hills of Athens where high-class residences are located. On the other hand, Build type ***Bcl3***, is labeled as '*Spacious mid-rise'* because the mean Ground Space Index is low (~0.5), while Floor Space Index presents substantial values (~9.5, meaning approx.19m buildings on average). Build type ***Bcl4***, is labeled as '*Compact low-rise'* since Ground Space Index have medium values (~0.6) while Floor Space Index is considerably low (the mean building height is approx. 10m which is equivalent to 3-level buildings in Athens). As can be seen on Figure 3, the blocks identified as Type ***Bcl4*** work complementary with their ***Bcl3*** counterparts. The Type ***Bcl5.*** is conceptualized as '*Compact high-rise*', because Ground Space Index (GSI) presents medium values (~0.6), while Floor Space Index (FSI) values are significantly high (mean building height ~20m). The spatial signature of ***Bcl5*** is depicted in figure 3, and as can be seen ***Bcl5*** bocks can be found extensively in Athens (represents the 18.06% of Athens blocks), mostly in the middle-class neighborhoods of the city. Build type ***Bcl6***, is labeled as '*Dense mid-rise'* since Ground Space Index have high values (~0.7), while Floor Space Index is considerably lower, but substantial nevertheless (the mean building height is approx. 18m). The Type ***Bcl7.*** is labeled as '*Dense high-rise*', because both Ground Space Index (GSI) and Floor Space Index (FSI) present high values (mean GSI and FSI values are approx. 0.7 and 22 respectively). ***Bcl7*** clusters can be found alongside the important avenues of Athens (e.g. Patision Avenue, Kifisias Avenue, Mesogeion Avenue) and also around Syntagma Square and Omonoia Square (the two most important squares/centres of Athens).

To sum up, the key findings of the identified building types for Athens are that ***Bcl2, Bcl3, and Bcl4*** (*Spacious low-rise, Spacious mid-rise* and *Compact low-rise* accordingly) work complementary, mostly found in upper mid-class neighborhoods of Athens around important green spaces and hills of the city (e.g. Lycabetous Hill, Acopolis Hill, Attican Grove). This is probably due to zoning restrictions–regarding the building height and coverage of built-up area- which in turn affect the price of land there. ***Bcl7*** (*Dense high-rise)* clusters are identified in the commercial clusters of the city, either alongside important avenues or around important squares/centers (e.g. around the 2 most emblematic squares of Athens: Syntagma and Omonoia). Furthermore, *mixed* clusters of ***Bcl7*** (*Dense high-rise*) are also found in the densely populated neighborhoods of Athens (e.g Ampelokipoi and Paitisia).

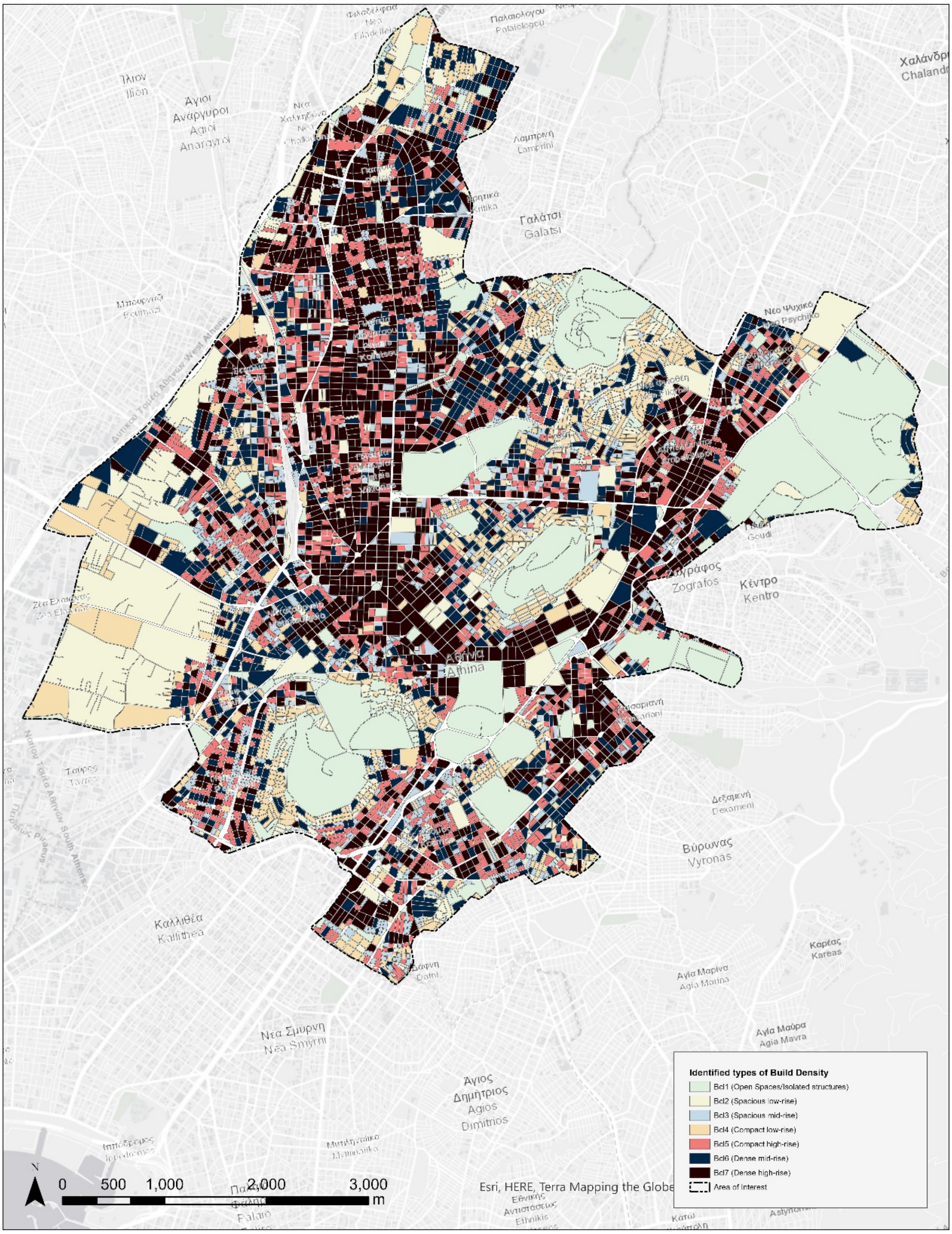

Figure 3: The geography of the identified build types in Athens

4.3 The street types of Athens

For identifying the street types of Athens we use the motorized network from Open Street Map, and K-means clustering are implemented for the space syntax measure of angular choice (also known as angular betweenness) in 18 radii from 250-10km.

The statistical signature of the identified classes can be seen in the boxplot in Figure 4, while their distribution is mapped in Figure 5. The following four street types are found for Athens:

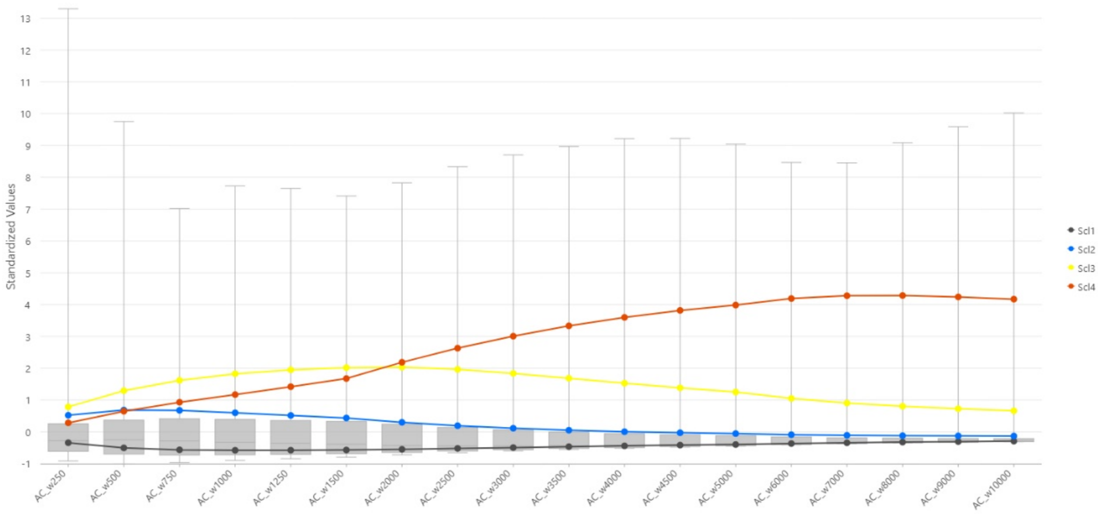

Figure 4: The statistical signature of the identified street types in Athens

Table 3: Statistics of the identified street types in Athens

Cluster Code	Number of Segments	Ratio
Scl1	16103	61.34%
Scl2	6846	26.08%
Scl3	2224	8.47%
Scl4	997	3.80%
Grad Total	*26170*	*100%*

The Type ***Scl1*** is labeled as *'Background streets'* because they present minimal centrality values in all radii. Make up most of the city's network (61%) and they represent the *quiet*, the uninteresting streets of the city and the areas of the city with limited network. The street type ***Scl2*** is labelled as '*Neighborhood Streets'* since they present high values in the small –walkable- radii of 250m and 500m while gradually dropping in the larger radii and is minimal in car-related radii after 5 km. The identified ***Scl2*** streets of Athens form clusters in the active/lively residential neighborhoods of Athens (e.g. Kipseli, Petralona, Koukaki). ***Scl3*** street type is labelled as '*City Streets'* because they exhibit high centrality values in almost all streets with the exception of higher radii (after 5 km). The Athens streets that have been identified as ***Scl3*** form a network that connects the main avenues of the city. The Type ***Scl4*** is labeled as *'Metropolitan Streets'* since they have relatively low centrality values in the lower radii while their centrality is gradually increased, especially in supra-local radii greater than 5 km. As can be seen in Figure 5, ***Scl4*** identifies the important car-oriented routes of Athens.

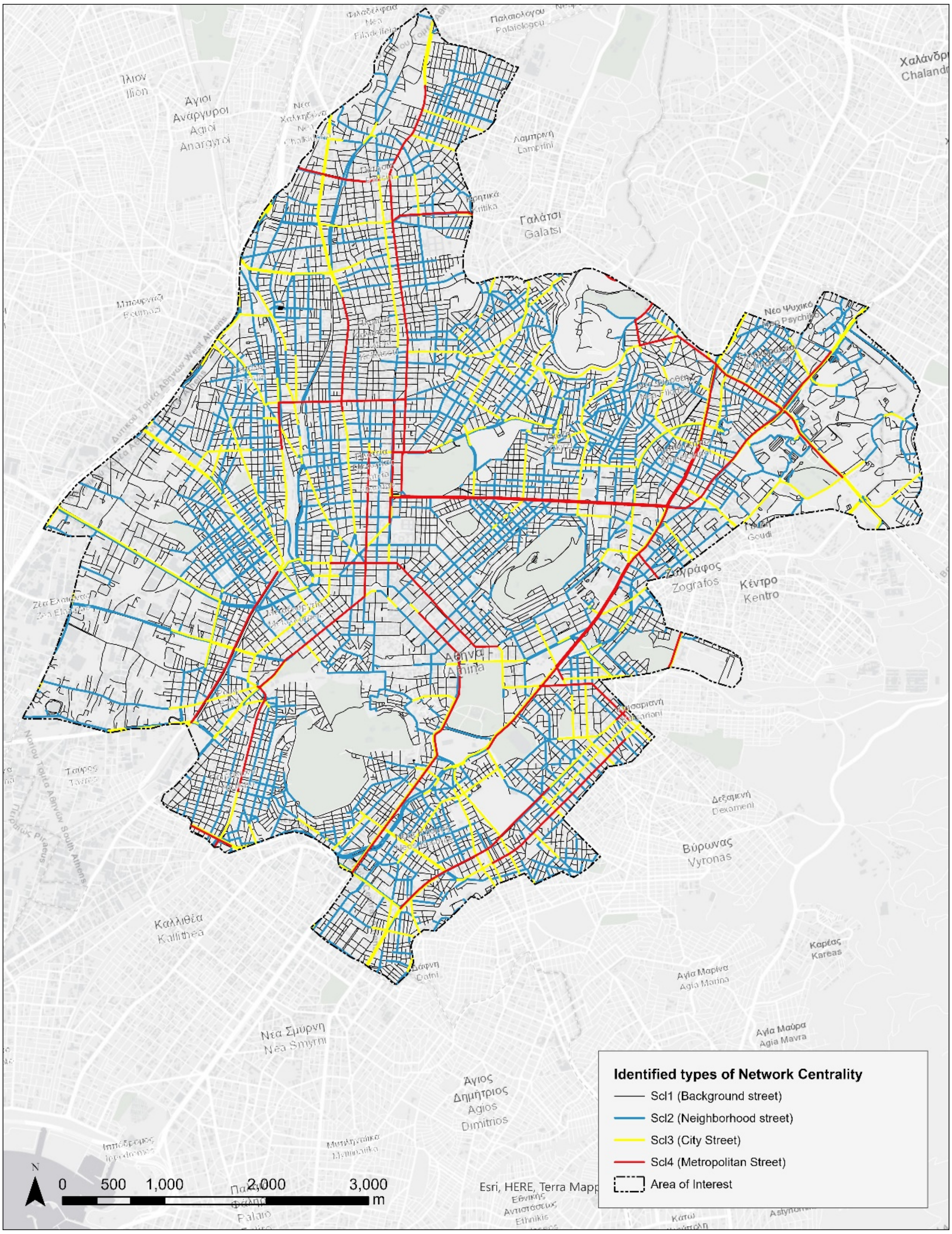

Figure 5: The geography of the identified street types in Athens

Summarizing some key results from the identified types of network centrality, as expected ***Scl1*** *(Background street)* is the most common type of the network while the important car-oriented routes of Athens has been identified as ***Scl4*** *('Metropolitan)* Interestingly, ***Scl2*** ('*Neighborhood Streets')* create clusters in the various Athenian neighborhoods which are then connected via ***Scl3*** *('City streets')* and ***Scl4*** ('*Metropolitan Streets')* (e.g. in Kipseli, in Koukaki, in Akadimia Platonos). Also, in a lot of instances ***Scl4*** *(Metropolitan Street)* are converted into ***Scl3*** (*City Streets)* when related to less global city structures.

4.4 The functional mixture types of Athens

The typologies of functional mixture are identified via the K-means clustering of the analytical components (i.e. Population Density, Functional Density, Functional Diversity, and Density of Public Open Spaces). The statistical signature of the identified functional mixture types can be seen in Figure 6, while their spatial signatures can be seen in Figure 7. The following 9 urban types of Functional mix are identified for Athens

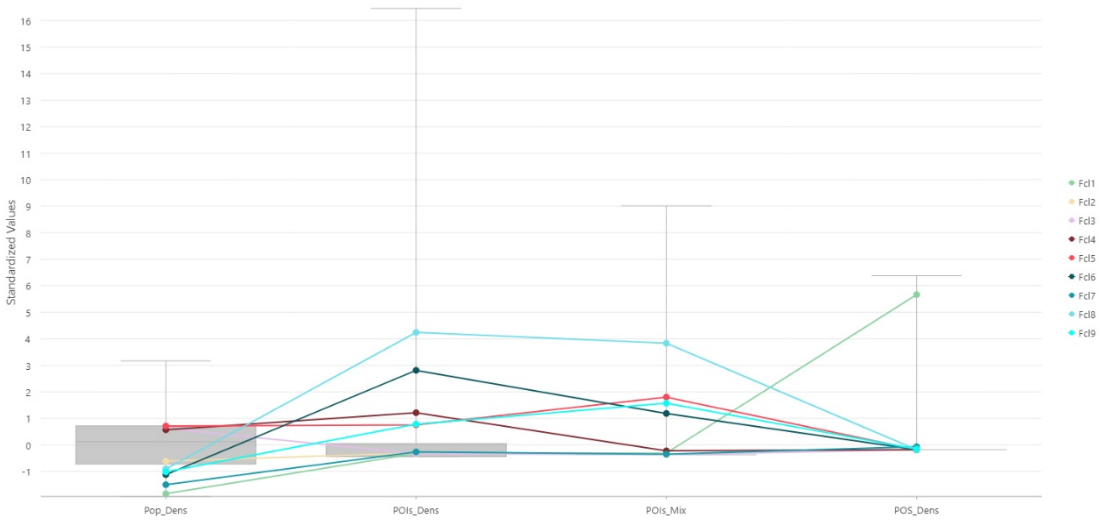

Figure 6: The statistical signature of the identified functional mixture types in Athens

Table 4: Statistics of the identified functional mixture types in Athens

Cluster Code	Number of Blocks	Ratio
Fcl1	165	2.82%
Fcl2	905	15.45%
Fcl3	3069	52.39%
Fcl4	142	2.42%
Fcl5	469	8.01%
Fcl6	106	1.81%
Fcl7	680	11.61%
Fcl8	131	2.24%
Fcl9	191	3.26%
Grand Total	*5858*	*100.00%*

Urban Type ***Fcl1*** exhibits minimal -almost zero- values in all analytical components with the notable exception of Density of Public Open Spaces and therefore is labeled as '*Public open spaces*'. In Athens, ***Fcl1*** blocks single out the green spaces of Athens (smaller and larger) and other public spaces (e.g. squares, pedestrian streets etc.)

The ***Fcl2*** urban type has very low values in all analytical component, without them being at the minimal levels of ***Fcl1***. Therefore is labeled as '*Sparsely populated residential blocks, without public open spaces*' and identifies blocks in mid- and high-class areas of Athens around public open spaces of Athens, but also blocks in the sparsely populated industrial areas of the city (e.g. Eleonas).

Urban Type ***Fcl3*** presents high values of Population Density and at the same time has low -but not negligible- values of Functional density. The other two analytical components (Functional Diversity and Density of Public Spaces) exhibit low values. As a result ***Fcl3*** type is labeled as '*Residential blocks, unidimensional, without public open spaces'*. Interestingly, but not unexpectedly, ***Fcl3*** is found in the majority of Athens blocks (represents 52.39% of the total blocks) since most residential areas of Athens are classified as ***Fcl3***.

Fcl4 type has fairly high values of Population Density and Functional Density and on the other hand has low values of Functional Diversity and Density of Public Open Spaces. Therefore is labeled as '*Residential activity nodes, unidimensional, without public open spaces*' meaning that the ***Fcl4***-identified blocks act as neighborhood centralities with substantial presence of non-residential activities, but without mixed uses or public open spaces.

Fcl5 also exhibits low values of Public Open Spaces and high values of Population Density and Functional Density but, unlike Fcl4, exhibits high values of Functional Diversity and thus is labeled as '*Residential activity nodes, multidimensional, without public open spaces*'. As such it identifies blocks where residence coexists with relatively intense and diverse non-residential activity but with the absence of public open spaces. This type (***Fcl5***) has identified blocks in the areas of Athens that combine residential and commercial character, such as blocks alongside commercial avenues that are adjacent to residential areas.

Fcl6 type has low values of Population Density while also has high values of Functional Density. Furthermore, it has low values of Population Diversity and low values of Density of Public Open Spaces. Therefore is labeled as '*Non-Residential activity nodes, unidimensional, without public open spaces*' meaning that residential character is absent, and the commercial (or generally non-residential) activity prevails, but without a remarkable mix of activities and urban green spaces.

Fcl7 type has low values of Population Density while also has high values of Functional Density. Furthermore, it has low values of Population Diversity but substantial values of Density of Public Open Spaces. Therefore, Fcl7 is labeled as '*Non-Residential activity nodes, unidimensional, with public open spaces*' and identifies blocks of special conditions with central public facilities such as hospitals, museums, and universities as well as blocks that neighboring/are adjacent to the hills of Athens where high-class residences are located.

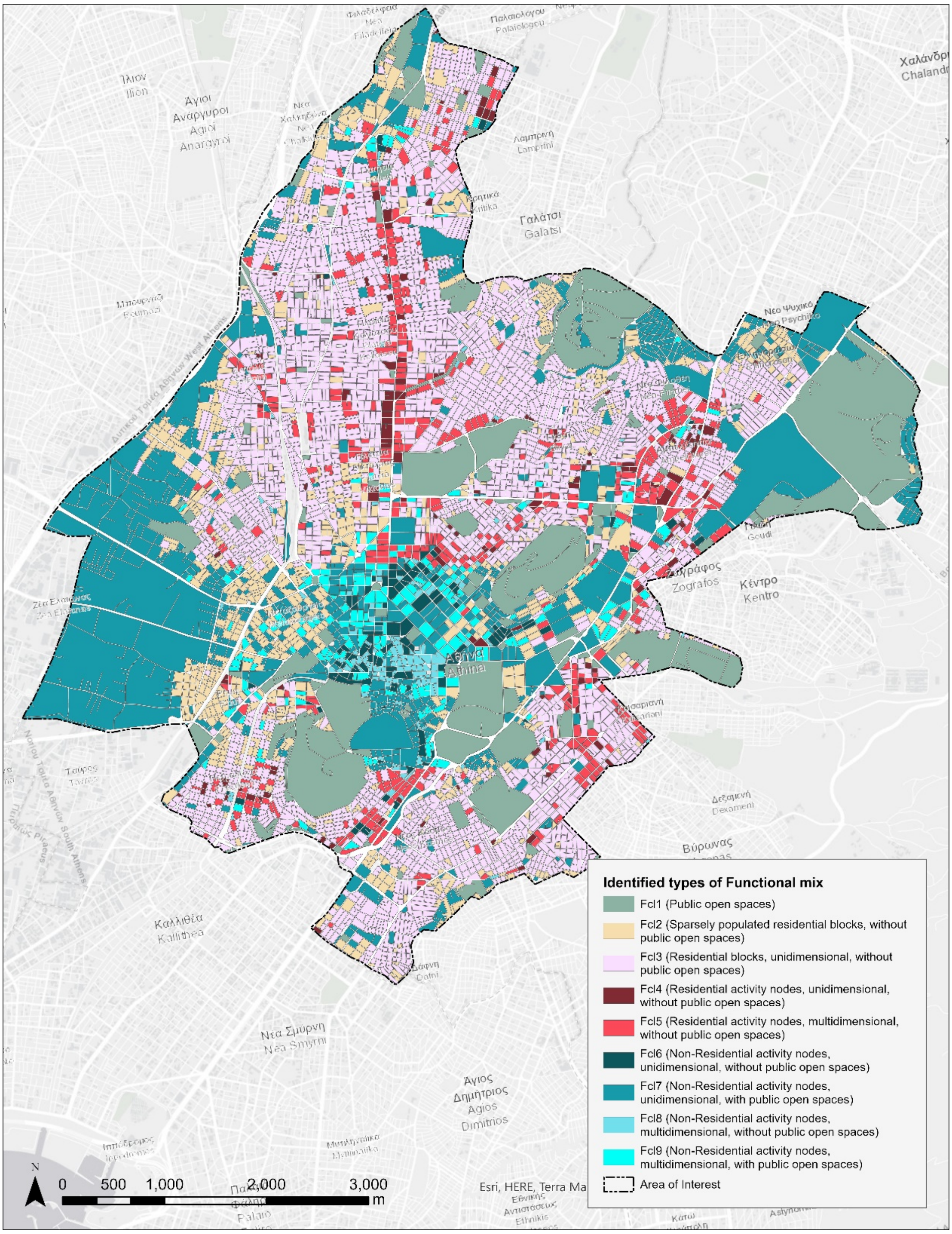

Figure 7: The geography of the identified functional mixture types in Athens

Fcl8 presents low values of Population Density while also has high values of Functional Density. Furthermore, it has significant values of Population Diversity but low values of Density of Public Open Spaces. As a result, Fcl8 is labeled as '*Non-Residential activity nodes, multidimensional, without public open spaces*' and identifies a few blocks in the historic centre of Athens.

Fcl9 has low values of Population Density but exhibits –more or less- high values in the other three analytical components (Functional Density, Functional Diversity and Density of Public

Open Spaces) and thus is labeled as '*Non-Residential activity nodes, multidimensional, with public open spaces*'. The blocks classified as Fcl9 are found in the traditional commercial centre of Athens (around Omonoia and Syntagma, in Exarcheia and in Kolonaki).

To sum up some key results from the identified types of functional mixture, the residential areas of city have been identified as ***Fcl3*** (*Residential blocks, unidimensional, without public green spaces*) while the blocks alongside important routes of the city that cross densely populated areas (e.g. Patision Avenue, Fokionos Negri, Panormou Avenue) have been mostly identified as ***Fcl5*** (*Residential activity nodes, unidimensional, without public green spaces*). Furthermore, blocks of special conditions with supralocal facilities/functions such as hospitals, museums, universities are identified as ***Fcl7*** (*Non-Residential activity nodes, unidimensional, with public green spaces*) while the traditional and historical centre of Athens around Sytagma, Akropolis and Omonoia have been classified as ***Fcl8*** (*Residential activity nodes, multidimensional without public open spaces*).

4.5 Comparative analysis and Evaluation of the results

An important element of this paper is that the identified urban form types of Athens have been examined and evaluated by local experts. To this end, two online focus groups were conducted in November of 2021 with the participation of a diverse panel of 20 experts. Each focus group lasted about an hour and a half, and one of the subjects discussed was the identified types of urban form in Athens. The diversity of the panel concerns both their field of expertise and their profile. More specifically, participated not only academics (i.e. professors, researchers) but also practitioners (i.e. professionals conducting studies and commercial projects), in the field of urban planning/urban geography and mobility planning/transport geography. In the figure 8, the composition of the focus groups can be seen in detail. It should be clear, that the two focus groups had the same theme, agenda and structure and they were conducted in two dates -2 November 2021 and 4 November 2021, with the participation of 9 and 11 experts, accordingly- to ensure that the groups shall be small enough to facilitate the dialog among the experts while providing the needed interdisciplinary and plethora of opinions.

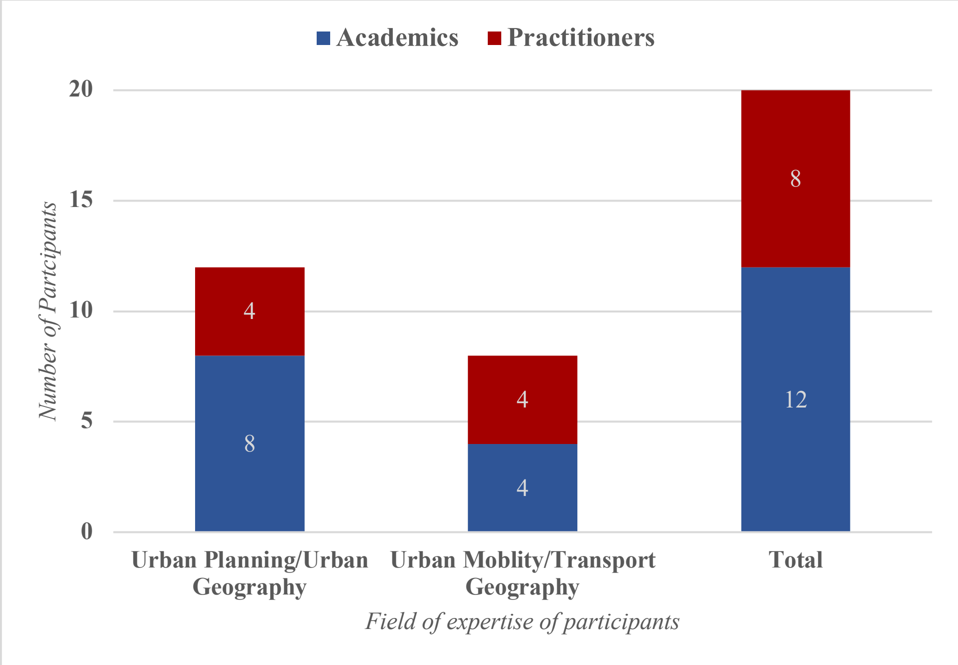

Figure 8: Composition of focus groups

The consensus of these two focus groups is that the identified types of urban form (built density, network centrality and functional mixture), describe successfully the character of Athens in city-level or neighbourhood-level, despite the flaws/glitches that you may encounter if you zoom in the block-level. Built types in particular, were considered the most accurate result, since it was able to highlight the reduced built intensity around the Athenian Hills and parks, as well as the morphological characteristics alongside important routes of Athens. Regarding street types, experts with experience with space syntax were more content with the results, while other participants (mostly practitioners) had a few questions about some specific areas but all participants agreed with the streets identified as ***Scl4*** (Metropolitan Streets). However, it is worth mentioning a comment made from a practitioner (Urban Planner) "*I cannot understand why and how, but the identified street types depict the way that I move in the city*". About the typologies of functional mixture, the results were satisfactory for most of the participants. Although, one of the experts -a researcher in the field of urban geography with deep knowledge of Athens-expressed some concerns regarding the extensive identification of "non-residential activity nodes" (Fcl6, Fcl7, Fcl8, Fcl9) in the residential –to some extent- areas north of Syntagma and Omonoia (Exarcheia, Kolonaki and Vathi), probably due to the overrepresentation of points of interests from open street map, resulting in high functional density.

Finally, in order to comparatively analyse the results for Athens and following the suggestions of the focus groups, we tried to map the identified urban types at neighbourhood level. Specifically, the law-designated neighbourhoods/districts of Athens municipality is used, as found in geoadata.gov.gr the official open data catalogue for Greece. In the next figure (Figure 9), the prevailing type is mapped in every neighbourhood, as well as the ratio of each type.

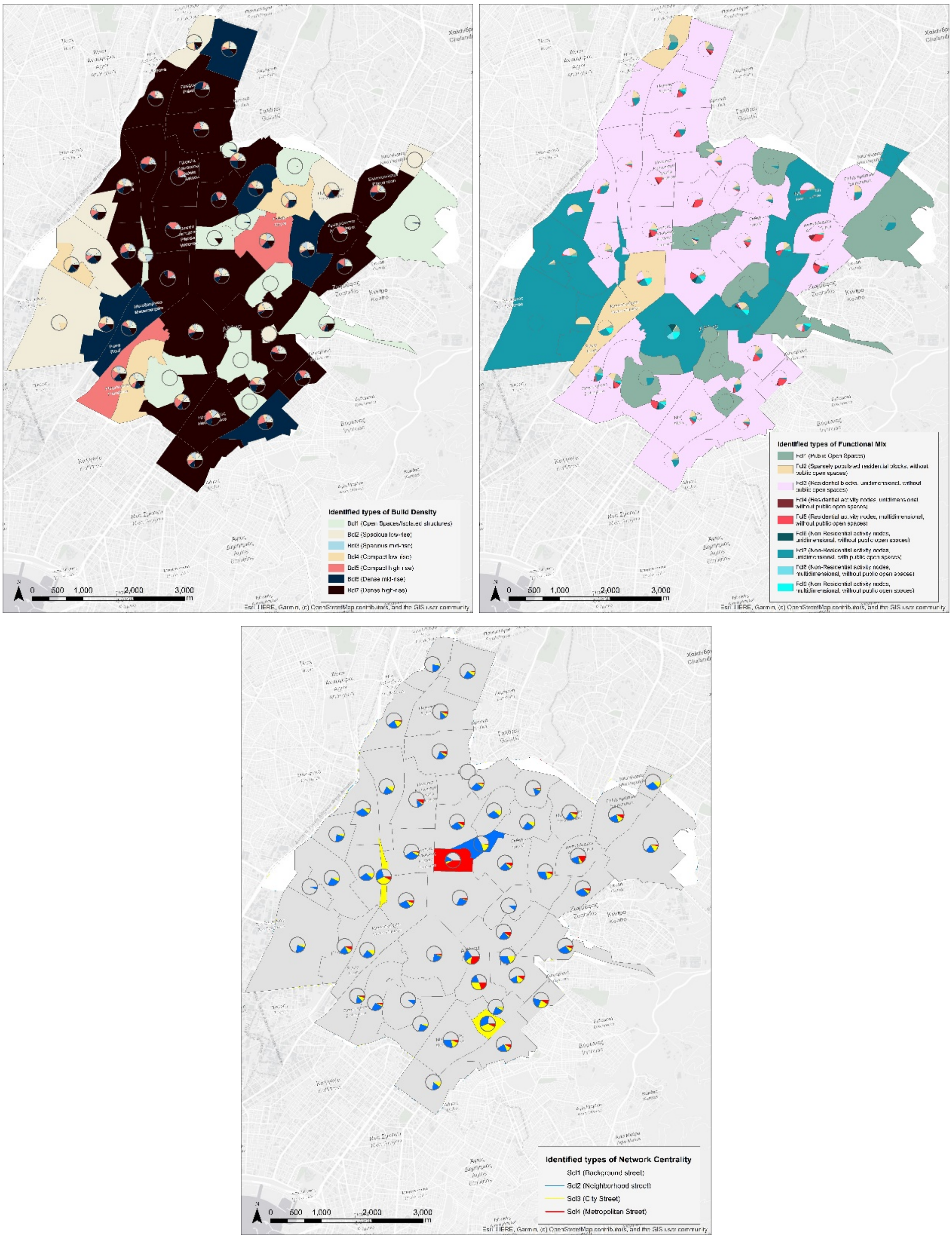

Figure 9: The prevailing urban types of Athens neighborhoods (clockwise: built density, functional mixture, network centrality)

As expected the prevailing type of network centrality in the vast majority of neighborhoods is ***Scl1*** (Background street) and the only neighborhoods with different type are four outliers (parks characterized as small neighborhoods). However, the typologies of built density and functional mixture depict a very interesting result for Athens when mapped in neighborhood level. More specifically, the neighborhoods characterized as ***Bcl1*** (*Open Spaces/Isolated structures*) are also expectedly identified as ***Fcl1*** (*Public Open spaces*). However, what is truly interesting is the correlation between ***Bcl2*** (*Spacious low-rise)* and ***Fcl7*** (*Non-Residential activity nodes, unidimensional, with public green spaces*) and the main reason behind it, is that they identify blocks with special conditions (regarding built density and function) meaning blocks with supralocal facilities/functions such as museums, universities and public administration. Furthermore, an interesting finding of the cross-tabulation of building and functional types in neighborhood level, is that the ***Fcl3*** type (*Residential blocks, unidimensional, without public open spaces*) -which constitutes the vast majority of the residential areas of Athens- are densely built areas, identified as ***Bcl7*** (*Dense high-rise*) and to a much lesser extent as ***Bcl6*** (*Dense high-rise*).

Also, it is extremely interesting that the identified *non-residential activity nodes* (***Fcl6, Fcl7, Fcl8*****,** and ***Fcl9***) and the *residential activity nodes* (***Fcl4, Fcl5***) are found alongside *city streets* (***Scl3***) and *metropolitan streets* (***Scl4***). A notable exception is the extensive ***Fcl7*** cluster (*Non-Residential activity nodes, unidimensional, with public open spaces*) in the historic centre of Athens south of Syntagma and Omonoia (in the neighbourhood of Monastiraki - Plaka) that does not have the corresponding network centrality types. In this historic and tourist part of the city, various attractors are located (e.g. Acropolis, Ancient Agora of Athens, Theatre of Herodes Atticus) that affect centrality independently of network configuration. Additionally, a substantial portion of its network is pedestrianized, meaning that is not included in this analysis, resulting in lower network centrality values.

5 CONCLUSIONS

In this paper, we employed a methodological framework integrating typo-morphology and advanced spatial analysis to quantitatively describe the patterns of urban form in the historic Mediterranean city of Athens, Greece. Specifically, we examined three foundational elements of urban form: buildings, streets and land-uses/functions, as defined by build density, network centrality and functional mixture and identified by open data available at the European urban space.

There lies an important contribution of our research, since the implemented methodology can be replicated for the majority of the European urban space, in the cities where urban atlas data and open street map data are available. Another substantial contribution of this research, is the identification of functional mixture types based on multiple analytical components describing the various aspects of the functional dimension of cities (i.e. residential density, functional density, functional density, and public open spaces density). The introduction of functional mixture in a typo-morphological research approach is important since is mostly missing from the relevant literature except from some notable exceptions that still do not utilize multiple variables (Ye & van Nes, 2014; Ye, et al., 2017; Araldi & Fusco, 2019). Furthermore, we implemented the developed methodology in Athens, Greece, a historic Mediterranean city that is missing from the quantitative typo-morphological research which is mostly focusing on cities outside of the

Mediterranean. What is more, the implemented methodology in Athens, yields satisfactory results according to a diverse panel of twenty local experts that participated in two focus groups, to discuss the identified urban types of Athens.

Regarding, the identified types of urban form in Athens, they compose a diverse urban mosaic in all three elements of urban form explored in this paper. Regarding building types, Athens is characterized by dense built-up area with high-rise and mid-rise building, since the corresponding types (***Bcl7*** and ***Bcl6***) comprise 40% of Athens urban fabric. It is worth mentioning that only the 6% of Athens blocks are characterized as '*Open Spaces/Isolated structures'* (***Bcl1***). This percentage drops even more, when researching the functional dimension of urban form since the corresponding functional mixture type (***Fcl1***. *Public open spaces*) represents only the 2.8% of Athens city blocks. More particularly, in Athens nine types of functional mixture types are found and ***Fcl3*** *(Residential blocks, unidimensional, without public open spaces*) is identified in the majority of city blocks (52.4%) mapping the *active* residential areas of Athens. Ultimately, the geography that functional mixture creates in Athens is characterized by an extensive core of *Non-Residential Nodes of Activities* (Fcl6, Fcl7, Fcl8 and Fcl9) in the traditional centre of the city around Syntagma and Omonoia, and also by linear configurations of ***Fcl5*** (*Residential activity nodes, multidimensional, without public open spaces)* alongside the important routes of Athens adjacent to its residential neighborhoods. Concerning network centrality, four street types are identified and expectedly the vast majority of streets are classified as ***Scl1*** (*Background network*) while the street types associated with significant network centrality (***Scl3*** and ***Scl4***) represent only 12.3% of the network (8.5% and 3.5% accordingly). However, the most interesting finding about network centrality typologies is that the ***Scl2*** (*Neighbourhood Streets*) create patches in the residential areas of the city, describing the everyday (pedestrian) activity, which they are connected via ***Scl3*** (*City Streets*) with the ***Scl4*** (*Metropolitan Streets)* representing the global structures of the city.

The present research provides a methodological tool for mapping the patterns of urban form that could be incorporated into participatory planning procedures to facilitate the dialog between experts and non-experts, as also proposed by Talen (2020), because rather than discussing complex metrics requiring formal training (e.g. Space syntax, advanced metrics of built density and functional mixture etc.), it provides a somewhat intuitive depiction of the city. Furthermore, the identified urban form typologies could be "*translated"* to typologies of planning interventions, in relation with form-based codes (e.g. Talen, 2009; Palaiologou, et al., 2020) especially if additional elements are included.

With regards to the limitations of this research, most of them derive from the exclusive use of open data. In particular, to quantify functional density and functional diversity we use data from open street map (points of interest and points of worship), resulting in overrepresentation of activities related with commercial activities (cafes, shops etc.), especially in the tourist areas of the city. This limitation has been addressed to some extent by including the population density in the analytical components as a proxy of residential use. Furthermore, the use of urban atlas data for quantifying public open spaces come with some limitations and assumptions, since the smaller and/or informal public open spaces are disregarded (e.g. a small pocket park located in a densely built city block) while it includes spaces that are not always accessible to the public (e.g. stadiums)

However, the topic employed in this paper is full of complexity, since it comprises only a part of a broad research field. Hence, it is suggested that new studies going beyond the scope of this one or improving some possible limitations, should emerge in the near future. The validation of the results of the applied methodology is an ongoing procedure that includes not only the opinion of experts –which was collected during the implemented expert focus groups- but also the opinion of various stakeholders without formal education on the subject (citizens, city official and public administration). To the same point, the conceptual names/labels of the identified types have not been validated by their target audience as already mentioned (citizens, city official and public administration) and this constitutes an important subject for further research in order to produce urban types that will be functional/useful for experts but also symbolic/understandable for non-experts. Beyond that, it goes without saying that an interesting advancement of this research is to apply the proposed methodology in different European city (or even cities), which is the reason behind exclusively using open data. Finally, another appealing research path, inspired by the relevant work on social types by Maloutas and Spyrellis (2020), could be the investigation of urban and social form of Athens, by comparing the urban and social types of the city.

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