The network analysis of urban streets of Tirana

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Abstract

In this article we use Multiple Centrality Assessment (MCA) based on the idea of Sergio Porta [Por06]**.** We apply MCA for the urban streets of Tirana. MCA is based on primal, rather than dual, street graphs, it works within a metric, rather than topological, framework and it investigates a plurality of peer centrality indices. We show that, in the MCA primal approach, some centrality indices nicely capture the 'skeleton' of the urban structure that impacts so much on economic and cultural development of the city, which is also the purpose of our study. Moreover, the distributions of centrality in self-organized cities are different from those in planned cities. In our analysis we are considering all roads for vehicles, pedestrian paths and even the closed roads, which appear as leaves in the primary graph (vertex degree k=1). The area considered in this study is $4.392052 \cdot 10^6$ m^2 (1.7 $miles^2$). We have built two databases for the sake of the study. One database contains information about edges like the vertex pairs of each edge and their weight (length in meters). The total number of edges is K = 1964. The other database contains information about geographical location of vertices (Longitude, Latitude for each vertex). The total number of edges is N=1565. After all the analysis, we'll see if Tirana is a self-organized city or a planned one.

1 Introduction

The study of complex networks is a new area of scientific research (since 2000) inspired of real-world networks such as computer networks, technological networks, brain networks and social networks. But, spatial networks were actually the subject a long time ago of many studies in quantitative geography. Objects of studies in geography are locations, activities and flows of individuals and goods. Already in the 1970s the scientists working in quantitative geography focused on networks evolving in time and space. The network analysis of territorial cases has a long tradition, especially in transportation and economic geography. All these approaches, like 'closeness', 'connectivity', or 'cost' focus on the idea that some places (or streets) are more important than others because they are more *central*. [Por06]

Two coordinates (Longitude, Latitude)[1], used in the database of vertices, uniquely determine a point in the area and specifically a geographic position on Earth. The picture below explains it better.

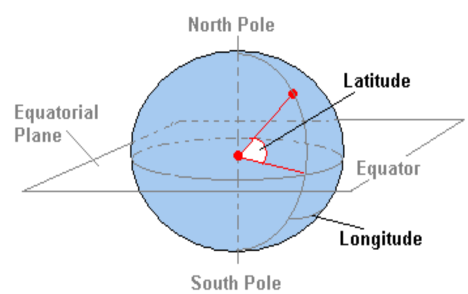

Figure 1: Longitude, Latitude

To calculate the Euclidean distance between two points in Earth, we apply the Haversine formula. This formula is a special case of spherical trigonometry and it is used for the first time in 1801 by spanish

[1] https://www.google.al/search?q=longitude+and+latitude&newwindow=1&espv=2&rlz=1C1TSNF_enGR420GR420&source=lnms&tbm=isch&sa=X&ved=0ahUKEwj7wJr96ILPAhVDvRoKHS8aANsQ_AUICCgB&biw=1366&bih=643#imgrc=dUAQi979hwA9NM%3A

mathematician and astronomer José de Mendoza y Ríos[2]. To implement this formula, we need longitude, latitude and the radius of Earth $R = 6371 \cdot 10^6$ m.

For data processing we have used the software program R: package igraph for construction of graphs, package Geosphere to perform calculations and package RColorBrewer for coloring graphs according to different algorithms.

2 The primal approach of urban streets of Tirana

By using the primal approach, where networks of streets and intersections can be represented by spatial graphs in which zero-dimensional geographic entities (such as intersections) are turned into zero-dimensional graph entities (nodes) placed into a two-dimensional Euclidean space, and one-dimensional geographic entities (such as streets) are turned into one-dimensional graph entities (edges or links). The primal approach is also the world standard in geospatial dataset construction. [Por06]

Moreover for us it is more important the metric distance rather than topological one. So, according to primal approach, the streets will be represented by the edges and intersections will be represented by the nodes. Of course, that the graph will be a weighted graph. So, each edge will be attached the weight that in this case will be the length (in meters). Each vertex of graph will be identified by a number that will be unique for each vertex. Also the graph will not be oriented, since we're not considering the directions of motion.
Four primal approaches (Figure 2, Figure 3) [Por06] namely Ahmedabad, Venice, Richmond, CA, and Walnut Creek, CA, are here given closer focus in order to frame the comparison between those cities and Tirana (Figure 4, Figure 5).

On one hand Ahmedabad and Venice are typical self-organized patterns, in that they `spontaneously' emerged from a historical process outside of any central coordination (the graph network visualization is disorganized). On the other hand Richmond and Walnut Creek are planned patterns, developed following one coordinating layout in a relatively short period of time (the graph network visualization is quadratic). [Por06]

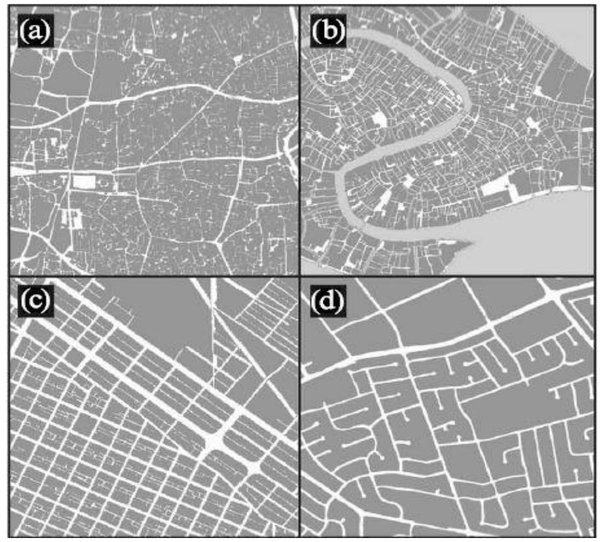

Figure 2: Map of (a) Ahmedabad; (b) Venice; (c) Richmond; (d) Walnut Creek [Por06]

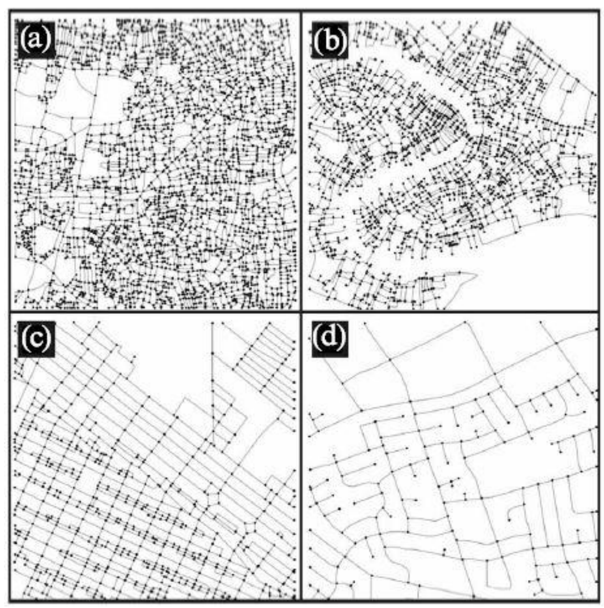

Figure 3: Primal approach of (a) Ahmedabad; (b) Venice; (c) Richmond; (d) Walnut Creek [Por06]

[2] https://en.wikipedia.org/wiki/Haversine_formula

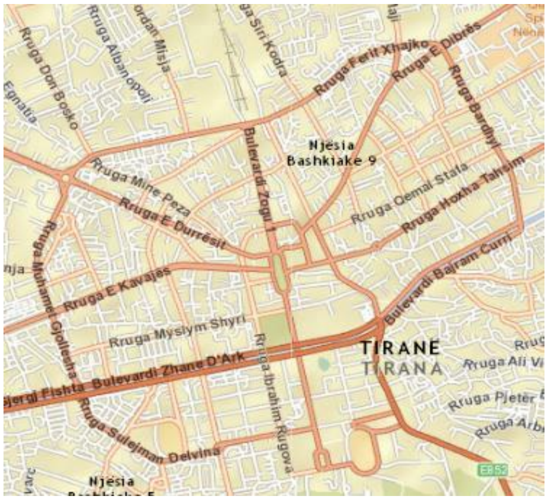

Figure 4: Map of Tirana[3]

Figure 5: Primal graph of Tirana

[3] http://www.arcgis.com/home/webmap/viewer.html?webmap=1cefeb8113724e489ef63f29629683c4

As we see the primal graph, we can judge that Tirana is a city, which can be regarded as self-organized.

3 Defining centrality indices

Network's cost W is the sum of all edges lengths [Por06]:

$$W = \sum_{i,j \in N; i \neq j} l_{ij}$$

Network's cost for Tirana W_{Tir} = 112 468 m. The calculations are made for 1 mile[2].

The characteristic path length L (Watts and Strogatz, 1998) [Wat98] is defined as the average length of the shortest paths (with the average being calculated over all the couples of nodes in the network):

$$L = \frac{1}{N(N-1)} \sum_{i,j \in N; i \neq j} d_{ij}$$

L is a good measure of the connectivity properties of the network. For Tirana, we got the result L_{Tir}=1456.764m.

Average path length <l>[4] is a concept in network topology that is defined as the average number of steps along the shortest paths for all possible pairs of network nodes. It is a measure of the efficiency of information or mass transport on a network. Our result was $<l>_{Tir}$=19.92. It means that it takes 20 steps on average to go along the shortest paths for all possible pairs of intersections in Tirana.

High values of W and L low values of <l> are properties of self-organized cities.

Diameter D[5] is the shortest distance between the two most distant nodes in the network. In other words, once

[4] https://en.wikipedia.org/wiki/Average_path_length

[5] https://en.wikipedia.org/wiki/Network_science

the shortest path length from every node to all other nodes is calculated, the diameter is the longest of all the calculated path lengths. Diameter of Tirana (Figure 6) is D=3590m, while the Euclidian distance between those nodes is d_E=2867m. Thus , the diameter is 1.25 times greater than the Euclidian distance.

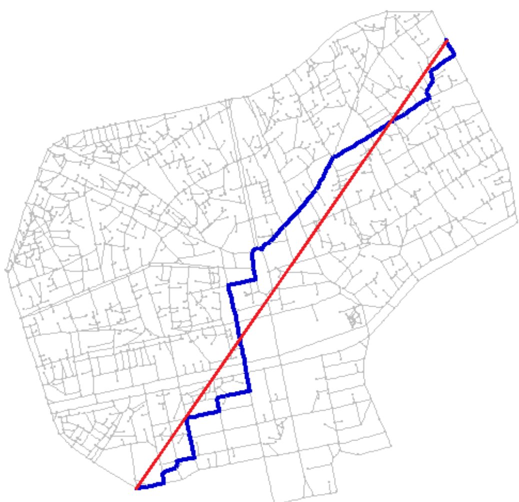

Figure 6: Diameter (blue) and Euclidian distance (red)

In the tables below we have made a ranking of 19 cities [Cru06], including Tirana, according to the number of nodes N , the number edges K, the cost W and average path length <*l*>. It is obvious, that Tirana is ranked near the self-organized cities like Ahmedabad, Venice, Cairo and Seoul.

Table 1: Ranking of the cities according to N [Cru06]

Ranking of the cities according to N					
No.	City	N	K	W	<*l*>
1	Ahmedabad	2870	4870	121037	27,59
2	Venice	1840	2407	75219	31,25
3	Cairo	1496	2255	84395	37,47
4	Tirana	921	1155	66158	19,92
5	Seoul	869	1307	68121	52,12
6	Richmond	697	1086	62608	57,65
7	Savannah	584	958	62050	64,77
8	Bologna	541	773	51219	66,26
9	London	488	730	52800	72,33
10	Vienna	467	692	49935	72,16
11	Paris	335	494	44109	89,29
12	New Delhi	252	334	32281	96,56
13	New York	248	419	36172	86,33
14	Los Angeles	240	340	38716	113,87
15	Barcelona	210	323	36179	112,01
16	Washington	192	303	36342	119,94
17	Brasilia	179	230	30910	134,39
18	San Francisco	169	271	38187	140,91
19	Walnut Creek	169	197	25131	127,57

Table 2: Ranking of the cities according to K [Cru06]

Ranking of the cities according to K					
No	City	N	K	W	<*l*>
1	Ahmedabad	2870	4870	121037	27,59
2	Venice	1840	2407	75219	31,25
3	Cairo	1496	2255	84395	37,47
4	Seoul	869	1307	68121	52,12
5	Tirana	921	1155	66158	19,92
6	Richmond	697	1086	62608	57,65
7	Savannah	584	958	62050	64,77
8	Bologna	541	773	51219	66,26
9	London	488	730	52800	72,33
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14	New Delhi	252	334	32281	96,56
15	Barcelona	210	323	36179	112,0

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16	Washington	192	303	36342	119,94
17	San Francisco	169	271	38187	140,91
18	Brasilia	179	230	30910	134,39
19	Walnut Creek	169	197	25131	127,57

Table 3: Ranking of the cities according to W [Cru06]

Ranking of the cities according to W					
No.	Qyteti	N	K	W	<l>
1	Ahmedabad	2870	4870	121037	27,59
2	Cairo	1496	2255	84395	37,47
3	Venice	1840	2407	75219	31,25
4	Seoul	869	1307	68121	52,12
5	Tirana	921	1155	66158	19,92
6	Richmond	697	1086	62608	57,65
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15	Barcelona	210	323	36179	112,01
16	New York	248	419	36172	86,33
17	New Delhi	252	334	32281	96,56
18	Brasilia	179	230	30910	134,39
19	Walnut Creek	169	197	25131	127,57

Table 4: Ranking of the cities according to **<*l*>** [Cru06]

Ranking of the cities according to <*l*>					
No.	City	N	K	W	<*l*>
1	San Francisco	169	271	38187	140,91
2	Brasilia	179	230	30910	134,39
3	Walnut Creek	169	197	25131	127,57
4	Washington	192	303	36342	119,94
5	Los Angeles	240	340	38716	113,87
6	Barcelona	210	323	36179	112,01
7	New Delhi	252	334	32281	96,56
8	Paris	335	494	44109	89,29
9	New York	248	419	36172	86,33
10	London	488	730	52800	72,33
11	Vienna	467	692	49935	72,16
12	Bologna	541	773	51219	66,26
13	Savannah	584	958	62050	64,77
14	Richmond	697	1086	62608	57,65
15	Seoul	869	1307	68121	52,12
16	Cairo	1496	2255	84395	37,47
17	Venice	1840	2407	75219	31,25
18	Ahmedabad	2870	4870	121037	27,59
19	Tirana	921	1155	66158	19,92

3.1 Being near others: Closeness Centrality

Closeness centrality, C^C, [Por06] measures to which extent a node i is near to all the other nodes along the shortest paths, and is defined as [Por06]:

$$C_i^C = \frac{N-1}{\sum_{j \in N, j \neq i} d_{ij}}$$

where d_{ij} is the shortest path length between *i* and *j*, defined, in a valued graph, as the smallest sum of the edges length *l* throughout all the possible paths in the graph between *i* and *j*. [Por06]

Implemented on primal graphs, the spatial flow of C^C is dominated by the so-called `border effect', in the sense that higher C^C scores consistently group around the geo-metric center of the image. To some extent less evident in less dense cases such as Walnut Creek, the border effect is overwhelming in denser urban fabrics such as those of Ahmedabad and Venice (Figure 7 a,b) [Por06]. Also the primal graph of Tirana is dominated by this effect (Figure 8).

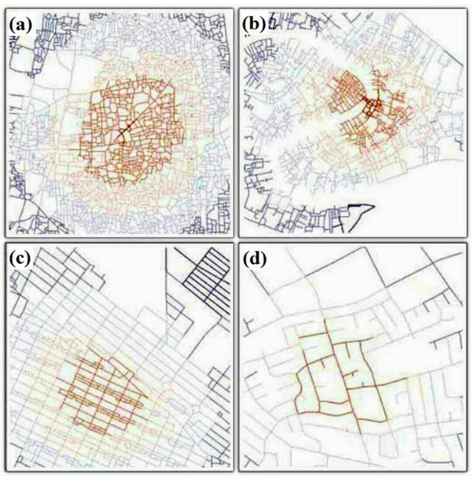

Figure 7: C^C (a) Ahmedabad; (b) Venice; (c) Richmond; (d) Walnut Creek [Por06]

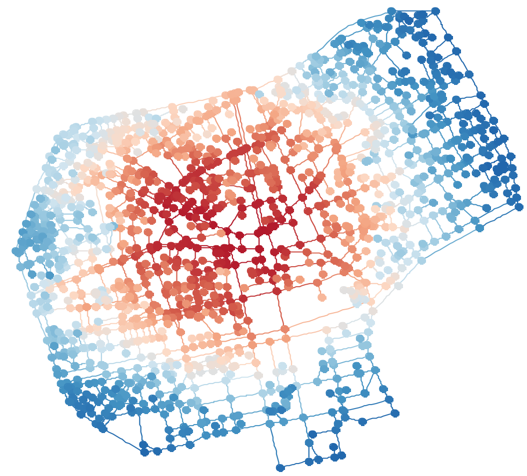

Figure 8: C^C, Tirana[6]

The problem: as we have just shown, the C^C integration index simply does not work on such primal graphs because C^C is vulnerable to the border effect. But C^C is not the only option. Centrality is a multifold concept and we have many indices at hand. Thus, to overcome this problem we can limit the analysis of C^C to a local scale, at which it maintains a good potential. [Por06]

A review of Ahmedabad [Por06] and of my results for Tirana are offered in the figures below.

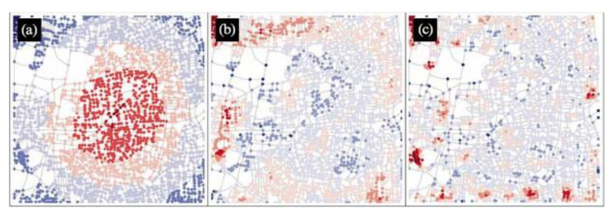

Figure 9: C^C Ahmebadad: (a) general C^C (b) Local C^C, d<400m; (c) Local C^C, d<200m [Por06]

[6] We notice that the graph coloring is done scalable from dark red to dark blue. With dark red are colored vertices with higher values of C^C, while with dark blue are colored vertices with lower values C^C.

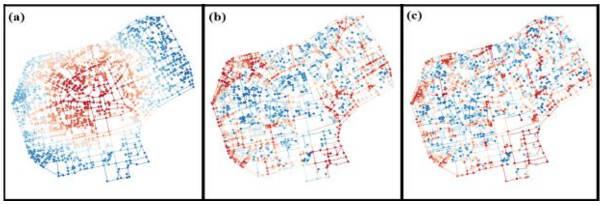

Figure 10: C^C Tirana: (a) general C^C (b) Local C^C, d<600m; (c) Local C^C, d<200m

Now, the concept of 'being near others' is more meaningful, because in this way are defined locations (intersections and roads) that are more important for certain areas of the city. This type of analysis can help entrepreneurs increase their economic activities in such areas, which can be considered optimal (for example supermarket chains).

3.2 Being between others: Betweenness Centrality

Betweenness centrality, C^B, [Por06] is based on the idea that a node is central if it lies between many other nodes, in the sense that it is traversed by many of the shortest paths connecting couples of nodes. The betweenness centrality of node i is [Por06]:

$$C_i^B = \frac{1}{(N-1)(N-2)} \sum_{j,k \in N; j \neq k; j,k \neq i} \frac{\eta_{jk}(i)}{\eta_{jk}}$$

where n_{jk} is the number of shortest paths between j and k, and $n_{jk}(i)$ is the number of shortest paths between *j* and *k* that contain node *i*.

Figure 11 shows visual presentation of C^B for Ahmedabad, Venice, Richmond and Walnut Creek [Por06]. While figure 12 shows visual presentation of C^B, that I have made, for Tirana.

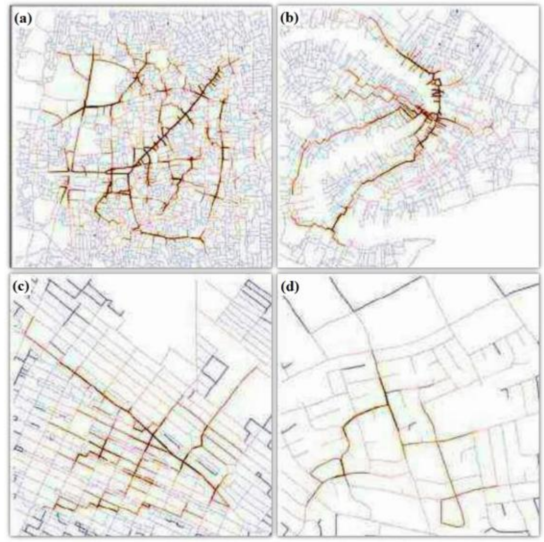

Figure 11: C^B (a) Ahmebadad; (b) Venice; (c) Richmond; (d) Walnut Creek [Por06]

From the visual presentation of C^B for Tirana, we notice that the most important streets, that influence most the rest of the street network, are "Fortuzi" street, Durrësi street, Dibra street, Kavaja street and "Myslym Shyri " street.

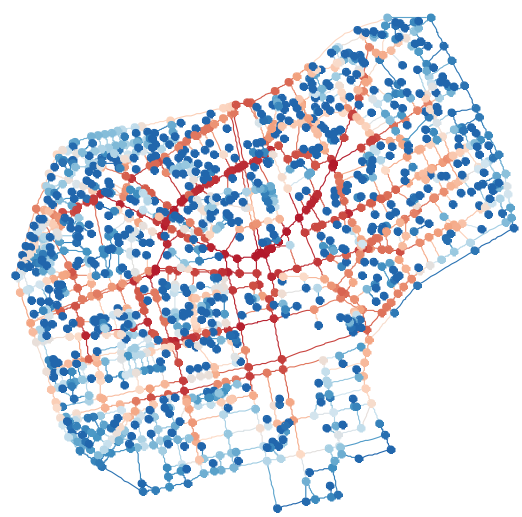

Figure 12: C^B, Tirana

3.3 Being direct to the others: Straightness Centrality

Straightness centrality, C^S, [Por06] originates from the idea that the efficiency in the communication between two nodes *i* and *j* is equal to the inverse of the shortest path length d_{ij}. The straightness centrality of node *i* is defined as [Por06]:

$$C_i^S = \frac{1}{N-1} \sum_{j \in N; j \neq i} \frac{d_{ij}^{Eucl}}{d_{ij}}$$

where $d_{Eucl\ ij}$ is the Euclidean distance between nodes i and j along a straight line, and we have adopted a normalization recently proposed for geographic networks. This measure captures to which extent the connecting route between nodes *i* and *j* deviates from the virtual straight route.

Figure 13 shows visual presentation of C^S for Ahmedabad, Venice, Richmond and Walnut Creek [Por06]. While figure 14 shows visual presentation of C^S, that I have made, for Tirana.

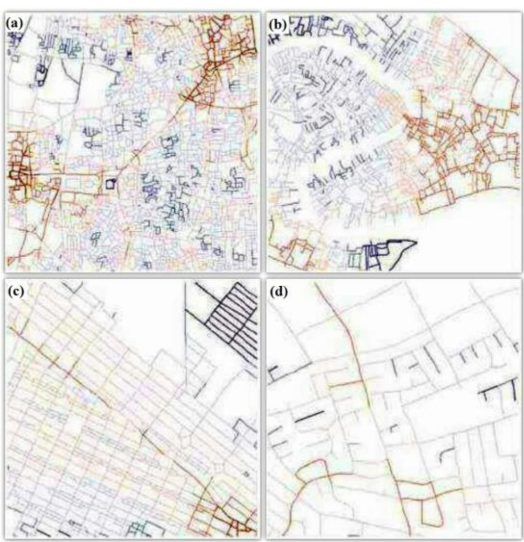

Figure 13: C^S (a) Ahmebadad; (b) Venice; (c) Richmond; (d) Walnut Creek [Por06]

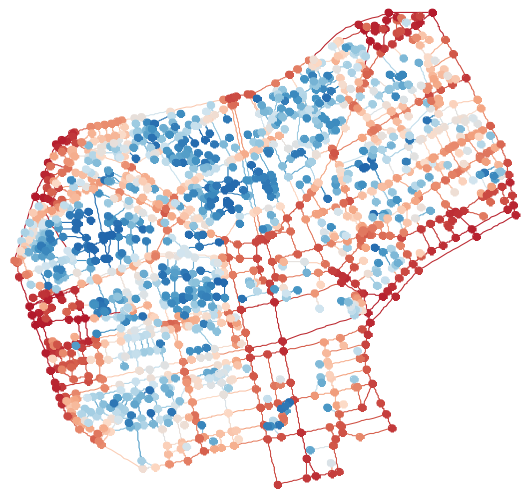

Figure 14: C^S, Tirana

From this visual representation of C^S for Tirana, we notice that the straight streets, that directly link two intersections are mainly boulevards like "Dëshmorët e Kombit" boulevard, "Zhan D'Ark" boulevard and "Bajram Curri" boulevard. While some other streets are "Muhamet Gjollesha" street, "Asim Vokshi" street, etc. It was the first urban planning made in 1923, by the Austrians, which attempted to build straight streets for the capital city of Albania[7].

3.4 Being critical for all the others: Information Centrality

Information centrality, C^I , [Por06] relates the node centrality to the ability of the network to respond to the deactivation of the node. The information centrality of node *i* is defined as the relative drop in the network efficiency E[G] caused by the removal from G of the edges incident in *i* [Por06]:

$$C_i^I = \frac{\Delta E}{E} = \frac{E(G) - E(G')}{E}$$

[7] Planet Urbanistike të Tiranës në vite, Arkivi Qendror Teknik i Ndërtimit (AQTN)

where the efficiency of a graph G is defined as [Por06]:

$$E(G) = \frac{1}{N(N-1)} \left(\sum_{i,j \in N; i \neq j} \frac{d_{ij}^{Eucl}}{d_{ij}} \right)$$

and where G′ is the graph with N nodes and K – k_i edges obtained by removing from the original graph G the k_i edges incident in node i. An advantage of using the efficiency to measure the performance of a graph is that E[G] is finite even for disconnected graphs.
The spatial distribution of node centralities can be visualized as the one of Tirana reported in Figure 16. While figure 15 shows visual presentation of C^S for Ahmedabad, Venice, Richmond and Walnut Creek [Por06].

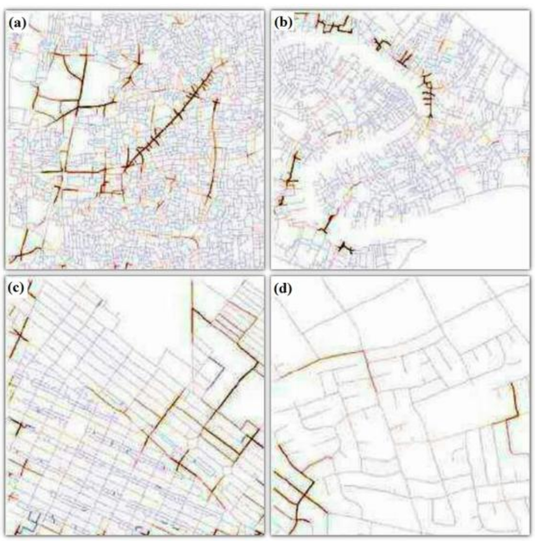

Figure 15: C^I (a) Ahmebadad; (b) Venice; (c) Richmond; (d) Walnut Creek [Por06]

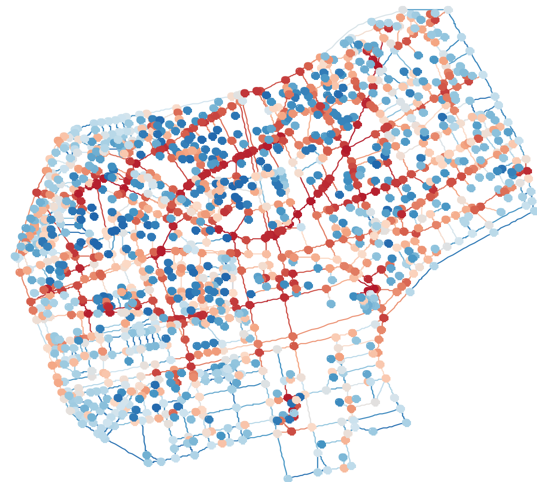

Figure 16: C^I, Tirana

From this visual representation of C^I for Tirana, we notice that some of the most critical streets, that are very important for the connectivity of the street network in Tirana, playing in this way the role of ‘bridges’, are “Fortuzi” street, Durrësi street, Bogdanët street, “Myslym Shyri” street, Dibra street, “Qemal Stafa” street, Saraçët street, etc.

4 Results and Future Work

In this article we used MCA method and we concluded that Tirana is a self-organized city. We also defined some of the most important streets of Tirana that capture the ‘skeleton’ of the urban structure that impacts so much on economic and cultural development of the city. In the future, it will be of great interest to use MCA method even for other cities of Albania. For example we may use MCA for the city of Korça, that can be prejudged as a planned city. In this way we can make comparisons between different cities of Albania.

5 Acknowledgments

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Municipality of Tirana, especially to the head of Traffic Control Sector Mr. Kreshnik Bajraktari for supporting me with updated information on network of urban streets of Tirana.

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