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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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STREET NETWORK ANALYSIS BASED ON SUBDISTRICTS OF BUDAPEST

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Abstract

Morphological analyzation of street networks of settlements has become very popular in the last decades. Settlements and their subdistricts have different shapes and types of street networks. Connection between them and land use are not always predictable. This paper has been sought the connection among land use and built landscapes of subdistricts and urban street measuring indices for 4 built landscapes and 48 subdistricts. The analyzed built landscapes were the following: superblock, downtown, garden suburb on plate and garden suburb on hillside. The outcomes of morphological analysis methods such as street segment density, street network density, intersection density, connectivity index, shape ratio index and ratio of one-way streets were compared to each other. The author established connection among street network indexes with Mann-Whitney U test. The results show that built landscapes are predictable based on street networks in case of Budapest. These outcomes could support the regular urban design steps.

Keywords: *street network morphological analysis, urban street network, residential areas, built landscape, mann-whitney u test*

1 Introduction

Urban street network is the vascular system of settlements. Street network ensures the connection between subdistricts of cities and discloses the them. Moreover, the structure of street network depends on its tasks of transportation. Results of these influencing factors are often a complex network which depends on the environment of street, the land use. It is represented by the economic nature of activities such as production, consumption, residence and transport. The shape and size of cities have changed over time, but their street networks bear the stamp of original land use, in most cases. In generally subdistricts also known as neighbourhoods have specific population and housing density, which are influenced by the features mentioned above. Connection of land use and transportation are deeply studied and a lot of coherences have been found between them until this time [1, 2]. The parts of the towns have different impacts for traffic generation, attraction, under similar land use types [3]. For instance, superblock or microdistrict with multi-storey apartment buildings and suburb residential area with single family-housing have similar residential land use. All the same, huge differences exist between qualitative and quantitative characteristics of transportation in these areas. These sub-parts of settlements have different street network patterns which are connecting to specific land use and built-up zones in most cases. Moreover, the subdistricts have geographical, hydrographical, historical and transportation (i.e. railways, motorways) limitations. Street networks of different residential land use types have been examined for this reason. The analyzed 48 subdistricts of Budapest were grouped into the following bu-

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ilt landscape sets: estate as superblock, closed row as downtown, free standing as garden suburb on a plain, and free standing on a hilside as garden suburb on hillside. There are many methods are available for morphology analysis of street networks [4, 5]. Most of them are taking into account the intersection density, street segment density and connectivity index. During the research project [6], the mentioned indexes were used beside shape ratio index, and ratio of one-way streets. Based on the results, differences were detected among street networks of subdistricts using specific data sources and methodology.
The paper is organized as follows. Section 2 describs the selected subdistricts in Budapest, data processing methods of street networks and introducing the topological metrics. Section 3 presents the results of the measurements and discussion concerning the findings. The last section contains the summary and concludes the paper.

2 Data collecting and Methodology

2.1 Data collecting

Subdistricts with different land use and built landscapes are the building component of settlements [7]. For adequate results in this paper, 4 different built landscape zones were analyzed in Budapest. They are the following ones, zone of (1) Estate with multi-storey apartment buildings, 11 cases; (2) Closed row with tenements at downtown, 13 cases; (3) Free standing (on plain) with detached houses, 13 cases; (4) Free standing on hillside with detached house, 11 cases. Zones were selected based on the available data from land use and built landscapes in Budapest [8]. Chosen subdistricts of Budapest have different street layout due to geographical limitations (terrian and hydrography) and historical development (building period). Therefore, they have various planar configurations. For instance, tree, cellular and grid patterns. They have also difference size, population and number of dwellings. Density values were used to compare statistical characteristics with street network measures. The chosen 48 subdistricts are shown in Fig 1., and Fig. 2. contains general top-view layout of each built landsacpes.

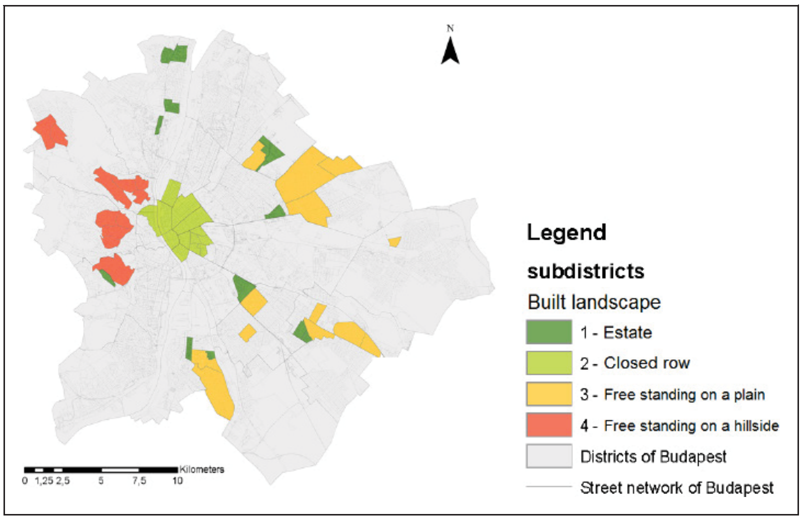

Figure 1 Analyzed subdistricts in Budapest

Appropriate data collecting was the first part of analyzing process. First, street network data and subdistrict territory of Budapest were collected from www.openstreetmap.org (OSM), which is an online open source map. ArcGIS [9] software was used for data storage of downloaded information and for the analyzation of street networks. Intersections were defined as nodes and street networks were changed to street segments as links in the end of this process. Moreover, the connecting road network of subdistricts were also taking into account.

In everyday transportation, the restrictions of streets have a great influence on the traffic flow. It determines the passable routes also in private and public transportation modes. In this paper, one (in the case of one-way street) or two (in the case of two-way street) street segments were determined between adjacent intersection. Therefore, every street segment has been directed as it appears in reality.

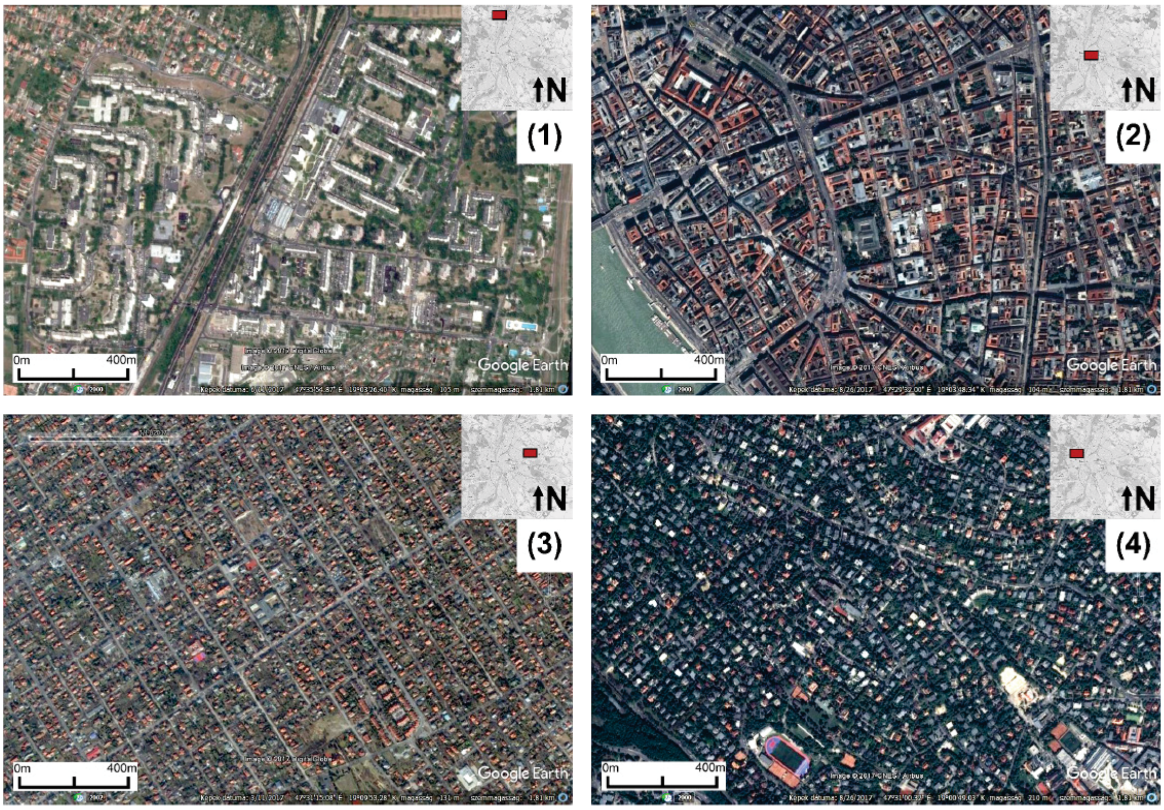

Figure 2 Analyzed subdistricts of Budapest in top-view, (1) Estate, (2) Closed row, (3) Free standing on a plain, (4) Free standing on hillside; source: GoogleEarth

Administration level from OSM was the same as the administrative divisions in Budapest. Examination of subdistricts with homogeneous built landscape was important boundary condition during research work. Area of subdistricts were important measurements next to population density. Population density is a measurement of population per unit area [people/km^2]. Information about population of areas are up-to-date available in the used administration level from webpage of Hungarian Central Statistical Office [10]. Hence, the street network measures were comparable to statistical data of subdistricts administration level. Area and population density are shown by Fig. 2.
Fig. 2. shows area of examined subdistricts are close to each other, only three cases of Free standing on a plain have higher value than the other ones. The population density could be separates into two subsets. In case of Estate and Closed row have higher outcomes (approx. 20000 people/km^2) than in the other two cases (approx. 4000 people/km^2). This correlation comes from the relationship of with housing density and sprawl area [11].

2.2 Methodology

The following definitions are mainly using in urban street network morphology. These metrics were used in this paper with the earlier mentioned supplementation of street segments. The updated street networks were used in analyzing process. As earlier mentioned, the analyzed 48 subdistricts have different size and urban street layout. Therefore, the following indexes were used in the process of data analyzing. These ratios have many variants and they have long term usages as it was mentioned in the Introduction. Street network density (SND) is equal to the length of street segments divided by the area of subdistrict. Street segment density (SSD) is defined as the number of street segments divided by the area of subdistrict. Intersection density (ID) is defined as the number of intersections divided by the area of subdistrict. Connectivity index (CI) called Link to Node Ratio. It is equal to the number of street segments divided by the number of intersections. Shape ratio index (SRI) is defined as the area of circumscribed circle of subdistrict divided by area of subdistrict. Besides, shape ratio of square equals to 0.637. Lower value than ratio is the more oblong the area is. Shape of area has been characterized by this ratio index. The ratio of one-way streets (ONE) is defined as the number of one-way streets divided by the number of every street.

3 Results and Discussion

3.1 Analysis of street networks

This section contains the results of morphological street network analysis of selected subdistricts of Budapest. Box plot graphs were used for representation of results (Fig. 2 and Fig. 3) Green circles are shown the data, and black graphs are shown normal distributions of the data. In the box plot, the bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The ends of the whiskers are the standard deviation. At the graphs, black X are 1 % and 99 % values simultaneously, and the vertical black lines are represented the arithmetic mean value.

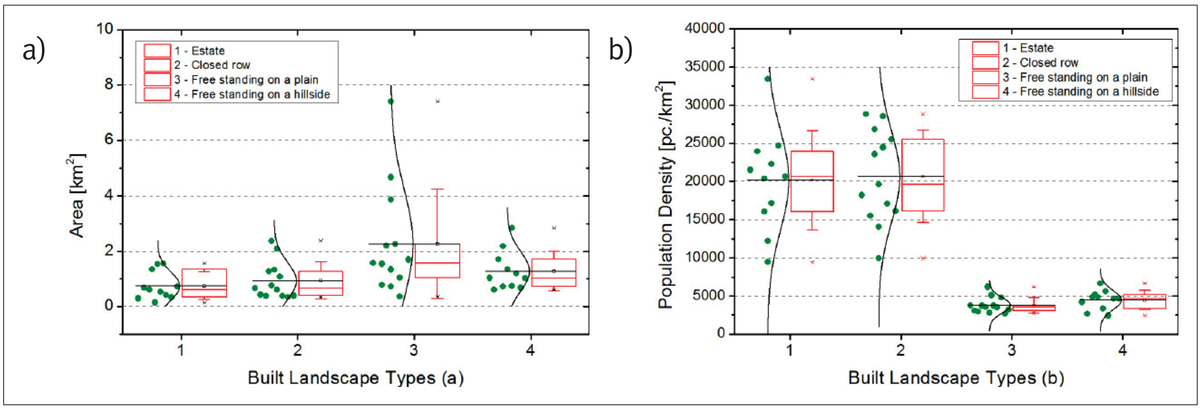

Figure 3 Area (a) and Population density (b) distribution of selected subdistricts.

The Street Network Density (SND) is shown in Fig. 3. (a). According to the results, mean and median values of Estate (44 km/km^2) are about 1,5 times higher than the other three built landscape types (30-33 km/km^2). In addition, there are some differences exists among Estate results. This comes from the diverse of building approach and period of construction. Furthermore, the high values of results in this case derive from the high-density housing and density street network. Streets are close to the apartment buildings and service roads ensure intensive surface parking. In the other three built landscape cases, the reason for the lower values are that the street networks are characterized by regular installation. Those locks larger blocks around. The results of these have a little bit diverse mean and median values from each other. Values of Closed row has the shortest length of directed streets, and Free standing on a hillside has the highest ones among rest of the cases. Hence this result shows that functions and layouts of the streets are similar. The following analyzed index was the street network density (SND), Fig. 2. (b) shows the outcomes. In this case the characteristics of results are similar to the values of SND. According to the results, mean and median values of Estate (600 pc./km^2) are about 1,5 times higher than the other three built landscape types (350-400 pc./km^2).

The reason for the difference in results in the same as earlier mentioned at SND. In the other three cases, mean and median results of data different from each other. Closed row has higher and Free standing on a plain has lower outcomes. The intersection density (ID) of analyzed urban districts represents in Fig. 2. (c). Estate (260 pc./km^2) and Closed row (230 pc./km^2) have higher values than Free standing on a plain (120 pc./km^2) and Free standing on a hillside (150 pc./km^2), they have still low outcomes. The large number of one-way streets justifies the high value of Closed row case compared to SND and SSD. Connectivity index (CI) in Fig. 2. (d), also known as link to node ratio, shows the main differences in analyzed subdistricts. It represents the node to node connection via links. If this value is low, for instance in case of Closed row, where average values are lower than 2.0 pc./pc., the examined parts of town have a lot of one-way streets. This statement could be confirmed by comparison of the case of SND and IS. SND is average, but ID is relatively high in Closed row. Traffic are heavy, streets are narrow, and the on-street parking need lots space in the core of the towns, hence using one-way streets as traffic calming method is widespread. The most of the values in case of Estate and Free standing on a hillside are between 2.0 and 2.5 pc./pc. Free standing on a plain has the highest Connectivity outcomes. It means that most of the streets are bidirected and number of one-way streets are lower than other cases. The street patterns have traditionally grid layout at this part of the city [12].

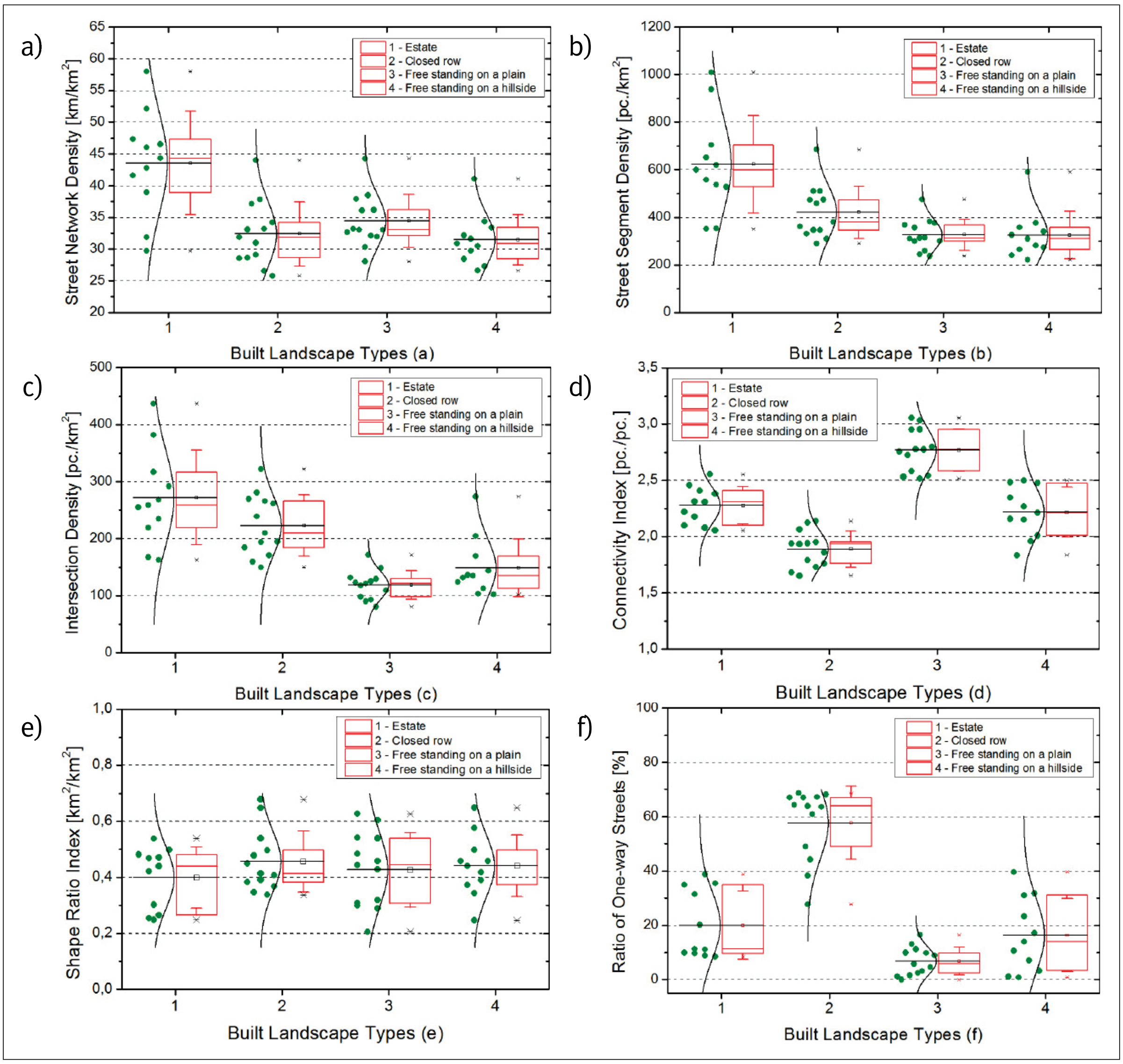

Figure 4 Outcomes of street network analyzation, street network density (a), street segment density (b), intersection density (c), connectivity index (d), shape ratio index (e), ratio of one-way streets (f)

Shape ratio index (SRI) in Fig. 3. (e) has highly diverse results in every case. However, means and medians are always between 0.40 and 0.45. High values of standard deviations are shown the shape of subdistricts area independent from built landscapes. Nevertheless, presence of geographical limitations i.e. hills could be influence the street network patterns and results. In previous sections, the importance of the ratio of one-way streets (ONE) were mentioned. Fig. 2. (f) contains the results of this ratio. One-way streets used in aspect of traffic calming and management. As the graphs show, in most cases it is used in downtown areas as closed row, where the pavement of the streets is narrow for two-way traffic and parking spots simultaneously. One-way streets hardly ever exist at Free standing on a plain. In case of Estate and Free standing on a hillside, the mean value is approximate 20 %. The spread of one-way streets is various as it is shown by the outcomes of Estate. The different rates of use depend on the local environment in most cases.

3.2 Statistical test for street networks

During the study, the analyzed subdistricts outcomes (SSD, SND, ID, CI, SRI, ONE) were compared with Mann-Whitney U test. The Mann-Whitney U test is a nonparametric test of the nul hypothesis that it is equally likely that a randomly selected value from one simple will be less than or greater than a randomly selected value from a second sample. This test can be used to determine whether two independent samples were selected from populations having the same distribution. The level of significance was 5 % (p = 0,05) during the test, and statistical tests were performed in pairs. Fig 4. contains the outcomes of test.

SND	1	2	3	4	SSD	1	2	3	4	ID	1	2	3	4
1	-	0.0021	0.0091	0.0016	1	-	0.0045	4.09E-04	8.11E-04	1	-	0.2025	6.40E-05	0.0013
2	-	-	0.2592	0.7281	2	-	-	0.0313	0.0150	2	-	-	3.27E-05	0.0026
3	-	-	-	0.0725	3	-	-	-	0.6430	3	-	-	-	0.0725
4	-	-	-	-	4	-	-	-	-	4	-	-	-	-
CI	1	2	3	4	SRI	1	2	3	4	ONE	1	2	3	4
1	-	2.09E-04	8.16E-05	0.5994	1	-	0.49	0.49	0.79	1	-	1.31E-04	0.0077	0.4701
2	-	-	1.65E-05	9.59E-04	2	-	-	0.64	1.00	2	-	-	1.65E-05	1.04E-04
3	-	-	-	3.90E-05	3	-	-	-	0.86	3	-	-	-	0.0929
4	-	-	-	-	4	-	-	-	-	4	-	-	-	-

Figure 5 Results of statistical test, green: different distribution, red: same distribution. SND: street network density, SSD: street segment density, ID: intersection density, CI: connectivity index, SRI: shape ratio index, ONE: ratio of one-way streets, 1: Estate, 2: Closed row, 3: Free standing on a plain, 4: Free standing on a hillside

Following the significance test, it can be stated that the street networks of different types of subdistricts differ from each other. Results obtained during statistical tests, in some cases, they do not appear visually, which is due to the low number of cases and the weakness of nonparametric testing. In the nonparametric independence test, the arithmetic mean, and the deviation is ignored. The first, second and third quartiles were also taken into account in the visual observation. In the next section, the results are analyzed and the independence of the street networks of subdistricts under consideration is presented.

Estates are different from other built landscapes in the following cases. There is a significant difference from others in SND and SSD, which differences are visually displayed clearly. In case of Closed row, according to statistical test, there is a significant difference from others in SSD, CI, and ONE. It should be noted, however, that the difference is visually for the CI and ONE, at the same time, the difference with SSD does not appear clearly. In case of Free standing on a plain, according to statistical test, there is a significant difference from others in CI. Regarding the other parameters considered, the results are close to the case of Free standing on a hillside. That is, based on statistical analysis, not possible to distinguish itself from other types of subdistricts on the basis of one of the examined street network parameters. Additionally, taking into consideration CI (distinction of Closed row and Free standing on a plain) and SND or SSD (distinction of Superblock) the difference can be established based on the common examination.

4 Conclusion

In this paper, street networks of different subdistricts of Budapest have been compared. Taking into consideration the one-way streets, it was shown by Mann-Whitney U test that the street network of subdistricts with different built landscape (estate (superblock), closed row (downtown), free standing on a plain (garden suburb), free standing on a hillside (garden suburb on hillside)) differed according to the examined street network characteristics (street network density, street segment density, intersection density). Only data from Budapest were analyzed in the study, so the results can be compared with settlements with historical development like Budapest. Based on the results, the built-in methods studied can be separated from each other by the complex examination of their street network.

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