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SPATIAL SCALE, ORGANIC AND DESIGNED NATURE OF ROAD NETWORKS

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Abstract: The human footprint on the surface of our planet is increasingly well documented and accessible in form of spatial data. Linear spatial structures describing the network of corridors used for movement of people and goods show surprising stability based on their evolutionary nature. It has been shown that specific shape of network implies spatial patterns of urban land use, or travel behavior less affected by randomness than it would be expected. We measure and fit four empirical distributions of the network centrality based on shortest paths over multiple scales using a unique cellular approach. Our findings support the evidence from other contexts pointing at a clear distinction between self-organized and top-down design of urban form, capturing the process of organic development interrupted by large scale modernist period in the area of Bratislava, Slovakia.

Key words: Bratislava, centrality, evolution, road network, spatial planning

1 INTRODUCTION

The analysis of design of built environment belongs to traditional fields of interest in urban geography. The evolution of the urban form, often taken as seemingly unchanging object, offers an attractive reflection for evolving human society. Historical documents show a city decades or centuries back in time and identify its fragments surviving technological development and unfortunate historical episodes of destruction. There is a great amount of attention devoted to efforts to restore what is left and even more to figure out how the city changes in coming years. Stretched between the past and the future, urban morphology has established a research tradition at the edge of many social sciences, offering useful analytical concepts like urban morphological cycle or fringe belts (Whitehand and Morton, 2003, 2006). The available historical maps and "relative ease with which they can be digitized" has made them subject to a renewed research interest (Offen, 2013).

All of the analytical tools are relying primarily on the spatial aspects of built environment. These clearly point at the evolutionary character of urban form

(Barthélemy et al., 2013; Masucci et al., 2013; Strano et al., 2012). Recognition of the process deep within what we observe as unchanging, from our limited time perspective, is probably the most important message. Urban plan is considered to be an object both self-organized, organic, and engineered, top-down designed, moreover to a certain extent at the same time (Batty, 2008; Buhl et al., 2006; White and Engelen, 1993). Finding equilibrium between these two is the key objective of urban planning (Kane et al., 2014), however, we do not look for it in this analysis. Our intention is to describe a city as an artifact blending these two designs at various levels of spatial scale because scale appears to be crucial for understanding cities (Batty, 2013; Bettencourt, 2013).

Based on the concept of a city as a local cluster of human interaction (Koehler, 2014; Porter, 2000), we consider the urban form to be a materialized part of these interactions. This idea allows us to step out of the realm of traditional urban morphology and to enter a fast developing field of network science. Networks increasingly spread across search for solutions in a variety of research problems in areas including spatial economy, transportation, and even biological sciences, where the identification of interacting actors is straightforward. Multiple observations indicate that economic sectors essential in the life of urban inhabitants tend to locate within reach of hierarchically most important arterials (Jiang, 2009; Lämmer et al., 2006; Mehaffy et al., 2010; Porta et al., 2012; Tomko et al., 2008).

Our attempt to translate the question of evolving urban form into the language of network science is already well established (Barthélemy, 2011; Jiang and Claramunt, 2002; Jiang, 2007; Turner, 2007) and debated (Hillier and Penn, 2004; Ratti, 2004). It has been recognized a long time ago, that a city is in the fact a multi-scalar network spread in various dimensions of human activity. Geographic simulation approach, too, has recently been employed in this research area. Jiang and Jia (2011) find flows “mainly shaped by the underlying street structure” with behavioral aspects (random and purposive) with “little effect on the aggregate flow”. This concept includes application of methods as cellular automata, actor based network models or attempts using fractal geometry to study the city. All of the listed methods are to some extent successful, though at the same time complementary. It seems that network approach could offer a unifying basis. Therefore the motivation for this paper is in our expectation that network description of urban form can provide us with the opportunity to understand a few more principles than is usual.

A conventional approach to analysis of urban form is to take city as a large and dense cluster of buildings projected in the plan. Buildings are connected to each other by roads used by vehicles of various transport modes. This naturally leads to the finding that density of built-up areas is spatially varying. Local clusters of elevated density correspond with the presence of people using space for various purposes, for example housing.

Using cellular automata allows us to go one step further in generalizing of this concept (Batty et al., 1999; White et al., 1993). In this method, the urban plan is transformed into a binary raster of cells where the values represent contrasts between cells containing no and at least one buildings. These values are in the following step predicted by suitable regression framework aiming at identifying the driving forces from few candidate variables. However, no matter how sophisticated technique is used, conclusions from this class of models always end up in a rather unproductive outcome.

An evolving urban plan is found to have following characteristics: high path dependence, retaining environmental suitability linked mostly with terrain and water bodies in the area, transportation network as the backbone and spatial autocorrelation, all at the same time. Moreover, the evolution occurs in cycles, which are irregular and connected to business cycle driving the real estate markets. This observation entails an analytical complication, which is questioning traditional linear statistical tools used with the concept. Urban dynamics is highly nonlinear, at least in the material sense. There are boom phases when urban form quantitatively explodes either consuming large open landscapes or adding tall buildings to the city skyline. This idea connects a temporal perspective back to the study of polarity between organic and designed urban forms. Actually, both forms are designed by people. The main difference is in the amount of time available for their evolution. Small scale long developing structures appear different to large scale structures built at once. The idea of reversing the traditional view of urban form is therefore worth exploration. Road network seems to be closer to the core of the research problem than location of buildings in a city and what is more, roads prove to be more stable element in the urban plan.

The question of stability is inherently included within the concept of the morphological cycle. This hypothesis focuses change of plot coverage density within a defined block of land, separated by nothing but roads, which creates the basic theoretical framework for cartographic urban morphology analysis (Pinho and Oliveira, 2009). Respecting the reverse approach suggested before, movement corridors for people, goods, and information are probably even more crucial than the places adjacent to these corridors. Moreover, this approach has advantage in the possibility of applying network science tools for exploration and later hypothesis testing. Research connecting evolving networks with urban form appears to be promising (Masucci et al., 2014; Viana et al., 2013). The path followed in this paper builds upon the progress recently made in this line of research.

In the first main part of this paper we summarized techniques usable for network representation as well as description of urban form. Empirical results from the application in Bratislava area are presented afterwards. Important findings are discussed and conclusions are shown in the final part.

2 METHODS AND DATA

The approach chosen for this article is an explorative one. Our intention is to see how a typical urban form is seen by the tools of network science at multiple scales. We do not follow a network perspective commonly used in transportation literature. We will place the focus of this work rather at the edge between current network and traditional urban morphology. The first objective is to find an adequate quantification of suitable network differentiating value. The probability of development can be based upon this variable, similar to other modeling strategies. By knowing the relative differences in the variable we might be able to predict future extents of morphology. Alternatively, we might be able to construct retrospective explanations for observed evolution patterns visible in the historical plans. Although, we are strictly using single recent representation of road network in this research. The second objective is to understand spatial and statistical distribution of the network in a specific research area.

According to the preceding, the value from the first objective is an expression of the role that a node has in the network. This is the objective of basic network description techniques that provide us with a useful method. According to preliminary research work (Crucitti et al., 2006a, 2006b), the most suitable method appears to be betweenness centrality, a measure based on shortest paths in many different variants (Brandes, 2008). Porta et al. (2009) found retail and services in Bologna, Italy best correlated with betweenness in the street network. Wang et al. (2011), using their case study in Baton Rouge, United States on the other hand give preference to closeness and straightness above betweenness. Rui and Ban (2014) examine different street centralities linked to land-use in Stockholm, Sweden.

Background for this method is interdisciplinary, both sociological and mathematical. Large amount of practical applications have recently used it to understand the role of distribution in variety of real-world networks. Many applications of this concept prove extremely valuable, though there are critical differences in terms of ways how the network under consideration is represented. Our implementation resembles to a certain extent common usage in traffic cellular automata (Maerivoet and De Moor, 2005).

Betweenness centrality is employing the concept of the shortest path, as a series of nodes and edges provides the most efficient connection between two different parts of the network. In the spatial terms the shortest path connects all different places in the area by minimum distance. Node specific betweenness centrality is the fraction of the shortest paths between all pairs of vertices which are passing through a node. According to common definition, betweenness centrality $C^B(i)$ of the node *i* depends on the portion of the shortest paths n_{jk} from node *j* to *k* that passes through node *i*

$$C^B(i)=\frac{1}{(N-1)(N-2)}\sum_{i\neq j\neq k}\frac{n_{jk}(i)}{n_{jk}}$$

Betweenness centralization, since it is a measure for the whole network, is counted as average of betweenness centrality of all nodes in the network. Values of betweenness centrality vary between zero and one where zero as the lower limit corresponds to circle-shaped network and one as the upper limit corresponds to star-shaped network.

Prior to applying this centrality method, we need to define roads in the form of network. The most straightforward technical possibility is to use road network in polyline representation and consider both endpoints and crossings as nodes. Nodes are connected only in the case of existing road fragment between them. Connections can be weighted by distance variable taking into account spatial complexities, driving speed, etc. However, this strategy leaves majority of the urban plan without any estimated value. Useful compromise between estimating value only for true network nodes and estimating some kind of centrality for every location in the area is to estimate values for all locations on the network. The idea of giving value even to land without development but with increased probability to be developed in the process is in agreement with the outcomes of competing geographic simulation techniques.

Development of any kind can be contiguous or leapfrogging. Basic statistical observations show that places adjacent to roads tend to be physically urbanized much easier than places far from roads. This statement applies to roads in various stages of development including roads in open landscape used mainly by farmers. Roads, as parts of urban form, can have organic or designed origin. There are examples of large road networks designed at once and outlined as parts of commercial development projects. These only rarely have large-scale effect and so change basic architecture of long evolving organic networks and thus reorganize usual distribution of flows across the area. The only successful examples of exceptions are constructions of bridges, underground passes and other major infrastructure projects, because they possess the power to modify the existing network topology. The potential of these structures to redirect flow corridors and attract large amount of random paths can be realized on economic basis only under the condition of offering significant saving of time and resources.

To confirm previous statements about spatial impact of designed roads, we choose the strategy to construct a scalable network. Firstly, we convert polyline road network representation into regular lattice of square grid according to the presence or absence of poly-line segment within the square cell. In the next step, a network is built from the grid depending on the contiguity of cells including a road fragments. In order to reduce network size and have minimal losses we decided to use the Rook type of contiguity. Therefore, every grid cell with a road segment has to have from zero to four neighbors with a road segment. In other words, there is an existing road used for transportation between the cell and its neighbor. Despite being rather exceptional, minor road structures that are separated from network may occur. These can arise in particular artificially at the edge of our sample area.

Data for the purposes described above for Bratislava area are all freely available in the OpenStreetMap project. We are using polyline road network representation as available online at the beginning of June 2013. This data-source includes all linear structures, both existing and proposed, of different class level, ranging from paths to motorways, which can be used for traffic or only for pedestrians.

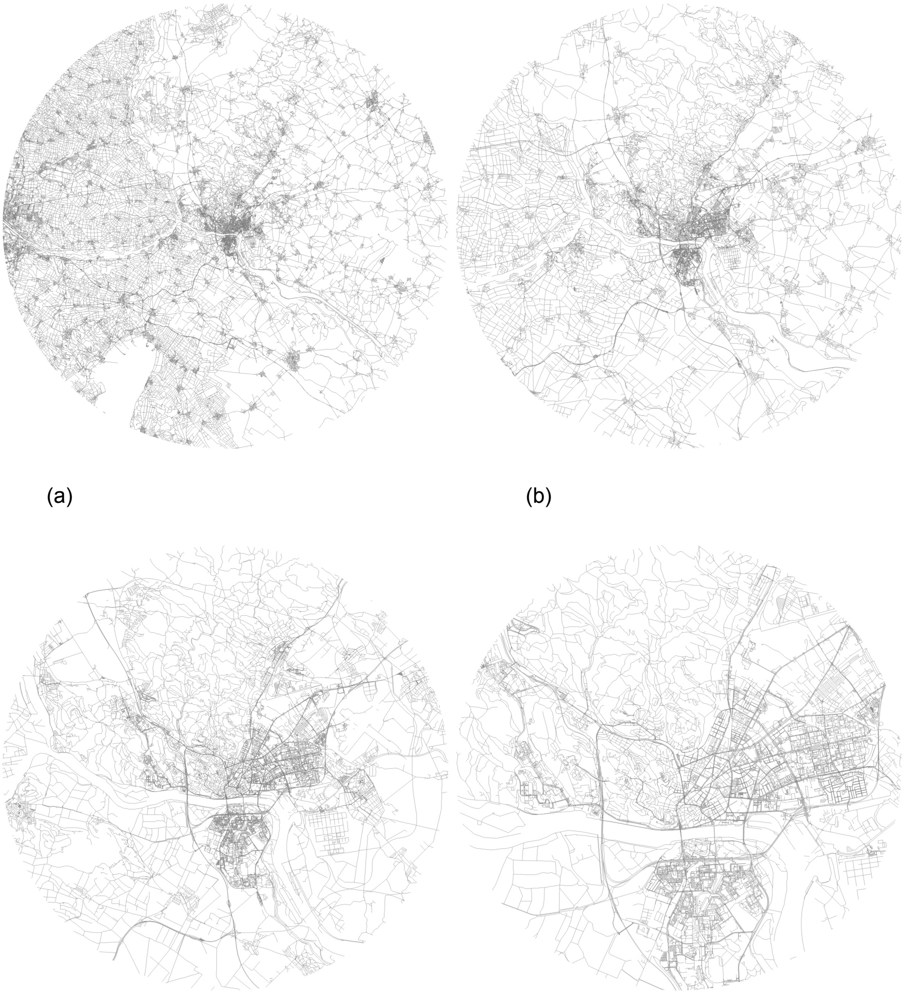
Bratislava area is an interesting empirical example for several reasons. Originally a small regional center has mainly been transformed in the process of state managed modernization during the socialist period in the 20th century. Modernization was relying on the development of manufacturing plants and mass housing and was implemented by well defined construction boom phases. Post-socialism has firstly brought a deep development gap during which only a tiny fraction of actual demand was saturated. Supply was compensated later, after real estate market institutions have emerged. The change of real estate market caused transferring of the initiative to individual actors, to some extent even to self-supplying. Additionally, Bratislava is an international city touching Austrian and Hungarian borders. Only few kilometers from the center of the city, development in adjacent Austrian and Hungarian border areas visibly accelerates. This can occur due to Schengen Agreement and with it removed barriers for development within the European Union.

The issue of spatial extent and resolution is resolved by four-scale setting resembling zooming a digital photography in three steps, each step reducing the extent to one half and at the same time increasing resolution twice (Figure 1). All four sample areas have the shape of a circle with the same center through all scales at the crossroad of Štefánikova, Šancová and Pražská streets at the north periphery of city center meeting main railway station. We consider this point crucial, in agreement with the conclusions of network analysis applied on Bratislava public transport system from January 2013 (Ondoš et al., 2013).

The first scale level is bounded by the diameter of 50 kilometers around the center and we have decided that the resolution 100 meters would be sufficient for this macro-regional perspective. After creating square lattice grid, there can be identified total number of 239.6 thousand cells including road segments. If we zoom in our perspective to the second level, the number of cells will reduce below 200.0 thousand, as shown in Table 1. If we look closer to characteristics, giant component is technically sparse graph, densities appear between 1.12×10^{-5} and 1.55×10^{-5}. Average degrees tell us that a representative cell is on average linked to between 2.6 and 2.7 neighboring cells, which is between 63.8 and 67.0 percent of the potential.

Table 1 Descriptive statistics characterizing the network representation of four scale levels of road network in Bratislava

Radius (km)	Coverage (km^2)	Resolution (m)	Cells	Coverage (%)	Giant component	Arcs	Average Degree
50	7,854	100	239,561	30.5	239,557	642,436	5.364
25	1,963	50	170,339	21.7	170,336	434,870	5.106
12.5	491	25	160,392	20.4	160,391	414,264	5.166
6.25	123	12.5	172,371	21.9	172,369	459,470	5.331



(a) (b)

(c) (d)

Figure 1 Road network in Bratislava area. Four scale levels show: (a) the lattice of 100 m cells up to 50 km; (b) the lattice of 50 m cells up to 25 km; (c) the lattice of 25 m cells up to 12.5 km; and (d) the lattice of 12.5 m cells up to 6.25 km around the center.

3 RESULTS

By the representation procedure applied to data, we were able to estimate new variable C^B, betweenness centralization, for varying number of observations according to the size of giant component of each scale level. Cells of giant component are connected in a unique way that describes the topology of real-world object, road network, at a specific scale level. Betweenness centralization of large region network is identified at the level of 0.161. Centralization of network of small region according to the value of this quantity has decreases to 0.126, what is practically the same as value 0.124 in the citywide network and 0.102 in the inner city network. This indicates that the city wide structure could be analogous to the surrounding small region.

If we focus on the change between consequent levels, we will find out that each step, decline of the radius with improvement in resolution, results in reduction of the analyzed area by 75 percent. Table 2 shows that each of the three steps leads to different changes in coverage of the area by road network, values of average degree and betweenness centrality.

Table 2 The change in selected parameters of the network between four scale levels

Radius (km)	Coverage (%)	Average Degree (%)	Betweenness Centralization (%)
50 → 25	-28.9	-4.8	-22.1
25 → 12.5	-5.8	1.2	-1.4
12.5 → 6.25	7.5	3.2	-17.5

The first level change, from large to small region, leads to reduction in coverage by almost one third while in connection and centralization by one quarter. Significant part of this effect must be probably ascribed to zooming out of the city of Vienna, which appears with its suburbs within the large region sample at the West edge (Figure 2a). The difference between small-regional and citywide sample is less pronounced. There is further reduction in coverage. Cells appear to be little more connected with neighbors and the network is less centralized again. The last reduction in radius results in the rise of coverage, which is natural as this step excluded most of the city suburbs that are present in citywide sample and not in inner city sample. Same reason causes the rising degree of cells with road segments, because we are now focusing on relatively dense inner city. Furthermore, we observe significant reduction of centralization.

To interpret observed differences reliably, one should at least have similar samples from different urban contexts, for example neighboring cities Vienna or Budapest, or urban territories of similar magnitude in terms of population and density. Even without availability of these comparative samples, one can speculate that the most star-like from the four levels should be the large region sample and the most circle-like is the inner city sample. Small region and citywide sample are somewhere on the half-way between these two extremes, both samples are practically the same in perspective of this quantity.

The pattern generated by spatial distribution of betweenness centrality values remindes of naturally evolved organic networks, very similar to vascular systems in biological structures (Bettencourt et al., 2007). Even more interesting is the correct identification of functional hierarchy upon which the spatial distribution of road network is built. Almost perfect backbone, corresponding to the real world one, appears in the sequence of three figures (Figure 2b, 2c and 2d). The corridors with the heaviest theoretical traffic can be identified as Brnianska, Pražská, and Račianska Street and all four city bridges. Betweenness centrality incorrectly places more focus than is optimum on forest roads. It is the outcome of missing population distribution and inclusion of all kinds of roads, also those not suitable for driving or where driving is not permitted. Figure 2d can serve as fully functional replacement of common road network plan suitable for valuation for traffic flow in individual network segments.

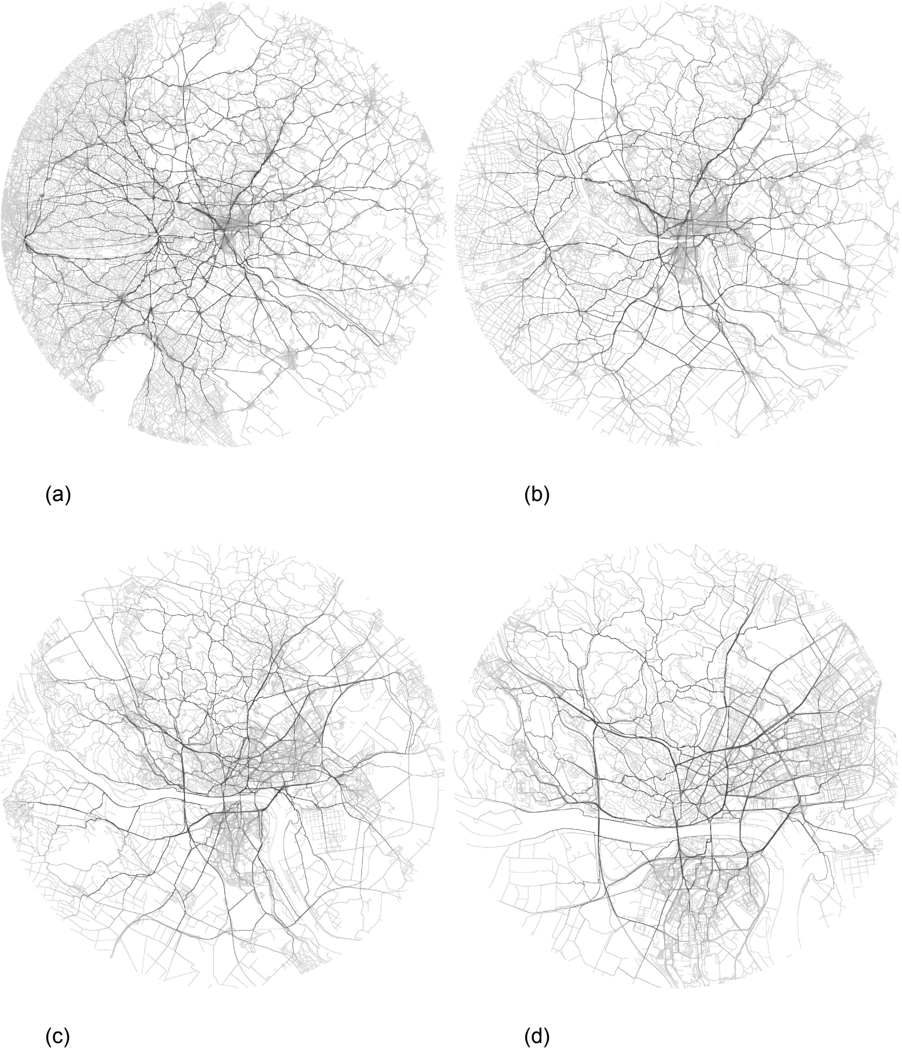
Previous statement is true for most of the city territory but there are still places in strong disagreement with it. Petržalka, large city district built mostly in the second half of the 20th century on the right bank of the Danube, is correctly separated from the river by busy corridor of Einsteinova Street. However, if we move our focus to the South, there is identified nothing that resembles real road hierarhy. It is surprising, because no similar problem appeared in other city quarters with similarly appearing urban design, such as Ružinov or Karlova Ves. Therefore, there arise a speculative question about the quality of urban design of Petržalka. Could the reason be the morphological difference to, for example, Ružinov or Karlova Ves? To get the answer, further analysis quantifying the levels of agreement would be needed. In words of Mehaffy et al. (2010), we might be observing exactly, what they describe as pathological urban structure fragmented and dispersed, designed according to standards suitable for automobile users.

As detailed samples, the large-regional one also offer identification of hierarchical polarity of roads. The central part of the first image (Figure 2a) shows huge crossing of two corridors, both of which clearly pass along the Carpathian mountain slopes. The large-regional network is constructed with substantial sensitivity to the location of bridges crossing Danube: the Praterbrücke in Vienna, the connection between Hainburg an der Donau and Marchegg, and all Bratislava city bridges. The city of Vienna itself is out of focus while its suburbs appear at the Western edge of the spatial sample. In accordance with previous findings, betweenness centrality has the abbility to identify important nodes scattered across the area, and suppress the importance of rural roads to truly local.

Further, to better understand the nature of examined networks, we are interested to find out how the differences observed visually are translated into statistical distributions and how they are modified with the scale changing between the samples. In order to quantify different empirical distributions we define the probability

$$P(C^B)=\int_{C^B}^{+\infty} \frac{N_{(C^B)}}{N} dC^B \quad ,$$

where N_{C^B} is number of nodes equal to centrality C^B. Figure 3 and Table 3 summarize first two fitting exercises, assuming exponential and Gaussian laws behind the cummulative distributions of betweenness centrality.


(a) (b)

(c) (d)

Figure 2 The values of betweenness centrality zoomed on: (a) 50 km,; (b) 25 km; (c) 12.5 km; and (d) 6.25 km lattice around the center. All four illustrations identify transit corridors between the regional and the inner city importance.

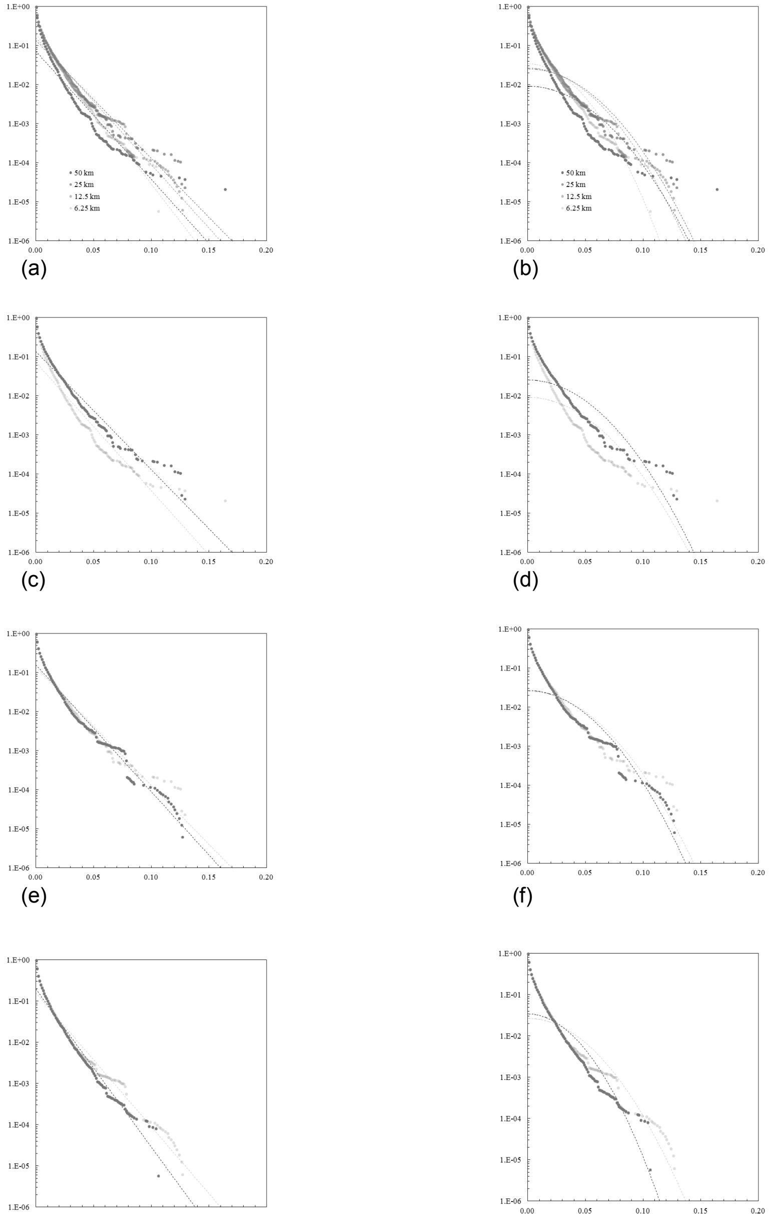
The exponential fit to the empirical distribution is of the kind $P(C^B) \sim \exp(C^B/s)$. The left column of Figure 3 (3a, 3c, 3e, 3g) shows how the trend line moves according to shifting empirical observations, but still preserves a similar value for the s parameter estimate. We observe 8.5 percent increase in s in the scale transition between the large and small region sample, 7.0 percent decrease between small region and citywide sample, and finally 15.3 percent decrease between citywide and inner-city sample. Exponential cummulative distribution is in the literature (Crucitti et al., 2006a, 2006b; Scellato et al., 2006) identified as the one corresponding to organic forms. In the case of Bratislava, a fairly high correspondence (Exponential R^2) is found.

As a competing explanation to exponential fit, Gaussian fit in the form $P(C^B) \sim \exp(-1/2 C^{B2}/\sigma^2)$ is considered more suitable in empirical case of planned cities. Results from this alternative are shown in the right column (Figure 3b, 3d, 3f, 3h). Even a simple visual check removes this option from consideration, further supported by significantly smaller agreement between empirical and fit data (Gaussian R^2). Nevertheless, inspecting the estimates for the value of parameter sigma (σ) can still be of some interest and significance. Table 3 shows that the estimated value is again very similar across all samples, difference is only in the sign between regional and city sample pairs. Regional samples have a positive σ, city samples have negative σ. At the same time, each increase in scale leads to decline of magnitude towards zero. The change between large and small region sample is by 2.3 percent, small regional and citywide sample by 5.2 percent and citywide and inner city sample by 17.4 percent. Despite the disagreement and very poor fit, the empirical regularity seems to be too well shaped to be just an outcome of noise. The Gaussian R^2 culminates at the scale of citywide sample, which might indicate that this level is the most planned one of the four.

Table 3 Fitting of the statistical distribution *P(C^B)* of betweenness centrality

Radius (km^2)	***s***	**Exponential *R^2***	**σ**	**Gaussian *R^2***	**s_1**	**s_2**	**Double exponential *R^2***
50	0.013	0.881	0.033	0.571	-15.437	0.052	0.997
25	0.014	0.934	0.032	0.727	-0.364	0.044	0.992
12.5	0.013	0.965	-0.030	0.831	-0.134	0.020	0.988
6.25	0.011	0.966	-0.025	0.816	-0.174	0.034	0.989

As we were interested in fitting the empirical distributions by other than the two proposed functional relationships and not satisfied with previous results, we have done several experiments combining more than one exponential trend line. A surprising agreement appears in all the cases when double exponential fit is the form $P(C^B) \sim \exp(\exp(-C^B/s_1) + \exp(-C^B/s_2))$ used instead. Double exponential fit is constructed as two different exponential lines nested within a third exponential function. Alternative, sigmoidal Richards functional form is also four-parametric, but the fit has lower quality on our data.



(a) (b)

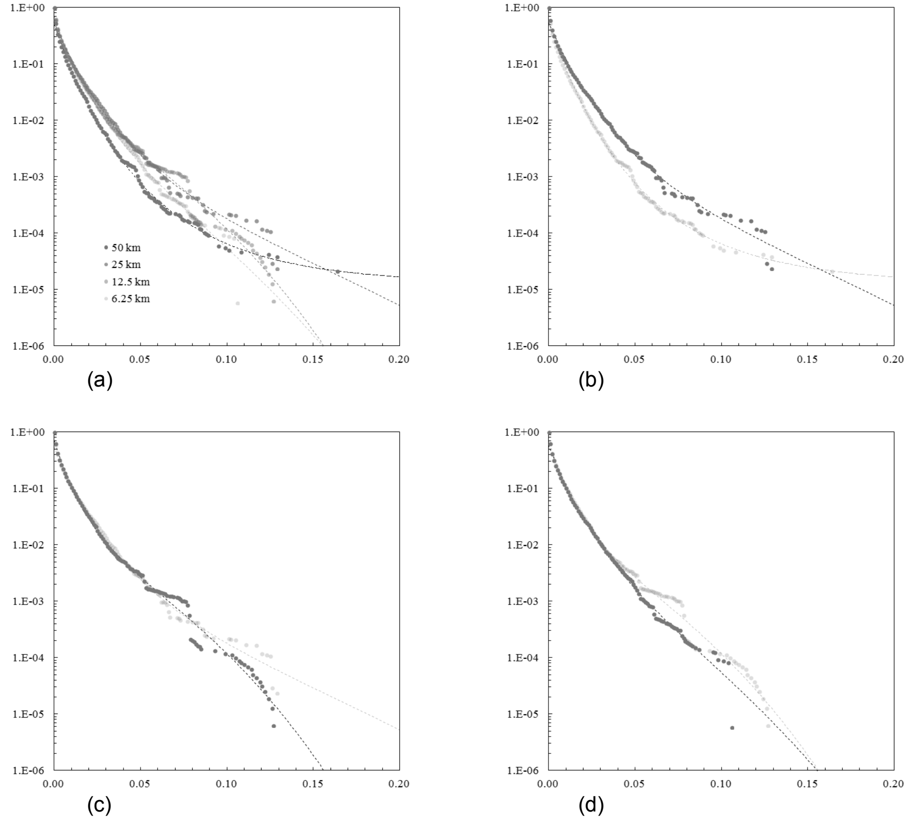
(c) (d)

(e) (f)

(g) (h)

Figure 3 Betweenness centrality in a cumulative distribution in: (a, b) four different lattices and the effect of scale changes (c, d) between 50 and 25 km, (e, f) 25 and 12.5 km and (g, h) 12.5 and 6.25 km. The dashed lines are (in the left column) exponential fits $P(C^B) \sim \exp(-C^B/s)$ and (in the right column) Gaussian fits $P(C^B) \sim \exp(-1/2 C^{B2}/\sigma^2)$.

Resulting plots in Figure 4 and parameter estimates s_1 and s_2 in Table 3 tell a story not much different from the two previous exercises, only this time much more precisely (Double exponential R^2), putting the findings into a single conceptual context as we will show below. This fact reveals that cumulative distribution of betweenness centrality appears to have slightly more complex shape than is a simple exponential or a Gaussian. The parameter dyads s_1 and s_2 are equivalent in their order, considering the additive functional form $f(x)=ae^{bx}+ce^{dx}$ from which their values are recalled by using $\log P(C^B)$ as empirical basis.



(a)

(b)

(c)

(d)

Figure 4 Betweenness centrality in cumulative distribution: (a) in four different lattices and the effect of scale changes; (b) between 50 and 25 km; (c) 25 and 12.5 km; and (d) 12.5 and 6.25 km. The dashed lines are double exponential fits $P(C^B) \sim \exp(\exp(-C^B/s_1)+\exp(-C^B/s_2))$.

Double exponential fit seems to solve a part of the story hidden from previous approaches. At the same time, a place for new interpretation opens up. As we move from one scale to another, the specific functional form is modified towards Gaussian shape corresponding to planned territorial structures. Though the specific meaning of s_1 and s_2 remains unclear, we observe regularity potentially indicating some parts of it. One of the parameters is always positive compensated by another negative. Except the first sample where s_1 is calculated from b that is insignificant at the 5 percent level of confidence, we can see that the negative parameter is 8.3-times, 6.7-times and 5.1-times bigger in magnitude than the positive one. The shape of resulting line is therefore shaped dominantly by only one of the elementary exponential functions, influenced slightly with the other one as the scale level increases.

According to the presented empirical evidence coming from multiple scales, it seems that physical urbanization can be described as the outcome of two opposing processes. These processes differ in the spatial structure of networks along which they are constructed. The one described by function $f_1(x) \sim -e^x$ is in our case with stronger influence, driving the cumulative distribution of betweenness centrality to slower decrease the more we approach towards high values of $x(C^B)$. The process corresponding to the function $f_2(x) \sim -e^x$ is the minor one, but hypothetically significantly less weak in case of planned cities. Cumulative distribution approaches Gaussian form, lowering the line towards relative high values of betweenness centrality. In case of our multi-scalar framework, we may suggest that such interpretation is intuitively correct.

4 CONCLUSION

After zooming in from the large region to inner-city sample we expected to see the domination of intentionally designed and planned network structures to rise. On the other hand, after moving in opposite direction we expected to see more organic structures that are out of reach of spatial planning, especially since the sample is international, covering three different countries without any development coordination. In the case of double exponential fit, we observed decreasing magnitude of both parameters between the first and the third sample. Inner-city sample went some way back towards small region dimension in both s_1 and s_2. Real world explanation for this phenomenon is again in agreement with expectations. Bratislava inner city is to large extent a historical urban structure surrounded by modernist quarters added in the second half of the 20th Century. These quarters appear completely in the focus only in third, citywide sample and therefore we have observed planned character of the city culminating right here, same as in the case of the Gaussian fit.

Organic spatial networks generate many important locations in the network, while planned spatial networks generate only few huge hubs resembling a star shape. The multi-scalar context and changing focus on single city gave us reasonable evidence suggesting that a city can be both organic and planned at the same time, but in different equilibrium at various scale levels. What does it actually mean for the design of everyday life in such a city has to be left for future research. But we may even now hypothesize that consequences are already present. Transportation along the lines of fully organic network can be expected to have different qualities than along the lines of fully planned network. Before future research, there have to be proposed and performed a study using dynamic approach directly focusing functionality linked to the network architecture described. Additionally, different cities around the world should be approached in the same way as we have approached Bratislava in order to gather enough evidence supporting this line of thinking.

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Priestorová mierka, organická a dizajnovaná cestná sieť

Súhrn

Analýza zastavaného prostredia patrí k tradičným oblastiam záujmu v geografii mesta. Vývoj mestskej formy ponúka atraktívny obraz meniacej sa ľudskej spoločnosti. Historické dokumenty ukazujú mesto spred desaťročí a storočí, fragmenty prežívajúce technologický rozvoj a etapy deštrukcie. Dostupné historické mapy, digitalizované dáta a analytické nástroje poukazujú čoraz viac na evolučný charakter mestskej formy, proces hlboko vnútri zdanlivo nemenného z nášho obmedzeného časového hľadiska. Pôdorys mesta je samoorganizujúci a taktiež cielene racionálne dizajnovaný do istej miery súčasne. Zámerom štúdie je popísať mesto ako artefakt zložený z týchto dvoch častí, zmiešaný na rôznych úrovniach priestorovej mierky reprezentácie územia mesta. Urbánna dynamika je nelineárna. Striedajú sa krátke rozvojové etapy, kedy mestská forma kvantitatívne exploduje do otvorenej krajiny alebo do výšky meniac panorámu mesta, a etapy relatívneho pokoja. Táto myšlienka nás privádza k spojeniu medzi časovou perspektívou a polaritou medzi organickými a dizajnovanými mestskými formami. V skutočnosti sú všetky formy dizajnované ľuďmi. Rozdiel je v množstve času k dispozícii pre ich vývoj.

Systematickou zmenou medzi mestským regiónom a centrom sme očakávali, že uvidíme dominanciu dizajnovaných sieťových štruktúr stúpať na úkor organických. Naopak, zmenou mierky v opačnom smere sme očakávali viac organických štruktúr, ktoré sú mimo dosahu územného plánovania, okrem iného aj preto, že vzorka v tom prípade zahŕňa tri rôzne krajiny bez priamej koordinácie svojho rozvoja. V prípade dvojitého exponenciálneho modelu distribúcie sme pozorovali klesajúce veľkosti oboch parametrov medzi prvou a treťou vzorkou. Vzorky vnútorného mesta do určitej miery smerujú späť k dimenzii regiónu. Vysvetlenie tohto javu je v súlade s očakávaním. Vnútorné mesto je do značnej miery historická urbanistická štruktúra obklopená modernistickým mestom štvrtí vybudovaným v druhej polovici 20. storočia. Tieto štvrte sa dostali do centra pozornosti v tretej, celomestskej vzorke a preto sme pozorovali najvýraznejšie dizajnovaný charakter mesta práve tu, rovnako ako v prípade Gaussovej distribúcie. Organické priestorové siete vytvárajú celú hierarchiu uzlov, kým dizajnované siete iba niekoľko. Kontext viac-mierkovej analýzy s meniacim sa územným záberom prináša dôkaz o tom, že mesto je organické aj cielene dizajnované súčasne, no v inej rovnováhe na rôznych úrovniach priestorovej mierky. Čo to znamená pre každodenný života v meste nevieme. Môžeme iba predpokladať, že následky prítomné sú a znášame ich prinajmenšom v súvislosti s energetickou efektívnosťou prúdenia tovaru a osôb v urbanizovanom priestore.