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Belgrade's Urban Transformation during the 19th Century: a Space Syntax Approach

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Abstract

This paper focuses on the change in terms of spatial structure of the city centre of Belgrade occurred during the 19th century with the urban renewal and sprawl. Space Syntax methodology was used in order to analyse and quantify the spatial configuration properties of the old town inherited from the Medieval and Ottoman period, but also to understand the changes produced by the remodelling of the borough during the Principality of Serbia according to the academic architectural style. A scan from the Radoje Dedinac plan of Belgrade from 1815-1830 conserved at the City Museum of Belgrade has been used in order to capture the old town morphology. Despite an abundant literature describing the incredible metamorphosis of the oriental part of the old town, the sources that have scientifically evaluated the urban transformation produced are very few. The Space Syntax methodology helps filling this gap. Axial maps of Belgrade between 1815-1830 and of nowadays have been generated and analysed in order to capture spatial intelligibility and synergy of the city before and after the urban transformation. Finally angular segment analysis has been used to understand the spatial morphology of both the organic urban form and the modern grid system.

Keywords: Space Syntax; spatial configuration; urban history; urban morphology cognitive space; Belgrade

Introduction

From the first decades of the 19th century, Belgrade experienced a huge urban transformation which reshaped the cityscape and erased the oriental character of the town (Đurić-Zamolo, 1977). The affirmation of the Serbian sovereignty after several centuries of Ottoman rule stimulated the dazzling urban growth of the town chosen as the capital city of the new state (Attila Aytekin, 2016; Vuksanović-Macura, 2018; Ćorović, 2018). In addition to the urban sprawl due to the population growth, the whole aspect of the city radically changed following the architectural standards in vogue in the major European capital at that time (Blagojević & Radivojević, 2007). With the exception of rare buildings and some toponyms all traces of the Ottoman past were erased. Settled in the core of the Belgrade urban area, the Stari Grad municipality is one of the oldest neighbourhoods of the Serbian capital city. During the 19th century the street network has been redesigned, moving from a medieval oriental layout to a more western and modern one (Vukotić & Danilović Hristić, 2015). Nowadays Stari Grad is a residential, mixed-use district with a lot of fast fashion retails but also industrial buildings located close to the Danube riverbanks (Hirt, 2009).

How was Belgrade shaped in the early years of the Principality of Serbia (1815-1882)? What did the urban transformation occurred during the 19th century, change in Belgrade in terms of spatial integration and segregation? To what extent the parcel structure inherited from the medieval and Ottoman period influ-

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enced the urban planning of the late modern era? Has the new urban configuration of the city improved its intelligibility and synergy?

All the concepts above mentioned refer to the Space Syntax theory which is a methodology developed since 1970 by Bill Hillier, Julienne Hanson and their colleagues from the Faculty of the Built Environment of the University College London. Based on a set of theories and techniques Space Syntax aims to quantify the spatial configuration of city open spaces and buildings. According to the theory the way a space is laid out affects the human behaviour and movement (Hillier& Hanson, 1984). People and socio-economic activities are differently distributed both in urban open spaces and building interiors due to the properties of their spatial configurations.

Spatial configurations are mathematically assessed by converting a spatial layout into a topological dual-graph. There are three methods to represent interior or exterior spaces. Convex map and isovist polygons are used to analyse properties inside a building whereas axial lines are drawn to study urban areas. Axial lines are defined as the minimum number of longest visibility or accessible lines covering the opens spaces between the buildings left free for the movement of pedestrians and vehicles (Hillier & Hanson, 1984; Turner et al., 2005). Space Syntax studies how the spatial configuration affects the human behaviour, movement and cognitive representation of the space, arguing that there is a dynamic interaction between space and society, which act one on the other (Bafna, 2003). According to Hillier (2016), cities are made to create contact. For this reason, the spatial cognitive quality is very important as human behaviour, during travel, is directly influenced by spatial knowledge. The information received affects the strategy of movement and the choice of a route to reach a destination. The possibility offered by Space Syntax to compare different spatial morphologies is also very important to understand the history of cities. For example researchers investigated the influence of big events, as well as socio-economic changes on the built fabric (Hanson, 1989). The syntactical morphological history analyses the urban transformation throughout times (Griffiths, 2012). Space Syntax provides quantitative variables to evaluate the passage from an organic structure, developed without centralized planning, to a modern grid system. The computation of different measures makes possible the comparative analysis of different urban morphologies.

Methodology

A scan of the Radoje Dedinac plan preserved at the City Museum of Belgrade has been used to capture the spatial configuration of the oriental and medieval structure of the ancient town (Figure 1). The original plan is a lithograph on paper with a size of 26.5 × 20 centimetres, representing Belgrade between 1815 and 1830, at a scale of 1:12000 metres. Dedinac drew the map in 1901 based on the Josimović's regulation plan published in 1867, at a time when the Ottoman cityscape was still present. The map was published as an appendix in Joakim Vujić book called *Putešestvije po Srbiji*. The slow process of urban transformation to affirm the Serbian identity was in its infancy. Actually, the change of physiognomy really began in 1841, when Belgrade was officially elevated to the rank of capital (Prpa & Branković, 2003).

After being imported in a Geographical Information System, the raster file has been referenced using the EPSG 3909. Then polygons representing the built parcels and the fortress have been drawn in order to obtain the shape of the open spaces at the beginning of the 19th century, when Belgrade was a semi-independent state within the Ottoman Empire (Figure 2).

It is yet possible to discern the layout of current streets, for example, the Cara Dušana street, but also the Kralja Petra which continues straight to the Dubrovačka (Figure 2). The Academic park was already present at the beginning of the 19th century, but not the actual Trg Republike.

Once the parcel shape extracted the boundaries of the neighbourhood have been determined according to the limits drawn on the map: rivers, fortress, and moats. Only the borough located within the Trenches has been selected. The small proto area of Liman settles on the Sava's riverbank was not considered for the analysis. According to the Serbian geographer the surface of Belgrade between the fortress and the moats was about 156.45 hectares and there were 112 parcels covering a total area of 75.6 hectares. This means that the majority of the space located inside the Trenches was not urbanized: about 48.31% of the whole area was covered by built parcels. The method chosen automatically drew axial lines from the urban map represented as polygon with holes, standing for the open spaces between the parcels. The two polygon layers representing the limits and the built parcels have been selected to create a new file in DXF format. Then the new file was imported in the Space Syntax software known as Depthmap X version 0.3b to generate the axial map of the layout design. Axial lines have been generated by clicking the icon "Create an all-line axial map". This method consists into drawing axial lines within the open spaces of a built environment.

Figure 1. Extract from the Radoje Dedinac's Plan of Belgrade between 1815-1830
Source: Belgrade City museum

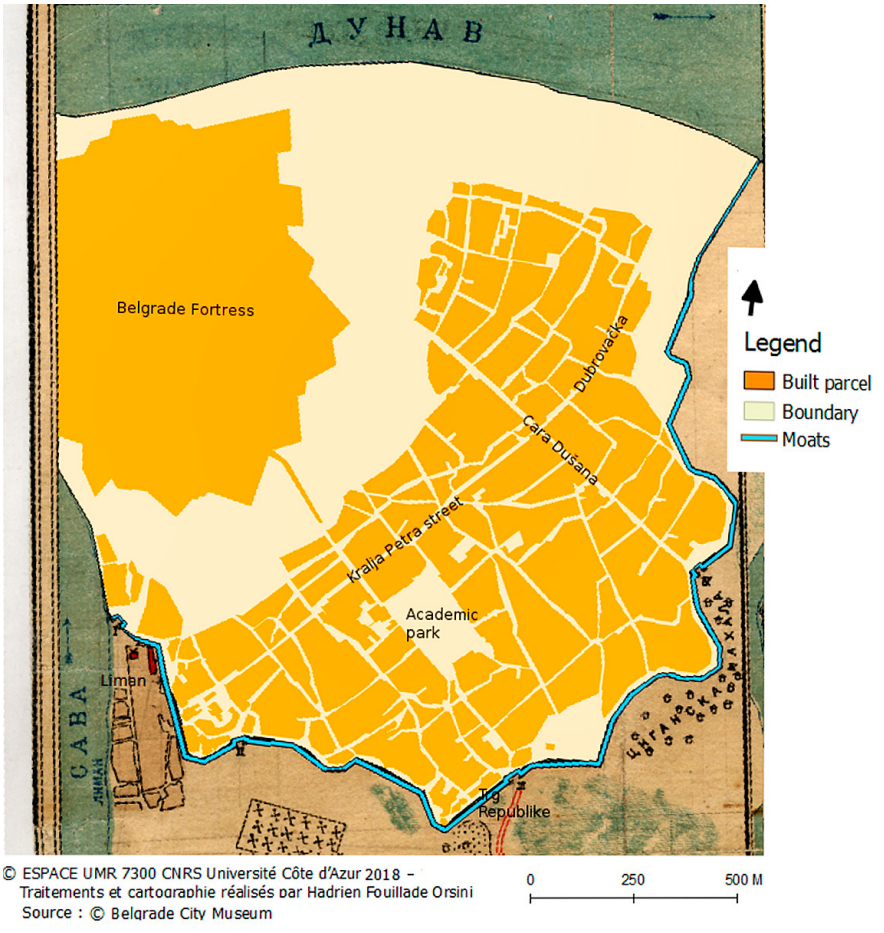

Figure 2. Belgrade's urban layout 1815-1830 according to Radoje Dedinac's map

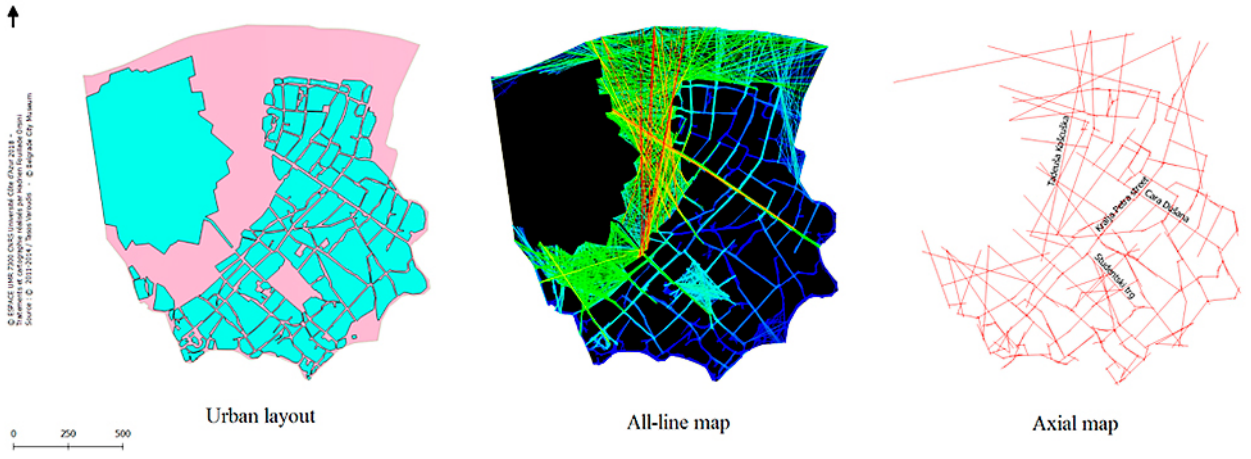

Figure 3. Axial map of Belgrade according to Radoje Dedinac's map

The all-line map generated contains 3 621 lines, while the axial map has 204 lines (Figure 3).

It is important to notice that the automatic process of drawing axial map has generated current arteries which did not exist at that time, especially the Tadeuša Košćuška Street whose computation will confirm its great importance within the system. For decades, the axial map, which is a cognitive representation of an urban morphology, has constituted the basis of the Space Syntax analysis (Hillier, 1996, 2007). The radii used to analyse the axial map calculate the topological relation between axial lines. The distance, measured on the number of steps, quantifies the direction changes (Turner, 2007). The indexes have been computed at radii 2, 3, 5 and n in order to take into account both local and global limits. By convention, radius 3 represents the limit of pedestrian movements, whereas radii 5 or 7 are rather used to study motorized mobility. Radius 5 could be considered as the limit of movement pulled by animals.

Axial map analysis of Belgrade's morphology between 1815 and 1830

The analysis of the axial map of Belgrade's urban space drawn by Radoje Dedinac highlights the distribution of the most integrated and segregated spaces within the system. The Space Syntax analysis reveals which axial lines are the most important in the urban grid constituted by all the open spaces. Among all the measures calculated, the most important are the connectivity, the integration and the mean depth.

The connectivity which quantifies how many lines are directly connected to each axial line describes the local network structure of the urban grid (Al-Sayed et al., 2014). The measure of connectivity underlines the leading role played by the Cara Dušana. It also reveals the importance taken by the space where the Tadeuša Košćuškog Street will be later traced just like the axis standing for the current Uzun Mirkova and Knez Sime Markovića street (Figure 4).

On the other hand, spaces located in the urban neighbourhood of Kosančićev venac, Dorćol but also closed to the moats appear among the areas with the lowest value of spatial connectivity. The Mean Depth value quantifies how many lines have to been crossed to reach all the other spaces that compose the system. That is the reason why axial lines with the lowest Mean Depth value are actually the most closely accessible. According to Alasdair Turner (2000), this variable is well correlated with human movement measured in space. The Mean Depth indicates that Kralja Petra Street was the most important axis of the oriental structure. The Mean Depth computation also highlights the current Cara Dušana and Uzun Mirkova streets which, at that time, was the single road leading directly to the fortress. The integration value has a huge correlation with the population distribution that is the reason why this variable is the most powerful in the axial map (Hillier et al., 1993).Global integration highlights the most integrated axes but also the segregated areas which correspond to the current Zadarska Street and the locations close to the current Obilićev venac and Trg Republike. It could have been considered that this result was a consequence of the edge effect. However, even after the application of a topological radius these areas still appear as the most segregated spaces of the system. Finally, and as if the arteries did not exist at that time, it is also interesting to notice the importance of the axial lines located on the site of the current Tadeuša Košćuškog at each computation. On the other hand, the current Knez Mihailova pedestrian street is not among the most integrated spaces excepted during

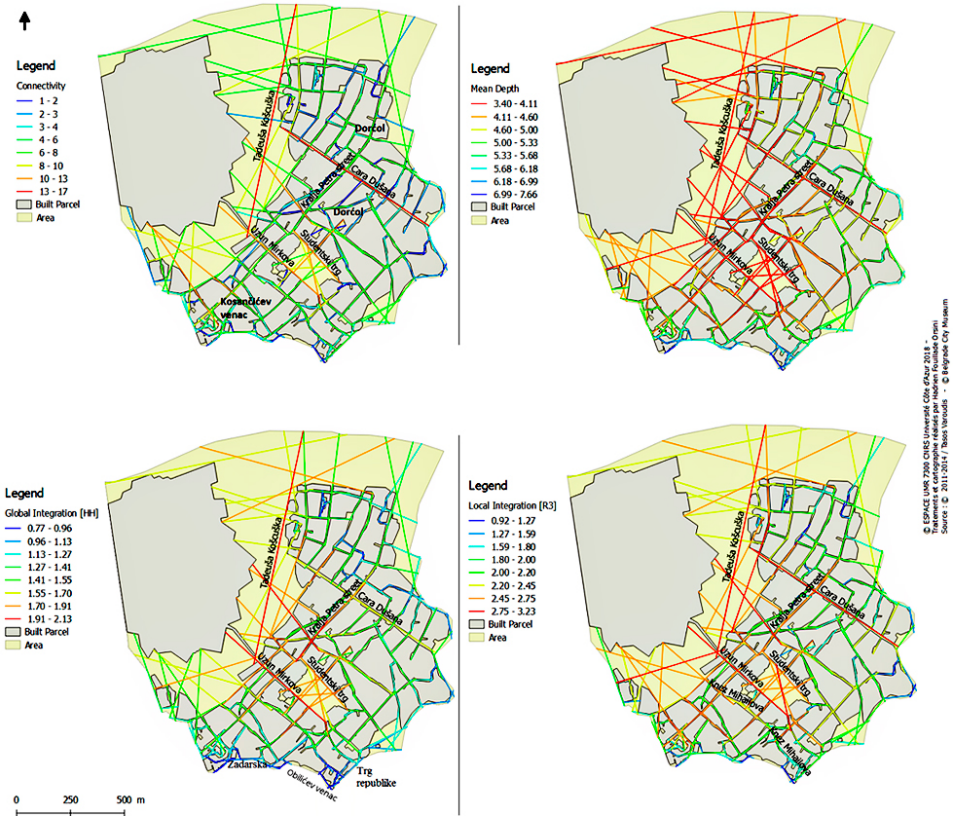

Figure 4. Chromatic representation of some measures of the Axial map analysis of the old borough

the representation of the Integration set at radius 3. As a conclusion the spaces close to the moats appear as the most segregated locations just like some parts of the Dorćol neighbourhood.

The table 1 sum-up the most important values computed and illustrated in the Figure 4. These topological measures can be correlated in order to reveal the configurational properties related to wayfinding of the study area (Peponis, 2016). The concept of intelligibility introduces by Bill Hillier in 1996 is closely related to the theory of legibility developed by Kevin Lynch (1960).

Table 1. Syntactic measures of the axial map of the old borough

	Average	Minimum	Maximum
Connectivity	4.95	1	17
Mean depth	4.99	3.40	7.65
Global integration	1.34	0.77	2.13
Local Integration (R3)	2.03	0.99	3.23

Spatial cognition quality of the old borough

Intelligibility is an indicator which values the ease of movement based on the cognitive quality of the urban configuration. The measure is calculated by correlating connectivity which is a local index with global integration. The higher the correlation is the more the system is spatially understandable. That means that the cognitive quality of the urban layout at a local level allows pedestrian to move through and to understand the overall structure. (Hillier, 2008, 2007). The other second order measure is the axial synergy which is calculated by correlating local (R_x) with global integration (R_n). A high correlation value means that the overall structure is closer to the local one. Both measures reflect the relation between local and global structure.

If the index of spatial intelligibility is rather weak, with a score less than 0,5 the axial synergy is high (Figure 5). Both second order measures confirm that the spatial homogeneity of the old town was good.

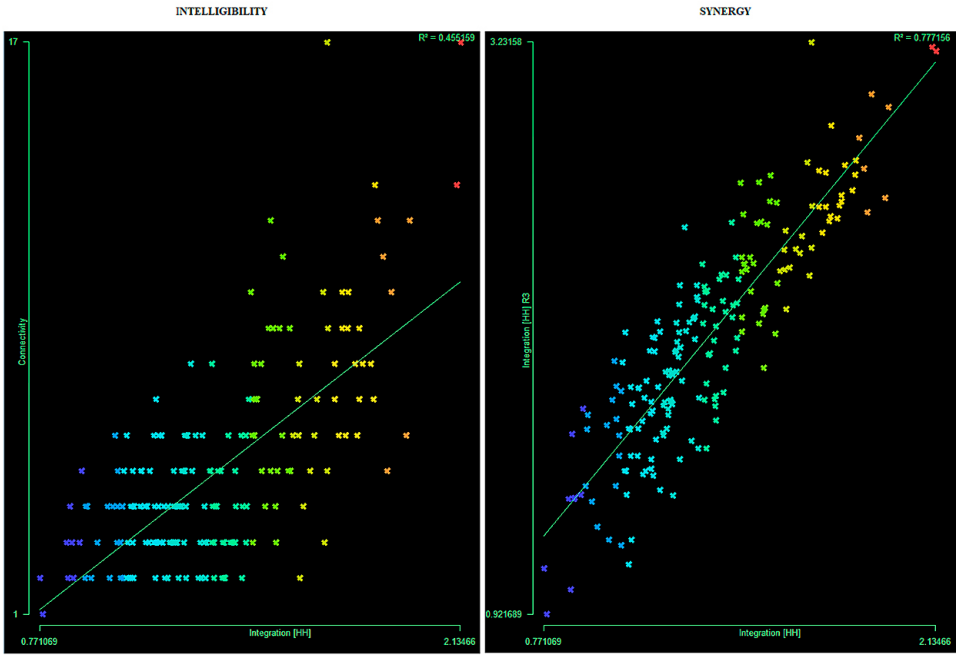

Figure 5. Scatter plot of local and global indexes of the axial map of Belgrade (1815-1830)

Axial map analysis of the current study area

In order to analyse the present configuration and make possible the comparison with the old structure, the boundaries drawn by Radoje Dedinac have been used again, with the difference that the main arteries have been taken into account to fix the limits of the current study area. Just the Belgrade fortress and Kalemegdan park have not been taken into account due to the fact that nowadays the citadel is an open space only accessible to pedestrians. The urban layout in figure 6 shows the difference between the two boundaries.

The all-line map generated in Depthmap is made of 3 538 axial lines whereas the axial map counts 141 lines. The urban redevelopment of the borough located inside the Trenches carried out under Prince Obrenović imposed a more regular mesh which has deeply reshaped the network of open spaces. The current urban configuration is a direct heritage from this period. Currently there are 164 built parcels covering a surface of 139,6 hectares, representing a ratio of 65% from the whole study area. Compared to the map representing Belgrade between 1815-1830, it is not only the shape which have been transformed, but also the density of the built fabric, as the population greatly increased in more than one hundred and fifty years. If Belgrade didnot count more than one hundred thousand inhabitants until the first decades of the 20th century, the population increased constantly and went be-

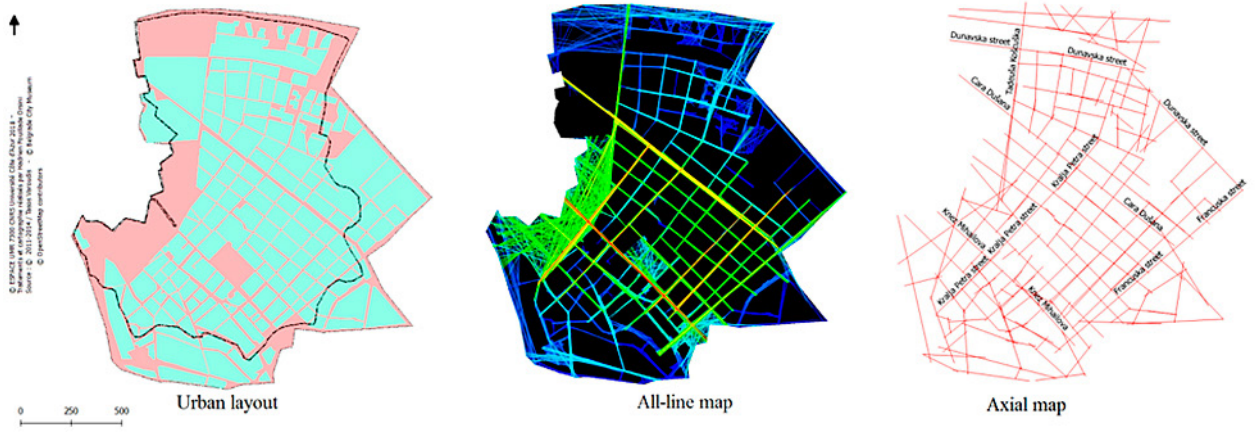

Figure 6. The construction of the Axial map of the oldest part of the municipality of Stari Grad

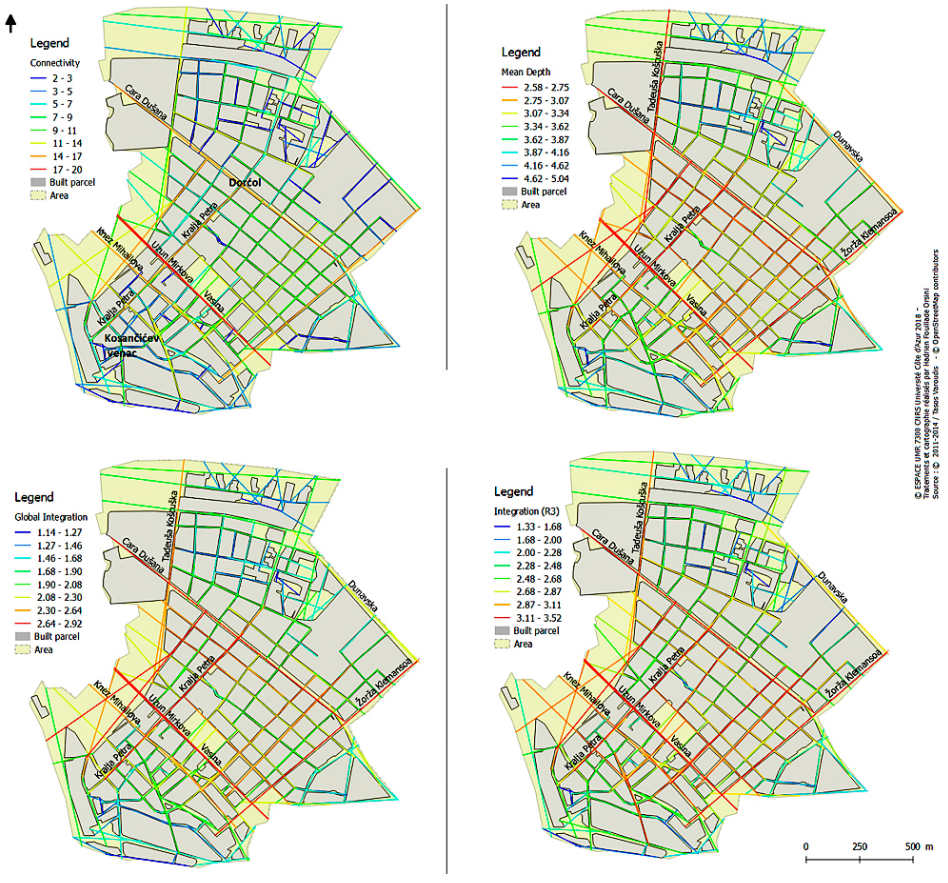

Figure 7. Chromatic representation of the axial map analysis of Stari Grad

yond one million persons during the 80's. In a first time, the urban changes only concerned the Christian quarters located close to the residence of Prince Miloš Obrenović (Princess Ljubica's konak). From 1850 to1860, the population was multiplied by two due to the settlement of south Slav immigrants who left the Habsburg provinces. Belgrade had 26 000 inhabitants then. After the departure of the last Ottoman soldiers in 1867 from the Belgrade's fortress Muslim and Jewish quarters located in Dorćol were redesigned according to the Josimović's plan of 1867 with the application of a regular grid that reshaped the neighbourhood which definitively lost his oriental layout.

The different analyses illustrated in the figure 7 indicate the continuing importance of some old arteries like the Cara Dušana or Kralja Petra streets or the axes going from Uzun Mirkova toVasina Street. Not to mention, to a lesser extent, the Tadeuša Košćuška Street. It is also important to notice the appearance of new major axial lines within the system such as the axes from Pariska to Rige od fere, from Fransucka to Žorža Klemensoa, but also the Knez Mihailova pedestrian zone just like other streets of Dorćol located in the square formed by Cara Dušana, Kralja Petra, Vasina and Francuska streets. The most isolated spaces within the system are located in some parts of Dorćol, mostly on the other side of the Cara Dušana. As if some computations confirms the importance of the Dunavska Street. Finally, spaces situated in the neighbourhood of Kosančićev Venac appear among the most segregated areas within the whole system. However, it is possible that this finding might be the consequence of the edge effect.

The different computations indicate that the urban transformation of the oriental borough has increased the spatial accessibility of the whole area (Table 2).

Comparing to the axial map of Belgrade between 1815 and 1830, the different syntactic measures testi-

Table 2. Syntactic measure of the current Belgrade axial map

	Average	Minimum	Maximum
Connectivity	6.60	2	20
Mean Depth	3.60	2.58	5.04
Global integration	1.86	1.14	2.92
Local Integration (R3)	2.30	1.33	3.52

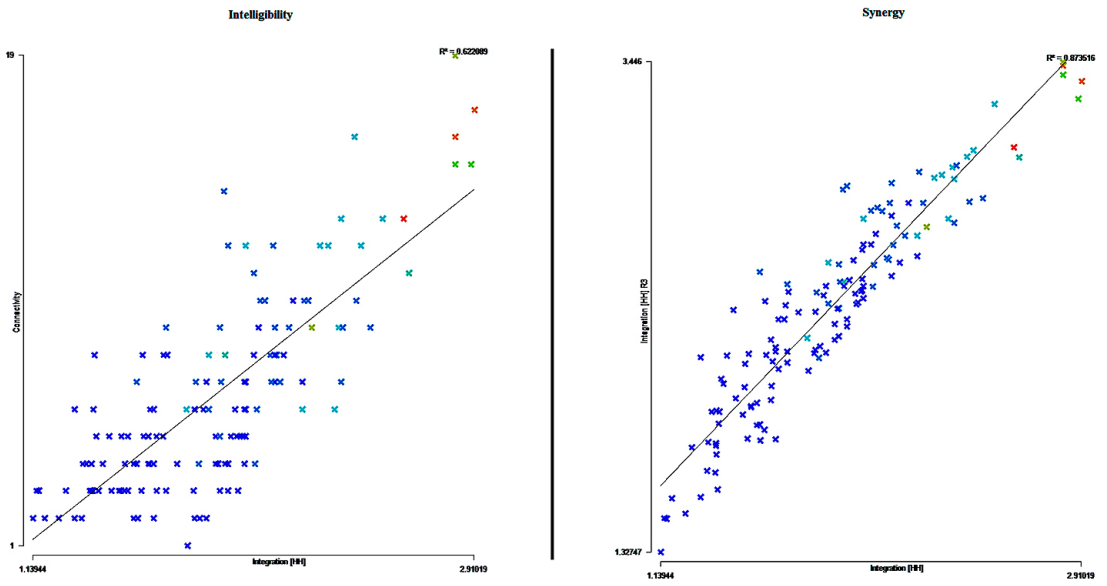

Figure 8. Scatter plot of second order measures of the present study area

fy that the application of a regular mesh has enhanced the attractiveness of the area. The second order measures also testify the improvement of the cognitive quality of the current spatial configuration as both the values of axial intelligibility and synergy have increased (Figure 8).

Both attraction and cognitive quality explain the importance of this local area within the current Belgrade's agglomeration. This part of Stari Grad is surely one of the most frequented neighbourhoods, with the presence of the pedestrian zone hosting fast fashion retails, banks, museums, restaurants, cultural centres, theatre etc.

Angular segment analysis of both configurations

For more than 30 years, the axial map have constituted the basis of the Space Syntax. However from the beginning of the 21th century, angular segment analysis by metric distance become a more powerful tools (Carmona, 2014). The great contribution of the new method is the introduction of both physical and human movement behaviour properties of space (Kim & Piao, 2017). The physical properties of space are reflected by summing the angular connection between axial segments arguing that angle of turn better seize

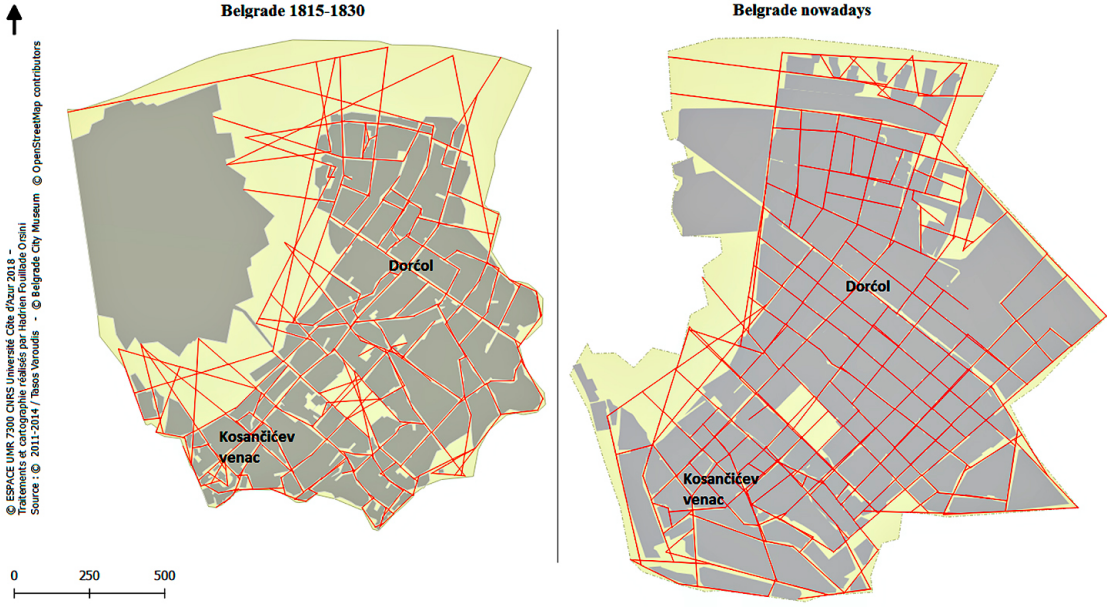

Figure 9. Segment maps of the study area before and after the urban renewal

the way people are moving into space (Montello, 1991; Hochmair & Franck, 2002). Segment maps were generated by breaking the original axial lines at their intersections. The segment map of Belgrade between 1815 and 1830 has 648 axial segments while the current study area counts 975 segments (Figure 9).

It is possible to notice that the organic structure has been kept near to the Kosančićev Venac neighbourhood while Dorćol was affected by a huge urban transformation. The reason of this difference can be explained by the fact that Kosančićev Venac was the Christian neighbourhood whereas Dorćol was a Muslim area under the Ottoman Empire. When Turkish soldiers left the fortress, Muslim populations left the town. For this reason, it was easier to reshape the depopulated parcels.

The most important variables calculated by the angular segment analysis are choice and integration. While integration calculates the distance between all origin and destination spaces in a system (closeness), choice, known as betweenness centrality in graph theory, deals with the decision-making process and highlights which itinerary is preferred to move anywhere in the study area. Actually the variable quantifies the flow passing through each space, by summing all nodes located on the shortest paths joining any destination from an origin space. For this reason, the measure has to be normalised as the nodes located in segregated areas have total and average values higher than the nodes located in integrated areas. Choice values of each segment are divided by their total depth (Hillier et al., 2012a).

Robustness of foreground and background network can be assessed with the angular normalisation of both integration and choice variables. The two measures provide information on the spatial performance and morphological properties of the study area. Normalised angular choice (NACH) allows to understand the spatial structure of cities on foreground (maximum value) and on background (mean value) while Normalised angular integration (NAIN) indicates how both foreground (Max) and background (Mean) networks are easily accessible. The potential to and through-movement in the background network is represented by Mean values of NACH and NAIN and by Maximum NACH and NAIN indexes in the foreground network (Hillier et al., 2012b).

Table 3 indicates that the whole indexes have increased between the two periods, except the maximum NACH value. Nevertheless, the creation of a regular grid improved the accessibility of the area. The star model of nowadays borough indicates that the Maximum NAIN value has increased hence the to-movement in the foreground network is easier. The higher the NAIN value, the better the potential accessibility distribution is (Figure 11).

In Belgrade between 1815 and 1830 the background network is stronger than the foreground structure due to the presence of disconnected sub-local areas. In general, mean NACH values for real cities

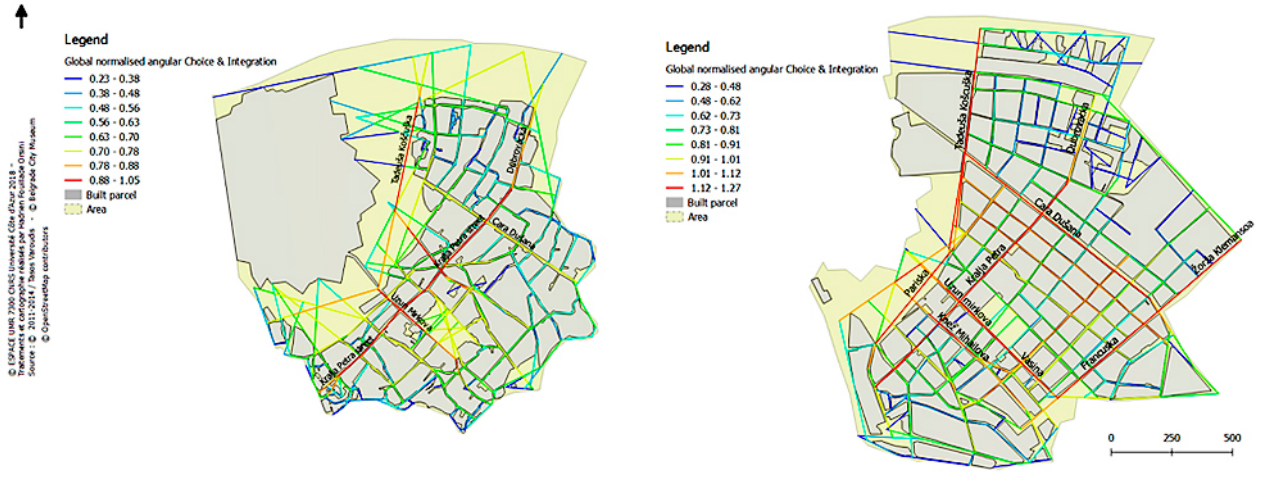

Figure 10. Combination of global normalised angular Choice and Integration values

Table 3. Mean and max normalised choice and integration values for Belgrade between 1815-1830 and nowadays

	Max NACH	Mean NACH	Max NAIN	Mean NAIN
Belgrade 1815-1830	1.56428	0.998489	2.0542	1.42865
Belgrade today	1.55177	1.09609	2.3057	1.71925

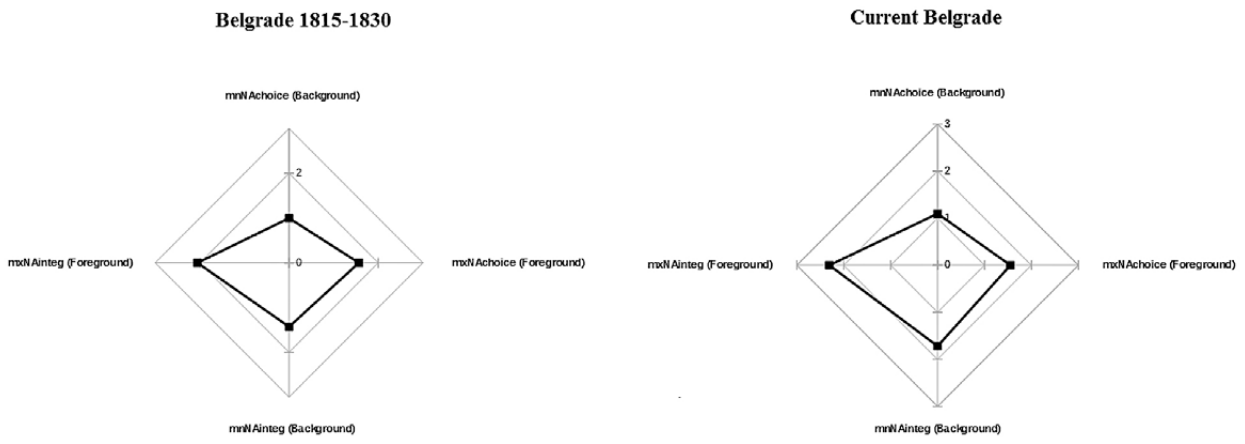

Figure 11. Star model of both urban spatial structures

vary from 0.7 to 1.2. The mean NACH value attests the irregularity of the two grids analysed. The mean NACH indexes obtained for Belgrade before and after the urban renewal may be explained by the sinuosity of the arteries located close to Kosančićev Venac.

Conclusion

Space Syntax is a relevant method to analyse urban morphologies of different historical periods. Despite many books and articles focusing on the urban metamorphosis of Belgrade in the 19th century, there are few quantitative analyses of that urban change. The analysis of spatial configurations after and before the urban transformation with the Space Syntax methodology proved that the modern planning increased the spatial performance of one of the most important area within the Serbian capital city. Both cognitive quality and accessibility of the space have been increased as the grid was regularised, mostly within the Dorćol neighbourhood. It is interesting to notice that some spaces which were not yet urbanized during the period of the Serbian Principality were among the most integrated spaces in the system analysed. For instance the current Tadeuša Košćuškog street was still important within the urban configuration of the old borough according to the limits settled. The different Space Syntax analyses demonstrated the continuation of the importance of some arteries in the two systems studied. For instance, the current Cara Dušana or Kralja Petra streets were already important axes within the ancient town. Regarding the Knez Mihailova pedestrian street, which could be considered as the most important artery nowadays, its importance in the system has increased due to the grid regulation. The analysis of the axial maps has also revealed how the cognitive quality of the urban layout improved with the urban renewal from the mid-19th century. Whereas the angular segment analysis has highlighted the confrontational properties of both study areas in terms of accessibility and spatial articulations between background and foreground networks. Further studies could be led by correlating some data from the Ottoman period with the Space Syntax measures obtained in order to understand the relation between spatial configuration and socio-economic activities. To going further, it could be interesting to analyse the Belgrade's urban growth from the beginning of the 19th century until nowadays at different and regular periods of time.

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