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Cardiogram of the Park: Quantitative Analysis of Walking Scenarios of Trakų Vokė Historic Park

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Abstract. In this research, the concept of isovist [1,6] was employed to analyze spaces of the park as a container and catalyser of human activities and experiences in quantitative terms. The concept of the isovist defines the visual environment as a system of objects that structures the light as a source of stimuli for human perception. Trakų Vokė ensemble was selected as a case study object to test this quantitative approach towards historic park analysis. Methods of the research include a literature review on specific characteristics of Trakų Vokė ensemble, observation on site, analysis of available maps and satellite images, development of linear drawing of the park using AutoCAD, modelling using Isovist_App and ESRI ArcMap software, analysis, and discussion of results. The research has demonstrated that the results of the isovist and visual graph-based analysis reflect the observed spatial features of Trakų Vokė Park quite well and can be used for various purposes, including a more detailed description of valuable features of heritage objects, a detailed comparison between different parks, simulative reconstruction of the character of the historical park in the past based on historical data, maintenance and management of the park, parametric design of landscape spaces, etc.

Keywords: Trakų Vokė, historic park, walking scenarios, quantitative analysis, isovist

Introduction

Historic parks and gardens of private residential ensembles created in the 18th and 19th centuries play an important role in the history, culture, and landscapes of European countries, including Lithuania. Walking, and itinerative exploration on foot, was the inherent function of these landscape architecture creations. Considering this, the research focuses on the walking dimension of the selected historic park of former private residence in Lithuania Trakų Vokė designed by French landscape architect E. Andre. According to the Florence Charter [5], "a historic garden is an architectural and horticultural composition of interest to the public from the historical or artistic point of view", thus the research employs a quantitative approach in order to understand the usage of the park by walking in its contemporary situation and how the artistic and historic values can be perceived in this itinerative way. The concept of isovist [1; 6] was employed as the primary theoretical model allowing quantitative analysis of the park for this research.

Methods of the research include a literature review on specific characteristics of Trakų Vokė ensemble, observation on site, analysis of available maps and satellite images, development of linear drawing of the park using AutoCAD, modeling using Isovist_App [8] and ESRI ArcMap software, analysis, and discussion of results.

Trakų Voke ensemble and its historical context

A major part of survived Lithuanian manor residencies with parks and gardens were created or reconstructed in the second half of the 19th century. Trakų Vokė's residence owned by the members of the Tyszkiewicz family also belongs to this category. After the uprising of 1861 against the czarist regime and following repressions Lithuanian noblemen were even more in opposition to the Russian culture and were directed to the West. Consequently, the design of residencies also followed western trends, and neo-styles, such as neogothic, and neoclassicism, and architects form Poland and from more distant countries to the west were invited. Leandro Jan Ludwik Marconi (1834–1919), son of the architect of Italian origin Henryk Marconi, created the architectural ensemble of Trakų Vokė manor residence [9] (Fig. 1a). The invitation of landscape architect E. Andre to design the park in the residence also reflects this orientation towards western culture.

In the 19th century, regular planning of residencies and regular garden design were increasingly abandoned, in favor of irregular landscape style, and Trakų Vokė corresponds to this trend; however, the distinctiveness of the residence is determined by the park design of E. Andre. According to M. Omilanowska [12], E. Andre is considered to be the creator and proponent of the so-called mixed park design style, sometimes referred to as composite style

a) b) c)

Fig. 1. Trakų Vokė residence: a) the perspective view of the main facade of the palace framed by the lime tree alley; b) scenic view visible from the observation deck behind the palace; c) spaces and landscaping details of landscape style Trakų Vokė Park designed by E. Andre

[4], integrating formal, symmetrical design in the vicinity of a palace and landscape style park stretching in a further distance. This tendency is visible in Trakų Vokė Park.

Not only the architectural ensemble but also the park existed in the residence of Trakų Vokė before the intervention of E. Andre. Consequently, E. Andre, while designing Trakų Vokė Park, had considered the local landscape of Vokė river valley and the preexisting ensemble. This caused a more regular design of the ensemble: representative and utilitarian zones are regular with perpendicular alleys; in the center of the residence, a shield-formed parterre extends in front of the palace. At the end of the 19th century system of fish breeding ponds was created in the northern part of the territory of the residence. Only park extending in the eastern and southeastern parts of the residence, limited from the north by railway tracks, and from the south by the road to Vilnius, was designed in an organic landscape style (Fig. 1c). The palace building was situated on a steeply descending plateau that offered a scenic view (Fig. 1b).

It is possible to distinguish the features of this park, representing both the creative genius of E. Andre and the landscape architecture trends of his epoch: emphasis on picturesque accents, contrasts created by alternating picturesque and intimate scenes, connections between landscape and architectural elements created using thematic and dynamic spaces, perspective views formed and framed by green structures, mutual relationship between the park and its surroundings (scenic views, observation from the park, parks and buildings of the ensemble as significant landscape component) [4; 13]. E. Andre has also introduced elements of mountainous landscape unusual in Lithuanian landscape and reflecting his unique style. Characteristic E. Andre landscape design elements are still visible today in the landscape part of the ensemble: picturesque groups of artificial rocks, multi-step cascade, steps, and benches from unworked stone [11; 12; 14].

During the Soviet period, Trakų Vokė manor residence was adapted to the needs of the Lithuanian Agricultural Institute. The ensemble was declared the local architectural monument, though this had not prevented the construction of new buildings of poor architectural quality, distorting the integrity of the ensemble [11]. In 2013 the palace of Trakai Vokė residence was taken over by Vilnius City Municipality; currently, the palace is owned by the public institution "Trakų Vokė manor homestead" established by Vilnius City Municipality. Excursions, exhibitions, and various events are organized in the residence [16; 17].

Quantitative analysis of Trakų Vokė Park and selected routes

Methodology

In order to analyse spaces of the park as a container and catalyser of human activities, experiences and various possible scenarios of usage, the concept of isovist was employed as the basic theoretical model based on the works of Gibson and Benedikt [1; 6], it defines the visual environment as a system of objects which structures the light as a source of stimuli for human perception: "Ambient light is structured as an array at a point of view in accordance with laws of ecological optics... The array at a stationary point consists of the perspective projections of things in the world – the surfaces, corners, curvatures, and edges of the permanent layout - and the changing perspectives of moving or changing things." "The most obvious cause of the structuring of light is the geometrical structure, the layout, of the environment" [6].

Benedikt [1], based on the above-mentioned ideas of Gibson, offers the concept of isovist as "... a method to for recording landscape ". In simple words, the isovist could be described as the volume of space visible from a single point. Features of such a form could be analysed either in 3D volume or 2D planes, either horizontal or vertical. Each point within the spatial structure has its own isovist. According to Benedikt, "... various perceptual and cognitive factors are well presented by certain numerical measures of shape and size attached to the isovist "[1]. According to Wiener and Franz [20], isovists could be seen as "... as objectively determinable basic elements "of visual environment, which "... capture environmental properties of space that are relevant for spatial behaviour and experience".

Based on conducted experiments, it was concluded that "For experiential qualities and navigation behaviour, already single isovist measurements were sufficient to widely explain the variance in the behavioural data." [20].

The simulative mathematical graph model allows to analyse properties of 2D isovists if based on so-called visual graph analysis [18]. It is a part of the Space Syntax methodology, which looks at a space primarily as a container of social content. The mathematical graph model is constructed out of nodes and links or edges. In the case of spatial structure, a street segment, visual axis, cell of visual space, building could be modelled as a node. Links in the graph represent connections or direct interaction between nodes, e.g.: common crossroad between street segments, entrance to a building from a street, symmetric intervisibility of buildings or spaces, etc. In the case of visual graph analysis, first of all, all space within defined boundaries is tessellated into cells of equal size – each cell becomes a node of a graph. In the next stage, l inks of a graph are created – in a visual graph two cells or nodes of visual space are considered as having a common link if they are either visible from each other and a person can move from one cell to another without changing a direction of movement or if cells-nodes are just visible from each other. Both ways to create links in the visual graph were used in the presented research. According to Hillier [7], various centralities of the graph nodes could be calculated starting from connectivity as a simple sum of links with the neighbouring nodes and ending with more complex ones as normalised closeness centrality (integration), etc. The properties of the isovists, which will be described and explained in detail while presenting the results of the modelling, are calculated based on the briefly described visual graph. It is important to note, that such mathematical, simulative modelling of architectural spaces allows to perform analysis, which otherwise would be difficult to realise in any bigger structure because of a big number of observation points and the complexity of forms of the isovists.

The Isovist_App software [8] was used for the visual graph analysis. The choice was caused by the possibility in the app to represent various types of boundaries as solid, transparent, and reflective, while the well-known Space Syntax analysis tool Depthmap [19] does not have such a possibility. The need for this expanded modelling functionality was caused by the specificity of the park, where edges of groups of trees could be seen either as partially transparent or solid boundaries. Both variants were tested and compared between themselves.

The other tools which were used in the research were ESRI ArcMap software for additional precise analysis of selected routes in the park as Isovist demonstrated a lack of precision in such modelling because of the big size of the graph; AutoCAD for preparation of the input data (Fig. 2) for modelling and MS Excel as a tool for both numerical and visual analysis of received data based on comparison of visual scatterplots.

The research was conducted in two stages:

1. Modelling and analysis of the isovists of the whole park to understand the essential features of the structure from the point of view of observer and to test if the model catches the observed character of landscape spaces and could be used for a more detailed description of the DNA of the object.
2. Analysis of the isovists properties along the specific selected segments of park routes to test if mathematical modelling is able to reflect different characters of the routes.

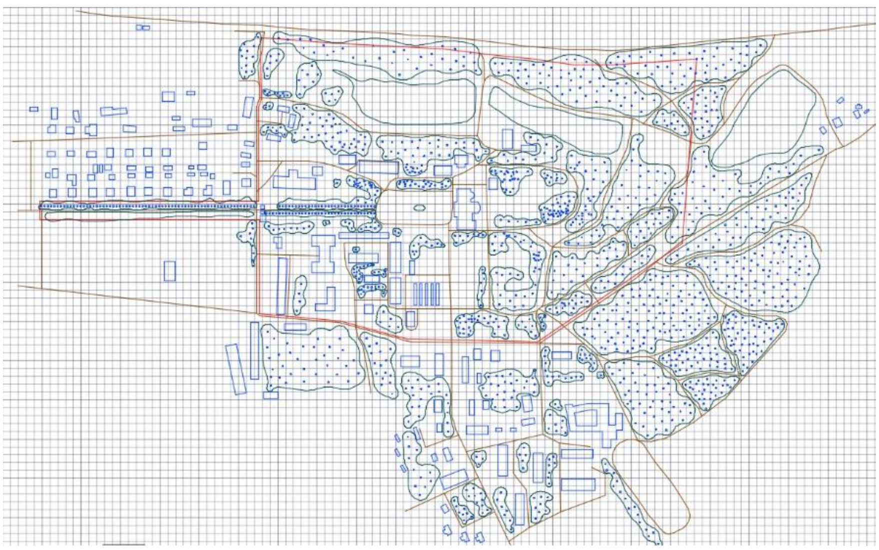

Fig. 2. Park plan. Solid boundaries are presented by buildings and tree trunks; partially transparent and transparent boundaries are shown as edges of tree groups and water ponds, park routes, and the boundaries of the park [from authors private archive]

As it was mentioned above, the analysis of isovists was conducted in two ways: with both solid and translucent boundaries represented based on the idea that perforated green borders affect properties of the isovists; with all boundaries modelled as solid based on the idea that even perforated or totally transparent boundary still is a boundary that marks some perceived limitations of the exact space. It could be stated that these two models might represent park in the summer and winter period, but in the future results of both calculations should be validated on empirical data and observation but within this research, the aim was to see if there are significant and radical changes in the park model appear if green boundaries are marked in a different way, or the character of the park is reflected similarly in both ways thus verifying if further investigation is needed.

Results of the analysis of the park

The first and the simplest measure of the isovists, which was calculated in the investigated park was ***Area*** of an isovist. In terms of the mathematical graph, it represents the number of nodes or visual cells which have a common link with the calculated node (connectivity of this node) or are visible from it if speaking in simple terms. Traditionally in Depthmap software, connectivity is calculated by multiplying connectivity and the area of one cell. In the Isovist_App, the calculation is not so straightforward and is presented by the following formula [15]:

$$A_v = \frac{\pi}{n} \sum_{i=1}^{n} L_i^2$$

Where A_v means area, V is a point for which calculation is conducted, i means every connected or visible node from V, L_i means radial length between the calculated point and any other node i visible from it, n is the total number of radials sampled. In this case, the area is calculated as a mean of the areas of all circles visible from V with radiuses L_i. L_i is calculated based on the scale of the drawing, and in the presented case, one linear unit of the drawing was taken for 10 meters.

The results of the calculations are visualised in Fig 3 (A). Three types of calculations were conducted:

- With all boundaries (edges of ponds and tree groups, buildings) modelled as solid. All boundaries create a limit for movement and view.
- With both solid (buildings and tree trunks) and transparent (edges of ponds and tree groups) boundaries are modelled. In this case, solid boundaries create limits for both movement and view, while transparent boundaries limit just movement.
- Both models were merged by multiplying the numerical results of the calculation for each point. In this case, synergy between both models was analysed. These results are presented in the visualization (Fig 3 (A)).

Visualisation of the results was based on standard deviation where a bigger standard deviation value and more hot colour allow us to identify how many isovists with similar values exist in the park, e.g.: +- 1 st.dev. means that the presented visual field falls within 64.2% of the values close to mean; +- 2 st.dev. show that the exact isovist represents smaller groups uo tp 13.6%; +- 3 st.dev. show that there are only 2.1 % of similar isovists in the park, etc. In such a case, the bigger positive and smaller negative values show more important, exceptional, unique spaces in the investigated area.

In the first model with solid boundaries only, the biggest isovists could be found in front of the palace and beside the southern entrance to the park – in most public spaces. However, suppose the size of the space could be related to various types of psychological distances such as intimate, private, social, and public. In that case, the location of the biggest visual spaces in the most representative area of the park looks logical.

In the second model with transparent or perforated boundaries modelled, the biggest isovists are located around the ponds, thus reflecting the openness of the landscape of the park beside water bodies. In this case, they represent the unique in terms of space openness recreational zone in the park.

The combination of both models indicates both patterns of the biggest isovists – in the representative area in front of the palace and the recreational zone beside the water. In this case, the combination of the two previous models looks quite promising but the question should be asked: are the other properties of the isovists affected in the same way by perforated boundaries?

Compactness of the isovists was calculated as the second indicator. The indicator shows closeness of the visual spaces to the most compact – circular form. It could be expected that in the more compact spaces, observers visual experience is more coherent and less versatile because boundaries of the isovist are evenly allocated around the central isovists point and similarity of views in different directions, etc. Compactness in Isovist_App is calculated by the following formula [15]:

$$C_V = \frac{4\pi A_V}{P_V^{\,2}}$$

Where C_v is compactness, A_v is the area of isovists from point V; P_v – the perimeter of the isovist. In essence, the formula compares the actual length of the perimeter of the isovist with the length of the perimeter of circular isovists of the same area. Based on the area and perimeter of the circle formulas, it could be demonstrated that compactness of a circle is equal to 1 if the above-presented formula is used:

$C_{circle} = 4\pi(\pi R^2)/(2\pi R)^2 = 4\pi^2R^2/4\pi^2R^2=1.$

The least compact isovists will have an index closer to zero value.

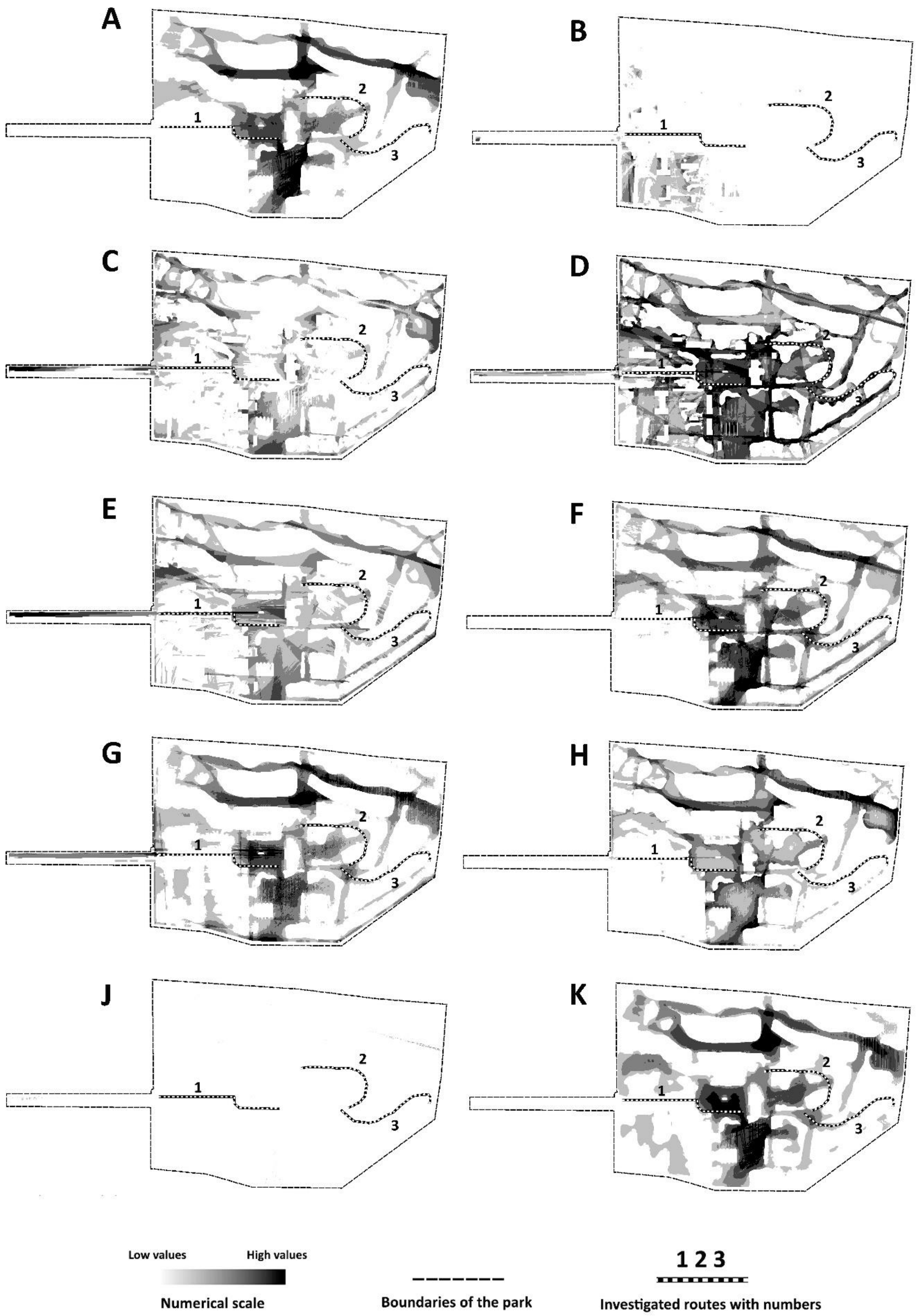

Fig. 3. Properties of the isovists: A – area, B – compactness, C – drift, D – occlusivity, E – vista lenght, F – perimeter, G – closed perimeter, H – variance, J – skeness, K – average radius [created by authors]

Fig. 3 (B) represents compactness calculation results. The biggest or closest to zero values in all three cases are observed just in zone of household buildings while the rest of the park demonstrates various values fluctuating around mean compactness. In essence, the result is logical as the park offers a diversity of changing perspectives, planes, and views. It should be noted that in this case, perforated or translucent boundaries do not change the position of the exact isovists in terms of compactness within the park – the most compact zone remains the same in both cases.

Drift index of isovist calculates distance from the calculated point from which isovist is generated to its geometrical or gravity centre [3]. Based on the fundamental concepts of static and dynamic architectural compositions [2], it could be assumed that big drift value represents a more dynamic composition which encourages or invites observer to move to the centre of gravity, e.g.: while standing at the beginning of the corridor or the tunnel. In Space Syntax drift magnitude is calculated based on the simple following formula [10]:

$$Drift\ Manitude = \sqrt{(G_x-V_x)^2+(G_y-V_y)^2}$$

Where G_x and G_y are x and y coordinates of the gravity centre of the isovist; V_x and V_y are coordinates of the point for which calculation is conducted and which serves as the isovist generation point. Square lifting eliminates negative values which might appear depending on the starting point of the coordinate system used in the calculation. Square root brings the scale of the final calculation closer to the initial scale of the measurement, e.g.: meters, decimeters, etc. The bigger value shows bigger drift as a certain distance according to the scale of the map.

Calculation of the drift in Isovist_App is not so straightforward in this case and is not a direct calculation of drift as such, but rather a measure of the spatial properties of the isovist. First, the area-weighted mean of all radial-plan intersections with the boundaries of the isovist for point V is calculated based on the formula [15]:

$$M_V = \left(\sum_{i=1}^{n} \left| L_i^2 \cdot R_i \right| \right) / \left(\sum_{i=1}^{n} L_i^2 \right)$$

Where M_v is mean of vertex V, R_i are the coordinates of the nearest intersection of the isovist radial with its perimeter, L_i is radial length from V to the intersection i. The original literature source [15] does not explain the calculation of the coordinates, but it could be presumed that in order to get values suitable for weighting the negative values should be eliminated in a similar manner as in Drift formula explained by Koutsolampros et al. [10] just using the intersection points instead gravity centre coordinates. Such a formula might look the following:

$$R_i = \sqrt{(i_x-V_x)^2+(i_y-V_y)^2}$$

Where R_i is the generalised index of coordinates of the radial and the isovist boundary intersection points i which demonstrates how far away is the boundary node from the isovist generation point V; i_x,V_x, i_y, V_y are x and y coordinates of every point i and the isovist generation point V.

It could be stated that the calculation allows to identify the point M in the isovist which has the same mean access to all intersection points for the App. Therefore, the measured distance between M and V gives a similar result as drift magnitude in Space Syntax and is presented as the final drift value.

Drift calculations presented in the Fig. 3 (C), in essence, demonstrate significant uniformity between all three models (just solid boundaries, both solid and perforated boundaries, combined both models) with more "dynamic", presenting bigger drift isovist being clustered at the outskirts of the park and in more linear spaces. It is interesting that the combined model looks more precise with demonstrating some rhythm of "static" and "dynamic" isovists when approaching the palace. In general, it could be stated that in each park character of interaction between "static" and "dynamic" spaces could be very different but revealed certain rhythm of its change reflects the attempt of the designer to create certain variation and complexity of landscape along the park routes in order to avoid uniformous visual stimuli.

Occlusivity represents the proportion of the boundaries of the isovist which are formed not by physical elements directly, but because visual space is blocked by some closer elements within the visual field and is invisible from the isovist point, e.g.: zero occlusivity is observed in an empty room while standing in its centre, and high occlusivity could be observed in a forest where trees block view and create a big number of invisible not physically defined edges. According to Benedikt [1; 10], occlusivity is "… pointing out potential stimuli as a person moves in areas "just around the corner". In Space Syntax, it is calculated simply as the length of the occlusive perimeter of the isovist. The Isovist_App calculates it like "occlusive importance" based on the following formula [15]:

$$O_V = \frac{k}{nP_V} \sum_{i=1}^{n} \left| E_{i\_occ}^{\ 2} \cdot L_i \right|$$

Where O_v means occlusivity, L_i means the radial length from isovist generation point V to every point i on the edge of the visual field; E_{i_occ} is the fraction of occluded edge; P_v is the perimeter of the isovist; n is the total number of radials sampled and k is the number of samples in one 360-degree cycle. The bigger result of the calculation means that the fraction of the occluded perimeter points is bigger and distance to the V is smaller so it could be seen as a kind of normalised value.

The results of Occlusivity calculation are presented in Fig. 3 (D). In the first two models, the results of calculation are practically identical, and the least occlusive spaces formed by buildings in the homestead zone in west-south corner of the park; mean values could be seen in the representative part of the park in front of the palace; the more private zone behind the palace in the eastern part demonstrates the biggest values and, in this way, reflects more "adventure offering" Environment there. The combined model points out the highest occlusivity along the narrowing spaces around the park routes thus demonstrating some culmination moments before the visual discovery on new views.

Vista length accordingly shows what the longest visual axe or view is available in every isovist. the Isovist_App calculates the indicator by the following formula [15]:

$$H_v = \max\left(H_v, L_i\right)$$

Where H_v means vista length and L_i is radius length.

The results of vista length calculation are presented in Fig. 3 (E). The first two models demonstrate the longest visual axes created at the outskirts of the park and in the representative zone in front of the palace. The combined model, again, is more specific and strongly points out the man symmetrical representative alley in front of the palace and some banks of the water ponds. The maps, in general, demonstrate a certain rhythm of spaces with longer and shorter perspectives in the area thus reflecting the complex and diverse nature of the landscape.

Perimeter is measured as the total length of the boundaries of the isovist. However, the Isovist_App calculates it not directly as a length of isovist polygon borders but in indirect way, based on the following formulas [15]:

$$P_v = \frac{k}{n}\sum_{i=1}^{n} E_i$$

$$E_i = \sqrt{\left(X_i - X_{i-1}\right)^2 + \left(Y_i - Y_{i-1}\right)^2}$$

Where P_v means perimeter, E_i is the 'edge' length between radial ends or graph nodes which form isovist boundary, X_i and Y_i are the coordinates of the nearest boundary nodes, n – the total number of radials-boundary nodes sampled, and k is the number of samples in one 360-degree cycle. In simple words the perimeter is calculated as a sum of distances between the graph nodes, which form boundary of isovist.

The longer perimeter may provide more visual information and richer experience for perception in the park. The results of the calculation (Fig. 3 (F)) show the biggest perimeter values in the recreational zone of the park, while representative zone holds the mean results and household zone – the minimal values. Thus, the first and the second models (just solid boundaries, solid and transparent boundaries) quite clearly represent idea of the park where representative zone provides a limited amount of visual information, thus allowing to focus on the main object – the palace; the area designed for recreational walks provides a maximum of information. However, the situation looks a little different if the third–combined model is analysed. It reveals certain pulsation between the isovists rich and relatively poor with visual information with the highest values concentrated around the palace and water ponds. This result demonstrates that the palace and water ponds, as the factors that increase landscape diversity, are catalysing production of quantity of visual information.

Closed perimeter simply represents length of closed edges of the isovist and could be seen as an opposite to occlusivity. In the Isovist_App it is measured by extracting occluded perimeter from the total perimeter of the visual field. Perimeter or edge length is calculated in the same way as in the formula of the perimeter. The closed perimeter formula looks following [15]:

$$U_v = \frac{k}{n}\left(\sum_{i=1}^{n} E_i - \sum_{i=1}^{n} E_{occ}\right)$$

Where U_v is closed perimeter, E_i is the 'edge' length between radial ends or graph nodes which form isovist boundary; E_{occ} is for 'edge' length between graph nodes which form boundary of the isovist detected as being occlusive; n is the total number of radials sampled; k is the number of samples in one 360-degree cycle. A bigger amount of closed perimeter creates more clearly defined, visually autonomous, introvertic and, depending on radius length – even more intimate spaces, where activities are less seen from outside and visual concentrations stay within a space.

The results of the calculation of closed perimeter for Trakų Vokė Park look similar to all three models. In Fig. 3 (G), two zones which are more autonomous visually and catalyse concentration on "own" visual content are located around the palace and around the water ponds. The results look quite logical as both objects are possibly the most contrasting and attractive objects in the landscape so it might be that the designer's idea was to support visual dominance of them by creating specific types of content.

Variance, according to Benedikt [1], expresses the mean of the square of deviation between all radial lengths and average radial length of an isovist. The bigger numerical value shows a bigger variety of radials within the isovist and, correspondingly, more rich visual experience because of higher diversity in terms of close-mean-distant visual planes. It corresponds to the so-called point second moment in space syntax model [13], which is calculated as the sum of differences between all radiuses and the mean radius of the isovists raised by square. Square raise eliminates negative values when real radius is shorter than the mean one. The Isovist_App performs calculation in a similar way by the following formula [15]:

$$T_V = \sqrt[2]{\frac{1}{n}\sum_{i=1}^{n}\left|L_i - Q_v\right|^2}$$

Where T_v is variance of the isovist visible from the node V; L_i is radial length; Q_v the average radial length from V; n is the total number of radials sampled. If compared to the Point Second moment calculation, the Isovist_App shrinks the scale of the results by dividing sum of squared radial differences by the number of radiuses used in calculations and by taking square root from it, but in essence results demonstrate the same spatial properties.

Variance calculations with the first two models (Fig. 3 (H)) look very similar and demonstrate concentration of the most diverse spaces in terms of the presence of close-medium-distant planes around the water ponds thus reflecting exceptional and visually rich character of this area in the park. The third model, besides the above-mentioned zone, points out perimetric areas of the representative zone beside the palace. Such a result corresponds to observed facts that the diversity of visual planes is potentially increasing closer to the boundaries of bigger open spaces.

Skewness demonstrates a more prolonged character of the form of the isovist. In Space Syntax, it is named as the Point First moment, and it is calculated in a similar way as the Point Second moment – by calculating a sum of differences between radials and mean radial of the isovist, but without raising those differences by square. In such a case, the negative values are not eliminated, and the total sum is bigger when more radials are longer than mean radial. The Isovit_app calculates skewness by the following formula [15]:

$$S_V = \sqrt[3]{\frac{1}{n}\sum_{i=1}^{n}\left|L_i - Q_v\right|^3}$$

Where S_v is Skewness of the isovist visible from the node V; L_i is radial length; Q_v the average radial length from V; n is the total number of radials sampled. If compared to the Space Syntax formula [10], the scale of the calculation results is shrunk, but results demonstrate the same properties of spaces.

Skewness or degree of prolongation of the isovist could be seen as an expression of intelligibility of the route or path pattern which could be related to some visual landmarks or functional nodes of the analysed spatial structure.

While analyzing the calculation results of the two first models, the higher values of skewness are demonstrated at the boundary of the park, where bigger open spaces are accessible. At the same time, the "dotted" character of the results when not continuous clusters of the isovists with similar properties are nested beside each other should be noted – it means that even a slight change of the position of an observer can change the perception of Skewness radically. The third combined model (Fig. 3 (J)) demonstrates bigger Skewness values just in a very limited number of spots. The results, in essence, clarify that the investigated park is not of geometrical nature and quite well reflects the typology of landscape parks. It could be stated that, at least in the investigated case, the indicators of Skewness are less important if compared with the other numerical properties of the isovists.

Average radial simply represents the mean radial of the isovist and is calculated by the following formula [15]:

$$Q_v = \frac{1}{n}\sum_{i=1}^{n} L_i$$

Where Q_v means average radial, L_i is radial length, n is the total number of radials in the isovist.

Average radial is a good indicator of the size of the isovist as are gives no clues about the form of the visual field.

The results of calculation (Fig. 3 (K)) demonstrate similar results based on all three models: bigger mean radius concentration around the ponds and palace. In this way, it shows that the bigger landscape "rooms" or visual spaces are created around the objects which should be admired during the walks in the park and need to be demonstrated more.

It could be concluded that the results of the visual graph analysis reflect the observed spatial features of the park quite well and might be used for various purposes as follows:

- More detailed description of valuable features which, at the moment, quite often are limited to the term "valuable spatial structure and greenery";
- Detailed comparison of various parks;
- Simulative reconstruction of the character of the historical park based on historical data, if available, etc.
- Maintenance and management of the parks.

Despite the demonstrated potential usefulness of simulative modelling for various purposes related to the analysis, design, and management of historical parks, two questions still remain unanswered. The first one: which of three models should be used for analysis – one with just solid boundaries, one with both solid and transparent boundaries of the combinations of both? It is impossible to give the final answer based on the investigation of just one park, but at least initial insight could be obtained even within the presented research.

Tables 1, 2 and 3 represent mean and maximum values, sums, and sizes of dastard deviations of all the indicators calculated. The numerical values demonstrate the diversity of the numerical scales which makes even the same indicator in different models hardly comparable, so, the normalisation procedure was conducted in two ways: 1) first while dividing the mean from the standard deviation; 2) second while looking at ration between max and mean values. The results of the second normalisation, which include both indicators (max and mean values), were found to be the most unified in scales for all indicators and are presented in Fig. 4. According to those results, all three models demonstrate similar tendencies in change of relative values but, while having in mind the above presented visual analysis of the isovist properties, it could be preliminary concluded that it is still useful to use all three models as in some cases they supplement each other and provide additional clarification for specific zones of the park.

TABLE 1

Solid boundary model calculation results [created by authors]

#	area	compactness	drift	occlusivity	vista length	perimeter	closed perimeter	variance	skewness	average radius
Maximum:	0.85109	0.724272	1.49741	0.913749	3.96883	19.6571	7.10259	36.1559	7562660	0.440333
Sum:	101154	65977.77269	90849.68	208101.5	433134.7 42	1899872.6	860869.5165	3449690	2379064477	80790.40937
Mean:	0.249155	0.162511	0.223774	0.512579	1.066863	4.679616	2.120426	8.497003	5859.923489	0.198997
Standard Deviation:	0.169407	0.094323	0.153711	0.124391	0.505843	2.231759	0.824434	5.656952	70066.84724	0.085634

TABLE 2

Solid and transparent boundary model calculation results [created by authors]

#	area	compactness	drift	occlusivity	vista length	perimeter	closed perimeter	variance	skewness	average radius
Maximum:	4.53439	0.495099	2.35515	0.980933	4.90431	159.074	14.2762	215.242	53612400	0.997749
Sum:	709428.2	3393.921788	255615.2	372060.5	1239721. 59	31368155	1813747.118	26467689	8.03563E+11	208423.1 293
Mean:	1.747407	0.00836	0.629611	0.91643	3.053584	77.263558	4.467478	65.19312	1979273.728	0.513371
Standard Deviation:	1.122753	0.015216	0.452408	0.070201	0.869731	38.468695	1.656168	41.21086	3304017.428	0.210244

TABLE 3

Combined model calculation results [created by authors]

#	area	compactness	drift	occlusivity	vista length	perimeter	closed perimeter	variance	skewness	average radius
Maximum:	1.784014	0.245123	2.362449	0.870592	17.49694 4	1993.9262	65.214703	3799.615	5.39782E+13	0.303125
Sum:	180518	572.124678	57768.12	191256	1338512. 92	146914242	3997230.488	2.26E+08	5.52E+15	42569.82 786
Mean:	0.444638	0.001409	0.14229	0.471087	3.296919	361.86754	9.845662	557.3708	13604756428	0.104855
Standard Deviation:	0.394604	0.003698	0.162708	0.122596	2.002099	251.63323	5.815019	508.943	2.98538E+11	0.063732

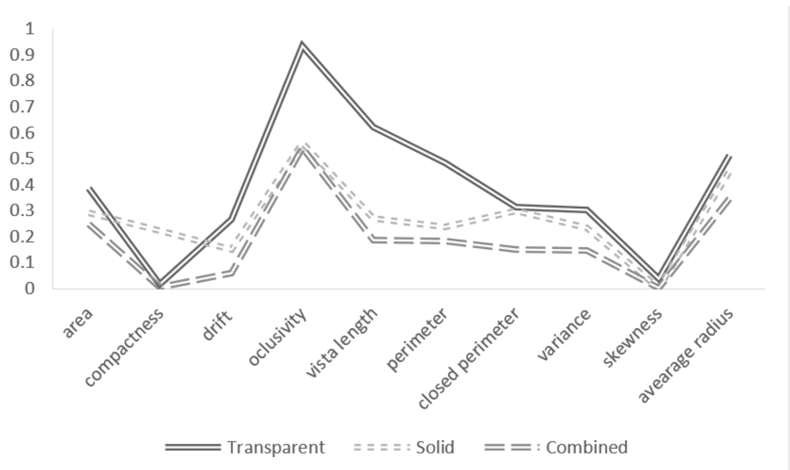

Fig. 4. Mean max ratio changes of the isovist measurements [created by authors]

The second unanswered quest is the following: could the isovist properties be related to certain scenarios of park usage based on historical of newly designed park routes?

Results of the analysis of the routes

To test the possibility to use the visual graph analysis for the identification of the character of the park routes, the second part of modelling was conducted. First of all, three segments of the routes with *in situ* observed different characters were selected (Fig. 3): representative route (No.1), the scenic route (No.2), and the "forest" route (No.3).

Even if the Isovist_App [8] offers the possibility to analyse the isovists along the selected route, but it is limited just to a certain number of automatically pre-selected indicators and looks that the precision of the results is not good enough if the investigated area is relatively big with a high diversity of sizes of spaces, so the ESRI ArcMap was used for this purpose. The procedure consisted of the importing data into GIS environment, drawing the selected route segments as lines on a separate layer, making spatial join of the visual graph point and the route lines, and exporting the numerical route data for further analysis into MS Excel.

It was noted that some indicators of the isovist properties are supplementary to each other, so to make a comparison of the routes easier, it was decided to select just part of the indicators while using the following argumentation:

- Area of the isovist could be related to social, public, or private character of spaces and the rhythm of such spaces along a route, but in essence, the average radius allows to analyse the same attributes more precisely as is directly based on the visible distance. Therefore, the indicator was not selected for further analysis.
- Compactness was not selected for further analysis as mean values of this indicator are quite close to zero values, thus demonstrating that it is not the essential feature of landscape park spaces.
- Drift was selected as an indicator which demonstrates the dynamic character of spaces along the route.
- Occlusivity is opposite to closed perimeter, so there is no need to use both indicators. They are both calculated in a similar way, but the final preference was given to the closed perimeter as the indicator that created clearer patterns of clusterisation during the visual graph analysis.
- Vista length could be seen as supplementary to skewness, but the last one produces not so clear patterns and does not demonstrate the clear territorial clusters in the investigated park, so vista length was selected as the indicators to be used for further analysis.
- Perimeter was selected for further analysis as the indicator of the amount of visual information of the isovists.
- Closed perimeter was selected instead of occlusivity as mentioned above.
- Variance was chosen as an important feature which demonstrates the diversity of visual planes of the isovists.
- Skewness was omitted because the visual graph analysis demonstrated its insignificance for the investigated park.
- Average radius was chosen instead of the isovists area as the indicator important for the identifications of the private/social/public character of the visual spaces.

The scatterplot of the first–representative route is presented in Fig 5. In order to make scales of the different indicators more visually comparable on the scatterplot, the numerical scales were normalised by dividing them by standard deviation. Such normalisation allows easily to identify the most exceptional or unique aspects of the route both within its indicators and within the context of the whole park.

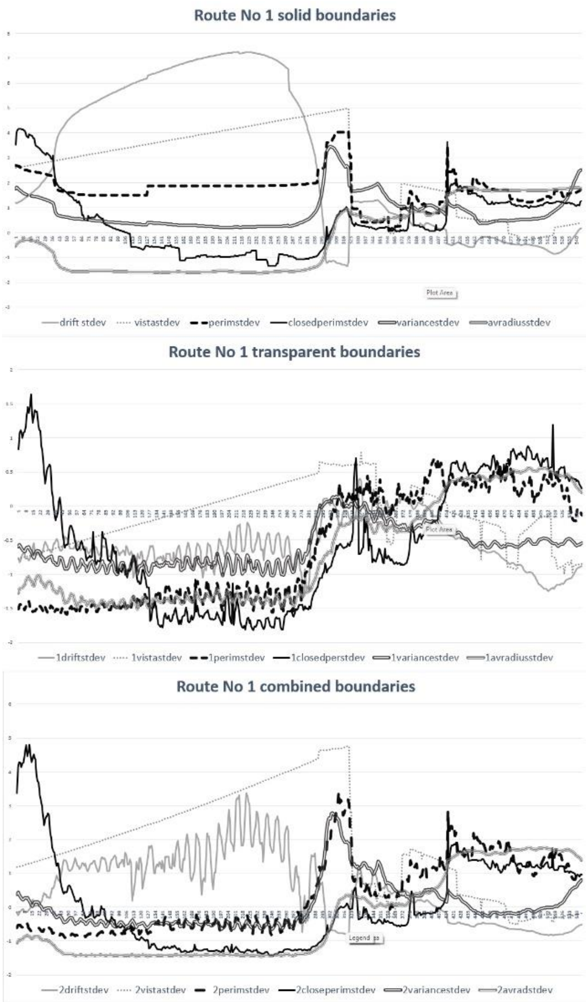

Fig. 5. Route No 1 (representative) scatterplots. Vertical scale represents the size of standard deviation, horizontal – movement sequence from the starting point till the end of the selected route according to the Fig. 3 [created by authors]

There are two clearly distinguishable parts that could be identified in route No 1 scatterplot (Fig. 16): Linear alley and route around the parterre in front of the palace. The first part could be described as more dynamic (higher drift values), with more strongly expressed route archetype (bigger vista length values), smaller perimeter and closed perimeter and variance. The calculated indicators quite well describe the space which aims to orient the observer towards one object without the provision of other visual alternatives. The second part, which represents the route around the parterre in front of the palace, is quite different – it demonstrates significant fall if drift and vista length as the observer has arrived into the representative space which is inseparable from the palace itself and its views need to be enjoyed. From the other side, such indicators as perimeters, closed perimeter, variance and average radial are not only increasing but demonstrating certain rhythmical variations thus reflecting visual intrigue created in the representative space or marking the entrance point to it.

If the fists and the second models of route No 1 are compared (solid boundaries versus solid and transparent boundaries), it could be noted that perforation of the "walls" of the landscape spaces or rooms, creates additional visual fluctuations of the indicators based on certain rhythm (e.g.: by opening regularly a wider view on landscape spaces) but it is not affecting the essential changes of the character of the segments of the route in general. Drift and perimeter are increasing while approaching the parterre space by the alley – they exceed 1 st dev. in this part thus demonstrating the uniqueness of the space within the whole park context. At the same time, the closed perimeter, variance, and average radius increase after the entrance to the parterre, thus demonstrating a more informative, diverse, and visually attractive space in from of the palace. Average radius and perimeter in the alley part of the route are beneath -1 st dev. thus showing the smallest extremes within the investigated park.

The route No 2 (scenic) (Fig. 6) demonstrates a clear and regular rhythm of increasing and decreasing drift, variance, closed perimeter, total perimeter, and average radius, with vista length partially supporting such rhythm. Three "quiet" spaces are indicated by a decrease in the above-mentioned indicators on the route. If these three "quiet" spaces are compared between themselves, the variety could be noted as well – the middle space has a longer vista length and slightly bigger other indicators except drift. As in the case of route No 1, perforation of the "green walls" creates additional diversity and smaller rhythm along the route, without changing the general features. In general, if compared to route No 1, the scenic route demonstrates quite a different character with more regular change of all investigated properties of spaces along it.

The route No 3 (forest route) (Fig. 7) demonstrates the rhythm of the three negative peeks of the higher occlusivity of spaces where less visually predictable experience of what will be seen next is created, followed by small fluctuations of drift, vista length, average radius with contracting culmination at the end. Because of the low standard deviation values of many indicators, we can expect similar characteristics in many routes in the park. Culmination in terms of bigger values of the closed perimeter, average radius and decrease in variance and drift could be observed at the end of the route thus demonstrating "arrival" to final, different space and shift of the character of the walk. Perforation of the "walls" adds additional smaller rhythm to otherwise a little monotonous rhythmical spaces but does not exclude culmination of the indicators at the end of the route.

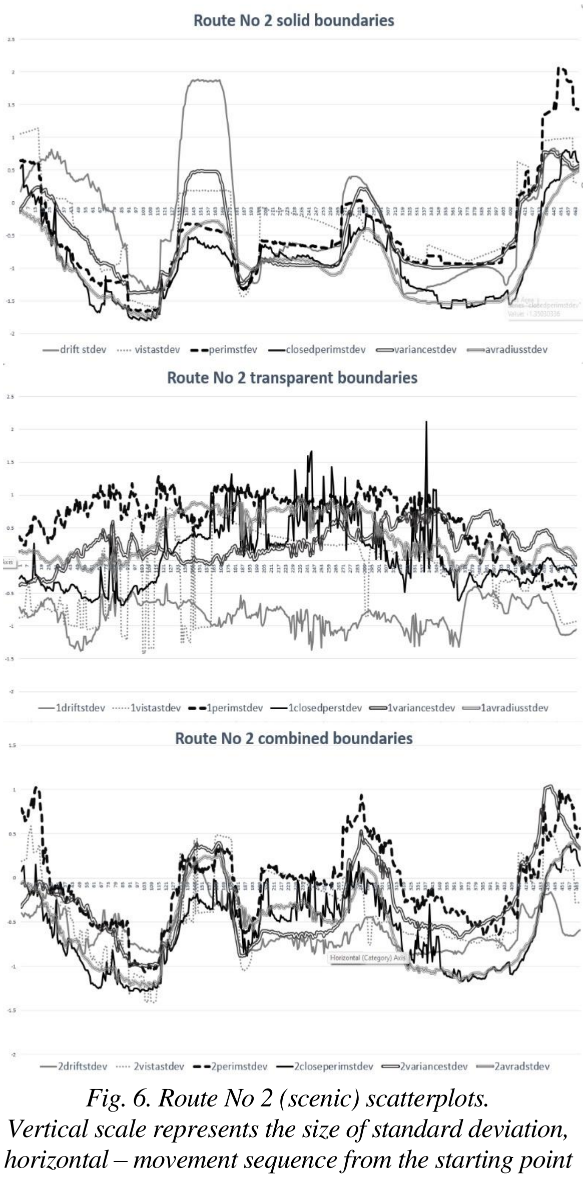

Fig. 6. Route No 2 (scenic) scatterplots.
Vertical scale represents the size of standard deviation, horizontal – movement sequence from the starting point

till the end of the selected route according to the Fig. 3 [created by authors]

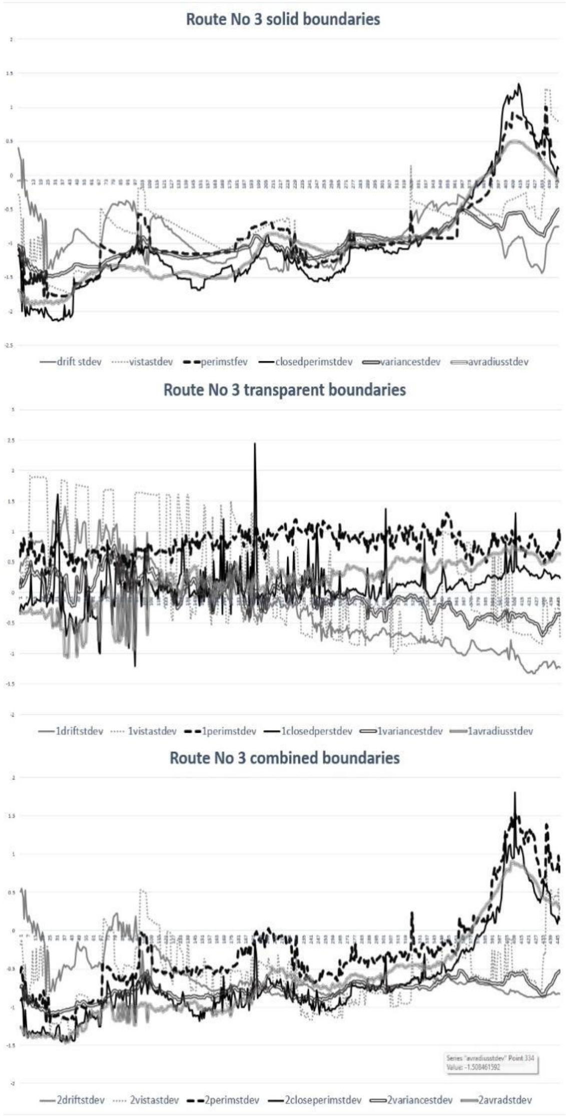

Fig. 7. Route No 3 (forest) scatterplots. Vertical scale represents the size of standard deviation, horizontal – movement sequence from the starting point till the end of the selected route according to the Fig. 3 [created by authors]

It could be finalised that in the case of the three selected routes, the numerical indicators of the isovists correspond to the subjectively perceived character of the routes and reflect their unique character. Such analysis of all the routes in the park can make a background for in-depth inventorization of the valuable features of the object and monitoring of its changes caused by natural processes.

Conclusions

Trakų Vokė Park is one of the mixed or composite style parks that E. Andre designed with special landscape park features. It contains all thematic and dynamic elements which create different scenarios in its every route with different perspectives, which can form and frame green structures and mutual relationships with the park and its surroundings. The analysis, which was performed on the selected three segments of the routes that were chosen by the researchers due to their different characteristics, produced interesting results.

The results of isovist and visual graph-based analysis reflect the observed spatial features of the investigated Trakų Vokė park quite well and might be used for various purposes as following:

- More detailed description of valuable features of landscape heritage objects, which, at the moment, quite often are limited to the term “valuable spatial structure and greenery”;
- Detailed comparison between different parks.
- Simulative reconstruction of the character of the historical park based on historical data, if available.
- Maintenance and management of the parks;
- Parametric design of landscape spaces, etc.

It could be finalised that in the case of three selected routes in Trakų Vokė Park, the numerical indicators of the isovists correspond to the subjectively perceived character of the routes and reflect their unique character. Consequently, the isovist and visual graph-based analysis of the walking routes in the park can make a background for in-depth inventorization of the valuable features of the object and monitoring of its changes caused by natural processes.

The method should be tested in the other parks and validated with more precise comparison with observation in situ results of the bigger number of observers.

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Kopsavilkums. Rakstā ietvertas vairākas metodes, kas sniedz daudzpusīgus materiālus un rezultātus par *Trakų Vokė* parku. Pētījuma metodes ietver literatūras apskatu par *Trakų Vokė* ansambļa specifiskajām īpašībām, novērošanu uz vietas, pieejamo karšu un satelītattēlu analīzi, parka lineāro zīmējumu izstrādi, izmantojot AutoCAD, modelēšanu, izmantojot *Isovist_App* un *ESRI ArcMap* programmatūru. Pētījumā ir pierādīts, ka izmantotās vizuāli grafiskās analīzes rezultāti diezgan labi atspoguļo novērotās *Trakų Vokė* parka telpiskās iezīmes un ir izmantojamas dažādiem citiem mērķiem. Piemēram, pie pētījumu izstrādes iespējams iegūt daudz detalizētākus mantojuma objektu vērtīgo iezīmju aprakstus, simulatīvu vēsturiskā parka rakstura rekonstrukciju pagātnē, pamatojoties uz vēsturiskiem datiem, parka uzturēšanu un apsaimniekošanu, ainavu telpu parametrisko dizainu u.c.