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Research paper

Principles of Street and Urban Road Space Formation in Modern Cities

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Abstract

The work is devoted to improving the principles of streets and urban roads beautification elements placing. The classification of streets and urban roads beautification elements is structured. The principles of streets and urban roads beautification elements placing by using new spatial corridor principle simulation are improved. Streets and urban roads beautification elements according to hierarchical levels are structured. The street structural model spatial corridor with distribution in sub corridors to deploy beautification elements is constructed. The spatial corridor and subcorridors characterized by linear parameters and formulas for their determination are suggested. The methodology of comprehensive streets and urban roads beautification designing according to the offered principle is improved. Reconstruction beautification experimental design of Shevchenko Street in Poltava, Ukraine is done.

Keywords: *streets and urban roads beautification elements; spatial corridor; design principle; perception; 4D-modeling.*

1. Introduction

Network of streets and urban roads is the basis of urban space, which forms city planning framework. Many streets of Ukraine settlements are overloaded with various elements, in particular, the equipment for business, seasonal trade, advertising, etc. (Fig.1).

Fig. 1: Shevchenko Street in Poltava

Therefore, the quality of urban space and its visual perception are sharply dropped (Bongiorno et al., 2017). At the same time, it contributes to the reduction of goods and services promotion effectiveness, the development of the shadow economy, the construction of "consumption society" principles and the reduction of people mental health (irritation with the free passage impossibility, irritation from the feeling of imperfection, etc.). The results of Kiev beautification study, presented in the Concept of urban space integrated management "Comfortable City" (Kontseptsiya, 2015) reveal that there is no integrated approach in the design and creation of street space, the situation is similar in all settlements of Ukraine. In 2015, a Directory for the arrangement of Kyiv's urban space was developed (Dovidnyk, 2015), it describes in detail the ways of solving the problems of streets and urban roads network individual beautification elements placing. To solve such problems, other settlements in Ukraine need scientifically based, modern monitoring systems and quality standards (comfort, accessibility, security, service level) of urban environment, which would allow it to effectively assess its condition and develop measures for solving problems using modern electronic means and software. A significant contribution of this problem study was made by the researchers: Sardarov Armen from Belarus (Sardarov, 2001); Matthew Carmona from United Kingdom (Carmona, 2017); Shu Lin from China (Lin et al., 2017); Francesco Bella from Italy (Bella, Silvestri, 2017); Cole D. Fitzpatrick from United States (Fitzpatrick, 2013; Fitzpatrick et al., 2014); Christina Blumentrath from Norway (Blumentrath, Tveit, 2014); Avinoam Borowsky from Israel (Borowsky et al., 2016); Bhadradri Raghuram Kadali from India (Kadali, Vedagiri, 2016); Belén Martín from Spain (Martín et al., 2016) and other.

2. Defining the Problem

After researching and analyzing the streets and urban roads network beautification of Ukraine, the authors found that it consists of three systems beautification elements: pedestrian – sidewalks – environment; bicycle – bikeway – environment, automobile –

roadway – environment (fig. 2). Beautification elements of each system were also structured (fig. 3 – 5).

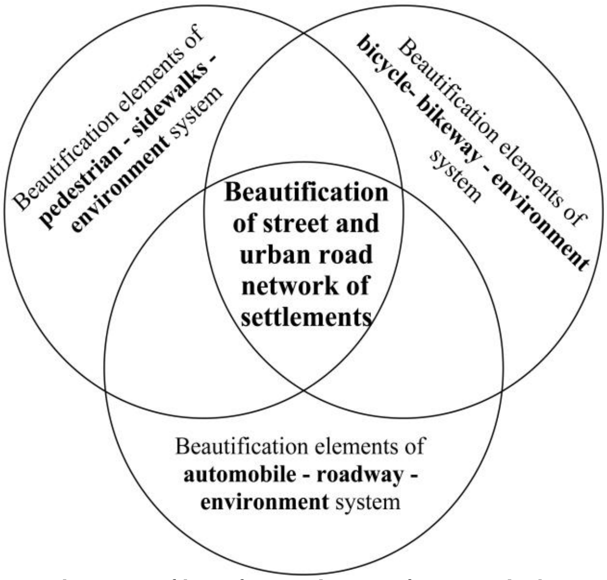

Fig. 2: The system of beautification elements of streets and urban roads environment in settlements

Finally, the following conclusion was drawn: there are a large number of streets and urban roads network elements which require placement systematization. All beautification elements of streets and urban roads network integrated placement need to be scientifically substantiated.

3. The Conceptual Approach to Modeling the Street Spatial Corridor

To solve the problem of streets and urban roads network beautification complex improvement, the authors suggest to use a new design principle – street and urban road spatial corridor modeling. A similar principle to place the beautification elements along highways was suggested by authors in previous research (Lytvynenko, 2017). Now authors suggest to apply this principle for simulation the street and urban road spatial corridor, taking into account the urban space characteristics.

In accordance with purpose, street and urban roads beautification elements were distributed by importance level into four groups.

Beautification elements, ensuring continuous movement function suggested to include to the **I** importance **level**, the function of safe movement – to the **II** importance **level**, the function of ecological – to the **III** importance **level**, the function of easy movement, which depends on the satisfaction of physiological and psychological needs of movement and environment – to the **IV** importance **level** (Fig. 3 – 5).

Street structural model spatial corridor was constructed and divided into four subcorridors for placing beautification elements of appropriate importance level (Fig. 6).

Spatial corridor of transit way is characterized by following parameters: B_{cor}, H_{cor}, L_{cor} – width, height and length of spatial corridor in accordance; B_1, H_1, L_1; B_2, H_2, L_2; B_3, H_3, L_3; B_4, H_4, L_4 – width, height and length of spatial subcorridors in accordance, the size of which varies from the transit way type (Fig. 7, 8, 9).

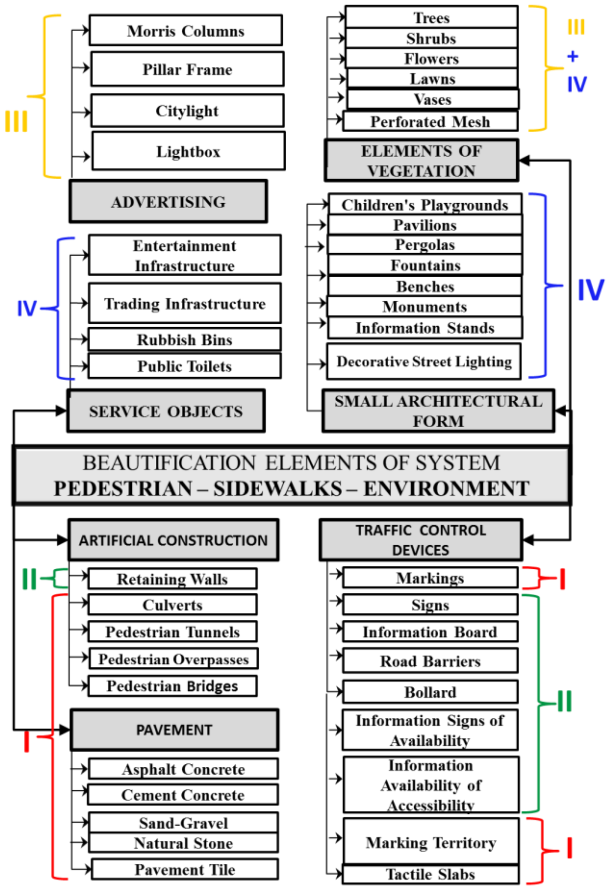

Fig. 3: Beautification elements of system **pedestrian – sidewalks – environment** and their hierarchical levels structuring

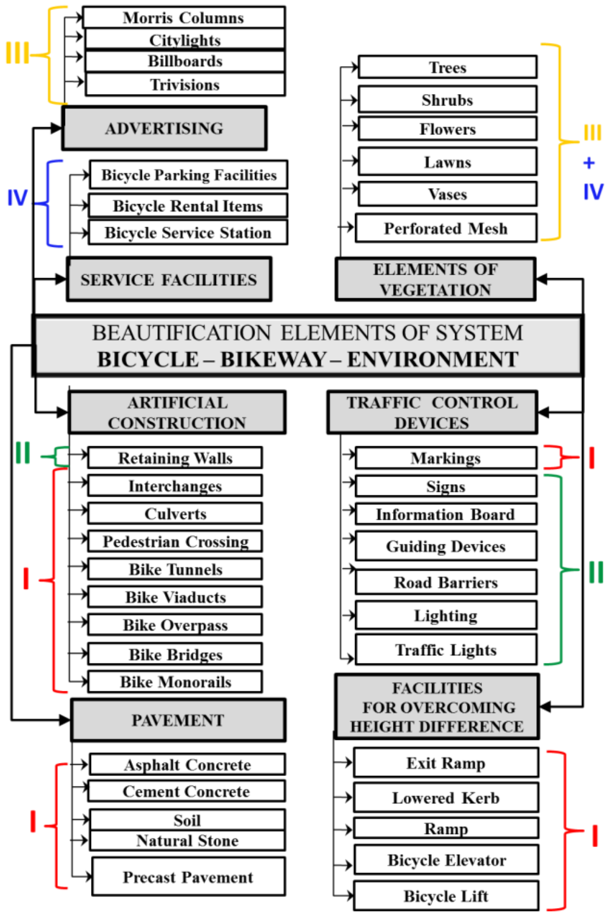

Fig. 4: Beautification elements of system **bicycle – bikeway – environment** and their hierarchical levels structuring

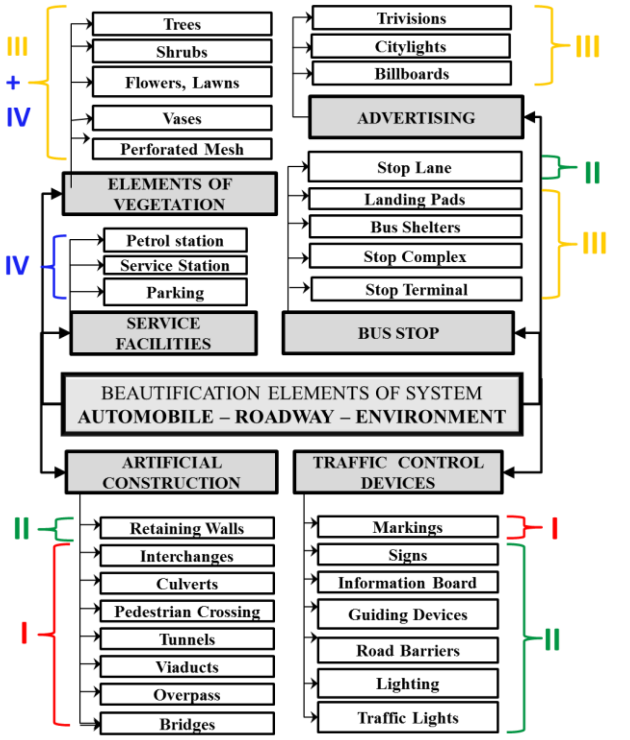

Fig. 5: Beautification elements of system **automobile – roadway – environment** and their hierarchical levels structuring

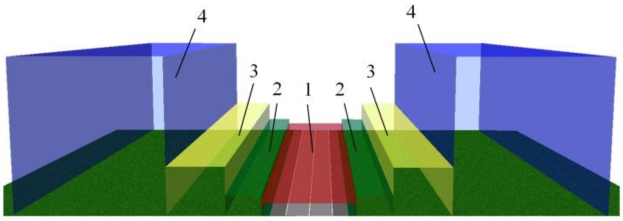

Fig. 6: The structural model of street spatial corridor: 1, 2, 3, 4 – first, second, third and fourth spatial subcorridors

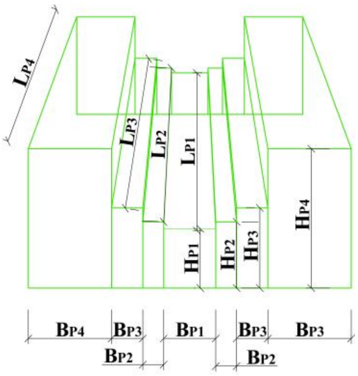

Fig. 7: Parameters of **sidewalk** spatial corridor

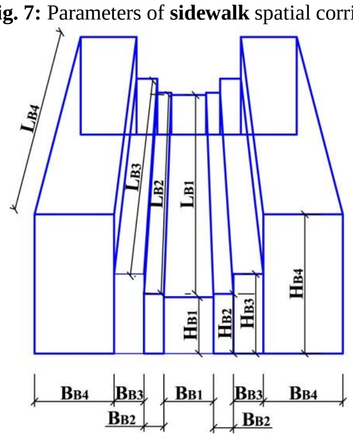

Fig. 8: Parameters of **bikeway** spatial corridor

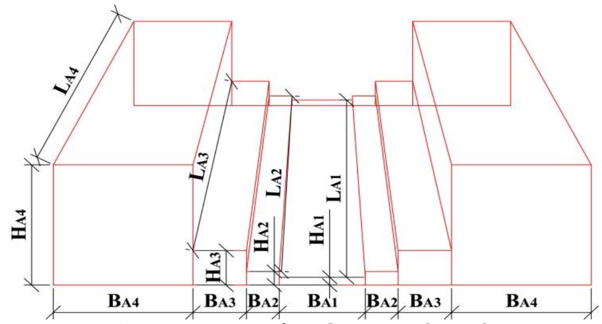

Fig. 9: Parameters of **roadway** spatial corridor

The next stage of work was finding the formulas for spatial corridor and subcorridors calculating parameters.

There are some transit ways of different purposes on the streets and urban roads network of settlements: roadway for automobiles (A Policy, 2004), bikeway for bicycles (Guide, 2012) and sidewalk for pedestrians (Guide, 2004). Therefore, it is necessary to design the system user (driver, bicyclist, pedestrian) – transit way (roadway, bikeway, sidewalk) – environment (from facade to facade).

User – transit way – environment system designing should be done according to the laws of harmonious unity, when favorable conditions for user's optimal psychological state are established. The geometric generalization of this system can be created, if its elements are considered in interconnectedness, interpenetration, mutual agreement. Street space elements harmony consists of correspondence factors and equilibrium, rhythm, contrast, magnitude, symmetry and asymmetry, the regulatory element of which is the proportionality (Fig. 10).

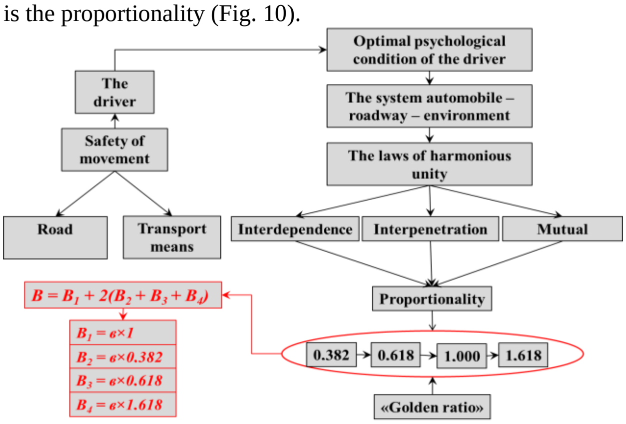

Fig. 10: Algorithm for finding the formulas for calculating the width of street spatial corridor and subcorridors.

While system user – transit way – environment is proportioning, the dimensions of subcorridors for beautification elements placement must be consistent with fixed system elements – the size of the sidewalk width, bikeway and roadway. The transit way width is a significant part of street space perception and it should be taken into account when entire corridor size is determining.

The degree of external influence on a person is determined by energy, consumed on sensory organs to obtain information.

The best perception of segments aggregate is possible and provided if their lengths are in a certain relation to each other (Wu, Liang, 2017).

Corresponding to this relation are segments of «Golden ratio» (Livio, Mario, 2002): 0.382; 0.618; 1; 1.618. Two quantities are in the golden ratio if their ratio is the same as the ratio of their sum to the larger of the two quantities (Fig. 11). Golden ratio sections are calculated by the gradual division of the coefficient (1.618) into the golden cross section, as pointed in (1).

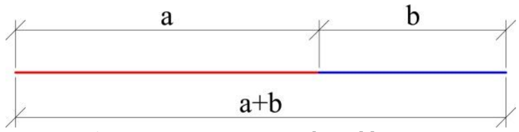

Fig. 11: Line segments in the golden ratio

$$\varphi = \frac{a+b}{a} = \frac{a}{b} \approx 1{,}618 \quad (1)$$

According to the basic law of psychophysical perception – Weber-Fechner's law – *the difference in the number intensity of stimuli seems to be the same, if this intensity forms a geomorphic progression*. The eyes that are accustomed to a certain ratio do not get tired or overloaded with information. Proportions built on the «golden ratio» give the calmest perception, and it should be used in cases where the proportions themselves are not carriers of information and should not attract attention.

Calculating the size of the spatial corridor and the subcorridors of the streets, taking into account the proportional relationship between them and the width of the transit way will optimize the psychophysical condition of users.

The minimum *width of spatial subcorridors of different importance levels* in terms of *optimal human perception* is proposed by the authors to calculate the formulas, as in (2-6):

$$B_1 = в \times 1; \quad (2)$$

$$B_2 = в \times 0.382; \quad (3)$$

$$B_3 = в \times 0.618; \quad (4)$$

$$B_4 = в \times 1.618; \quad (5)$$

where B_1; B_2; B_3; B_4 – the width of first, second, third and fourth spatial subcorridors of transit way in accordance; *0.382; 0.618; 1; 1.618* – the coefficients of the «Golden ratio»; *в* – the width of roadway, bikeway or sidewalk.

When calculating all these transit ways of the street we will receive 4 subcorridors per each. Spatial corridors of the 1st and 2nd importance level are mandatory for each transit way. Spatial corridors of the 3rd and 4th importance level may be imposing on such neighboring transit way. To select the final subcorridors, it is suggested to take advantage of the European countries' experience (Copenhagen, Berlin etc.), in which the design of a street space uses the so-called *pyramid of priority*, by which the pedestrian occupies the first step, cycling transport – the second, then followed by public transport, commercial and private transport [10]. Therefore, when calculating the minimum width of the street spatial corridor it is suggested to take into account pedestrian path as the basic of the spatial subcorridors and then all others according to priority. Consequently, the street spatial corridor width consists of transit ways width and of the four subcorridors pedestrian path width, as in (6, 7) (Fig. 12). The formula 6 or 7 (the one that will have bigger value) is selected.

$$B_{cor} = B_{A1} + 2B_{A2} + B_B + B_{B1} + 2B_{B2} + 2B_P, \text{ або} \quad (6)$$

$$B_{cor} = B_{A1} + 2(B_{A2} + B_{A3} + B_{A4}), \quad (7)$$

where B_{cor} – the width of street spatial corridor.

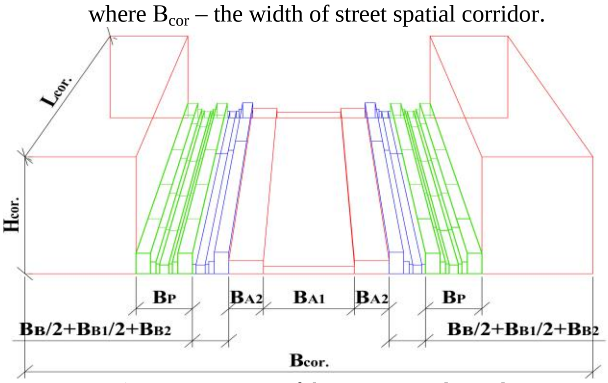

Fig. 12: Parameters of the **street** spatial corridor

Height of the spatial corridor. Distance of observation and related vertical angles of view related to appearing into human sense of closure. Depending on the height of buildings there is gradation from the complete closure to the complete lack of closure. The height of spatial subcorridors is proposed to determine by using vertical angles of perception, established by scientists empirically. The sense of closure depends on the distance and height ratio. When the height of the element is equal to the distance to it – the subject sees the movement at the angle of 45^0, and the space is felt closed. When the height of the element is half the distance to it, the vertical angle of 30^0 is formed, which is the upper limit of the normal person view field. If the elements height is one third of the distance from them, there is the angle of 18^0 – there is an advantage volume over the space. And at a distance that is four times the height of the element, the element is perceived at the angle of 14^0 and completely lost the sense of closure (Beliaeva, 1977). For each of the spatial subcorridor vertical angles of perception are assigned (Fig. 13):

$$\upsilon_{vert}^1 = 14^0; \ \upsilon_{vert}^2 = 18^0; \ \upsilon_{vert}^3 = 30^0; \ \upsilon_{vert}^4 = 45^0.$$

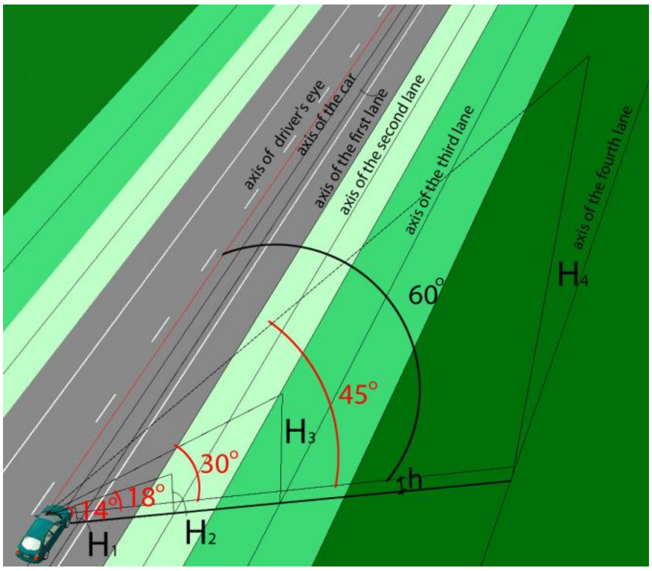

Fig. 13: Determine the height of the street spatial corridor

The beautification elements distance perception of appropriate importance level and the height of the spatial subcorridors is proposed to determine by using the formulas (7–11):

$$l_I = \frac{B_I}{2n} + c \quad (7)$$

$$l_{II} = l_I + \frac{B_{II}}{2} \quad (8)$$

$$l_{III} = l_{II} + \frac{B_{III}}{2} \quad (9)$$

$$l_{IV} = l_{III} + \frac{B_{IV}}{2} \quad (10)$$

$$H_i = tg\nu \times l_i + h \quad (11)$$

where *li* – the distance from the subject of perception to the middle of the *i*-th spatial subcorridor (m); *n* – the number of lanes (pieces); *c* = 0,45 m – the distance from the axis of the car to the axis of the driver eye; H_i – the the height of *i*-th spatial subcorridor; h = 1,20 m – the average driver's eyes level.

The length of the spatial corridor. When determining the rhythm of placing elements improvement along highways and streets one must remember that frequent vertical elements, that have the ability to hold a driver's view, create a shimmering effect in motion. Therefore the rhythm placing elements improvement should be not too small, not too frequent – in both cases perceiving system becomes insensitive. The time of perception in motion is governed by speed, therefore the proportions of corridors should be appoint-

ed from the conditions of clear construction. To the images perceived as separate, not merged and not shimmering effect, a pause between stimuli should be less than 1 s (Li et al., 2016).
The lengths of spatial subcorridors are proposed to determine by using the formulas: (12-15):

$$L_I = L_{\min} = \frac{V \times t}{3{,}6} \quad (12)$$

$$L_{II} = \frac{L_I \times l_{II}}{l_I} \quad (13)$$

$$L_{III} = \frac{L_{II} \times l_{III}}{l_{II}} \quad (14)$$

$$L_{IV} = L_{кор} = \frac{L_{III} \times l_{IV}}{l_{III}} \quad (15)$$

where V – design speed (km/h)*;* t – the pause between stimuli that prevents shimmering effect (t = 1sec); li – the distance from the subject of perception to the middle of the i-th spatial subcorridor (m); L_I, L_{II}, L_{III}, L_{IV} – the lengths of the first to fourth spatial subcorridors (m); L_{cor} – the length of street spatial corridor (m).
The turn of beautification elements in space. Those elements that should not distract the driver's attention should be placed along the long side of the visual ray (of driver or passenger). Those elements that should attract the driver's attention should be placed perpendicularly to the visual ray (of driver or passengers).

4. The Method of Streets Beautification Designing on The Basis of Spatial Corridor Modeling

The next stage of work becomes the development of *the method of streets beautification designing* on the basis of spatial corridor modeling. It consists of three steps: there are selection of the source data, calculation of spatial corridor parameters and subcorridors, 4D-modeling of street with beautification elements placement in four subcorridors (Fig. 14). The fourth dimension is achieved by simulating movement of a vehicle along the modeled corridor with calculated speed.
Based on the proposed algorithm for calculating, the spatial corridor parameters and streets subcorridors is developed with the application of computer program STREET BEAUTIFICATION for the calculations automation.
The program interface is created in HTML hypertext markup language, the algorithm is implemented in the programming language JavaScript using the library open source jQuery. An important feature of the program is that it is cross-platform, that means it can be running on any operating system where the browser is installed. Usage of the program accelerates and simplifies the design of complex roads and street beautification with the spatial corridor modeling principle.

5. Experimental Design

Before the experimental design, the authors performed a full-scale survey of the existing condition of the Shevchenko Street in Poltava, Ukraine (from the intersection of European Street to the intersection of Raisa Kirichenko Street).

The Shevchenko Street has the following parameters:
- street width (between the red lines): 25.0 m;
- width of the roadway: 15.0 m;
- width of the sidewalk: 6…7.5 m;
- unregulated land pedestrian crossing: 2 pc.
- public transport stops: 1 pc.

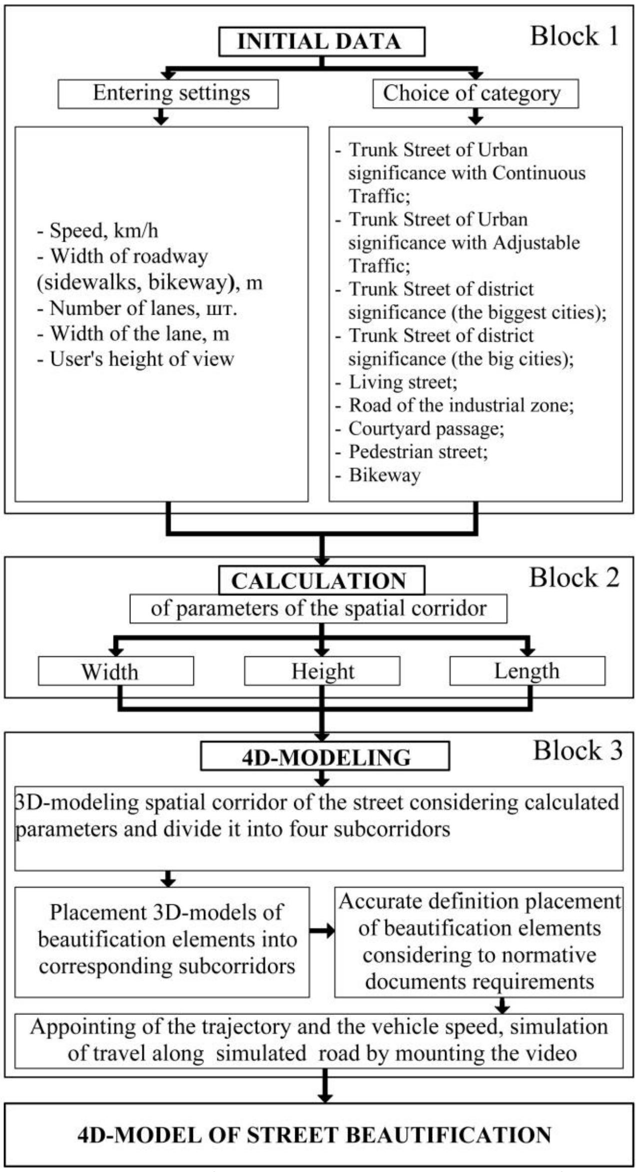

Fig. 14: The method of designing comprehensive streets beautification

Shevchenko Street from the intersection of European Street to the intersection of Raisa Kirichenko Street does not have any trees and any other elements of vegetation. Instead, this space is overloaded with the advertisements of stores, products, signboards with service information, etc. Vendor kiosks, that sale food and non-food products, occupy a lot of space. There are bus stops along one side, which makes the street loaded by pedestrians. All free space on the sidewalks is occupied by vendor kiosks, riverlamp and shop signs (Fig.1), which is prohibited according to DBN V.2.3-5-2001, p.2.21.
This creates the overload of sidewalks, traffic jams and other inconveniences. The intense traffic of machines causes the air to have a high content of both dust and exhaust gases.
For design of the reconstruction of this street, the principle of modeling the street spatial corridor was used. Using the computer program STREET BEAUTIFICATION, developed by the authors to simplify the process of calculating the spatial corridor parameters were calculated.
Initial data for calculation: speed: 60 km/h; width of the traffic lane: 15 m; number of lanes: 4 pcs.
The calculation results are presented in Table 1.
According to the calculation results, the street spatial corridor with the beautification elements placing was modeled (Fig. 15).

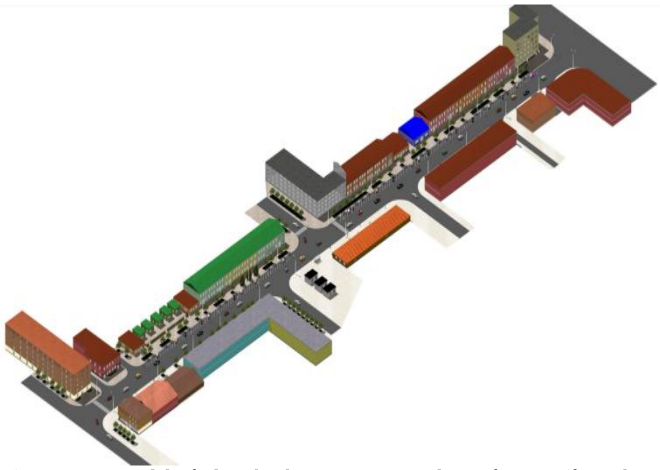

Fig. 15: 4-D model of Shevchenko Street section beautification (from the intersection of the European Street to the intersection of the Raisy Kirichenko Street) in Poltava town

With 4D-model of street improvement reconstruction, the quality of the streets space perception is verified by authors (Fig. 16).

Table 1: Results of calculating the parameters of Street Shevchenko in Poltava, Ukraine spatial corridor **roadway** part

No	Parameter name	Parameter designation	Parameter value, m
1	Width of spatial corridor	Bcor.	93.5
2	Height of spatial corridor	Hcor.	22.9
3	Length of spatial corridor	Lcor.	157.4
Parameters of the 1st subcorridor			
4	Width	B_I	15
5	Height	H_I	1.5
6	Length	L_I	16.7
Parameters of the 2nd subcorridor			
7	Width	B_2	5.7
8	Height	H_2	2.6
9	Length	L_2	37.2
Parameters of the 3rd subcorridor			
10	Width	B_3	9.3
11	Height	H_3	6.6
12	Length	L_3	70.4
Parameters of the 4th subcorridor			
13	Width	B_4	24.3
14	Height	H_4	22.9
15	Length	L_4	157.4

Table 2: Results of calculating the parameters of Street Shevchenko in Poltava, Ukraine spatial corridor **bikeway** part

No	Parameter	Parameter designation	Parameter value, m
1	Width of spatial corridor	Bcor.	9.4
2	Height of spatial corridor	Hcor.	4.2
3	Length of spatial corridor	Lcor.	30.2
Parameters of the 1st subcorridor			
4	Width	B_I	1.5
5	Height	H_I	1.7
6	Length	L_I	8.3
Parameters of the 2nd subcorridor			
7	Width	B_2	0.6
8	Height	H_2	1.8
9	Length	L_2	11.5
Parameters of the 3rd subcorridor			
10	Width	B_3	0.9
11	Height	H_3	2.4
12	Length	L_3	16.7
Parameters of the 4th subcorridor			
13	Width	B_4	2.4
14	Height	H_4	4.2
15	Length	L_4	22

Table 3: Results of calculating the parameters of Street Shevchenko in Poltava, Ukraine spatial corridor **sidewalk** part

No	Parameter	Parameter designation	Parameter value, m
1	Width of spatial corridor	Bcor.	9.4
2	Height of spatial corridor	Hcor.	4
3	Length of spatial corridor	Lcor.	6.9
Parameters of the 1st subcorridor			
4	Width	B_I	1.5
5	Height	H_I	1.7
6	Length	L_I	1.1
Parameters of the 2nd subcorridor			
7	Width	B_2	0.6
8	Height	H_2	1.9
9	Length	L_2	2.0
Parameters of the 3rd subcorridor			
10	Width	B_3	0.9
11	Height	H_3	2.3
12	Length	L_3	3.3
Parameters of the 4th subcorridor			
13	Width	B_4	2.4
14	Height	H_4	4.0
15	Length	L_4	6.9

Fig. 16: Photographs of simulated driving along the street

6. Conclusion

Thus, having completed the experimental design of the street beautification using the proposed methodology of complex designing improvement, based on the principle of modeling the spatial corridor, the possibility of its use was proved and the following advantages were revealed:

- possibility of complex beautification design, namely, placement of all elements in one model, which allows to check their mutual location;
- the possibility of rhythmical placement beautification elements, which contributes to the constant loading of the human brain without over-straining it;

- the possibility of directing the pedestrian's or driver's perception to the necessary elements for the safety of motion, and then to the elements designed to meet the physiological and human aesthetic needs;
- the possibility to check the quality of both static and dynamic (in motion) perception;
- the reduced term of project execution without loss of quality, achieved through the use of pre-created libraries of textures, small architectural forms, etc. (There is no need of drawing each small detail).

Acknowledgement

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