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THE STRUCTURE OF THE URBAN LANDSCAPE

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Структура городского ландшафта

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Рассматриваются вопросы субстанционной, пространственной и временной структуры урбанизированного ландшафта с позиций новых возможностей интеграции данных, открываемых ГИСтехнологией. Ландшафт интерпретируется как тотальный территориальный комплекс, охватывающий все материальные образования в пределах контакта литосферы и атмосферы, включая человеческое население и продукты его деятельности. Пространственные и временные границы городского ландшафта определяются наличием характерной плотной застройки. В качестве примеров приводится материал по городу Львову.

Субстанционная структура ландшафта может передаваться различными геокомпонентными моделями. Одним из вариантов является модель, в которой антропогенные компоненты, объединённые в антропогенный частичный геокомплекс, рассматриваются как аналоги уцелевших первичных природных компонентов, образующих первичный частичный геокомплекс городского ландшафта.

Пространственная структура ландшафта имеет два компонента – вертикальный, представленный геогоризонтами, и горизонтальный, передаваемый взаимодополняющими частичными ландшафтными территориальными структурами. Геолого-геоморфологические территориальные единицы дают возможность достаточно полно передать первичную пространственную дифференциацию ландшафта, а территориальные единицы городского архитектурного покрова – антропогенную. Эти картографические слои могут быть дополнены бассейновыми территориальными структурами, цифровой моделью рельефа, картой распределения зеленой фитомассы и т.п. Оверлейный анализ и ландшафтно-экологическое моделирование позволяют получать информацию высшего уровня интеграции, – например, карту техногенной преобразованности первичного ландшафта.

Временная структура ландшафта обусловлена сопряжением частных ландшафтных процессов, имеющих два динамических компонента – циклический (функциональный) и прогрессивный (эволюционный). Она представляется в виде дискретных функциональных и эволюционных состояний ландшафта. Временная структура городского ландшафта рассматривается как наложение антропогенных и спонтанных состояний.

Все три типа структур характеризуются дискретностью, иерархичностью и поливариантностью декомпозиции.

Large towns (over 100,000 dwellers) occupy a significant portion of the earth's densely inhabited area, contain more than one-fifth of the world's population as well as the major economic and cultural wealth of the humankind, which is to a great extent comprised in land (real estate). They also demonstrate sharp land use and environmental problems caused by the high concentration of population, services and industries. When considered in the context of the sustainable development strategy, mentioned circumstances make landscape studies of urban areas an essential applied exercise (Kruhlov, 1998). Not to mention that the research deals with a rather unexplored realm of integrated geography in general.

Relatively modest, if compared with applicatory potentialities, success of urban landscape studies can be explained, probably, by the non-traditional object (urban areas are mainly favoured by "pure" human geographers) and its complexity. While the technical problems of the urban landscape data collection, processing and presentation are mainly overcome by the implementation of remote sensing, GIS and GPS, the issue of the theoretical concepts that can be used as basis for the efficient application of new information technologies is now of outstanding importance.

Since certain aspects of the urban landscape-ecological information systems (ULEIS) were discussed elsewhere (Krouglov, 1997a, 1997b), this paper is concentrated on some essential concepts of landscape science, which can be used to integrate data on an urban area.

General Notions

The summary of ideas formulated in the main theoretical publications (e.g., Armand, 1975; Bobek und Schmithüsen, 1949; Carol, 1957; Haase, 1991; Hrodzynskyi, 1993; Isachenko, 1991; Neef, 1967; Sochava, 1978; N. Solntsev, 1949, 1963; V. Solntsev, 1981; Troll, 1966a, 1966b) can be expressed as a formal definition of the object and the subject of landscape studies given in the next paragraph.

A landscape, and an urban landscape in particular, is a 3-dimensional composite geographical body¹ in a certain way delimited at the contact of the lithosphere and the atmosphere, which includes all material formations within its spatial extent. It is regarded as a combination of the other geographical bodies distinguished according to the substantial organisation, and referred to as landscape components, or geocomponents. The study is concentrated on the interrelations between the geocomponents in space and time. The interrelations have biophysical and socio-economic manifestations that are subjects of respectively natural and human geography. Terms "geocomplex" and "geosystem" are frequently used as synonyms of "landscape". The discipline of the landscape is designated as "landscape studies", "landscape science", "landscape ecology".

The landscape is characterised by substantial, spatial and temporal structures controlled by the external inputs of information, energy and matter, as well as by the internal processes of selforganisation. The polystructural nature of the landscape (e.g., Hrodzynskyi, 1993) enables diverse interpretations of the structures. Correctly done, these interpretations are not contradictory, but complementary. The structures can be also considered as hierarchical.

The urban landscape is a version of the cultural landscape (e.g., Troll, 1966a), whose main peculiarity is the presence of the geocomponent of a dense urban building (FIGURE 1). Therefore, spatial and temporal limits of the urban landscape are also defined by the presence of the dense urban building, and do not necessarily coincide with, respectively, the city administrative boundaries and the time of the acquisition of town status.



FIGURE 1 The landscape of Lviv downtown (Photo by V. Myronuk)

РИСУНОК 1. Ландшафт центральной части города Львова (Фотография В. Миронюка).

Lviv is the largest city in Western Ukraine with about 0.8 million of inhabitants and administrative area of 113 km². It evolved on the Main European Waterdivide at a junction of five morphostructural units that are interpreted as natural regions (FIGURE 3).

The centre of the junction is the Poltva Basin with a wide bottom and steep slopes dissected by smaller valleys (on the photo). The altitude of the bottom is 270-290m, surrounding wide interfluves (Lviv-Lubin Plain and Lviv Plateau) have elevations of 310-340m, while the hills of the Holosko and the Davydiv Ridges reach 350-380m above the sea level. The highest point is the High Castle – 409m with an artificial mound of about 30m – forming NW termination of the Davydiv Ridge (seen on the photo).

Bedrock is represented by Maestrichtian marlstone, which is overlaid with Badenian sands including sandstone or limestone strata and fragments of a gypsum horizon. The Miocene cover is absent

¹ A geographical body is a compact or dispersed material formation on the earth's surface, whose area is large enough to be considered on the geographical scale. The levels of geographical scales are discussed, for example, by Haggett et al. (1965).

The climate can be characterised as temperate (mean temperature in January $- -4^{\circ}$ C, in July $+ 18^{\circ}$ C) moderately humid (680mm of annual precipitation).

Diverse natural-geographical conditions that are reflected in a complex primary landscape pattern (see FIGURE 3) were favoured by settlers who during centuries shaped it into the present urban landscape. Owing to bewildered political history, the area bares traces of Eastern and Western town-building culture as well as a distinct imprint of the communist planning approach (FIGURES 4, 7).

These circumstances make Lviv the perfect test area for urban landscape studies.

Substantial Structure

The substantial structure forms the main attribute of the landscape as a material object. It is represented by the combination of geocomponents and is studied in terms of differentiation in space and time. Different interpretations of the landscape's substantial structure, or different geocomponent models, can be applied depending on the nature of the study. Although never evidently recognised, the substantial structure has been extensively discussed in numerous publications.

Several geocomponent models have evolved spontaneously. Traditionally, geocomponents are identified as objects of traditional earth sciences – rocks (geology), landforms (geomorphology), climate (climatology), vegetation (phytogeography), etc. (e.g., Isachenko, 1991). N. Solntsev (1963) made a historical-genetic interpretation of interrelations between natural landscape components and eliminated some illogical statements of the traditional model². In B. Polynov's school of landscape chemistry the landscape's substance is frequently described as a combination of chemical elements (e.g., Perelman, 1975), while Beruchashvili (1986) developed rather detailed genetic hierarchical classification of natural geocomponents in the form of "geomasses" for studies in landscape physics.

Mentioned geocomponent models have the same shortcoming – they do not embrace the human population and the products of its activities. This can be explained by the fact that the landscape is understood here as only a *primary terrain complex (PTC)* (e.g., Solntsev, 1963; Isachenko, 1991; Hrodzynskyi, 1993). For urban landscape studies such limitations should be avoided, and the landscape should be interpreted as the totality of land features, including human population and its material products (e.g., Carol, 1957; Hadač et al. 1978; Haase, 1991).

One of the possible geocomponent models of the urban landscape is shown in FIGURE 2. It reflects the idea of Bobek and Schmithüsen (1949) about three integration levels of landscape phenomena – physical, biological and social (intelligent). The model is also built on the Isachenko's (1991) notion that anthropogenic landscape components can be regarded as analogues of those existed before the interference of man (primary landscape components). Thus, geocomponents are joined into respective groups, or *partial geocomplexes*. The primary partial geocomplex includes the fragments of primary landscape components that escaped destruction. The polystructural nature of the urban landscape's substantial organisation is manifested in the fact that one and the same geocomponent (e.g., cultural vegetation) may belong to different partial geocomplexes (biotic and anthropogenic, in the case).

The geocomponents can be interpreted hierarchically. For example, the geocomponent of cultural vegetation can be divided according to the growth form into trees, shrubs and grasses, while the latter – into perennial geophytes and annual therophytes, etc. Developing the idea of A. Krauklis (1979), landscape components may be also classified according to the variability in time – *static* (e.g., geological deposits, architectural structures) and *dynamic* (e.g., air masses, vegetation); mobility in space – *resident* (e.g., architectural structures, vegetation) and *migratory* (air masses, human population); ability to complicate (maintain) their structure – *passive* (non-living geocomponents) and *active* (biotic geocomponents and human population). The geocomponent of human population has a unique property – intelligence. In conventional landscape studies properties of static and resident geocomponents are used to define spatial and temporal structures of the landscape.

² Landforms and climate are merely properties of the lithosphere and the atmosphere respectively, and therefore cannot be regarded as landscape components from the strictly logical point of view (Solntsev, 1963).



FIGURE 2 The substantial structure of the urban landscape РИСУНОК 2. Субстанционная структура городского ландшафта.

When studied as a natural-geographical object, the anthropogenic partial geocomplex is regarded as having no genetic connection with its primary counterpart. This is caused by the fact that natural geography is not competent to explain genetically geocomponents of human origin or the human community itself, since they are essentially socio-economic phenomena. Therefore, anthropogenic components are characterised merely from the point of view of their natural (biophysical) properties. For example, human population is regarded as a biological species whose optimal habitat conditions can be defined in terms of insolation, absence of pollution, availability of open space, etc. (e.g., Krouglov, 1997b).

Spatial Structure

The landscape's spatial structure is the subject of *landscape morphology* (e.g., Solntsev, 1949; Troll, 1966a) or landscape chorology, geochorology (e.g., Haase, 1991). *The spatial structure reflects differentiation of the landscape's substantial totality in the 3-dimensional space of the contact zone between the lithosphere and the atmosphere.* One of the main properties of the landscape space is its unisotropy caused by the earth's gravity – differentiation of the geographical substance along the gravity vector, unlike in the lateral directions, has one-way character and no recurring pattern. Therefore, the landscape as a 3-dimensional body is described in terms of vertical and horizontal spatial structures.

The vertical spatial structure of the landscape conveys differentiation of the geocomplex's substance along the gravity vector. Beruchashvili (1986) introduced the concept of a **geohorizon** as a component of the landscape's vertical spatial structure. Since the vertical extent of the landscape is rather insignificant on the geographical scale, the vertical spatial structure mainly is not considered in the general landscape studies, though it can be a very important issue in special investigations, like in landscape physics or landscape ecology.

The horizontal spatial structure of the landscape or the areal structure of the landscape represents differentiation of the geocomplex's substance, normal to the vector of gravity. It is a

4

subject of the traditional geographical research, and is studied by means of conventional maps and GIS.

The main traditional problem in the representation of the landscape's areal structure is the issue of its reduction to one of the components or properties of the geocomplex. For example, in the majority of schools the areal structure of the "natural" landscape is reduced to geomorphological units – landforms (e.g., Solntsev, 1949, 1962; Troll, 1966a, 1966b). Sometimes it is merely presented as patches of different vegetation (e.g., Forman and Godron, 1986). In the case of the urban landscape, the areal structure is most commonly conveyed by architectural units (e.g., Brady et al., 1979; Forman and Godron, 1986; Breuste, 1991). This inevitably leads to a significantly simplified presentation of the structure, which is not always justified.

An alternative to such a reductionistic approach is description of the landscape's spatial structure by a set of complementary partial structures. For example, in the school of G. Haase (1991) the areal structure of the landscape is conveyed by two partial areal structures – those of the primary geocomplex (Naturraumstruktur) and of the anthropogenic geocomplex (Flächennutzungsstruktur). Similar approach has been used for some time in the Eastern-European urban landscape studies. The areal structure of the urban landscape is viewed there as a combination of primary landscape units represented by landforms and anthropogenic (technogenic) landscape units formed by architectural structures and other types of urban land cover (e.g., Tarasov, 1977).

It was mentioned that landforms are most frequently used to convey spatial distribution of other primary landscape features – topoclimate, soils, vegetation, etc. Landforms can be also used to retrospect spatial distribution of these features in the areas profoundly altered by humans, such as urban. The retrospection is built on the assumption that under similar geological-geomorphological and macroclimatic conditions similar climax vegetation and soil are formed. Therefore, in order to establish probable primary biotic geocomponents, landforms occupied, for example, by dense urban building are merely compared with similar landforms having better preserved primary biotic geocomponents, say, in the city green belt. Owing to proximate location differences in macroclimate can be neglected (Krouglov and Miller, 1993). Thus, geomorphological units can be used to interpret retrospectively primary morphology of the urban landscape³ (FIGURE 3).

The anthropogenic morphology represents landscape's spatial differentiation caused by human activities. In urban areas architectural structures create continuous land cover – *urban architectural cover*. It can be quantitatively described in terms of open-ground ratio (the portion of land surface not covered with impermeable material), built-up ratio (the portion of land surface occupied by architectural structures), average building height and building density (built-up ratio multiplied by average building height). The last index reflects building load upon the primary geocomplex and correlates well with human population density (Krouglov and Miller, 1993) (FIGURE 4).

The overlay of the two partial structures with landscape-ecological modelling can be used to derive other spatial information of a higher integration level – for example, to estimate integral technogenic transformation of the primary landscape (FIGURE 5). This estimation is based on the notion that the extent and the character of the environmental change depend both on the magnitude and peculiarities of building load (represented by building density) as well as on the inherent stability of the primary landscape withstanding this load (calculated on the basis of slope value and type of superficial geology) (Krouglov, 1997a).

³ Interpretation of landforms as primary areal landscape units is perfectly justified only in medium- and smallscale surveys. Considering that urban development significantly changes microrelief and, sometimes, mesorelief (e.g., mining or motorway construction), in the detailed surveys it is hard to tell primary landforms form the anthropogenic ones and thus to retrospect primary biotic components. Therefore, it is relevant to speak generally about geomorphological areal landscape units, not primary areal landscape units.



5	19.7			Eol-Dl sand (2-4m) on	Sod-podzolic	
				boulder clay		Pine-oak
6	0.5			Eol-Dl sand (1-2m) on	Light-grey	
		Gentle slopes	10-20	bedrock sand forest		
7	9.0	1		Eol-Dl loam (over 4m)	Dark-grey	Hornbeam-
					forest	oak
8	20.2	Steep slopes		Eol-Dl and El-Dl loam (1-	Grey and	Hornbeam-
		with structural	over 20	4m) on bedrock sand,	light-grey	beech
		terraces		sandstone and marlstone	forest	

Total 112.9 km² within the city administrative limit

a – Administrative city limit; b – Main streets and roads; c – Boundaries of natural regions: 1. Holosko Ridge; 2. Davydiv Ridge; 3. Lviv Plateau; 4. Lviv-Lubin Plain; 5. Poltva Lowland.

FIGURE 3 Lviv. Primary landscape morphology

РИСУНОК 3. Львов. Морфология первичного ландшафта.



#	Area (km²)	Technogenic cover type	Open grnd. ratio (%)	Built-up ratio (%)	Bld. hgt. (storeys)	Bld. dens. (points)
	22.4	Green plantations	70-100	0-5	1	0-5
	17.1	Vacant and agricultural land	90-100	0	0	0
	15.1	Low-storey dispersed building	60-80	5-10	2	10-20
	10.9	Medium-storey dispersed building	30-80	10-20	4	40-80
	3.4	Medium-storey dense building	5-20	20-40		80-160
	14.9	High-storey building	20-40	10-20	9	90-180
	29.1	Industrial building	5-40	10-40	3	30-120

Total 112.9 km² within the city administrative limit \mathbf{a} – Administrative city limit; \mathbf{b} – Main streets and roads

FIGURE 4 Lviv. Architectural cover morphology

РИСУНОК 4. Львов. Морфология архитектурного покрова

There are other partial areal structures that help to convey morphology of the urban landscape. Some of them can be presented in a form of choropleth (polygon) maps – for example, catchment units. The others are typical isopleth (grid) maps – for instance, elevations. These structures are used as complementary overlays in hydrological and topoclimatic analysis of the

landscape. Areal structures of dynamic landscape components, such as green phytomass, can be obtained via remote sensing (FIGURE 6).

Landscape morphology is traditionally based on hierarchical interpretations of the areal structures (e.g., Solntsev, 1949; Haase, 1991; Hrodzynskyi, 1993). However, implementation of GIS with relational data models gives grounds to question whether such an approach is always an optimal solution.



1...9 – Integral degree of environmental transformation (least transformed ... most transformed) a – Administrative city limit; b – Main streets and roads

FIGURE 5 Lviv. Technogenic transformation of the primary landscape РИСУНОК 5. Львов. Техногенная трансформированность первичного ландшафта.

Temporal Structure

The temporal structure of the landscape conveys a change of the latter's substantial totality in time. Research in the geocomplex's temporal structure, or landscape dynamics, landscape chronology (Troll, 1966a), extends the limits of landscape science beyond the scope of geography as a purely chorological discipline. If historical-genetic approach was the immanent feature of the discipline from the very beginning of its existence (e.g., Schlüter, 1920), the tradition of functional analysis was brought into landscape science later by ecologists (e.g., Troll, 1966a).

The experience of the research in landscape dynamics (e.g., Armand and Targulyan, 1976; Beruchashvili, 1986; Forman and Godron, 1983; Krauklis, 1979; Mamai, 1992; Sochava, 1978; N.

Solntsev, 1962; Troll, 1966b) affords some generalisation. Landscape dynamics can be described as the superimposition of various *partial landscape processes* that have two more or less pronounced components (aspects) of change – a cyclic component, which refers to *landscape functioning*, and a progressive component associated with *landscape development (landscape evolution* – in the broad sense). The functional cycles of diverse partial landscape processes have different *characteristic time*, or temporal scales of duration. The regular run of landscape dynamics is interrupted *by landscape disturbances* – external or internal impacts that force the parameters of the geocomplex to exceed or drop below their common range of variation. Disturbances cause the substitution of *stable functioning*, with its steady amplitudes and frequencies of cycles, by *variable functioning*, which is characterised by random or non-recurring amplitudes and/or frequencies. They can also provoke the replacement of gradual landscape development or, in other words, landscape evolution in the narrow sense, by the sudden, catastrophic irreversible changes that can be called *landscape revolution*.



FIGURE 6 Lviv. Distribution of green phytomass in summer 1992 NDVI (normalised difference vegetation index) calculation was applied to a multispectral SPOT image to produce this satellite map. The rectified image is overlaid with a street network and boundaries of natural regions.

РИСУНОК 6. Львов. Распределение зеленой фитомассы летом 1992 года.

When landscape's dynamics is traced as the set of changing parameters (partial processes), it can be presented only as a sequence of discrete *temporal* or *dynamic states of the landscape*

(Beruchashvili, 1986; Mamai, 1992). Temporal limits of a dynamic state are defined by the cycle of the partial landscape process, which is considered as controlling or most representative. For example, cycles of the solar radiation are frequently used to define temporal states (daily and annual states) in the study of the natural landscape's dynamics (e.g., Beruchashvili, 1986). Often dynamic states are viewed as hierarchically organised.

Stable functioning corresponds to *stable functional states of the landscape*. Variable functioning is associated with *variable functional states of the landscape*. The sequence of stable and variable functional states of different duration and hierarchical levels, which preserve some basic features of the geocomplex – *the invariant of the landscape* – compose longer-term *evolutionary states_(stages) of the landscape*. The row of evolutionary stages reflects landscape development. The *age of the landscape* is equal to the time of existence of the present invariant of the landscape (according to Sochava (1978) with some changes).

Thus, two main hierarchical subdivisions of landscape dynamic states are delineated – shorter-term reversible functional states (stable and variable) and longer-term irreversible evolutionary states. This division is conditional, and can be done in different ways depending on what features are considered as the landscape's invariant.

In the same way as the substantial structure, *the temporal structure of the urbanised landscape* can be regarded as the combination of primary landscape dynamics, controlled by the primary natural factors, and anthropogenic landscape dynamics, driven by the direct energy and matter inputs of human origin⁴. It is presented as the sequence of superimposed primary and anthropogenic dynamic states.

Primary landscape dynamics embraces different spontaneous phenomena with very diverse characteristic time – i.e., periods of continental glaciation endure tens of thousands years, while the flash of a lightning lasts less then a second. This makes possible to delimit a broad hierarchical array of **primary (spontaneous) dynamic states of the landscape** (e.g., Mamai, 1992). It should be mentioned that anthropogenic geocomponents are subjects of primary landscape dynamics too – cultural vegetation develops according to natural rhythms in the same way as its primary counterpart, and architectural structures experience weathering similarly to rocks.

Anthropogenic dynamics of the landscape is attributed to human population and its activities that change the appearance of the geocomplex – pedestrian and vehicle flows, tree cutting, construction activities, etc. In the same way as primary natural phenomena, they have different mean duration of the cyclic component. The latter can be estimated as tens to hundreds of years for existence of architectural structures, dozens of minutes for rush hour congestion in the streets, and less than a second for a cannon salute on a holiday. Therefore, human activities in the landscape can be conveyed as a hierarchy of *anthropogenic dynamic states of the landscape*.

In order to distinguish functional and evolutionary states, features that represent basic, invariant, properties of the urban landscape should be defined first. Majority of researchers considers geological-geomorphological and macroclimate conditions (static properties of the physical partial geocomplex) as those controlling temporal and spatial differentiation of the primary landscape's substance (e.g., Solntsev, 1960; Troll, 1966b). Thus, the spontaneous change of geological-geomorphological or macroclimatic conditions can be used to delineate primary (spontaneous) evolutionary states of the urban landscape.

Similarly, shifts of anthropogenic evolutionary states of the cultural landscape can be linked to the changes in its geological-geomorphological basement caused by the human impact⁵. In urban areas they are mainly produced by construction and mining. Replacement of old building by new structures can also be viewed as a profound modification of urban solid geocomponents, equal to the alteration of geological-geomorphological conditions of a non-built area.

As clearly seen in FIGURE 7, the anthropogenic evolution has much quicker pace than the spontaneous one. Therefore, in the evolutionary analysis of the urban landscape the primary

⁴ The idea of landscape dynamics as the combination of primary and anthropogenic dynamics was mentioned by Sochava (1978).

⁵ It is assumed that anthropogenic influence on the macroclimate is rather insignificant.

component can be neglected. Exclusions should be made for the cases of catastrophic spontaneous modifications of the geological-geomorphological basement caused by earthquakes, volcanism, etc.



FIGURE 7 Lviv. Landscape evolution

РИСУНОК 7. Львов. Эволюция ландшафта.

Conclusion

Substantial, spatial and temporal aspects of the landscape's structure, discussed in this article, have some distinct similarities. First, landscape's substantial, spatial and temporal differentiation has essentially a discrete nature. This is obvious for the substantial structure. It is also true for the spatial and temporal organisation, because in both cases it is conveyed by the set of variables. Second, the units of the three structures can be delimited differently, depending which parameter is chosen as a controlling (critical), and how thresholds are set. Third, the structures can be presented hierarchically, thus providing links between the different levels of generalisation of landscape properties.

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