Urban planning aspects of stability theory of ecological town planning systems

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Abstract. The study of the problems of sustainable development of the ecological and urban planning system " population ↔ environment" of various levels of its functional and spatial integrity (local, regional, national, world-wide) reveals a number of fundamental provisions that establish the conceptual foundations of a new direction in urban planning science that potentially exists in certain individual works.

The development of urban planning aspects of the stability theory is based on the fundamental concept of the physico-mathematical stability theory that is more developed at the present time and the research findings, which established the cyclical nature of the multilevel processes of wave development of the "population ↔ environment" system. The urban planning stability theory studies the nature of the vibrational development of urbanization processes accelerating in a multi-level ecological space.

The paper reveals a number of similarities and fundamental differences in the states of stability and the dynamic pattern that are inherent in the development of living and inanimate natural systems. Regarding the differences in state of equilibrium: equilibrium is the goal of development for living systems within a certain cycle and the level of their spatial integrity. For inanimate systems equilibrium is the initial state.

Concerning the differences in the stability of the location of the "center of mass": the "center of mass" should occupy the highest possible position (in the range of ecological equilibrium) for living systems; for the inanimate-to take the lowest possible position. When developing the urban development aspects of stability theory were used such concepts of physical and mathematical stability theory as: asymptotic stability; stability "in time" according to Lyapunov; stability "in space" ("stable − unstable node", "stable − nonstable focus ", "stable center"). Marked concepts are important for the analysis of multi-level processes of accelerating development of the ecological and urban planning system; forecasting the direction of its further changes; determination of focuses and parameters of application of urban planning regulatory influences; adapted sustainable development management.

Key words: urban development processes, ecologic-urban planning system, urban-eco-physical parallels, sustainable development, sustainability over time, sustainability over space.

INTRODUCTION

It is commonly known that the stability theory being a technical and physico-mathematical discipline explores regularities of the systems behavior under the influence of the external factors [4]. However, for hierarchically-arranged ecosystems formed by material, energy and information flows all influencing factors are internal in their nature, as in the tide of life there is always some higher level of its system organization. When viewed analytically, the stability theory is a section of mathematical theory of differential equations derived from the mechanics problems that require defining the coordinates of body movement speed and acceleration as a function of time varying under the influence of various external factors [4].

Analogies and subjection of the development processes of ecologic-urban planning system "Population – Environment" (EUPS) to general ecological and physical laws (particularly, the physics of vibrations – both mechanical and electromagnetic) allowed using the theoretical grounds of currently more developed physical and mathematical theory of stability when determining its urban-planning aspects [1 − 4].

MATERIALS AND METHODS

The purpose of investigation is to determine the fundamental principles of sustainable development and the urban-planning aspects of the stability theory of ecologic-urban planning systems. When carrying out this work, system approach, modeling methods and comparative analysis were used. The analog method was chosen as the basic one being the comparative analysis tool widely applied in ecology.

STARTING POSITION URBAN-ECO-PHYSICAL PARALLELS

In general terms the stability theory was developed by Aleksandr M. Lyapunov who formulated and established its basic theorems. The significant aspect of this theory is the issues of detecting and forecasting the sustainability reserves of complex multi-component dynamic various-factor systems and processes [4]. This is utterly important also for creating and maintaining appropriate conditions for sustainable development of ecologic-urban planning systems.

According to the theory Lagrange theorem constitutes a sufficient precondition for stable equilibrium of a conservative mechanical system. The theorem states that if potential energy of a mechanical system has a strict minimum in the state of equilibrium, such state is considered sustainable by Lyapunov [5].

The obtained results correspond with the theorem provisions. Thus, potential energy of the investigated system (defined by the demographic capacity of EUPS territory) also has a strict minimum in the state of ecologic equilibrium (Fig.1, Stage IV [6]). Such minimum is caused by the fact that the demographic capacity of EUPS in the state of equilibrium is depleted (the population parameter is equal to the value of its demographic capacity within the 10% tolerance range [7]) [1 − 3].

According to Lagrange theorem, in the uniform gravity field the state of mechanical system equilibrium will get stable, when the gravity center reaches the lowest position [5]. From this perspective the obtained result is opposite to this consequence. This can be explained by fundamental differences between development of animated and inanimate physical systems. Inanimate systems are initially balanced, the state of equilibrium is their primary state. As to animated systems, the state of equilibrium is the purpose of their development (equilibrium stage is a target stage of a specific development cycle (see Fig.1, Stage IV) [6 − 8].

Ecologic-urban planning systems appear and develop in nonhomogeneous ecological space and multi-level gravity fields (catchment areas) of the cities. Therefore, the equilibrium state of the investigated system will get stable when the population size reaches the value of its demographic capacity. This value defines the maximally possible, optimal for EUPS, number of its stable population. In other words, this happens when the gravity center of the system (within a specific development cycle and space integrity level) takes the highest possible equilibrium position (see Fig.1, Stage IV) [1 − 3].

SUSTAINABILITY OVER TIME – DEVELOPMENT PATHWAYS

A mathematical problem of stability in a specified point is usually studied in stability theory [4, 5]. In the aspect of EUPS sustainable-wavelike development, such point is most likely the point of branching into ecological equilibrium range (see Fig.1, Stage IV) [1-3]. However, under combined effect of certain external and internal factors development of the system can leave the range of equilibrium.

In unfavorable combination of external (depletion of natural resources, climate changes, pandemic diseases, external aggression, etc.) and internal factors (transformation of the targets and values system, behavioral patterns, public health status, etc.) the strategy of sustainable-wavelike development within the ecological equilibrium range can be changed with the strategy of decay for EUPS.

In case the abovementioned factors combine favorably (mastering of new natural resources, adaptation to climate changes, implementation of innovative technologies, improvement of psycho-physical health of population) the system can make a qualitative leap in development getting to a new space and resource-energy level EUPS integrity. In urban planning practice such leap usually consists in broadening of territorial boundaries of the urban-planning site.

It is well-known that the dynamic systems are mathematically described by the system of differential equations with certain initial conditions [4]. In our case the initial conditions of "Population ↔ Environment" system development are the measurable and constant (in certain time period) area of the urban-planning site territory and local natural and climatic conditions (our investigation proved that these very conditions define the demographic capacity parameters) [1].

In the specified context the important issue for urban-planning regulation of EUPS sustainable development conditions is how the changes in the initial conditions influence the behavior and the pathway of further development of the system at big time periods, or at $t \to \infty$ in the extreme case. As to the extreme case, for "Population ↔ Environment" system it complies with the target of a specific stage of its development, which is the state of ecological equilibrium (Fig.1).

As according to the definition, ecosystem in the equilibrium state can exist at a specific territory for an indefinitely long period by means of resources renewal [6, 8], the above-given definition of the system equilibrium state within the range of its ecological (vibration) balance (see Fig.1, Stage IV) is compliant with the mathematical definition of stability. This definition states that the system movement is stable, if under small perturbations the movement pathway changes against the initial position insignificantly [4].

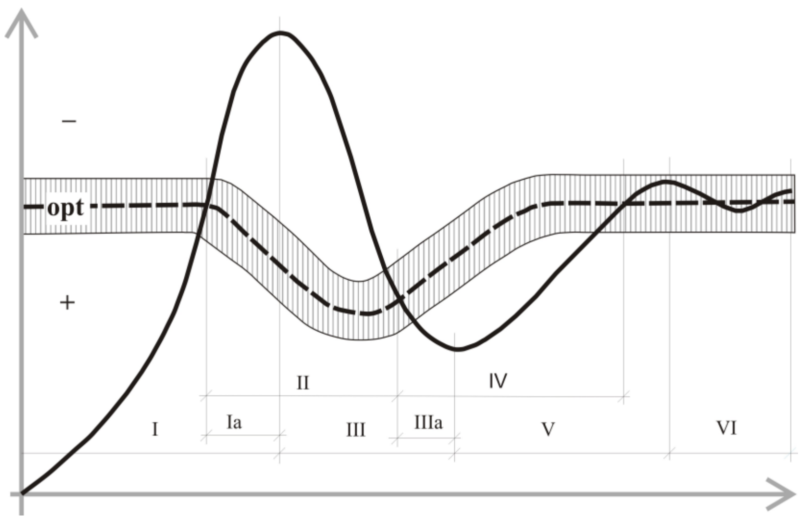


Fig.1. The self-regulation ecosystem by V. Dolnyk (*I-VI*): *I* – stages of ecosystem population capacity of the environment range of equilibrium; *II* – population; *III* – capacity of the environment; *IV* – range of equilibrium; *V* – ± opt; *VI* – quality of environment

There are several different formal definitions of stability. When describing the range of EUPS ecological equilibrium one should better use the stability definition given by Lyapunov. He defined stability as follows: and pathway X (t) stays inside the range with the maximal radius ε at all t ≥ 0 (Fig.2, *a*) [4].

Such definition allows formalizing the ecological equilibrium range and defining the stability parameters for various stages and space levels of EUPS development [1]. This can be in certain way traced:

- in wave dynamics of aligning development of urban-planning systems and formations per stages of their expansion in local, mental, global and temporal time and space (Fig.2, *b*) [9];
- in waves of biological life forms development on Earth (Fig.2, *c*) [10];
- in civilization waves of human development (Fig.2, *d*) [11].

To determine the parameters of urban-planning regulatory factors in terms of sustainable development, the definition of asymptotic stability is more suitable (Fig.3) [4]. Asymptotic stability means that all pathways X (t) not only remain inside the specified range but also gradually converge to the minimum radius φ (t) with increasing of t (Fig.3, *a*). To a certain extent, correspondence with asymptotic stability can be traced:

- in the model of joint changes of demographic capacity and population size parameters per EUPS development cycles (Fig.3, *b*) [1];
- in urbanization impulse fading in Western Europe (Fig.3, *c*) [12];
- in urban-planning intensity decay in the central Germany lands (Fig.3, *d*) [12].

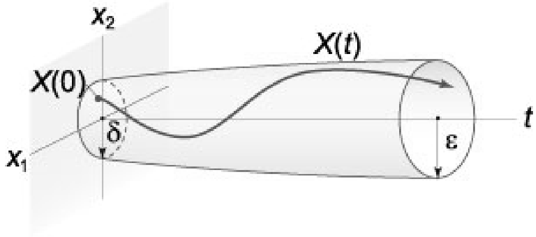
STABILITY OVER SPACE – STABLE UNIT, STABLE FOCUS, STABLE CENTER

In the physico-mathematical theory of stability, in addition to stability of the dynamical systems pathways, the simplest types of "stability points" are also studied. The "stable and unstable units", the "stable and unstable focus" and the "stable center" are of considerable interest among such points (Fig.4, 5, 6). Certain analogies with these "points" are extremely important for justification of the system of urban-planning regulatory influences [13].

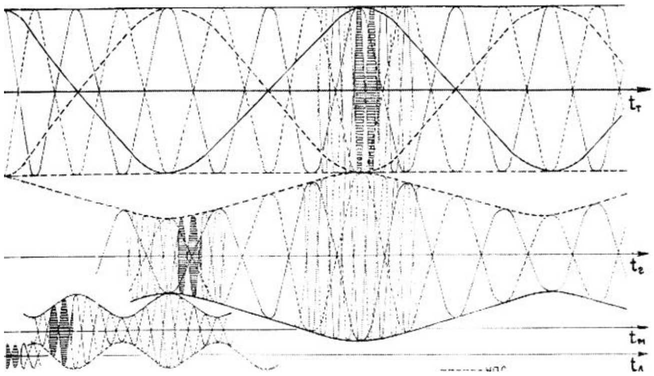
Spatial analogues of "stable and unstable units" in EUPS development processes can be either different cities (urban agglomerations), and the same city but in different periods of their development. Thus, investigating the agglomeration forms of settlement development, I. Fomin discovered the tendency of cyclic transitions from centralized to decentralized form of urban development and urban agglomerations as the functions and structure of the regions form become more complicated (Fig.4, *b*) [14]. Thus, the stage of population concentration in the city and the centralized form of urban agglomeration development (Fig.4, *b*.1) correspond to the mathematical definition of the "stable unit" (Fig.4, *a*.1), while the stage of population deconcentration and the decentralized form (Fig.4, *b*.2) correspond to the definition of the "unstable unit" (Fig.4, *a*.2).

According to I. Fomin, the development forms are of cyclical nature due to the fact that development of "forms reaches the specified critical boundary in a certain way" [14, p.54-55]. According to our research, this boundary is the demographic capacity of the territory at a certain level of EUPS integrity. Transition to a new cycle of the city development, the urban agglomeration, determines the possibility of their growth "at larger scale and at higher level of structural complexity" of the urban-planning site [14, p.55]. This causes transition of the urban-planning activity from local to regional, national and world level [14 − 19].

At small time intervals (seasons, days of week) the cyclic nature of the city and urban agglomeration development is demonstrated through its "pulsating functioning" (Fig.4, *c*.1) [20]. Based on the research of A. Makhrova and A. Treyvish, we found that the centripetal pulsating change in the density of Moscow city agglomeration population on a winter weekday (see Fig.4, *c*.1) corresponds to the mathematical definition of a "stable unit" (see Fig.4, *a*.1), while the centrifugal pulsating change in the population density on a summer day-off (Fig.4, *c*.2) corresponds to the define-



a



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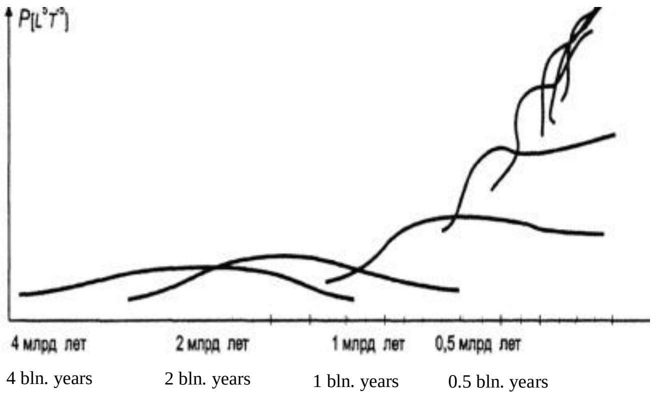

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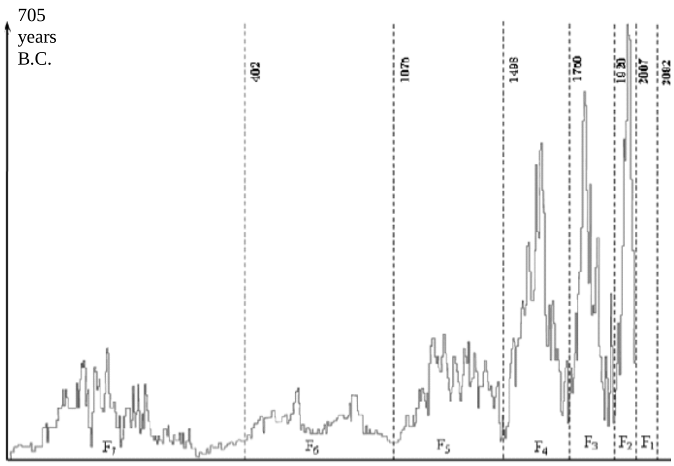
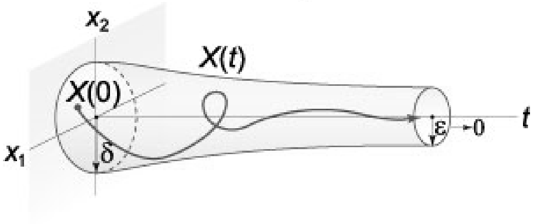


d

Fig.2. Stability by A. Lyapunov (*a*), wave dynamics of urban-planning systems development by V. Timokhin (*b*), waves of biological life forms development on Earth by O. Kuznetsov (*c*), civilization waves of human development by M. Zgurovskiy (*d*)



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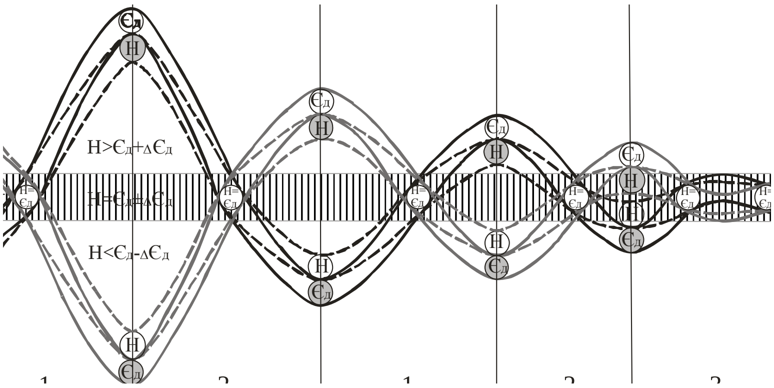

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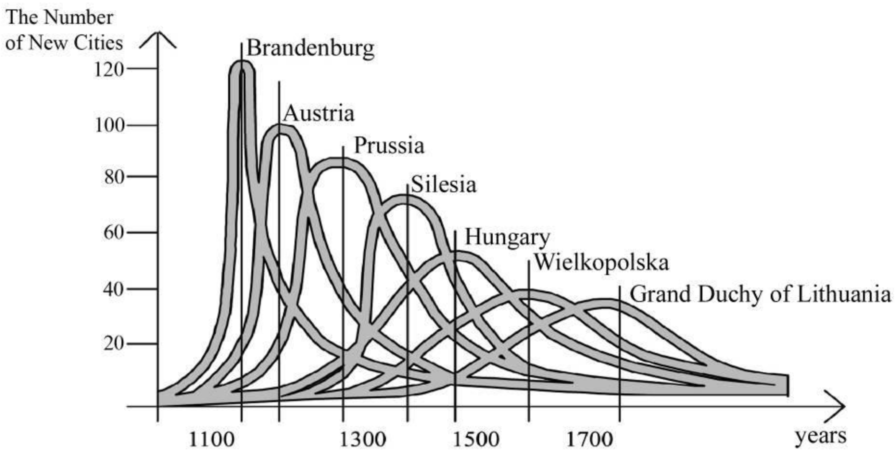

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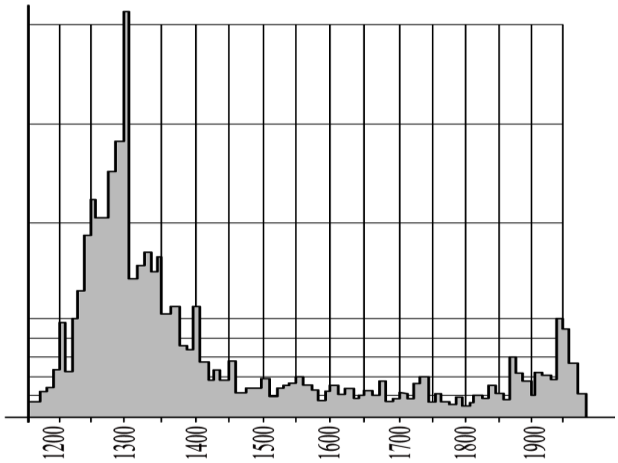
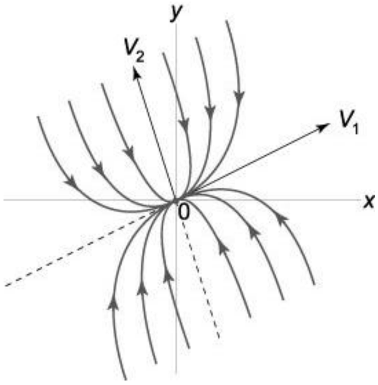
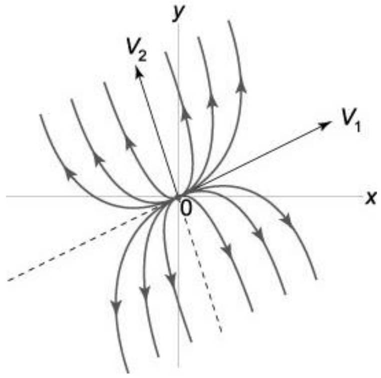


d

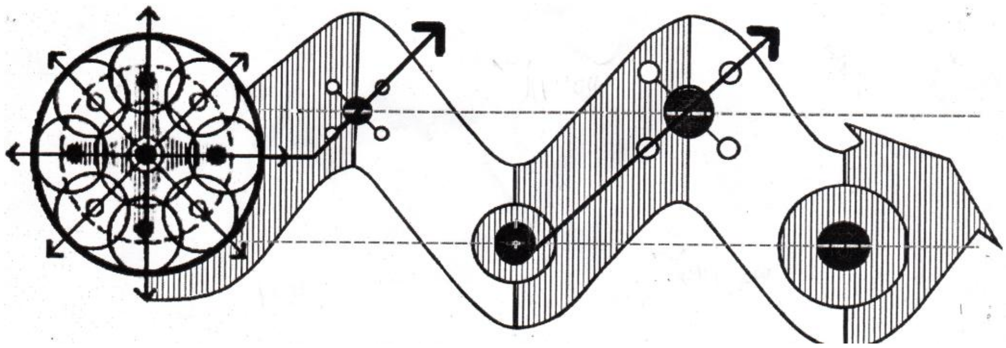
Fig.3. Asymptotic stability (*a*), joint changes of EUPR key parameters per development cycles (*b*), urbanization impulse fading in Western Europe by H. Petryshyn (*c*), urban-planning intensity decay in the central Germany lands by H. Petryshyn (*d*)



a.1 − Stable unit

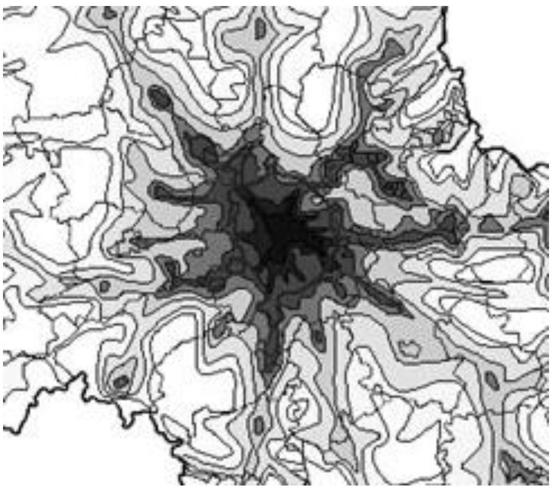


a.2 − Unstable unit

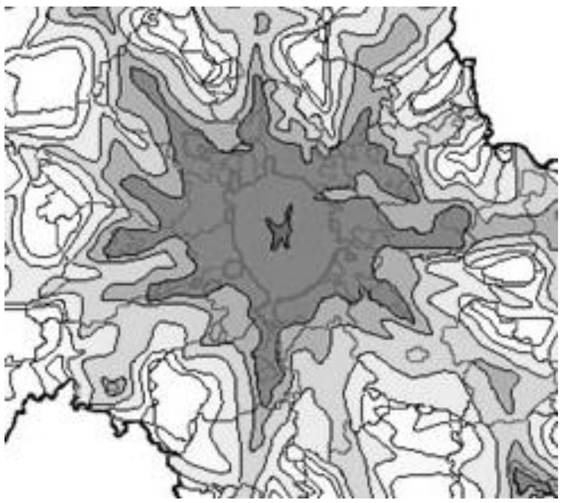


b.1 – Concentration

b.2 – Deconcentration



c.1 − Winter weekday



c.2 − Summer day-off

c − Changes in density of Moscow city agglomeration population

Fig.4. Types of "spatial units" in the physico-mathematical (*a*) and urban-planning theory of stability: the cyclical nature of the forms of the city and the urban agglomeration development by I. Fomin (*b*), pulsating functioning of Moscow urban agglomeration by A. Makhrova, A. Treyvish (*c*)

tion of an "unstable unit" (see Fig.4, *a*.2).

As to analogy with the "stable and unstable focus", in the mathematical theory the focus in which the centripetal helical rotation goes clockwise is stable (Fig.5, *a*.1), while the focus in which the centrifugal helical rotation goes clockwise (Fig.5, *a*.2) is unstable, respectively. Certain analogies in urban development can be traced in the materials of the study by N. Shebek [21].

When considering direction of clockwise centripetal and centrifugal helical rotation of the urban-planning structure, it can be noted that, as in the case with the units, such spatial focuses are both different cities (Fig.5, *b*, *c*) and the same city (Fig.5, *d*). So, as to clockwise centripetal helical rotation of the urban-planning structure in the regional space (Fig.5, *b*) – in mathematical theory corresponding to the stable focus (Fig.5, *a*.1) – the plans of the cities of Kharkov and Lviv differ (Fig.5, *b*.1, *b*.2). As to clockwise centrifugal helical rotation (Fig.5, *c*) – in the mathematical theory corresponding to the unstable focus (Fig.5, *a*.2) – the plans of the cities of Zhitomir and Chernigov differ (Fig.5, *c*.1, *c*.2).

According to these parameters, development of the planning structure of Kyiv, in which the clockwise direction is followed by both centripetal and centrifugal helical rotation of its planning structure, is unique (Fig.5, *d*) [1, 21].

As for the analogy with the "stable center" (Fig. 6.a), the spatial development of the city also causes growth of the areas of influence. This was considered at the examples of spatial development of Kyiv and its urban agglomeration [1, 15, 16]. Consistent increase of the concentric areas of Kyiv influence reveals transition of its sustainable development processes to higher territorial levels of ecosystem integrity: from local to regional, national and continental spatial levels (Fig.6, *b*, *c*, *d*).

RESULTS AND EXPLANATIONS

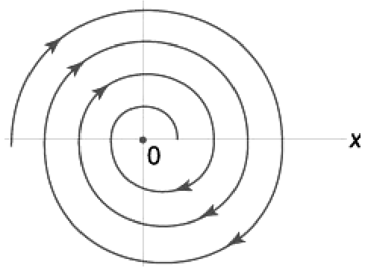
The obtained result can indicate that the cyclical form of the cities and the urban agglomerations development, both in orientation, centripetal or centrifugal (stable, unstable units), and in helical rotation direction, counterclockwise or clockwise (stable, unstable focus), in a short period of time (seasons, days of week) is also a processes pulsation in course development in ecological space.

It is most likely the pulsation of spatial development that contributes to accumulation of its internal forces (development reserves) in the city (urban agglomeration). The purpose of such accumulation is to make a qualitative leap to a new level of EUPS integrity, i.e. "to border and pass through the existing form" for the new spatial resources mastering, or to return to the urban area reconstruction through "kicking off from this border" and "fitting into the form", when its development reaches "a certain critical point".

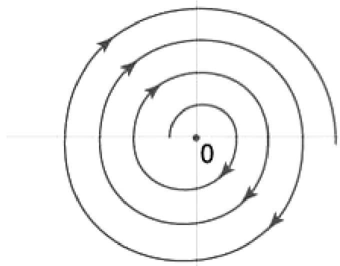
It should be noted that the phases of urban (urban agglomeration) development processes "exiting" its planning boundaries or "kicking off" from these boundaries and "fitting" into the form determine the cyclical nature of the urban-planning efforts of adaptive-regulatory influences for sustainable development of EUPS. Therefore, when the city "exits" its planning boundaries, mastering of external territories prevails; and when it "fits" the form, the activities for re-mastering and additional densification of urban areas, reconstruction of buildings prevail.

CONCLUSIONS

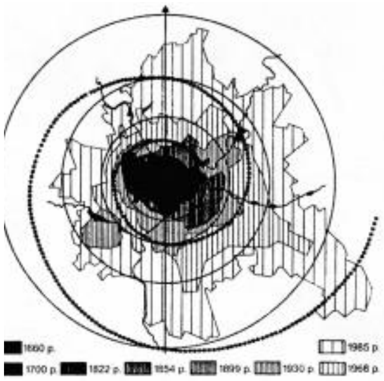
1. Fundamental differences in stability states and conditions of animated and inanimate systems (as to equilibrium: for the first ones it is the purpose of development within a certain cycle and spatial level of integrity, while for the second ones it is the initial state; as to "gravity center" position: for the first ones it should take the highest possible position, i.e. to be in the range of ecological equilibrium, and for the second ones it should take the lowest possible position) prevent "analogous" application of the "stability" term to the issues of ecological and urban-planning systems development.



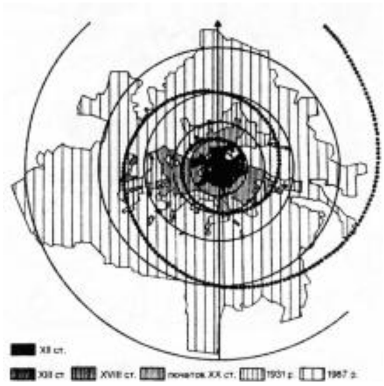
a.1 – Stable focus



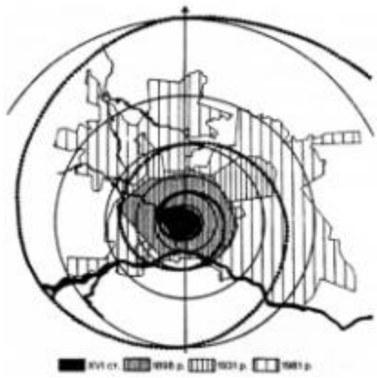
a.2 – Unstable focus



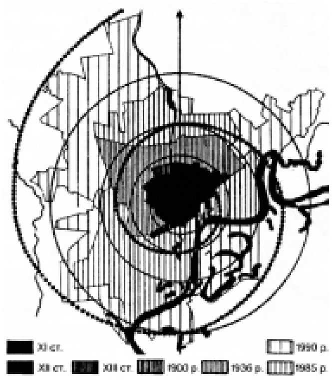
b.1 – Kharkiv



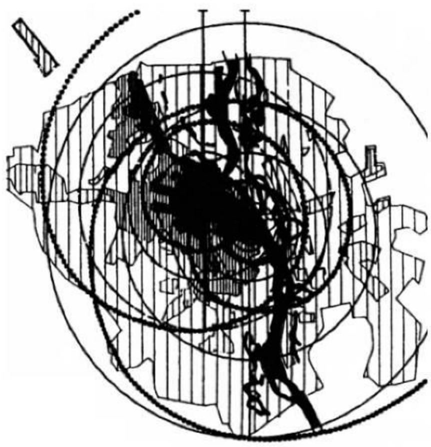
b.2 – Lviv



c.1 – Zhytomyr

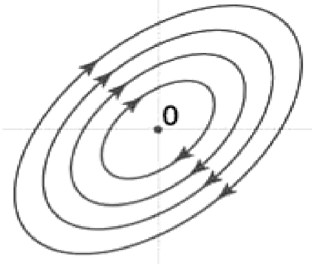


c.2 – Chernihiv



Kyiv

Fig.5. Types of "spatial focuses" in the physico-mathematical (*a*) and urban-planning theory of stability: the spatial-helical development of cities by N. Shebek (*b, c, d*)



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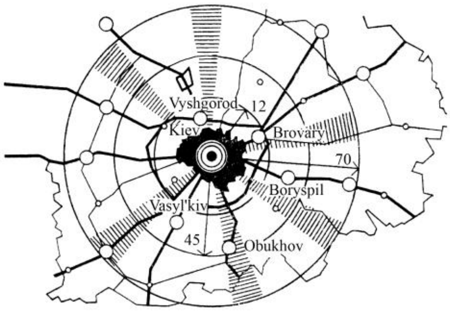
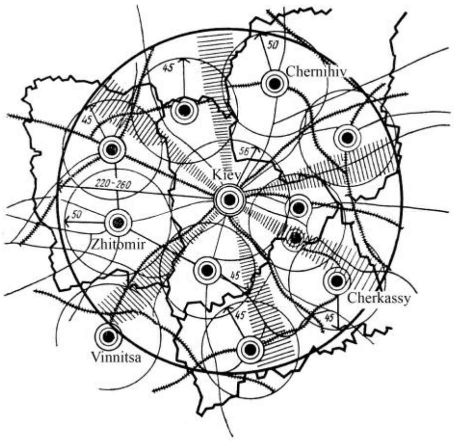
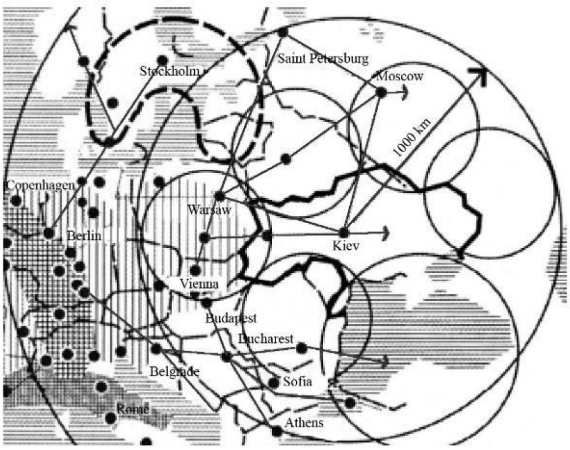


b − Kyiv areas of influence in Kyiv urban agglomeration



c − Kyiv areas of influence in Kyiv metropolitan area



d − Ukraine areas of influence in Europe

Fig.6. Stable center in physico-mathematical (*a*) and urban-planning theory of stability: Kyiv areas of influence by M. Diomin (*b*, *c*), Yu. Bilokon (*d*)

It has been established that sustainable development of EUPS is a wave process that accelerates in a multi-level ecological space. In the context of urban-planning regulation, the concept of "sustainable development" is proposed to be used to establish the degree of EUPS wavelike development processes convergence within certain spatial limits to the state of stability desired and possible under the given time conditions.

2. Based on the basic notions of the physico-mathematical theory of stability being more developed in our time, particularly on definitions of stability given by Lyapunov and of asymptotic sustainability, the "urban-planning theory of stability" allows formalizing the range of ecological equilibrium, the sustainability parameters and the values of urban-planning regulation influences for different phases within the cycles of ecologic-urban planning systems development.

3. Identification of such "stability points" as "stable and unstable unit", "stable and unstable focus" and "stable center" in the multi-level ecological space is the important tool for quantitative assessment of the current state, forecasting of further development direction, determination of focuses and parameters of urban-planning influences application, and also adapted management of EUPS sustainable development.

4. Further development of the urban-planning theory of stability makes necessary the improvement of the conceptual apparatus and the methodology for analyzing the states of stability, the synthesis of its parameters and their characteristics in the following directions: expansion of the range of empirical studies of self-regulation processes and self-organization of the cities, regions and countries development; broadening and deepening of researches differentiated according to the levels of EUPS integrity, the processes of stage-cyclical urban development in the ecological space; increasing the role of identifying the foundations of researching evolution of the system "Population ↔ Environment" as a noosphere phenomenon.

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Градостроительные аспекты теории устойчивости эколого-градостроительных систем

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Аннотация. Исследованием проблем устойчивого развития эколого-градостроительной системы «население ↔ среда» различного уровня ее функционально-пространственной целостности (локальный, региональный, национальный, мировой) выявлен ряд принципиальных положений, устанавливающих концептуальные основы потенциально существующего в отдельных работах нового направления в градостроительной науке.

Разработка градостроительных аспектов теории устойчивости базируется на основных понятиях более развитой в настоящее время физико-математической теории устойчивости и результатах исследования, которым установлена цикличность многоуровневых процессов волнового развития системы «население ↔ среда». Градостроительная теория устойчивости изучает естественный характер колебательного развития урбанизационных процессов, ускоряющихся в многоуровневом экологическом пространстве.

В работе выявлен ряд подобий и фундаментальных различий в состояниях устойчивости и динамике изменений, которые присущи развитию живых и неживых природных систем. Относительно различий в состояниях равновесия: для живых систем равновесие является целью развития в рамках определенного цикла и уровня их пространственной целостности; для неживых систем – исходным состоянием. Относительно различий в устойчивости размещения «центра масс»: для живых систем «центр массы» должен занять наивысше из возможных положений (находиться в диапазоне экологического равновесия); для неживых –занять наиболее низкое из возможных положений.

При разработке градостроительных аспектов теории устойчивости использованы такие понятия физико-математической теории устойчивости как: асимптотическая устойчивость; устойчивость «во времени» по Ляпунову; устойчивость «в пространстве» («устойчивый – неустойчивый узел», «устойчивый – неустойчивый фокус», «устойчивый центр»). Выделенные понятия важны для анализа многоуровневых процессов ускоряющегося развития эколого-градостроительной системы; прогнозирования направленности ее дальнейших изменений; определения фокусов и параметров приложения градостроительных регулирующих воздействий; адаптированного управления устойчивым развитием.

Ключевые слова: урбанизационные процессы, эколого-градостроительные системы, урбо-экофизические параллели, устойчивое развитие, устойчивость в пространстве, устойчивость во времени.