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METHOD OF CLUSTER ANALYSIS IN THE INVESTIGATION OF THE CITY AS AN OPEN DYNAMIC SYSTEM

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ABSTRACT

The trend of the development of modern architecture is the idea of the city as a single dynamic system, all elements of which are connected through the processes of their life activity. A lot of challenges facing our civilization have caused the urgent need to optimize the functioning of the urban environment. Such an approach significantly influences the methods of work of the architect. Today, it has become necessary not only to design an innovative architecture, but also to imagine the consequences of its integration into the urban environment. It requires a new set of tools that allows you to analyze both the current state of the city's system and its elements in terms of sustainability and crisis, and to forecast their future possible states.

Key words: architecture, urban environment, cluster, system, development, functioning, dynamics.

1. DEFINITION OF THE PROBLEM

Prior to the onset of the postindustrial stage of the development of civilization, cities were deterministic, i.e. the forecast of their behavior could be given for a sufficiently long period of time. In the last thirty years, the cities have begun to change markedly. Formally, they remain deterministic. Knowing exactly their current state, one can assume the parameters of their functioning in the future. At the same time, it is becoming increasingly difficult to predict their development in the context of the struggle against impending crises. An arbitrarily small intervention in the work of the initial state of the city's system grows with time, and at some point we lose the opportunity to predict anything. Here it would be appropriate to recall the famous "butterfly effect".

The "butterfly effect" is a term in the natural sciences, which denotes a property of some chaotic systems. A minor impact on the system can have large and unpredictable effects somewhere else and at some other time. The term "butterfly effect" arose in 1972 thanks to the American meteorologist Edward Lorenz, who gave a lecture on the topic: "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" To track the weather, Lorenz used a computer model in which he rounded off by several orders of magnitude a long series of figures, believing that nothing would happen. However, he found that this completely changed the weather forecast in the world.

The discovery of Lorenz disproved the notion that all processes in the world are subject to strict laws, and the causes clearly correspond to the consequences. The flap of the butterfly's wings symbolizes tiny variations in the initial state of the system, which cause a chain of events leading to large-scale changes [2].

Some of the changes taking place in modern cities resemble "The butterfly effect". However, here it is appropriate to quote from the book "Survivor", a novel by Chuck Palahniuk: "What we call chaos is just patterns we haven't recognized. What we call random is just patterns we can't decipher. What we can't understand we call nonsense. What we can't read we call gibberish". All unexpected things happening to a city are the consequences of the patterns the meaning of which we have not understood. But when the external factors interfere in the city system and make it change rapidly, the feeling of chaos is growing.

Today, every decade, the laws regulating the rules for designing, operating and utilizing buildings are amended. The new requirements are reflected in almost all aspects of the city's livelihoods - the financial status of its inhabitants, the production, import and export of equipment, the budgets of urban and rural communities, etc. The growth in the number of critical systemic and conceptual design errors over the last 30 years points to the urgent need for architects to take into account not only the legal framework, but also the response of the city and district system to the changes introduced to their environment. Here we have a case with other requirements to the justification approach in the design of both individual objects and the urban environment as a whole.

The formed ideas about what an innovative architecture is, makes us abandon the last century concepts of a type: "a house is a machine for accommodation" [1]. It is rather an architecture integrated into the natural environment on the basis of an equitable non-destructive exchange with the remaining matter and energy. And the main problem of building a new relationship between the artificial and natural human habitats is that it is almost impossible to predict at what level this process will stop. Only one thing is known, that in terms of its technical content and aesthetic requirements, in thirty years architecture can differ significantly from what we see today.

It becomes obvious that changes in requirements for the designed facilities will occur earlier than the end of their operation. Therefore, here the problem of forecasting changes in such requirements comes to the forefront and the possibility of adaptations of the city to them is taken into account. In this context, the issue raises the question of cre-

ating an imitation model that allows adequate assessing the state of the urban life and predicts its response to the introduced changes.

The "city" system must be viewed from the point of view of two modes of existence: functioning and development.

Functioning is preservation of vital activity, maintenance of functions that determine its unity and content characteristics.

Development is acquisition of a new quality of life of a system under the influence of changing environmental factors. Development and functioning show the dialectical unity of the main components of the system. Development brings on changes in the system, which ensures the emergence of a new quality that increases stability, destroys many processes of functioning, but at the same time creates the conditions for the emergence of new ones. Functioning limits development, but at the same time it nourishes it.

Thus, on the basis of the available ideas, the goal of the proposed study is formulated: the development of methodological bases for the analysis and assessment of the processes of functioning and development of the city as an efficiently functioning ecologically positive system in the dynamics of changes in external and internal factors.

Theoretically, the processes occurring in the city can be modeled and it is even establish a direct and reverse response of the created digital model of the city. Here the main problem is the correct choice of methods for modeling and exploring the city as an open dynamic system. From an architectural point of view, this is an extremely interesting task. The knowledge accumulated by the architects is sufficient to solve many such non-trivial tasks.

The city is a controversial form of the territorial organization of society. Contradictions are inherent in it initially and are contained in its very essence. They can be weakened by well-thought-out regulation, or they can be amplified by errors and miscalculations of supervision individuals and designers. But the root of problems and contradictions is only partly caused by the actions of people. The city itself generates its contradictions and problems.

The successful functioning and development of the city as a system is the result of optimally compiled compromises between its elements, often in antagonistic relations: residential areas that should be compacted and recreation zones; industry and ecology; employment of residents and robotization of manufacture; comfort and ideology of ethical consumption; private transport and air pollution due to exhaust gases of cars, etc.

In the current apparent and hidden relationships among almost all aspects of the life of the city, most local solutions for adjusting any one crisis can have unforeseen consequences. A good analogy is the situation when you catch a cold – if you have your feet wet, you will have a sore throat. It is extremely difficult to foresee, without a complex of verified views about the city as a single system - how it will react to operational intervention. At the same time, delaying the resolution of the conflict among the elements of the system with a certain degree of probability can transfer the crisis into a catastrophe. For the city, a catastrophe is the loss of its residents.

The first and most significant question of constructing the information model of the city is the problem of creating a hierarchical tree of its elements, what is more, all of these elements must be interrelated. In fact, in the model being created, it is necessary to combine a classification system similar to the Carl Linnaeus classification system, tabular parameterization methods, cluster analysis methods and to add the possibility of introducing into the model methods for calculating the impact on it of ideal components (laws, traditions and customs, difference in ideology of the population, etc.). At first glance, the task seems unsolvable, but it should be noted that science including architecture have moved rather far in this direction and there are a number of techniques that allow some generalizations.

The first stage of the study was the definition of the idea of the city as a result of interaction among:

- its inhabitants (society/socium) which have a certain set of needs that must be met;
- technosphere – artifacts, knowledge and skills designed to meet the needs of the society;
- ecosphere - the environment that provides resources and waste processing that arise in the process of satisfying the needs of the society.

In turn, the Ecosphere, the Technosphere and the Socium are themselves complex systems that have their own ramified hierarchical trees. Being the basic constituent subsystems of the city system, due to effects of essential differences of vital needs, they are in the conditions of a conflict of interests among themselves. Under such conditions, it is impossible to satisfy all the requirements that are put forward by the elements of the system, without prejudice to adjacent elements.

At the second stage of the research it was decided to consider the city as a set of its constituent elements, interconnected by the processes that occur in them.

The city is an ecological, engineering, social and economic system including many other systems of unprecedented complexity. These systems are subject to natural and economic patterns, they are exposed to a variety of heterogeneous random factors and are at risk of losing the equilibrium state. The study of processes occurring in the city is a multilevel and ambiguous task in its solution, since these processes occur in complex dynamic systems.

Traditional methods of forecasting and modeling applied at the macro level and in territorial management are not effective for an adequate description of complex systems, such as the city in modern non-stationary conditions, with a large number of interactions and influence factors characterized by environmental variability and structural rearrangements. They do not work properly with constantly changing information/data.

Thus, the city is proposed to consider as a set of ordered objects classified by certain attributes. The formation of this issue caused the need of addressing to the methods of cluster analysis.

2. APPLICATION OF METHODS OF CLUSTER ANALYSIS IN THE STUDY OF THE CITY AS AN OPEN DYNAMIC SYSTEM

Cluster analysis is a method of classification analysis; its main purpose is the classifying of the set of objects and attributes under investigation into groups that are homogeneous in a certain sense, or clusters. This is a multidimensional statistical method, therefore it is assumed that the initial data can be of considerable volume, i.e. both the quantity of objects of research (observations) and the parameters characterizing these objects can be an essentially large number [3].

A great advantage of cluster analysis is that it makes it possible to produce a partitioning of objects not according to one feature, but according to a number of features. In addition, cluster analysis, in contrast to most mathematical and statistical methods, does not impose any restrictions on the type of objects under consideration and allows us to study a lot of initial data of almost arbitrary nature [5].

In our case, clustering of objects located on some specific territory under analysis is assumed. Details of the clustering depend on the level of tasks assigned to an architect. Potentially, even the smallest objects, such as flower vases and bicycle parking lots, can be included in the analysis.

Each, even the smallest, object of the urban environment has its own unique set of statistics. With a digitized package of statistical data we have an opportunity to automatically

build a dynamic model which shows the development of the processes occurring with the considered object over time. Even static objects that do not have a complex structure are inevitably connected with other objects of the analyzed territory through their life processes (for example, a park bench can be an element of landscape design, a part of enhancing the comfort of the urban environment and an object that increases employment). This thesis forces us to include not only architecture as a part of the technosphere, but also all objects related to society and the ecosphere in the objects of clustering.

The hierarchical tree of architecture in the first stage of the study is as follows: object / building / block / district / city. As a rule, the lower level, being an independent cluster, becomes a part of the higher-order cluster. All clusters are interrelated by urban infrastructure, social life cycles and life cycles of the environment in which the city system is integrated. Having the described dynamic model of each individual cluster, it is possible to create a complex dynamic model of the analyzed territory through the methods of system dynamics.

System dynamics methods are used in the research as an environment for studying complex systems that are subject to changes over time, as well as systems in transient processes, under conditions of structural adjustment, uncertainty and dynamism of changes in the external environment. These methods allow us to take into account the fundamental interrelations between the system elements (clusters) and fluctuations in the dynamics of its development, and also to determine the way life processes of each cluster influence the dynamics of development of other system elements.

Thus, when operating with statistical data sets and a time indicator, and having correctly estimated data on the overall dynamics of the city system development, it becomes possible to assess the current state of the city system together with its elements, and also predict those problems that may appear in future.

The approach to clustering the urban environment in terms of typology of buildings and structures appears to be logical for architectural problems. In fact, the typology is a kind of hierarchical tree whose structure itself defines the direction and area of clustering the objects. Thus, we obtained the lower hierarchical level of clustering - the object typological cluster (Fig. 1).

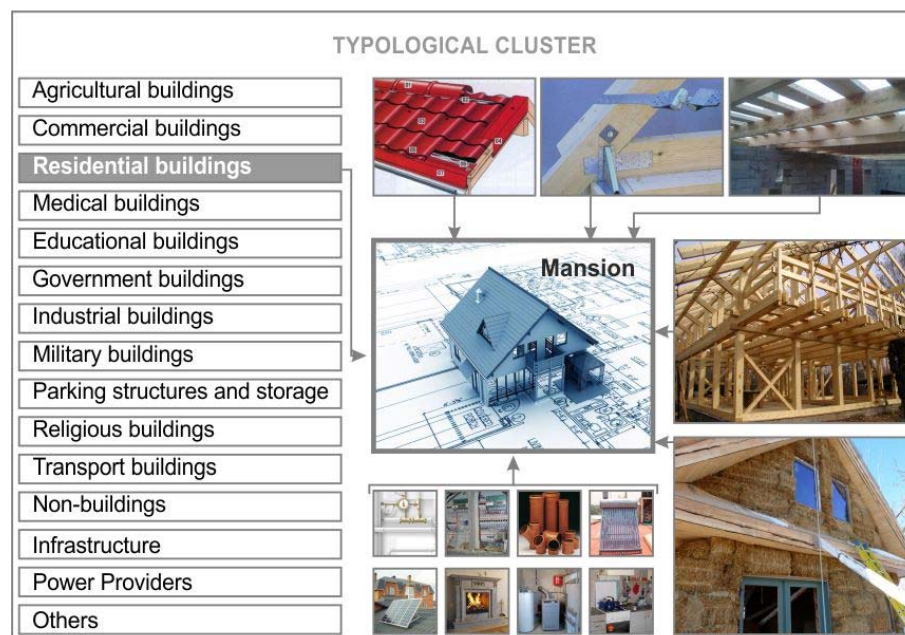


Fig. 1. Example of an object typological cluster

At this lower level, each object of the urban environment is treated as a separate cluster and described with maximum accessible fullness of information about it. Since there are certain dynamic processes associated with any existing object, the description of the cluster is divided into three main groups of features, which correspond to the above-mentioned city subsystems: the ecosphere, the technosphere and the society. Thus, each object can be evaluated from the standpoint of its environmental impact and it can be described as a physical object and its social component and significance can be determined.

At this stage of the research the following information structure of the object typological cluster has been developed (Fig. 2.):

a1 - This cell contains the object identifier. Identification is made by its name, type and address. If it is necessary, clustering of objects in the urban environment can be so elaborate that orderly bins can be identified. In this case their GPS coordinates will be used instead of the address. In this example, a typical five-story building is considered. Since the purpose of the study is not to analyze this structure or a similar one, the example demonstrates a certain degree of abstraction.

a2 - the Ecosphere. Each of the subsystems (the Ecosphere, the Technosphere, the So-cium) is divided into a material and an information level.

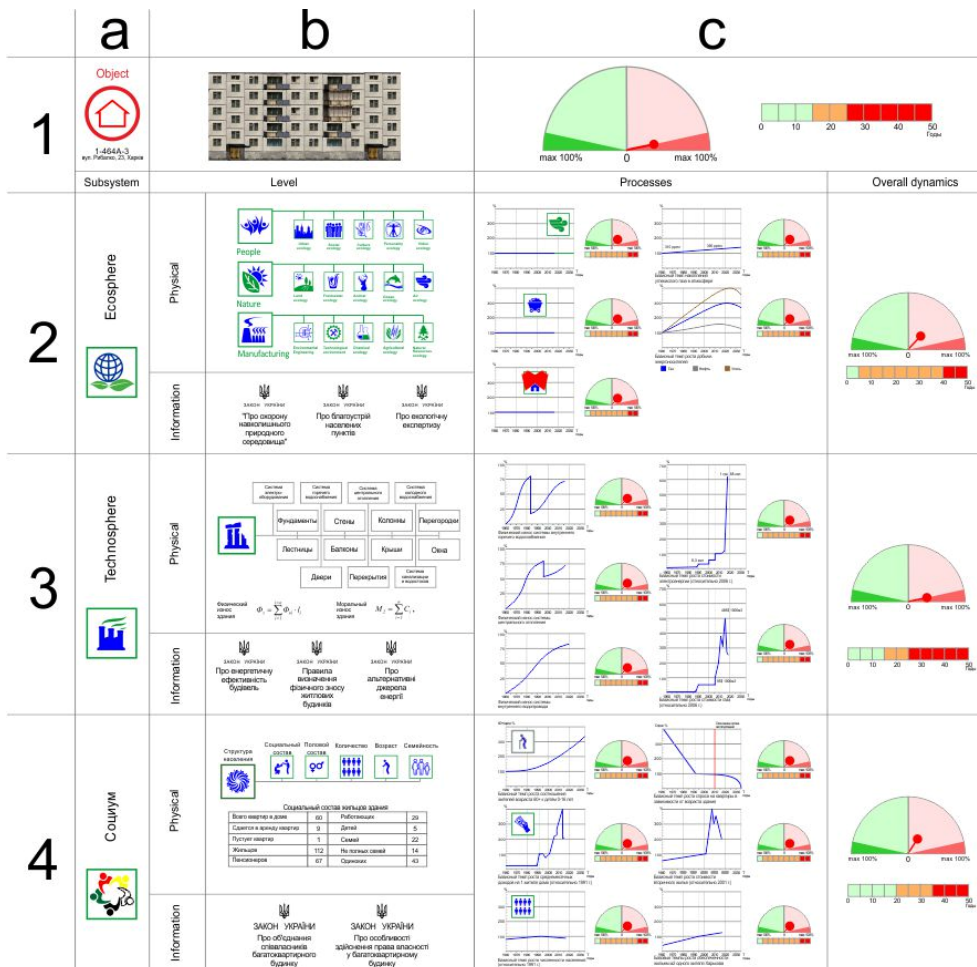


Fig. 2. Information structure of the object typological cluster

At the material level, the ecological state of the object is described in the Ecosphere subsystem: quality of water, air, building materials, presence of pests, the bacterial state, production of wastes by occupants and so on. Each indicator revealed in the described building has a certain statistic history. Since the created model is interactive and each of its elements is described digitally, every element of the cluster can have its own pop-up menu with the necessary information attached to it. Taking into account the successful experience of using icons in iOS and Android, it was decided that it would be viable to group some information blocks in this way (Fig. 3.).

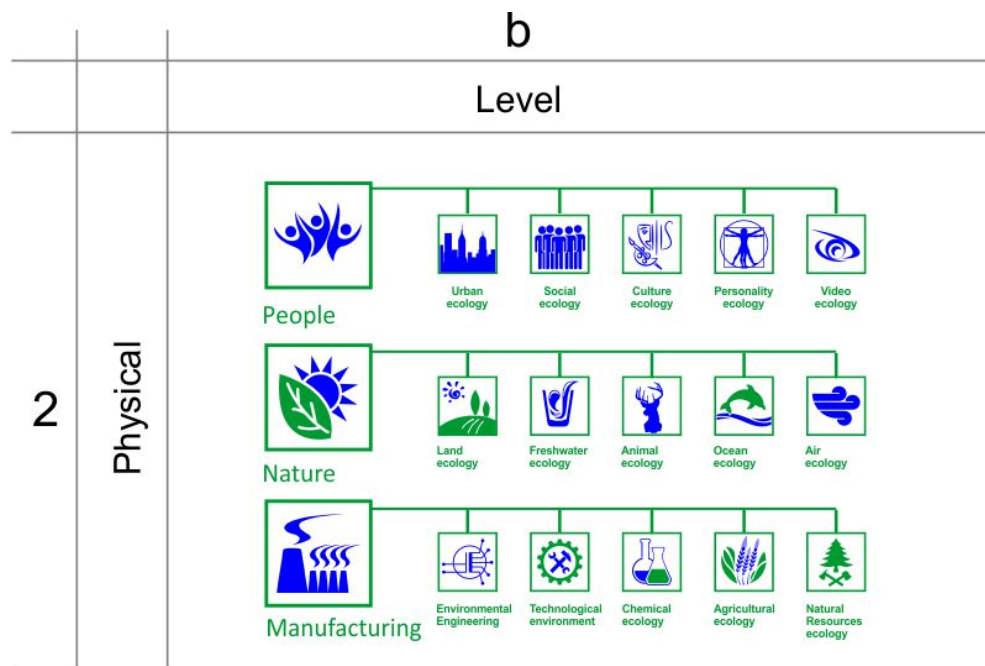


Fig. 3. Representation of information blocks in the form of pictograms. The Ecosphere subsystem

At the information level, the possible influence of the ideal component of the Ecosphere subsystem is evaluated. Such components may include: laws, regulations, ideology, religious and ideological imperatives of the population, etc. Naturally, it is almost impossible to make an adequate assessment of some ideal components but the legal requirements for the object and their impact on the it and on the system as a whole can be estimated.

Being a field of knowledge related not only to architecture but also to a number of other paradigms, presentation of the cluster data in the Ecosphere subsystem requires coordinated multidisciplinary research. Therefore, as an example of the information level elements of the ecosphere, only three laws of Ukraine are chosen: «About Natural Environment Protection», «About community redevelopment» and «About ecological expertise». In the following (on the example of the Technosphere), we will consider the variants how the information level affects the material one and the system as a whole.

2c - Evaluation of dynamics of processes associated with functioning of the object. To compare data packets that are different in their structure and nature, the method of analyzing them according to the basic rate of increase was chosen.

Rate of increase, relative statistical and plan indicators that characterize the intensity of the dynamics of the phenomenon is calculated by dividing the absolute level of the phenomenon in the accounting or prospected period by its absolute level in the reference

period (in the period with which it is compared). [4]. With the graph of the growth rate of a phenomenon, we have the opportunity to assess its state (growth, degradation, stagnation).

By extrapolating the obtained data, one can predict the development of the problem through to the forecast horizon. Thus, it is possible to assess the prospects for development of the system from the standpoint of sustainability, crisis or a possible pre-catastrophic state. This problem will be considered in the following, using the case of changing the law "On energy efficiency of buildings" and its impact on the Technosphere subsystem and the entire cluster as an example.

In fact, each cluster can be considered as a kind of passport of the object where all the information available to analysis is recorded. Naturally, even at the level of an apartment building, the flow of information can create such dense information chaos that any sense will be lost. Therefore, currently an intuitive interface for direct and feedback dialogue with digital arrays of data is being developed. Here we face with necessity to use methods for mass-data processing - "Big Data". As a prototype of visual representation of the obtained results, a car speedometer with a pointer was selected (Fig. 4.).

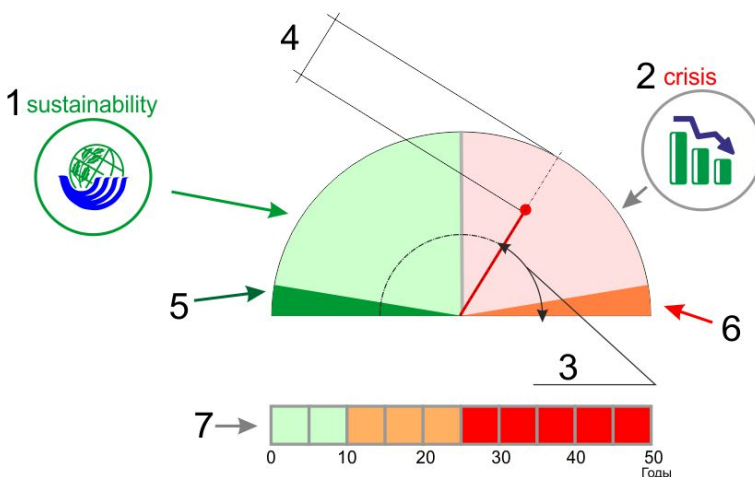


Fig. 4. State display of item / object / system

The state display of element/ object/ system is made in the form of a semicircle divided vertically into two equal halves. The left half is light green indicating that the system is in a stable state (1, Fig. 4). The right half - light red – shows that the system is in crisis (2, Fig. 4). The indicator has a moving pointer whose angle of inclination indicates a stable or crisis state of the system (3, Fig. 4). The distance from the tip of the pointer to the outer edge of the semicircle indicator indicates the significance of the event (4, Fig. 4).

The significance of the event. Taking into account that each cluster is a data packet interacting in a model with other packets, it was necessary to determine how strong its influence on the environment is. For this purpose, a coefficient of significance was developed. It represents the ratio of significance of the dynamics of the object's element to the total dynamics of the object itself and the ratio of the obtained result to the dynamics of the system they belong to. It is possible to demonstrate that this ratio is necessary using the example of comparison of two events: the first one - at night hooligans smeared all the door handles of the house with honey and the second - the house sank during the Great Flood. In both cases the event affected all tenants of the house. Without the ratio indicating how significant the process that takes place for the object and for the system is, these events may appear equivalent.

In the lower zones of the indicator there are segments with brighter colors: the green segment suggests stagnation of the system (5, Fig. 4), red - pre-catastrophic state (6, Fig. 4). Under the indicator is a scale graduated by years making forecast of the state of the system for a certain period under condition that existing trends persist (7, Fig. 4).

Thus, the dynamics of the cluster can be considered as a set of dynamic processes of functioning of all its elements, which are displayed in column "C" of the cluster (Fig. 2).

3a and 3b – the Technosphere. In fact, all the information concerning the considered subsystem can be reduced to the Building Information Model (BIM) data packet. The only addition to it is evaluation of the dynamic changes of all structural elements and their state. It should be borne in mind that when analyzing the entire cluster as a whole, the Technosphere subsystem sets the time limits of the study - from commissioning of the facility to the end of its operation and recycling. In column 3c, the dynamics of age-related changes in the structure of the building, the impact of its refurbishment and capital repairs on these processes, energy efficiency, the payback period from various measures for improving its performance properties, etc. are evaluated.

As for the information aspect of the regulation of functioning of buildings and structures, it is extremely interesting to consider changes in the law "On the Energy Efficiency of Buildings", which provides new energy saving requirements and measures to achieve the desired effect. In this law there are also requirements for thermal upgrading of existing buildings.

According to paragraph 2 of Article 12 of the Law: Energy efficiency of buildings can be provided by:

- 1) increase of thermo-technical indices of enclosing buildings` structures;
- 2) installation of metering devices (including means of differential (hourly) recording of electric energy consumption) and regulation of energy resources consumption;
- 3) introduction of automated systems for monitoring and managing the engineering systems;
- 4) increasing the energy efficiency of the building's engineering systems;
- 5) use of renewable and/or alternative sources of energy and / or fuels (using building engineering systems)
- 6) application of accumulative electric heating systems during hours of minimal load in power network;
- 7) implementation of other measures to ensure (improve) the energy efficiency of buildings.

Thus, the dynamics of energy efficiency of the building should look like this (Fig. 5.).

All the measures mentioned in the law will inevitably affect the ecological and social subsystems of the cluster. This thesis will be decoded in the second part of the article.

3. CONCLUSIONS

Today there are technical and scientific prerequisites for developing an innovation model for taking adequate decisions on adaptation of the urban system to the rapid torrent of external changes. For this, the author develops a methodological apparatus that combines multi-level data into a single, intuitive, interactive model of functioning of the city as an open dynamic system.

This model is an attempt to combine precision of mathematical calculations with philosophical and epistemological instruments of understanding the reality, of psychological sociological methods, data of cultural research, and so on. At the same time, by combining a multitude of paradigms that reflect the diversity of urban life, it is necessary to obtain a

clearly assessed and comprehensible model that allows identifying those measures that can bring on positive changes in the entire urban system without losing positive qualities accumulated by it.

This is a somewhat utilitarian approach to society. Even such a concept as person's psycho-physiological need for beauty and harmony is considered in the context of territory branding as a part of enhancing visual comfort and getting higher competitive advantages over other areas through it. Comfort, beauty, security, and quality of life can significantly improve the human potential of the territory, and hence, survival of the city.

One of the main objectives of the research was development of algorithms for the interactive model that makes possible real-time assessment and prediction of urban functioning as an open dynamic system. In the condition where architecture is obliged to integrate into the environment, absence of such or a similar model turns the architect's work into a number of empirical attempts to "blindly" guess an acceptable scenario of developing the innovative architecture and urbanistics, for which we have neither time nor resources.

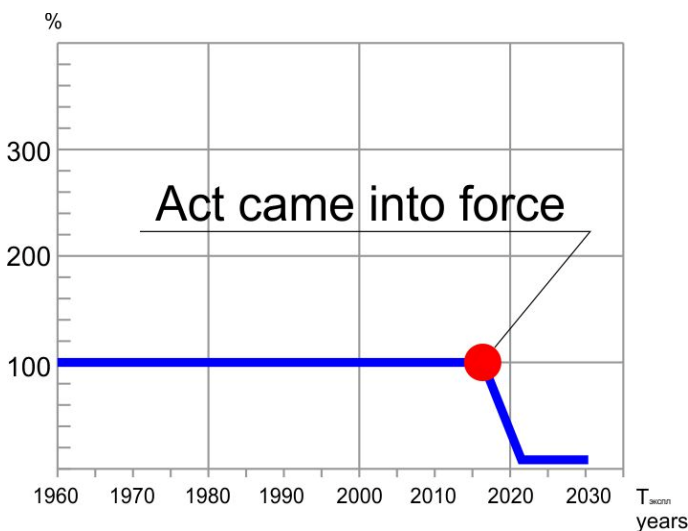


Fig. 5. The basic growth rate of energy costs of a building in accordance with the law «On Energy Efficiency of Buildings» adopted in 2017

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AUTHOR'S NOTE

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