UDC 620.9:711.1.504

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"Green Square", innovation and sustainability of energy infrastructure of the modern urban ecosystem

The purpose of the research of the presented scientific and practical paper is to identify, systematize and analyze the basic principles of modern sustainable construction, study innovative and technical solutions in the field of ecology and management of urban real estate creation projects, infrastructure projects that ensure the functioning of cities. The author of the paper solves the problems of actualization of modern ecosystem problems faced by the urban planning industry all over the world. The methods used in the presented paper are the empirical method, methodological apparatus of cross-cutting analysis, as well as the development of classifications according to the principles inherent in the object of study. In addition to the general scientific approach to the study of problems of eco-sustainability of construction. The author provides experimental conclusions about the convenience of applying specific means of achieving the goals of eco-sustainability of projects. The author has also presented his own definition of sustainable construction taking into account the increasing world energy consumption, including those aimed at cooling the air against the background of global climate warming, the increasing consumption of food and water against the background of planetary population growth, the trend towards diversification of waste treatment. The paper identifies key drivers for the active implementation of innovative technologies in the industry.
Keywords: *ecosystem, sustainable construction and innovation, effective innovation and technical solutions*

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INTRODUCTION

In formulating the key problems of the study, the author asks such research questions as the existence of interrelationships: what is common and what is different in the energy efficient approach and "green" construction — the so-called term-trend of the first quarter of the 21st century. Moreover how nuclear power projects, largely characterized by international scepticism, can become the basis for sustainable urban planning. Is only the issue of safety of nuclear power projects a key factor to overcome in order to scale up the implementation of innovative NPP projects already implemented in some countries of the world (Turkey, Bangladesh, Hungary, etc.) that incorporate ecosystem infrastructure solutions, including RES, "smart city", integrated infrastructure development of territories (hereinafter — IIDT)? The bright hypothesis of the presented scientific and practical research is that NPP projects can become the central axis of urban ecosystem, transferring the projection of Reimers' ecosystem approach, where the central role is given to the Sun, to the modern sustainable City, Agglomeration, State and World.

MATERIALS AND METHODS

For completeness of the research the author provides a cross-cutting analysis of the development of innovation theory in science, such scientists as B. Twiss, B. Santo, N. Kondratiev, J. Schumpeter, F. Nixon, S. Kuznets, C. Glazyev, G. Itskovitz, L. Leydesdorf devoted their works to the study of innovation [1–3].

Systematizing various approaches, the author gives his own definition of innovation, which is reduced to the concept of "an innovation introduced to improve the efficiency of production and (or) the quality of goods and services that corresponds to current socio-cultural needs, and a documented innovation is a patent".

It is important to note that according to the theoretical foundations of "innovativeness" (innovation theory), the following should be distinguished as a result of analyzing different types of innovation situations leading to the emergence of innovations (so-called innovation situations):

- development of methods for earlier risk assessment (classification);
- production-related situations;
- marketing mistakes;
- errors related to financial and economic support;
- innovation needs related to the human resources of the organization and management;
- innovations of legal information support for the project;
- political errors due to changes in the political environment;
- environmental, related to the consequences of natural disasters;
- brought in, consisting in the formation of innovation policy by governmental bodies [4, 5].

There are three main innovation models of development, on the basis of which national innovation systems (hereinafter referred to as NIS) of states are built, namely:

- the European model, including all stages of the innovation process;
- the Asian model, excluding fundamental research;
- the triple helix model, providing for the interaction of three institutional sectors — universities, business and government.

The Triplex Helix Model is the basis for cluster development (Silicon Valley, Erisunn region — Danish-Swedish cluster, Medicon Valley in Western Europe, etc.), which combines the collective interaction of enterprises with unique market conditions for the development of certain industries of goods and services. The cluster model based on the triple helix model also finds application in the theoretical foundations of the "green square" model, in which the cooperation of "clusters-energizations" has a complementary, synergetic vector and result rather than a competing one.

In the early 2020s, in addition to geometry and time-cost characteristics of construction projects, 6D- and 7D-modelling technologies have entered the practice of construction process management, in which the 6th dimension presents the study of building sustainability in the aspect of the environment, justifying the relevance of eco-sustainability of construction objects by introducing this facto into the model. The 7th dimension is applied to the life cycle management of building objects and urban environment. Thus, the 6D and 7D models take into account factors such as energy efficiency analyses, lighting coefficients, geographical features of the project, various components and details of buildings.

The application of construction modelling technologies in the design of objects with the use of "green technologies" due to the possibilities of integration and analysis of environmental problems in architectural and construction projects is especially useful.

Construction modelling technologies solve such problems as increasing the degree of eco-sustainability of the construction industry by improving the accuracy of data analysis, allowing to take into account the multifactor nature of design tasks, including the inclusion in the project of the world practice of solving environmental problems, improving the logistics of resources, reducing costs, thereby reducing the negative impact on the environment and the ecosystem as a whole, increasing the degree of consistency between the sections of the project documentation, thereby reducing the number of possible project risks that may have negative consequences for the sustainability of the construction project.

A vivid example of mankind's aspirations to create an environmentally sustainable construction project in the world practice is the adaptation in 1999–2001 of a large energy facility — four gasholders (namely, in the part of gas gauges of gasholders dated 1896–1899) for a multifunctional complex — a modern space for living. The former energy facilities — coke oven gas storage facilities — were mothballed in 1984 due to the transition to natural gas, which does not require storage. Thus, four renowned architects created residential, office and retail infrastructure on the territory of the cylindrical-shaped buildings, with a concert hall, a cinema, an archive, as well as their own community (Fig. 1, 2).

1. The use of construction process automation and the application of robotics and robotic technologies is the next building block of sustainable construction. A number of examples of robotic applications substantiate the understanding of the necessity and, most importantly, the possibility to reduce human participation in hazardous construction processes, such as welding works, assembly of heavy metal structures, masonry works and the speed of their production, plastering and levelling works, lifting works, conveyor-type works, high-rise works, works at depth, as well as works in the zone of high (low) temperature conditions. Also widely applicable technologies for printing parts and entire objects on 3D printers, in particular, the existence of the practice of printing a house, a bridge in its entirety. The use of 3D printing in construction reduces the cost of construction and reduces the time of work, thereby increasing the environmental sustainability of the project, reducing resources. The use of already known numerical control (NC-technologies) allows to schedule the work of equipment according to a predetermined plan-programme without human participation in the very process of work production, the process of equipping construction equipment with programmable devices is one of the fundamental in the organization of automation and robotization of construction production and strengthening the role in the eco-sustainability of the construction industry as a whole.

2. Expanding the scope of information technology, cloud services, artificial intelligence, digital twins, the internet of things and the use of big-data technologies as integrated measures play a major role in the modernization process of the construction industry, increasing its transparency, manageability, efficiency and environmental sustainability.

For example, the use of sensors connected to the Internet and forming a unified system of monitoring and control of engineering systems of construction projects and the entire urban system, providing high standards of energy efficiency and optimizing operating costs in monetary, time and quality terms, thereby increasing the sustainability of building systems and the industry as a whole. Digital twin models allow for virtual testing of different object states, thereby predicting differentiated scenarios and thus optimizing current object states in real time.

The use of artificial intelligence (hereinafter referred to as AI) in the formation of sustainable projects in the field of urban planning allows to optimize project calculations, simulate scenarios, thereby developing risk-reducing solutions. The main advantage of AI

Fig. 1. Photograph of gasometers A, B, C, D in Vienna [6]

Fig. 2. Photograph of a multifunctional complex in Vienna, Austria, after gasometer reconstruction [7–9]

application is the ability to analyze a large amount of data with minimal time consumption, global arrays of which can make it difficult to make the most balanced decisions.

Connecting design, construction and operational systems to cloud services and mobile solutions allows to unite specialists from different industries and geography in a single urban planning project, allow to get advice, expert opinion of unique specialists, without face-to-face presence in the design, working group.

3. Integrated solutions in the field of ecology and safety — such solutions in the field of energy-saving technologies using renewable energy and waste recycling are called "green construction" and affect labour safety. Thus, technologies based on exoskeletons, augmented reality systems, "smart" work wear — clothes with built-in sensors that increase the safety of construction workers and reduce possible occupational injuries — are becoming widely used. The use of cameras, laser scanners, aerial and underwater drones, and other non-contact quality control methods help to reduce the level of environmental threats during project implementation, including increasing the environmental sustainability of the project and the entire ecosystem around it.

A separate block in the study should be devoted to innovative technological solutions combining traditional types of energy with "green" ones. Thus, according to the new concept of energy security in the scope of eco-sustainability of urban systems is the concept of "green square", developed by SC "Rosatom" in 2024 [10].

For example, according to the head of Rosatom, climate goals can only be achieved by combining wind, solar, nuclear and hydropower, and the concept presented by A. Likhachev at the session "Nuclear Power and Renewable Energy for a Carbon Neutral Future" at the COP26 conference in Glasgow was widely supported. The concept presented by A. Likhachev at the session "Nuclear Power and Renewable Energy Sources for a Carbon Neutral Future" at the COP26 conference in Glasgow was widely supported. The term 'green square' combines four low-carbon energy sources, namely nuclear, hydro, wind and solar.

According to A. Likhachev, "climate goals can only be achieved by combining wind, solar, nuclear and hydropower".

In the context of the presented "green square" concept, the nuclear power project as an element of environmental sustainability is assigned a special role — the role of the core of a safe energy system, which is complemented by the inclusion in the grid of the generated energy from the use of solar panels on the roofs and facades of urban buildings, when such panels are used as a modern "facing" material, as well as hectares of land covered with ridges of solar panels [10–14]. In this case, the NPP object acts as a source of electricity and a place for the location of renewable energy sources (hereinafter — RES). Since the total area of the NPP site is large, modern wind turbines are recommended to be installed on the project land allotment.

As a separate element of the infrastructure of an eco-resistant city, whose energy sector is built according to the "green square" system, prospective urban planning projects should provide for the development of environmentally friendly modes of transport, both individual and public, as well as charging infrastructure to them.

Currently, with the support of major state corporations, working groups are being set up to develop a single international standard for sustainable construction in order to unify the requirements and, most importantly, the procedures for preparing, approving and implementing construction projects in urban agglomerations and beyond.

The author of the presented scientific and practical paper concludes that the theory of ecosystem approach in addition to ecological science is applicable, according to the author of the presented paper, to the analysis of urban planning process, urban ecosystems, as well as the construction industry in general [15].

The concept of "ecosystem" was first proposed in 1935 by Arthur Tansley and further actively developed by Vasily Dokuchaev, the world's leading scientists, developed in the direction of unity and diverse interaction between living and non-living environments, organisms and inorganic materials. The main feature of an ecosystem is its ability to self-organization, self-regulation and self-development. The ecosystem of the urban environment without human participation is impossible, which, by its intrinsic feature, provides the ecosystem with the "self"-possibilities described above. Let us consider the flowchart of the ecosystem approach in scientific research (Fig. 3).

Next, we should systematize the main features of ecosystems, which are as follows:

1. Sustainability and existence of internal laws of development.
2. Existence of interacting links between elements.
3. Ability to self-development, self-organization and self-regulation.
4. Presence of organic and inorganic, living and non-living elements.

Composition of ecosystems:

1. Organic (living) part.
2. Inorganic (non-living part).

Types of ecosystems by origin:

1. Natural.
2. Artificial (man-made).

Thus, a building ecosystem refers to an artificial type of ecosystem. In addition to the ecosystem type under study, there are other types of artificial ecosystems such as:

1. Banking ecosystem, e-commerce ecosystem — characterized by inter-connectedness of mostly virtual services with the possibility to receive offline services with the condition of

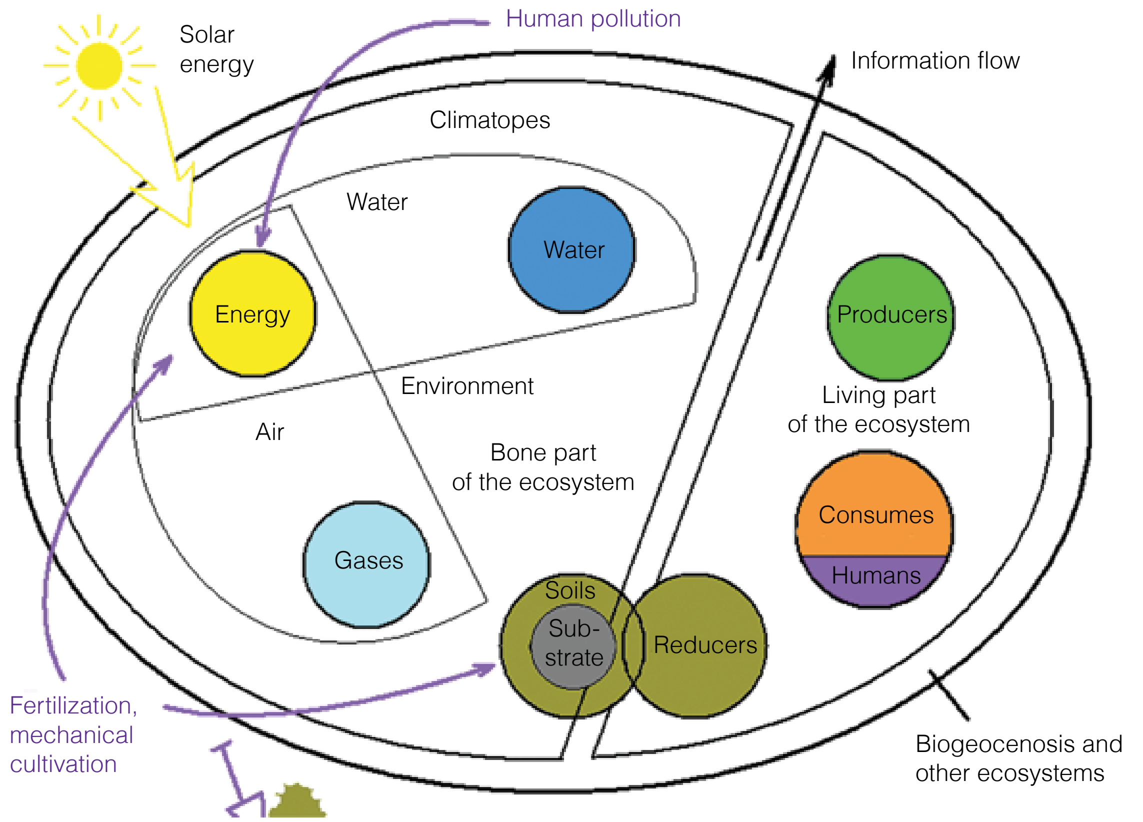

Fig. 3. Ecosystem structure according to Reimers' theory

receiving additional bonuses and then spending them within the ecosystem.
2. Urban ecosystem.
3. International ecosystem.

An interesting classification of ecosystems is given by scientist Eugene Odum, dividing them by energy type into:

1. Natural — sun-driven, non-subsidized.
2. Natural — driven by the sun, subsidized by another energy source or by humans.
3. Industrial-urban, fuel-driven, both fossil, other organic, and nuclear fuels.
4. In his work, the scientist proposed the concept of ecological niche, comparing it to a profession — the ecological purpose of a species in an ecosystem, and a habitat — to the address. Such a comparison allows us to scientifically substantiate the ecosystem approach to economic and other human activities, as well as in the man-made organization of the man-made environment surrounding humans. The presented paper develops the ideas of the ecosystem approach to the general planning of cities, the fundamental energy basis for the development of which are energy-nuclear facilities.

And in the basics of land ecology (otherwise, geoecology) V.G. Marachevsky introduces the ranking of ecosystems, dividing them into facies, tracts, landscapes, geographical areas, geographical regions, biomes and biosphere, thus laying the foundation for the modern understanding of the ecosystem of the urban environment

Urban ecosystem is a complex functional complex of man-made artificial habitat, including cities with their agglomerations, smaller settlements, urbanized areas outside settlements and cities, characterized by uniform management laws.

An interesting example is the formation of the so-called banking ecosystem, which is an example of an innovative form of organization of banking business due to the trend towards digitalization of modern society, the global digital transformation of commercial, financial and lending activities, and the growing popularity of the ecosystem approach in general.

At the same time, according to the author of the presented paper, the banking ecosystem is an element of the urban ecosystem in terms of the digital "superstructure" of the economic processes of the urban economy.

Urban territory and infrastructure has been formed everywhere for many centuries. Today it represents a system of the following elements:

- industrial buildings;
- administrative buildings;
- residential buildings;
- various life support systems (including hospitals, clinics, schools, kindergartens, educational institutions);
- elements of transport infrastructure, including road network, transport interchanges, bridges, tunnels;
- utilities and buildings;
- green space areas;
- other city facilities.

The growth of land costs in the central districts and large cities gradually led to the need to design buildings with higher storeys, and with the increase in the height of the construction object, the problems of safety and life support began to increase. In these conditions, there was a necessity to solve problems in the multitasking mode, which can be solved with the help of automated control systems that take on the functions of prompt response to changes in the modes of operation of a large number of technical devices that ensure the normal operation of buildings, structures or complex of objects. From the technical point of view, the way to solve these problems is to develop a system, which is conventionally called "*Intelligent system of building facility operation*", consisting of a set of four main subsystems:

1) distribution of energy resources;
2) technological;
3) security;
4) "smart home" systems, including multi-room.

Let us consider the specific features of sustainable construction depending on the climatic zone where the object of analysis is located. Thus, due to the specific climatic conditions of the Russian territory, the subject of primary concern in large cities is the length of heat and gas networks, overhead high-voltage and cable lines, which sometimes reach hundreds and thousands of kilometres within the urban area.

Regardless of the climatic zone, the basic condition for the normal functioning of urban ecosystems is the availability of a modern road network that provides convenient and accessible transport services for citizens, including underground and elevated facilities for the safe movement of citizens and high-speed movement of all types of transport. Thus, to improve traffic flow, new radial and ring roads are being created to bypass the city centre districts. They are accompanied by motor transport services (petrol stations, campsites, roadside hotels, parking garages for temporary and permanent storage of cars and road equipment, etc.), with accommodation of road maintenance and other services with posts of specialized road safety stations.

In the process of reconstruction of the road network, if necessary, existing railway tracks can be effectively used with the use of rolling stock of the "land metro" type with the equipment of transfer stations, taking into account the maximum proximity of passenger flows to other modes of transport.

The normal operation of water supply and sewerage systems with obligatory provision of necessary requirements to the quality of drinking water and the level of wastewater treatment has an important place in the urban economy. The vulnerability of water supply sources from technogenic impacts should be reduced, the issues of sanitary cleaning of the city should be solved with the organization of incinerators and recycling plants, construction of sewage treatment systems, land reclamation, installations for melting snow removed from city roads, and enterprises for processing biological waste should be organized.

Residential and industrial stock on the territory of the existing development is modernized and reconstructed in accordance with modern requirements by means of redevelopment of premises, improvement of sanitary equipment, installation of attics and lifts, increase of storeys, improvement of thermal and physical characteristics of enclosing structures. Engineering solutions for the development of underground spaces for the construction of garages, warehouses, pedestrian crossings, shops, etc. should be considered as a special topic in the structure of urban renewal.

DISCUSSION

The main controversial issue that the author raises in this study is the question of how to assess the contribution of the infrastructure component to the sustainability of an urban development project. In the concept of "green square", where 1/4 each of atomic, hydro, solar and wind energy belongs, it is necessary to take into account climatic and geographical peculiarities of this or that region where the infrastructure project is located: for example, the construction of hydroelectric power plants requires a powerful waterway, the construction of wind power plants requires an analysis of wind loads and environmental impact.

CONCLUSIONS

Implementation of urban planning plans for reconstruction, revitalization, rehabilitation and renewal of the existing urban development should be addressed as a systemic task, including:

- coordination of architectural and construction developments and implementation of effective structural, production, investment, financial, tariff and tax policies, development of priority areas and spheres of urban economy and infrastructure for the perspective period;
- ensuring accounting, registration, assessment and efficient use of city property, including land plots and other real estate objects;
- organization of interaction between city authorities and market infrastructure entities (commercial banks, stock exchanges, insurance companies, etc.) on issues related to real estate objects that are both privately and publicly owned;
- attracting investment in housing construction through sales of housing, construction in progress, land lease rights, private investment, etc.;
- creation and development of an investment and loan system and mortgage lending with the issue of municipal bonded housing loans, etc.;
- the energy infrastructure of the "green square" of the modern urban ecosystem is a balance of innovation and eco-sustainability.

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«Зеленый квадрат», инновации и экоустойчивость энергетической инфраструктуры современной городской экосистемы

Целью исследования представленной научно-практической статьи является выявление, систематизация и анализ основных принципов современного экоустойчивого строительства, изучение инновационно-технических решений в области экологии и управления проектами создания городской недвижимости, инфраструктурными проектами, обеспечивающими функционирование городов. Автор статьи решает задачи актуализации современных экосистемных проблем, с которыми сталкивается градостроительная отрасль всего мира. В качестве методов в представленной статье используются эмпирический метод, методологический аппарат сквозного анализа, а также разработка классификаций по принципам, присущим объекту исследования. Помимо общенаучного подхода к изучению проблем экоустойчивости строительства, автор приводит экспериментальные выводы об удобстве применения конкретных средств достижения целей экоустойчивости проектов. Также автор представил собственное определение экоустойчивого строительства с учетом нарастающего мирового энергопотребления, в том числе направленного на охлаждение воздуха на фоне глобального потепления климата, возрастающего потребления продуктов питания и воды на фоне общепланетарного роста численности населения, тенденции на диверсификацию переработки отходов. В статье определяются ключевые драйверы для активного внедрения инновационных технологий в отрасли.

Ключевые слова: *экосистема, экоустойчивое строительство и инновации, эффективные инновационно-технические решения в строительстве*

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For citation: Sezemin D.E. “Green Square”, innovation and sustainability of energy infrastructure of the modern urban ecosystem. *Real Estate: Economics, Management*. 2024; 2:78-83.

Для цитирования: *Сезёмин Д.Е.* “Green Square”, innovation and sustainability of energy infrastructure of the modern urban ecosystem // Недвижимость: экономика, управление. 2024. № 2. С. 78–83.