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DEVELOPMENT AND APPLICATION OF ENVIRONMENTAL PARAMETERS AND BIOCLIMATIC PRINCIPLES IN THE ARCHITECTURAL DESIGN OF BUILDINGS

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Abstract

In modern conditions of consumption of natural, primarily energy resources, and environmental pollution, buildings are ranked among the biggest consumers and polluters, and that at the world level. The paper provides an overview of contemporary trends, as well as challenges regarding the use of created and available natural resources, by determining the relationship that exists between the economic, efficient, and effective use of natural resources on the one hand, and the reduction of environmental pressures of buildings on the other hand, but also by considering alternative scenarios in the future, in which ecological parameters and bioclimatic principles would be more relevant for the design of ecologically correct, sustainable buildings. The emergence, development, and application of ecological parameters of bioclimatic principles in architectural design, as it was concluded in this paper, was motivated to a lesser extent solely by requirements to reduce negative pressure on the living environment, and to a greater extent dominated by the desire to ensure continuity in the supply of resources. This conclusion is supported by the fact that it was only in the last decades of the last century that awareness regarding the condition and negative contribution of human activities in terms of environmental pollution has matured sufficiently. Accordingly, the paper analyzes the reasons for the application of ecological parameters and bioclimatic principles in the context of the architectural design of buildings.

Key words: *Building Design, Contemporary Concepts, Sustainability, Challenges*

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1. INTRODUCTION

With the development of civilization, people learned to exploit and later cultivate natural resources, ensuring humanity's survival, growth, and development. The feedback connection with the natural and created environment is the basis of life on the planet. The industrial revolutions intensified human activities and the use of resources available in the Earth's systems. But, there have been changes with unpredictable and irreversible ecological effects. The impacts on nature have been particularly pronounced in the last two hundred years. However, human awareness of them developed only at the end of the 20th century when the political and sociological focus of our issue of environmental protection [1]. In general, the impacts of human activity on nature can be created in three groups of effects:

1. Immediate or direct environmental impacts – pollution that can be proven in situ (related to a specific area). For example: penetration of polluting substances into water, soil, or air during the production of building materials.
2. Medium-term effects - pollution occurs in a wider spatial and temporal range, disturbs the natural balance, and later manifests itself in humans. For example: uncontrolled deforestation first causes soil erosion, then air quality deteriorates, which in the medium term has consequences for humans.
3. Long-term effects - manifest themselves after a long period and affect humanity. For example: greenhouse gas emissions, as a consequence of human activity, lead to a series of chain reactions and to climate change (global warming, rise in world sea level). [2]

The time and space distance from the place of generation of the negative impact to its manifestation on the environment is a determining factor that affects the type and extent of the required reaction. This means that knowing the effects of human activities leads to an understanding of the pressure on the environment and is the basis for reducing degradation.

2. ANTHROPOGENIC, ESPECIALLY CONSTRUCTION INFLUENCES ON THE ENVIRONMENT

People have an innate tendency to focus on life and life processes. Man's complex relationship with nature and built heritage is based on biological, cultural, psychological, and ethical connections. The primordial need for a harmonious relationship between man and nature dates back to the earliest examples of human creativity. Ecological systems include living entities and their created environment. Symbiotically, they function in complex cycles, which have changed over the past years, along with changes in environmental conditions. [3] According to knowledge from the natural sciences, in the previous 12,000 years, a climate favorable to the survival and development of human society was developed on Earth, and this period began after the ice age and was called the Holocene era or the interglacial period. In this phase, only negligible climatic changes occurred, such as cold periods during the 16th and 17th centuries [4].

Buildings and written evidence of the development of civilizations enable the reconstruction of past systems of human action, ways of using available resources, and impact on nature. Through their construction activities, people have influenced the natural environment for centuries, primarily through changes in the soil surface. Innovations and technological development, especially since the 19th century, led to intensive exploitation of natural resources; at the same time, they encouraged the appearance of pressures that are known today as anthropogenic impacts on the environment. Industrialization continuously encourages the consumption of resources, and consequently, the environmental impact increases with the accelerated rate of change in the natural and built environment. Economic growth in the years after World War II resulted in the mass production and supply of various devices, available to a large part of society. This growth in living standards and comfort is accompanied by a significant increase in energy consumption. The boom in the construction industry has led to the mass production of a wide variety of building materials, and their environmental impact during the life cycle is only now being examined. The continuous growth in the use of natural resources, such as non-renewable sources of energy, water, soil, raw materials, and materials, is accompanied by the intensification of the production of residuals that are disposed directly into the natural environment. People believed in the inexhaustible power of nature to constantly regenerate the raw materials that man needs, but also that nature recycles all the waste created by human activity. Such a belief has led to the pollution of water, air, and soil, and the generation of huge amounts of waste and emissions, which the modern human population faces. The result of the modern way of life is that the connection between humans and other segments of nature has largely been broken. New, created products in the built environment and its expansion at the expense of the natural environment have become sources of environmental pollution and degradation. At the same time, the number and intensity of environmental accidents and extreme weather events are increasing with the increase in the average global temperature and increasingly pronounced climate changes. In order to ensure continuity in the development of civilization, it is necessary to study the trends in the consumption of resources, with constant concern for future needs. At the same time, it is necessary to deal with the consequences of past anthropogenic impacts and activities, such as, for example, climate change. This further implies that bioclimatic factors must be regularly and seriously taken into account when performing all activities, including those related to construction, especially when considering that the results of this activity have a long life continuity

2.1. Sustainability and environmentalism - development and place in construction

The warnings of scientists in the 19th century regarding the dangers to nature were more the exception than the rule [5], while the generally accepted reaction to the state of the environment was consolidated only at the end of the 20th century. The publication of the book Silent Spring (Carson, 2002) is considered the originator of the development of the environmental movement in the USA. For the first time, on April 22, 1970, Earth Day was celebrated, while in 1972 the Greenpeace organization was established, and the Club of Rome published the report The Limits of Growth, in which the picture of the near future was shown as dramatic [6]. Although the predictions regarding the depletion of oil deposits by 1990 turned out to be incorrect, the translation of this report into thirty world languages is evidence of the spread of international interest in environmental problems.

In the Brundtland report Our Common Future [7], the consequences of human action and relationship with nature expressed global concern. The very term sustainability is again actualized and generally accepted. (Originally this term comes from the context of forestry, created in the 18th century to describe the extent of forest cutting, i.e., the amount of cut trees should not exceed the amount of seedlings used to regenerate the forest.) To explain the interrelationship between sustainability and the ecological movement, the author O'Riordan [8] defined the term "new environmental movement" as the aim "to devise a series of strategies that enable people to see how their interests, as well as the interests of the planet as a whole, are affected by reforms within the triad of sustainability, environmentally sound development on at the local level, and realization of basic needs and political rights".

Today, the term sustainability is applied in a broad social context, so its meaning is also complex. According to the Oxford dictionary, the verb to sustain can refer to "the goal of continuing for a long period of time or without interruption" [9]. Sustainability represents the main condition of continuous global prosperity, and today it includes aspects of ecology, economy, and society, their mutual correlations. In the design of architectural objects, sustainability refers to the ecological and economic dimensions.

3. ECOLOGICAL MODELS FOR MODERN BUILDING FRAMEWORKS

In 2016, the European Commission included nature-based solutions among the focus areas of environmental research and innovation and gave the following definition: nature-based solutions are 'solutions that are inspired and supported by nature, that are cost-effective, while providing ecological, social, and economic benefits and help build resilience. Such solutions bring more and more diverse nature and natural features and processes to cities, landscapes, and seascapes, through locally adapted, resource-efficient, and systemic interventions' [10]. Nature-based solutions addressing social, economic, and environmental challenges have also been promoted in the context of global policy, by scientific organizations, the World Bank, and the United Nations [11].

The analogy with living beings, applied to the ecologically sustainable building system, linked to the intelligence component, as well as the basic design concept, aims to support the efficient use of natural resources and reduce the negative impact on the environment. Ecological parameters and bioclimatic principles are applied to achieve energy efficiency of the building, i.e., to reduce the demand for energy and for energy production (e.g., by introducing solar panels based on photosynthesis). Some measures based on biological parameters are multi-beneficial: facades with integrated algae, for example, capture carbon, produce oxygen, and generate renewable energy [12]. A special contribution of living water efficiency systems is recognized in the domains of water collection and wastewater recycling. Similarly, living organisms can contribute to the decomposition of organic waste *in situ*. However, the greatest progress in the application of ecological parameters in the modern construction context has been achieved so far in the field of materials. Frei Otto's experimental and research work in the field of minimum surfaces and their analogies with natural principles could be compared today with the optimal use of building materials covered by the concepts of sustainability and circularity. In addition, there is a wide range of bio-inspired building materials whose modified characteristics ultimately result in better environmental quality, from improved durability (e.g., self-healing materials [13]) to improved interaction with the environment (e.g., intelligent glass that responds to changes in temperature or light), to carbon storage [14]. Green movements emerging from the 1970s shed new light on plant and animal-based materials and raised awareness of their environmental benefits, including abundance, renewability, low CO^2 emissions, low ecotoxicity and toxicity, ensuring good indoor air quality, biodegradability, recyclability, etc.

The desire to reduce energy consumption and the generation of greenhouse gases in the building sector puts passive and sustainable architectural objects in the foreground. Simple methods and techniques that permeate with appropriate design measures and the choice of materials and systems and that reflect the consideration of elements of the local environment, such as air and solar radiation, ensure thermal and visual comfort with less use of non-renewable energy sources. These techniques are called ecological parameters and bioclimatic design principles. There are two basic types of measures: passive and active.

3.1. Different approaches in designing sustainable buildings

Several authors have considered the implementation of energy-saving strategies in the context of their organization based on several different parameters. Thus, in 1991, Lechner proposed a three-level approach to the design of sustainable buildings [15]. The first level involves the application of basic design strategies such as orientation, insulation, and the use of external solar protection. If this is not enough to meet the requirements, which is often the case in warm climates, a second level of measures is introduced that includes passive and hybrid systems. The second level measures are based on natural energy and concern the introduction of evaporative cooling, land use, and day/night ventilation. Finally, as part of the third level of measures, mechanical equipment can be introduced into the building that was previously passively optimized if necessary. Herzog, Krippner, and Lang similarly defined two sets of strategies for managing the regulatory functions of facades [16]. Here, priority is given to consideration of measures such as thermal insulation, use of solar protection, and even vegetation. This is followed by interventions in the field of introducing additional building services such as artificial lighting and air conditioning, but only if necessary. The authors also considered the use of thermal collectors or photovoltaic panels, which are linked to the hybrid use of natural energy that Lechner described as an alternative to the use of fossil fuels. In 1996, Lysen introduced the term 'trias energetica' [17] to rank sustainability measures in the construction industry. In the first place, there is the prevention of energy use, then the use of renewable sources to the greatest extent possible and, finally, if it is still necessary, the use of fossil fuels in the most efficient way possible. International acceptance of the energy trinity began in 2001 with the adoption of the model by the former president of the International Solar Energy Society [18]. For zero-energy buildings and, in particular, houses, the third step suggests a very efficient use of finite energy sources and 100% compensation with renewable energy [17].

In recent times, the energy trinity has been replaced by the New Stepped Strategy. Here, a significant step was introduced between the minimization of requirements and the use of renewable sources, and a waste flow strategy based on the Cradle-to-Cradle principle was included. The previous last step, which nevertheless accepted the use of fossil fuels, is obsolete with the new model [19].

Common to all mentioned approaches is the fact that the measures applied in the design of environmentally sound buildings can generally be classified as passive and active. Passive measures refer to the design of the building and the properties and function of its envelope, while active measures refer to the use of mechanical equipment. The purpose of both passive and active measures is to enhance the flow of heat to and from the useful space, with the ultimate goal being to achieve thermal comfort.

3.2. Passive and active design strategies

In this part, passive and active measures are presented that are in accordance with ecological and bioclimatic principles and are applied to ensure thermal comfort in buildings with minimum or no use of non-renewable energy sources. The main activities involve the prevention/minimization of energy requirements for heating and cooling and the efficient use of energy from renewable sources. The presented measures, summarized in Table 1, are related to the way heat is treated by the building envelope and its systems. Since these measures are not opposed, but interact with each other and complement each other, they should be considered in parallel when designing, while avoiding skipping the necessary steps. While the application of passive measures results in providing thermal protection, achieving solar heat gains, and rejecting unwanted heat, active measures are associated with heat dissipation and energy generation. Finally, energy use in buildings is related to user requirements and behavior. When describing the measures, energy requirements, such as heating, cooling, and ventilation, were taken into account, and user satisfaction was considered a prerequisite. The user's energy requirements related to the use of energy required for the operation of devices, artificial lighting, and water heating, for example, are not directly influenced by the building design. However, some of the considered measures, for example, generating electricity or increasing natural lighting, can contribute to reducing energy consumption.

Table 1. Overview of passive and active measures and their purpose in the context of environmentally sound design [20]

	Energy Management Systems and Processes	Building Energy Efficiency Technologies and Strategies	Materials and systems
		Isolation	Organic Mineral Petroleum products Other

Passive design measures	Thermal protection	Insulated windows	Insulated glass panels Insulated frames
		Infiltration	
		Solar protection	Permanent elements (consoles) Fixed solar cells Movable/adaptable solar cells Glass with solar protection function
	Solar heat gains	Direct solar gains	
		Solar buffer spaces	Winter garden Double facade
		Indirect solar gains	Trombe wall Add a greenhouse
	Heat rejection	Ventilation	Daily ventilation Night ventilation
		Evaporative cooling / adiabatic cooling	Directly Indirectly
Active measures and equipment	Heat generation	Heating with efficient use of non-renewable sources	Boiler Thermal pump Combined systems (heat + electricity)
		Heating using renewable energy	Solar collectors Renewable fuels Geothermal energy
	Heat dissipation	Electric cooling Vapor-compression cycle	Fully air systems Fully water systems Air and water systems Direct systems with cooler
		Alternative cooling systems Cooling by heat	Sorptive With desiccant
	Electricity	Day light	
		Electrical devices	Efficient lighting Efficient devices
		Generation of electricity from renewable sources	Photovoltaic panels on the building Integrated photovoltaic panels Microturbines

Passive design principles tend to minimize the energy demand in the building. Proper consideration of local climate conditions and environmental elements, building shape, and material properties makes the reduction of energy requirements possible. According to their basic function, passive principles can be divided into passive measures for thermal protection, realization of solar heat gains, and heat rejection.

Active measures - applying passive design principles alone cannot meet all energy needs throughout the year. Even after the application of passive measures, the necessary additional energy is provided by the building's technical systems, i.e., single or combined technical equipment for heating, cooling, ventilation, water heating, and lighting.

4. CHALLENGES, CURRENT RESPONSES AND FUTURE SOLUTIONS

Despite progress, the application of ecological parameters and bioclimatic principles in building design is still under development [21]. Sustainable construction is one of the most important segments of sustainable development, and it includes the use of building materials that are not harmful to the environment and the energy efficiency of buildings. Additionally, there is a pervasive desire for simultaneous economic growth and preservation of the environment and for sustainable development. On a larger level, in the process of more massive construction, the compact city is seen as an appropriate concept and model that can support the realization of the strategy's goals, because it represents a potential effective response to growing global challenges and problems such as rapid urbanization and climate change [22]. The importance of designing and building energy-efficient buildings is reflected in the financial effects of the exploitation of such superior buildings, the comfort and quality of housing, the extended operational life of the building, and the contribution to environmental protection and the reduction of harmful gas emissions into the environment, as well as global climate change. Simple systematizations of the application of ecological parameters and bioclimatic principles in the construction context can be made according to:

- Types of living organisms;
- Characteristics of individual living organisms or entire ecosystems, e.g., in terms of content, structure, form, function, or process;
- Scope of analogy: from mono-characteristics to system solutions;
- Type of analogy: argumentative transfer of biological characteristics or actual introduction of living organisms into the context of the building;
- Hierarchy of analogy: materials, components, or structures.

The study of living organisms from the point of view of analogy in the process of architectural design includes several related biological branches, primarily these are: 1) external morphology or bionomics, which studies the external appearance of living beings; 2) anatomy (internal morphology); and 3) physiology. Anatomical studies are divided into microscopic anatomical studies of structural units that are small enough to be seen only with a microscope, and macroanatomical studies of those body structures and forms that are large enough to be examined without the aid of a magnifying device [23]. Physiology studies the functions of living organisms and their constituent parts - tissues and cells. These functions include: metabolism, transport, information transfer, and regulation [24]. Therefore, studies of form and function can be conducted at different scales of living organisms. Therefore, the application of biological principles in the modern construction context requires "the transfer of knowledge from biology and ecology to architectural design in a way that goes beyond poorly understood and applied analogies or metaphors" [25]. The establishment of interdisciplinary and multidisciplinary design and research teams is an imperative for future development.

It is reasonable to ask the question: what affects the slow environmental impact when it comes to architecture and construction? The famous saying of the architect Le Corbusier that a building is a "machine for housing" has had a strong influence on the realization of many buildings for decades, given that it is sometimes taken literally by architects and admirers. Many buildings created under this influence, in their expression of the environment in which they were built, have a dehumanized character. Static observation of the object is important in scientific analyses (daylight, ventilation of the object, energy flow), but increasingly complex environmental problems point to new considerations. Buildings are part of a complex interaction between people, climate, and environment. New approaches to the design, construction, and use of the facility should support the ecosystem, not destroy it. The urban environment was created as a product of the relationship between society and nature. For a long time, these relations were opposed to the detriment of nature. The realization that society and building culture are separate systems from nature has resulted in unsustainable built structures in a degraded living environment [26].

The lack of classifications, different interpretations of key terms, insufficient knowledge from biological science, and scarce evidence of benefits related to sustainability, circularity, resilience, and regeneration worsen the perception of designers about the possibilities of applying ecological parameters and bioclimatic principles in building design. Likewise, there is a need to develop evidence-based databases that could confirm the specific benefits of applied measures in the construction context. When the benefits of applying bioclimatic principles are justified by a sufficient number of realized cases, pre- and post-construction assessment systems can be developed, and their criteria and indicators determined. Considering the level of specialization that includes natural sciences with construction science, there is a need to promote the development of interdisciplinary research units, to improve experimental work, and to connect these laboratories with education and practice. This need is indicated by the already proven advantages of building, for example, energy-efficient buildings, and they refer to the fact that: 1) Funds invested in energy efficiency are returned in a period of 5-7 years; 2) By energy renovation of old houses and buildings, especially those built before 1980, it is possible to save about 60% in heat energy consumption; 3) Windows are the main source of heat loss, replacing windows is an opportunity to save up to 50% of energy; 4) The application of green roofs improves air quality, reduces city noise, and reduces the effect of heat islands; 5) Energy efficiency helps to control rising energy costs and affects the reduction of climate change. It is particularly useful to apply these measures to buildings built in the late 70s and early 80s, which in terms of usable area have higher CO^2 emissions than those built in the early 90s or later. [27] An energy-efficient building is a building that consumes the minimum amount of energy while providing the necessary comfort conditions (air, heat, light, and sound comfort).

5. CONCLUSION

Awareness of the outcomes of human activities is the basis for reducing environmental pollution and degradation. The type and scope of actions to reduce harmful effects on the environment depend on the field of action. Architecture is a field that has no future without sustainability because of the great influence it exerts through various fields of its application. In architectural design, knowledge of the ecological dimension is fundamental for defining technical, social, and economic measures. In this sense, this work establishes a platform of facts needed to understand the progressive anthropogenic impact on the environment, explains the genesis and development of ecologically correct objects in wider social conditions, and looks in detail at the segments that are currently the most developed. The paper deals with the main challenges in contemporary architectural design from the aspect of consumption of natural resources: water, land, energy, and materials, and at the same time elaborates possible scenarios of a resource-efficient future.

Economic development has caused greater production of construction materials, more intensive construction of residential, business, and industrial facilities, and at the same time, these activities have been reflected in a greater demand for construction land, and all of these activities have a negative impact on the global ecosystem. That is why it is extremely important to take responsibility for the impact that architecture has on the environment, so that future generations can realize their needs.

From the very beginning of construction, the building has an impact on the environment through various activities and processes (production of building materials, transport, construction, installation of materials, reconstruction, demolition, recycling, waste disposal). All these activities can cause environmental damage. Also, during the construction process itself, the construction site produces waste and noise, which also have a great impact on the environment. The impact that occurs even after the construction of the facility is not negligible because, during exploitation, there are also consequences for the ecosystem. It is very important to note that when a building loses its function (it is no longer in use or due to circumstances it was left unfinished and not brought to its intended purpose), its negative impact on the environment is extremely high. If such an object is not recycled (reconstruction or change of purpose or complete demolition and waste recycling), everything invested in the production, transportation, installation, and maintenance of such an object can be considered a loss and a constant negative impact on the environment. With a sustainable approach/design, and the consumption of non-renewable resources is reduced, the use of renewable energy sources is promoted, waste is reduced to a minimum, and a healthier and more rational living and working space is created. The principle of sustainable architecture implies the rational use of construction land, the use of ecological materials, the rational use of energy and water, the optimization of the process of functioning and maintenance of the building, as well as the improvement of conditions for living and working in the building and on a larger scale the design of compact cities.

The future of architecture depends on a responsible (sustainable) approach to the design, construction, and use of the building. Growing environmental problems lead to the realization that there is no future development of society (and therefore architecture) without harmonizing the relationship with nature. So this time attention is drawn to the importance of the ecological aspect in sustainable architecture and construction.

The emergence of ecological thinking is certainly the first step in improving the mutual relationship between humans and nature. As architecture has a significant impact on the environment, the impact of ecology is increasingly important in the approach to designing, building, and using buildings. In order to efficiently implement the impact of ecology, it is necessary to revise the building norms and rules, which slow down this process of environmental impact to a good extent.

Applying the principle of ecological correctness improves the performance of buildings, whether the design ambition concerns the design of a comfortable and functional architectural object with rational energy requirements or the achievement of sustainability standards such as a zero-energy or passive house. The choice of measures is ultimately a design choice on which the architectural quality and form expression of the building, as well as its function, will depend. And finally, regardless of the stated importance, although the climatic characteristics and ecological conditions of the local environment should be taken into account, the decision cannot be solely based on these items, due to the presence of many other parameters that are considered.

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