

BIOCLIMATIC UNDERGROUND ARCHITECTURE: DEVELOPMENT AND PRINCIPLES

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Abstract. *The principal idea of paper lies in analyzing contemporary architectural challenges, concerning climate changes, global warming, renewable energy deficiency and population growth. The relevant examples and principles of sustainable and self-sustainable architecture development throughout history are presented. Underground structures as passive solar systems, vegetation used as insulation, ventilation and isolation are given as one of possible solutions for this global phenomenon. By studying the model of Nature, certain solutions imitating systems and laws of flora and fauna are given that will insure the necessary savings of non-renewable energy during the building construction and their later energy consumption.*

Key words: *Bioclimatic Underground Architecture, Development, Principles of Sustainable*

1. INTRODUCTION

Industrial development, since the second half of 19th century cause an immense consumption of resources and energy and an increase in the emission of harmful matter in the environment, generated in the entire production cycle and even by the produced goods themselves. Consequences of such a treatment of nature lead to the climatic changes (harmful solar radiation, draughts, acidic rain occurrence, eutrophication, photochemical formation of ozone, global warming, glacier meltdown etc.) as well as to an increased emission of poisonous chemicals to air, increased risk of natural disasters etc. The limited resources of raw materials and energy and increasing demands for energy production and consumption brought about a rise in usage of renewable energy sources and recycling, on one hand, and usage of passive energy on the other hand.

Nowadays, the renewable energy sources and materials became relevant factors of contemporary societies, due to the grave energy and material deficiency. Developed countries, as opposed to the underdeveloped and developing countries, mostly optimize and standardize energy and material consumption. It is implemented through systemic and

legislative arrangements in order to conserve the natural resources. The basic requirements are that production has low energy demands and low levels of harmful matters emission in production and usage. A special attention in production is paid to recycling and waste matter disposal, reduction of noise, dust and vibrations. It should be noted that in civil engineering, during construction and demolition activities, large quantities of waste material are generated, so there is a growing demand for an increased re-use and recycling of building material, and stringent waste materials control.

Environmental, bioclimatic design, includes all these parameters. Therefore, **environmental awareness** and energy saving does not rely only on education of population, but fuses with all the scientific disciplines and becomes a code of conduct of contemporary societies.

XX century as an age of industry and technology, but rapidly changed its character into an age of information and environment. [7].

The second issue is the constant growth of population and creation of gigantic metropolises. These metropolises are at the same time the highest consumers, not only of non-renewable sources of energy and raw materials, but limited usable housing. In this way, in the course of incessant growth of population and the cities, other useful areas are shrinking, such as arable land, forests etc. By the expansion of cities, industrial zones, illicit settlements and the unplanned expansion of week-end settlements, the problem of physical reduction of natural resources is generated, that is, of renewal of energy from nature. Also, during such continuing physical changes, along with a number of harmful factors, this problem assumes larger proportions, such as disturbance of eco-systems, endangering of plant and animal species and eventually a threat to the humankind.

If we know that the total surface area of the Earth is around seven billion square kilometers, and that only one fifth is suitable for living, how then organize the limited planetary surface for the future immense human community? These are the words of Fabre-Luce in his book "Six billion of insects". Demographic explosion, which double the population of the Earth every forty years, indicates that in around three hundred years there will be seven hundred billion people on the Earth. In 2260, there will be only 10 square meters of the Earth surface area per each inhabitant of the planet, and in 2400 only 1 square meter! [2].

Exactly out of this thesis a number of favorable alternative solutions were created with the aim of provision of living and housing space, which was logically applied by the civil engineering, carried by the political and social changes. Namely, emergence of high towers, skyscrapers, even the city-sized buildings, and the entire concept of floor organization in architecture, in the time of high technical potential were created in the metropolises where the concentration of the population is the highest, and thus the issue of deficient building land was solved. However, such structures, apart from the high requirements in structural and formal sense, from the perspective bioclimatic principles of design are considered immense energy consumers, regarding the high degree of heat loss through a variety of apertures on the façade, irrespective of whether that is a housing or public type architecture.

Eventually, when discussing the heat losses, *underground architecture* demonstrates considerably better results in terms of sustainability. The advantages of an underground structures are multiple.

If XX century was a time of high-rise structures, XXI century will be the age of underground construction. [9]

2. DEVELOPMENT AND PRINCIPLES OF BIOCLIMATIC UNDERGROUND ARCHITECTURE

In the stone age, when mankind was born as a species separate from the animals, and gained reason, the first settlements were formed, inhabited by the hordes (primeval human communities). These habitats were mostly the temporary natural shelters, such as tree crowns and caves. In a desire to create a shelter for himself and protect from the changeable natural conditions of the environment, men created better environment for life, regarding climate, terrain properties and availability of raw materials.

The notions such as isolation, orientation, location and similar, date back to the pre-historic times, and they represent the basic factors in contemporary bioclimatic designing.



Fig. 1 The cave in Trogliti village, Tunisia



Fig. 2 The cave, Iran

Irrefutably, the most representative example of primeval housing are caves, where mankind sought protection from the severe weather conditions; cold, excessive sunlight, temperature changes, wind, precipitations etc. The cave examples are presented in the Fig. 1 and Fig. 2.

Primitive tools, made mostly of stone and wood were used to begin construction of first man-made structures of primeval habitats. First building materials were stone, wood and soil. Soil, mixed with water was an excellent flexible materiel, which was later often used in construction, as a filling, cladding or binder. When the fire was discovered, at the later date, it brought about revolution in human societies, as well as discovery of new building materials.

In time, these primeval primitive habitats evolved, together with mankind and its understanding of nature. Human settlement differed mostly because of the topographic and climatic conditions at certain localities – accordingly, the level of protection from the weather conditions differed. "The Hanging Gardens of Babylon", built in 6th century BC, one of the Seven Wonders of the World (Fig. 3), is an example of the protection form external weather conditions, which employed a watertight roof, constructed of densely packed reed and thick shrubbery with natural greenery. The tower was built in receding tiers, and each tier contained exotic plants, which had a protective role, apart from the aesthetic one. It is assumed that the builders of the time constructed an irrigation system for the variety of plants, using

only natural energy, and thus maintained the required humidity of the layers covered by greenery. Tightly packed layers of reed, with a layer of vegetation on their tops, supported by stone columns served both as thermal and hydro insulation.

Sod houses – The European and Asian continents are full of examples where soil and vegetation were used as insulation materials. Some of the preserved examples testify the human respect and observation of natural laws and his subordination to them. Men observed the law from the animal and plant world and adapted them to their needs. Even nowadays, study of the *ecosystems or isolation and ventilation mechanisms in plant and animal world is an inspiration for application in the structures, and it may even become inevitable*. [1].

The sod house represents the oldest form of human houses (figure 4). People used the sod houses mostly for dwelling, or as shelters for domestic animals. They were constructed over a hole or a hollow, and fully or partially dug in the ground. Such building method provided a pleasant atmosphere and optimum temperature for dwelling in all seasons. The prevalent construction material was soil, which mixed with natural binders (straw, vegetation) served as an excellent insulation material, but wood and stone were also used, as structural elements. Sod houses, according to their parameters, represents one of the first systems of passive solar architecture. The sod house dwelling in Novo Miloševu in Serbia is shown in Fig. 4.



Fig. 4 Sod house dwelling in 1947
(Serbia, Novo Miloševu)

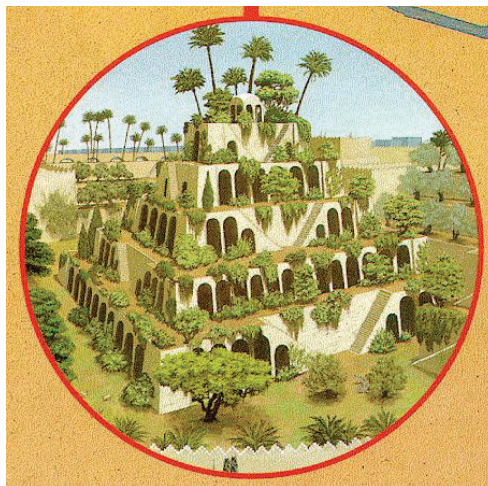


Fig. 3 Hanging Gardens of Babylon

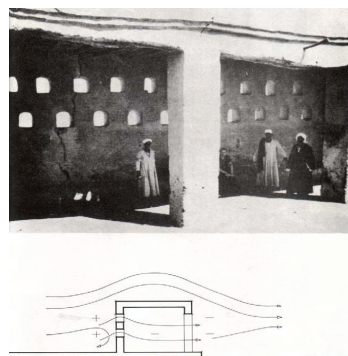


Fig. 5 Ventilation of a wall with openings
according to aerodynamic
principles, Gournah (Egypt)

"The sod house was built in 1947 after the model of the sod house that had already been built in Serbia. The house floor level is 1,5m lower than the surrounding ground level. The structure had now walls. The hipped roof touches the ground, and roof structure is composed of the ridge board supported by a support with lathes which are on one end laid on the ground. A layer of reed covers the roof structure, with mud on top, as a final layer." [8].

Throughout history, along with the development of technology in civil engineering, the underground architecture developed in variety. There are many examples of underground buildings, such as Egyptian pyramids, catacombs (sanctuaries and burial chambers) from the Roman period, underground labyrinths, gunpowder storages from the Ottoman period, tunnels and many others. One might gain considerable knowledge about passive construction techniques from these examples, for instance principles of ventilation, climatization, heating and insulation, using biodegradable material from renewable energy sources, primarily from the Sun, water and wind. In Fig. 5 is presented ventilation via a wall with openings according to the aerodynamic principles, Gournah- Egypt.

As early as 3000 BC Assyrian merchants knew about the air conditioning technique by evaporation of dispersed water. The palace of King Arzaw from Anatolia, 1200 BC was heated by warm air. Heating with ventilation, circulation of fresh air was implemented in Roman construction in Orata, near Neapel in 80 BC. Caliph Mahdi's summer residence in Baghdad was cooled by placing snow into the double walls in 775 AD. Leonardo da Vinci significantly contributed to the improvement of cooling and ventilation technology around 1500 by designing a fan powered by water.

In the period since 1700 till 1800 Boyle, Gay-Lussac and Dalton formulated the humid air thermodynamic. The genuine development of air-conditioning occurred after 1850 when ventilation and air-conditioning was widely used in industry, in the environments with high temperatures, dust, unpleasant smells. In 1870 Karl von Linde designed the first compressor refrigerator. Carrier (precursor of the contemporary air conditioning systems) designed in Brooklyn the first high-pressure air conditioning system. However, by the development of air conditioning systems, the energy consumption soared. After the energy crisis of 1973, energy saving in the area of air conditioning was promoted.

Studying the natural models and mimicking the flora and fauna systems and principles, considerable energy savings and reductions of CO₂ emissions could be accomplished. Thus, the global climate can be unaffected, and at the same time the required comfort, optimal temperature, air humidity and aeration of the premises can be maintained. A Swiss biologist M. Lüscher conducted a research in 1950 on a model of termite towers (Fig. 6 and Fig. 7). In that research it was documented that termites constructed a system for temperature regulation and ventilation inside the tower, and a thermo-siphon model was made. Different density and specific gravity of cool and warm air provides continuous air exchange and ventilation, and replacement of the stale air inside the tower by the fresh one.



Fig. 6 Termite tower

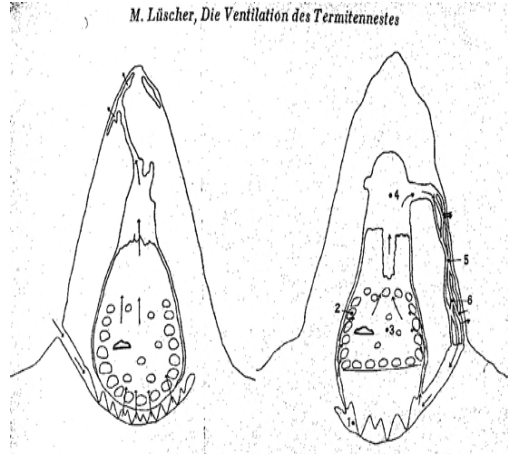


Fig. 7 Ventilation and temperature regulation

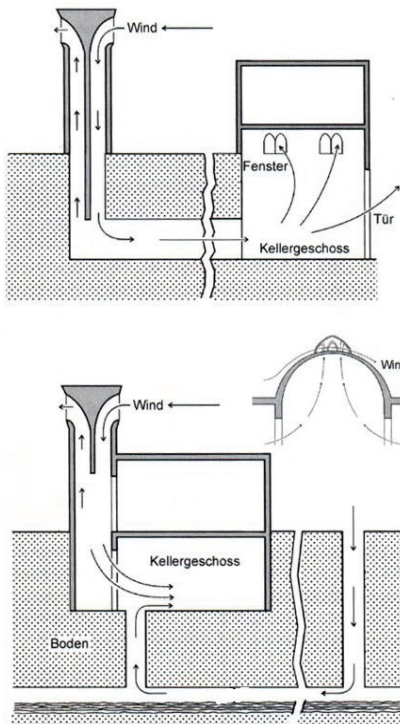


Fig. 8 Principles of cooling by air flow over ground water

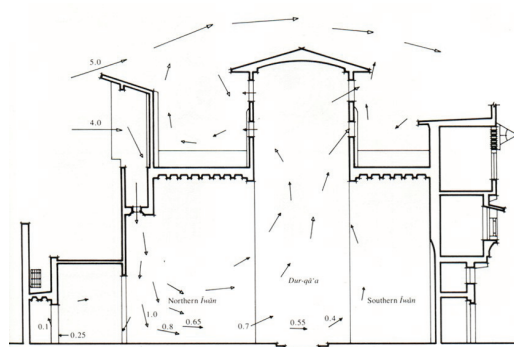


Fig. 9 Cooling by air flow, Othman Katrkud building, Egypt

Underground structures, throughout history, were mainly constructed for food storage, but also for weaponry, requiring minimum of dampness and constant temperature. Specific conditions required, such as constant temperature, absence of noise, safety, protection from fire, warfare, were mostly met by underground structures. The principles of cooling via flow of air over ground water through the tower and air ducts are shown in Fig. 8.

Cooling by air flow through special openings in Othman Katrkud building in Egypt is presented in Fig. 9.

The first genuine examples of dug-in structures covered by peat soil and green roofs can be found in old Scandinavian villages, in the cold and damp climate. Such roofs apart from being insulation were accumulators of heat. Soil, particularly one covered by vegetation, is slowly cooling and warming up, and the temperature in the building does not drop below 12°C in the coldest season of the year, even in the most extreme climatic conditions.

In the recent history, in the time of expansion of innovative materials and cruel architecture of concrete and glass, in the time of industrialization and reckless building aimed at satisfaction of current aesthetic forms of cities, and neglecting of natural bioclimatic principles and advantages inherited by the humanity, civil engineering started to realize the issue of global sustainability of the planet.

There are many examples in housing architecture from autochthonous environments, in the structures which were created for purely functional but also traditional needs, where coherence with nature is evident.

This so called "*Folk architecture, as anonymous buildings were termed by Victor Hugo, architecture without architects as termed by Rudofski, architecture without pedigree, that is spontaneous, immediate, popular, vernacular, organic building are all the names of this particular architecture, which was neglected for so long and from which one could learn a great deal*" [6]. Nowadays in XXI century, contemporary architecture is returning to earlier values..

First "organic architecture", movement was initiated by Le Corbusier and Frank Lloyd Wright through a philosophy of architectonic forms originating in the organic structures of villages at the turn of XX century. This idea was pioneering the latter movements such as green architecture, earth architecture, territecture, geotecture, passive solar architecture. Green architecture, relationship of nature towards mankind and vice versa, according to the words and deeds of two leading figures of modern architecture, was focused on re-interpretation of environmental philosophy, and implementation of structures into the nature, becoming a part of it in the process.

The underground structures, partially or completely dug-in are progressively becoming a trend in global architecture. The most of these structures was built in the USA and Europe. Motivation for construction of underground structures varies. The most frequent motive stems from the functional needs, due to the deficiency of valuable densely constructed city area, for infrastructural needs etc. whereas in the recent period, the motivation is coinciding with the concept of sustainability and natural resources conservation, as well as with the high energy efficiency. Spectacular examples of underground structures of XX century and contemporary architecture worldwide become very attractive and significant parameters in the further progress of city development. Many structures were built deep underground in densely built-up city cores. Underground architecture is inevitable in consecutive implementation of requisite infrastructure, traffic lines, metro, tunnels and other things such as shopping centers, galleries, libraries, scientific centers, schools etc.



Fig. 10 The Faculty of Art and Design – University of Singapore

In the last thirty years there is an increasing number of examples in Russia, China and Japan, where the useful surface area is lacking and where cities are overpopulated. Spectacular architecture, subordination to nature and its formal characteristics, energy efficiency, are the main traits of underground structures. The Faculty of Arts of Singapore (Fig. 10) demonstrates one completely attractive and modern approach to green architecture. The roof is constructed of a layer of soil covered by turf. Its radial form, combined by green surface is completely integrated within environment, becoming a part of earth cell.



Fig. 11 The Academy of Science San Francisco, California – Renzo Piano

The Academy of Sciences in California (Fig. 11), was built in 2008 representing a futuristic approach in design. The structure was built of contemporary material, steel and glass. The entire roof is composed of a layer of soil covered by vegetation, so the struc-

ture is fully integrated with the environment. Through skilful design, the roof mounds were covered by window panes, which illuminate the interior from the zenith. Savings in heating and cooling, without additional energy are provided by the controlled ventilation system. Excess water collected on the "living roof" is drained via siphons and conducted to the underground water system. The collected precipitation water is later used in the structure, among other things for heating purposes.

3. CONCLUSION

The data which are daily encumbering human freedom, are in effect, results of inconsiderateness and carelessness of the mankind. All the data continually indicate the inevitable usage of renewable energy from nature.

The priority in such view of the world and architecture is conservation of bio diversity and ecosystems. Knowledge of limited reserves of fossil oil and pollution of the planet, are urging for saving the energy and usage of solar energy. Such architectonic philosophy is a harbinger of a new age in progress and development of architectural forms. Such idea could be included in plans of reconstructions of existing structures and entire settlements. Every existing building must be reinvestigated, as the solutions are frequently very different. Underground architecture, apart from a high degree of energy saving, frees up the deficient surface area of the cities, and alleviates functioning at the same location by at various levels. Such construction is paying back in a variety of ways in the long run. Façade and its maintenance are excluded from the charges, and the soil serving as a thermal insulation is also completely for free.

Underground architecture could, to a certain extent, contribute to architectonic diversity of cities, but also of some future suburban areas. It is special not only for the energy efficiency, but also for its unique aesthetics. The feeling of freedom, space and pleasure instead of cramped, closed and same places created by monotonous housing districts is a privilege of modern man. Organized and planned construction of underground structures would solve the overpopulation problem in certain areas, and the surface area of agricultural land is increased, agricultural production as well and consequentially, the employment. It is a circle of causes and consequences, where human kind is benefiting the most. Above all, we must bear in mind that environment affect human psycho-physical health. The place and environment where we dwell, and work should be "healthy" and humane. The Capitalism as a system converted people into working machine, which detached itself from the nature. It is now necessary to raise the awareness of these primordial values, particularly for the sake of those who will inherit the Earth. Underground architecture is in one part, small but not insignificant, attempting to reduce the load of the environment, use the nature without interfering with its laws. The entire state of affairs indicates that XXI century is the age of sustainable architecture.

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BIOKLIMATSKA PODZEMNA ARHITEKTURA: RAZVOJ I PRINCIPI

Jasmina Stojić, Danica Stanković

Osnovna ideja rada sastoji se u analizi arhitektonske problematike savremenog doba, suočenim sa klimatskim promenama, globalnim otopljavanjem planete, deficitom neobnovljive energije, ogromnim porastom populacije. Dati su relevantni primeri i principi razvitka održive ali i samoodržive arhitekture kroz različite vremenske epohe. Podzemni objekti kao (pasivni solarni sistemi, izolacija zemljanom pokrivačem i vegetacijom, ventilacija i izolacija), dati su kao jedno od mogućih rešenja ovog globalnog problema. Proučavanjem modela iz prirode, po ugledu na sisteme i zakonitosti iz flore i faune data su određena rešenja, kojima se objašnjava kako postići velike uštede neobnovljive energije tokom izgradnje i konzumacije ovakvih objekata.

Ključne reči: *bioklimatska podzemna arhitektura, razvoj, principi održivosti*