Light & Engineering
Vol. 27, No. 2, pp. 23–31, 2019 *https://doi.org/10.33383/2018-030*

INNOVATIVE CONCEPTIONS OF NATURAL LIGHT USING AS AN ESSENTIAL COMPONENT OF THE FORMAION OF ARCHITECTURAL SPACE

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ABSTRACT

The purpose of the article is identification of the innovative conceptions of using natural light properties to form architectural space interactively associated with the habitable environment. It is noted that the natural light, being an extremely powerful tool for the organization of architectural objects, attracts attention of many scientists and designers working in different fields of architecture. The results of the review of their architectural researches and developments are presented in connection with the considered problem. It is established that the innovative conceptions of the natural light modelling can be used to create the appropriate objects of architecture. The obtained results can be useful for the theory and practice of habitat formation opening up completely new opportunities in architecture.

Keywords: light environment, artificial sunlight, energy potential, natural light

1. INTRODUCTION

Relevance and Actuality

It is known, that natural light not only provides visual perception of a person, but also performs psychological, biological and aesthetic functions. It plays a major role in the habitable space, changing architectonics, proportions, and the nature of the emotional impact. Depending on its quality, impressions can be very diverse and have a profound effect on the perception and enrichment of our understanding of the environment. The features of light for spatial organization and optimization of the light environment of architectural objects are very important. The shape formation and space in architecture appear only in the presence of light. It should be noted the environmental aspect of natural lighting due to its significantly higher energy efficiency compared to artificial lighting, what may be a decisive indicator of the optimization of future possibilities of the architecture. The problem of inhabited space organization by means of the natural light use always was in the architectures interests. Suffice it to recall such masterpieces of architectural creativity as the building of the Central city library of Vyborg town in Russia, built in 1933–1935 by the Finnish architect A. Aalto. In the main hall of the library there are no traditional windows (the surface of the walls was left for hanging bookshelves). Natural diffused light, which not makes shadows, enters in the room through the round window on the roof. Another well-known example is the building of the headquarters of the company "Johnson wax "(1936–1939), in Racine (Wisconsin, USA), in which the constructive basis of the Central hall of the company is designed in the form of "tree" expanding upward columns by the American architect F.L. Wright. Light is carried out through transparent glass tubes, giving a smooth soothing lighting throughout the room. Later, 13 years later, a research complex was built, and there is the outer glazing of the laboratory tower was made of bent glass tubes giving an extremely pleasant aesthetic effect of diffused soft light. In this regard, the purpose of the article is to identify innovative ways of

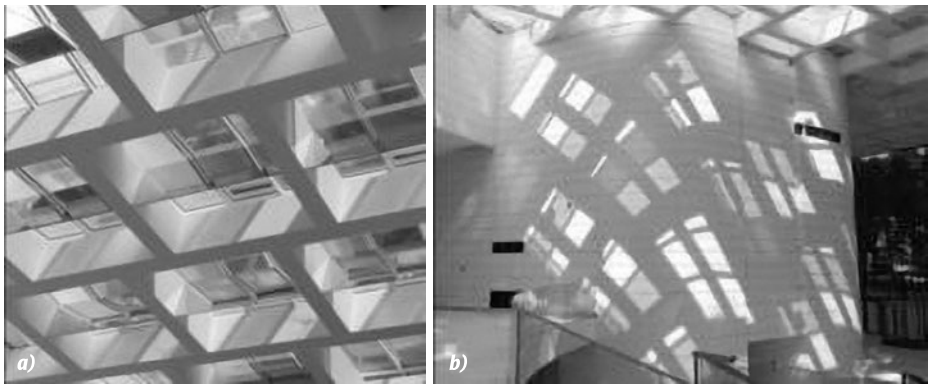

Fig. 1. Trap of light in the lobby of the tower " Eqho "(Paris): a – lattice structure of mirror ceiling panels; b – coloured light spots on the inner wall facing North placed in direct, in which sunlight never gets

using natural light as an important component of the architectural space lighting interactively associated with the environment. This is due to the fact that the versatility and complexity of using of natural light as well as the breadth of its "manifestation" techniques requires consideration of the relevant concepts in some aspects. In connection with the relevance of this problem, a review of existing architectural solutions for the use of natural light in the formation of the architectural environment was carried out in different areas.

2. CONCENTRATION AND TRANSPORTATION OF THE NATURAL LIGHT

In accordance with present time requirements to the shaping of spatial habitat in the practice of design and construction of the architectural objects there are a variety of proposals for the use of the natural light to change the perception of space during the day and the season's changes.

Among the examples there are the modernization of the facade of the 130-meter tower "Eqho", built in 1988 in the business district Defance (Paris), and the reconstruction of its lobby, that allowed the natural light penetration to it.

Development of the project of transformation of day and night appearance of the lobby was carried out by the architectural Studio Hubert & Roy with the participation of Studio Concepto specializing in the field of lighting design [1]. The architecture of the lobby, due to the presence of a glass roof, allows incoming natural light to change the perception of its space during the day by projection on the walls and the floor of shadows from the special elements located at the top (Fig. 1).

The use of dichroic glass allows painting the light passing through it, changing its colour within the specified limits depending on the angle of incidence of sunlight. This is provided by the deflection of certain rays of light with the help of mirror panels suspended inside the metal lattice structure, which allows coloured rays directing to the inner wall. The proposed lighting system as a "trap"

Fig.2. Trap of light in the transport interchange hub "Fulton Center"(New York): a – general view of the building node; b – internal space with a mesh structure of the dome

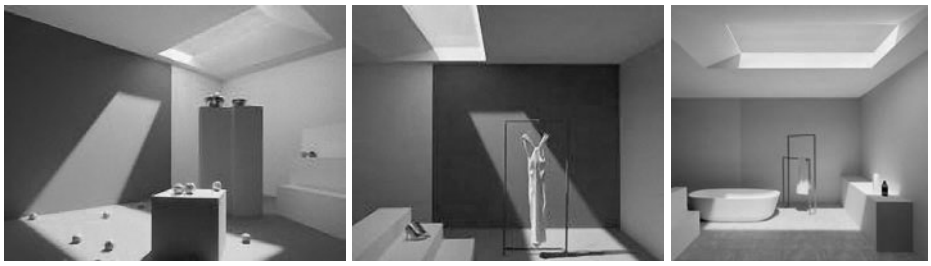

Fig.3 Device simulating sunlight "CoeLux": examples of interior solutions

of light allows you to enhance the impression of the perceived space of the lobby and to control natural light for 24 hours a day, as long as you want. The ability to transport natural light for its delivery to the subway platform is provided in a large transport interchange hub "Fulton Centre" in the heart of lower Manhattan, which combines 11 subway lines (the authors of the project – Grimshaw Architects Bureau together with engineering and design company Arup). The glazed rectangular volume of the interchange unit is about 34000 m**²**. It has a spacious atrium with a height of about 34 m with a waiting room in the centre and outlets at the edges. The steel dome with an angled light aperture, under which the lift surrounded by a ladder stand is located, completes the construction (Fig. 2).

On the inner walls of the dome, complex mesh structure is fixed on the crisscrossing steel cables with a height of over 21 meters and a diameter of about 15m (developed by the office of James Carpenter Design Associates). In this case, the process of creating a mobile design by engineers who needed to first understand how it will work depending on pressure, air temperature, air conditioning system and other factors is of professional interest. At the same time, the behaviour of the object in 815 situations, both standard (heat, cold, time changes) and force majeure, as well as in case of fire, was simulated using special software. Having thus determined the optimal form of the structure, the engineers studied and calculated the distribution of the levels of natural and artificial lighting depending on the external conditions. It should be noted that the electric lighting in the interchange unit is used only in pedestrian crossings, where a kind of grid of fluorescent lamps is also used [2]. An example of the creation of "artificial sunlight" to simulate realistic natural lighting in enclosed spaces (rooms without Windows, museums, metro stations) is the unique device "CoeLux" developed by Professor Paolo Trapani from the University of Insabria (Italy). It looks like an ordinary skylight and is designed to recreate realistic "sunlight" in enclosed spaces. A complex optical system that accurately simulates the sun and its rays uses LEDs with high colour quality. A special visualization mechanism has an interface designed to simulate the sky and sunlight falling into the windows (Fig. 3) [3]. "CoeLux" not only delivers artificial daylight in enclosed spaces, but can be programmed to emulate three lighting scenarios depending on geographical location (for example, providing warm light, typical for Northern regions, or Equatorial, vertical type lighting, cool shades and more dramatic shadows). The device has a small thickness and can be built into any suspended ceiling. The usual methods of using and transformation of natural light, scientists try to complement by the new ways. For example, physicists from Chile and Germany have developed a two-dimensional optical trap of light using mutu-

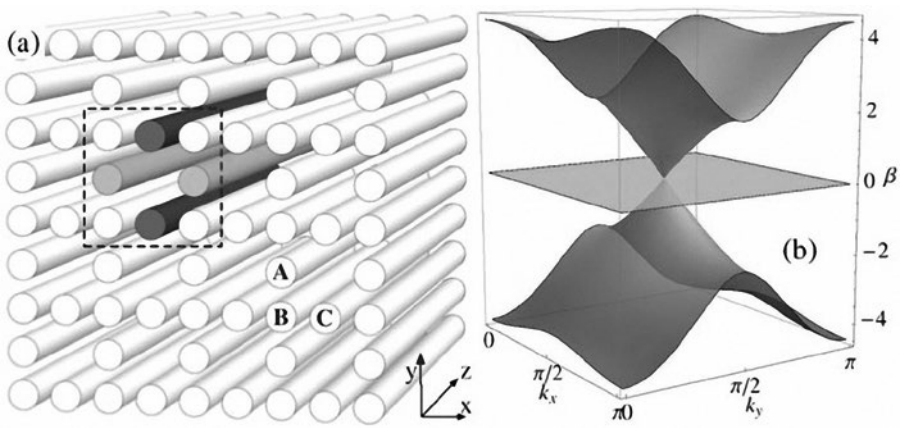

Fig. 4 Model and diagram of natural light blocking in two-dimensional trap

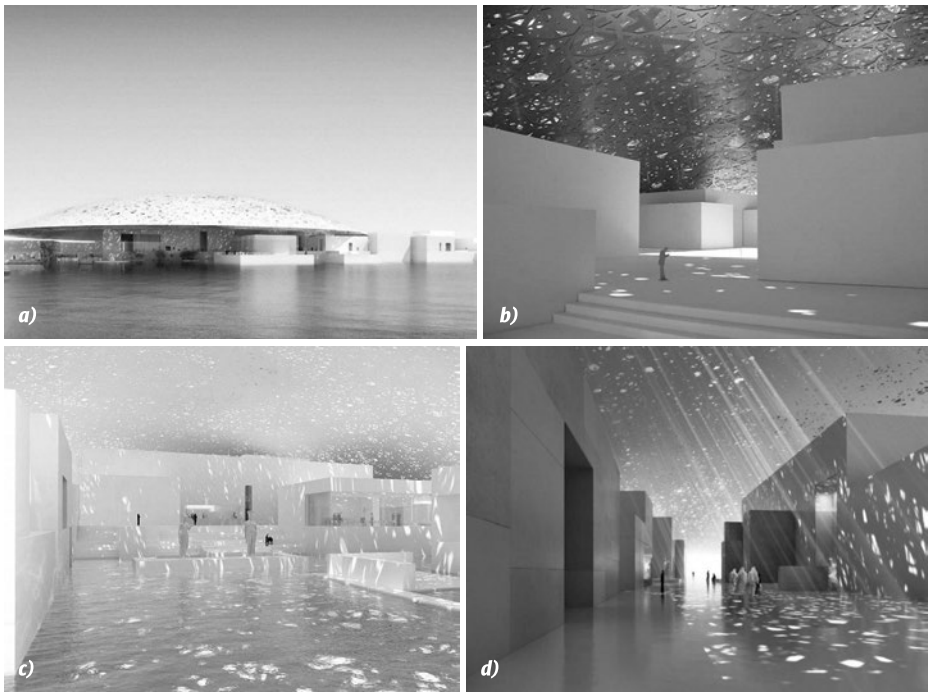

Fig. 5 Complex "Louvre Abu Dhabi" (UAE) a – general view; b, c, d – options for solving of the interior space

al interference of electromagnetic oscillations. It is a two-dimensional version of the crystal structure of perovskite – one of the hardest materials on Earth. The method, where light is blocked on the two coordinate axes and can freely spread in the third one, has advantages over other methods. It is much simpler and requires materials with a small refractive index (Fig. 4) [4].

It is absolutely obvious that the considered tendency of concentration and transportation of natural light would be absolutely impossible without the using of parametric approach to the formation of architectural space as a system of conceptual, technological and aesthetic components.

3. PROTECTION FROM SOLAR RADIATION AND CONTROL OF NATURAL LIGHT

Another aspect of natural light modelling is protection from solar radiation.

This problem is widely described in publications about practical and theoretical developments in the field of shadow systems of sun protection [5–6], etc.

The developments using new methods of working with light, using innovative approaches, manifested in two forms: static and dynamic, are of interest.

An example of a static approach is the complex "Louvre Abu Dhabi" which was opened in November 2017 (UAE) and had been developed by the winner of the Pritzker prize architect J. Nouvel. In this complex city with exhibition area about 8000m^2, 55 Museum buildings are covered with a floating dome.

The complex pattern of the dome, as a result of geometric design repeated in different volumes and angles, is formed by eight layers, which are arranged in a certain order (four outer one and four inner one), which gives the dome an exquisite mesh structure, which realizes the constant struggle of shadow and light expressing the nature of this country. The geometric lace dome of "Louvre Abu Dhabi" creates the impression of intertwined palm leaves traditionally used in this country as a roofing material producing the effect of "rain of light" (Fig. (5) [7]. Inside the huge "floating" dome, the rain of light patterns illuminates the micro-city small galleries, lakes and landscapes.

The dome covers two-thirds of the Museum, creating shading and reducing energy consumption. In addition, the Museum complex passes light through the underground water channel, turning the space into a refreshing oasis. An example of dynamic reception in natural light control is the al Bahr office towers in Abu Dhabi, which also have a sun protection system. Fully glazed buildings have a movable facade consisting of 2000 dynamic panels, which can completely close or open the facade areas. The panels are equipped with photovoltaic cells, which react to sunlight and accumulate solar energy (Fig. 6),8]. This allows you to reduce

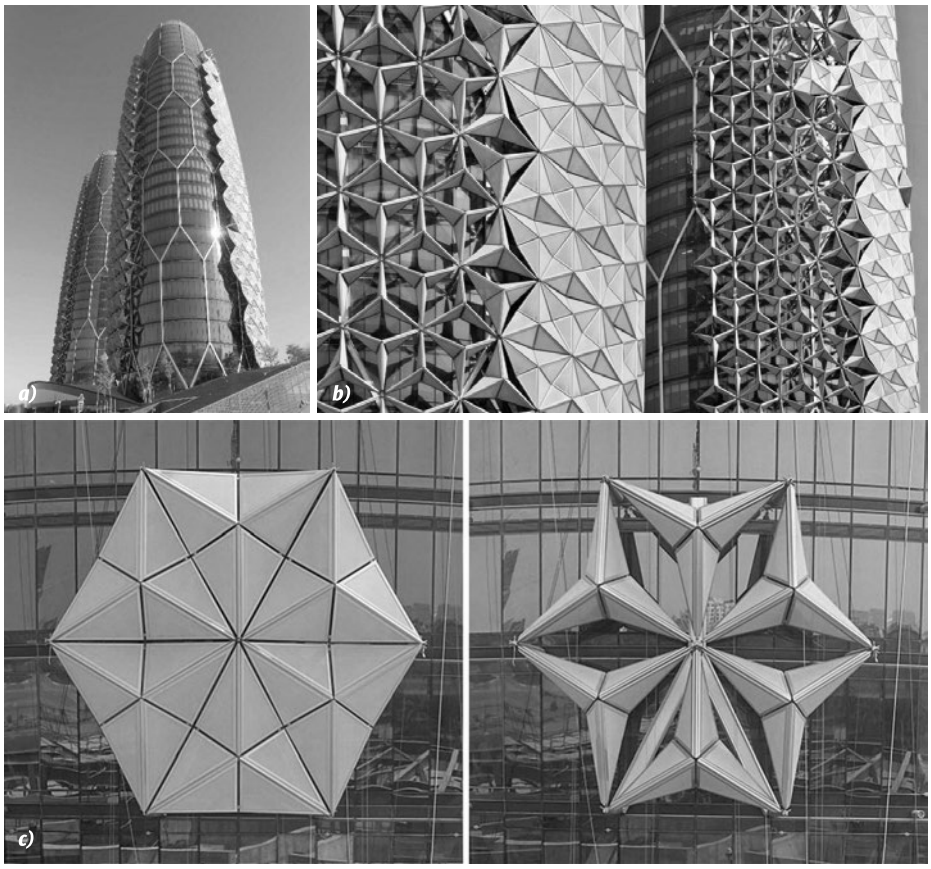

Fig. 6. The system of sun protection in the office towers "Al Bahr" in Abu Dhabi:
a – general view;
b – modification of sun protection devices;
c – transformation scheme panels

the temperature of the rooms and supply buildings with electricity.

The art centre in Shanghai also has a movable façade built by the Foster + Partners Bureau and the Heatherwick Studio [9]. A feature of the complex is a constantly changing, dynamic facade, which, in accordance with the required lighting of the interior space, can be transformed and significantly changes building view by moving a set of bronze pipes arranged in three rows and covering the main volume of the building, Fig. 7, [9].

Protection from solar radiation and control the fluorescent light causes the necessity of development and implementation in the development of kinematic methods of formation and functioning of architectural objects. This is due to the fact that natural changes and the nature of human activity determine the contradiction between the static and dynamic components of the environment under the influence of constantly changing factors of socio-cultural and natural environment.

4. ORGANIZATION OF LIGHT ENVIRONMENT OF ARCHITECTURAL OBJECTS

Innovative approaches to the formation of habitat are directly related to the modelling of natural light in the organization of the light environment of architectural objects.

This is manifested in the creative pursuits of the Swiss architect P. Zumthor. In 2010, the architect

Fig. 7. Dynamic facade of the art centre in Shanghai (China): general view (transformation options)

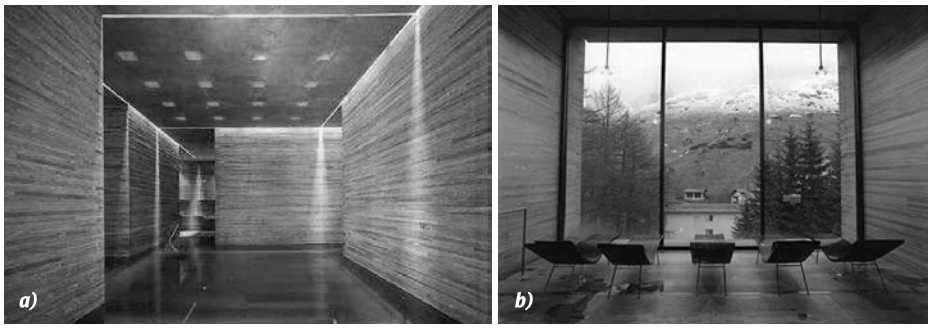

Fig. 8. Baths in Vals (Switzerland): a – the interior of the pool; b – the interior of the restroom

P. Zumthor won first prize at the prestigious competition "Daylight – Award" (in the category "Architecture")[1] for the project term in the Vals.

The thermal baths in the Vals, according to experts, gave reasons to take in attention the relationship of properties of water and stone, light and shadow (Fig. 8) [11]. At the same time, the light in the building of the Museum "Columbus" of the Cologne diocese plays a crucial role – "it snatches out space in time and broadcasts it to people, offering them to decide on the time." (P. Zumthor). Significant for P. Zumthor the construction of the chapel of St. Benedict in Sumvitg (Graubünden, Switzerland) (Fig. 9), [10, 11] may be attributed to an analogical case.

The trend of using bionic methods of consumption of the maximum amount of solar energy throughout the day is manifested in the project "solar cycle", developed by the architectural Studio "Paolo Venturella & Meno Meno Piu Architects" for the amusement Park "Freshkills park " (New York, USA). The object is both a large-scale solar battery and a multi-purpose pavilion for concerts, sports events, lectures, etc. The shape of the building structure aimed at the trajectory of the sun collects its rays at all angles (Fig. 10) [12]. The "solar cycle" has two surfaces. The first one, the photoelectric surface, looks always to the Sun, and the second one, the mirror, reflects everything around and multiplies the entertainment of the landscape distributing natural light under the closed part of the pavilion. In addition to the well-known and sufficiently detailed methods of collecting and concentration of natural light, the most effective solution is guaranteed by light-water systems [13, 14]. Such systems collect natural light through light intakes, installed on the roof and walls, and transmit it into the interior through hollow pipes with mirror surfaces.

The application in architecture of methods using biologically useful structures are the subject of research and design of architectural objects by many creative groups of architects, using in their activities, the methods of computational design.

[1] It should be noted that the idea of evaluating architectural works in the context of modelling light belongs to the Swiss foundation VELUX STIFTUNG, since 1980 supporting and financing projects related to the study of natural light and optimal possibilities for its use in medicine and architecture [10].

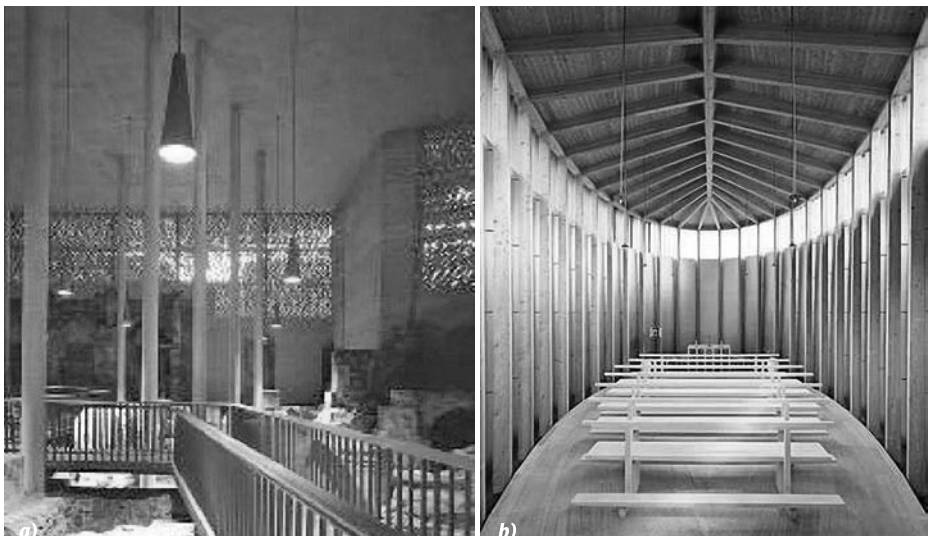

Fig. 9. Architecture of natural light by Peter Zumthor:
a – Museum, Cologne diocese of Columbus;
b – St. Benedict chapel in Sumvitg

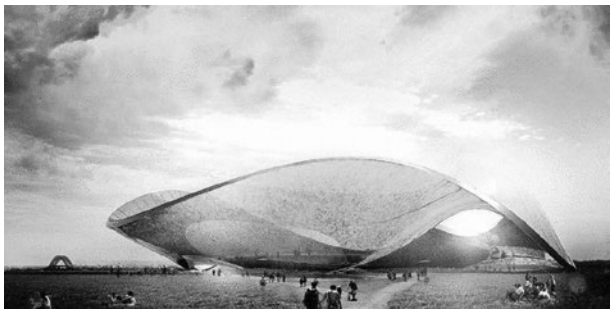

Fig. 10. Pavilion " Solar cycle"

The progressive direction in the development of architecture, using new environmentally friendly technologies in the creation of project proposals, is associated with a new attitude to the importance of maintaining of the environment and to the conservation of energy.

5. ENERGY POTENTIAL OF NATURAL LIGHT

Alongside with the considered methods of natural light modelling, the potential possibilities of solar radiation energy management arouse professional interest now. So, according to a well-known legend, Archimedes almost completely burned the Roman fleet, which attacked in 212 BC his native Syracuse in Ancient Greece to do this, he used an array of concave mirrors made of polished copper [15]. On the other hand, architects have always considered and took into account the power of solar lighting of buildings. And it is fraught with failure to account for force majeure situations. So, the new skyscraper, "Walkie-Toki", in the financial district of London, thanks to its configuration, reflects sunlight so intensely that it is able to melt the plastic parts of cars parked nearby (Fig. 11) [16]. The correct using of solar energy was demonstrated in 1970, in the creation of the solar furnace in Von ROM-Odeyo (Eastern Pyrenees, France) as an ecological source of high temperatures. The mirror structure has a diameter of 54 m and consists of 10,000 concave mirrors that reflect and focus the Sun's rays on a size measuring 40 cm diagonally. The group of mirrors acts as a parabolic reflector, which concentrates light in its focus. The furnace power is 1 MW. While on the contrary a parabolic mirror set a heliostat is a special mirror 63 plate with 180 partitions. The array of mirrors acts as a parabolic reflector, concentrating light in its focus. Each heliostat has a parabola sector, which reflects the collected light. On the concave mirror the Sun's rays gather at the point of focus, where the temperature reaches 3500 °C, and the temperature in the huge solar furnace can be adjusted by installing mirrors at different angles. Heliostats move after the Sun to maximize the collection of solar energy (Fig. 12) [17]. An illustration of the potential use of solar energy is the Solar Ark, the largest solar energy monument in Gifu (Japan) created by the company Sanyo, which is connected with the 50-year history of human relations with clean energy. A large photovoltaic system (declared maximum power of 630 kW) is combined with a modern scientific centre. The building has a "Solar energy Museum" and "Solar laboratory", which hold symposiums and forums to discuss problems and exchange ideas (in cooperation with the science Foundation of Japan and international organizations). The total length of the structure-315 m, height is the 31.6 m in the centre and 37.1 m at the edges, width is the 13.7 m at the bottom and 4.6 m at the top, weight is the 3000 tons.

Fig. 11. The skyscraper "Walkie-talkie", (London)

Fig. 12. Solar furnace in the Pyrenees (France)

Fig. 13. Solar energy monument "Solar Ark" (Japan):
a – facade; b – general view

The number of photovoltaic cells is equal to 5046, in the dark time on the façade 77200 cells of red, blue and green LEDs, controlled from a computer, are switching on.

The complex has water and air purification systems (95 tons of carbon per year).

"Sunny ark" is surrounded by a kind of Aqua Park, which includes fountains and two ponds, each of which has a waterfall (Fig. 13) [18]. The interior lighting of the complex is carried out by "Solight" lamps (unique products equipped with a compact engine controlled by a small solar battery), which automatically change the direction of radiation in accordance with the movement of the Sun in the sky, which is used as a source of natural light due to the lack of Windows in restaurants and other rooms.

In this regard, it is important to note the need to revise the usual means of architecture, taking into account the achievements in other fields of science and technology, especially to improve the comfort and safety of the environment, as well as to save financial costs and energy resources.

6. CONCLUSION

The typology of architecture is updated today with new types of architectural objects, which are the scientific and technological denominators of our epoch. Innovative ways of using natural light as an important component of the environment are presented in this article-review in the context of the conceptions considered in it.

The concentration and transportation of natural light change the perception of the surrounding space during the day and as the seasons change.

There is a possibility of natural lighting of underground spaces. More and more new ways of collecting of the natural light and creating "artificial sunlight" for the device to simulate realistic natural lighting in enclosed spaces are being invented.

Modern methods of working with light in different areas of man's activity are manifested in the sun and natural light control, which are associated with the use of new kinematic techniques of formation and functioning of architectural objects, using innovative approaches to working with light and manifested in two forms: static and dynamic. This indicates the need to revise the usual means of architecture and to expand the use of achievements in other areas of science and technology. Alternative approaches to the organization of the light environment of architectural objects are manifested in the creative researches of modern architects-researchers of light, sound and space. The emergence of the concept of "living light" and the trend of using bionic methods of consumption of the maximum amount of solar energy during a day is manifested in the developments of architectural objects, which is associated with a new attitude to the value of the environment, conservation of energy, increase comfort and safety of the people habitat. The energy potential of natural light (p. 5) and control of the latter are of the professional interest. A competent attitude to the use of natural radiation would be impossible without appropriate technical means and the development of high technologies, without the application of environmental principles in architecture.

The considered directions in the use of natural light, as an important component of existence, indicate the breadth of methods of its manifestation, and the variety of means of its transformation and regulation. In this regard, it should be noted that these examples of the use of natural light in the formation of the architectural environment arose due to many areas of knowledge, which are developing very actively.

The obtained results can be useful for the theory and practice of habitat formation, opening up completely new opportunities in architecture. This sets the task of further research of completely new methods of work in this direction.

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