USE OF UNDERGROUND SPACE IN DESIGN OF NEW AND ENLARGEMENT OF EXISTING MUSEUMS

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SUMMARY

The architecture of museums, as objects of building heritage and contemporary museums, which are aimed at linking the present and past by exhibiting the creativity of people and civilizations from the past, creates a framework for visitors to gain certain experience. In this regard, the paper discusses the use of underground space for expansion and revitalization of museums, as well as opportunities for the construction of new buildings according to condition fulfillment that ensure the quality of interior space and are in accordance with requirements for museum buildings. This paper concerns the underground structures in a natural environment with the aim of improving the ecological aspects of construction and achieving the energy efficiency. By analyzing possible positions in the ground, it is pointed to the use of passive building elements and directions for the future development of the museum architecture are given.

INTRODUCTION

Underground buildings are characterized by the unrecognizable form. Talking about museums, this fact at the same time has its advantages and disadvantages. The advantage is the fact that the horizontal and vertical plan of the building can develop freely, without reference to the compactness of the form, almost without limit, yet the functional solution must be taken into account. The lack of invisibility of the form is in the experience that is caused by a monumental building and the impossibility of representing environmental landmark of the place where it is located.

Underground architecture of the museum is sometimes a necessity and sometimes the symbol of a certain location where the construction is planned. The necessity implies the lack of space for expansion and extension of the existing building, or an architectural concept is like that in protected areas, whether it is the case of natural environment or significant places, as also in the case of connecting “past and present” through the underground architecture, aimed at preserving the old styles of building. There are also cases linking the old buildings of the museum with new ones of the modern construction, where the underground space is a physical link between two periods.

CONDITIONS FOR THE DESIGN AND CONSTRUCTION OF UNDERGROUND MUSEUMS

Designing the underground museum should primarily meet the requirements of the functional organization of the space, so that, in the unrecognizable space, the visitor would be directed with clear lines of communication to the contents that are the subject of his interest. The concept of the underground space of the museum, with a complete content, should be developed both horizontally and vertically, into the depth of the underground space. In relation to the need for natural light, the time of occupation and levels of social interaction, rooms should be grouped in the way that nearest to the surface and the entrance are those with the highest frequency (café-restaurants, souvenir shops). After that, there are exhibition rooms, and farthest from the entrance, levels with the shortest retention, that do not require natural lighting [4].

Constructive stability of the structure involves the use of materials resistant to the environment in which they are located, and concrete and steel are often used as a supporting construction. Underground structures are characterized by a longer lifetime compared to surface structures and better protection against all types of natural disasters [8]. The safety of people and exhibits in the building refers to the safe evacuation, and for that reason, communications must be straight, clear, easily accessible and in straight line [2].

Conditions for achieving ambient comfort in the underground space are concerned with the penetration of natural light, optimum temperature and air humidity for people's stay and exhibit conservation.

Due to the lack of windows in underground rooms which require natural light (rooms with a high level of interaction) and the feeling of comfortable stay that should be achieved in the underground space, the resort can be a roof light, if there is a possibility to create slits for natural lighting. It largely depends on the position of the building in the soil, in relation to the surface planning of the location, as well as the depth at which the underground building is located.

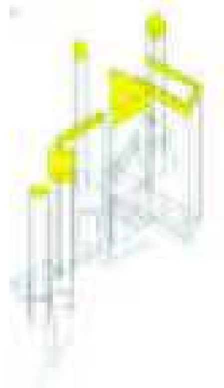


Fig. 1 Chichu Art Museum, Naoshima, Japan [4];

Fig. 2 The volumes that come to the surface and allow the penetration of natural light [4]

Underground building Chichu Art Museum, in Naoshima island, in Japan, is designed by Tado Ando [3] (Fig.1). Located deeply in the hillside, the museum is designed so that there is a possibility of penetration of sunlight even to the deepest spaces, through the carved volumes into the soil, which come to the surface, but in the way as not to disturb the natural environment (Fig.2).

Parameters which have to fulfill conditions under the regulatory requirements for museums are the temperature and humidity. Table 1 provides the optimal values, depending on items which are displayed.

Item on display	Temperature (°C)	Temperature variation (°C)	Humidity (%)	Humidity variation (%)
Books and paintings	18±2	2-5	50-55	5
Textile	18±2	2-5	50-55	5
Lacquerwork	18±2	2-5	60-65	5
Folk-custom	18±2	2-5	50-65	5
Metalwork	18±2	2-5	45-50	5

Table 1 – Optimal environmental conditions for preserving historical relics [8]

On the basis of many years of measurement, it is founded that in the shallow underground spaces, the temperature varies in the range 8-25 ° C and the values for humidity are 60 - 70%, per year [8], which is within the limits of prescribed values and supports the use of underground space for the museums.

Higher values of humidity are directly related to the characteristics of the environment in which the building is placed. They can be reduced by ventilation which prevents the appearance of moisture inside the building.

The fact that it is talking about underground buildings, it can be concluded that objects have a good sound-proof protection and are isolated from the noise of overhead events, which represents one of the conditions for designing museums.

Fulfillment of given conditions for construction and exploitation of underground museums ensures a long life of a building and maintaining of exhibits, and provides visitors with a pleasant stay within the underground space.

UNDERGROUND BUILDINGS WAYS OF FORMING

Underground architecture is typified by four design approaches illustrated by the relationship of the building’s mass to the surface (Fig.3). The building forms are categorized based on varying criteria such as exposure to sunlight and views, as well as their impact on the surface [4].

The task of designers is to harmonize the form of the underground building and its location in relation to the requirements of the project and characteristics of the soil in which the construction is planned. In this regard, it is done an analysis of typologies that represent: earth – covered spaces, submerged spaces, fully underground spaces and multi – level spaces.

Fig. 3 Underground buildings ways of forming [4]

Buildings covered by soil are characterized by a visible entrance and access from the ground level. In this typology a horizontal plan of an object is developed, dictated by the position of the entrance (Fig. 3a). Natural lighting can be provided from a front entrance, and the possibility of a roof light depends on the depth of the structure in regard to the top of the hill in which it is built, or the arrangement of the exterior when it is covered with a thin layer of soil.

La Valette German Underground Military Museum is an example of an object embedded into the hill, in the Channel Islands, in Great Britain [10]. The form of the object cannot be predicted, and only the entrance to the building is visible (Fig.4), where the only penetration of sunlight is possible (Fig.5). A horizontal plan of the building is developed into the depth of the hill, in the form of a tunnel, because its original purpose was a fuel depot. The natural environment is not disturbed by the existence of this building and it can be concluded that its form is well used for the needs of a museum.

Submerged buildings represent underground objects just below the soil surface, which in this case, is not a roof, but the area of the building is visually exposed to external events (Fig.3b). A plan for buildings of this type is such that it can be developed in depth. Access to the inside is achieved by vertical lines of communication. The form of the building cannot be seen, but this object can be a landmark, which is related to the roof. The roof is mostly made of glass, in order to use the penetration of natural light. Sunlight and exposure to outside environment are a favorable influence on the consciousness of visitors, making their stay enjoyable and time spent in the building longer. In this typology of building, the impact on the environment and its design is the most pronounced. As the negative side of this type of buildings, the limits in a horizontal plan development can be specified.

Fig. 4 The entrance of La Valette German Underground Military Museum [11];

Fig. 5 Looking towards the entrance from the inside of the building [12]

Extension of the Louvre Museum (Musée du Louvre) in Paris, France, is the most famous example of this typology of buildings [8]. Due to the necessary expansion of the building capacity and the inability to extend on the site, there was an idea to use the space under the Napoleon square for underground extension. The modern architecture of a glass pyramid that rises above the underground object is embedded in the environment in the best way and as a landmark structure is a blend of past and present (Fig.6). The main entrance to the museum is through the glass roof and vertical lines of communication leads to the central hall (Fig.7). Although in this case it is not about the building which was created in a natural setting, the Louvre is the inevitable example of a typology of buildings submerged into the ground.

Fig. 6 Display of the old building of the Louvre Museum and the underground extension covered with the glass pyramid [13];

Fig. 7 Access to the central hall by vertical lines of communication [11]

Fully underground buildings may be located at lower or greater depths within the soil, so that their position does not disturb the arrangement of the surface (Fig.3v). The objects have minimal connections with the outer environment, and the connection is realized only through the entrance, or through underground spaces of adjacent of buildings. The design is reduced to a functional plan and interior decoration, which means that the form of the building is not visible. Access communications may be long and, in that case, there is no possibility of natural lighting and ventilation, which is compensated by mechanical devices. The position in the ground, for buildings of this typology, has advantages of heat and noise isolation from the influence of the outer environment, which is a condition for museum construction.

An example of a fully underground object is Takayama Festival Underground Art Museum, in Takayama, in Japan (Fig.8) [9]. It was built within the rocks, at depth greater than 30m. There are two accesses to the building, in the way of horizontal tunnels, 80m and 70m long, leading to the exhibit hall, which is in the form of a hemisphere with a diameter of 40.5m. For the purpose of security, additional tunnels were formed around the hall.

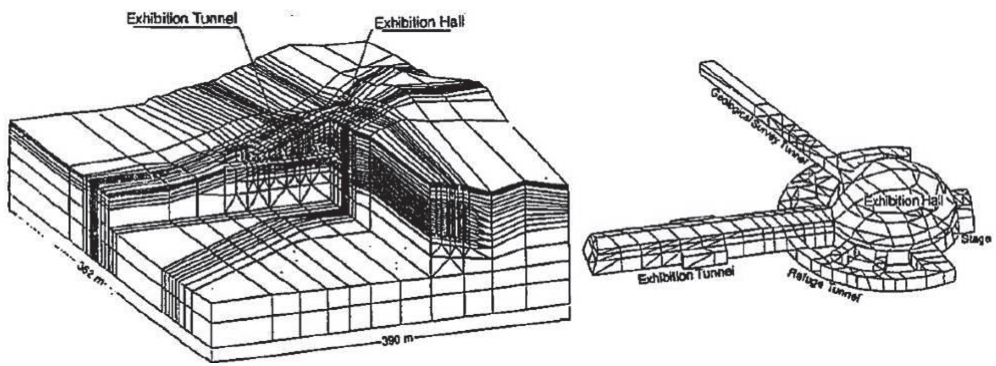


Fig. 8 3D terrain representation with a marked building location and form of the museum [9]

Multi – level buildings physically and visually link the surface with the underground space (Fig.3g). Although a similar bond is conducted in the case of a typology of buildings submerged in the ground, a difference in venue interactions can be made, which in this case is conducted through the building, and in the previous one, exclusively through the entrance on the surface. Position of a building affects the arrangement of the environment. The entrance is usually at the ground level, which increases the number of visitors. This typology provides good opportunities for functional organization, so that spaces of social interaction could be grouped in the above ground level, and exhibition spaces in the underground, because they demand a better isolation and limited penetration of solar lighting.

The project of Chatham Sofer Memorial in Bratislava, in Slovakia, is designed by architect Martin Kvasnica [4]. By the architectural plan of the building on two levels, and the form and processing of the overhead level of the building, the existence of the underground space and its purpose is stressed (Fig.9).

Natural light has a penetration through the entrance and from the top of the prism, which is open to the sky. In the underground level of the building is deepening the sense of mystery, and the dark expanse of graves and monuments, in addition to dim artificial light, is illuminated by sunlight which is introduced into the space through the openings in the roof structure, which corresponds to the location of the monuments in the basis

(Fig.10). Symbolic transparent elements of the panel form emerge through these openings to the surface and make a base plan visible on the site, which is arranged with greenery.


Fig. 9 Chatham Sofer Memorial [4];

Fig. 10 Penetration of sunlight into underground level of the building [4]

Presented typology and examples of buildings create a successful image of the underground design and construction, and offer visitors the possibility that symbolism of dark and closed space experience in another way.

THE INFLUENCE OF UNDERGROUND SPACE ON ENERGY EFFICIENCY OF BUILDINGS

One of the most important advantages of underground buildings is energy efficiency [1]. Given that energy efficiency means saving all kinds of energy from the start of construction and during operation, this paper will deal with the utilization of passive building elements which are related to decisions made by the designer, concerning the selection of location, position in the soil, building orientation, insolation etc.

The possibility of utilization of natural light depends on the typology of the designed building, its position in soil, the depth of spreading and ground arrangements. In the presented typologies of buildings, in all cases it is possible to partly expose the underground structure to the sunlight, except when it is fully underground and deep in the soil.

The use of natural lighting not only reduces the need for artificial light, but it is irreplaceable in the psychological sense of connecting the human with the natural environment and creating a feeling of pleasant stay in the underground space. Sunlight is from that side preferred in the spaces of social interaction. Although the best visibility of exhibits is in this light, it is avoided because of destructive effects of direct radiation to exhibits, so it is suggested that, if the options allow, when designing the underground museum, the light should be indirect. Direct lighting can negatively affect people and elements in the interior, due to excessive heat in summer, and then it is resorted to protection in the form of curtains.

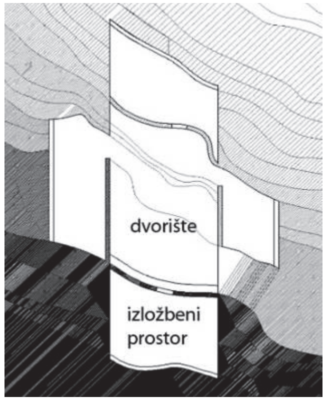
Based on the characteristics of underground space it can be concluded that buildings isolated by ground have thermal stability throughout the year and small temperature fluctuations in relation to temperature differences on the surface, and also a good sound-proof protection, so that museums can be built even in places which are characterized by above-ground noise. In this regard, thermal and sound conductivity of soil is minimal.

Thermal stability is provided and it increases with the thickness of the soil above the building. In this case, thermal insulation is not needed or is reduced, depending on the climate zone in which the building is located. If the soil layer is thinner, construction of green roofs is suggested to improve energy efficiency and reduce heat loss in winter and heat gain in summer. Typologies of buildings suitable for the performance of green roofs are buildings covered with soil, fully underground buildings and multi – level buildings.

The case when the underground object is in shallow soil or is peripherally placed underground in relation to overhead levels, allows the construction of an intensive green roof [7] above the underground part of the building. The construction of this type of roof is characterized by great load and consequently may have a role of park areas. In addition to environmental factors, which are reflected in the increase of surface vegetation, whether it comes to urban city centers or the preservation of the natural environment, green roofs are important for achieving energy efficiency by insulating properties of the layers of the roof. Greater thickness of soil, or substrate as a green roof layer, and homogeneous vegetation, retains heat in summer solar radiation in layers, a part of radiation is absorbed, and other part is reflected, while plants in winter in hibernation phase, under a layer of snow, and the soil, act as thermal insulation and prevent heat emission from the interior. According to research, green roofs reduce heat flow by 70 - 90% in summer and winter heat losses by 10 - 30% on an annual basis, and reduce the need for cooling and heating systems in accordance to seasons [6].

Increased air humidity in underground buildings is directly related to the environment and reduced possibility for natural ventilation. In this case, ventilation must be provided with mechanical devices. Beside ventilation, the best way to secure a lower relative humidity is the selection of the type of soil, and research shows that clay contributes to reduction of 35% or more [1].

Groundwater level also affects the increasing of humidity inside the underground building and on that basis, it is recommended to use materials which prevent the occurrence of moisture (asphalt, waterproof concrete, sheet metal, etc.) and constructing elements which can eliminate the excess moisture, like vapor permeable facades and vapor absorptive interior dividing walls [1].



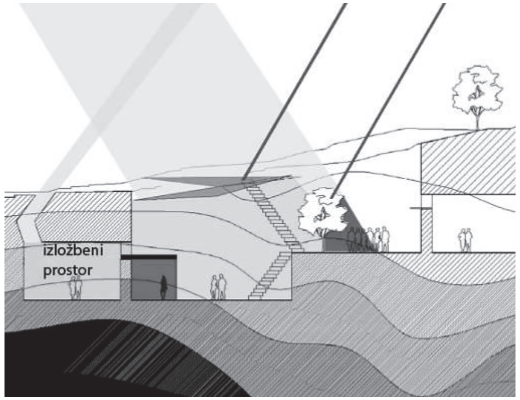


Fig.11 Horizontal plan of the underground museum [5];

Fig. 12 Cross section showing the intrusion of direct and indirect solar radiation [5]

Since the relative humidity of the underground space is approximately 60 - 70% [8], and on the basis of prescribed values for exhibits from 45 - 65% (Table 1), it can be concluded that the underground building meets the requirements for exhibit display.

Stability of environment is what characterizes underground spaces and it is more important for museum buildings than individual temperature values and relative air humidity.

An underground museum in the village of Sahmuratli, in Turkey [5], was designed so the passive building elements were used. It is located in the natural environment and buried in the ground, which prevents the influence of dominant winds. The museum plan consists of four underground spaces around a common courtyard (Fig.11), where the microclimate is created due to sun shade and vegetation densities in it. Orientation of the rooms is such that the exhibition hall is on the north, in order to ensure indirect lighting. A series of windows set high on the visible facade, and a horizontal range on the ground surface which allows the roof lights, are designed in order to have better insight into the exhibits in the exhibition space (Fig.12). Direct solar radiation is alleviated by high vegetation.

Based on the simulation which was made for this model and which is relevant to thermal performances, it has led to the fact that in summer months the internal temperature was about 10°C lower in regard to external, and daily fluctuations were 4°C for internal, compared with 18°C for external temperature. The constant temperature of 20°C, in fact, represents the ideal temperature for preservation of exhibits. It can be concluded that energy consumption for cooling the building, during the summer, is significantly lower than it would be for ground building in the same climatic zone. Relative humidity of 80%, in summer, is higher than required for museum buildings. If we take into account the daily fluctuations of 10% for indoor humidity and 50% for humidity of external environment, it can be concluded that minor deviations have better effect on exhibits even in the case of increased values, which can be reduced by the ventilation system and reach the value around 50%.

CONCLUSION

The use of underground space in design of new and enlargement of existing museum is of great importance, especially for this type of buildings. Underground space as a symbol of mystery, mysticism and the unknown, is a good starting point in the concept of designing museums, because due to inability of visual perception of the building, visitors are attracted to the symbolic position in the soil in which objects are located.

Limited demand for natural lighting in underground museums, meet the basic requirement of the underground design and justifies the concept. Thermal stability, acoustic isolation, security, safety and longer life of the underground objects, are in favor of preserving exhibits and purpose of the building.

By the importance of specific location and the symbolism which it has for the construction of the museum, its existence is justified precisely on the place where it is scheduled. Due to limitations which may arise for the construction of the building above ground, one of four established typologies of underground structures can be selected, where an underground building can be partly exposed to outer environment, or may be fully underground. In cases which are not subject to restrictions of construction, the selection of a typology is on the designer.

Underground buildings, in accordance with ecological aspects of construction, enable the creation of greenery on the surface location and the use of passive building elements in order to achieve energy efficiency, which provides guidelines for the museum architecture in the future.

BIBLIOGRAPHY

[1] Alves, H.; Mendoca, P. - "Underground Contemporary Houses in the North of Portugal", Conference On Technology & Sustainability in the Built Environment, Riyadh, Saudi Arabia, 2010., pp. 649 – 670.

[2] Cooper, G. – "Project Japan: Architecture and Art Media Edo to Now", Images Publishing, 2009.

[3] Crimm, W. L.; Morris, M.; Wharton, L. C. – "Planning successful museum building projects", Rowman Altamira, 2009.

[4] Devers, M. G. – "Building Under the Ground: An Exploration of Spirituality, Visibility and Presence in Architecture", MARCH paper, 2010.

[5] Gomez, M. M. – "Thermal performance of an underground museum in Turkey", International Conference - Passive and Low Energy Cooling for the Built Environment, Santorini, Greece, 2005., pp. 203 – 206.

[6] Lui, K.; Minor, J. – "Performance Evaluation of an Extensive Green Roof", Greening Rooftops for Sustainable Communities, Washington, D.C., USA, 2005., pp. 1 – 11.

[7] Peck, S.W.; Callaghan, C.; Kuhn, M.E.; Bass, B. – "Greenbacks from green roofs: Forging a new industry in Canada", Canada Mortgage and Housing Corporation, Ottawa, Canada, 1999.

[8] Ping, Z.; Zhilog, C.; Hongyu, Y.; Hui, W. – "On utilization of underground space to protect historical relics model", Tunneling and Underground Space Technology, 24, 2009., pp. 245 – 249.

[9] Sakurai, S.; Chikahisa, H.; Kobayashi, K.; Tsutsui, M. – "Design and construction of the festival underground art museum, Japan", Underground Construction in Modern Infrastructure, Rotterdam, Nederland, 1998., pp. 3 – 11.

websites:
[10] http://www.thetraveleditor.com
[11] http://www.flickr.com
[12] http://members.virtualtourist.com
[13] http://www.vidisvet.com