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The Performance of Natural Light by Roof Systems in Cultural Buildings

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***Abstract*—**This paper presents an approach to the performance of the natural lighting, when the use of appropriated solar lighting systems on the roof is applied in cultural buildings such as museums and foundations. The roofs, as a part of contact between the building and the external environment, require special attention in projects that aim at energy efficiency, being an important element for the capture of natural light in greater quantity, but also for being the most important point of generation of photovoltaic solar energy, even semitransparent, allowing the partial passage of light. Transparent elements in roofs, as well as superior protection of the building, can also play other roles, such as: meeting the needs of natural light for the accomplishment of the internal tasks, attending to the visual comfort; to bring benefits to the human perception and about the interior experience in a building. When these resources are well dimensioned, they also contribute to the energy efficiency and consequent character of sustainability of the building. Therefore, when properly designed and executed, a roof light system can bring higher quality natural light to the interior of the building, which is related to the human health and well-being dimension. Furthermore, it can meet the technologic, economic and environmental yearnings, making possible the more efficient use of that primordial resource, which is the light of the Sun. The article presents the analysis of buildings that used zenith light systems in search of better lighting performance in museums and foundations: the Solomon R. Guggenheim Museum in the United States, the Iberê Camargo Foundation in Brazil, the Museum of Fine Arts in Castellón in Spain and the Pinacoteca of São Paulo.

***Keywords*—**Natural lighting, roof lighting systems, natural lighting in museums, comfort lighting.

I. Introduction

CULTURAL places, especially museums, need a great deal of attention in the design of the systems, especially with what will allow the visibility of the exposed art, that means, the adequate lighting project.

The use of zenithal systems of natural light allows the performance of different roles, which can be fulfilled if properly designed, such as: meeting the needs of natural light for the accomplishment of the internal tasks, attending to the visual comfort; to bring benefits to the human perception and its experience in the space, besides contributing, when well dimensioned, to the energy efficiency and consequent sustainability character of the building.

Visual comfort is one of the criteria of environmental comfort in architecture, it is considered that "a person is comfortable in relation to an event or phenomenon when he can observe or feel it without worry or discomfort" [5]. According to this premise, it can be said that the user is in a situation of visual comfort when in the environment there is the necessary illuminance to carry out the task, well distributed, with the appropriate contrasts and absence of glare. However, this technical panorama should be broadened in the search for visual/ light comfort to an area geared to the experience in place, because light influences the user's environmental perception.

The perception and experience of the individual or in the group in the environment and the human relationship with the sunlight is a relevant factor not only for life to be possible on Earth, but it is also responsible for some physiological and psychological aspects, but it is also responsible for some physiological and psychological aspects influencing the human perception. It is essential that architecture appropriate this light for the experience lived inside the spaces. According to Hopkinson, "light is a visual manifestation of radiant energy and, consequently, is closely related to human sensations" [8].

The human relationship with the sun's light reaches these dimensions mentioned, since from our ancestors we relate to the sun and the light produced by it, affecting cycles, providing life, influencing the perception of the place. This relation goes beyond the physiological influence in the beings; there are proven psychological influences, as well as those in the perception/ relation with the environment.

The perception of the surrounding environment is mostly by visual perception and this depends on the light to occur.

> "But light is more than a physical cause of what we see. Even psychologically it remains one of the most fundamental and powerful human experiences ... For man, as for all diurnal animals, it is the prerequisite for most activities. It is the visual counterpart of that other animating power, the heat. It interprets for the eyes the life cycle of hours and seasons" [1].

Therefore, natural light contributes to the identification of the individual with the environment, through its spectrum more appropriate to the human eye and understanding that these relations are completed in the mind of each one, with their respective load of lived experience, and with different cultures and expectations.

Another necessary role is to meet the criteria of energy efficiency in the built environment. The economics of the use of artificial lighting systems must be one of the premises of a more efficient project and the use of natural light should be the first strategy to be considered.

In a critical energy scenario, there would be no chance of a return to solutions like those adopted in some post-war museums that ignored the use of natural light. Nowadays, it is necessary for buildings have higher energy efficient and

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environmental qualities, including museum buildings:

According to Gauzin-Müller,

> "the search for environmental quality is an ancestral attitude that seeks to establish a harmonious balance between man and the nature that surrounds him. Practiced by necessity for centuries, in particular in domestic and vernacular architecture, it fell into disuse after the Industrial Revolution, at a time when man believed in his omnipotence and exploited, without control the resources of the planet" [7].

The large zenithal lighting systems are widely used in shopping centers and corporate buildings, and may be a suitable solution for museum coverage.

Cultural centers receive many visitors and need constant conditioning of temperature and humidity of the air, so energy consumption is an important factor to be considered in the design of a museum and the use of these systems can contribute to reduce unnecessary energy consumption.

The optimized use of natural lighting, therefore, whether zenith or lateral, contributes to the conservation of energy in buildings by avoiding the use of artificial lighting unnecessarily, as well as favoring the visual perception of the user, and thus, raising the project´s quality.

Nowadays it be expected from museums, and probably has always been expected in addition to the collections, to have an environment in which the experience lived while traveling is culturally rich in sensations, knowledge, contemplation, questioning, and everything else that the art can provoke.

The architecture can, with the zenith lighting properly designed and executed, assist and even promote these goals in the relation between user-space-environment.

II. The Importance of Using Zenith Light in Museum´s Architecture

Natural light was the only way of illumination of the collections in museums until the beginning of the 20th century. From the advent of artificial lighting as we use it today, different currents of scholars of the area defend divergent opinions about the use of natural light for museums. Frank Lloyd Wright, author of the Guggenheim project in New York that will be presented later, advocated the use of natural light in works of art exhibitions:

> "To show any painting as the healer is usually desired to be seen in a constant flow of fixed artificial light, directed from the chosen point and regulated to a standard need. But the charm of any art work, as well as painting, sculpture or architecture is to be seen under natural, usually variable light These changes of light are natural for the range of paintings as well as for all objects of art and, then, are more interesting to the observer scholar" [11].

Zenithal light, defined by the standard NBR 15215-2, "is considered as the natural light that enters through the upper closures (roofs) of the internal spaces" [3], has enormous capacity in capturing the luminous solar radiation, direct and diffuse from the celestial vault and reflections of the environment. It is a feature that provides greater uniformity of distribution of light than lateral lightning.

The premises for the good illumination of museums can be considered as: uniformity; minimum levels of illuminance (measured in lux); flexibility of local service; excellent color reproduction; controlled contrast; energy conservation and conservation of works of art. Direct sunlight needs to be avoided for the maintenance of the collection and so as not to cause the unwanted effect of glare to the observers.

Different characteristics of the artwork will require a more specific general lighting project. The standard NBR 8995-1 [2] recommends illuminance of 300 lux for exposure sites, but stresses that this orientation is general and not specific, and that the type of work of art and the form of exposure must be observed before the determination of the lighting levels.

It should also be noted that films of semi-transparent photovoltaic films are already being used in zenith light resources for the local generation of energy, which could be applied in museums for the performance of greater energy efficiency.

Fig. 1 Semi-transparent photovoltaic system of the Isofóton factory, Spain [4]

In addition to the technical assistance, zenithal illumination of natural light may ultimately contribute to life within in the museum space, influencing the perception of the user and their interrelationship with the built environment.

III. The Zenithal Lighting Systems: References in the Cultural Arena

The following article presents museums that have been taken as positive references in the performance of natural light.

A. Solomon R. Guggenheim Museum in the United States and the Iberê Camargo Foundation in Brazil: Clarinet and Atrium System

A masterpiece of architecture designed by Frank Lloyd Wright, the New York Guggenheim, built from 1956 to 1959, has in its central spiral form the most compelling purpose of penetrating natural light that "shapes" itself through the effects of light and shadow, full and empty, like a spiral-shaped building covered by a large skylight.

Wright developed the Guggenheim to include elements of nature as a premise of design, such as plants, water, more

natural materials and finally, natural light. Therefore, the light of the sun is one of the fundamental axes of this work.

Fig. 3 shows the floor plan with the proportion of the skylight in relation to the set, allowing to visualize the size of the light intervention in the whole.

Fig. 2 New York Guggenheim atrium skylight [12]

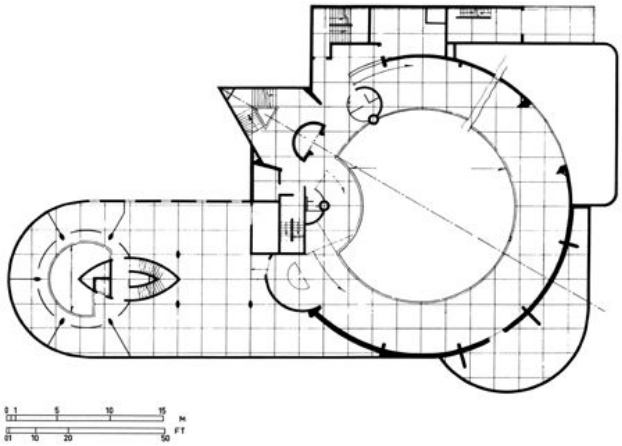

Fig. 3 The New York Guggenheim floor plan [12]

Natural light plays the main role in the formal internal composition of the project, interfering with the experience lived in the interior, expanding a positive visual perception that certainly collaborated with all the recognition of the work. The building stimulates the experience of going through it, always presenting itself in different ways, from different angles of observation. For this way of experiencing the place, natural light has a prominent role, with its seasonality, its variations of the temperate of color (in Kelvin unit), and in the case of the Guggenheim, collaborates for the different observations that the place suggests:

> "In many buildings you notice them better by standing still in one place and taking them in. But the only real way to experience the roundabout is to move along the spiral... Because it's the experience of…feeling the space change, feeling yourself go round and round at this remarkable pace that Wright sets for you… seeing a piece of art that you have just seen close-up again across the rotunda from a distance. All those things are essential to the experience of the Guggenheim. It's a building that you cannot experience by sitting in one place…. It was Wright's idea that the building is about movement through space as much as it is about space itself" [10].

A parallel of the formal concepts of the Guggenheim with the Iberê Camargo Foundation, Alvaro Siza's first project in Brazil, has already been done by authors who compare the way of contemplation and living through movement within these buildings. In the case of this foundation in Porto Alegre, on arrival, the visitor is led to climb up the elevator to the top floor and down the ramps the three floors of the building for the experience to occur.

Fig. 4 Atrium skylight of the Iberê Camargo Foundation of Porto Alegre [13]

The opacity glass skylight on the last floor permeates light through the atrium and a lighting system controlled by computerized sensors balances the external light coming from the skylight with the artificial system distributed in the other floors. The systems with lamps on the lower floors reproduce the same intensity as the natural light, based on the light that enters the light system, saving energy and harmonizing the integration of the natural and artificial systems. This system allows the propagation of external light in a diffused way, which is considered a very appropriate resource, as it enables a more uniform distribution of light, an important result for exhibition spaces and avoiding unwanted glare. A very similar solution can be observed in James Stirling's postmodern architecture for the 1984 Neue Staatsgalerie in Germany, as can be seen in Fig. 6.

Fig. 5 Skylight on the last floor and artificial light systems on other floors; view from the atrium of the Iberê Camargo Foundation [13]

Fig. 6 Diffuse natural light system. Neue Staatsgalerie [15]

B. Museum of Belles Arts of Castéllon, Spain: Zenithal Light System

The Spanish Museum of Fine Arts in Castellón was designed by Luis Moreno Mansilla and Emilio Tuñón, creators of a number of other museums. Opened in 2001, it is considered by Montaner as a "context-inspired architecture" [9]. And in the context of its functions, the museum makes use of a lightning system in series that allow the access of natural light to the interior.

The museum is organized in three distinct buildings, following the same typology of coverage. However, the light is directly accessible to the environment, or diffusely by the presence of shutters implanted with a distance from the facade where the glass spans are found, as can be seen in Figs. 7-9.

Fig. 7 System of lighting in the roofs at the Museum of Fine Arts of Castellón [16]

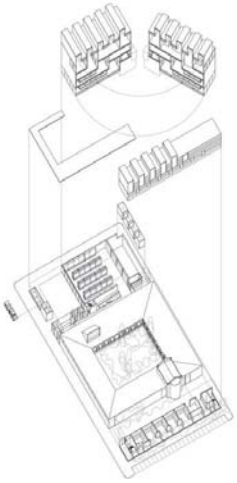

Fig. 8 Perspective design of roofing systems at the Museum of Fine Arts of Castellón [16]

Fig. 9 Internal view of the lantern system in the roofs at the Museum of Fine Arts of Castellón [16]

This system, because it brings lateral incidences of natural light, must be compensated with a project of artificial lighting attending the sides disadvantaged by the distribution of natural lightning relation to the points of the exhibition.

This light system series was also the resource used in the Museum of Grenoble, France, as can be seen in Fig. 10.

Fig. 10 System of light in the roofs at the Museum of Grenoble [14]

C. Pinacoteca of São Paulo, by Paulo Mendes da Rocha

The Pinacoteca of the State of São Paulo received a great skylight when interventions were made in its original architecture by the architect Paulo Mendes da Rocha.

The skylight caters to a large central region where sculptures are displayed. Effects of light and shade that the natural light of direct incidence brings are the best results for this category of exposure, valuing the contrasts and the shapes.

A major concern in projects with a direct incidence of radiation is overheating because,

> "In tropical regions as in the case of Brazil, and especially in the example of the Pinacoteca, where there is excess colorless glass without any protection; because of the greater vulnerability they present from a thermal point of view, they cause a greater discomfort for the user, an increase in the use of air conditioning and, consequently, a higher consumption of energy" [6].

Fig. 11 Skylight in the central area in Pinacoteca of São Paulo [17]

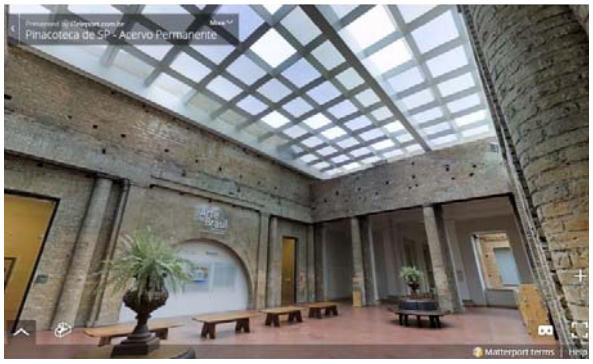

Fig. 12 Skylight in the central area in Pinacoteca of São Paulo [17]

In spite of the fact that they are located under favorable climatic conditions in the countries of the American and European (Northern Hemisphere), also is necessary to make use of this resource in the Southern Hemisphere, especially in Brazil which the solar radiation is abundant and that´s means quality in natural lighting gains in buildings.

All the care taken in the orientation of the project in relation to the sun, such as the specification of the elements of transparent closures, glasses with adequate solar factor, for example, appropriate sizing of the spans, are guidelines to captured natural lighting with the smallest heat transfer to the interior of the building.

The selected museum projects have contributed to fuzzy assessments about the management of superior access sunlight in these environments.

IV. Conclusion

It possible to say that zenith lighting is an appropriate resource for museums attending to a wide range of exhibition types, based on the research of the bibliography studied and the analysis of the references presented in this article.

The understanding of the research leads to the encouragement of the use of natural light in an adequate way, because in this way it can play important roles and meet different dimensions in museums, such as: the dimension of visual comfort, the dimension of user perception and dimension sustainability in the built environment.

In order to correctly design zenithal light systems from the environmental point of view and comfort to the user, it is necessary to encourage research and studies aimed at its design, energy calculations and assessment of thermal and visual comfort standards; in this way, elements can contribute considerably to the quality of the project as a whole, with a positive environmental interrelation.

The prescriptive and software's for design calculations with natural light need to be more user friendly and accessible to enable more interaction with architects, and thus, the quality of the use of sunlight is magnified.

Research that advances towards better solutions for the use of the natural light of the sun is relevant, as it will bring unfolding at different levels: economic, human and environmental.

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