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Daylighting simulation as an architectural design process in museums installed with toplights

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ABSTRACT

Museums have the most complicated lighting criteria of common building types. A stable lighting environment for visitors and artworks should be guaranteed within the exhibition areas of museums. This paper presents a challenge to the application of daylighting simulation integrated into the architectural design process (DSADP). The scale model measurements and computer simulations were carried out to verify the computer program RADIANCE. A comparison between the measurement and simulation results showed that there was considerable relative error at measurement points. Therefore, a correction factor (CF) and corrected simulation (CS) were recalculated to correct the simulation results. The Seoul Museum of Art (SMOA) was selected to make an application of DSADP. The monitor and sawtooth-shaped toplights were chosen as attractive alternatives for the existing skylight of SMOA. The application of DSADP was carried out by changing the light transmission efficiency and opening size of the toplights. The RADIANCE results showed that computer simulation models can accurately represent the lighting environment under clear sky conditions, and more importantly, they can be used to propose an alternative toplight for SMOA. Therefore, the research results showed that DSADP technology would be very useful during the schematic design stage of the architectural design process. The findings of this research also suggested that there are large differences between the real sky conditions for scale model measurements and the CIE sky conditions for computer simulations. More studies are required to reduce the differences between real and simulated sky conditions.

1. Introduction

Over the past two centuries, museums have evolved with the changing needs of their visitors and the shift in the focus of their exhibits. Currently, museums seem to fulfill multiple functions, including the display and conservation of artworks, research, public education programs, and cultural events. Therefore, exhibits should be displayed in ways that enable visitors to see, manipulate, and interact with them, and more importantly, in ways that attract a visitor's attention to their subject matter.

Many architects have tried to support richer visitor experiences by enhancing the effectiveness of display methods during the design process. It has also been believed that art objects should be displayed and viewed under the same lighting conditions as those under which they were created. Historically, architects have opted for natural light in museums. Their main responsibility was to ensure optimum illumination for each artwork by effectively controlling the duration and total exposure to natural light, and thus providing the correct intensity of illumination [1]. In particular, there has been a need to handle bright daylight cautiously in order to maintain the ideal illuminance distribution for revealing the unique beauty of each artwork to the museum visitors. Nonetheless, the irregular distribution of daylight and the direct sunlight passing through windows and other openings have caused difficulties not only in the display of artworks but also in their conservation.

Architects are interested in natural light for its energy conservation benefits as well as the opportunities it presents for utilizing various light qualities and color rendering effects. Museums benefit more from the qualitative than the quantitative aspects of daylighting. In the circulation areas of museums, the principal objective of the lighting environment is satisfying the information needs of visitors. Daylighting can be valuable for orientation and visual relief, particularly in very large institutions, where the visitors' experience will be much more enjoyable and less tiring if they do not feel lost in an endless maze of rooms. Daylighting can emphasize important or beautiful architectural forms and the natural illumination of surfaces adds a quiet sparkle to spaces.

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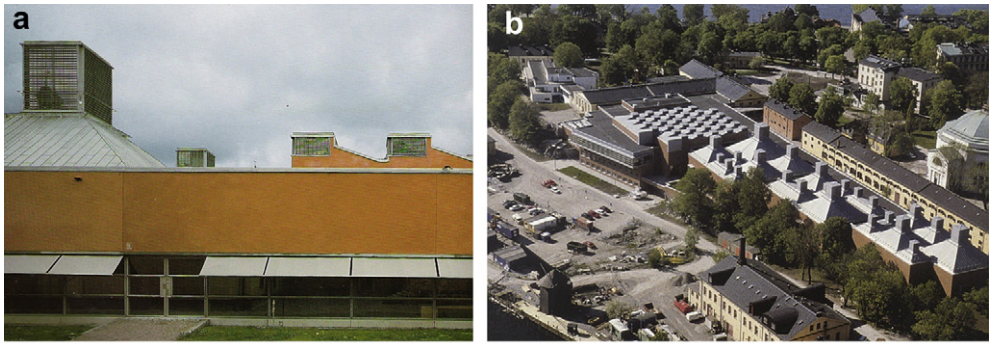

Fig. 1. Examples of museums installed with monitor-shaped toplight.

However, the deterioration of collections and the glare problems have caused a major reassessment of the use of daylight in museums despite its benefits [2,3].

The SMOA has faced numerous problems as a result of excessive sunlight entering through the skylight. Because these problems have not yet been resolved, they have raised serious concerns about the preservation and conservation of the artworks on display.

A monitor-shaped toplight system (MTS) and sawtooth-shaped toplight system (STS) [4] were selected as attractive alternatives to the existing skylight of SMOA. The MTS toplight system is constructed perpendicular to a roof surface, and it can effectively block direct sunlight from entering the exhibition space because of its deep light well. Architects have often used this type of system in museum projects to provide display conditions that benefit both the visitors and the exhibits. For example, Raphael Moneo and Josef Paul Kleihues used it in the Museum of Modern Art and the Museum of Contemporary Art, respectively (see Fig. 1).

The STS toplight system was originally used in factories and warehouses. However, architects have recently begun using it in museums because of its unique ability to control the sunlight entering an exhibition space. The architects Annette Gigon and Robert Irwin used this system in the Extension of the Winterthur Museum of Art and the Beacon Museum, respectively (see Fig. 2).

The use of daylight has only recently been regarded as an important element of architectural design for the additional benefits of energy conservation and being environmentally friendly [5,6]. Architects can gain the full benefits of the use of daylight by adopting the most advanced technologies in their daylighting designs.

Daylighting simulation has been used to predict internal illuminance, with graphical simulations providing a high degree of accuracy for museums under different sky conditions. It enables architects and lighting engineers to simulate complex lighting environments during the architectural design phases.

In this study, the computer program RADIANCE was used to evaluate the use of daylight in the exhibition spaces of SMOA. These exhibition spaces were designed to take advantage of daylight as a source of natural light. However, exhibits have been irreparably damaged because of their excessive exposure to sunlight.

The use of computer programs for daylighting design has attracted the interest of architects and lighting engineers. RADIANCE is a ray-tracing software that enables accurate and physically valid lighting and daylighting simulations. It has been successfully applied to the design of many buildings, although its use is limited by constraints such as the differences between real and simulated sky conditions.

Researchers have previously used RADIANCE to predict various aspects of daylight illuminance, including the illuminance distribution based on information about the incoming light [7–9], the problem of glare [10,11], energy savings [12,13], and sky luminance distribution [14]. Although the quantitative and qualitative aspects of daylighting have been evaluated, daylighting has not been studied as an integral element of the architectural design process. Consequently, this study attempted to show how it can be integrated into an architectural design using the daylighting analysis software RADIANCE. The basic steps of the research process are shown in Fig. 3.

2. Spatial characteristics of SMOA

In this study, RADIANCE was applied to assist with the design of SMOA in Seoul, South Korea. SMOA is located in the Jeong-Dong area of Seoul, where many cultural facilities have been built and countless historic relics are preserved. The building housed the Supreme Court of Korea until 1995. It was remodeled and converted into a museum in 2002 (see Fig. 4). Only the front facade of the old Supreme Court building was preserved, whereas the other parts of

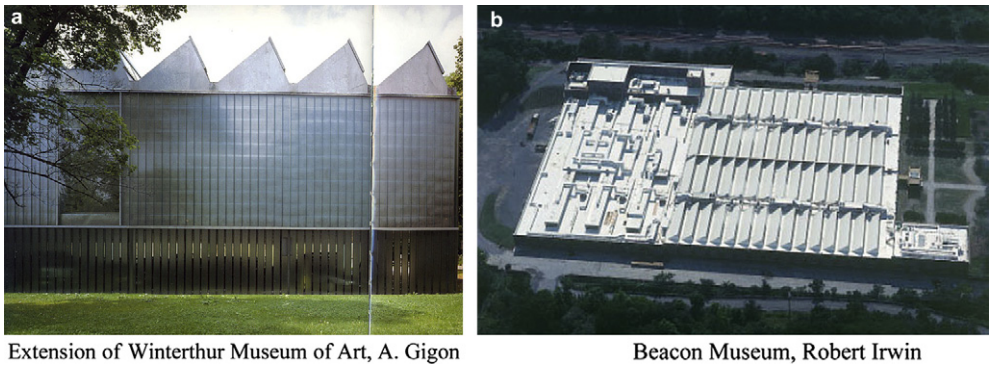

Fig. 2. Examples of museums installed with sawtooth-shaped toplight.