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This research explores a proposal for natural light restoration design for exhibition spaces in the Ein Harod Museum of Art. The original design and method of introducing daylight are described and their mechanisms depicted. The reasons for recent modifications, mostly due to conservation demands, and their impact on light quality are discussed. Owing to the Museum's unique design achievement and the worldwide influence on late twentieth century museum architecture, the research emphasizes the necessity for a light restoration project. The applied approach of introducing light also invites rethinking the current paradigm of using natural light in art exhibition spaces. Restoration objectives are determined and a design based on laser cut panels (LCPs) technology is proposed. Sets of experiments are presented: devising a LCP gable roof form geometry; analysing LCP daylight performance; and examining the original design. Finally, the performance of the proposed design is studied and is shown to be adequate for current conservation demands. Both quantitative and qualitative experimental methods were used: radiance light simulations, scale model measurements using photography, high-dynamic-range imaging photography (luminance levels) and HOBO data loggers. The findings propose integrating a louver system together with an LCP roof structure, a combination that restores daylight performance and preserves the quality and spirit of the original design.

Keywords: daylight restoration; LCP technology; Ein Harod Museum; Shmuel Bickels; exhibition space lighting

Introduction

The Ein Harod Museum of Art was designed in Kibbutz Ein Harod in northern Israel by a newcomer to Israel, Shmuel Bickels, who arrived from Poland to the emerging state of Israel. Bickels had a masterful combination of abilities: architect, construction engineer, visual artist and a talented musician. He enjoyed a fruitful career as an architect, who built major public buildings and master planned more than 80 new kibbutz plans. However, his most acclaimed achievement was his design of this little gem museum, and specifically, the daylight–space solution for the exhibition environment (Le Thierry 2001).

The design and construction of the Ein Harod Museum took more than 10 years, from 1948 to 1957, in three major phases: Bickels built new sections for the Museum at each phase, while further developing his light–space approach and designs. This lengthy timespan facilitated one of the most unique research processes of natural light–space design in twentieth century architecture, whereby with every phase, the designer improved his design solutions to tame and control the intense local sun (latitude 32.55° north, longitude 35.38°). The original exciting result brought fame to the Museum and further influenced key designers such as Renzo Piano, putting Bickels in the same line as other modern masters like Alvar Aalto and Louis Kahn (Robbins 1994).

In his light–space design, Bickels further developed a model first proposed by New Zealand architect, Hearst Seager (see Figure 1). In Seager's design, the ceiling is lowered to become part of a light conduit system (Seager 1912). Bickels developed and improved this model further by

(1) Using a hyper-parabolic floating ceiling that served as a four-sided light funnel, which improved the ability to collect light coming from all sky directions (see Figure 2).
(2) Introducing tilted light funnels that increase the redirection and channelling of light.
(3) Using a louver system that directs light towards the light funnels and prevents direct sunlight penetration.
(4) Using clear glass for all clerestory windows.

Light quality according to Bickels

In this design, Bickels implements a redirecting or light-bouncing mechanism that acts as a semi-specular reflection mechanism. This mechanism facilitates daylight penetrating partially with its natural directional and dynamic character, and maintaining its daylight colour qualities. More practically, this mechanism is theoretically capable of completely removing hazardous ultraviolet (UV)

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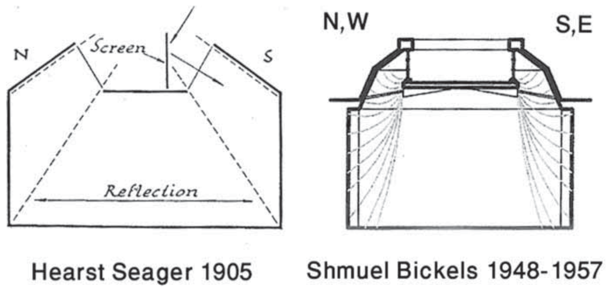

Figure 1. Seager space–light (left) design compared with Bickels' design (right) (based on Seager 1912 and Le Thierry 2001).

Figure 2. Ein Harod Museum of Art exhibition space.

radiation in a simple and maintenance-free way. However, the original design resulted in high light levels (approximately 1800 lux), and in practice, direct sunlight penetration was experienced on some occasions.

Bickels' research was conducted during a period when there was little awareness about the hazards that high light levels could bring to artwork; therefore, he plays equilaterally with introducing light from all possible directions – north, south, east and west. Bickels' novel light–space design suggests an alternative approach to the well-accepted paradigm of the use of natural light that in exhibition space, natural light should be introduced solely from the north (Thomsons 1978; Sixsmith 1999; Cuttle 2004). The reason for using light from the north in the northern hemisphere with no admitted direct solar radiation is to ensure minimal variation in illuminance throughout the year and time of day. The result gives a specific character to the light, stable in hue, and cold with its high colour temperature appearances. This research examines the strategy and possibility of introducing light from all sky directions and not solely from the north, while still complying with light conservation demands. The research aims at preserving the original daylight characteristics of Bickels' design with its natural directional and dynamic character, and maintaining its daylight colour qualities.

Unlike natural light, electric light is constant in appearance and easy to manipulate and control. Electric light is used predominantly for task lighting and illuminating exhibition space when natural light is not available, or when designers adopt a design strategy based only on electric light. The noticeable character of natural light is in the quality of human experience it offers. Natural light is variable and contains a continuous spectrum of colours, dependent on different seasons, alongside changes in composition during the course of the day, colours that constitute the evolving appearance of white light. Together with defining the appearance of the space and its objects, which is unique and different at every visit, natural light gives the sense of the passing of time as well as a sense of place. This characteristic of light is able to transform an exhibition space visit into a singular unforgettable experience, and consequently could lead to success of a museum building. Today, more than ever, when sustainability has a real value in design, we raise the question and value of using natural light as the predominant lighting agent in the art exhibition space.

Changes that took place in 1990 to comply with conservation requirements for art displays affected the Ein Harod Museum envelope structure. Owing to light measures of about seven times more than the acceptable value (200 lux; Cuttle 2004), there was a need to control Israeli light further. This was done by replacing the original clear glass with frosted glass having UV filters. Furthermore, the entire original louver system was removed, without being replaced, and a translucent polycarbonate roof was added (see Figure 3), thus totally changing the light-bouncing mechanism of the original design. Consequently, the resulting light in the exhibition space lost some of its fundamental characteristics affecting its appearance during seasons and the course of the day.

The motivation for examining ways of restoring the original light of Bickels' design came after discovering images taken by the artist-photographer Margalit Mannor in 1989 (Mannor 1990), one year before the envelope changes took place (see Figure 4). The images show the presence of a system of louvers and clear glass, which were consequently removed a year later. This research and the experiments that were carried out developed out of the curiosity in determining if a possible state-of-the-art solution exists

Figure 3. The gallery roof system today: polycarbonate lightweight roof (right), opaque windows and an air-conditioning system on the hyperbolic lightweight roof (left).

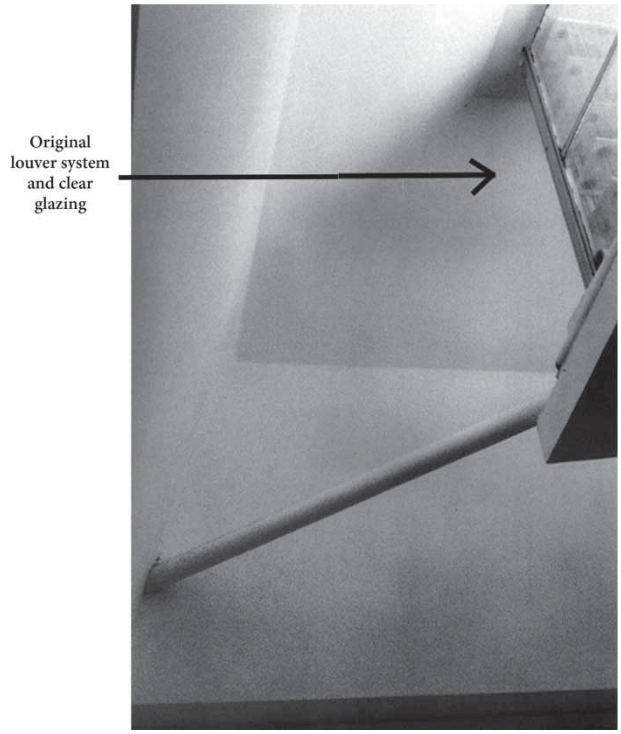

Figure 4. A 1989 photograph of the louver system by Margalit Mannor.

today of retaining the light–space qualities described above, while still complying with updated museum conservation standards.

The exhibition space case study

Out of five different types of light spaces existing in the Museum, the space chosen for the light restoration research process was the one that reflected the greatest achievement of Bickels' light–space design. The design introduces daylight indirectly from all sky directions, resulting in light characterized by daylight qualities: a directional nature and a dynamic characteristic that also maintains daylight colour qualities. As noted above, this design suggests an alternative for the well-founded paradigm of introducing natural light into art museums space that allows only light coming from the north to penetrate. In contrast to the high colour temperature, having the characteristic of a blue-cold light usually occurring in museum galleries, the resulting light of Bickels' design is rich in daylight character and is dynamic in its appearance through the course of the day and season. Furthermore, when Bickels designed the extension of the Ein Harod Museum (see Figure 5, the proposal was never realized), he used this type of space as the space unit for future extensions, suggesting a similar strategy for Le Corbusier's model of 'museum of infinite growth' (Gans 1987). Together with the daylight qualities achieved, this light–space design marks Bickels' greatest accomplishment and contribution to museum architectural design.

The light–space design chosen for this research is also the type selected out of five that suffered the most from art conservation requirements to reduce light levels to meet conservation demands. A series of unprofessional design decisions produced severe modifications in original light quality, a situation that offers a rare challenge to find a design that will include technological solutions to restore original light characteristics.

Current situation

When visiting the Ein Harod Museum today, the exhibition space at first appears neat and tranquil, with the appearance of well-balanced, diffused light (see Figure 2). Only after observing the details and comparing them with the original design may the modifications be discovered. Sketches by Bickels presented here confirm, as previously stated, that a louver system that had existed in the past was removed (see Figure 6). Clear glass windows were changed to frosted glass having a UV radiation filter. A translucent polycarbonate roof structure was added in order to further filter the light and reduce light levels. On top of the central hyperparabolic ceiling, that is acting as a light funnel structure, heating, ventilation, and air conditioning (HVAC) ducts were installed, reducing the light collecting surface by about 50% (see Figure 3). These changes generated different light qualities to space, presenting a different strategy of introducing and controlling natural light. According to Bickels, the

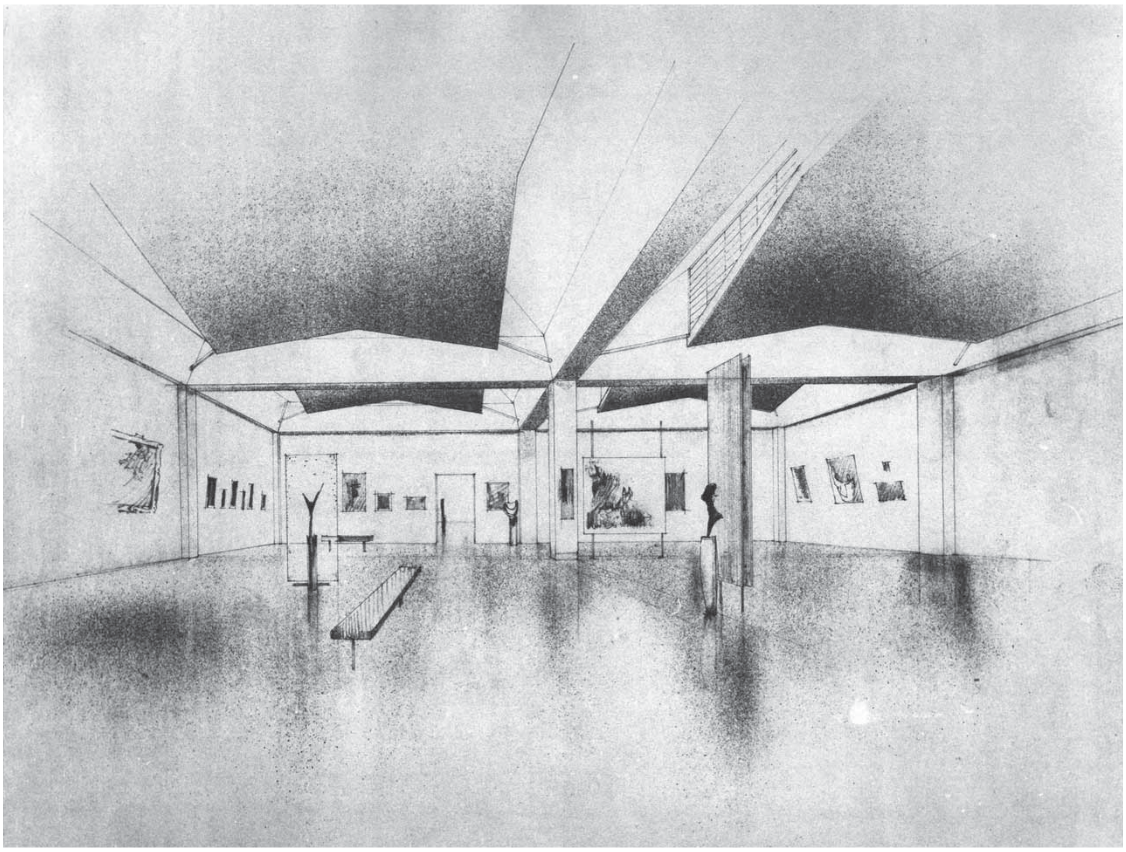

Figure 5. An interior view sketch of a museum extension proposal by Bickels.

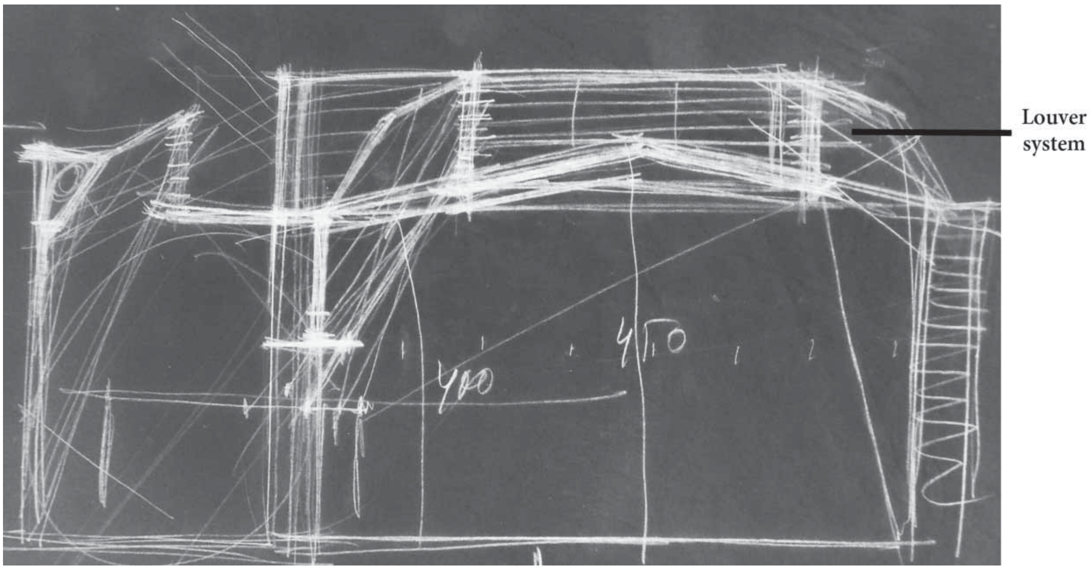

Figure 6. Sketches by Bickels illustrating the louver system.

best light quality could be achieved using a light-bouncing mechanism, whereby the light keeps its colour quality and directionality in gallery space. The current situation brings in totally diffused light whereby homogeneous light filters into space.

Together with dealing in high light levels, the recent modification dealt with practical problems in Bickels' design. The low-level ceiling caused maintenance problems as rain leaked in during the winter, dust, insects and reptiles penetrated inside, and pigeons nested in between the louver system components. Any conservation proposal must deal seriously with the difficult maintenance task that this daylight design poses.

Elsewhere, we demonstrated (Behar 2009) that Bickels' design clearly inspired and influenced the contemporary museum design master, Renzo Piano, with his design of the de Menil Gallery as one of the greatest achievements for this building type in the second half of the twentieth century. Furthermore, these two museums use similar strategies and techniques for introducing daylight into exhibition space. The task of restoring the original characteristics of light in the Ein Harod Museum is a valuable historical and educational challenge for future generations. Moreover, this project serves as a case study to demonstrate that the current paradigm about using natural light in exhibition space is to be questioned, challenged and consequently reformulated.

The restoration objectives

(1) To determine an appropriate design solution that would fully reflect Bickels' original light–space design within the framework of exhibition space functionality.
(2) To propose a technical solution that would reduce light levels without altering original light characteristics within the framework of Bickels' design and within the constraints of the Museum's light conservation demands.
(3) To prove feasibility by using daylight research methods and technologies.

The proposed design

In examining Bickels' original light–space design solution, several limitations in considering a conservation solution were introduced:

(1) Keeping the light–space design with its hyperbolic hanged ceiling without altering its overall appearance.
(2) Working within the framework strategy chosen by Bickels to introduce light in the form of a light-bouncing mechanism rather than the well-accepted light-diffusion mechanism.
(3) Addressing maintenance issues and practicalities.

This set of requirements led us to examine and seek redirecting light technologies that would be effective enough in reducing light levels without altering daylight characteristics.

The laser cut panel (LCP) technologies developed in Brisbane, Australia (Edmonds 1993) were found suitable for the task. LCP acrylic panel is manufactured by cutting voids into the acrylic layer using a laser cutter. This process leaves an array of perpendicular and well-polished surfaces within the acrylic layer. The surface of each laser cut

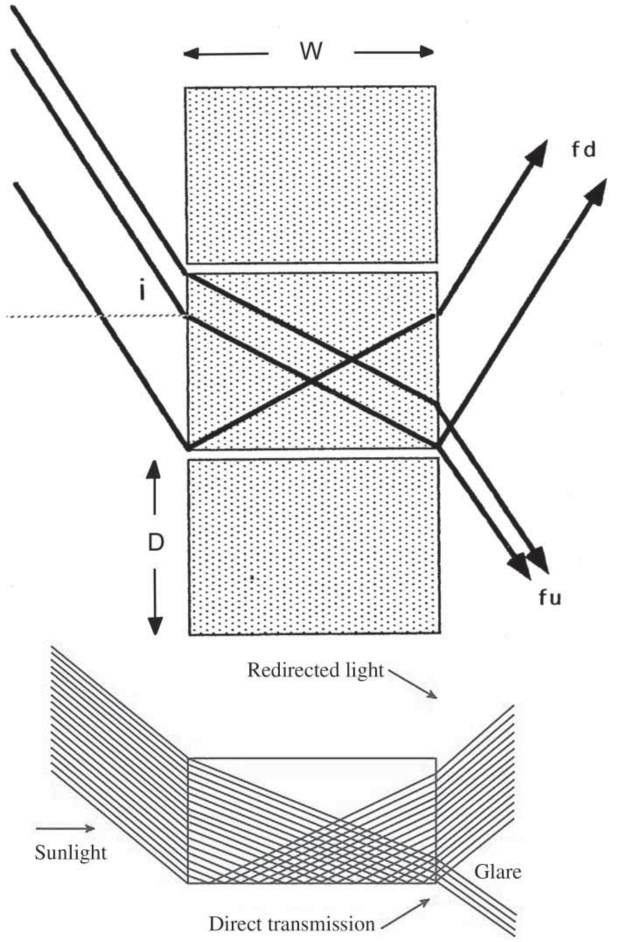

Figure 7. A section of LCP technology for a given incident angle (i): light is deflected mostly (fd) where the remaining light is transmitted without deflection (fu) (based on Edmonds and Greenup 2002).

becomes a small internal reflector that deflects light passing through the panel. Light is deflected in each set of two successive laser cuts by sequential refraction > deflection > refraction. The fraction of deflected light is dependent on the ratio of D/W between cut spacing (the distance between the cuts, D) and cut depth (the distance the cuts extend through the acrylic plastic sheet, W). The deflected light can reach up to 90% for a ratio of $D/W = 0.3$ at an incident angle of 20° (see Figure 7) (Edmonds and Greenup 2002). Once the incident angle is lower than 20°, light is transmitted with little disturbance, thus ensuring clear visibility. This characteristic of LCP acrylic panels led to a range of uses such as high windows where light is redirected towards the ceiling, and as an ideal solution for skylight window structures for climatic areas having high light levels. One of the advantages of using LCP technology is that it not only reduces light levels but it could also decrease heat gains during summer (see Figure 8).

Within the limitations described above and using the geometry of Bickels' light–space design, a hovering square

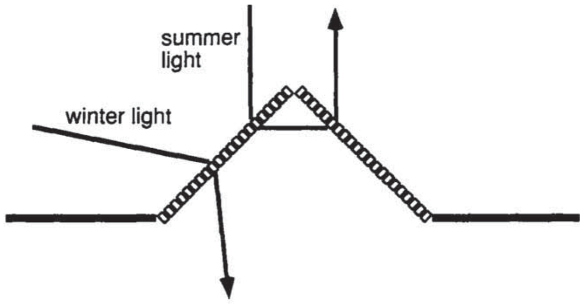

Figure 8. Section drawing of a pyramid geometry showing light behaviour within the LCP glass during summer and winter (based on Edmonds 1993).

pyramid composed of LCP panels was proposed (see Figures 9 and 10). This geometry is similar to a roof gable, and will be termed a gable or LCP gable in future references. The rationale behind this was to use this apparatus as a means for reducing light levels (the gable geometry was determined after discussions with LCP inventor, Dr. Ian Edmonds). The proposed gable geometry fits the existing rectangular opening of the roof, thus enabling light to penetrate from all sky directions. The added gable performs similar to a roof-like structure that deals in a simple fashion with previous maintenance issues.

Description of experiments

The experiments are presented here in four stages:

(1) Designing the preferred LCP gable geometry.
(2) Analysing LCP daylight performance.
(3) Examining Bickels' design.
(4) Suggesting and examining light restoration design.

The first set of calculations and experiments were determined to establish the exact geometry of the LCP apparatus that would enable good performance both in terms of quantitative (light levels) and qualitative (light direction and colour) aspects. In order to obtain a significant reduction in light levels during the summer, we related to the summer solstice zenith angle at Ein Harod (81°). Thus, the north–south section of the gable was determined in an off-centred manner in relation to the roof opening. Later on, we angled the peak of the gable towards the sun with a reasonably sharp angle of 40° (half summer solstice angle) so as to allow maximal distribution of light and minimal surface area for the southern face of the pyramidal structure (see Figure 9). The depth of the cuts and the spacing in between the cuts (cut spacing to cut depth ratio, D/W) were determined in relation to the way the sun hit the southern face of the gable during the year, with a maximal incident angle of 50°. Hence, the cut spacing to cut depth ratio was determined as $D/W = 0.6$ to achieve a maximal theoretical value for light deflection from LCP panels (see Edmonds 1993),

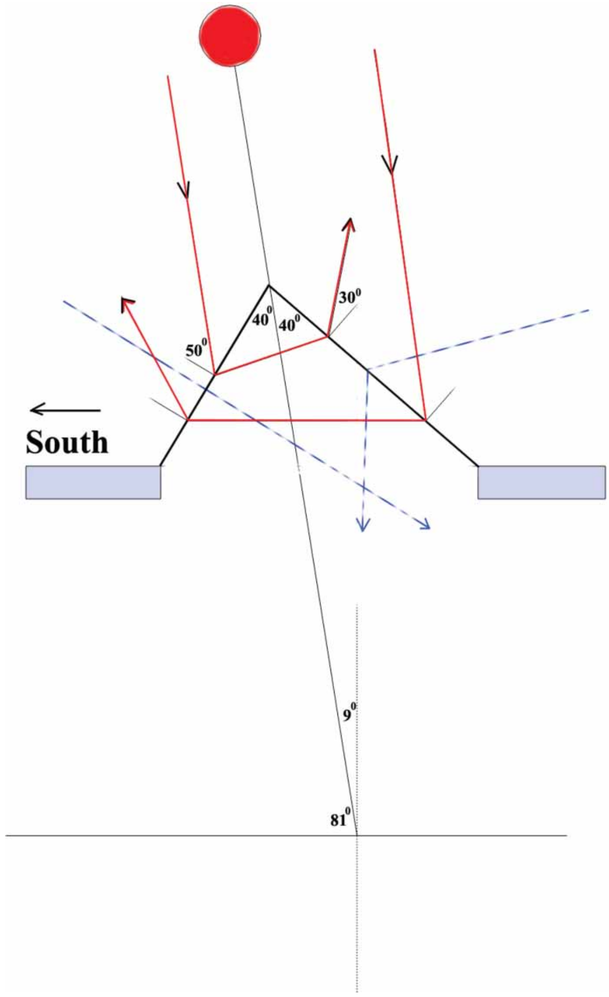

Figure 9. LCP gable geometry in relation to the summer solstice zenith at noontime; scattered lines refer to diffused light.

with a cut spacing of 4.2mm and a cut depth value of the total panel thickness of 7mm.

The inclinations of the eastern and western faces of the gable were analysed using radiance light simulations (Ward 1994; Greenup, Edmonds, and Compagnon 2000) (see Figure 10 for the tested gable geometries). The degree of inclination directly affects the area of the southern face, thus having a direct influence on light levels in space. Furthermore, due to the reflecting characteristic of LCP, there is a possibility of reflecting light from low angles, thus reflecting diffuse light coming from the surrounding landscape. This characteristic of LCP can distract the natural colour balance of light towards outdoor environment colours. Therefore, it is important to seek a desirable geometry where such disturbances are avoided.

LCP performance and Bickels' original design were analysed and compared with both simulation methods and physical measurements on a scale model using high-dynamic-range imaging (HDRI) photography (Reinhard et al. 2006) and data loggers HOBO H8

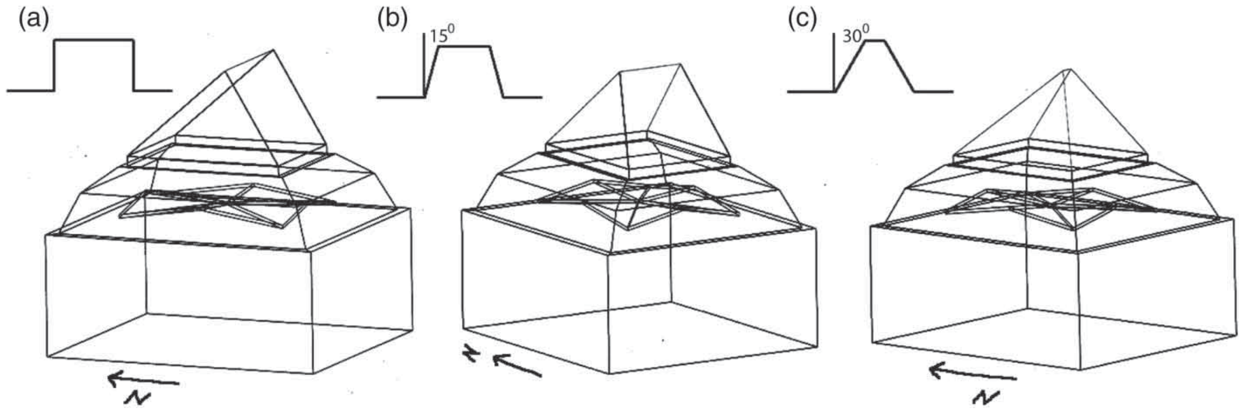

Figure 10. Three tested geometries for east and west roof inclinations: $A = 0°$, $B = 15°$ and $C = 30°$.

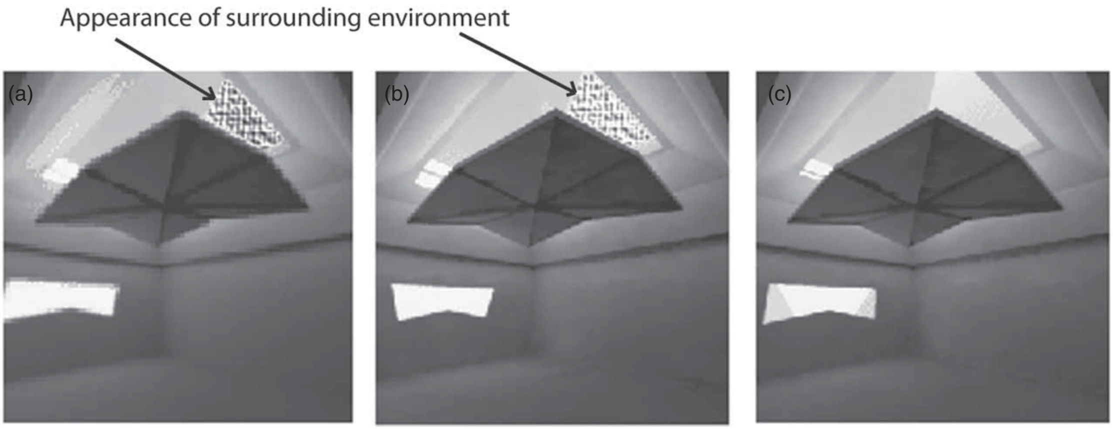

Figure 11. Radiance simulations for three different LCP gable geometries: equinox 12 pm, with an inclination parameter for east and west faces, $A = 0°$, $B = 15°$ and $C = 30°$; note the textured areas where the appearance of the surrounding area is evident.

measuring illuminance (lux) (produced by Onset Computer Corporation, MA, USA). This combination of experimental methods allowed a research perspective to juxtapose both quantitative and qualitative aspects of natural light.

Results

According to the inclination slope angles of the eastern and western faces described above, experiments were conducted for 5° inclination angle increments. Here, we present the results of three different geometries: 0° (perpendicular), 15° and 30° (see Figure 11). As can be seen clearly in the first geometry (the perpendicular geometry) the surrounding environment is strongly present in both eastern and western faces (presented here with textured surfaces), thus offsetting the natural colour balance.

This effect is further reduced (15°) until it disappears at 30°. This result demonstrates that the preferred gable geometry must have a minimal inclination of 30° of eastern and western faces. Together with the north–south section devised from the summer solstice zenith, as mentioned above, the final geometry of the LCP gable was determined. This result paved the way for building a 1:30 scale model for further experimentation and analysis.

Analysing the light-reducing effect of the LCP gable

A set of radiance simulations was conducted around three key dates: summer and winter solstice, and the equinox. The wall reflectance value was set at 85% according to measurements. Here, we present a comparison of simulations with and without the LCP gable, demonstrating the clear positive effect of the presence of the LCP gable (see Figure 12). The results show:

(1) A three- to five-fold reduction in light levels, with best results in equinox time. The light is distributed better in the exhibition space in the presence of the LCP gable, generating homogeneous values of light levels in the critical areas of display, below 2/3 of the wall height.
(2) A good light distribution with a gradual horizontal decrease of light levels is achieved during the summer solstice, when external light levels are at their yearly maximum.
(3) The generation of two patches of direct sunlight penetration inside space, a fact that must be addressed within the proposed design for light restoration.

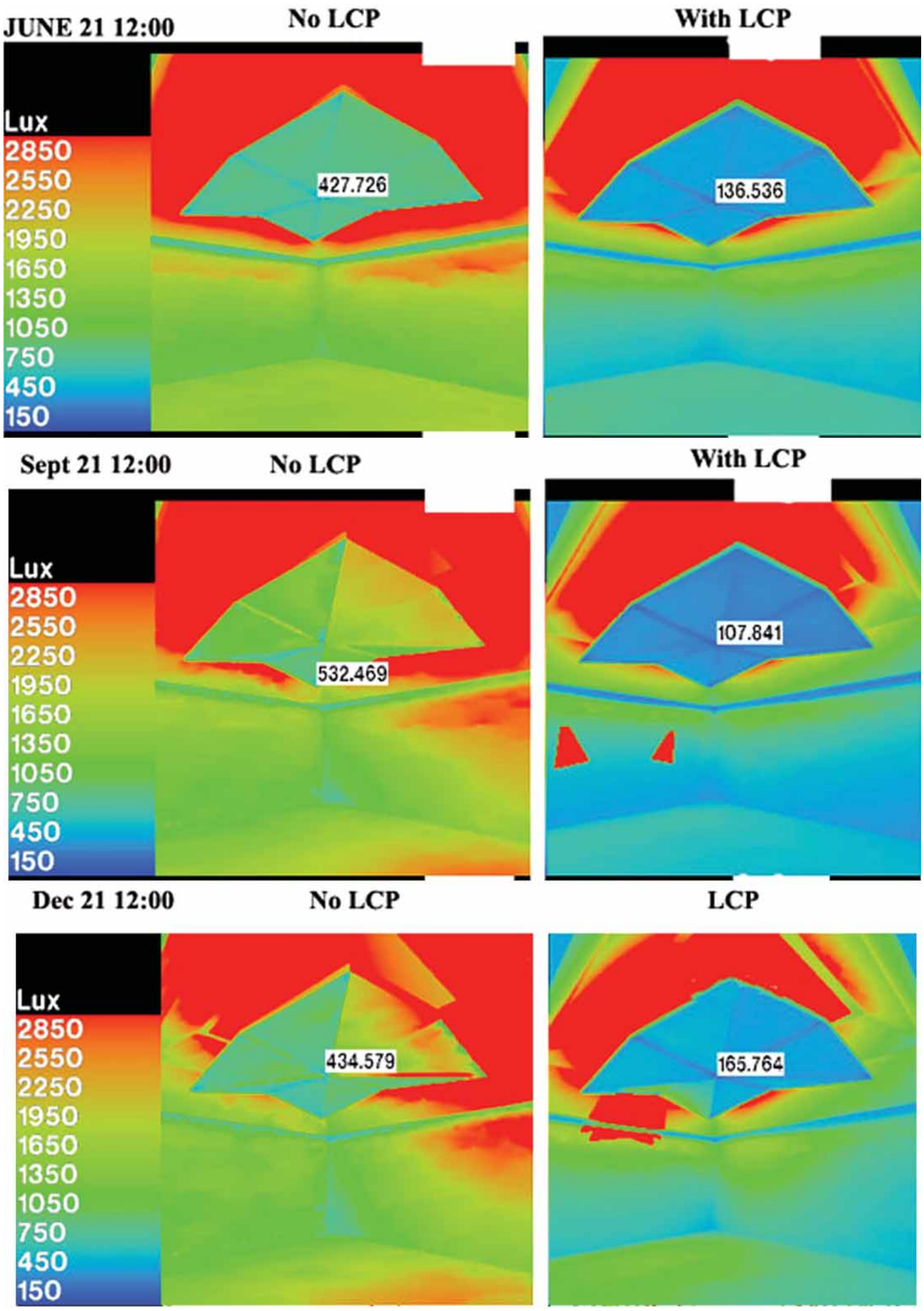

Figure 12. Comparison of radiance simulations with and without the LCP gable at three different times: summer solstice (top), winter solstice (bottom) and equinox (middle).

Scale model experiments

A 1:30 scale model was constructed by reproducing the same space geometries and surface qualities according to the dimensions of a 1:30 LCP acrylic sheet sample material (see Figure 13). Since we used a 1:30 model, LCP cut spacing and cut depth (panel thickness) were scaled accordingly. The walls were painted with a white colour having a similar reflectance value of 85% as found by the measurements. The first experiment aimed at tracking the light dynamics in the space along the equinox. To this end, a wide-angle camera was placed in the space, and HDRI photographs were taken at hourly increments (see Figure 14). The photographs were taken with the same aperture (f8) but with different exposure times (1/10, 1/20, 1/45, 1/60, 1/90, 1/125, 1/180, 1/250, 1/350, 1/500, 1/750 and 1/1000). All 12 photographs were processed

Figure 13. A 1:30 scale model of exhibition space and the proposed LCP gable.

and juxtaposed to produce one HDRI image. The results show the dynamic appearance of light during the day and the dynamic presence of direct sunlight penetration. From the results, a symmetry in light performance is observed around mid-day, where maximal light levels are achieved, with two minimums at the beginning and end of the day. These results suggest that introduction of a second system is needed to further manipulate and redirect the light to prevent direct sunlight penetration.

Scale model qualitative and quantitative measurements

A light intensity measurement unit (data logger HOBO H8) was introduced into the scale model at a specific point in space, as shown in Figure 14. The measurements were made from sunrise to sunset, and were conducted under real sky conditions in sets of two consecutive clear sky days with and without the LCP gable to allow qualitative and quantitative comparisons. The measurements were made at different times of the year, and all produced similar results, as described below. We present one typical measurement for September (Figure 15) that shows a clear difference in the performance of light levels with and without the LCP gable. As a reference, the average external horizontal illuminance for September at noon is about 95,000 lux (Neeman 2002). In qualitative perspective, one can identify the difference in the dynamics of light levels throughout the course of the day. Without the LCP gable, two maxima are clearly identified before and after mid-day, with an intensity difference between pre-noon and afternoon levels. With the LCP gable, the two maxima are still present, but with a less pronounced intensity difference. This demonstrates that the LCP technology generates a better and homogeneous appearance of light levels (most searched for in display strategies), keeping its original daylight.

HDRI photography was used to evaluate luminance values by processing the HDRI results using radiance analysis procedures (Ward 1994). The experiment was set for various dates: here, we present one typical result for 6 March at noontime with and without the LCP gable (see Figure 16). As a reference, the average external horizontal illuminance for the month March at 12:00 noon is about 70,000 lux (Neeman 2002). Through the result, we can clearly identify positive effect on luminance values, a reduction of roughly three timefolds. Furthermore, the distribution of luminance levels in space is more homogeneous with the LCP gable. However, direct sunlight penetration is present in both cases and must be treated, a fact that raises an interesting comparison with the original design, which had included a louver system.

Analysing the effect of the louver system on Bickels' design

As noted before, original sketches by Bickels and Margalit Mannor's photograph clearly demonstrate that a louver system was part of the original design. Therefore, the next set of experiments was performed in order to evaluate the effect of the louver system on light levels in space. Radiance simulations were performed for simple white louver systems having a width of 5cm and a 5cm gap in between layers. The results (Figure 17) were compared with previous

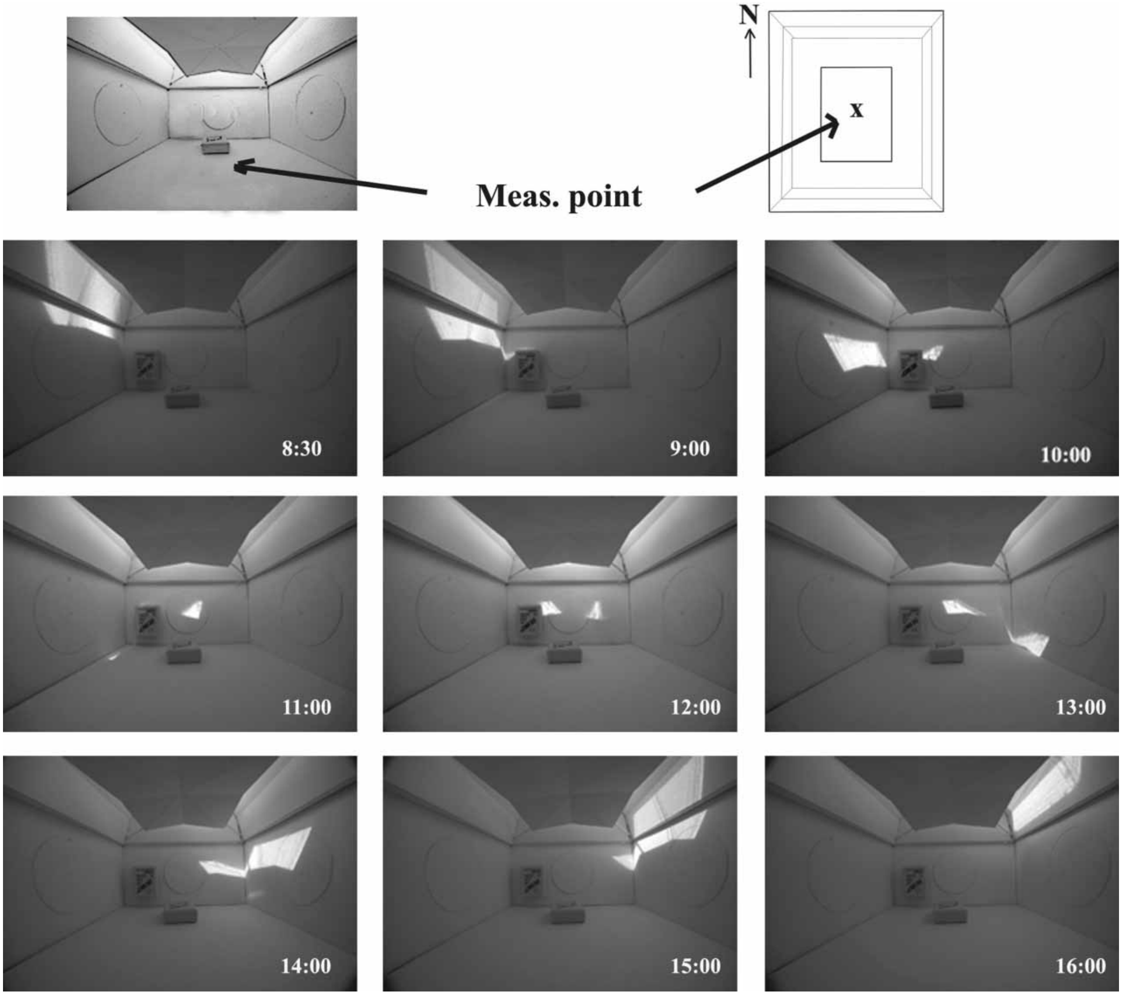

Figure 14. An hourly series photograph taken from the interior of the 1:30 scale model during the March equinox.

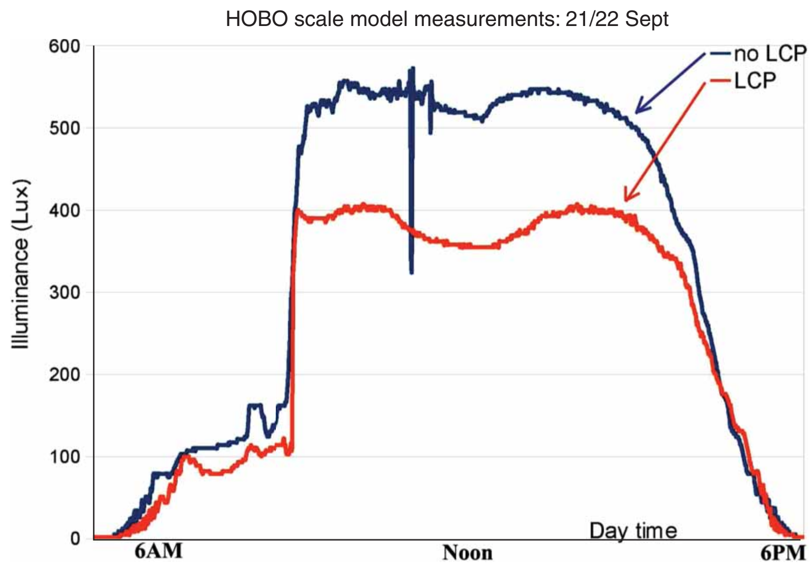

Figure 15. HOBO measurement results of the scale model with and without the LCP gable.

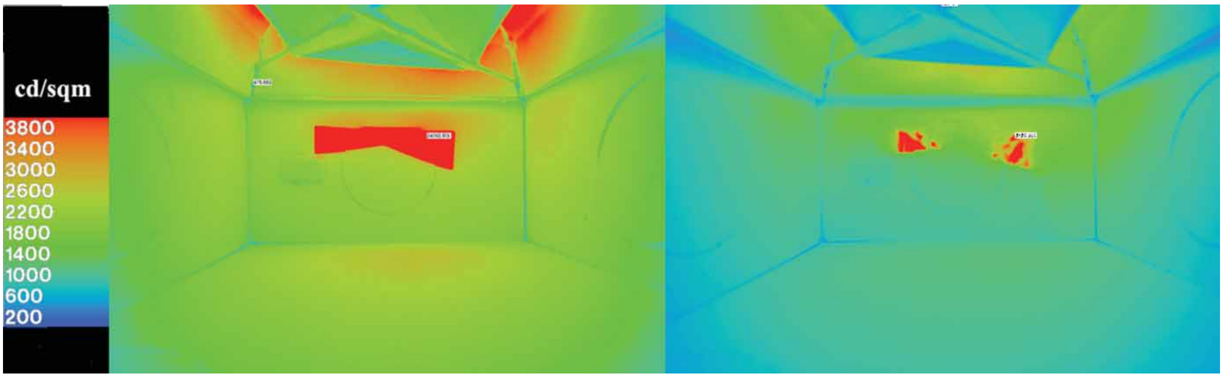

Figure 16. HDRI image analysis of the scale model with and without the LCP gable at noontime, 6 March.

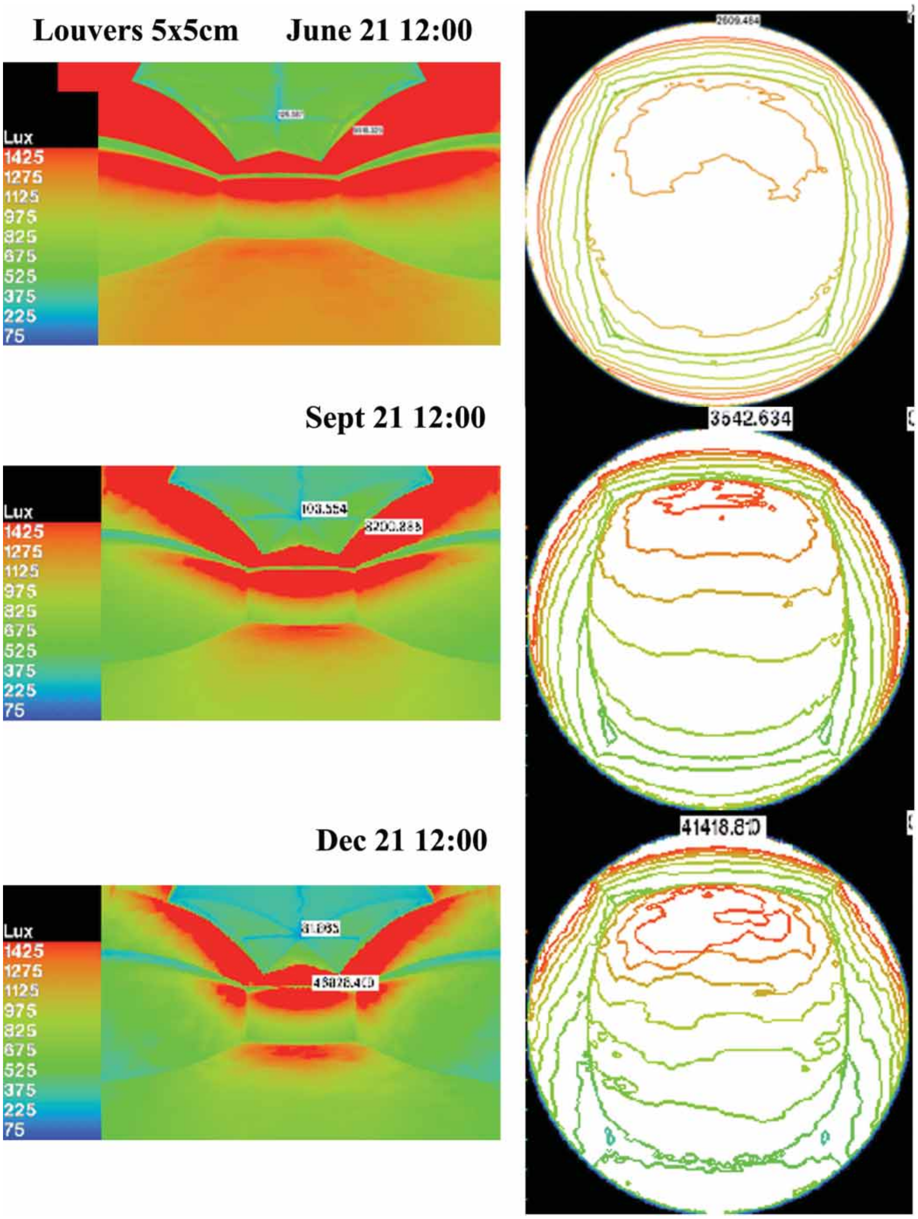

Figure 17. Light simulation of the illuminance level for the louver technology, view of east, north and west walls, and a top overview of space. The result is to be compared with Figure 12.

measurements of space, where no louvers were present (Figure 12). The results clearly show that the louver system generates a light distribution having a good gradual horizontal decrease of light levels during the summer solstice, when light levels are the highest. These findings raise doubts as to the reason for their permanent removal from the Ein Harod Museum.

Suggestion of a light restoration design

The above results (Figures 12, 15 and 16) explored the performance of the proposed LCP gable and showed the ability of this technology to reduce light levels. However, introducing the LCP gable is not sufficient for achieving the desired daylight performance due to direct sunlight penetration, and the integration of an additional system is required.

Furthermore, after analysing the performance of the original technology (Figure 17), we suggest integrating a louver system for the light restoration design proposal. This would solve the problem of direct sunlight penetration into exhibition space and maintain the spirit of Bickels' original design.

Analysing the proposed light restoration design

Together with the LCP gable, we introduced a louver system attached to the four clerestory windows. The analysis of a 5-cm-wide white louver system with 5cm gaps in between the layers is presented (Figure 18). A clear glass was chosen for the experiments to facilitate a redirecting mechanism rather than a diffuse mechanism, which results from the use of frosted glass. This choice takes advantage of the light-bouncing mechanism, which removes UV radiation (Neeman 2002). Following Bickels' design principles, the light bounces off exterior surfaces (mostly the top hyperparabolic surface), louver surfaces and interior surfaces before it arrives to art objects. Since the resulting light is generated from semi-specular reflections, it keeps in total a downward directionality.

Radiance simulations were conducted for the integrated system at three different times: 21 June, 21 September and 21 December at 12:00. The CIE (Commission Internationale de l'Eclairage) clear sky description that is representative of Israeli conditions was used as daylight external reference illuminance. Measurements of horizontal diffuse irradiance were used to generate the sky's luminance distribution (Neeman 2002). The results (Figure 19) demonstrated the following behaviour:

(1) A highly homogeneous light distribution with good gradual horizontal decrease in light levels is achieved during the summer solstice when light levels are at their maximal levels.
(2) Light levels found in the range of light conservation demands (250 lux).

These results validate the proposed solution as being suitable for the light conservation process in the Ein Harod Museum, although further fine-tuning is required. For example, the simulation shows that during the winter solstice, high light levels can be present on the north-facing wall. This may be resolved by increasing the width of the louver system in north, northeast and northwest directions, or decreasing the distance between louver slabs. The results also show high illuminance values around the ceiling area, which is outside the visual field. Therefore, despite the high contrast levels between maximum and minimum values, this will not interfere with the experience of viewing the art, which is suspended on the lower part of the walls and receives a reasonable and uniform spread of light.

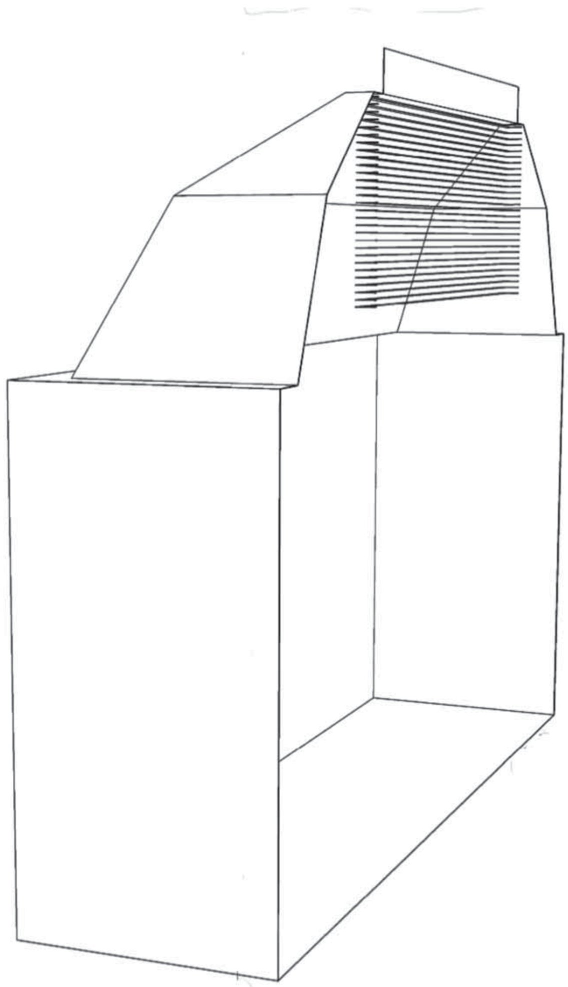

Figure 18. View of the louver system (one of four).

Although the gable LCP solution acts like a roof structure, and in this way prevents previous maintenance problems, further measures must be taken. In order to avoid dust accumulation on the LCP, which could decrease its reflective performance, clear glass layer could be added on both sides of the panel. Furthermore, in order to comply with light conservation demands, additional fine adjustments should be made. For example, the clear window glass could be treated further with partial ceramic frit having a density that fits the required compensation (Carmody et al. 2004).

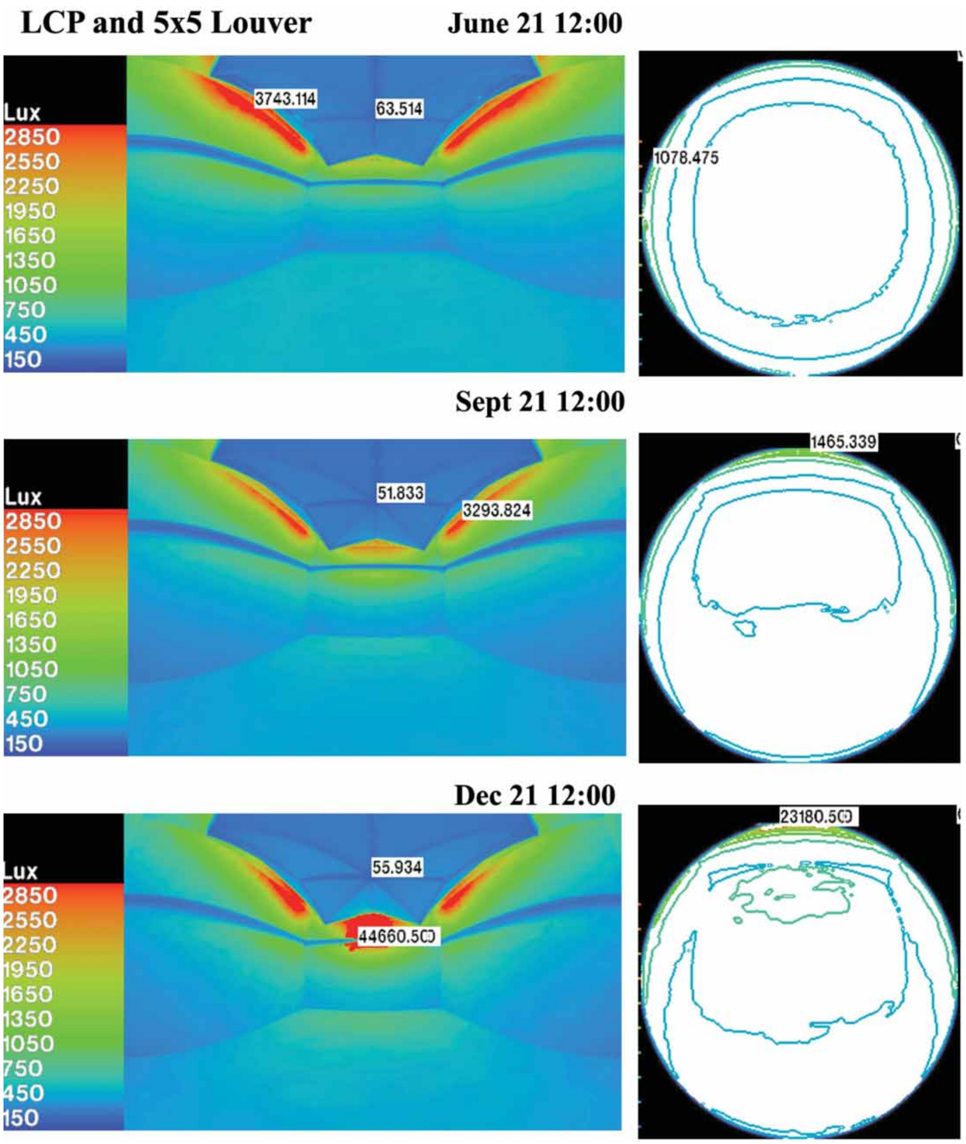

Figure 19. Radiance simulations of illuminance levels for the integrated LCP and louver technologies, view on east, north and west walls, and a top overview of space.

Summary and conclusions

The set of experiments described above addressed and assessed both qualitative and quantitative aspects of natural light in order to examine the feasibility of the proposed design for natural light restoration in the Ein Harod Museum gallery space. The various methods used were examined within a model of a synergy of approaches, which we felt could best reflect the varied nature of light according to the original design. The scale model measurements provided direct observations of the resulting light, as well as measurements of light levels and distribution of luminance levels during the day. Radiance light simulations enabled an analysis of different design alternatives and the prediction of light levels and their distribution in space. Furthermore, the simulations also described how the external environment could affect the resulting light and its colour character inside exhibition space. These findings are characteristic of LCP technology and could not be clearly identified by scale model observations. Afterwards, radiance simulations were used to determine and assess alternative designs that could generate a result that maintains original light quality. Photographing the dynamics of light during the course of the day gave a sense of the behaviour of light using the proposed LCP technology. The results indicated the penetration of direct sunlight inside the space, a problem that needed to be addressed, thus pointing to the necessity for introducing and integrating another technology.

Illuminance measurements in the model with and without the LCP gable provided an insight into the way LCP technology affects the performance of light levels during the course of the day and year. HDRI measurements demonstrated a change in luminance levels and distribution in space due to the implementation of LCP technology. Studying Bickels' design indicated the necessity for preparing a design that integrates a louver system due to its ability to solve direct sun penetration and its capability in uniformly distributing light levels in exhibition space. The proposed design offers a simple solution for dealing with previous maintenance problems, although further research is needed to determine an unobtrusive presence for the HVAC ducts.

In conclusion, the results demonstrate that combining LCP technology with a louver system could generate a more homogeneous distribution of light together with reducing light levels to conservation demands. This result is achieved by using the light-bouncing mechanism (semi-specular reflection) of Bickels' original design, thus maintaining the nature of the light, its character, directionality and colour through the course of the day and season. This result is appropriate in terms of both quantity and quality, and poses a challenge for bringing back the light to Bickels' Ein Harod Museum exhibition space. We assume that this use of LCP technology could bring an amplification of natural light colour phenomena into space during the early and late daylight hours when light is scarcely deflected by the panels. This might generate an interesting juxtaposition between light, time and sense of place.

This research demonstrated that by using novel daylight technologies, one can maintain the use of natural light and control light in a way that still preserves natural light qualities. Today, when doubts are being raised about the value of daylight in exhibition spaces, this research shows that this essential light source, which is a formative material for this building type, can still be used to achieve light quality and ensure acceptable performance within the perspective of restoration demands. Moreover, we hope that once this restoration proposal materializes, it will raise further the need to challenge current paradigms in museum lighting design.

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