Investigation of the Luminous Environment in Louis I. Kahn's Kimbell Art Museum

A qualitative and quantitative study

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ABSTRACT: The Kimbell Art Museum is one of the most significant buildings among the realised museum projects in Louis I Kahn's architectural career. Research on how Louis I. Kahn shaped his architecture with regards to his philosophy of light is plentiful. However, there is a research gap in the published literature in terms of the interplay of light and form which evoke distinctive luminous environment from both qualitative and quantitative perspective. This paper attempts to fill this gap. The study starts with subjective appreciation of the internal spaces and luminous environment through building images, simulated views and analytical diagrams. Fenestration design and window typologies have been studied in detail. Physical scale model testing of the Kimbell Art Museum has also been carried out to explore the luminous environment under overcast sky condition. The quantitative investigation involves the assessment of daylighting performance and visual perception through digital modelling.

This study concluded that Louis I. Kahn created a distinctive luminous environment by developing a unique top-lit museum which is enhanced by side lighting through internal courts and facade apertures. The central roof light works as both reflector and diffuser to admit light into the gallery spaces. This specially designed roof aperture works harmoniously with the windows on facade walls, creating a well balanced luminous environment for both visitors and work of art. In addition, the borrowed light from the internal courts further enhances both daylight illuminance and visual perception of exhibits in the museum.

Keywords: The Kimbell Art Museum, luminous environment, quantitative and qualitative investigation, physical scale model studies, digital modelling

INTRODUCTION

Light enhances spatial poetics and our visual perception and allows our body to orientate itself in its surrounding environment [1]. Daylight contributes to this relationship by "maintaining our biological rhythms and hormonal distribution" [1]. "Our bodies and minds are now closely tuned to its cycles and spectrum" [1], which makes daylight incomparable with artificial light sources.

The integration of light and form has a vital significance and constitutes the essence of architecture. Steane expressed that "material announces itself properly only in daylight" [2]. The dynamism of daylight consolidates this integration as "any daylit room at any moment is unique. Its pattern of brightness depends on where it is in the world, and on the time of year and time of day. Variability in space and time is the dominating characteristic of natural light" [3].

In the 20th century; Louis I. Kahn, as one of the pioneer architects of this era, aspired to use natural light for shaping his architecture throughout his career. Kahn "sensed a magical quality in the interaction of light and architecture and believed that light possessed an awesome power" [4]. The relation between Louis I. Kahn's buildings and natural light can be evaluated as part of Kahn's consideration related to nature. Sauter indicated that nature had significant impact on Kahn's architecture [5].

The museums designed by Kahn vividly demonstrate the significance he gave to the interplay of architecture and light. Although there is a large amount of literature describing the luminous environment in the Kimbell Art Museum, structured qualitative and quantitative studies are rare. This research aims at investigating the light in the gallery spaces in this museum from both subjective and objective perspectives.

LUMINOUS ENVIRONMENTS IN MUSEUMS

As one of key considerations in art galleries and museums, "the situation in which it is viewed" directly affects how display is exhibited and perceived [6]:

- "Windows providing general room lighting and views out" can create "appearance of a daylit room and may simulate the original ambience of an art work".

- "Side windows providing illumination on art works may simulate the original ambience" and has advantages as "good colour rendering and good modelling of three-dimensional form".
- "Specially designed roof lights illuminating art works" has "good colour rendering, direction of light reduces shiny reflections, daylight can be controlled with louvers and blinds" [6].

Visual appearance in museum is evaluated through the relation between objects and ambience in terms of illuminance and brightness contrast [7]. In terms of illuminance, as a benchmark; "50 lux is considered to be a minimum for displaying objects that require the perception of detail and colour" [8]. Related to the brightness contrast, the luminance ratio between the exhibited object and its background is significant in display environments for "providing good visibility and an interesting appearance" [9]. The differences in luminance ratios result in different highlight and shadow patterns on and around the display, which result in different appearance and perception of the 3D displays (Fig. 1). "Highlights reveal the nature of surfaces. Shadows reveal form and texture" [10]. These lighting references and principles have been used to guide the investigation of light in the Kimbell Art Museum.

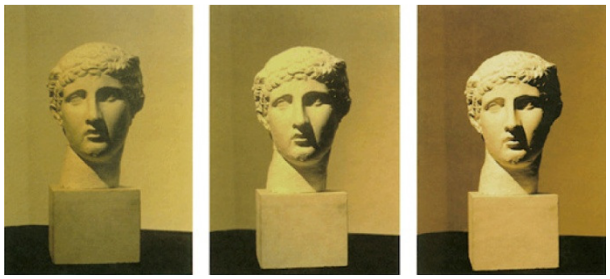

Figure 1: Demonstration regarding to the effect of various luminance ratios: 2:1 (left), 5:1 (centre) and 12:1 (right) [9].

THE KIMBELL ART MUSEUM: ITS SITE, ARCHITECTURE, SPATIAL EXPERIENCE AND LIGHT

In order to have a holistic understanding of the luminous environment in the Kimbell Art Museum, this study started with the site micro-climate analysis, and then followed by the analysis of architecture, space and light.

- **Site micro-climate analysis**

The Kimbell Art Museum is located in Fort Worth, Texas, which is located on latitude 32.8°N and longitude -97.1°W. The orientation of the building is towards north & south on its longitudinal axis (Fig. 2). The gallery spaces are orientated towards north and south with their vault-shaped facades, on which they have only narrow semi-circular light slits. The galleries have also elevations facing east and west, which are blind facades except the narrow linear light slit on the west orientated portico side. The roof lights are positioned on the north-south axis.

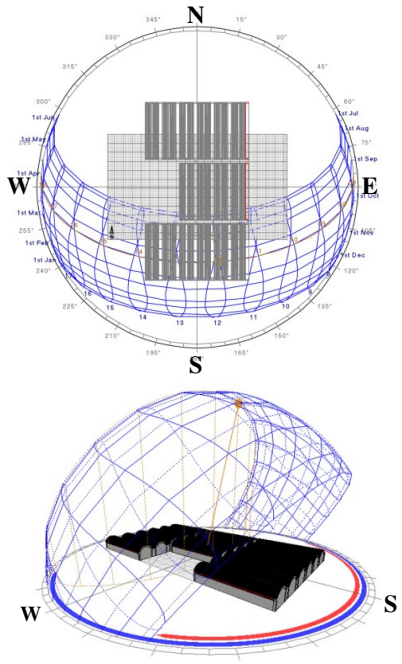

Figure 2: Sun-path diagram overlaid on the site plan (above) and three-dimensional model (below) of the Kimbell Art Museum (original source for plan: [11], redrawn by the author, model & diagrams by the author).

The overshadowing analysis shows that there is no adjacent building which overshadow on the museum. As the location is close to equator, the solar angles are generally high throughout the year and in summer, the sun is mostly overhead and the shadows are relatively short.

- **Architecture**

The Kimbell Art Museum was founded by the Kimbell Art Foundation and opened in 1972 (Fig. 3) [12]. Kahn always considered the vaulted space idea and his project captain developed the "cycloidal section": "It may have been the example of ancient Roman warehouses like the Porticus Aemilia, with their concentrated barrel vaults, that had implemented this form in Kahn's imagination" [13]. Goldhagen described that "cycloid vaults both bring the roofline close to the user and disaggregate the building into smaller cells that are more related to the scale of the human body" [14]. It has been stated that "the cycloidal vaults fulfilled his greatest dream, defining spaces through the unification of light and structure" [15].

Figure 3: Exterior view of the Kimbell Art Museum with its surroundings, source for image: Kimbell Art Museum [12].

The plan of this museum contains three bays, each of which are approximately 32m long and contain six barrel vaults. The entrance facade hosts two porticos under the vaults. The entrance is from the centre of the plan with a set-back, which is approached from the portico and a glazed entrance wall. The entrance leads directly to the galleries, stairs to basement floor, shop and library (Fig. 4). Exhibition galleries are on both side of the entrance and located under the vaults. Light courts are positioned inside the galleries and integrated into the vaults. In terms of fenestration design, the exterior facade of the museum contains narrow linear light slits on the end and side walls, which are largely opaque. As a contrast, the entrance facade towards west is fully glazed. The light courts, which are north and south courts, are located inside the vaults and act as light traps to bring light into the exhibition spaces with their transparent facades. The unique rooflight is located horizontally on the centre of vaults.

Figure 4: Ground floor plan of the Kimbell Art Museum (original source for plan: [11], redrawn by the author).

- **Spatial experience**

The main entrance on the ground floor, which is at the centre of the museum, is reached through a vaulted portico and fully glazed facade. The exhibition spaces are located on both sides of the entrance (Fig. 5). Through the exhibition spaces, the visitors face the north court and this court brings the exterior ambience into the museum.

The impact of exterior ambience is replaced with the dominance of the concrete vaults. The south court, which is on the opposite side of the entrance, is closer to the west orientated wall in contrast to the north court, which is at the centre of the museum.

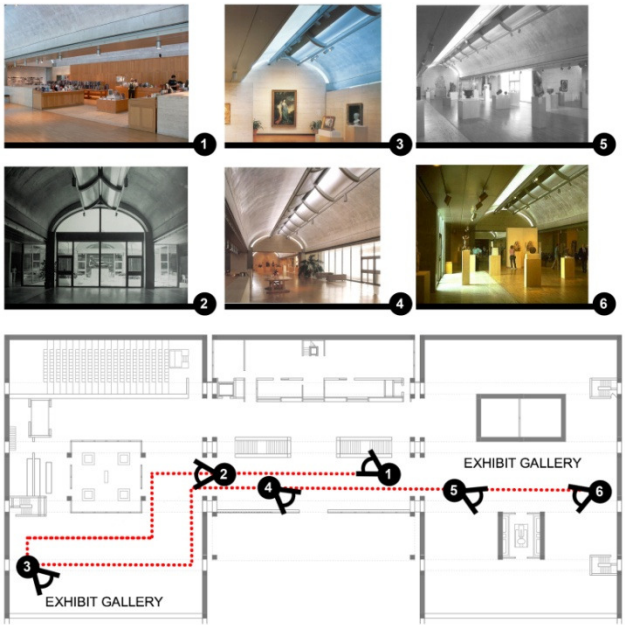

Figure 5: Sequence of space (original source for plan: [11]; redrawn by author, diagram by author, source for image 1: [16]; image 2: [17]; images 3,4,5: [18], image 6: [19]).

- **Light**

In the Kimbell Art Museum, Kahn created this unique top-lit museum environment, in which daylight plays the key role, and he skillfully integrated the rooflight and light courts into the museum's architecture (Fig. 6). The structural design allowed the cycloidal vaults to be "supported on only four columns each, that allowed a continuous roof light at the apex of the roof and an arc glazing between the soffit" [20]. The dynamism of daylight is integrated by the open-air courts with different dimensions, transparency and reflectance [21].

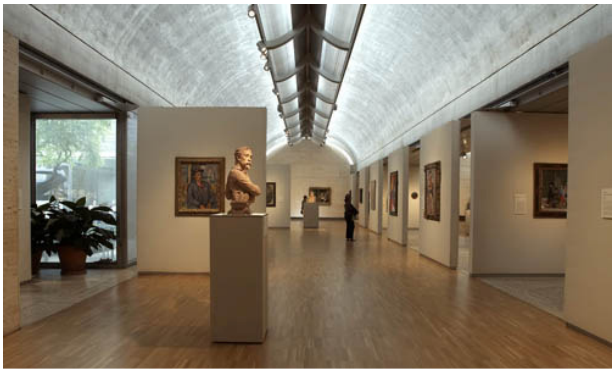

Figure 6: The top-lit museum ambience and light court with vertical glazed surfaces, source for image: Kimbell Art Museum [12].

THE QUALITATIVE ANALYSIS OF THE LUMINOUS ENVIRONMENT IN THE KIMBELL ART MUSEUM

Narrow roof lights are located at the centre of the concrete vaults. The reflector below the rooflight both reflects and diffuses daylight, making the vault ceiling as one of the brightest surfaces in the galleries. The light intensity of the direct sun is tempered by the rooflight and the incoming light is directed towards the vault surface first and then the interior space, with a gradual decrease in luminosity towards walls. While directing the sunlight towards the ceiling, the perforated zone of the reflector allows the controlled light beams to radiate into the gallery spaces. The linear light slits on travertine side walls and the semi-circular light slits on end walls echo the bright linear reflector surface and enhance luminance balance.

Due to the high solar angle and almost overhead position of the sun in summer, the configuration of rooflight prevents the direct solar ingress entering the gallery spaces creating a diffused lighting condition (Fig. 7). Although there is linear light slit on west facade, the portico and travertine wall prevent the penetration of direct sun through the slit.

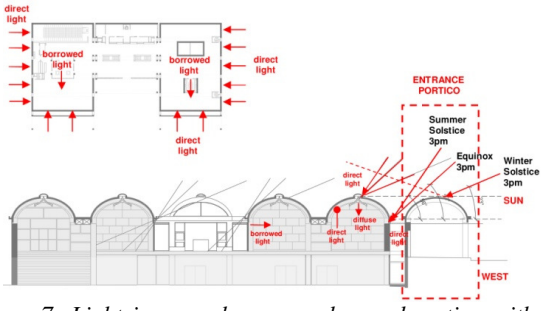

Figure 7: Light ingress shown on plan and section with the solar angles related to west orientated facade shown on section (original source for plan: [11]; redrawn by the author, diagrams by the author).

As part of the qualitative studies, a physical scale model of the museum was built and tested under the artificial sky to explore the light under overcast sky condition. The two testing images in Figure 8 show the well balanced top-lit luminous environment and the impact of light courts on the adjacent gallery spaces (Fig. 8).

Figure 8: The visual environment in the Kimbell Art Museum as in the pictures of physical model testing under artificial sky (physical model and pictures by the author).

THE QUANTITATIVE ANALYSIS OF THE LUMINOUS ENVIRONMENT IN THE KIMBELL ART MUSEUM

Two gallery spaces have been selected for the quantitative studies in order to compare the luminous environment in the north and south wings (Fig. 9).

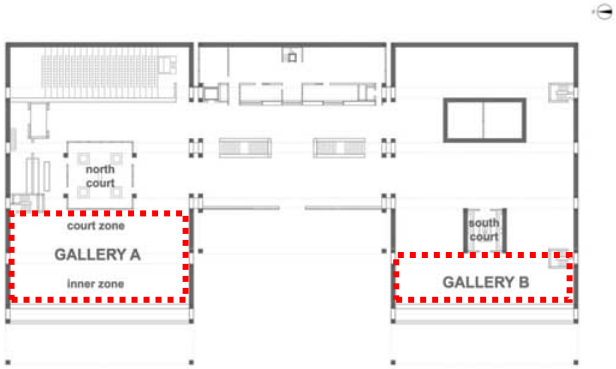

Figure 9: Label of simulated galleries on ground floor plan.

- **Daylighting performance analysis**

Daylighting performance has been evaluated through daylight distribution and daylight factor (DF) of the gallery spaces. The performative studies were conducted by using Autodesk ECOTECT / RADIANCE. The measurement grid plane has been set at 0.85m from the finished floor level. The average daylight factor in the entire Gallery A is 2.0 percent. This indicates a luminous environment which requires supplementary artificial lighting (Fig. 10). While the court zone is a well daylit space with daylight factor around 5 percent, inner zone has a rather low daylight factor around 1

percent. It is evident that the court zone benefits from the light trapped by the north court. In Gallery B facing the south court, the average daylight factor is 2.3 percent suggesting a relatively low daylit appearance for the gallery space.

Uniformity ratio (UR) is calculated to investigate the daylight distribution in the galleries. In Gallery A, the uniformity ratio is 0.5, which indicates an uniform lighting condition. The daylight factor distribution curves, which show the light distribution on the horizontal and vertical axis, reveal that the daylight factor is higher in the centre of the Gallery A due to the north court on *X*-axis (Fig. 11). The line graph on *Y*-axis shows the drop in daylight factor value starting from court. The light distribution remains uniform on the inner zone of the gallery.

In Gallery B, the uniformity ratio is slightly lower (0.4) indicating a less uniform daylight distribution. While the *X*-axis shows a similar characteristic, the Y-axis differs from the Gallery A. The light distribution is uniform for the majority of the gallery as it is narrower than Gallery A.

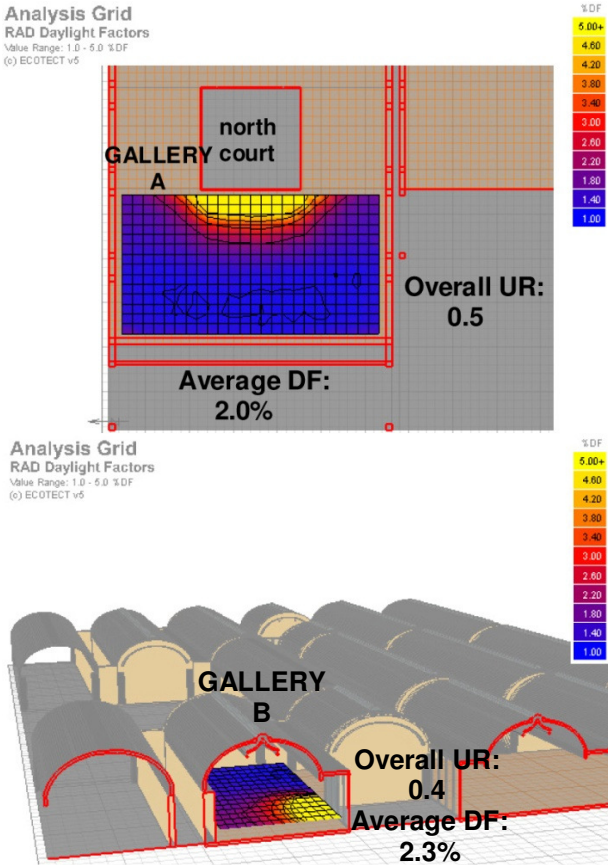

Figure 10: Daylight factor isolux plot of Gallery A in plan (above) and Gallery B in perspective (below) (model and diagram by the author).

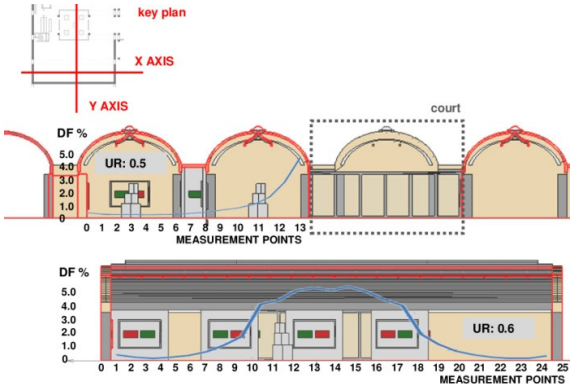

Figure 11: Daylight factor distribution curves on section for Gallery A: The line-graph showing X axis as below and the line-graph showing Y axis as above with related key plan (model and diagram by the author).

- **Visual environment**

The illuminance and luminance simulations have been conducted in Autodesk ECOTECT / RADIANCE under overcast sky condition to observe the worst case scenario and sunny sky condition on Summer Solstice to evaluate the light impact from the high angle summer sun.

Related to the daylight illuminance; the highest value of illuminance is on the vault surfaces and decreases gradually from the reflector towards ceiling and walls in Gallery A's inner zone under overcast sky condition. Similar pattern is observed under sunny sky condition, in which gallery space is brighter due to the reflected and diffused sunlight (Fig. 12).

In Gallery A's court zone and Gallery B, which is close to light courts, side lighting from the courts dominates under overcast sky condition. In Gallery B, the south court provides good three-dimensional modelling of the exhibits (Fig. 13). The illuminance ratio between the object and the rear wall is 6.5 : 1 achieving a higher ratio than the recommended one (3 : 1), indicating a dramatic lighting condition [22]. Similar illuminance ratio can be found in Gallery A's court zone, the ratio between sculpture and the rear wall is 5.2 : 1 on Summer Solstice 12pm, which also indicates a dramatic luminous environment. These findings confirm that the light conditions in the galleries enhance the three-dimensional modelling of the exhibits.

The brightness contrast studies have been carried out to investigate the luminance distribution in the galleries. In the inner zone of Gallery A on Summer Solstice, the luminance ratio between task and immediate and far surround is 1 : 1.23 : 1.7 (Fig. 14). This ratio is in the reversed order of the recommended luminance range as 10 : 3 : 1 [23], which indicates that the exhibit is de-emphasized. In Gallery A's court zone, the light court

provides better two-dimensional and three-dimensional modelling under overcast sky condition. The luminance ratio between sculpture and immediate surround is 1.96 : 1, which adequately reveals the three dimensional quality of the exhibit. Due to the bright ceiling and court window surfaces, the ratio between task to far surround is 1.67 : 1, an acceptable brightness ratio which enhances visual perception, but not causing glare. The associated luminance ratio 1.67 : 0.85 : 1 falls within the recommended luminance ratio.

In Gallery B, the luminance ratio between task and its immediate surround is 1.44 : 1 under sunny sky conditions (Fig. 15). Thus, abrupt brightness contrast is not present here. The internal courts further enhance two-dimensional and three-dimensional modelling of exhibits here.

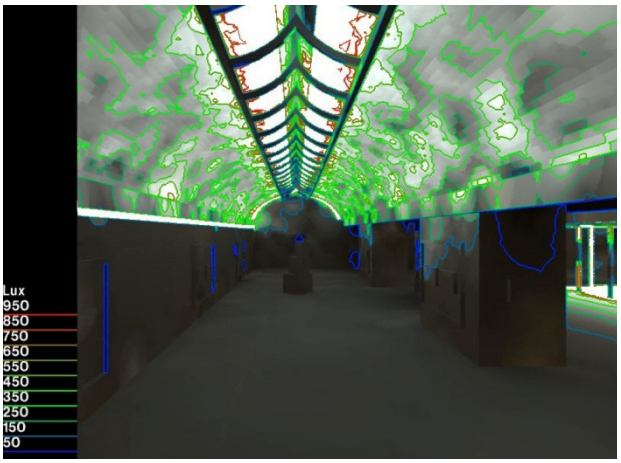

Figure 12: Illuminance plot of Gallery A inner zone in Kimbell Art Museum under sunny sky condition for Summer Solstice 12pm with isolux contour lines.

Figure 13: Selected illuminance readings of Gallery B in Kimbell Art Museum as an example to galleries close to courts under overcast sky condition.

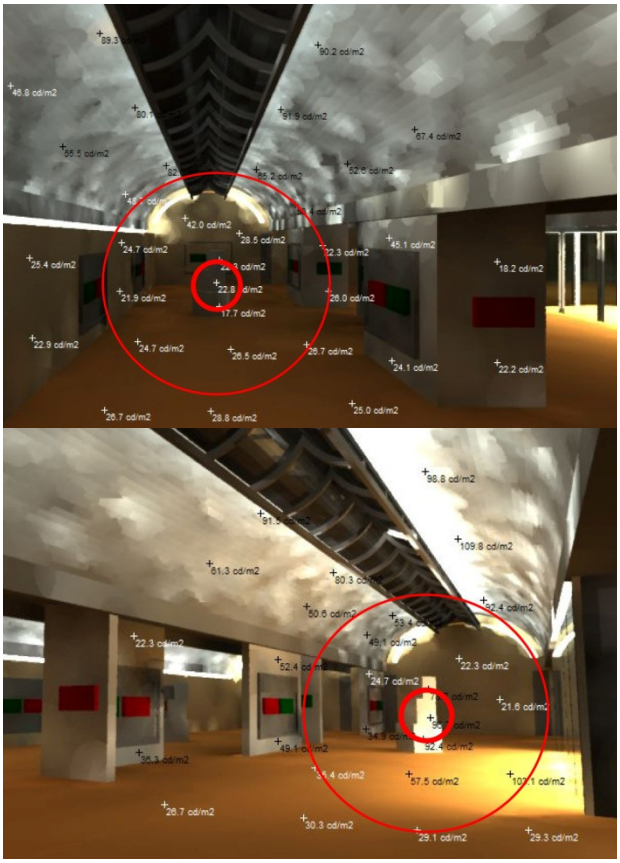

Figure 14: Selected luminance readings in Gallery A inner zone (above) and court zone (below) under sunny sky condition for Summer Solstice 12pm.

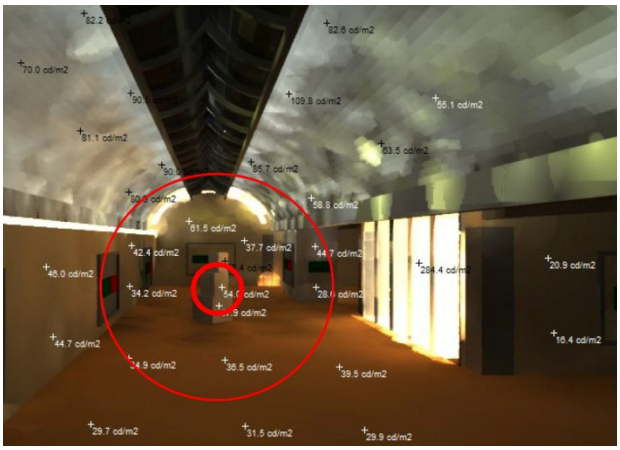

Figure 15: Selected luminance readings in Gallery B under sunny sky condition for Summer Solstice 12pm.

RESULTS OF ANALYSIS

The qualitative and quantitative studies have revealed that the Kimbell museum has a unique luminous environment combining the interplay between top light and side light. The vault ceiling works as a light reflector re-directing light back into the space and

creating glare free and well balanced luminous environments. The galleries adjacent to light courts have the enhanced three-dimensional modelling due to the abundant side light coming from of courts. The end galleries have more stable lighting conditions due to uniform luminosity under the rooflight.

CONCLUSION

The Kimbell Art Museum is a significant building for understanding Louis Kahn's lighting idea about integration of architecture and light. Kahn created this unique luminous environment by using both top light and side light to enrich and enhance the lighting conditions inside the gallery spaces. By tempering the light through light reflector, vaulted ceiling and internal light courts, undesirable glare which may potentially caused by the overhead sun in Texas has been skillfully avoided. In addition, the narrow light slits on opaque facade further balance the luminous environment in the galleries.

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