The Quest for Light in Indian Architectural Heritage

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Abstract

Due to the effect of impinging solar radiation, high thermal loads can be predicted in buildings in many climates of South-East Asia and thus components devised to protect and ventilate the façades have been known for centuries. Features such as the "jalis" or stone lattice work combined with deep overhangs and elements conceived to reflect excessive sunlight such as ritual ponds or even elaborate water tanks have adorned Indian-style palaces and temples since ancient times. These features have subsequently inspired modern architects like Le Corbusier, Antonin Raymond, Benjamin Polk and Geoffrey Bawa to cite just a few. Climatic control elements were well adapted to the craftsmanship of traditional architecture but their use as industrial products suitable for prefabrication is more controversial. Not only has the climate changed since the origin of Indian architecture, but also the use of glazing has increased in an alarming way and thus the need to protect openings is now even more demanding. In this paper, within the context of Indian civilization, the author will present the simulation of the radiative field generated by different types of solar protection and reflective surfaces, especially ponds and systems of louvres or brise-soleil. By virtue of this process it is intended to extrapolate the procedures used for ancient fabrics to their more modern counterparts found in internationally acclaimed buildings and to obtain useful design insights for future projects.

Keywords: solar protection; day-lighting simulation; tropical architecture

1. Introduction

The problem of dealing with excessive solar radiation in architecture is certainly not a new one. Likewise, it has to be recognized that this question was not related to the buildings of temperate climates but rather to the requirements of hot and humid tropical climates. Such climates were scarcely known to the Europeans, although they constitute one of the distinctive features of vast areas in Asia, considered by many the cradle of civilization, due in great part to its unique art and architecture.

In the ancient monuments of South-East Asia, India, China and Japan, elements such as canopies, awnings, jalousies and ponds to reflect the light were so much in use that they reached the status of religious symbols.

These creations were always connected to at least two of the most subtle and powerful events that occur in the natural world: wind and light.

Craftsmen of all epochs had striven to ensure that the design solutions implemented conveyed the light and wind as far as the materials and technology allowed, without rejecting or impeding the beneficial effects of nature.

Think, for instance of the delicately carved stone balusters at the window bays of Angkor Wat in Cambodia (Fig.1.).

Fig.1. Stone balusters at a window bay in the temple of Angkor Wat, Siem Reap (Cambodia)

Some of these measure three meters high and weigh more than one hundred kilograms. The reader can imagine the tremendous effort needed to sculpt and put such columns in place. Upon close examination, it is impossible to believe that their makers were not deeply inspired by environmental affairs.

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Similar stances could be taken to comment on precious jalīs appearing throughout the main Indian monuments from south to north (See Figs.2., 3. and 4.).

Fig.2. The entire wall is made of jalīs (jalousie) at this tomb in Qutub Minar, New Delhi (India)

Fig.3. An exquisite jalīs at Lal Qila (Red Fort) New Delhi (India). Notice also how if necessary, water can be conducted under the screen to further enhance evaporation.

Fig.4. Detail of a stone jalīs at Lal Qila, New Delhi (India)

Contemporary architects recalled many of those buildings as a sound basis for their forthcoming works, but their visionary approach was often confined to design gestures or elaborate idioms of reduced efficacy. Because of this, some of the solutions proudly displayed during the modern period were doomed by time and dwellers and subsequently abandoned.

From a scientific point of view the author is now in a position to offer some powerful, simple tools that may help to bridge the gap between the design expectations and the real performance.

2. Techniques of Analysis

In order to find the amount of radiation emitted by different design elements taking into account their reflective properties, the theory of the radiative field founded by Yamauchi [1] and later expanded by P. H. Moon [2] has been developed and programmed for Matlab®. According to those authors, such an analysis would imply methods of geometric optics for determining the form factor equations that appear under different configurations of reflective surfaces and their associated obstacles. The author will show that these equations can be readily solved in most cases.

The Japanese Scientist Jiro Yamauchi proposed around 1930 a unified theory of the Illumination Field [3]. Yamauchi was instrumental in the development of artificial lighting in Japan but he seldom referred to radiation or day-lighting. However, his algorithms and tables, obtained without the aid of computers, can still be widely employed. For instance, he proposes several solutions for the complex expressions of F_{12} (the form factor between two surfaces 1 and 2), whether parallel or perpendicular sharing a common edge, based on the knowledge of a certain function Φ . [4] (Fig.5.)

$$\phi_0(\mu) = \frac{1}{2}(\mu - \frac{1}{2} \tan \mu \ln \sin \mu + \frac{1}{2} \cot g \mu \ln \cos \mu) \quad (1)$$

So that,

$$F_{12} = \frac{2 \cdot b}{\pi} \left[a \cdot \phi_0(\alpha) + c \cdot \phi_0(\beta) - (\sqrt{a^2 + c^2}) \cdot \phi_0(\beta_1) \right] \quad (2)$$

Fig.5. Values of the Φ function from 0° to 90°

In the former expressions, a , b and c are the dimensions in metrical units of the given surfaces (Fig.6.), and it is only necessary to find geometric quantities such as, $\alpha = \arctan(b/a)$, $\beta = \arctan(b/c)$ or

$$\beta_1 = \arctan b / \sqrt{a^2 + c^2}$$

Fig.6. The form factor between 1 and 2 is a function solely of the length and width of the surfaces involved

This and other algorithms are extremely powerful for their use in computer calculations and based on them the author has derived the simulation program DianaX © [4]. In the discussion that follows its applicability to well-known buildings extracted from Indian-style architecture of all epochs will be demonstrated.

3. Examples in Ancient Architecture

1. Cave Temples of Ajanta

The author has drawn an example in which the form factor approach can be used conveniently from the famous underground temples or Chaitya in India (4th century). In them, lighting is fundamentally produced by a single semi-circular clerestory, similar in shape to the opening of a tunnel.

Let us study cave number 26, oriented to the west [5], in September, when the last effects of the monsoon leave an overcast sky with a high illuminance of around 10.000 lux.

Because the radius of the semi-circle is 2 metres and the distance to the inner *stupa* or sanctuary 14 metres, values of only 6.03 lux, are found on the horizontal plane. Therefore it is surmised that the

Fig.7. View of the entrance to cave n. 26 in Ajanta, Photo: Kamiya Takeo

internal reflections (not detailed here) are mandatory for acceptable vision and the rich veneering materials employed at the time should have augmented the available brightness.

Fig.8. The lighting levels decrease steeply inside the chaitya.

Fig.9. Semicircular emitting source used for the calculations of light distribution inside the temple.

Fig.10. Partial radiation field over the plan of the Chaitya n.26 in Ajanta (India) with illuminance levels (3000-50 lux, reflections not included).

2. Surya Temple at Modhera

Another interesting example lies in the Surya Temple in Modhera, Gujarat (11th century). In this case, the pool called "baoli", also a water supply, is oriented to the east of the compound to benefit from the rays of sunrise, considered to be sacred in India [5].

The light reflected from this "kund" or "baoli" plays an important role in the morning ceremonies that were once conducted there. This is proved by the fact that the steps are finely carved with statues and inlays of gods and other religious characters from the Hindu pantheon. Besides, due to the slanted profile of the tank, the sunrays find few obstacles in their way to the painted ceiling of the "mandapa" or main hall.

Fig.11. View of the Mandapa or Hall of the Surya Temple at Modhera

Fig.12. Plan of the stepped-well and the Temple of Surya at Modhera (India). For a solar height of 20° we find values on the ceiling of the mandapa of over 300 lux.

Cardinal orientation is a constant for this type of stepped-well structures and the curious effects of illumination, the shadows from the sun or even the moon, have been incessantly revered. Some of the wells decorated with solar disks made of bronze, even receive the name of "Lolarka" which means the "trembling sun".

4. Performance of Obstacles

As previously stated, many buildings did not possess openings or light sources as simple as the ones just analyzed. Bearing in mind the ideas of Yamauchi and Shukuya, the author has devised a procedure to treat systems of louvers and other reflective obstacles of arbitrary shape. This would entail creating an intermediate space composed of two slats, a layer of glass or "interior space" and limiting planes at the front and side ends of the imaginary "box" (not necessarily parallel or plane).

Fig.13. Section of the "box" created to study radiative exchange and inter-reflections due to different obstacles

Fig.14. Sectional view of a typical space with blinds used for the ensuing simulation

In the limit plane the user introduces as emissive power the values of diffuse radiation and the lower slat may also receive direct radiation depending on the time of the year. First the program calculates all data for a given location and then the involved form factors to obtain the radiative exchange, finally producing a result that can be applied to the opening plane. This is a new value that the program uses, as for a normal aperture, by reiterating the process.

Thus, the system of blinds is conceived as a sieve or filter for radiation that can be analyzed separately or suppressed and the output is later superimposed on the façade element, apertures, etc.

Inter-reflections and nuances such as the effect of changing the colour or the material of the slats can also be taken into account by virtue of the following technique; reflected radiation E_R in a given volume is a function of direct radiation E_d as expressed in 3. [6]

$$E_r = F_{rd} * E_d; F_{rd} = F_r^{-1} * F_d \quad (3)$$

And

$$F_r = \begin{bmatrix} 1 & -F_{12}\rho_2 & \dots & -F_{1j}\rho_j \\ -F_{21}\rho_1 & 1 & \dots & -F_{2j}\rho_j \\ \dots & \dots & 1 & \dots \\ -F_{i1}\rho_1 & -F_{i2}\rho_2 & \dots & 1 \end{bmatrix} \quad (4)$$

$$F_d = \begin{bmatrix} 0 & F_{12}\rho_2 & \dots & F_{1j}\rho_j \\ F_{21}\rho_1 & 0 & \dots & F_{2j}\rho_j \\ \dots & \dots & 0 & \dots \\ F_{i1}\rho_1 & F_{i2}\rho_2 & \dots & 0 \end{bmatrix} \quad (5)$$

F_{ij} are the previously described form factors from surface i to surface j , and ρ_i is a new term defined as the coefficient of diffuse or direct reflectivity from surface i .

A table with results for the louvres painted in white as defined in Fig.14., is given below.

Table 1. Values of total illuminance on the different surfaces of the "box" after infinite reflections (Surface 1. Limit plane. 2. Lower slat. 3. Glass. 4. Upper slat). March 21st. 12 hours clear sky plus sun and overcast sky for latitude of 30°, corresponding to New Delhi (India).

TYPE	FINAL	PREVIOUS	FINAL	PREVIOUS
DATE	Mar 21	Clear+sun		Overcast
1	44859	13065.9	8652	7545.7
2	74893	4485.4	3330	2590.4
3	37867	6829.2	4965	3943.9
4	37649	4485.4	3330	2590.4
SURFACE	LUX			

Notice that for a clear sky with sun the values on the glass are more than two times higher than those for the unobstructed window (Surface 1), which ensures a better performance.

As an example of skewed geometries, in the common situation of inclined or displaced blinds, different form factors and areas could be combined in order to treat them either as slanted or non-aligned parallel surfaces following Equation 6.

$$A_{2+3}F_{2+3,4+5} = 0.5*(A_{1+2+3}*F_{1+2+3,4+5+6}) + 0.5A_2*F_{2,5}-A_3F_{3,6} \quad (6)$$

Fig.15. Proposed division of inclined blinds to treat them as displaced parallel surfaces.

Below follows an example of how the form factor varies with inclination for the same blinds of Fig.14.

Fig.16. Form factors for different angles of louvres (initial dimensions 0.20 m. width and 0.30 m. height).

The fundamental problems of radiative exchange can be resolved in this way but in some cases it is still advisable to check for visibility through the blinds as this will also give an estimate of the "transmittance" of the system and the possibilities for ventilation. A typical expression to measure the visible portion of sky between blinds is equation 7. [4]

$$P_v = \frac{1}{h} \left[(h - l * \sin\beta) * (z_1 - z_2) - \frac{l}{2 * y} * \cos\beta * (z_1^2 - z_2^2) \right] \quad (7)$$

Where β is the angle of inclination of the slats, z_1 and z_2 are the upper and lower heights of a chosen interval of blinds taken from the working plane and y is the horizontal distance to the point considered.

Another problem if the available space for light is too narrow is the spreading of light energy, namely diffraction. The author has experienced that the traditional jalis carved on stucco or stone materials (Fig.4.) is wide enough to prevent the sun from entering through the apertures, and thus reduce the problem. However, wooden frames and modern metallic imitations of negligible thickness cannot avoid diffraction in some cases and great caution should be taken when deciding the dimensions of these filtering elements.

5. Modern Architectural Examples

1. Aurobindo's Ashram in Pondicherry (Tamil Nadu)

The author would like to draw on the case of an outstanding Indian building that used louvres as its main design feature: the Sri Aurobindo Ashram

(dormitory) constructed around 1937 by the Czech-American architect Antonin Raymond and designed in collaboration with the Japanese master Kunio Maekawa, a former disciple of Le Corbusier [7], thus explaining why the word "persienne" (louvre in French) appears in one of the project plans.

The façade is entirely composed of large horizontal louvres that enhance cross ventilation and through their changes in texture soothe the modern material displayed in the two volumes of the complex. (Fig.17). A construction drawing by Raymond (Fig.18.) explains succinctly that this façade is a "window arrangement for tropical countries." [8]

Antonin Raymond, assisted by François Sammer and George Nakashima departed from the original plans and decided to cover the building with vaults of precast concrete to provide for a vented roof.

Stone from the local quarries and a touch of wood add a sense of warmth and intimacy that goes far

Fig.17. View from the north of the Sri Aurobindo Ashram in Pondicherry (India), Antonin Raymond (1937).

Fig.18. Detail of the wooden system for rotating the louvres of the façade.

beyond the rigid codes of industrial materials and raw concrete that prevailed in the latter modern buildings at Chandigarh and Ahmedabad (especially in those designed by Le Corbusier) (Fig.19.).

Fig.19. The brise-soleil seen from the interior of the rooms facing South.

The rooms for the disciples have been simulated with the formerly described technique. Such a system of louvers performs much better than conventional windows as can be seen in Fig.20.

Fig.20. Simulation of the effect of blinds of different colours in Raymond's project, compared with a room without blinds oriented to the south and to the east.

Attesting to the good results of the louvre-façade system is the quote of the American Architect Benjamin Polk who worked extensively in India and Nepal from 1952 to 1964 recognising that "the brise-soleil sun-protection system comes as an extension of the column and lintel from the nature of the structural concrete frame. It replaces the dust-collecting masonry open-work screens that have become an almost ever present "petticoat" laid over tropical buildings in the name of modern architecture." [9]

2. The Architectural Oeuvre of Geoffrey Bawa

A second contemporary example comes from the partnership of Geoffrey Bawa and Ulrik Plesner. Throughout their career these architects of the Tropical Modernism showed an increasing concern for bioclimatic design. [10]

Fig.21. Detail of the brise soleil at the Pieris House designed by Ulrik Plesner for the architect Minette de Silva. (1956, Sri Lanka)

Fig.22. The southern façade protected with louvres at the main building of Ekala Industrial Estate (Jaala. Sri Lanka 1959).

The louvre-theme is a constant in their many projects, as are the cantilevered and deep-shaded facades, the ponds and courtyards (midula) with vegetation introduced to the core of the building and the traditional tiled roof. Although thus far no simulations have been applied, the author has measured the lighting performance of these buildings and presents them only as a suggestion regarding their potential.

Fig.23. Beautifully carved wooden shutters at the Buddhist temple designed by Bawa in Beira Lake (Colombo, Sri Lanka)

Fig.24. Geoffrey Bawa's Studio in Colombo, with wooden galleries and a reflective pond.

Fig.25. View of the entrance ceremonial pond of the Sri Lankan Parliament at Kotte. (1974)

Fig.26. The rear wing of the Kandalama Hotel near Dambulla (Sri Lanka), one of Bawa's latest projects (1994). Through walls and roofs covered with vegetation this building is totally integrated into the surrounding landscape.

6. Conclusion

Traditional Indian architecture has been modelled by the climes and the environment. Thus it has developed a unique sensibility towards lighting features and strategies.

Reflective surfaces interposed on façades such as louvres and brise-soleil are a good alternative to reduce radiant exposure and minimize cooling loads. That is why they have been employed in a wide variety of works ranging from the mastery of the jalis, "jaffrey" and baoli of antiquity to the modern building.

As in several parts of the world, independent experiences involving the environment took place in India during the 20th century. Undoubtedly, a number of architects strove at the time to restore the solutions that were so inspirational in their work and that still continue to exert a positive influence on designers from all countries who approach this question with contemplative eyes. [11]

Though many of their simple and unassuming projects kindled the debate on modern responses to tropical architecture, an objective answer to the new and open design questions was not readily available.

Thus, it is the author's belief that the diverse simulation techniques presented here can help to evaluate the quality and efficacy of both traditional and modern design solutions,

The tools explained, and among them the superimposition principle that the author has developed, reduce computation time and help to visualize the results in a user-friendly way to improve the design process. Due to this research the effect on radiation of reflective elements is predictable and not just surmised. Consequently, designers, upon using these resources, will become aware of and appreciate their potential.

It is hoped that this, in turn, will encourage the reliance on architectural light as a timeless way of building with nature in Asia.

The same Sri Aurobindo Ghose who commissioned the Architect Antonin Raymond with the construction of the aforementioned Ashram, and which eventually became a source of spiritual inspiration for him, wrote in his well-known book *The Renaissance in India*:

"Indian sacred architecture of whatever date, style or dedication goes back to something timelessly ancient and now outside India almost wholly lost, something which belongs to the past, and yet it goes forward too (though this the rationalistic mind will not easily admit) to something which will return upon us and is already beginning to return, something which belongs to the future."

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