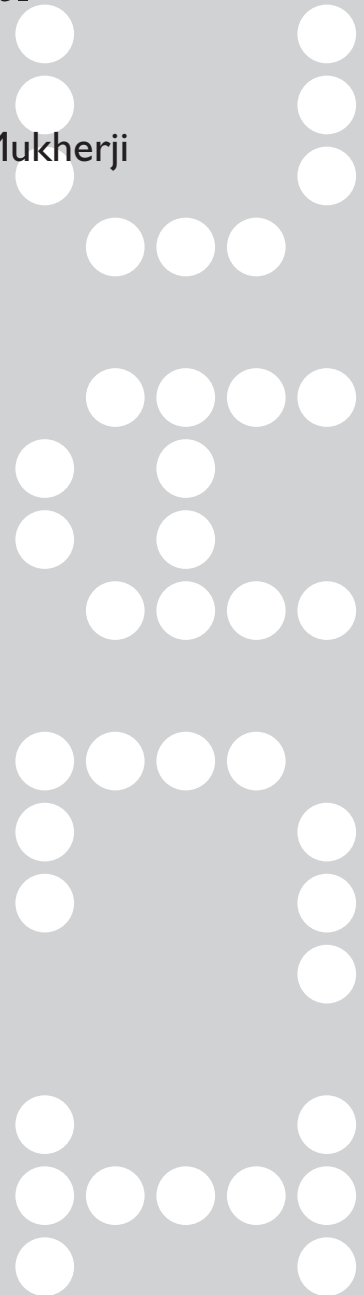


A Study of Light/Darkness in Sacred Settings: Digital Simulations

Anat Geva and Anuradha Mukherji



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Studying light/darkness and sacred architecture reveals that the “holy” light dramatizes the spiritual state and affects the mood of the user in the sacred space. Furthermore, it shows that faith dictates the treatment of light/darkness in the sacred setting as means to enhance the spiritual experience. These two premises were investigated by conducting digital daylight simulations on the Brihadeshvara Hindu Temple (1010 AD) of Tanjore, Tamilnadu, India. This sacred monument, listed as one of UNESCO’s World Heritage Sites, is an intriguing case study since the treatment of the ‘holy light’ in the temple is actually the treatment of the ‘holy darkness’. The simulated values were compared to the Illuminating Engineering Society (IES) standards. The results demonstrate that digitized simulations can illustrate the significance of light/darkness in sacred settings as a spiritual experience. Moreover, this quantitative investigation can augment the qualitative studies in the field of historic sacred architecture. The work presented here unites and extends some previously published work [20],[29].

I. LIGHT AND DIVINITY

“The design of human environment is, in effect, the design of human sensory experience; [therefore] all visual design is de facto also lighting design...” [1].

One of the most dramatic effects of light as a visual experience is light/darkness in sacred settings. As Arnold [2] posited, man needs to be given a glimpse of the fire/light descending from above showing the presence of God. The design of sacred settings can be perceived as an attempt to enrich the inner spiritual experience of Lord as Light. He further suggests that design provides light to connect to the divine and to highlight the rituals associated with this connection: “They shine through the darkness, a light for the upright; they are glorious, merciful and just” (Psalm 112:4).

Numerous studies [3], [4], [5], and [6] illustrate the symbolism of light and its relation to the celestial body. Others [7], [8], and [9] demonstrate that light provides premonitions and points of departure for spiritual and mystical transcendence, creating a bridge from the profane (the earthly world) to the sacred (a state of pure light), and puts us in touch with the eternal.

Thus, a premise can be drawn that the *“holy” light dramatizes the spiritual state and affects the mood of the user in the sacred space.*

A brief history of the use of daylight as symbolic and synonymous with heavenly light illustrates the association of light with cleanliness, purity, knowledge, and cosmic powers [4], [9]. The relation to the cosmos and its mystical significance is also expressed in geometric forms used by ancient and medieval cultures [5]. The proportioning systems were used to understand and attribute meaning to the rhythms and the cycles of the sun and the moon. This understanding was later incorporated into sacred architecture through various lighting techniques. Eliade [3] states, “Even before any religious values have been set upon the sky it reveals its transcendence. The sky symbolizes transcendence, power and changelessness simply by being there. It exists because it is high, infinite, immovable, powerful”. Thus, the sky provides the connection to divine light that in turn is a special aspect of symbolic light that represents the deity [6].

Sacred light connects us with a higher order of things, with the essential, with the immutable truth. It is not tied to revelation of a particular deity, or to a particular religion, or even to a typical house of worship. Rather, light as well as darkness remind us that a higher order exists [6], and symbolizes that which is beyond our normal comprehension: “Light and darkness, for instance symbolizes at once the day and night of nature, the appearance and disappearance of any sort of form, death and resurrection, the creation and dissolution of the cosmos, the potential and the actual” [3]. Light and darkness are rich in associations and carry with them the potential for expressing meaning, which can be translated into a built form. The various

interpretations of these associations produce different treatments of light/darkness in sacred settings.

Hence, a second premise can be introduced: *Faith dictates the treatment of light/darkness in the sacred setting as means to enhance the spiritual experience.*

The impact of a specific faith requirements on the architecture of the house of God can be studied in various religious manifests (e.g. Roman Catholic Canon Laws), as well as in contemporary literature [10], [11], which emphasizes the dynamic three-dimensional spiritual experience that stems out of the way symbols and rituals are transformed into architectural plan, geometry, surface, form, and space. The interplay of these features impacts directly the treatments of light/darkness. Techniques such as light reflected from the walls creating mysterious shadows, subdued light filtering through the openings, light/darkness serving as focal points, are some of the ways that natural light represents itself as a fundamental connection to god.

Although the literature establishes the link between light as architectural expression and divinity, most of the research on lighting evaluation was conducted on secular buildings. The review of examples of this line of research reveals the use of four major methods of evaluation: (a) recording (measurements) on site to determine the various lighting tasks and evaluate the quality of light accordingly [12]; (b) the investigation of quality of light in relation to human/cultural perception and experience [13], [14]; (c) development of guidelines of 'design with light' [15], [16], [17] and (d) digital expressions of lighting evaluation. The latter method includes the development of visual images that represent changing daylight and spatial variations [18]; the use of commercial computerized software such as *CAD*, *Forum Z*, *Lightscape* to generate light and shadows [19], [20]; and development of new lighting computerized simulations [21], [22].

The objective of the paper is to demonstrate the study's two premises that address the link of architectural treatment of natural light to the faith dicta by using *Lightscape*, a digital daylight simulation software [23]. To validate the simulations, the results are compared to the Illuminating Engineering Society (IES) standards, established for specific places and behaviors [24].

To illustrate the dramatic expression of the holy light/darkness, light analyses were conducted on the sacred monument of Brihadeshvara Hindu Temple of Tanjore, Tamilnadu, South India (1010 AD). This temple was selected for this investigation since it is an intriguing case where the treatment of the 'holy light' in the temple is actually the treatment of the 'holy darkness'.

2. THE HINDU TEMPLE AND LIGHT/DARKNESS

Hindu temples were built not only as monuments providing shelter to the religious symbols and the worshippers, but as the cosmos itself [25]. Evolving from a cave, onto a hut or a modest abode of timber, the temple gradually developed into a substantial structure embellished with decorative

moldings and ornaments and meaningful sculptures [26]. The ancient scriptures and the religious beliefs dictated the architecture of the temples. The use of the square as the basic unit in Indian temple architecture was chiefly a matter of religious significance. The square was considered as the mystical and absolute form, which did not permit any variation in the course of construction. The ground plan of the temple was based on a square grid. Each of the squares was thought to be the abode of a deity, and the location of the square within the ground plan accorded with the importance attached to the deity. According to the Vastupurushamandala, which is the diagram of the Hindu Temple's program, as well as its metaphysical plan, the Vastu (signifies residence) was a place of adjustments of the solar and lunar cycles for placement of the deities. The 32 divinities (padadevatas) in the square borders include the regents of the cardinal points and the 28 stars (nakshtras). The black square in the center, the garbhagriha (the womb chamber), is the location of the central shrine, the place for the main deity, the seat of Brahman (one of the chief Indian Gods, known as the creator of all living beings) [27],[31]. Other parts of the temple are organized around this chamber. The sequences of porches and halls, normally aligned on an east-west axis, lead in a succession of spaces towards the object of worship [25].

The black square (chamber) in the center of the temples follows the Hindu faith. It is believed that when a worshipper is in the presence of the divine, there should be nothing to distract his/her senses, including vision. God shall reveal himself to his devotee gradually [26]. Therefore, the innermost sanctum of the temple is shrouded in total darkness and the progression into the temple is a ritual movement where the devotee goes through the dynamic experience of the darkening spaces before reaching the darkest sacred chamber [25],[31]. This journey is both spiritual and physiological. The treatment of light ensures that by the time the pilgrim reaches the innermost chamber (garbhagriha) his/her eyes slowly become accustomed to the darkness and his/her state of mind befitting worship and is no longer plagued by worldly thoughts. During this procession, one passes through many doorways, colonnaded halls and corridors, which are decorated with sacred carvings. These sacred symbols have a profound impact on the mind of the devotee; they simulate the mystery that envelops the universe and the divine spirit that illumines the universe [26]. Reaching the holy sanctum, the worshipper enters a place for individual self-realization and personal relation with the divine. Thus, along the two previously mentioned premises the design of the Hindu Temple accommodated the faith, creating a procession toward the "holy darkness" that enhanced the spiritual experience.

3. THE BRIHADESHVARA HINDU TEMPLE

The Brihadeshvara Hindu Temple of Tanjore, Tamilnadu, in South India, built in 1010 AD, is listed on the UNESCO's World Heritage Sites as part of the

three Chola temples of Southern India. These temples represent an outstanding creative achievement in the architectural conception of the pure form of the Dravida temples [32]. This style, originally known as Dravidadesha style, was practiced during several dynasties only in the state of Tamilnadu in South India. An outstanding feature of the Dravidian temple architecture is its two types of towers, the vimana and the gopuram. The vimana (the holy shrine) is square in plan and structure and has a rounded cupola as its finial, whereas the gopuram is oblong and has an oblong vaulted roof [27].

The Brihadeshvara Temple (or Rajarajeshvara) was built in 'Tanjore,' the capital of the Chola dynasty by Rajaraja the Great (985-1014 AD) and has been dedicated to Shiva. It was built of granite stone during a span of six years. This monument not only expresses the Chola power and prosperity but is also considered as one of the finest architectural examples of intricate craftsmanship in stone (see Figure 1).

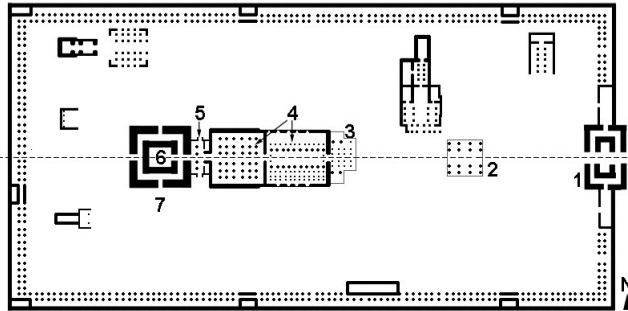


◀ Figure 1: Brihadeshvara Temple of Tanjore: Vimana, the shrine (based on [30])

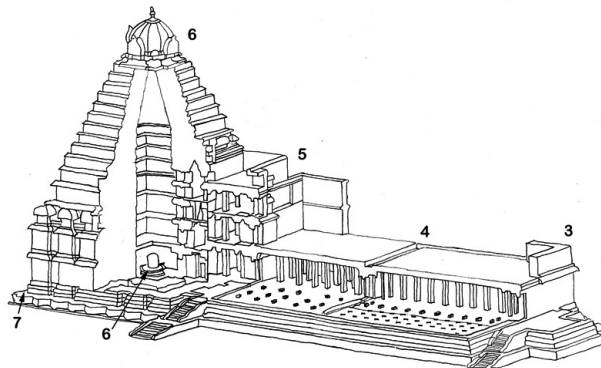
Figure 2 shows the linear plan of the complex of the Brihadeshvara Temple, while Figure 3 illustrates in an axonometric section the plan of the temple itself. The temple is located in the middle of a large rectangular walled courtyard (150m x 75m), and centrally aligned on an east-west axis with the Nandi pavilion (1), and the gopuras (2) (pyramidal gateways at the entrance to the courtyard). The entrance porch of the Brihadeshvara Temple (3) leads into two adjoining mandapas (4) (colonnade halls). Art historians believe that they were either built subsequent to the collapse of an original structure, or they had remained incomplete and were finished several centuries later [16]. The mandapa adjoins the antarala (5) (vestibule) and the garbhagriha (6) (innermost cell). The antarala is a triple story structure with openings on the north and south sides, which can be accessed by a monumental set of stairs. The square garbhagriha (8 meters side x 3.66

meters height) is raised on a high plinth and surrounded by a narrow pradakshinapath (7) (surrounding ambulatory passageway) with four cardinal openings that are inaccessible from the courtyard and serve as windows. The Vimana (6) (tower) located on top of the garbhagriha (6) at the end of the linear procession was built as a pyramidal stone spire, which rises to a height of approximately 66 meters above the garbhagriha. Thirteen diminishing stories, each with pilastered walls, an eave and parapet, ascend towards an octagonal dome-like roof with a gold plated copper kalash (stupi) at the apex [25], [26].

► Figure 2: The linear axis of the Brihadeshwara Temple complex (drawn by authors, based on [33])



► Figure 3: An axonometric section of the Brihadeshwara Temple (drawn by authors, based on [31])



4. METHOD, ANALYSES, RESULTS

The analyses of the treatment of light/darkness in Brihadeshwara Temple were performed in two stages: (a) running digital daylight simulation software — *Lightscape*; and (b) comparing the simulations values to the IES guidelines for houses of worship and standards for ‘public places with dark surroundings’.

4.1. Research instrument

The study utilized digital lighting simulations (*Lightscape*) to investigate the light/darkness design in the Brihadeshwara Temple. *Lightscape* is an advanced

lighting and visualization application founded on a physically based simulation of the propagation of light through space. Based on a description of light arriving at a surface, *Local Illumination* algorithms portrait how individual surfaces reflect or transmit light and can predict the intensity, spectral character (color), and distribution of the light leaving that surface. To achieve more accurate images, the program's *Global Illumination* algorithms use a combination of *Ray Traced and Radiosity* images, to render the transfer of light between surfaces in the model [23]. The Ray Tracing algorithm is used for accurate rendering of direct illumination, shadow, specular reflections (e.g. mirrors), transparency effects, and being memory efficient. Its disadvantages are that it is computationally expensive, time consuming depending on the number of light sources, the process must be repeated for each view, and does not account for diffuse inter-reflections (i.e. images may appear flat).

To address the shortcomings of the ray tracing algorithm, an alternative technique called Radiosity was developed for calculating global illumination [23]. Radiosity differs fundamentally from ray tracing. Rather than determining the color for each pixel on a screen, radiosity calculates the intensity for discrete points in the environment. This is accomplished by first dividing the original surfaces into a mesh of smaller surfaces known as elements. The radiosity process calculates the amount of light distributed from each mesh element to every other mesh element. Then it stores the final radiosity values for each element of the mesh. Its advantages are that it calculates diffuse inter-reflections between surfaces, is view independent for fast display of arbitrary views and produces immediate visual result, progressively improving in accuracy and quality. Its disadvantages are that the 3D mesh requires more memory than the original surfaces, surface-sampling algorithm is more susceptible to imaging artifacts than ray tracing, and it does not account for specular reflections or transparency effects [23].

Neither radiosity nor ray tracing offers a complete solution for simulating all global illumination effects. By integrating both techniques, the simulation results portray highly realistic renderings with accurate measurements of the distribution of light within the scene [23].

Figure 4 illustrates the simulation's two stages - the Preparation and the Solution stages. In the preparation stage, a 3-D Cad model of the target building is imported into *Lightscape* as an input file. Then, the surfaces and openings of the model are assigned their materials, texture and physical parameters (such as color transparency, shininess, refractive index). In addition, the lighting systems are defined according to the geographical location, date, time, and sky conditions.

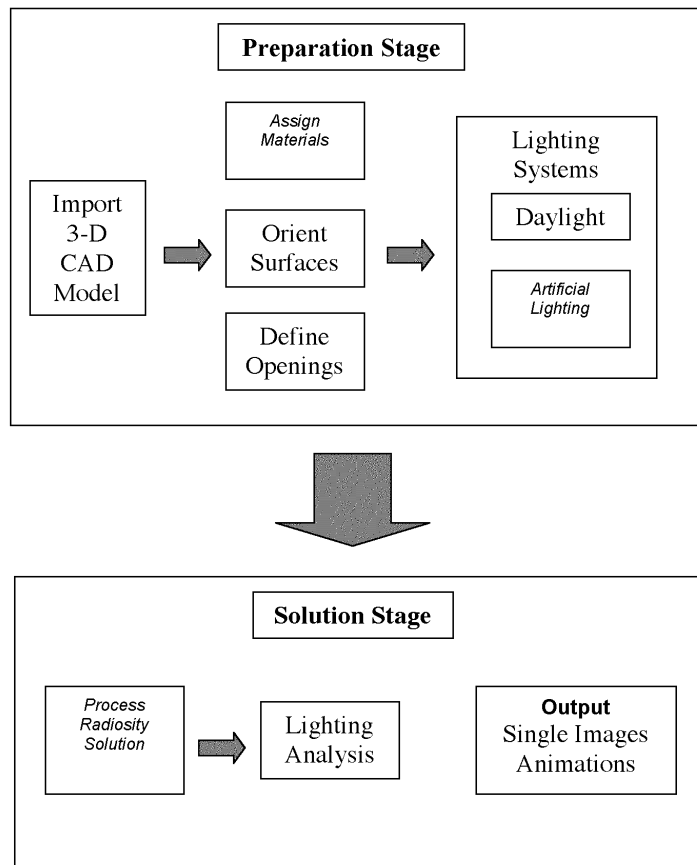
In the solution stage, *Lightscape* processes the radiosity solution of the model and saves it as an output file. In this latter stage one can no longer manipulate the geometry or add lights to the model, modification can be

made only in Lightscape preparation file. The output of the solution files consists of lighting analysis (for analysis), single images (for analysis and presentation), and animations such as walk-through images (for presentation).

The lighting analysis produces statistical data such as averages, minimum and maximum values, and criteria ratings to evaluate luminance (distribution of light reflected off of the surfaces) or illuminance (distribution of light incident on the surfaces) for a specific surface or a point on a surface. In addition, these analyses display the different ratios of the average, minimum, and maximum values. These three ratios are used in conjunction with the average value to roughly measure the uniformity of the distribution of the light over a selected surface [23].

To validate the simulations results, the values obtained from the lighting analysis were compared to the standard illumination values for lighting design recommended by the Illuminating Engineering Society (IES). Factors such as illuminance, luminance ratios, visual comfort, reflected glare, disability glare, veiling reflections, color and shadows were considered for the illumination considerations [24].

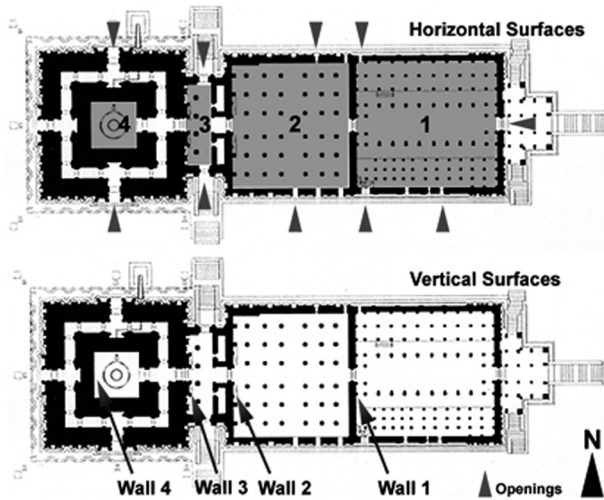
► Figure 4: Schematic structure of the lighting simulation process in *Lightscape* (based on [29])



4.2. Simulation

A 3-D CAD interior model of the temple was created based on the documentation drawings by Pierre Pichard [28], and imported into *Lightscape* as an input file. The model was constructed as 3D surfaces, instead of solid walls, to optimize the model for radiosity processing. As described earlier, a vital aspect of Hindu worship is the actual progression from the outermost spaces (well lit) to the innermost sacred spaces (completely dark) of a temple. Hence, a series of horizontal and vertical surfaces along the sequence of the procession in the Brihadeshvara Temple were analyzed. The floors of each of the successive four spaces were coded as the horizontal surfaces, while, the four main walls that would directly face a person while walking towards the innermost part, were selected as the vertical surfaces (see Figure 5).

The surfaces and openings of the model were assigned their material (granite), texture and physical parameters. In addition, the lighting systems (natural light) were defined according to the geographical location, date, time, and sky conditions. The simulation targeted three time frames on March 21st (the equinox): sunrise and sunset, which are spiritually important in the Hindu Faith; and the high noon for maximum light. The location of Tanjore, India (10° North Latitude, 79° East Longitude) was used for light conditions.

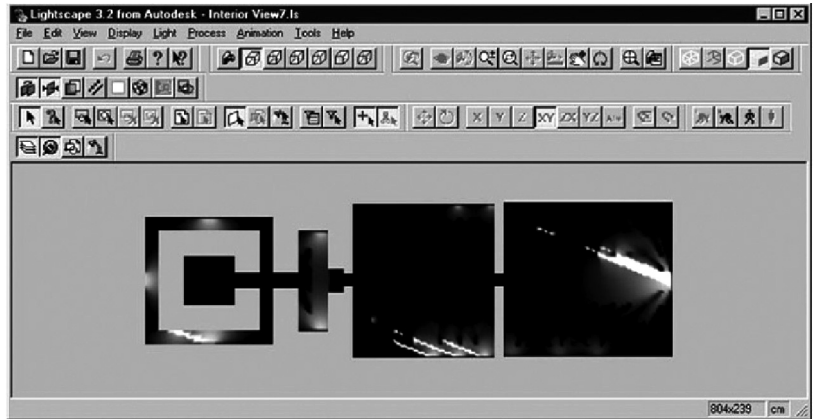


◀ Figure 5: Plans of Brihadeshvara Hindu Temple with openings and sequences of horizontal and vertical surfaces (based on [29])

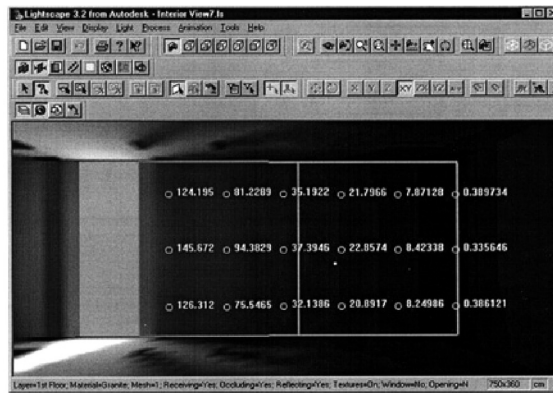
The results of the simulations show the illumination values in lux for each of the horizontal and vertical surfaces in the monument within a specific time frame. Three types of the simulation output were used for analysis and presentation: (a) single images of daylight renderings (see Figure 6); (b) lighting analysis. Figure 7 shows an example of the results of the illumination values on a surface in a grid format; and (c) walk-through images that is

shown in this study as a lighting animation from 6:00 am to 6:00 pm (See Figure 8). This animation was produced in *Quick Time* to illustrate the dynamic of the light drama that supports the ritual and spiritual movement from the lit outside toward the dark inner spaces.

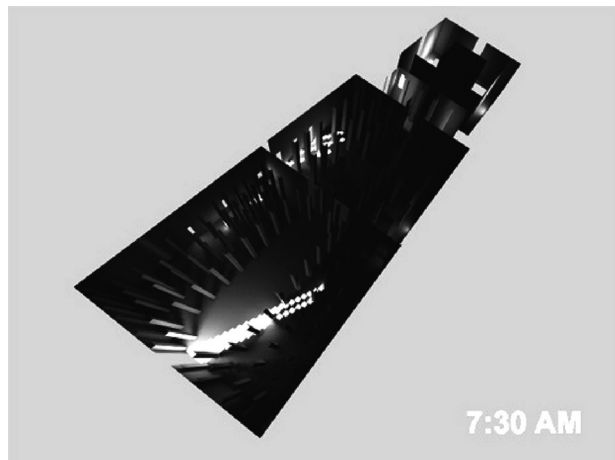
► Figure 6: Main window in Lightscape and a sample of the simulations single image



► Figure 7: A sample of the illumination values on a surface in a grid format



► Figure 8: A captured image of the walk-through lighting animation



The results of the simulations illustrate a progressively decreased luminance towards the dark innermost chamber: from Floor 1 (119 lux) through Floor 4 (0.40 lux) and from Wall 1 (38 lux) through Wall 4 (0.43 lux). Due to major openings on either side of the vestibule (*antarala*) space, Floor 3 (313 lux) and Wall 3 (169 lux) show a deviation from the general pattern. According to historians the presence of a pair of grand stairs and entrances on either side of the vestibule is unusual in ancient Hindu temple architecture and is a distinct feature of the Brihadeshvara temple [28].

The findings of this analysis demonstrate that the average illumination values for the specific surfaces correspond to the Hindu faith expectation of a procession sequence toward the holy darkness.

4.3. A comparison of the simulations results with IES standards

The second part of the analyses is the comparison of the simulations results (the average illumination values) of each of the temple's surfaces to the IES standards. The study used the standards recommended ranges of luminance for 'public places with dark surroundings' (30 lux) and for 'public places for short temporary visits' (75 lux).

Tables 1 and 2 show the comparison of the simulations results to the standards of the horizontal (floors) and vertical (walls) surfaces correspondingly. The average illumination values of the holy inner chamber of the temple are considerable lower (i.e. darker) than the current IES standards illumination level required for these spaces: Floor 4 (0.40 lux) and Wall 4 (0.43 lux). These results support the Hindu faith requirements of creating the "holy darkness" in the holy sanctum.

The entrance opening located in the east enables a strong focused light to hit Floor 1 and Wall 1 at sunrise (see Figures 6 and 8). Therefore, the average illumination values of Floor 1 (119 lux) and Wall 1 (38 lux) are higher than the IES standards illumination levels. These results demonstrate the importance of the first rays of sunlight from the east (entrance), which symbolize the Sun God. According to the Hindu faith, the rising sun is worshipped before beginning the rituals for the residing deity of the temple.

The floor of the second space from the entrance is still illuminated and its floor's average illumination values (75.6 lux) are almost compatible with the standards, while the average illumination values of Wall 2 (3.27 lux), which is farther from the entrance are much lower (darker) than the standards. These findings support the notion of a procession from the lit entrance toward darkness as dictated by the faith.

While, Floors and Walls of spaces 1, 2 and 4 are progressively darker than the IES standards, the average illumination values of Floor 3 (313 lux) and Wall 3 (169 lux) are higher than the IES standards. These findings show the unique design of the *antarala* (vestibule) of Brihadeshvara Temple. As described before (Figures 3, 5) due to the major staircases and openings on either side of the *antarala*, light enters this space.

► **Table 1: A comparison of IES standards for ‘public places with dark surroundings’ with the simulations average illumination values of the horizontal surfaces**

	Floor 1 (lux)	Floor 2 (lux)	Floor 3 (lux)	Floor 4 (lux)
Average (horizontal surfaces)	118.67	75.65	313.03	0.40
Public space with dark surroundings	30	30	30	30
Short temporary visits	75	75	75	75

► **Table 2: A comparison of IES standards for ‘public places with dark surroundings’ with the simulations average illumination values of the vertical surfaces**

	Wall 1 (lux)	Wall 2 (lux)	Wall 3 (lux)	Wall 4 (lux)
Average (vertical surfaces)	38.33	3.27	168.64	0.43
Public space with dark surroundings	30	30	30	30
Short temporary visits	75	75	75	75

5. CONCLUSION

The results of the digital simulations and the comparison to the IES standards demonstrate that strong religious light/darkness requirements dictated the quality of light inside the Hindu temple and thus overruled any other considerations. The findings of this examination support the basic premises of the paper and illustrate the ritual procession toward the “holy darkness”, and how light/darkness can dramatize the spiritual experience in the sacred spaces of the temple. The temple interiors were designed to be dark so the human eye is not distracted by the material world to let the mind enter the spiritual world of God. As seen in the Brihadeshvara Temple, natural light is introduced in a progressive light quality from brightness to darkness accommodating the ritual movement of the worshiper, and adjusting his/her eyes.

It is interesting to note that the historic design of this spiritual experience complies with the current IES four major principles of lighting design in houses of worship [24]. The Temple’s light/darkness combine task lighting (functional), accent lighting (spiritual), architectural lighting (functional and spiritual), and celebration light (spiritual).

The findings that deviated from the expected simulation patterns trigger an interesting question to be further investigated about the impact of non-original elements of the historic building (such as the monumental stairs of the vestibule in Brihadeshvara Temple) on the treatment of light. Moreover, these findings highlight the multi dimensionality of religious dicta.

Another interesting conclusion can be drawn. The reduction level of light quality in the temple also contributes to the thermal comfort in the building. Thick walls, small windows, and reduced light maintain cool and dry conditions for better thermal comfort in the hot humid climate of Tamilnadu. Thus, the Hindu worshippers are not distracted visually or thermally enabling to focus one’s mind on God.

Finally, the analyses suggest that digitized media such as computerized daylight simulations can examine the significance of light/darkness in sacred monuments as a spiritual experience, and can be applied in preservation of the architectural features that relate to light. This quantitative investigation can augment the qualitative studies of light and spiritual conditions in sacred settings. Yet, further investigations are recommended, such as corroboration of the simulations results with actual recording (measurements) of light. This evaluation method not only will further validate the simulation instrument, but also will help to interpret the quality of light as task or/and spiritual lighting. Moreover, in order to introduce the human factor, it is recommended to conduct interviews and surveys with users of the sacred space and learn about their perception and experience of the light/darkness treatment.

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