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Perceptual Dimension of Interior Daylight in Sacred Architecture: Analytical Study of the Lighting Programs in Five Sacred Buildings of Different Styles

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Abstract: This paper investigates and compares different types of lighting programs in sacred buildings. A general study exploring lighting techniques throughout the history is performed and followed by an analysis for some prominent lighting programs, in which five featuring constructions are examined in order to investigate lighting qualities in each of them. The aim of the paper is to investigate the luminous environment produced by these lighting schemes through a comparative study conducted by both qualitative and empirical methods, using sun angle charts to study the positions of sunbeams inside buildings and Autodesk Ecotect software to study the patterns of daylight distribution in these buildings. Studying these buildings, which depended on daylight as the primary light source, provides us with valuable insights to maximize the accentuating quality of light and to enhance the building's aesthetic schemes, without the need of extra energy exhaustion. The paper is a step towards sustainable lighting schemes for religious buildings that help to create significant atmosphere with minimum use of energy.

Keywords: Lighting program, daylight, top-light, peripheral light, dome-lighting, clerestory

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1 INTRODUCTION

Light is what gives character to architecture; without light form, color, or texture are not to be comprehended. It was considered as a celestial substance and the ultimate source of visual beauty in architecture since the earliest buildings. Depending on how it is used, light can transform the spatial context; create agreeable or disagreeable, sublime or mysterious sensations; or simply highlight aspects of the space that interest the viewer. Therefore, the history of architecture can be also told by referring to how natural light has been treated in accordance with different styles.

Light has been used in the sacred buildings, not only to provide the necessary visual condition for the ritual acts to be performed, but also to evoke mystical and spiritual feelings. In ancient Egypt, where the sun was thought to be the eye of *Ra*, creator of the universe, temples were designed, so that, the sanctuary and processional paths were oriented according to its movement. In ancient Greek civilization temples were also orientated towards the east to relate directly to the first light of the day. The Romans, the first to consciously design interior space, also used light to enhance and articulate space and the most representative example for this concept was the Pantheon in Rome. Light was also given great significance in the early Judaism, Christianity and Islam. From the Byzantine monuments to the Gothic and Renaissance monuments, light was employed as the medium, through which the representation of heaven was given a temporal earthly reading.

The hypothesis of this paper is that, in sacred buildings, the perceptual dimension of light has more importance than visual clarity and that there are certain aspects of space that may emphasize this dimension. The paper aims to analyze some of the most outstanding luminous environments in the history of architecture in order to assess the perceptual experience in each of them and grasp the logic behind these experiences. In doing this, the methodology of the paper

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depends not only on qualitative and configurative measures, but also on quantitative and empirical measures that will be applied on these lighting programs. An analytical-comparative study of daylight is attempted in two folds, using both sun angle charts to study the different positions of sunbeams inside the buildings under study, and computer analysis by Ecotect software to study the patterns of daylight distribution in these buildings. The paper came to the conclusion that the architects of these buildings employed, actually, very little amount of light to produce remarkable effects that depended on the study of the sun's altitude and a deliberate distribution of apertures. Doing this, the study gives a proof that some carefully designed transitions for the interior daylight may result in a perception of a much higher lighting level than those actually measured. It proves that the visual experiences in these buildings were not about the amount of light, but rather about the perceptual effects produced by this amount of light.

The paper is structured as follows: an introduction, four main parts, and a conclusion. In the introduction part, an overall view of the notions of the paper is introduced. The first part brings in a chronological study of lighting programs in sacred buildings, while in the second part, these programs are classified according to lighting source and a particular building is selected to represent each type. In the third part, criteria for evaluating the qualities of daylight in religious building are determined and the lighting programs of the selected buildings are examined against them. The results of this analysis are discussed in part four, and the findings of the research are summarized in the conclusion.

2 CHRONOLOGICAL STUDY OF LIGHTING PROGRAMS IN SACRED BUILDINGS

From the ornamented light of Egyptian architecture and throughout the distilled light of Classical Architecture, the supernatural light through stained glass windows in Gothic architecture and Mashrabeyah screens in Islamic architecture, reaching to the sublime light of the Renaissance and Baroque architecture, light metaphor has always been employed to engender the metaphysical virtue of the heaven and the Divine.

2.1 Ancient Egyptian Temples

In Ancient Egyptian temples light was admitted to the Hypostyle Halls by clerestory, formed by the increased height of the columns in the central aisle, while the sanctuary was left dark or only dimly lit. Less prominent, but very common, lighting solutions included cutting angled slits or square holes into the roof slabs to allow daylight to enter the space (LaChiusa 2009).

Figure 1. The sanctuary of the Temple of Abu Simbel

The most remarkable lighting scheme in Ancient Egyptian temples is the solar phenomenon at The Great Temple of Abu Simbel (Figure 1), where the axis of the temple was positioned in such a way that on October 21 and February 21 (allegedly the king's birthday and coronation day), the rays of the sun penetrate the sanctuary and illuminate the sculptures on the back wall, except for that of Ptah, the god of the Underworld, who should always remain in darkness. Due to the displacement of the temple and the accumulated drift of the Tropic of Cancer during 3,280 years, these two dates have moved one day closer to the Solstice, occurring now on October 22 and February 20 (Skliar 2005; Siliotti 2008)

2.2 Classical Temples

As for Greek temples, their roofs have all disappeared, and with them all the evidences regarding the method adopted for lighting them have been lost; with one exception (the temple at Agrigentum) there is a general absence of windows. This has given rise to several theories as to the method of admitting light; a clerestory concealed in the roof is the system favored by Fergusson (1893); while Bötticher (1888) suggested skylights. Other researchers hold that light entered solely through the door opening and was occasionally planned to fall on the statue in the Naos. Others contend that this light was supplemented by transparent Parian marble or alabaster roofing slabs (Fletcher 1905).

Temples were occasionally '*hypaethral*' or partly open to the sky, but this system appears to have been reserved for the larger temples such as the Olympieion, Athens. However, the most acceptable system is that of a row of windows over the internal colonnades (Fletcher 1905). In Roman architecture, natural light was a domain, to which Vitruvius devoted a whole chapter in his book '*De Architectura*'. Roman space was concerned with lighting that allows interior decorations to be seen clearly. The oculus of the Pantheon is the most prominent treatment from this era, where light comes only from a round hole in the dome, about 9 meters in diameter, alluding to the (circular) perfection of the

(a) (b)

(a) Clerestory between two roofs in St Nicolai Church, Stralsund (left)

(b) Clerestory, triforium, and arcade in Malmesbury Abbey, Wiltshire (right)

Figure 2. Openings in Romanesque and early Gothic churches

heaven and placing the emperor-god in direct relation with the heavens.

2.3 Early Christian and Byzantine Churches

Light was treated in Byzantine Architecture as the materialized representation of the Divine. In the bright climate of the Eastern Roman Empire, small openings sufficed to admit the necessary light, and the employment of mosaic rendered the use of large windows quite inadmissible. Light was sometimes filtered through thin sheets of alabaster to create even softer illumination. Early Christian, and some Byzantine, churches maintained the form of the Roman Basilica with central nave flanked by lower aisles and a wall pierced by clerestory windows in-between. But the most preferable system was a ring of windows at the base of the dome, and/or openings grouped in the gable ends or within the semicircular arch beneath the dome (Fletcher 1905).

2.4 Medieval Cathedrals

In Romanesque Architecture, interiors were heavy and had dim lighting. The nave was usually of two levels; arcade and clerestory (some churches have only barrel vaulted ceilings with no clerestory). A third level was later inserted between them, a gallery called the '*triforium*', which opened into the space beneath the sloping roof of the aisle (Figure 2).

Unlike this, Gothic Architecture was characterized by lightness and soaring spaces and buildings were 'designed around light' (Swaan 1988), where cathedrals used different methods to capture light and bring it into the spaces. Gothic churches employed vast expanses of stained glass, displaying a visual attempt to create a setting 'where people could get a taste of heaven' (Scott 2003).

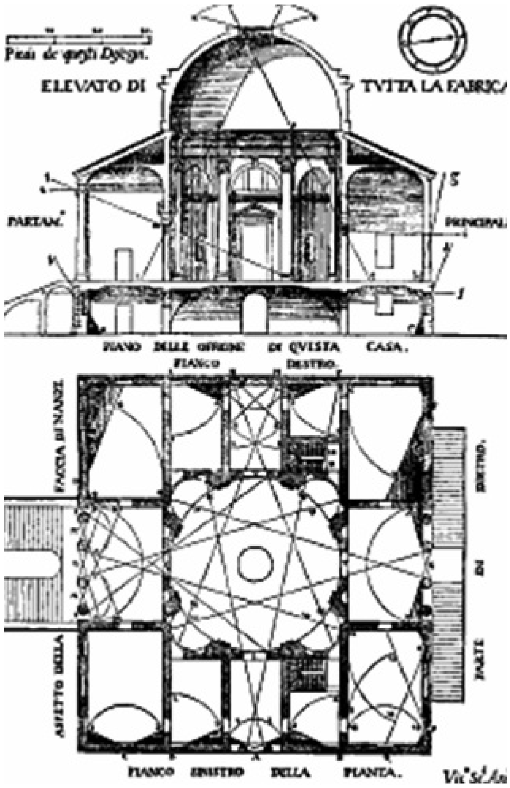


Figure 3. Scamozzi's scheme of architectural illumination (Scamozzi, 1615)

2.5 Renaissance and Baroque Cathedrals

In Renaissance Architecture, pure light from nature was the ideal tool and no more diffusion of light was

(a) The nave (b) The dome (c) The throne

Figure 4. Basilica Di San Pietro

(a) Sheikh Lotfollah mosque (b) Suleymaniye mosque

Figure 5. Islamic Architecture

used. The return to Classical Architecture produced a turn back to *oculi*, this time in the form of the lantern, which was a cupola-like structure mounted on top of a dome.

Studies of different shapes of windows marked the architecture of this era. In his earliest recorded project in Venice, Vincenzo Scamozzi proposed a systematic typology of architectural illumination that was differentiated into six kinds of light within a construction and traced them on a typical plan and section of a paradigmatic central-plan model (Figure 3), which had later dominated the illumination schemes of the period. In this model, the theme of altar illumination was explicitly raised, where the '*quadro*', or the '*pala*' (the ornate front of the altar), receive double light shafts from two openings on both sides (Davis 2002). Light shafts were used to create three major phenomena: first, to fall onto the altar in the morning; second, to fall on certain icons in certain dates; and third, to pore light on Jesus' image in the dome's interior.

In Baroque style, light was used dramatically with high contrasts of light and shadow. *Chiaroscuro* effect was the term that has been used to describe this contrast, which means 'light-dark' in Italian. The supreme example of this period was that of The Basilica Di San Pietro (Figure 4), where the sunbeams from the clerestories reflect from the polished surfaces, bathing them in ethereal glow. Michelangelo's dome, weightless and serene, floats above a circle of light from the windows beneath it flooding the medallions of the pendentives with light. The climax of this spatial journey is Bernini's throne of St. Peter, which beckons amidst a blaze of heavenly light from a circular opening.

2.6 Islamic Mosques

The notion of light was also remarkable in Islamic Architecture (Figure 5). Where little furniture is traditionally used and there are no pictures or statues, light is used to accentuate the space and increase the complexity of visual effects. Typical devices of Islamic architectural decoration, such as muqarnas, were used to trap light and diffuse it, so that it reflects and refracts light (Jones 1984). It is for the same purpose that the Muslim architects transformed other surfaces, such as '*Mashrabeyah*' screens, into perforated relief to filter the light (Omer 2011).

From the 16th century onwards ottoman mosques employed the Byzantine program of lighting with a ring of openings at the base of the dome and maximum reflection of light by intensively using shiny tiles and glossy surfaces. Sidewall-windows contributed to the general lighting and create a diffuse lighting, while windows at the wall of the niche '*Keblah*' provided accentuation and local illumination at it (Goodwin 1993).

2.7 Modern Churches

Masters of the Modern Architecture like Le Corbusier, Alvar Aalto and Louis Khan also believed in the importance of bringing the natural light into divine spaces. In his asymmetric and fascinating lighting scheme in Ronchamp Chapel (Figure 6), Le Corbusier created a series of spatial dramas in which light animates the space by creating different moods at different times of the day and in different seasons.

Figure 6. Ronchamp Chapel: South wall

Rays of light pierce through a thin gap between the wall and the massive roof, making the roof appears to 'hover'. The size of the windows, as well as the depth and the direction of the splays, varies from one opening to another, thus sunlight is admitted at different angles and with varying degree of brightness. The colored glass in the splayed windows softens the incoming light and creates colored shadows in delicate hues on the roughly plastered surface (Lau 2008).

Santiago Calatrava, who is known for combining architecture and engineering to broaden the potential of a wall, frequently uses motion techniques to adjust the intensity of natural light on his interiors and create dynamic space (Attmann 2012). Treatments like these are seen in his recent project of the Cathedral of St. John the Divine and the new St. Nicholas Church on the Zero Ground, both are to be built in New York.

3 CLASSIFICATION OF LIGHTING PROGRAMS IN SACRED BUILDINGS

In this part, lighting programs in sacred buildings, which had been historically overviewed in the previous part, are classified according to the position of the apertures. One building, mostly the earliest appearance of the lighting scheme, is appointed to represent each category.

3.1 Clerestory

The technology of clerestory appears to originate in the temples of ancient Egypt, where lighting was admitted to the Hypostyle Hall over the stone roofs of the adjoining aisles, through slits pierced in vertical slabs of stone. Clerestory appeared in Egypt as early as the Amarna period or even earlier (University of Memphis 2013) and had different versions in Roman basilica and the naves of Romanesque and Gothic churches.

Figure 7. Clerestory in the Hypostyle Hall at Karnak

The example that was chosen to represent this category is The Hypostyle Hall in the Temple of Karnak in Luxor, as one of the earliest and the most original treatments of this type. Here, the raised central nave was lined with grilled windows of clerestory (Figure 7) 24 meters above the floor, which allowed sunlight to enter the hall, while maintaining the privacy and secrecy of the space. The grills were composed of two sections, one stacked atop the other, and secured in place by being fitted tightly into grooves in the side of the bordering piers (University of Memphis 2013). Sunrays coming through this clearstory were further obstructed by the projection of the gorge cornice, so that the hall is mostly kept in shadows.

3.2 Screened Windows at Eye-level

Windows are the most common way to admit daylight into a space. They usually take vertical direction, so that they selectively admit sunlight and diffuse daylight at different times of the day and year. Screens, such as alabaster panels, stained glass or '*Mashrabeyah*' screens, were usually used in sacred architecture to filter the direct light and give it special effects by casting intricate patterns and colors.

St Denis Chapel in Paris (Figure 8), as the earliest representation of Gothic style, is the best example to represent this category. Abbot Suger (1081-1151), the abbot of St Denis Chapel, had strong views about the value and meaning of light (Boorstin 1992). His radiant masterpiece soars as weightlessly as any modern glass edifice, where bright and glittering stained glass filters daylight in the most subtle ways 'like standing in a crystal' (Swaan 1988).

To achieve his vision, his masons drew on several new elements, which evolved or had been introduced to Romanesque architecture to enable the insertion of large windows (Boorstin 1992). They used slender ribs of stone to separate the nine adjoining chapels lit by sixteen stained-glass windows, beaming multicolored light to be reflected on the polished mosaic floor and on the dazzling altar of gold and gems (Boorstin 1992). Another striking feature in the church was the rose window of stained glass, which was placed over the middle of the three portals on the western side.

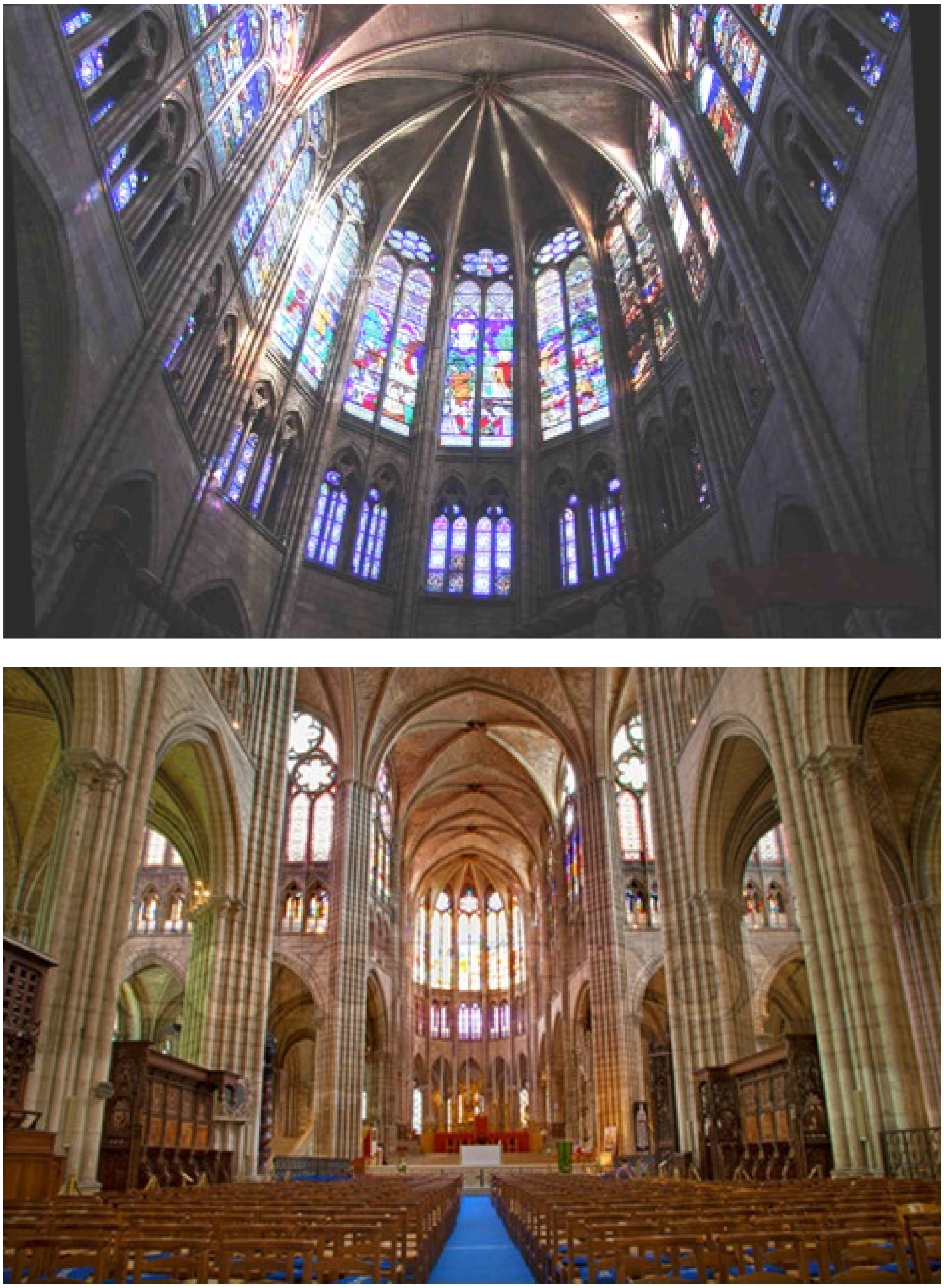


Figure 8. Soaring stained glass windows in St Denis Chapel in Paris

3.3 Dome-lighting

Though domes usually tend to be heavy and somewhat portentous, some inspiring treatments made them look graceful, colorful and even lightly floating despite their bulk. In these treatments light that is admitted through these domes became the most important characteristic of the space, adding brightness and transparency to the interior. These treatments might be categorized into the following two types:

A - At the apex (oculus or lantern)

Oculus is the Latin word for eye and it was the Romans who first realized its architectural potential. *Oculi* appeared also in some Renaissance churches in the form of lantern, which became even more popular in Baroque Architecture. The oculus at the apex of the dome allows a single shaft of sunlight to fall and travel across the interior of the building, generating a great visual effect and giving a unifying sense of harmony and constant sense of uplift.

The Pantheon in Rome is the earliest and the most significant building, in which this lighting scheme occurred (Figure 9). The lighting that is admitted to the building is actually very little that only three base-niches and only three windows (with their symmetric ones, of course) are ever illuminated; all others remain in dark for the whole year, as the sun fails to be at a sufficient altitude to illuminate them (Magli 2011).

Figure 9. The oculus in the Pantheon

Nevertheless, this magical light assures that daylight diffuses gently in the entire space while the shaft of sunlight directly falls inside and moves along the coffers of the inner dome surface and slashes across the cavernous space, reflecting back up from the polished marble floors and transforming the attitude of sunlight/daylight from natural into spiritual.

B - Around the base

This treatment was characteristic for both Byzantine and Ottoman Architecture and was still further embellished in the Renaissance with the addition of a high drum encircled by peristyle or colonnade. In this treatment, light is introduced through a ring of small windows piercing the lower portion of the dome, creating dazzling interior light-effects that make the dome looks like as if floating upon a wave of light and suggesting an upward appeal by attracting the believers' eyes towards the light to 'feel the presence of God' (Falahat and Zare 2011).

The Church of Hagia Sophia in Istanbul is the earliest application of this technique and is, therefore, appointed to represent it. Lighting here is mainly produced by forty small windows that pierced the dome at its base. Procopius describes this dome as 'standing upon the interior circle as if suspended from heaven' (Lethabv and Swainson 2005). Additional light is introduced through twelve windows in each of the spandrel walls, north and south, under the great arches that support the dome (Figure 10) (Fletcher 1905). The brilliant natural light of the East is tamed by the position of the windows, their relatively small size and their large number. It enters the space at a slant and 'turns back on itself to be diffused everywhere' (Ousterhout 1999). This mystic light gains an overwhelming character because of the nave's gloomy lighting level; the daylight reflecting from the golden mosaics was taken as a solution for illuminating the interior space and gave further support to the spiritual effect.

Figure 10. The dome in Hagia Sophia

(a) From outside (b) From inside

Figure 11. Light scoops in Jubilee Church

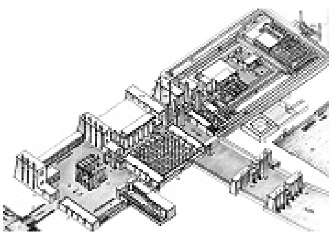
3.4 Light Scoops

The typology of divine light and its pattern had largely changed in Modern Architecture in order to cope with the contemporary requirements for today's and future's materials and forms. New forms of apertures, where large areas of glass blend into the walls or the roofs in different innovative forms, is now the most common option to introduce ambient light into contemporary religious buildings.

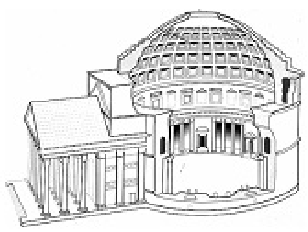
Richard Meier's Jubilee Church (*Dio Padre Misericordioso*) is an outstanding example of these new forms (Figure 11). Instead of admitting light through an oculus or lantern, light slips through intervals between free-standing, vertical planes that do not quite meet. Thereby, they act as both light scoops and shading devices. In this church, Meier allows rays of light to bounce through gaps between billowing concrete 'sails', reflecting from travertine plaza into interior and around corners from unseen sources and illuminating travertine walls with a mystical light (Archnewsnow 2003).

4 EVALUATING THE EFFECTS OF LIGHTING SCHEMES

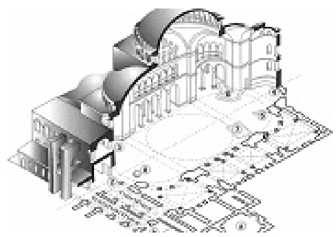
In this part, the criteria for evaluating the lighting programs in the five buildings are determined, and a double fold analysis is performed on the five buildings to assess their performance concerning these criteria.



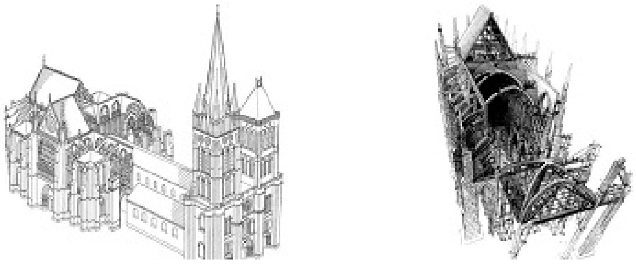
(a) The Temple of Karnak in Aswan



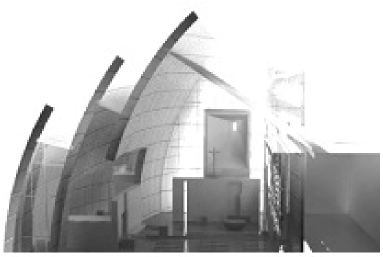
(b) The Pantheon in Rome



(c) Hagia Sophia in Istanbul



(d) St Denis Chapel in Paris



(e) The Jubilee Church

Figure 12. Perspective-sections in the five buildings

4.1 Criteria of Evaluation

The characteristics of light in sacred architecture are mostly related to the creation of an environment, where the worshipper needs to feel the essence of the religion, rather than to regular visual comfort objectives. In his study of subjective responses to low energy and nonuniform lighting systems, John Flynn developed criteria of lighting modes that might reinforce certain subjective impressions (Flynn 1977). From the modes that he included in his study, the most plausible impressions to be associated with religious buildings are probably these of relaxation and pleasure, which he related to non-uniform distribution and low level of light as well as peripheral (wall) emphasis, rather than overhead lighting. In a study by Sanders et al. (1974), it was also found that by measuring the level of noise produced by groups of people in an assembly room, low, uneven illumination pattern was associated with less noise and less activity and vice versa.

In another attempt, an experimental study by Loe et al. (1994), shows that people like to face or see brightness, but do not like to sit in brightness. In the same direction, Antonakaki (2006) came to a similar conclusion that people gravitate towards bright areas but rather than moving into them, they choose to sit facing them. The employment of natural light was always crucial to show off a room's potential; shadows could be used to dramatic effect in apses and sculptural niches. But, while the 'mysteriousness' of shadow is closely linked to evoking silence and awe, deep shadows are related to darkness and may evoke uncertainty and a potential of danger (Schielke 2013). This concept was emphasizes by J. Michael Gillet in his book 'Designing with Light', where he says that a non-continuous luminance gradient across a surface may create confusion, miss-information, or the perception of darkness and gloom (Gillette 1998). He adds that high levels of visual stimulation encourage participation and increase enjoyment, while low levels help a person to feel contented, comfortable, focused, and relaxed.

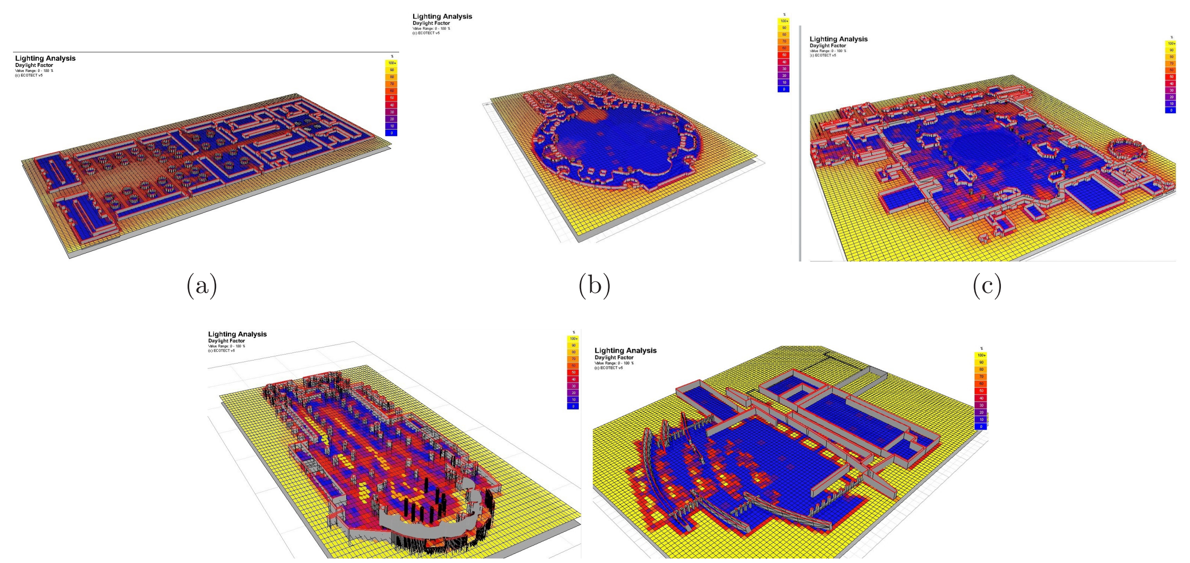
Accordingly, it could be said that the feelings of relaxation, quietness, contentment, and owe, which are most desirable in sacred architecture, are related to the following criteria of light:

1. Non-uniform distribution
2. Low levels of illumination
3. Seen but not immediate
4. Peripheral (or wall) lighting
5. Avoid deep shadows
6. Dynamic quality of light

4.2 Application of Criteria on the Five Buildings

To examine the fulfillment of the aforementioned criteria in each of the selected five buildings (Figure 12), a computer analysis of lighting levels throughout the year was performed by Autodesk Ecotect software in concern of the first two criteria. The results of the analysis are illustrated in Figure 13.

To evaluate the buildings performance in concern of the other three criteria, the different positions of sun and the expected behavior of sunrays inside the buildings throughout the year were analyzed as illustrated in (Figures 15-19). To achieve this, a simplified two-dimensional model for each building was employed, fixing the time at local noon in the course of the year (at this time of the day, light comes always from the southern direction) and studying the position of sunbeams in four specific dates: summer solstice, the two equinoxes, and winter solstice. The latitudes of the four cities, in which the five monuments are located, are:



(a) (b) (c) (d) (e)

Figure 13. Average distribution of light in the five buildings throughout the year

Aswan (Egypt) on 30°N, both Rome (Italy) and Istanbul (Turkey) on 41°N, and Paris (France) on 48°N. The solar altitudes at the five buildings in the four specified dates are obtained using sun angles charts (Figure 14).

From these analyses, as illustrated in the six figures (Figure 13 and Figures 15-19), the performance of daylight in the five buildings can be traced as in the following:

A - The Hypostyle Hall of the Karnak Temple

Looking at the average distribution of light in the Hypostyle Hall of the Karnak temple (Figure 13(a)), an uneven distribution of light is immediately realized, with a daylight factor of about 50% in the middle area and about 10% on the side aisles.

The diagram at (Figure 15) shows that at summer solstice, the projection of the *Gorge* blocks the sunbeam until February. At the autumn equinox, a spot of sunlight starts to touch the interior. This spot starts to move down at winter solstices to illuminate the side aisles and the sun 'spends' winter in the aisles until the spring equinox, when the beam starts to move back on the floor towards the central area until it disappears again in summer. So, only the subtle sun of winter is fully allowed to enter the space, while the summer sun is almost fully blocked and only a thin sunbeam can enter the middle area during the equinoxes.

B - The Pantheon, Rome

In the Pantheon, the differences in orientation and position of apertures resulted in a totally reversed movement (Figure 16). At the autumn equinox, a spot of sunlight starts to touch the interior springing of the upper hemisphere and starts to move up until it reaches a maximum height in the roof over the entrance at winter solstice. Thereafter, it moves down, touching again the base of the dome at the spring equinox. So, the sun 'spends' the winter and the two equinoxes in the hemisphere of the dome. In the subsequent days, the beam moves down, illuminating the entrance from inside. Around 21 April, this midday spot starts to 'enter' the building and starts moving on the floor towards the centre of the building (which it, of course, never reaches, as the sun never crosses the zenith at the latitude of Rome). From the summer solstice the beam turns back, re-crossing the entrance between the end of August and the autumn equinox (Magli 2011).

Accordingly, it is normal to see that the average distribution of light (Figure 13(b)) indicates that the area that receives the highest amount of light at eye-level throughout the year is the area in front of the entrance. During the course of the day, the sunbeam

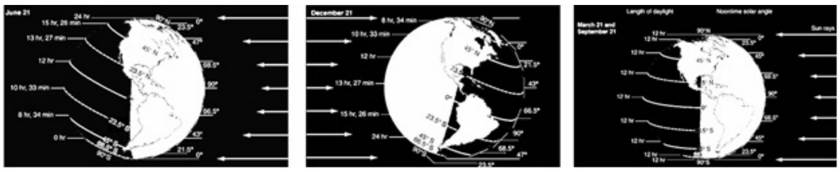
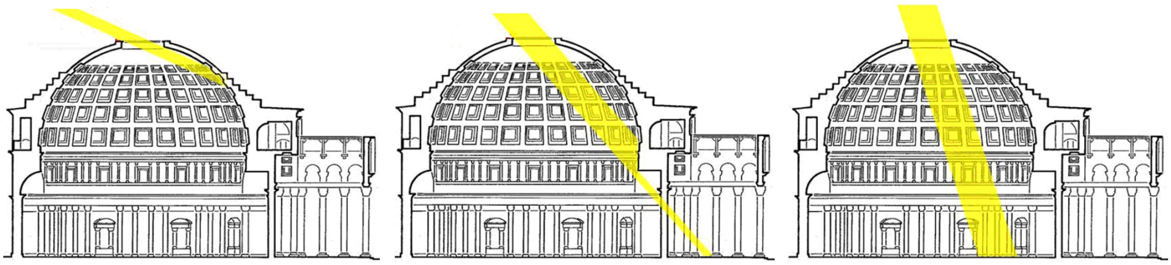


Figure 14. Sun angle charts: Northern Hemisphere summer solstice (left), Northern Hemisphere winter solstice (middle), and Equinoxes (right) (Based on the charts in NASA Goddard Training Manual, 2003)

(a) (b) (c)

(a) Winter solstice (sun at altitude 23.5°) (b) Equinoxes (sun at altitude 47°) (c) Summer solstice (sun at altitude 70.5°)

Figure 15. The fall of the noon sunlight on the Hypostyle Hall in Karnak Temple in different dates of the year



(a) (b) (c)

(a) Winter solstice (sun at altitude 24°) (b) Equinoxes (sun at altitude 48°) (c) Summer solstice (sun at altitude 72°)

Figure 16. The fall of the noon sunlight on the Pantheon in different dates of the year

depicts an arc from west to east, which remains on the upper hemisphere during autumn and winter, touches the base of the entrance around 31 March then reaches the floor and wanders across it in the central hours of the day from the end of April to the end of August. Therefore, the analysis shows that a fair amount of light reaches other areas of the building throughout the year, especially the side apses, as the sun moves from the east to the west during the day.

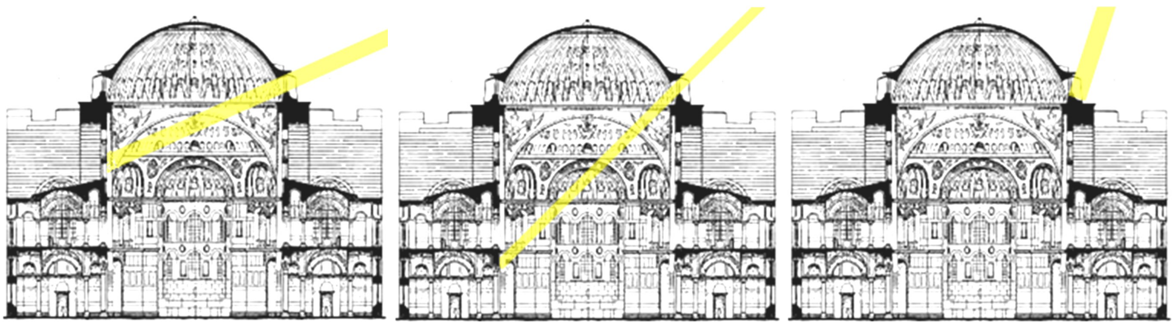
C - The Church of Hagia Sophia, Istanbul

In the church of Hagia Sophia (Figure 17), patterns of daylight are similar to these at Karnak, except for that they never reach the ground. At the autumn equinox, a thread of sunlight penetrates to the interior and falls on the rims of the northern aisle's arches. At winter solstice, this spot of sunlight gets wider as it moves up on the walls of the nave towards the dome and reaches its maximum area around the end of February. Thereafter, it moves down, touching the rim of the arches again at the spring equinox, but never reaches the ground. Starting from the summer solstice, the beam is blocked by the wall-thickness at the base of the dome until the autumn equinox (Magli 2011). So, only the sublime sunbeam of winter sun is allowed to enter the building in its full brightness to be kept 'suspended' in the upper part of the nave for the first half of the year. During the equinoxes its brightness is reduced and it is not allowed to touch the ground until it is completely blocked in summer, where its diffusion is kept 'floating' around the dome.

The average distribution of light, as shown in (Figure 13(c)), is in support of this analysis. It shows that, at eye-level, the least lit area is the area under the dome with an average daylight factor of less than 10%, as light in this area is always kept suspended higher than eye-level. The overall lighting level is very low, but some spots of light were produced by small openings arranged in zones on sidewalls, with two light zones at the northwest and southeast corners of the church. Special emphasis was given to lighting the apse, where the highest daylight factor at the building (60%), is measured.

D - St Denis Chapel, Paris

At St Denis Chapel (Figure 18), the patterns of daylight are, again, similar to these at Hagia Sophia and the Karnak temple, except for that windows are arranged on two levels, the lower one of which is almost at eye-level. At the summer solstice, the sunbeam fails to enter the nave from the upper windows until the beginning of August, but a thread of light penetrates the interior through the lower row. At the autumn equinox, two beams of sunlight start to appear on the floor at the aisles and starts to move up at winter solstice, to be kept suspended in the upper part of the nave un-



(a) (b) (c)

(a) Winter solstice (sun at altitude 24°) (b) Equinoxes (sun at altitude 48°) (c) Summer solstice (sun at altitude 72°)

Figure 17. The fall of the noon sunlight on Hagia Sophia in different dates of the year

(a) (b) (c)

(a) Winter solstice (sun at altitude 24°) (b) Equinoxes (sun at altitude 48°) (c) Summer solstice (sun at altitude 72°)

Figure 18. The fall of the noon sunlight on St Denis Chapel in different dates of the year

til the spring equinox, when they move back down to the floor and start crawling towards the central area, but only one of them can reach it around the end of November. So, again, only the subtle sun of winter is fully allowed to enter the space to be kept suspended in the upper area of the nave, while most of the summer sun and part of the equinoxes sun are blocked, leaving a chance to the other part to 'spend' the equinoxes in the aisles.

The average distribution of light, as shown in (Figure 13(d)), shows a homogeneous distribution of light with average daylight factor of about 50%, which is relatively high ratio. This is especially significant in the late afternoon when the sun sets. Special emphasis was given to the apse, where the daylight factor reaches 90% alongside the walls of the apse.

E - The Jubilee Church, Rome

As for the Jubilee Church (Figure 19), as the sun moves through the year, it is first partially blocked by the sails in the winter solstice and only the upper part of the first sail is touched by sunrays. In the spring equinox it starts to slide in from the gaps between the sails, but it does not reach the floor of the nave and part of it is kept suspended in its upper part, where the other part reaches the -only- northern aisle. Towards summer solstice, the sun is admitted over and around the altar platform and penetrates through a large punched opening on the sides, splayed to reduce the glare. Towards autumn equinox, the sun beam moves back to the aisle and is kept suspended in the nave until next summer.

The average distribution of light in (Figure 13-e) shows that the northern area is the brightest zone with a distinctive luminous environment. Most of the daylight is captured through the south-facing sails, although the light source is concealed by their blades. In this area, average daylight factor is around 40%. The light intensity is gradually reduced towards the central nave, where the daylight factor is around 1- 10%.

5 DISCUSSION OF RESULTS

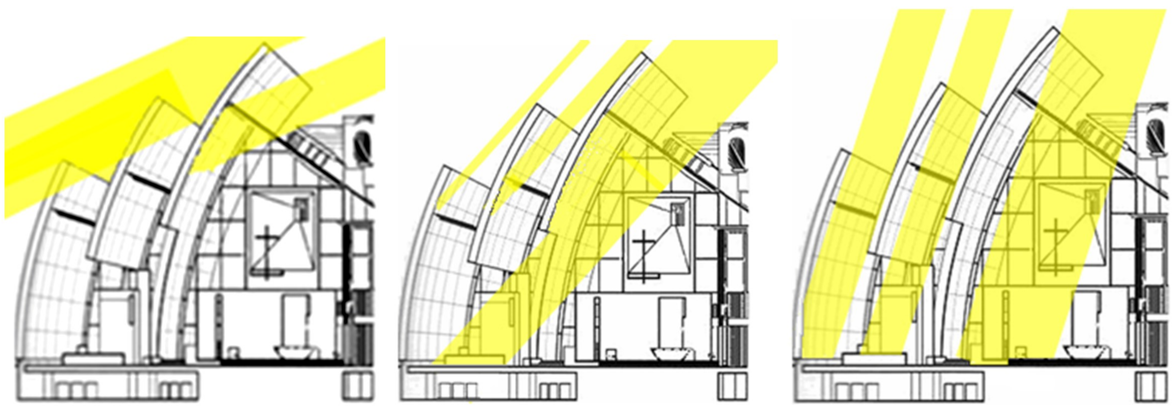
The results of the analysis, as performed in part 4-2, are summarized in Table 1. Considering these results in relation to the criteria in part 4.1, the following conclusions are to be found:

5.1 Distribution of Light

The luminous environments inside the five buildings can be distinguished into the following categories: (a) bright spaces with homogenous light; (b) bright spaces with instant or local lights; and (c) half-dark areas around instant or local light. Instant light here refers to the beam of light or a light shaft that produces a spot of light, where the downpour of light falls as in (Figure 9), while local light refers to a more uniformly lit zone produced by a group of openings that illuminate a whole zone as in (Figure 6). In both cases the luminous environment is characterized by uneven distribution of light. In (Figure 10) the two types coexist side by side; instant light is introduced into the area under the dome by the openings at its base, where in the corners zones of local lights are produced by groups of small windows.

5.2 Lighting Level

The Ecotect analysis in (Figure 13) shows that the average daylight factor in the three buildings with top-apertures is generally lower than that in the other two buildings with peripheral-apertures. However, in a study by Triantafyllides (Antonakaki 2007), it was found that by comparing the lighting levels in basilican churches and domed churches, the lighting levels produced at the centre of the basilica had been proven to be higher than that under the dome in a domed church. Yet, there is a misleading impression that the lighting levels are higher under the dome than at the centre of basilica. The reason for this phenomenon is that the concentrated (instant) light shaft under the dome appears stronger to the eye than the general ho-



(a) (b) (c)

(a) Winter solstice (sun at altitude 24°) (b) Equinoxes (sun at altitude 48°) (c) Summer solstice (sun at altitude 72°)

Figure 19. The fall of the noon sunlight on The Jubilee Church in different dates of the year

Table 1. The lighting distribution patterns in the five buildings

Building	Season	Level	Distribution	Diffusions	Visual Simulation
Karnak Temple	Summer	25%	Local (suspended)	Homogeneous	Heavy shadows
	Winter		Local	Bright/ Dark	
	Equinoxes		Local	Bright/ Dark	
The Pantheon	Summer	15%	Instant (on the ground)	Bright/ Half dark	Shadowless - Dynamic light shafts
	Winter		Instant (suspended)	Bright/ Dark	
	Equinoxes		Instant (suspended)	Bright/ Half dark	
Hagia Sophia	Summer	15%	Local (suspended)	Half Dark	Shadowless - Dynamic light shafts
	Winter		Instant (suspended)	Bright / Half dark	
	Equinoxes		Instant (suspended)	Homogeneous	
St Denis Chapel	Summer	40%	Local (suspended)	Half Dark	Shadows on sides
	Winter		Local	Bright / Half dark	
	Equinoxes		Local	Bright / Half dark	
Jubilee Church	Summer	20%	General	Homogeneous	Shadow on one side
	Winter		Local (suspended)	Bright / Half dark	
	Equinoxes		General	Homogeneous	

Table 2. The fulfillment of the evaluating criteria in the five buildings

	St Denis Chapel	Jubilee Church	Karnak Temple	Pantheon	Hagia Sophia
Non-uniform distribution of light	×	✓	✓	✓	✓
Low levels of illumination	×	×	✓	✓	✓
Seen but not immediate.	×	✓	×	✓	✓
Peripheral (or wall) lighting	✓	×	✓	×	×
Avoid deep shadows	×	×	×	✓	✓
Dynamic light shafts	×	×	×	✓	✓

mogenous light that is evenly distributed through the windows of the basilica due to the high contrast between this bright light shaft and the area around it.

5.3 Relationship with the User (Seen but not Immediate)

In all the five buildings -except for St. Denis Chapel, where stained glass is used to partially fulfill this issue- the visual relationship between the interior and the exterior is minimized by keeping the openings higher than eye-level. Thick walls and small size of openings result in a further obstruction of daylight. Off the centre of the buildings, sunlight is allowed to penetrate into some spaces, constituting the liaison with the outside world.

The results in (Figure 13) show that peripheral-openings result in a distribution of light that is more even and closer to the eye level than that created by top-openings. Such immediate light, as previously explained, is less preferable by people, especially for this kind of buildings.

5.4 Position of Lighting (Peripheral-Top)

From the results in (Figure 13), it is also to be observed that to produce light through peripheral openings that is unevenly distributed and not immediate, lighting level should be very low (as explained in 5.2) and very heavy shadows will be produced, as in El Karnak temple. But by re-considering the concept of 'peripheral light' that Flynn defined as wall light, it might be suggested that the light that inters the building through the openings around the base of the dome, as that at Hagia Sophia, is rather 'peripheral', despite not a 'wall light'.

5.5 Visual Simulation (Avoid Deep Shadows)

Except for in the Jubilee Church, the brightest zone at eye-level in all the other buildings is the visual focus that is related to the main ritual area (the apse or the main *Naos*) and not the main activity area, where people sit. This guiding quality of light was employed in longitudinal buildings to emphasize the visual axes. In centralized buildings, daylight is concentrated above the eye-level at the central area, where people sit, and is kept relatively shadowless. Direct front light was avoided in this area to reduce the flat silhouette effect.

5.6 Dynamic Quality of Light

The analysis in part 4.2 shows that light shafts created by top-openings are more dynamic than those created by openings on the wall. The reason behind this is that during the day top-apertures, especially these at the dome, have better chances to trap the sunlight at different angles as it moves around it. In the course of the day, the sunbeams from these openings depict an arc from west to east lighting different angles in the space, which is unattainable for peripheral- openings. They also add visual interest and create a feeling of uplift, where light can be kept 'suspended' for the most part of the year (and/or the day) and barely touches the ground.

5.7 Fulfillment of the Evaluating Criteria

By comparing the lighting schemes in the five buildings in terms of their fulfillment of the evaluating criteria, the five building are to be arranged in ascending order from left to right as shown in Table 2.

The comparison shows that the lighting programs in both the Pantheon and Hagia Sophia have the best qualities according to these criteria. But the light that enters the building through the openings around the base of the dome, as that at Hagia Sophia, is somehow more 'peripheral'. Actually, it could be said that this particular lighting scheme has better qualities that overcome the negative sides of lighting from the walls: first, it produces strong lighting patterns that are uneven (instant) and more dynamic than that introduced from wall-openings; secondly, by keeping sunrays suspended in the upper area of the nave, glare is avoided at eye level and people see the brightness but do not get into it. Furthermore, in contrast with the two other forms of top-aperture, lighting produced by this scheme is more constant, as the windows all around the dome have more chances to capture sunlight all along the day. The comparison shows also that the lighting patterns that appear in Jubilee Church are closer in nature to that at St. Denis Chapel than it is to the other two buildings with top-apertures. This means that the quality of the lighting from the base of the dome is not only about its position as top-apertures, but rather about the round form of the dome itself, which allows it to trap the sun at different angles as the sun moves around it throughout the year and in the course of the day.

6 CONCLUSION

Throughout the history, light had a vivid role in religious architecture. Spatial structures constructed the religious environment, while light constructs the spiritual experience. The chronological study at the first part of this study shows how natural light can be used to cue attention, orientation and modes and how its directional characteristic was employed to turn the visual axes from upwards towards the central dome, as if heavenward, to frontward towards the sanctuary at the end of the naves.

The study of lighting levels and patterns of sunlight movements inside the five selected buildings, which are well known for their unique visual experiences, provided us with conclusive evidences that the architects of these buildings employed, actually, very little amount of light to produce remarkable effects that depended on: the study of the sun's altitude, the interplay between shadows and lights, the dynamic quality of daylight, and a deliberate distribution of openings. Windows were generally small or covered with screening materials or perforated elements to minimize the relationship between interior and exterior, while the brightest zone was used to appoint the visual focus that is related to the main ritual area, which had to be kept shadowless and not immediate to worshipers. Carefully designed transitions of interior lighting resulted in the perception of a much higher levels of lighting than those actually measured. The symmetrical balance of light and keeping the sunrays suspended above eye-level were used to reduce the uncomfortable brightness associated with a single opening in dimly lit space and to give this spiritual feeling of uplift.

Lighting in these buildings was, hence, not about the amount of light, but rather about the treatment of this little amount of light that made it able to produce such dramatic effects with accentuating qualities. The analysis in the previous chapter shows that the lighting levels produced by peripheral-apertures are usually higher than these produced by top-apertures. But, the instant light shaft from top-apertures appears stronger to the eye than the general homogenous light that is evenly distributed through the windows due to the high contrast between this bright light shafts and the area around it.

It has been also found that these instant light shafts have a dynamic nature that allows them, in the course of the day, to depict an arc from east to west as it falls on different areas in the building and in the course of the year, to move from one spot to another according to the height of the sun in the sky. Local light is more static during the day, but is however, still dynamic around the year. Such dramatic characteristic of instant light plays a very important rule in the visual interest and the accentuation of the space..

In today's religious building, natural lighting is no longer playing any role. The gloomy, but overwhelming, spiritual lighting of the Pantheon and the Byzantium cathedrals was replaced now with the bright uniform artificial lights. Bringing back the spirit of space through natural light, with its ever-changing qualities of intensity, color, shape, location and scenes, as shown in this study, is what is needed to bring the spirit back to religious buildings.

Studying the daylight programs at these building, as in this paper, provides us with valuable insights, which can be applied to contemporary architecture. Among other things, the notion of energy efficient buildings, were lighting effect is maximized to enhance the building's aesthetic schemes, without the need of extra brightness or energy exhaustion.

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