Article

Daylight, Shape, and Cross-Cultural Influences Through the Routes of Discoveries: The Case of Baroque Temples

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Abstract

Baroque temples were developed in the context of cross-cultural influences through new territories where the climatic conditions were often opposed to those prevailing in Europe. The nature of weather differences could not be predicted with the knowledge of the era and consequently, a set of gradual and successive transformations in the typologies "imported" from Europe was produced. These adaptations were lengthy, intuitive, and not always recognizable by the Metropolitan culture. Although daylight requirements played an important role in this process and its quality in baroque temples is celebrated by architectural historians, very few daylighting simulations and on-site measurements have been developed. Therefore, a twofold result is produced: Daylighting's beneficial effects can neither be transmitted nor reproduced in other new buildings. Consequently, we discuss in this article the results of a daylighting simulation program capable of analyzing complex baroque temples around the world and to show the implications of its environmental attitude.

Keywords

daylighting, baroque temples, simulation tools, monitoring, cross-cultural influences

Introduction

Europeans founded a large number of settlements along the routes of discoveries that led to the first direct and fluid contact between Europe, the American continent, and across vast Asian regions and determined, to a large extent, later cultural manifestations both in the new territories and in Europe (Kinsbruner, 2005). In the context of those cross-cultural influences, European models were adapted to other climatic conditions, often even opposed to those prevailing in the metropolis (Almodovar & Jimenez, 2008).

In the Americas, the Spaniards founded more than 1,000 cities, and the Portuguese spread out their cultural influence in the extensive territory of Brazil. On the other hand, the route of the Cape of Good Hope that for a period was shared by Spaniards and Portuguese, facilitated the

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establishment of cities and provisioning posts of particular interest. Among them, we can highlight Luanda, Lobito, and Mozambique Island in the Indian Ocean.

Subsequently, other points of the route located in Asia were reaching prominence, and even some settlements were established in the Arabian Peninsula, for instance in the Oman region. As we know, important cities were founded in India, due to the allure of Meliapor (supposed place of martyrdom of the Apostle Thomas). Further south, the town of Pondicherry was founded near Madras, the first enclave of Roman commerce where an amphitheater was discovered, which later became a Portuguese post. Finally, the place was refounded by Lenoir under the dominion of the French. We also want to highlight the golden and mythical Goa, as well as Daman, Diu, and Cochin for being relevant Portuguese settlements, along with Malacca, Macao, Manila, and finally, some enclaves on the Japanese coast, foe example, Nagasaki (Souza, 2004).

The American connection was completed at the other end by the famous Manila Galleon, which made the route from Acapulco to Manila twice a year. Therefore, the relationship between Asia and America was well established. This is evidenced by the abundance of the Philippine *sangleyes* art works found today in museums in Mexico, Peru, or Ecuador, as well as the many missionaries and martyrs that America sent to Japan, the Philippines, Taiwan, and the Pacific Islands (Carolinas, Palau, Guam). Some of them have been under Spanish rule until less than a century ago (Subrahmanyan, 2007).

Similarly, the establishment of Portuguese artists and builders—who formerly resided in India—in Minas Gerais (Brazil) speaks to the cross-cultural influences. They left India due to the incursions of the English and Dutch. The baroque architecture of Minas Gerais acquired its own characteristics that were later used as a reference by modern Brazilian architects, including Lucio Costa and Oscar Niemeyer, to provide an identity to Brazilian architecture in the modern world (Almodovar, Cabeza-Lainez, & Jimenez, 2008).

The architectural discoveries followed the way back toward the Metropolis, since the descriptions that missionaries and merchants made about the architecture of the new cities and their civilization were also influencing what was decided in Europe. In this regard, we would like to highlight the book published in 1585 "History of the most remarkable things, rites and customs of the great Kingdom of China" (in Spanish) by the St. Augustine priest Juan González de Mendoza, or the treaty of Bernardino de Escalante published in 1557: "Discourse of the navigation that the Portuguese carry out to the kingdoms and provinces of the East and the news about the greatness of the Kingdom of China" (in Spanish).

Subsequently, other relevant events took place such as the publication by European Jesuits of *Confucius Sinarum Philosophus* in 1687, which includes a complete compendium of Confucius's theories—or *Ko-shi* as he is known in the East. The work of the philosopher Leibniz titled "*Novissima Sinica*" in 1697, or later the edition of "The orphan of China" by Voltaire in France and, as curiosity, the opportune comments of J. W. Goethe on the Chinese architecture and its inhabitants.

Portuguese Capuchin friars arrived, for example, at Angkor Wat and studied the Khmer architecture in situ from the year 1500, writing several treatises on the subject, which unfortunately could not be published until a few centuries later, even after being transcribed by Diogo do Couto in the SXVIII. However, by various means, such as paintings, engravings, and decorative objects, these issues were known by the authorities as well as by architects and artists of the time in Europe.

Christophorus Clavius, in his book *Gnomonices Libri VIII* published in 1602, geometrically demonstrated the possibilities of building a sundial and established principles for the measurement of time. Following this interest in solar geometry, Athanasius Kircher wrote in 1646 the book *Ars Magna Lucis et Umbrae* in which he analyzes the properties of light and optics. This work led him to investigate the equivalence of solar trajectories in different places of the world and to invent a universal clock called *Holorogium Catholicum*. It represents the Society of Jesus

as an olive tree in which the names of the places in which the company was established are registered, indicating their time zones. In order to do this, he had to assess the length of numerous settlements located in Europe, America, and Asia.

Later, around 1660, Athanasius Kircher published his complete Sinology treaty based on the experiences of the great Mateo Ricci, who for the first time introduced the notions of the *Aula de Sphaera* of Sacrobosco and the theories of Clavius in the East. These lessons of mathematics and perspective were translated into Chinese and Japanese, which produced a great commotion in those countries scientific communities (Findlen, 2004).

The flow of cultural exchanges that took place through the new European settlements, led to a process of acculturation, which moved to architecture in a natural way, resulting in the emergence of what we refer to as "baroque reason," reason that maintains among other attributes the understanding of the world as a global system of cultural sensibilities and allows, for example, Brazilian historians such as Carlos Ott to locate the origin of Baroque in the Khmer architecture of Angkor Wat (Ott, 1991).

These new establishments led to the exportation of different architectural typologies, which had to follow a simultaneous process of climatic and cultural adaptation. However, the climatic conditions in the new territories were in most cases quite different to those prevailing in Europe. The nature of the weather differences was not subject to prediction with scientific knowledge available in the era. In this regard, we could outline the reverse position of solar paths in large areas of South America (Almodovar, 2006).

The former produced a set of gradual and successive transformations in the typologies "imported" from the Old Continent. These adaptations were lengthy, intuitive, and not always recognizable by the Metropolitan culture. In the field of environmental features, nothing is more distinctive for us than daylighting devices and especially the domes and cupolas constructed in baroque buildings that constituted a refined art in masonry construction.

The knowledge of daylighting has interested many architectural theorists, including Sigfried Giedion (1964), who said,

> It is light that induces the sensation of space. Space is annihilated by darkness. Light and space are inseparable. If light is eliminated, the emotional content of Space disappears, becomes impossible to apprehend. In the dark there is no difference between the emotional evaluation of a chasm and of a highly modeled interior. (p. 495)

Although the excellence of daylighting in baroque temples is celebrated by architectural historians, very few measurements of the real character of this illumination have been developed. We have to take into account that architectural literature has always shown a high degree of naivety regarding its most revered paradigms. Scientific analyses of the most important monuments from the past are seldom available. When we approach the question of environment in buildings, the aforementioned lack is more evident. As a consequence, a twofold result is produced: The quality of daylight effects cannot be transmitted, and the beneficial effects themselves cannot be reproduced in other new buildings. Moreover, when historical buildings need rehabilitation, the retrofit may not be respectful, to the extent of destroying the original environment through inadequate and permanent artificial lighting.

But monitoring daylighting in buildings from the past is not an easy task; the weather shows many variations of luminosity throughout the day, the month and the season. The sensors may be difficult to place and if the monuments receive visitors, the cells can be obstructed though, still, it is critical to find out illuminance levels at the place where visual tasks are performed. Henceforth, simulation and specifically deterministic simulation is a more than adequate tool to predict the performance of the spaces under consideration and to assess if the building deserves further monitoring to produce a stochastic simulation or a long-term monitoring.

The case of baroque churches is typical of the situation presented above, and consequently, we intend to discuss in this article the results of the first step of a daylighting simulation program capable of analyzing complex baroque temples and to show the implications of its environmental attitude.

To this end, a series of mathematical developments have been used that obviously exceed the objective of this article but are available for verification. The algorithms are based on the new method of configuration factors (Cabeza-Lainez, 2006) and take into account both direct and reflected illumination using matrix and finite difference methods. This procedure extends the radiation properties of diffuse sources to luminous exitance of all kinds of building surfaces irrespective of their shape. These surfaces are therefore treated as radiative emitters by means of the generalized law of the projected solid angle (Almodovar & La Roche, 2008; Cabeza-Lainez, 2012).

In brief, we hope to contribute to that "baroque reason" that constitutes, more than anything, a new mode of scientific thinking. Also, as Max Jammer (1993) stated,

> It is my firm conviction that the study of the history of scientific thought is most essential to a full understanding of the various aspects and achievements of modern culture. Such understanding is not to be reached by dealing with the problems of priority in the history of discoveries, the details of the chronology of inventions, or even the juxtaposition of all the histories of the particular sciences. It is the history of scientific thought in its broadest perspective against the cultural background of the period which has decisive importance for the modern mind. (p. IX)

And Giedion (1964) added, "the task of the Historian is not merely to elucidate the past but also to recognize the signs that lead us into the future" (p. 495).

European Precedents

When we focus on the analysis of architectural spaces, it is important to adequately establish the potential of its physical components. Therefore, we have compared with the help of the aforementioned simulation model and also through on-site measurements, the lighting performance of baroque religious buildings located in Europe, America, and Asia, and we will show some design sequels that affected its architectural composition.

In Europe, a daylighting analysis of examples like Sant'Ivo alla Sapienza in Rome or Saint Louis of the Frenchmen in Seville is critical to establish a comparison between Europe and the new territories in terms of baroque architecture.

Saint Louis of the Frenchmen

The Church of Saint Louis of the Frenchmen, located in Seville (37°22′ N), is one of the most relevant examples of good illumination found in Southern Spain. It was constructed by the Society of Jesus between 1699 and 1731. The oddity of its rounded plan, unusual in Seville and related to the tradition of the Jesuits, enhances the hypothesis of higher directions coming from the Society in Rome, to be followed by local artisans. In fact, resemblances to other constructions of the religious order, are clearly seen (e.g., in the Basilica of Loyola by Carlo Fontana). Precedents can also be traced in the Roman temples of Santa Agnese and Santa Maria dei Miracoli, both featuring designs by Carlo Rainaldi. The church has been considered as one of the most outstanding temples erected by the Society of Jesus in all times and comparable to the temple of Zorobadel, the world's eighth marvel of the ancient civilizations (Ravé, 2010).

The inner surfaces of the walls are decorated with innumerable artworks, including paintings, sculptures, gilded sculptures, engravings, and frescoes (Figure 1). Beyond the symbolic and

Figure 1. Interior of the church of Saint Louis of the Frenchmen, Seville, Spain.
Source. Jose M Almodovar-Melendo.

religious meaning of these decorations, there is an unequivocal aim to depict illumination in the space, which obviously regards both daylighting and inspiration, and refers to spiritual realms other than the European, as the Latin American, the oriental and especially the Japanese, territories in which the Society showed unmistakable interest from the beginning of its baroque expansion (Cabeza-Lainez, 1997; Cabeza-Lainez, Saiki, Almodovar, & Jimenez, 2006).

Regarding the dimensions and the typological structure of the project, the diameter of the dome is of 13.5 meters; it is supported by a drum 14.85 meters high, containing only 8 windows of 6.3 square meters (i.e., the proportion of window to total surface area is less than 10%).

The different positions of the sun in relation to the geometry of the church were considered to further investigate the distribution of sun-patches as sources of luminous exitance. Particularly, the winter and summer solstices and the equinoxes (March–September) have been studied (Figures 2 and 3). The coefficients employed in the simulation have been established through measurements on the spot and comparisons with glazing and color tables like RAE and Munsell color Charts.

Collateral monitoring has been developed to define the constants implicit in the calculations and to ensure that the results of the simulation were set within a range. In the case of thermal monitoring, the effect of the capacitive mass of the building is remarkable. During the summer, constant temperatures of around 24°C were identified in the floor level of the nave, while the external temperature would reach 45°C in the north face of the supporting drum (Figure 4).

In summary, the lighting field is in a range low enough to perform basic tasks in the church (100 lux), thereby avoiding excessive solar gains, which led to optimal thermal conditions, as demonstrated by the measurements above.

Therefore, the ways of conception of European baroque models were closely affected by the climate of Southern Europe, as Climate does not exist apart from History (Watsuji, 1986).

Sant'Ivo alla Sapienza

Sant'Ivo has been considered by many historians as a Borromini masterpiece. This relevant Baroque Italian architect designed spaces with an audacious geometry, using advanced scientific knowledge at that time. In fact, he linked the harmony of nature with mathematical principles, establishing a relationship between nature, science, and architecture.

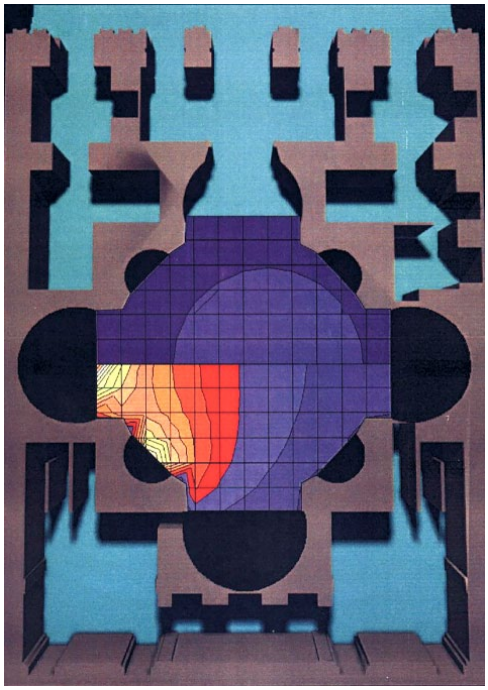

Figure 2. Saint Louis of the Frenchmen. Virtual reality depiction of the plan comparing cloudy and sunny conditions, June at 12:00 hours.
Source. Jose M Almodovar-Melendo.

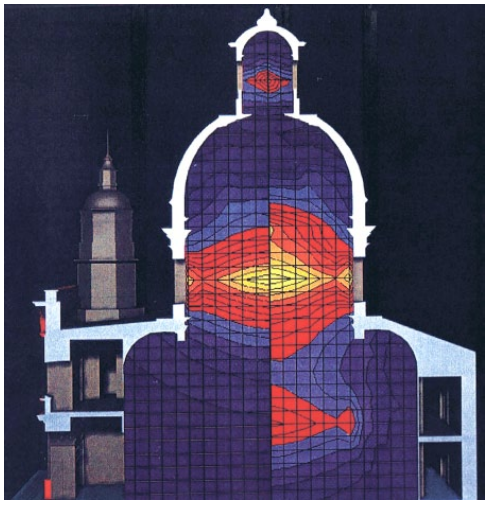

Figure 3. Saint Louis of the Frenchmen. Description of daylighting in section, comparing cloudy and sunny conditions of the weather, June at 12:00 hours.
Source. Jose M Almodovar-Melendo.

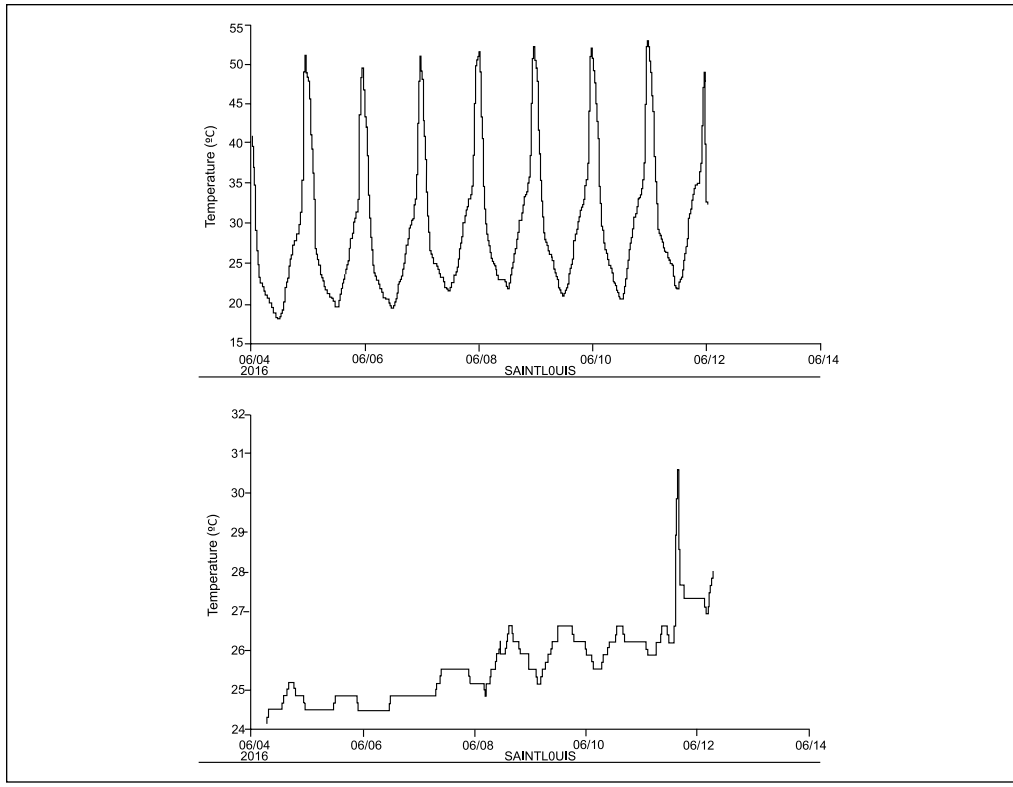

Figure 4. Temperature measured at the Church of Saint Louis of the Frenchmen in summer. (Above) Outside temperature at the dome. (Below) Inside temperature at the altar.
Source. Jose M Almodovar-Melendo.

The windows at Sant'Ivo were not vertical but tilted 85° from the horizontal; provided that diffusing glass was employed, the light was concentrated on the glazing plane and this inclination reinforces horizontal levels of daylighting.

A small sequence from a simulation film is presented below to depict different situations at the church, together with stereographic sun charts (Figures 5 and 6). It is clear that good lighting situations are experienced in this central plan temple located in a higher latitude than Seville (41° 54′ N).

Early Trials in the American Journey

The typologies that helped to convey light inside the buildings were experimented along the main routes established by the Iberians to the Americas. In this respect, the Canary Islands were an important enclave due to geographical reasons. In the latitude of 28° N, significant differences were appreciated with Iberian sun, because the main towns in Spain and Portugal were located higher than 37° N.

The Church of San Marcos

The village of Icod de los Vinos in the island of Tenerife, formerly uninhabited by Spaniards, experienced the construction of the church of San Marcos, to fulfill the religious requirements of the merchants and sailors who adventured in the American enterprise.

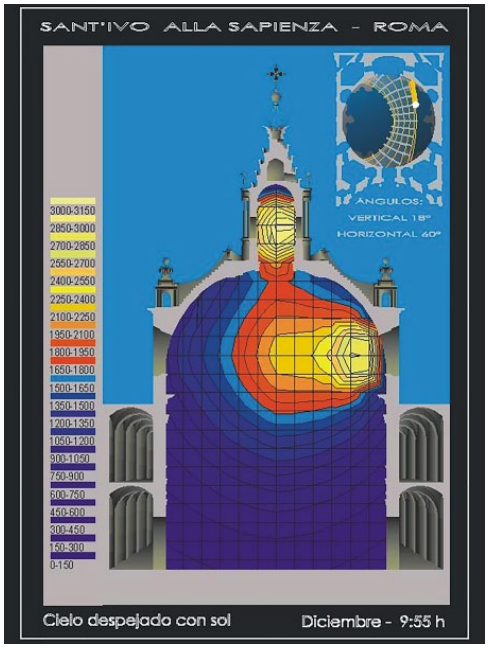

Figure 5. Excerpt from the simulation sequence of the interior of the church of Sant'Ivo, December at 9:45 hours (section).
Source. Jose M Almodovar-Melendo.

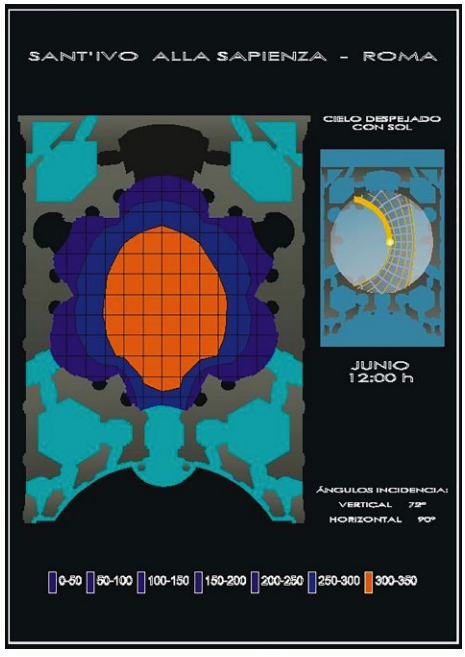

Figure 6. Excerpt from the simulation sequence of the interior of the church of Sant'Ivo, June at 12:00 hours (plan).
Source. Jose M Almodovar-Melendo.

Figure 7. The church of Saint Marcos in Tenerife, Canary Islands (Spain). Exterior view of the sky-light constructed over one of the lateral chapels.
Source. Jose M Almodovar-Melendo.

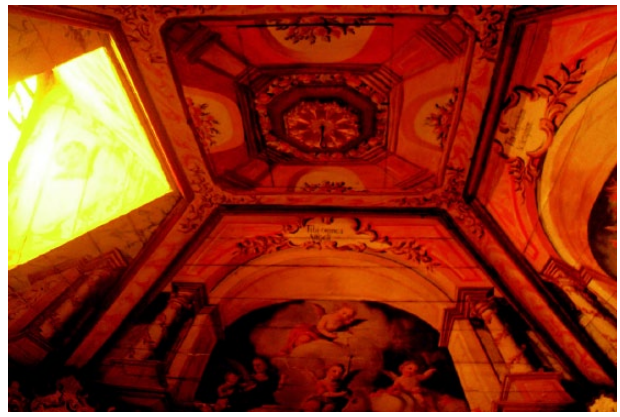

Figure 8. Interior view of the Saint Marcos's Church sky-light.
Source. Jose M Almodovar-Melendo.

In this church, for instance, we see how the typical lantern construction of central-southern Europe, with symmetrical fenestration in the drum below the cupola became insufficient because of high solar altitudes. The trivial solution to capture light in this situation was to open the roof. But roof openings in rainy climates or in frequently used spaces required constructive contrivances of moderate technology. The only precedents were Pantheon-like chambers, which are, for obvious reasons, not impervious. Hence, sundry implements for roof-lighting had to be developed with unequal fortune and expertise. In the church of Saint Marcos, we find a prototype of such devices in the shape of mansard roofing (Figures 7 and 8).

Difficulties of the System

Even so, adequate lighting was hard to experience as sun-light easily reached the floor plane and its efficacy was reduced because of furniture, dark floor materials, and failure to illuminate the task/working planes. However, no other solution was available at the time and the process continued open to innovations.

Figure 9. Chapel of El Rosario with golden veneer in Puebla, Mexico.
Source. https://www.flickr.com/photos/43547009@N00/30947998655/in/photolist-pLjvU7-oPrYhK-7KJSWG-7KJS6U-cfJumJ-cfJwrb-cfJtjw-eijHMg-cfJt71-cfJuS3-7KETFH-cfJuAJ-7KEUwT-7KEUbR-7KETmn-7KETMa-7KJTdJ-7KEU1r-7KETsZ-7KETzi-7KJSvw-7KEU6t-HjkT7W-dQ9upZ-P9LzMH-P1WESB-P1VBXR-NG5Zsu-EyHPDZ-EyHrwn-AG1VSq-EyHy7g-NG5vcb-NYrxg5-P1WHfT-pzLJvS-pLfqwz-ptKYUZ-ptKYNM-pLfpha-pLjGhm-pL1J7Z-oPoYKL-pLjz5L-pLjxVG-oPoR5q-ptQSqY-pL1tWK-dq8ue8-cfJxeW CC license 2.0; author: Alejandro).

Establishment in the Americas

General Overview

The diverse performance of American domes influenced not only its aspect and formal details but also the decorative arts associated with vaulting techniques, like veneers, frescoes, finishing, and sculpture.

The decoration systems were very much altered because of the presence of the prime matter of gold in several areas like Potosi or the gold mines of Valenciana in Guanajuato (Mexico), the golden veneers in centers like Rosario Chapel in Puebla or other Mexican towns like Cholula and Tepotzotlan, show many of the Asian influences that were conveyed by the Manila galleon and the many ships that came to America via Mexico and Acapulco.

Such need for extensive and brilliant finishing proves that the architects of the time had reached a distant limit. Light was insufficient with the available systems of composition, and ways to extend lighting performance had to be devised making use of local skills and material, but the results were often as meagre from the visual point of view, as they were grand art renderings (Figure 9). In a word, the models were not effective and perhaps inadequate for most regions of America. A new tradition had to be produced and is still being produced.

The Case of Brazilian Churches

In Brazil, we find many references to such limits in the church of Sao Bento in Salvador Bahia, where the architect is willing to augment the size of fenestration but rapidly becomes aware of the futility of this procedure because of increasing thermal radiation that does not correspond with higher levels of daylighting (Figures 10 and 11). It is an emotive check-point.

In Salvador Bahia, we find another revealing example, the church of Nossa Senhora da Conceiçao da Praia. The church was designed in Portugal and even the *sabao* stones with which the temple was built were transported from the metropolis. The original project designed in Portugal at a latitude over 38° N was not suitable to meet the lighting requirements in Salvador, located at latitude 12°58′ S. As a consequence, it was necessary to subsequently construct a lantern

Figure 10. Interior of the church of Sao Bento, Salvador in Bahia (Brazil).
Source. Jose M Almodovar-Melendo.

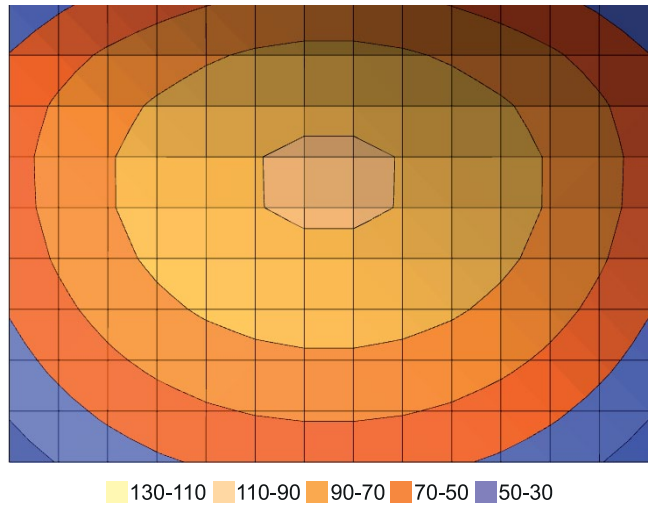

Figure 11. Simulations of daylighting in Sao Bento, Salvador in Bahia (Brazil).
Source. Jose M Almodovar-Melendo.

on the roof, which had not been foreseen in the original design. This new element had to be built with lightweight materials to not jeopardize the stability of the church (Figures 12 and 13).

The results of the monitoring carried out in the temple indicate that even with the help of the new lantern, the daylighting level inside the temple is critical. Measurements slightly more than 100 lux can only be found below the lantern while outside, the following values were simultaneously recorded (in lux): 14.161 (East), 11.100 (north), 4.683 (west), 9.898 (south), and 23.660 (horizontal plane).

Figure 12. Church of Conceiçao da Praia, Savador in Bahia (Brazil).
Source. Jose M Almodovar-Melendo.

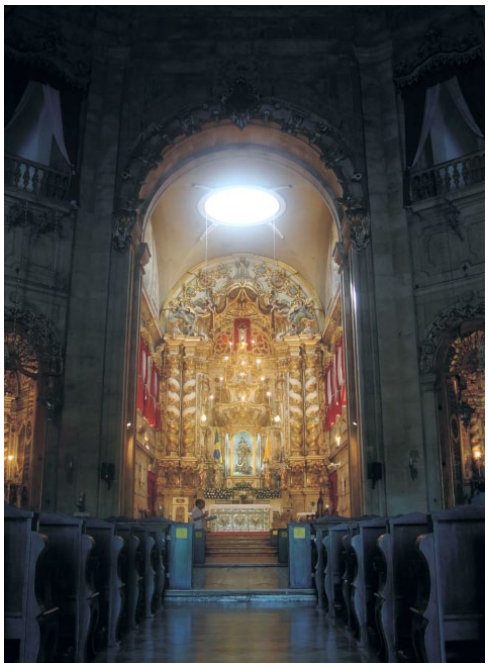

Figure 13. Interior of the church of Conceiçao da Praia.
Source. Jose M Almodovar-Melendo.

Figure 14. The church of San Francisco, Quito, Ecuador. Excess of apertures for a dimly lit interior.
Source. Joseph M Cabeza-Lainez.

Figure 15. The Jesuit church of Guanajato, Mexico.
Source. Joseph M Cabeza-Lainez.The domes executed in the late period of Colonial Baroque were mostly the expression of a kind of creole hegemony and were not especially connected with lighting problems, which, in any case, remained unsolved with the affordable means of the time.

Mannerism and Late Examples

In Ecuador and especially in the church of Saint Francisco by Jodocko Riecke (Figure 14), we find a similar problem, and in Mexico in many of the Jesuit churches the rows of fenestration are doubled or even tripled, as in Guanajato, to enhance light distribution (Figure 15).

Figure 16. Interior of Saint Joseph's Church, Macao.
Source. Joseph M Cabeza-Lainez.

Figure 17. Detail of the Saint Joseph's Church dome.
Source. Joseph M Cabeza-Lainez.

Some Examples in Asia

Saint Joseph's Church, Macao

In Macao (22°12′ N), the first European settlement in China, we want to bring up a further example, the St. Joseph Jesuit Seminary, whose construction began around 1750. Apparently, it was a replica of the St. Paul Old Seminary, but nevertheless it is admirably adapted to the climatic conditions. European motifs merge with others of Chinese or Indian origin. Lime is used on the walls to highlight the surrounding building, and lattice windows are made with teak wood and translucent shells replace the glasses.

Among the most outstanding features we want to highlight the layout of the dome, which has 32 square windows near the cusp (Figure 16). All the windows are protected from the sun by overhangs and can be opened to promote cross ventilation in the upper part of the church, which is very suitable to adapt the temple to the warm and humid climate of Macao (Figure 17).

Figure 18. Detail of the Divine Providence's Church dome, Goa, India.
Source. https://www.flickr.com/photos/eustaquio/9451578478/in/photolist-fooLSr-fpcNZC-foXzup-7E1AG5-7E1AD7-7DWLze-f9Z1AL-7CeLfu (CC license 2.0; author: Eustaquio Santimano).

The Society of Jesus has generally been very sensitive to Eastern influences, and in this church where the controversial Chinese rites (an adaptation of the Christian liturgy) were practiced at some point, we find a perfect realization of this synthesis in its architecture.

The Church of Divine Providence, Goa

Finally, we want to highlight the Church of Divine Providence in Goa (15°3′ N), located in the Seminary of Sao Caetano, made by the theatines. Its construction began around 1650 and reminds us the homonymous church that Guarino Guarini designed for Lisbon; but only partly, as its interiors and decoration with gildings and precious woods constitute a magnificent expression of the fusion of horizons that we have been emphasizing (Figure 18). Perhaps this is why the high windows and claristories in Peru, Ecuador and other zones of the Pacific are still called theatines.

Temples of Tile and Gold

Through contacts of Iberian soldiers and mainly Portuguese merchants with Asia, other techniques of light treatment were spread to Europe, which included detailed knowledge of gilded interiors of Japanese temples, as can be seen in the writings of the Jesuits Luis Frois, Joao de Lucena, and others. It is proved that San Francisco Javier, Luis Sotelo, and other religious figures had visited Japan and had contact with the main sculptural and architectural works of the Kamakura and Muromachi eras, including the Sanjusangendo and Kinkaku-ji temples (Figure 19).

Ceramics and azulejo tile—another Asian feature conveniently added to the walls were able to create a similar effect, as we see today in many Portuguese and Brazilian churches. It is interesting to stress that most azulejo-bearing examples in Portugal are late-baroque retrofits, such as the case of Sao Lorenzo's Chapel (Figure 20). This clearly indicates a change of mentality in relation to the interior design.

The Search for Solutions

In subtropical latitudes (near the Equator), the incidence of solar radiation is usually more intense than in mid or high latitudes. However, the availability of daylight in vertical surfaces, were

Figure 19. Kinkaku-ji temple in Kyoto, 1390.
Source. Jose M Almodovar-Melendo.

Figure 20. The chapel of Sao Lorenzo in Algarve (Portugal) totally covered with azulejo tile.
Source. Jose M Almodovar-Melendo.

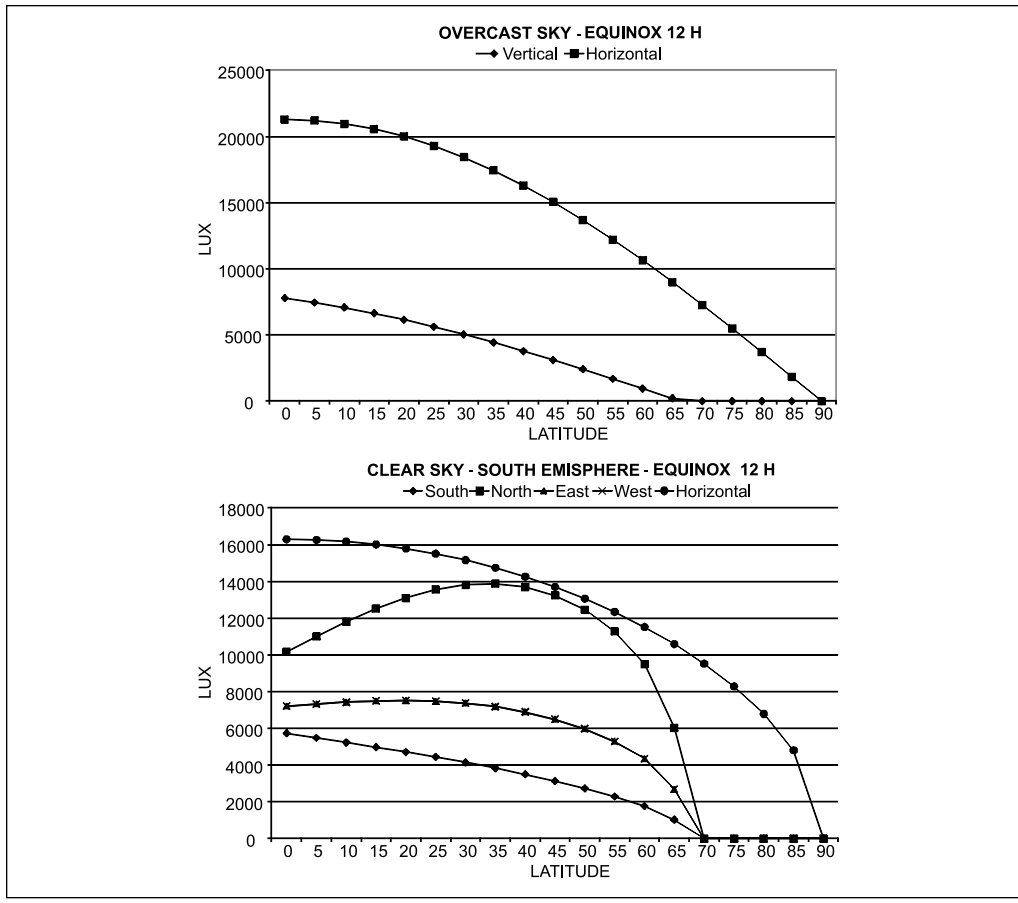

Figure 21. Illumination in lux as a function of the latitude, equinox 12:00 hours. (Above) Overcast sky. (Below) Clear sky.
Source. Jose M Almodovar-Melendo.

windows are often placed, is not as high as it would be expected (Almodovar, La Roche, Jimenez, & Dominguez, 2012). To analyze this question, we have used the Gillet, Pierpoint, and Treado (1984) sky model to assess daylighting values in vertical surfaces and in the horizontal plane as a function of the latitude. The sky model defines the vertical illumination (in lux) for clear sky based on the azimuth (Φ) and the height (θ), by the equation below.

$$Ev = 4000 * \theta^{1.3} + 12000 * \sin^{0.3}\theta * \cos^{1.3}\theta * \left[\left(2 + \cos\Phi\right) / \left(3 - \cos\Phi\right)\right]$$

And in the case of overcast sky, similar to the CIE model, using the following equation.

$$Ev = 8500 * \sin\theta$$

Results have been ordered in steps of 5° latitude from the equator (0°) to the poles (90°). The overcast sky method indicates that as the distance to the equator decreases, the altitude of the sun increases and daylight increases in vertical surfaces. Nevertheless, for clear sky, the daylight levels begin to descend when the relation between the greater solar altitude and the increase of the angle of incidence on vertical surfaces is unfavorable (Figure 21).

Figure 22. The dry-garden of Ryoan-ji in Kyoto, Japan.
Source. Jose M Almodovar-Melendo.

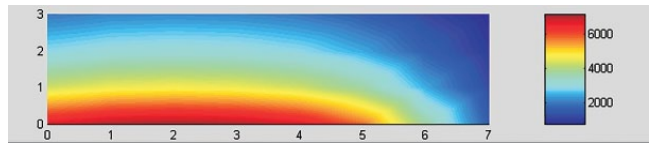

Figure 23. Simulations of the underside of the roof in Ryoan-ji with values up to 6000 lux.
Source. Joseph M Cabeza-Lainez. .

On the other hand, in low latitudes is difficult to take benefits from the sunlight in the tasking/working planes because frequently reach the floor, usually occupied by furniture and dark materials.

As a consequence, the only possible solution for such equatorial latitudes is perhaps the use of horizontal surfaces as a way to reflect the radiation impinging from very high altitudes, however, this was not a contemporary source of the repertoire and the only precedents can be found in Japan in the so-called Karesansui or dry-gardens like the ones we find at Ryoan-ji and the surroundings of Kyoto (Figure 22).

Simulations and measurements produced for Ryoan-ji reveal a significant increase in lighting levels due mainly to the clear color and Southern exposure of the dry-garden (Figure 23).

The centralized plans used in baroque temples would therefore have the limit of validity imposed by the interior reflections, always designed by local masters. This limit does not seem to reach much beyond the 35th parallel, which would be confirmed by the first data obtained in the Church of Sao Bento (Brazil, 8th South), where the same type of plant is maintained but the daylighting levels are clearly insufficient despite the high reflectance of its white interior walls and the introduction of oculus in the dome. The most southernmost point studied in Japan is located at 32° N while the latitude of Kyoto is 35° N, which would also explain the local need to use external reflection elements such as pavements or ponds. Nevertheless, the continuity of these experiments is what will eventually produce a firm conclusion of this historical analysis.

Conclusions

We have traced a historic and scientific pursuit that begins in the baroque and is not yet finished because American and Asian architectures are still searching and fighting for their identities in the modern world.

Cultural overtones cannot be ignored in this discussion, but the help of computers and simulation tools clarifies to a deep extreme the terms in the debate, in the sense that without some degree of objectivity we would not be able to overcome or even understand our ever-opening history.

In this regard, some results can be drawn from the first-stage analysis, as follows:

Simulation is a viable alternative both for knowledge of the historical patrimony and for help in the decision-making process of the retrofitting policy.

Daylighting simulations are a valuable tool in rehabilitation of spaces from the past, not only in the issues of supplementary artificial lighting but also in questions of space-qualification, energy-savings, and restoration and maintenance of artworks like paintings, gilds, and sculptures.

It is possible and necessary to overcome the constraints of former daylighting models based only on overcast-sky condition. The new method of configuration factors is capable of assuming this drawback even in complex geometries.

The diverse environmental strategies (lighting, thermal, etc.) should entwine for the sake of architectural opportunity, without ignoring human and cultural overtones.

That kind of holistic approach is now required from environmental architecture to ensure that the physical and aesthetic aims of all members of a multifaceted society are fulfilled.

Architecture and architectural analysis is no longer conceivable without objectivity and scientific support. As philosopher L. Wittgenstein would have stated, “in a world devoid of transcendence, we receive our culture from science” (Finch, 1995: 119).

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