

DAYLIGHT IN A CISTERCIAN HERITAGE CHURCH IN LISBON, FROM RURAL TO URBAN CONTEXT

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ABSTRACT

Light levels in the churches of the Cistercian Order are mostly related to the fulfilment of liturgical needs. The compound building of Bernardas' Convent includes a church at the utmost southern corner that dates back to the 17th century. It only has one façade facing due southeast. This paper analyses the relationship between daylight conditions within the building before and after the urbanisation of the surrounding area; taking into account the relationship between the church, its main activities, and solar trajectory. A comparative analysis of the relationship between the actual surrounding context and the initial period after it was built (open field) is given. The highest reflectance of the street canyon has augmented the levels of available daylight.

KEYWORDS

Sun-path, Daylight factor, Vertical daylight factor, Urban canyon, Cistercians, Heritage

1. INTRODUCTION

1.1 Historical perspective

The Monastery of Our Lady of Nazareth of Mocambo in Lisbon, Portugal, at a latitude of 38.71, usually known as Bernardas' Convent, was a Cistercian foundation. The first Cistercian monasteries appear in Portugal in the 12th century, far from the urban context. The foundations of the Cistercian order in this country, particularly in the first centuries of its history, were associated with occupation and land management objectives. It must be taken into account that the transformation and development of the territory have been responsible for isolated buildings and villages which have gradually been taken up by the expansion of the urban fabric (Martins, 2011). Although the Cistercians were an Order demanding solitude and isolation, established away from the urban context, over time some cities absorbed these fragments. This is a monastery once isolated that has become integrated, interacting and being part of the urban fabric of the contemporary city.

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A Cistercian monastery should be regarded as an ideal city and be endowed with all the necessary elements to survive. “The monastery should if possible, be arranged so that all the necessary elements such as water, mill, garden, and various crafts may be inside the enclosure” (St. Benedict). Besides all symbolic connotations, this is a functional and ordered place where everything has its justification. In order to understand The Bernardas’ Convent we must keep in mind that the monastic space can become a territorial organism which is taking over land, and is modelled and altered according to its needs.

The Monastery of Our Lady of Nazareth of Mocambo, better known as Bernardas’ Convent is located in Madragoa, a Lisbon neighbourhood in Portugal and was, as mentioned a Cistercian foundation. It was founded in 1653 over pre-existences but in fact this Monastery is a much more recent foundation because it was initially a gathering place for penitent and devoted women and then later became a convent. The neighbourhood of Madragoa was a fishing village which in the 16th century was integrated into a riverside path of expansion, towards the occidental part of Lisbon (Gaspar, 2002). In fact, until this time, Madragoa was a prolific area with monasteries and convents located outside the city walls. Over time, the city has been constructed around the convent. In 1755 the Bernardas’ Convent was totally destroyed during an earthquake and rebuilt later on by the Italian architect Giacomo Azzolini. After the extinction of the religious orders, in 1834, the convent was preserved until the death of the last nun and then was sold.

The Bernardas’ Convent has had various usages since then. There have been several schools in the historic building. In June 1924, the Convent’s church was used as a movie house and a theatre (the apse was even replaced by a stage). In addition, this space was used by an orchestra and subsequently transformed into a furniture store and warehouse. On the ground floor there were taverns and coal warehouses. At one point The Bernardas’ Convent was used as a “Vila Operária,” labour dwellings inside a pre-existing building, where, a significant population lived in precarious conditions, inside the monastic building.

In 1996, there was an architectural competition promoted by the City Council regarding the rehabilitation of the Bernardas’ Convent. The awarded project included the rehabilitation of the convent’s space distributed into 34 residences, a restaurant, 4 shops, a centre for the elderly, a social club and the Puppet Museum, as well as a multi-purpose room, originally the Church, which was connected to the Museum. The retrofitting and rehabilitation of the convent began in 1999 and was finished between 2001 and 2002. Today, the monastic building serves as a small condominium, a restaurant and Puppet Museum (Martins and Carlos, 2012). In spite of this major rehabilitation, the envelope of the building including its fenestration remains unchanged, without considering the availability of daylight into the building.

1.2. Natural light

Wa-Gichia (1988) has found that in clear sky conditions the contribution of the externally reflected component of daylight gives a general indication of the importance of opposing facades when sunlight is incident on them. Tsangrassoulis et al. (1999) has also studied the ratio of the light incident on a vertical surface which opposes another vertical south-oriented surface. Miguet and Groleau (2002) present numerical models for the simulation of natural light in the urban morphologies. Al-Maiyah and Elkadi (2007) have presented several situations where a window faces an opposing sunlit facade having demonstrated that daylight is significantly reduced. The same urban context is later on studied by Li et al. (2009). Strømman-Andersen and Sattrup (2011) describe how daylight is affected by increases in urban density.

FIGURE 1. Aerial view and cross section (adapted from Google Maps and Martins, 2011).



They found that the geometry of urban canyons plays an important role in daylight reflection. The study based on the height/width proportions of urban canyons showed that reflected light can be the greatest fraction of available daylight to housing and offices on the lower floors in high urban densities and its distribution of daylight is highly dependent on the reflectivity of building façades. The geometrical configurations of the street canyon present different vertical surfaces opposing each other. However, the cross section of this singular street in front of the church demonstrates that their windows are above the opposite façades and its roofs as represented in Fig. 1.

A simplified method presented by Tregenza (1995) is used with regard to the present geometry of different facade heights as Tsangrassoulis et al. (1999). Although the urban geometry is not as regular as presented, a similar model is used as Li et al. (2010). Two opposing buildings were used with non linear geometry that did not represent an infinitely long urban canyon. They compared the results of the calculated vertical daylight illuminance from an infinitely long urban canyon with the results simulated by the RADIANCE software and the field-measurement data (Tregenza, 1995) which were in agreement.

A simpler tool to predict the levels of daylight of a building is the daylight factor (Li et al., 2010). As stated by Cheng et al. (2007), “*It defines the level of illuminance at a specific point indoors, received from a sky of an assumed luminance distribution, without the presence of direct sunlight, and is expressed as a percentage of the horizontal illuminance outdoors from an unobstructed hemisphere of the same sky.*” The state of the art in lighting simulation examined by Ochoa et al. (2012), presented several possibilities of lighting simulation in the architectural design process where the daylight factor is present. Li et al. (2009) has defined the vertical daylight factor as the ratio of percentage of the total amount of daylight illuminance falling onto a vertical surface of a building to the instantaneous horizontal illuminance from a complete hemisphere of sky excluding direct sunlight. Besides the daylight factor (DF) and the vertical daylight factor (VDF), to examine the differences in the daylight availability in this church, a variable introduced by Tsangrassoulis et al. (1999) is also used in this study;

this is the Obstruction Illuminance Multiplier (OIM), which is defined as the ratio of the illuminance received on a vertical surface due to light received from the sky, ground, and the obstruction to the illuminance on the same surface without the presence of the obstruction. A new variable is introduced similar to the previous one but related only to the reflected light (OIM_{ref}). Comparing VDF based on a simple approach supported by the above referenced literature and also the OIM, this paper demonstrates that the canyon had augmented the level of luminance on the windowpanes. If not for the tree, the level of VDF would be higher than in an open field due to an extra reflectance from the surroundings. This is evident through a OIM_{ref} higher than the unity.

2. ACTIVITIES AT THE CHURCH

St. Benedict divides the year in two seasons: winter and summer. According to this calendar, winter began on the first day of November and came to an end at Easter and summer began at Easter and came to an end on the first day of November (Martins, 2011). The phase between sunrise and sunset is divided into twelve parts which corresponded to the canonical hours. The winter days were shorter, than the summer days, thus the hours were also shorter. Consequently, the Rule of St. Benedict says that each hour should be determined based on a reasonable calculus. So one hour corresponded to a time between 45 min and 75 min according to the actual standard hours depending on the season (RSB; ch. 66).

The day of a Cistercian, begins at the Church with the Vigils at 2h or 3h in the morning, depending on the time of year, and these last about 1h to 1h30min. At dawn the lauds begin, and the Eucharist is celebrated around 7h in the morning (Table 1). After this, the Officium, called the Prime, takes place in the Chapter-house. Later in a chapter of the Rule of Saint Benedict, the Capitulum, is read aloud. Then the Lectio Divina follows with one to two hours of spiritual reading until the next Officium, the Terce. After that, each Cistercian performs the tasks assigned by the Abbot, and around noon, work stops and the Sext officium takes place. Then comes the moment to eat in the refectory. At about 2 o'clock in the afternoon it is time for the None officium, followed by 2h to 2h30 min. of work depending on the season. At about 5 o'clock in the afternoon the Cistercians must be at the church for Vespers which is

TABLE 1. Diurnal canonical activities within the church.*

Canonical hour		Solar Time (hour)			Activity
		Solstice Winter	Equinox	Solstice Summer	
1st	Summer		6.0 to 7.0	4.6 to 5.9	Prime
3rd			8.0 to 9.0	7.1 to 8.3	Terce/Eucharist
1st	Winter	7.4 to 8.1	6.0 to 7.0		Prime/Eucharist
3rd		8.9 to 9.7	8.0 to 9.0		Terce
6th	Whole year	11.2 to 12.0	11.0 to 12.0	10.8 to 12.0	Sext
9th		13.5 to 14.3	14.0 to 15.0	14.5 to 15.7	None
11th ½		15.9 to 16.3	17.0 to 17.5	18.1 to 18.7	Vespers
12th		15.9 to 16.6	17.0 to 18.0	18.1 to 19.4	Compline

*Adapted from Martins [1]

FIGURE 2. Both sides of the street (Church on the right side).



followed by a light meal in the refectory. A small reading introduces the Officium of the Compline beginning at the gallery of the cloister, next to the Church, continuing into the Church. After this officium the Cistercians move, single lined, towards the dormitory, led by the Abbot who blesses them.

The monastic Cistercian life is divided between manual work and prayer during the several Officium, or, as it is known by the latin expression: Ora et Labora. Time is cyclical, as is the Cistercian cloister life, following summer and winter as well as the drama of light and shadow that gives value to the monastic architectural space, making it perfect for a contemplative experience (Martins, 2011). In fact, the church of the Bernardas' Convent stands about 8.50 meters above the street which has a section of 8 to 12 meters. Two sidewalks are paved with limestone pebbles and the lane with granite cobbles. The façade opposing this convent comprises buildings from two to four floors of various colours, built after the big earthquake in 1755. These new constructions surely have contributed to changes in daylight levels of the existing building (Almaiya and Elkadi, 2007). Two big deciduous trees, right in front of one of the windows of the church helps to change the perception of the building and also on the light levels across the seasons of the year (Fig. 2).

3. MEAN VERTICAL DAYLIGHT ILLUMINANCE

Buildings in an urban context partly obstruct each other's view of the hemispherical sky and under certain conditions (geometry, orientation, etc.) may obstruct the direct sunlight. The daylight illuminance on a vertical window in a street canyon (E_v , in lx) consists of the light falling directly from the sun and the sky and the light received from external reflecting facades of buildings and the street. It can be given by (Szokolay, 2008; Li et al., 2010):

$$E_v = E_d + E_r \quad (1)$$

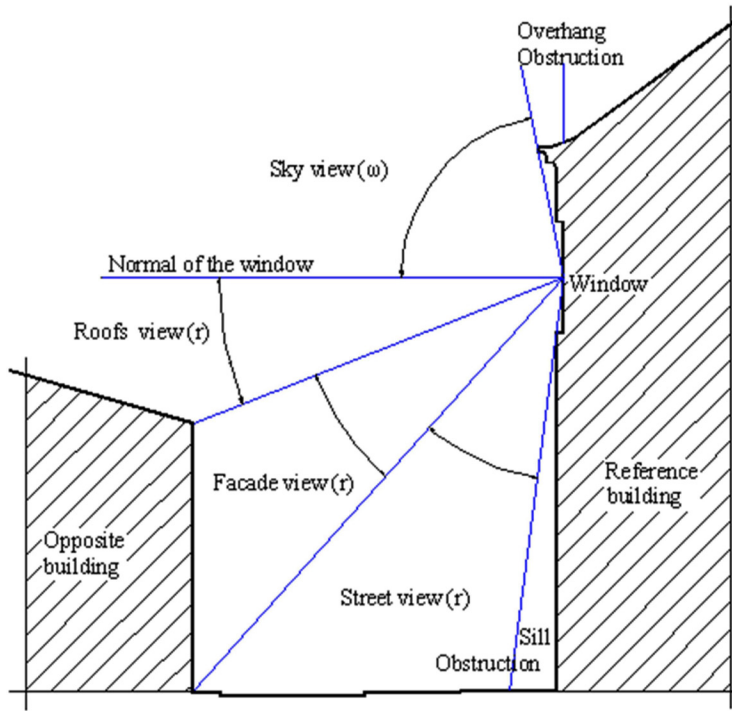


FIGURE 3. The angles used at the midpoint of the window.

where E_d , is the light coming directly from the sun and the visible sky (lx), E_r , is the reflected light from the external surfaces of the street canyon (lx). The illuminance reaching the vertical surface coming directly from the sun depends on its incident angle (θ , in degrees), which is determined by:

$$\cos(\theta) = \cos(y)\cos(\alpha_b - \alpha_s) \quad (2)$$

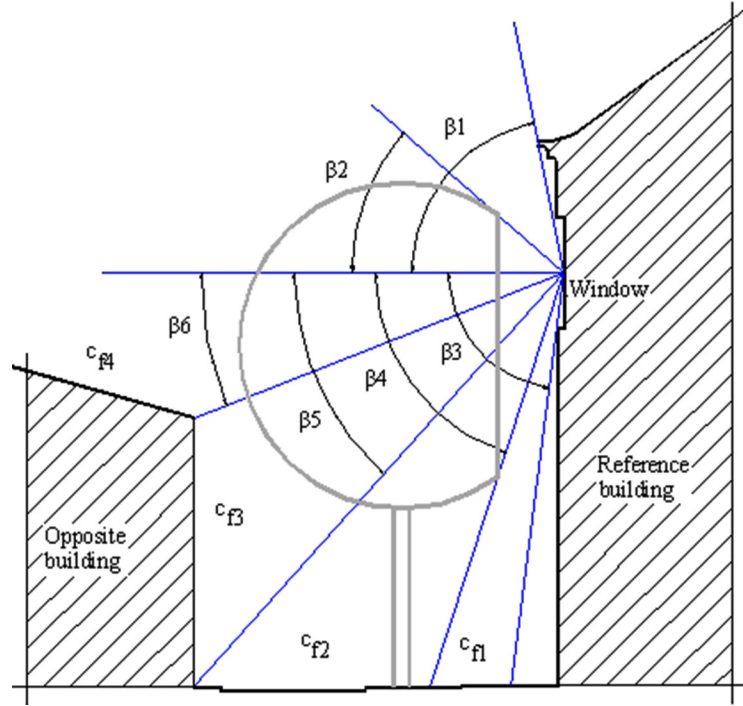
where, y , is the solar altitude (degrees), α_b , is the azimuth of the building facade (degrees) and α_s , is the solar azimuth (degrees). The diffuse illuminance depends on the portion of the sky that is viewed from the window. As the windows of the church are above the level of the skyline of the opposite buildings, another surface that reflects light onto the window must be added corresponding to the visible roofs. This component is handled within this field as an unobstructed ground. It is a simplification of several shape roofs seen from the window. The reference angles at the midpoint of the window are shown in Fig. 3.

Therefore the mean direct illuminance on the vertical window from the sun and the sky (E_d , in lx) come from:

$$E_d = E_n \cos(\theta)f_b + E_h \frac{\sin(\omega)}{2} \quad (3)$$

where, E_n , is the solar normal illuminance (lx), f_b , is the fraction of the sunlit building facade, E_h , is the unobstructed horizontal diffuse illuminance (lx) and ω , is the angle of the visible sky measured to the normal of the window (degrees). The first term is the illuminance from the sun and the second is the illuminance from sky. The shading from the trees consists of a row of two spherics trees as in Cascone et al. (2011), placed at a short distance from the window where some branches were cut off. Taking into account the angles as illustrated in Fig. 4, the mean illuminance on the window surface coming from the sun and sky (E_d , in lx) modifying the eq. (3) is estimated by:

FIGURE 4. The angles used at the midpoint of the window related to the trees.



$$E_d = E_n \cos(\theta) f_b \tau_t + E_h \frac{\sin(\beta 1)}{2} \tau_t + E_h \frac{\sin(\beta 2) - \sin(\beta 1)}{2} \quad (4)$$

where, $\beta 1 \dots \beta 6$, are the angles from Fig. 4 (degrees) and τ_t is the transmittance of the tree.

A clear sky condition is used in this study. The approximate values of the solar normal and diffuse illuminance can be estimated using the formulas given by (Tregenza, 1995; Tsan-grassoulis, 1999):

$$E_n = 127500 \exp\left(\frac{-21}{\sin(y)}\right) \quad (5)$$

and

$$E_h = 800 + 15500 \sqrt{\sin(y)} \quad (6)$$

Depending on the obstructed building and on the solar altitude, part of the vertical sunlit facade may be shadowed as well as the window on it. When a street has straight parallel facades, the street level may be partially sunlit. The perpendicular extension of the shade formed on the street by the obstructing building is given by:

$$H = h_b \frac{\cos(\alpha_b - \alpha_s)}{\tan(y)} \quad (7)$$

where, H , is the extension of the horizontal shade on the street (m), h_b , is the height of the building facade casting the shadow (m). If H is smaller than the street width then, the fraction of the street that is sunlit is (f_w):

$$f_w = 1 - \frac{H}{w} \quad (8)$$

where, w , is the street width (m). If $H > w$ the obstructing building casts the shadow also on the frontal building. The extension of the shade along the building (V , in m) from the ground, which may or may not reach a window, is:

$$V = \frac{(H - w)h_b}{H} \quad (9)$$

Therefore, the fraction of the sunlit building (f_b) is:

$$f_b = 1 - \frac{V}{h_1} \quad (10)$$

where, h_1 , is the height of the sunlit building (m). The facades and street also receive reflected light from each other. Thus, the inter-reflected light within the street canyon (E_c , in lx) can be estimated by (Tregenza, 2011):

$$E_c = \frac{E_d h_b \rho_b + E_w w \rho_w}{(2h + 2w)(1 - \rho_m)} \quad (11)$$

where, E_d , is the illuminance on the building facade from the sun and sky (lx), h_b , is the height of the building facade (m), ρ_b , is the reflectance of the facade, E_w , is the illuminance on the street from the sun and sky (lx), w , is the width of the street (m), ρ_w , is the reflectance of the street, and ρ_m , is the mean reflectance of the street canyon. The latter is given by:

$$\rho_m = \frac{h\rho_b + w\rho_w}{2h + 2w} \quad (12)$$

Surface materials and colours may correspond to different reflectance values. Lastly, the reflected light onto the window regarding Figure 4 is:

$$E_r = \sum E \rho c_f \tau_t \quad (13)$$

Where E , is the illuminance on the surface from the sun and the sky (lx), ρ , is the mean reflectance of the surface, c_f , is the configuration factor from the window to the surface, τ_t , is the transmittance of the tree. Three surfaces are to be taken into account; the street, the opposite building and the roofs. The configuration factor from the window to the street is the sum of c_{f1} and c_{f2} , where the transmittance of the tree with respect to c_{f1} is 1. The configuration factors from the window to each sunlit surface, according to the angles shown in Fig. 4 are:

$$c_{f1} = \frac{\sin(\beta_3) - \sin(\beta_4)}{2} \quad (14)$$

$$c_{f2} = \frac{\sin(\beta_4) - \sin(\beta_5)}{2} \quad (15)$$

$$c_{f3} = \frac{\sin(\beta_5) - \sin(\beta_6)}{2} \quad (16)$$

$$c_{f4} = \frac{\sin(\beta_6)}{2} \quad (17)$$

4. RESULTS AND DISCUSSION

4.1. Sun-path around the church

The combined orientation effect of the church's main axis and the sun trajectory determines how the sunlight reaches the interior of this architectural structure. The compass measurement of the longitudinal axis of this building's rectangular section deviates from the eastern orientation, being the sunlit façade facing due southeast. The main liturgy hours used to be associated to the sunrise and sunset hour depending on the daily patterns of the Earth's movements around the sun.

Using a stereographic projection of the sun's path for the latitude of the edifice, the church plant is positioned so that the essence of the circle is the same as the altar, therefore indicating the daily path of the sun around it. An outline of the church instead of the whole building is used in this particular study so that it is orientated in accordance with its longitudinal axis. In the projection model illustrated in Fig. 5 the summer and winter solstice as well the equinox path is plotted. Four projections lines define the canonical hours that impinge the direct sunlight onto the altar through the fenestration (F) nr. 3. These represent the 4th hour and 5th hour of the winter and summer solstice, respectively. Furthermore, the first and the last canonical daily hours as defined in Table 1 are shown. As one can see, due to the thickness of the walls the sunbeam never reaches the altar through the first and second fenestration. It indicates that the church is roughly aligned with the sun around the time of the early canonical hours. The three fenestrations are aligned with the passing sun between the time of Prime, at the first hour, through the liturgy and the sixth hour (at which the sunlight is most intense). The remaining hours are generally aligned with the southwest side of the building. Consequently, the natural lighting of the chamber assures as much intensity of light as possible the maximum possible intensity of light during the first period of the day (in the morning). Their southeast openings of the church are orientated in a way that suggests that the rays of light might fall onto the altar one time per day over a year in the late morning.

FIGURE 5. Sun-path around the church centred on the altar.

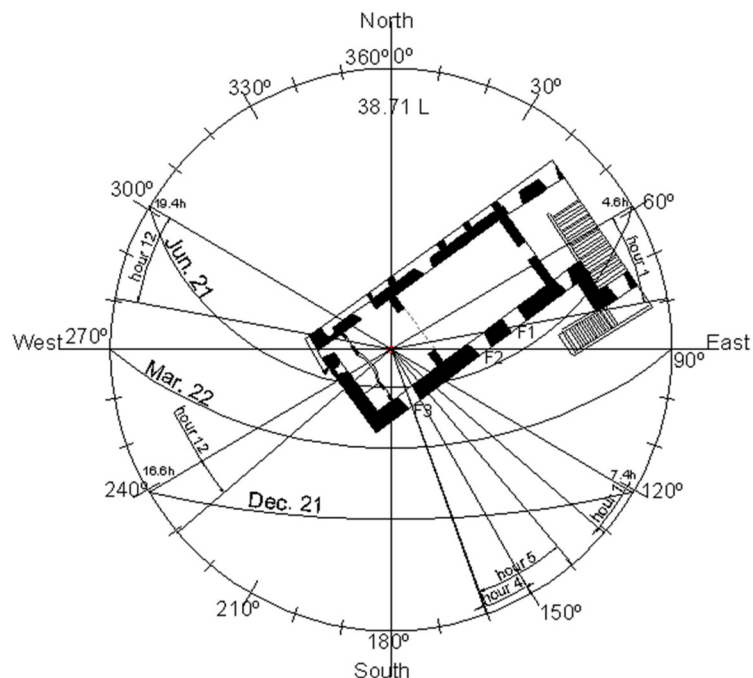
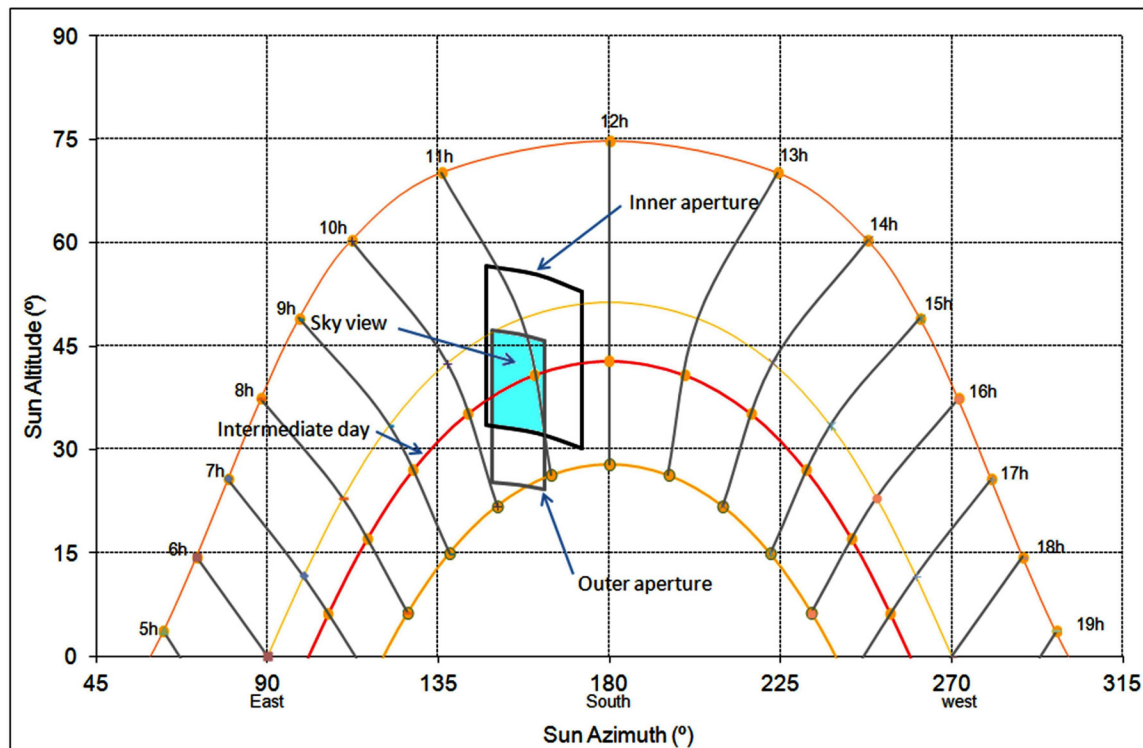


FIGURE 6. Sun-path and sky view from the altar through the fenestration 3.



Windows are distributed along the Southeast façade, the third one being arranged in the altar zone. Fig. 6 shows the relations between the sunbeam and the centre of the altar. It represents the vertical sun-path as viewed from the altar level facing due south. Due to the thickness of the wall, the third aperture seems reduced, and on this particular geometrical space the view of the sky vault is also reduced, as represented. This implies that the maximum period of time that the shaft of sunlight can pass onto the altar is 44 days a year, from February 18th to March 11th and from October 1st to October 22th. During the intermediate days represented in Fig. 6 (February 28th and October 12th) the sunbeam falls onto the altar for about 1.3 hours a day, a total of nearly 57.2 hours a year. Nevertheless, taking into account the deciduous trees and assuming they block out the sunbeam during the summer and that thin branches let all the daylight pass, the view of the sun is reduced by half, as the altar is only directly lit for about 28.6 hours a year. It seems that during a great deal of time the daylight is diffuse and relatively shadowy inside the church which is confirmed through a daylight factor (DF) of 0.4%. According to Tregenza and Wilson (2011) a DF less than 1% is often gloomy and electric lighting is required to carry out visual tasks. This level of light could be enough for a church where a spiritual atmosphere was required in a Cistercian church.

Without direct sunlight, the sky luminance distribution is assumed symmetrical in relation to zenith and changes to the vertical outdoor illuminance would be the same for all orientations. The DF will remain constant as the interior illuminance varies along the changes of the exterior daylight. It is usually measured at the same level of the working plane. The average daylight factor developed at the Building Research Establishment on a horizontal working plane is (Tregenza and Wilson, 2011):

$$DF = \frac{\omega \tau_{vis} A_g}{(1 - \rho_i^2) A_i} \quad (18)$$

where, ω is the angle of visible sky from the midpoint of the window ($^\circ$), τ_{vis} is the transmission factor of the glazing, A_g is the surface area of the glazing (m^2), ρ_i is the average reflection factor of all internal surfaces of the room, and A_i is the total internal surfaces area of the room (m^2).

4.2. Available daylight on the windows of the church

The Bernardas' convent is located in the city of Lisbon, Portugal. When it was built the place was an open field with no buildings around. The Tagus River was in front of it down the hill. With the expansion of the city particularly after the great earthquake of 1755 it became part of the city, surrounded by different kinds of buildings. In spite of the frontal buildings across the street, the light is not completely obstructed as they did not reach the height of the windows of the church (Fig. 2). From these glazes, one can see different geometric red ceramic roofs of buildings down the hill in the direction of the river. The street has compact buildings on both sides of different heights and colours which are not parallel to the church. The purpose of this study is to evaluate up to what extent the daylight level in the church is affected by the new surroundings. The church space is rectangular being the parameters for this case study presented in Table 2.

The density of the foliage of the deciduous trees is a season factor which determines the opacity values assigned monthly and reported in Table 3. The trees cast a shadow on fenestration 3 when the solar azimuth, as seen from the window, is between 72° and 220° and a solar altitude lower than 41° .

TABLE 2. Parameters for the case study (street canyon and church).

Street Canyon	
Window azimuth	143°
Initial ground reflectance	20% (earth dry - summer) 10% (earth moist - winter)
Opposite buildings average reflectance	45%
Building church average reflectance	68%
Street average reflectance	20%
Roofs average reflectance	20%
Church	
Church length	21.55 m
Church depth	8.38 m
Church height	12.16 m (centre vault)
Sill height	3.91 m
Average indoor reflectance	60% 11.96 m (from the street)
Window dimensions (3 identical)	3.62 m (height) by 1.47 m (length)
Glazing area (each one)	4.31 m^2
Glazing type	Single pane, clear, 80% transmittance

TABLE 3. Monthly foliage opacity values for deciduous plants (Cascone et al., 2011).

Month	%
January, February, December	40
March, November	50
April, October	60
May, September	70
June, July, August	80

As Tregenza and Wilson state “*For an obstructed sky the direct illuminance on the vertical surface is about 40% of that on open ground, and reflected light from the ground adds typically about 5%*”. It also suggests “... *that most formulae use can rarely be better than fair estimates*” (Tregenza and Wilson, 2011). A comparative study on VDF carried on by Li et al. (2009), predicted by the RADIANCE simulation software and Tre-

genza’s modified split-flux formulae had shown that the latter presented a lower VDF of more than 30%. By looking at the second term of the equation (3) the result would be of 50%, without the reflection from the ground. At the inception of this building, without any building environment surrounding it and for an unobstructed sky, the illuminance at the windows (VDF) would have corresponded to 57.7% of the illuminance to that same open field. This includes around 8.7% of the light reflected from the ground with a reflectance of 0.2. For a lower reflectance of 0.1, the VDF would have equated to 53.3% being about 4.3% reflected from the ground. Due to the actual surroundings, the available daylight at the window level may experiment some differences when compared to the building at its inception (Wa-Gichia, 1998; Strømman-Andersen Sattrup, 2011). In fact, the visible sky has been the same throughout time, so the DF is expected to divulge the same value, but the level beneath the horizon seen from the windows of the church is really different from the creation of the building. The VDF is approximately 58.4% including around 9.5% of reflected light from the surrounding urban context. And thus, as this lower level influences the difference to the amount of daylight on the windows, it is analysed when compared to the former surroundings.

The reflected light onto the windows of the church has three different sources: the street, the façades of the buildings, and also the visible roofs of the buildings seen from the glazings. The relevance of each source is analysed through the ratio of the illuminance received on the window due to the light reflected by each source to the illuminance on the unobstructed horizontal surface, as R_{street}/E_h (street), $R_{\text{façade}}/E_h$ (façades) and R_{roofs}/E_h (roofs). For an overcast sky the contribution of each source to the final vertical illuminance is 2.2% from the street, 3.6% from the façades and 3.7% from the roofs with a total reflected ratio of 9.5%. Under a clear sky, Figure 7 presents the ratio of the received reflected illuminance to the horizontal illuminance on the windows for the canonical hours during the solstices, equinox and also the intermediate days referenced in the previous chapter. These would correspond to the days which the altar would be lit directly by the solar beam.

As the sun rises in the sky the value of the reflected light from the façades decreases due to the increase of the incident angle of the solar beam. On the other hand the incident angle of this shaft approaches the line normal to the street and becomes less shadowed resulting into increased reflected light. When the solar beam illuminates the opposite façades the reflectance increases substantially, although the final value depends on the solar altitude. For instance, at higher solar altitude on June 21st when the window is lit at noon the reflectance from the façades is 5.8% and at 15 h when the opposite façades are lit the reflectance becomes 4.7%. For a lower solar altitude on December 21st when the window is lit at 14 h the reflectance from the façades is 3.6% and at 16 h when the opposite façades are lit the reflectance rises up to 4.4%. Figures 8 and 9 present the variables OIM and OIM_{ref} at the canonical reference hours under a

clear sky during the solstices, equinox and also the intermediate days of incident beam onto the altar. The first represents the street without a tree and the latter with a tree.

While Figure 7 compares the different light reflections from different sources, Figures 8 and 9 present comparative variables related to the illuminance received by the window between the initial period of the building and the urban context. This presents the total and reflected illuminance ratios. The tendency of these results is similar to the ones of Figure 7. The higher the sun, the higher the reflective component from the street canyon that reaches

FIGURE 7. Ratio of the reflected illuminance on the vertical window under a clear sky.

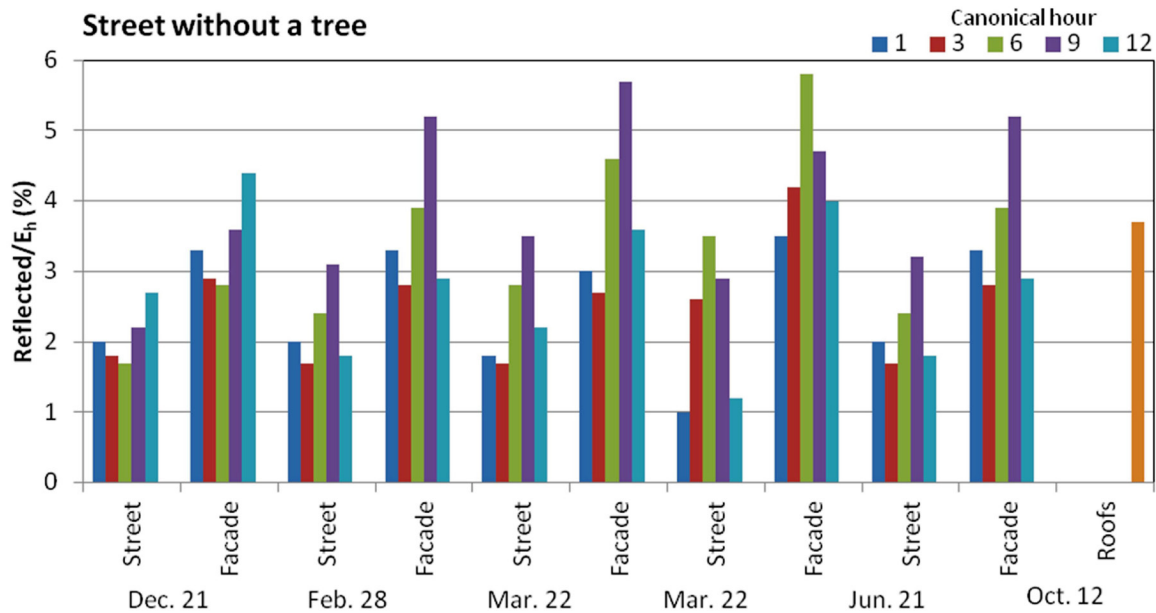


FIGURE 8. Comparison of the OIM and OIM_{ref} if there is not a tree under a clear sky.

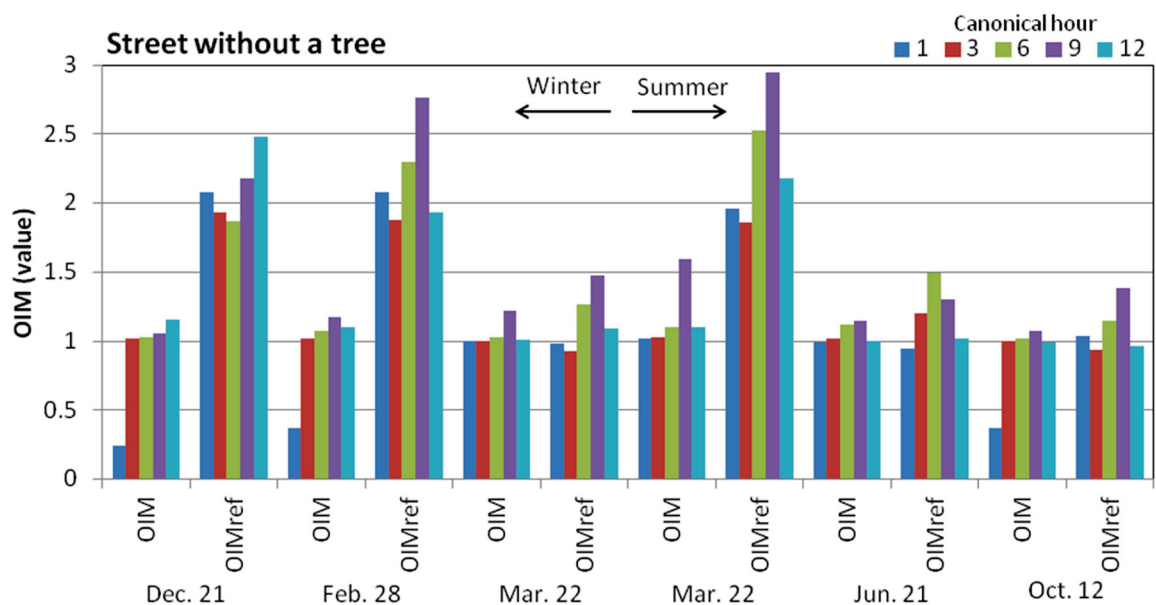
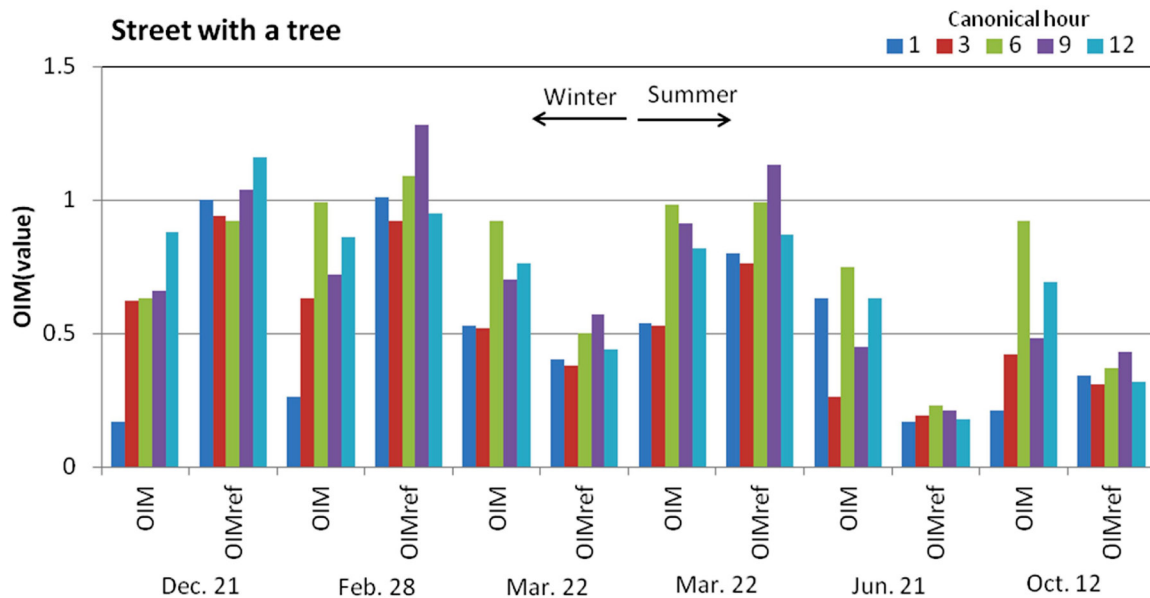


FIGURE 9. Comparison of the OIM and OIM_{ref} with a tree under a clear sky.



the window. With no obstructions to the solar beam, the differences of the received illuminance depend on the reflectance of the street canyon. This is more evident when the sun is incident on the opposite façades, increasing the reflective component of the illuminance.

The main entrance of the building (Fig. 1) is a vertical obstacle to the direct beam of the sun for each of the three windows of the church. This only affects the early morning incident light from the sun on summer days nearest the equinox, when the sun is low in the sky. This means that fenestrations no. 1 and no. 2 start to receive the direct light from the sun a little later than window no.3. In spite of this, their OIM and OIM_{ref} values are identical, both in summer and winter references, without the trees.

5. CONCLUSIONS

Historical buildings usually have different kinds of changes through times. As soon as the interior of the building undergoes a profound rehabilitation without compromising its historical value and identity, the new inhabitants may adapt to the merged modern life with a renovated old building. For historical reasons, this monastery has its façade unchanged; therefore, daylight conditions within the building have changed only due to its new urban environment. The church is situated on the southern corner of the monastery with only one outer façade facing due southeast. The primary sources of illumination are three windows arranged on this sidewall. One may conclude through the sun charts that the sun does not always fall onto the altar when the light is most needed. This is corroborated by a daylight factor of less than 1%. It is the most common and easy parameter to determine the level of light in an interior enclosed space and largely practiced in an experimental context (Cheng et al., 2007).

As one can see from the results and discussion, the urban environment brought more daylight to the window level than during its initial creation. The higher reflective street canyon is the cause of this increase. The visible sky from the window has remained unchanged, so the level below the window has a great influence on the VDF. Nevertheless, the trees act as a

filter to the light, reducing the possibility of adequate interior daylight. The OIM is mostly higher than 1 with an even higher value of the OIM_{ref} . Without the trees, the DF is always under 1%, a very low value for any indoor activity that requires illumination. Inevitably, artificial illumination is always present in that particular portion of the monastery—the church. However, this study cannot be extended to other locations and different canyon characteristics without further studies.

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