The retrofitting of the Bernardas' Convent in Lisbon

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\textbf{A B S T R A C T}

The Monastery of Our Lady of Nazareth of Mocambo in Lisbon, usually known as Bernardas’ Convent, was a Cistercian foundation (1653). In 1755 it was totally destroyed during earthquake and reconstructed later on by the Italian architect Giacomo Azzolini. After the extinction of the religious orders (1834) the Monastery had several uses. Nowadays, the monastic building serves a small condominium, a restaurant and the Puppet’s Museum. As the building had to be preserved under historical regulation its unchanged exterior walls, since Azzolini’s restoration, are made of solid masonry which dominates construction throughout the history. A well-known fact about this kind of buildings is their difficulty for temperature control that inevitably ends up using more energy to heat and cool, being experiencing a change in indoor climate due to different. Emphasis is placed in the thermal performance of these exterior walls from the view point of thermal comfort, following the ISO 7730 assumptions. The interior surfaces temperatures on heating season under climatic conditions of Lisbon are analysed. This paper aims to discuss, throughout a wide range of analysis, in which way the ideals and the realities of this historic building are divergent, but a factor of city growth and cultural development.

\textbf{1. Introduction and aims}

Around the world there are thousands of old buildings that are being challenged due to reuse, modern life and higher standards of comfort (acoustic, visual, thermal, etc.). Historical buildings, unlike more recent constructions, are based up on natural products from diversities of wood to stones. They are admired due to the majesty of the old-fashioned architecture and usually found in older cities. Portuguese's cities are no exception, some of which date back to the 12th century. While a portion of old buildings maintain their initial function, as one can see in central Lisbon where there are dwellings dating back to the 18th century, others experience some kind of intervention. Old schools are transformed into different public buildings, factories are becoming museums or schools (like the University of Beira Interior) old houses are used as a new houses or offices, and so on.

Building retrofitting strategies are influenced by numerous parameters as from sociocultural to economic criteria [1]. Other important factors can also have major or minor influence on the definitive choice (energy, comfort, costs, etc.). Wang and Zeng [2] had developed a methodology to evaluate the reuse of historical buildings. Although a sustainable retrofit of an existing building is expected to increase the market value of this building the decision still presents a number of challenges. The evaluation by the decision makers on historic buildings reuse should be supported on different expert fields, where thermal comfort must be included.

Aste et al. [3] considers that besides the \textit{U} value the thermal inertia is also significant on the thermal behaviour of buildings. High thermal inertia itself may reach to 10\% and 20\% of heating and cooling demand, respectively. Tavil [4] has analysed the thermal behaviour of several masonry walls. It was confirmed that low \textit{U} value reduces heat transfer and produces energy savings and high thermal mass reduces the exterior temperature swings on the inside. Said et al. [5] describes the long-term monitoring of the hygrothermal performance of a heritage house. It was once a residence now transformed into a museum with a controlled environment.

With new construction procedures, and with the help of mechanical devices, the historical buildings are transformed into a more tightly enclosure experiencing a changing in indoor climate. New challenges have emerged with the control of heat, the air flow through the building, and the moisture that outstands on higher standards of required comfort. The Bernardas’ Convent, in Lisbon, is now comprised of a small condominium, a restaurant and the Puppet Museum all of which require different environmental conditions (Fig. 1). Therefore this paper aims to discuss, throughout a wide range of analysis, in which way the ideals and the realities of
Nomenclature

\begin{align*}
A & \quad \text{amplitude} \\
f & \quad \text{decrement factor} \\
h & \quad \text{heat transfer coefficient, } \text{W}/(\text{m}^2 \cdot \text{C}) \\
I & \quad \text{solar irradiance, } \text{W/m}^2 \\
P & \quad \text{period} \\
q & \quad \text{heat flux, } \text{W/m}^2 \\
R & \quad \text{thermal resistance, } \text{m}^2 \cdot \text{C}/\text{W} \\
\alpha & \quad \text{absortivity} \\
\theta & \quad \text{temperature, } ^\circ \text{C} \\
\tau & \quad \text{time, h} \\
\Phi & \quad \text{time lag, h}
\end{align*}

Subscripts

\begin{align*}
a & \quad \text{air} \\
e & \quad \text{exterior surface} \\
i & \quad \text{interior surface} \\
in & \quad \text{interior} \\
max & \quad \text{maximum} \\
min & \quad \text{minimum} \\
o & \quad \text{outer surface} \\
o\mu & \quad \text{outdoor} \\
\text{sa} & \quad \text{solar-air} \\
w & \quad \text{wall}
\end{align*}

this historic building are divergent, but a factor of city growth and cultural development. This paper reflects also on the unchanging shell of the Bernardas’ Convent, and it is ever changing and varied interior functions, in particular when it concerns to actual thermal comfort standards.

2. Cistercian heritage and the Bernardas’ Convent

The Cistercian Order was introduced in Portugal, in the 12th century and its monasteries were associated with the development of the nation and the objectives of occupation and administration of the territory from the very beginning. The new monasteries were deployed to the image of Monastery of Clairvaux, from which branch they provide, defining a typology of the place. However, in 1567, occurs the separation of the Portuguese Cistercians from the obedience to Clairvaux, with the creation of the Autonomous Congregation of Alcobaça.

The genesis of Cistercian architectural austerity brought in a new perspective on Art that came with the treaty of St. Bernard’s “Apologia to Abbot William” resulting from a quarrel between Cistercians and Cluniacs, on the interpretation of the Rule of St. Benedict [6]. The Romanesque and then the Gothic, adjusted to the characteristics of the place, are the answer to the demands of the Cistercians, translating their spirituality. One must highlight the importance of the Cistercian Order, not only in Romanesque proliferation but also in the introduction of the Gothic, in Portugal. Portuguese Cistercian monasteries became worthy examples of the European Cistercian architecture, although over time they were adapted, enlarged and transformed according to the styles of each epoch [7].

After the extinction of the Orders in 1834, the country underwent numerous transformations and the Cistercians moved out of Portugal never to return. However, their architectural legacy was recovered and rehabilitated, evoking the ideals and the Cistercian spirituality, and does not let us forget of the importance of the Cistercian Order in Portugal. The Cistercian monasteries developed in accordance with the growth of Portugal reflecting and expressing each epoch. They were the target of numerous renovations, extensions and improvements. They also suffered from national events and disasters. Several of the Cistercian monasteries were restored using the romantic restoration ideals. The DGEMN (General Directorate of National Buildings and Monuments) applied these ideals at the beginning of the 20th century according to the theories in vogue. One of the restored Cistercian examples of this kind is the monastery of St Maria de Alcobaça that was declared a world heritage site by UNESCO in 1998 [8].

A city consists of complex relationships between both material and immaterial elements. The monastery should be seen as an ideal city, as a city of God and therefore be endowed with all the necessary elements to subsist. “The monastery should if possible, be arranged that all the necessary things such as water, mill, garden, and various crafts may be within the enclosure” [6]. Besides all symbolic connotations this is a functional and ordered place where everything has its justification. In order to understand de Bernardas’ Convent (or Monastery of Our Lady of Nazaré do Mocambo – Fig. 2) we must keep in mind that the monastic space can become a territorial organism which appropriates the territory, modelling and altering it according to its needs. The building must be considered not only as an integral part of and development of an urban environment, but also, as an element of construction and management of the territory. One must not forget the vital importance, both temporal and spatial, of the monastic Orders in the development of the urban fabric of a city which in turn is included in a country. It must be taken into account that the transformation and development of the territory has been responsible for isolated buildings and settlements which have gradually been absorbed by the expansion of the urban fabric [6]. The monastery once isolated becomes integrated, interacting and forming part of the urban fabric of the contemporary city like the Bernardas’ Convent.

3. The building’s usages

The monasteries have provided the contemporary city, especially from the 19th and 20th centuries, expectant spaces or new fields of experimentation as diverse as: rehabilitation, reuse, renovation, conversion, and so, on Cano and Adell [9]. These are new spaces which adapt to new situations and new uses, in short, they update themselves, including and integrating, in its history.
the values of the present. With the 20th century the campaigns of restoration, reconstruction, renewal, and rehabilitation begins under the responsibility of the different government agencies that persists.

The Municipalities also invested in the rehabilitation of the Cistercian architectures as is the case of the City hall of Lisbon with the Monastery of Our Lady of Nazaré of Mocambo, better known as Bernardas’ Convent which is located in Madragoa, a Lisbon neighbourhood as we have mentioned earlier. The Monastery of Our Lady of Nazareth of Mocambo in Lisbon, usually known as Bernardas’ Convent, was a Cistercian foundation. It was founded in 1653 over pre-existences but in fact this Convent is a much more recent foundation because it was initially a place of gathering of penitent and devoted women and then later became a convent.

The name “Bernardas’ Convent” was adopted because the nuns who inhabited it belonged to the Cistercian order as well as St. Bernard, who had a major role in the dissemination of the Order across Europe. The neighbourhood of Madragoa was a fishing village which from the 16th century was integrated into a riverside path of expansion, towards the occidental part of Lisbon [10]. In fact, until this time, Madragoa was an area prolific with monasteries and convents located outside the city walls. Over the time, around the convent, the city was being built.

In 1755 the Bernardas’ Convent was totally destroyed during earthquake and reconstructed 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 several uses since then. There were several schools inside the historical building: The Academic Lisbonense, Senhora da Conceição and Luis Rodrigues Politechnic. In June 1924, the Convent’s church was used as a cinema and a theatre (the apse was even replaced by a stage) and it was called “Cinema-Esperança”. In addition, this space was used by an orchestra and later transformed into a furniture shop and storage. A significant population lived, in precarious conditions, in the monastic building. On the ground floor there were taverns and coal storages. The Bernardas’ Convent was used as a “Vila Operária” a kind of labour dwellings inside a pre-existing 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 in 34 residences, a restaurant, 4 shops, a centre for the elderly, a social club and the Puppet Museum, as well as a multipurpose room, originally the Church which was connected with the Museum. The works of retrofitting and rehabilitation of the convent were initiated in 1999 and they were finished between 2001 and 2002. Nowadays, the monastic building serves as a small condominium, a restaurant and Puppet Museum. As the building had to be preserved under historical regulation its unchanged exterior walls, since Azzolini’s restoration, are made of solid masonry which
has dominated the construction throughout its history, as well the entire envelope. In fact, history is an instrument of analysis and criticism which allows different readings of the buildings, continuously renewed. Besides history, which allows a critical mode transformation, as Castillo understands, it also allows the “socialisation” of the historical building facing territorialisation that involves many different levels and disciplines as well as the participation of sciences such as geography, economics, sociology, anthropology, among others [11].

As Torsello [12] tells us, the opposition declared between the old and new, between conservation and innovation, is the very nature of the intervention, its constant and renewed historic condition. The monument – document is configured into an attention analytical and interpretative, but at the same time it is a place for a new use, forum of innovation, advanced technologies, or spatial conception of nowadays [12, 13]. According to article 7 of the European Charter for architectural heritage “integrated conservation is carried out through the application of appropriate techniques of restoration and with the right choice of appropriate functions. (…) it must be one of the first considerations to take into account in any regional and urban project”. These are spaces which can be adapted into new situations, into new uses, in sum spaces which are updated to include and integrate the values of the present in its history [13]. The transformation of historic buildings and its consequent adaptation to contemporary living needs are today one of the major concerns in the field of the construction of the contemporary city.

4. Thermal comfort criteria

Historic buildings are usually made of solid masonry walls (Fig. 3), single glazed wooden windows and wooden roof structure covered with clay tiles. The rehabilitation of this kind of old buildings requires an upgrading of the shell so that comfortable temperatures can be maintained to keep up with modern life. However, in order to preserve the heritage of the building, retrofitting was mainly carried out on the interior of the building maintaining all of its original exterior wall aspects. Insulation was added to the attic and windows were replaced by new ones of identical design and components. Exterior walls are made of 1 m thick

Fig. 3. Detail view from the interior.
limestone with plaster on both sides (and in some situations even thicker).

The thermal performance of any building element depends, among others, on the $U$ value, more currently called the heat transfer coefficient. It describes how well heat is conducted and influences thermal comfort. ISO 7730 [14] standard define a comfort zone for the body based on overall heat balance that expresses a condition of mind that expresses satisfaction with the thermal environment. However, one may experience discomfort even when there is a neutral overall heat balance. In an uniform environment, the contribution of the mean radiant temperature on comfort is considered approximately equal to that of the air temperature [15], though interior surface temperature is required to be between specified limits of indoor air temperature defined on the above referenced standards. Consider a homogeneous and one-dimensional heat flow through the walls of this building for steady-state conditions. It is assumed that the thermo physical properties of the structure are constant in time. The total heat flux of the interior and exterior surface, $q_i$ in W/m² and $q_e$ in W/m², are found by:

$$q_i = h_i(\theta_i - \theta_m)$$

$$q_e = h_e(\theta_e - \theta_a)$$

where $h_i$ and $h_e$ are the interior and exterior surface heat transfer coefficient (W/m²°C), respectively. $\theta_i, \theta_e, \theta_a, \theta_m$ are the solar-air temperature, the surface exterior temperature, the interior surface temperature and the indoor air temperature, respectively (°C). In the current study, the sol-air temperature is introduced to calculate the total heat gain through exterior surface (including solar radiative flux), which is defined by

$$\theta_{sa} = \theta_{sa0} + \alpha \frac{I}{R}$$

where $\theta_{sa0}$ is the outdoor air temperature (°C), $\alpha$ is the solar radiation absorptivity of a surface and $I$ is incident solar irradiance (W/m²). The inner surface temperature of external wall can be written as:

$$\theta_i = \theta_{sa} + \frac{\theta_{sa} + \theta_m}{R}$$

where $R$ is the total thermal resistance (m²°C/W) and can be calculated by:

$$R = \frac{1}{R_1} + \frac{1}{R_W} + \frac{1}{R_i}$$

where $R_W$ is the heat resistance (m²°C/W). The climate of Lisbon, is temperate and moderately cold in the winter. It is located at 38.7 latitude north, being at the southern and Mediterranean climatic zone [16] with sunshine during most of the year. Mean temperatures may range between 8 °C and 30 °C during the year, but seldom above 36 °C in summer and below 4 °C in winter. Is assumed that interior temperatures during the heating and cooling seasons follows the ISO standard [14], being 22 °C in winter time and 24.5 °C in summer time.

The unchanged shell's physical properties are the walls and windows. Solid masonry walls have dominated construction throughout times and the present building keeps its initial structure being the estimated $U$ value of 1.14 W/(m²°C). In the coldest part of winter, the inside face of this masonry wall can be 2.7°C lower than indoors. The temperatures on the inside face hardly dropped below 19.3 °C. In the hottest part of summer, the inside face of the masonry wall can be 1.7 °C higher than indoors to a maximum of 26.2 °C. The temperature surface of the section wall underneath the window, with a thickness of about 0.40 m, would reach as far as 27.6 °C in the hottest day and would drop down to 17.1 °C in the coldest day. The similar windows placed on the building, wooden sashes and single glazing has an estimated $U$ value of 5.1 W/(m²°C). In the coldest day the interior surface temperature of the window may drop down to 11.9 °C while in the hottest day reaches up to 32.1 °C.

A person located in a room with a non-uniform radiant heat, as in this building, is likely to experience uncomfortable conditions. As a guideline, ISO 7730 [14] states that vertical surfaces radiant asymmetry should be kept to less than 10 °C from air temperature. The temperature range between the wall and the window is about 9.3 °C for the lowest outdoor air temperature. However, the temperature range is much greater between the interior face of the window and the indoor environment, of 11.9 °C being above of the standard reference. The temperature range between the wall's surface and the interior environment is only 2.7 °C. In winter, radiant heat loss towards a cold window surface can make an occupant feel uncomfortable, particularly on a sedentary activity. Window surface temperatures often fluctuate more than other surfaces in a room, due to lower thermal resistance and lower heat capacity. On the other hand, the highest thermal mass of the wall slows down the response to the swinging of the outdoor temperature, as Tavil [4] has found which reduces the heating and cooling loads.

The term thermal mass is commonly used to signify the ability of materials to store significant amounts of thermal energy and delay heat transfer through a building component. The slower response time tends to moderate indoor temperature fluctuations under outdoor temperature swings, it reduces energy consumption in comparison to that for a similar low-mass building and it moves building energy demand to off-peak periods [17]. The time it takes for the heat wave to propagate from the outer surface to the inner surface is named as “time lag” and the decreasing ratio of its amplitude during is named as “decrement factor”. Time lag and decrement factor are very important characteristics to determine the heat storage capabilities of any material. So, the heat flux time lag ($\Phi$, in h) and decrement factor ($f$) are defined by the following equations:

$$\Phi = \tau_{q_i}, \text{max} = \tau_{q_e}, \text{max}$$

where $\tau_{q_i},\text{max}$ and $\tau_{q_e},\text{max}$ are the time that the interior surface heat flux and the exterior surface heat flux of the wall are being maximum, respectively (h) and

$$f = \frac{A_i}{A_o} = q_i, \text{max} - q_i, \text{min}$$

$$q_e, \text{max} - q_e, \text{min}$$

where $A_i$ and $A_o$ are the amplitudes of the wave in the inner and outer surfaces of the wall, respectively, $q_i,\text{max}, q_i,\text{min}, q_e,\text{max},$ and $q_e,\text{min}$ are the maximum and the minimum heat flux of the interior and the exterior surface of the wall, respectively (W/m²). The sol-air temperature includes the effects of the solar radiation combined with outside air temperature and changes periodically. This temperature is assumed to be sinusoidal variations during a 24-h period. Since time lag and decrement factor are dependent on only physical properties of the element, not on the climate, the equation of the solar-air temperature is taken as follows [18]:

$$\theta_{sa}(\tau) = \theta_{\text{max}} - \theta_{\text{min}} \sin \left( \frac{2\pi}{P} \frac{\tau}{2} \right) + \theta_{\text{max}} - \theta_{\text{min}} \frac{2}{2} + \theta_{\text{min}}$$

where $P$ is period, $\theta_{\text{max}}$ and $\theta_{\text{min}}$ are the maximum and minimum outdoor temperature, respectively (°C). Table 1 shows the thermal properties of the exterior wall and glass that are studied. The thermal properties have great influence on the temperature distribution on the building's component and vary with global solar radiation and thermal mass [19]. The solar absorption coefficient presents an important role on heat transfer between indoors and outdoors, assumed in this study a value of 0.48. To a higher solar absorption coefficient higher is the wall's internal surface temperature. For a hot summer and mild cold winter zone as
Table 1
Thermal properties of construction materials.

<table>
<thead>
<tr>
<th>Description</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (W/(mK))</th>
<th>Specific heat capacity (J/(kgK))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime plaster</td>
<td>1400</td>
<td>0.7</td>
<td>920</td>
</tr>
<tr>
<td>Limestone</td>
<td>2180</td>
<td>1.5</td>
<td>720</td>
</tr>
<tr>
<td>Glass</td>
<td>2500</td>
<td>1.05</td>
<td>750</td>
</tr>
</tbody>
</table>

Fig. 4. The variation of the temperature during a summer day.

Lisbon a high-coloured materials are also suitable to energy efficiency [20].

The Bernardas’ Convent building is orientated due NE, SE, SW and NW. The dynamic thermal performance is now analysed. Figs. 4 and 5 represent the variation of the surfaces temperature during a summer and a winter day. The thickness of the main wall is 1.0 m and the wall under the window of 0.4 m. It is assumed in these figures one façade without any sun’s obstruction (oriented due SW) and a façade without any incident solar radiation (turned to the court). The temperature time lag of the thicker wall (1.0 m) is 21 h and the temperature decrement factor is about 0.14. The temperature time lag of the thinner wall (0.4 m) is 9 h and the temperature decrement factor is about 0.26.

During the summer was not expected any local discomfort being all the surfaces temperature within the comfort zone. During the winter time the lowest surface temperature obtained by the walls, when there is no sun is about 17.7 °C for the thinner wall while the shadowed window is always below the comfort zone, with a maximum temperature of 12.3 °C. The temperature of the heaviest wall during winter never dropped below 19 °C. Comparing to the values obtained for steady-state conditions is about 2 °C higher. During summer time, with sun, it never surpassed 26 °C very close to the obtained 26.2 °C in previous conditions. The outdoor conditions especially air temperature becomes the predominant factor on the thermal comfort. Although, windows allow solar radiation to the indoor environment, in some conditions, overheating may occur. So, improving window performance reduces thermal discomfort on facades particularly where there is no direct solar radiation.

5. Conclusions

This study case is an example of multiple and successive adaptations. The extinction of the religious orders and the successive owners adapted the monastic space to their own needs. However, the original image of the convent, both outside and inside, still stands. All the functions stayed almost the same, with the exception of the church and the chapter house, now integrated into the Puppet Museum. The cells, when the monestary was converted into “Villa Operaria” gave place to minimum dwellings and currently apartments more adequate and modernized for today’s needs of comfort.

The interior surface temperatures in heating period decrease slower on walls than on windows. In summer, the thermal resistance of a wall also allows for reduced heat flow from the outdoor environment into the building. Windows are more fragile to the heat flux. In addition, windows may allow overheating especially on facades facing the sun. Thermal mass is most effective through reducing temperature swings, expecting superior comfort. An exposed heavy wall, when compared to a lighter window, is significantly warmer during the winter time and provides significant cooling in summer. During the winter time the surface temperature of the shadowed window is most of the time below of the comfort limit. Thermal performance of the windows could be improved by using double glazing, whilst, maintaining the window’s design. In this way, the historic value of the windows would be least affected with an increment of thermal comfort and also of energy saving. To take advantage of the sun during the heating period, the southern walls must not have any obstacle to the sun, being this neglected during the summer due to its high thermal mass. However, the use of solar protection on glazing is necessary during summer to avoid the peak high temperatures and probably some local discomfort.

We must highlight what Galvão [21] says when she relates to the inheritance, testimony and emblematic heritage resources of the identity of cities, communities and regions. There are increasingly an agenda of clear choice for management based in a sustainable development. In addition, the knowledge and the use of heritage are, currently, essential elements for their safeguarding, sustainability and evaluation as well as factors of progress in various aspects of development in particular underlining the interdependence between culture and the qualification of community life. In fact the Cistercian Monastery, which is the Bernardas’ Convent, is a piece of the Cistercian legacy in Portugal.

References