Article


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Abstract: The architectural heritage of a particular place, in most cases, is characterised by vernacular and unique constructions that have been adapted to local climate conditions. For this purpose, specific materials and construction methods have traditionally been used that, in addition to the durability of the construction, also allow for the consideration of the energy efficiency of the building itself. The present intersection of climate change and architecture has led to new exposure to the external agents for which constructions were designed, forcing, in most cases, a review of building envelopes and very costly proposals. From the point of view of efficiency, intervention strategies with passive measures are proposed that not only improve the energy performance and maintenance of buildings themselves, but also lower the overall energy consumption. Using a heritage case study of the city of Seville, the Moroccan Pavilion, at Expo 92, this work includes an analysis and proposal of effective action through a methodological study of energy efficiency. The problem of high energy consumption during the summer months in Seville is tested in the Pavilion. The results indicate an urgent need for renovation, and among different options, new intervention measures are recommended as an alternative to consumption based on knowledge and tradition; moreover, passive construction elements are proposed in accordance with the climatic reality of the environment for optimal conservation in new climate scenarios.

Keywords: passive architecture; heritage construction; Expo 92; energy consumption; sustainable construction; architectural heritage; the Morocco Pavilion; Seville; Cartuja Island

1. Introduction

Great international events, such as world expos, Olympic Games, and international summits, provide unique opportunities for showcasing innovative architecture on a global stage [1]. This paper examines the role of singular architecture in such events, focusing on a case study and design principles that contribute to environmental success. Singular buildings built for large international events are usually designed with the intention of breaking out of the routine of local design. Often, they are designed to be models and references that show the cultural identity of a town and its architectural culture, acting as a reflection of architectural know-how.

The Expo 92 Universal Exhibition in Seville was a great showcase of architectures designed to adapt to new environments (with greater or lesser success), reflecting every country and culture that participated in it [2]. In the specific case study of the Morocco Pavilion on La Cartuja Island in Seville, we encounter a building with low energy efficiency. This pavilion, designed with curtain wall solutions, represents a clear example of a construction not adapted to its environment, with increasingly longer and more intense summer periods every year. This paper presents a time-based study of its boundary conditions and possible interventions and recommendations from a regenerative and sustainable perspective.
We understand that the countries in immediate proximity to the host city had no difficulty in implementing an efficient product adapted to the environment. Climate and implementation methods could easily be extrapolated from these countries.

The rationale behind developing this architectural design is to decrease buildings’ environmental impact, improve the quality of the built environment, and increase the thermal comfort of buildings’ occupants and its performance [3].

Examples from other latitudes, for which climatic rigor forced decisions to be made, should be considered, as they were not always achieved successfully. It should be possible to maintain a comfortable range of conditions without resorting to the provision of artificial cooling by using measures such as shade, thermal mass air movement, lighting controls, and low-energy lighting [4].

In this way, the need to use passive measures in architecture with vernacular elements, such as mashrabiya, cannot be overlooked.

Mashrabiya works perfectly as a protection device from direct sunlight and effectively reduces heat gain, especially during hot seasons. In the current era, various shapes derived from mashrabiya can be found on the façades of buildings in various countries around the world. Also, several studies and applications have submitted new designs and proposals for the development of mashrabiya, either using different materials instead of wood, such as aluminium, steel, ceramics, or glass-fibre-reinforced concrete (GRC), or incorporating interactive techniques for opening and closing [5]. Moreover, this knowledge can be applied to modern buildings by combining the mashrabiya concept with new solutions, improving the design according to users’ needs in line with modern building systems in hot climates. Additionally, it could be effective to use this method in temperate climates, leading to thermal comfort periods [5].

An understanding of urban resilience in urban studies and planning is critical in analysing and combating the impacts of climate change in cities in the Global South [6].

2. Literature Review

Numerous attempts have been made to explain the concept of sustainability, introduced by the Brundtland Commission in their 1987 report, “Our Common Future” [7]. Consequently, various definitions have emerged to describe what constitutes sustainable architectural design. In the 1990s, the building sector began to acknowledge its significant environmental impact [8]. Since then, a crucial shift has occurred in the way buildings are designed, constructed, and operated to reduce their environmental footprint [9].

Initial ideas in construction must consider the very functioning of a building by considering its adaptation to external agents, its massiveness, and its final use. It must be understood that, until recently, structural and technical energy resources were used without sustainable limits and with the direct application of technologies. The concept of efficiency suggests that technology is not everything, and that production and consumption must be balanced [10]. It would be unfeasible to reach a balance without the use of passive measures [11].

This approach reduces the need for artificial lighting, thereby lowering energy consumption and enhancing occupant well-being. Effective passive lighting design incorporates various elements, including window placement, skylights, light shelves, reflective surfaces, and shading devices, to optimize natural light distribution while minimizing glare and heat gain [12].

2.1. Vernacular Culture/Architecture

The Islamic tradition, and consequently ours, is reflected in the architecture of the pavilion on its different fronts, although this challenges its operation on its southwest front, as shown in Figure 1a,b. The use of water, which is also a traditional and vernacular measure closely linked to Islamic tradition, requires technology for its operation [13]. The disuse of this measure in the pavilion creates a problem for its skin and façade.
1. Mashrabiya (مشربية): This is a traditional wooden lattice screen used in windows and balconies. The mashrabiya allows light and air to pass through while providing privacy and reducing heat gain. Often intricately carved, they add decorative value to the building façade. They can also refer to wooden or metal screens used to cover windows, similar to the concept of blinds. These can be adjusted to control the amount of light and air entering a room [20,21], as shown in Figure 2a.

2. Riwaq (رواق): A riwaq is a covered arcade or portico that surrounds courtyards and open spaces in mosques and palaces [22]. The arcades provide shaded walkways and cool resting areas, protecting occupants from direct sunlight, as shown in Figure 2b.

3. Muqarnas (مقرنص): This decorative element is a form of architectural ornamented vaulting, often used in domes, half-domes, and entrances. While primarily decorative, muqarnas structures also cast intricate shadows, contributing to the control of light and heat [23], as shown in Figure 3a.

Figure 1. (a) South elevation of Moroccan Pavilion. Isla de la Cartuja (Seville, Spain); (b) Southwest corner of Moroccan Pavilion. Isla de la Cartuja (Seville, Spain).

2.2. Passive Measures

Passive measures in buildings are those directly associated with the envelope of the construction, including its materiality, thickness and orientation [14]. Through these measures, vernacular architecture has achieved adaptation to the environment and local conditions without the need for extreme energy inputs. This historical wisdom has been proven to reduce the added costs of maintaining basic comfort conditions when the environment and the building are not prepared for it.

All shading devices play a crucial role in architectural design by controlling the amount of sunlight that enters a building, thereby enhancing occupant comfort, reducing glare, and minimizing energy consumption for cooling [15]. This literature review explores the various types of shading devices, their historical context, modern advancements, and the principles guiding their effective implementation.

2.3. Islamic Shading Elements

Islamic architecture is renowned for its intricate and functional designs, particularly in the use of shading devices [16]. These elements are essential in hot and arid climates where controlling sunlight and promoting natural ventilation are crucial for comfort [17]. Islamic shading devices are not only practical but also contribute to the aesthetic and cultural value of the architecture.

Shading devices in Islamic architecture were developed to address the harsh climatic conditions, primarily in the Middle East and North Africa, as well as in some countries of the Mediterranean Sea [18,19].

Key historical shading devices include:

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4. Courtyards (مَصَحْنَة): Central courtyards in Islamic architecture are surrounded by high walls or buildings, creating shaded areas. These courtyards often contain water features, which further help to cool the air [24], as shown in Figure 3b.

![Figure 2. (a) Mashrabiya. The Hall of Comares (Alhambra, Granada, Spain); (b) Riwaq. Court of the Lions (Alhambra, Granada, Spain).](image)

![Figure 3. (a) Muqarnas. Hall of the Abencerrajes (Alhambra, Granada, Spain); (b) Courtyards. Court of the Gilded Room (Alhambra, Granada, Spain).](image)

Key Features and Principles:

1. Ventilation and Airflow: Islamic shading devices are designed to enhance natural ventilation. The mashrabiya, for example, promotes airflow while blocking direct sunlight, creating a cooler indoor environment [25].

2. Thermal Comfort: By reducing heat gain, these devices help maintain comfortable indoor temperatures [26]. The materials used, such as wood and stone, also have thermal mass properties that contribute to temperature regulation.

3. Aesthetic Integration: Shading devices in Islamic architecture are not just functional; they are also highly decorative. The intricate designs and patterns of mashrabiya screens and muqarnas add visual interest and cultural significance to the buildings.

4. Privacy: Islamic shading devices often provide privacy for occupants while still allowing light and air to pass through [27]. This is particularly important in residential architecture, where maintaining a private indoor environment is culturally significant. Contemporary architects continue to draw inspiration from traditional Islamic shading devices, incorporating their principles into modern designs; these designs include:

   - Al Bahar Towers (Abu Dhabi, UAE): These towers feature a dynamic façade with a responsive mashrabiya system [28]. The shading screens open and close based on the
sun’s position, reducing solar heat gain and glare while maintaining natural light and views, as shown in Figure 4a.

- (KAPSARC) (Riyadh, Saudi Arabia): Designed by Zaha Hadid Architects, this complex uses geometric shading devices inspired by Islamic patterns. These elements provide effective sun control and enhance the building’s aesthetic [29].
- Doha Tower (Doha, Qatar): Designed by Jean Nouvel, the tower features a complex façade with aluminium mashrabiya elements [30]. These screens control sunlight and provide a unique visual identity that reflects traditional Islamic architecture, as shown in Figure 4b.

![Figure 4. (a) Mashrabiya system in Al Bahar Towers (Abu Dhabi, UAE); (b) Aluminium mashrabiya elements in Doha Tower (Doha, Qatar).](image)

2.4. Benefits of Islamic Shading Elements

1. Energy Efficiency: By reducing the need for artificial cooling and lighting, these devices contribute to significant energy savings.
2. Enhanced Comfort: Effective shading and ventilation improve thermal comfort for occupants, making indoor environments more liveable [31].
3. Cultural Continuity: Incorporating traditional shading elements preserves cultural heritage and provides a sense of continuity in modern architecture.
4. Aesthetic Value: The intricate designs of Islamic shading devices enhance the visual appeal of buildings, adding depth and texture to façades.

3. Methodology

In the reviewed literature, various measures exist for evaluating the environmental suitability of cultural heritage sites [32]. Some methodologies concentrate on the fluctuations in the microclimate throughout the year. Nonetheless, it is important to emphasize the need for a proper study that incorporates new parameters, aspects, and indices that impact the preservation of these highly sensitive heritage structures [33].

3.1. The Moroccan Pavilion in Seville

Located on the Isla de la Cartuja, the Moroccan Pavilion in Seville is part of the architectural ensemble planned for the International Expo’92 Exhibition. It is also adjacent to the most historic area of the island, next to the walls that enclose El Real Monasterio de la Cartuja, a significant architectural piece in Seville. This unique monastery’s architecture housed Carthusian monks and later served as an iconic ceramics and porcelain factory during the 19th century and much of the 20th century; its location is shown in Figure 5.
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**Figure 5.** Location plan of Moroccan Pavilion. Isla de la Cartuja (Seville, Spain).

This historic boundary described above, and the building’s architecture, make the pavilion a bridging construction and, in some way, a “gentle transition” to the more contemporary architecture of the other pavilions around the Cartuja. On the other hand, its freestanding architecture, while making it a unique piece visible from all sides, also exposes it to external elements. Therefore, its envelope is key to its interior comfort and functionality.

The building, with 5000 m² of constructed area over four levels (basement, ground floor, first floor, and second floor), has a layout developed around an interior courtyard with a gallery ambulatory that organizes the space, as shown in Figure 6. Its envelope is defined as a skin separated from all the interior constructed elements, designed to withstand external weather agents.

**Figure 6.** Transverse cross-section and ground-floor zoning plan of Moroccan Pavilion. Isla de la Cartuja (Seville, Spain).

Nowadays, this unique pavilion is part of the architectural heritage of the city of Seville and the preserved ensemble from the Exhibition Expo’92, aiming to be a refer-
ence in Seville’s heritage. After numerous failed renovations, action is needed, and a new restoration project has been approved with a particular focus on energy efficiency and sustainability.

3.2. Climate Data for Seville

The city of Seville in southern Spain experiences a Mediterranean climate characterized by hot, dry summers and mild, wet winters. Here is a detailed look at the climatic data (source AEMET, Agencia Estatal de Meteorología):

3.2.1. Temperature

Seville experiences significant temperature variations throughout the year:

- Winter (December to February): Average temperatures range from 5.9 °C to 17 °C. The coldest month is January, with temperatures ranging from 5.9 °C to 15.4 °C.
- Spring (March to May): Temperatures increase from an average of 14.2 °C in March to 26.7 °C in May.
- Summer (June to August): This period is characterized by high temperatures, averaging from 25.7 °C to 35.3 °C. July and August are the hottest months, with maximum temperatures often exceeding 35 °C.
- Autumn (September to November): Temperatures gradually decrease from an average of 30.6 °C in September to around 18.8 °C in November.

3.2.2. Humidity

Humidity in Seville varies across the year:

- Winter: The highest relative humidity, around 75%, is observed in December and January.
- Summer: The lowest humidity levels occur in July, with an average of 39%.

3.2.3. Solar Radiation

Seville enjoys a high number of sunshine hours, particularly in the summer:

- Winter: Average daily sunshine hours range from 6.5 to 8 hours in December and January.
- Summer: The average daily sunshine hours peak in July, with approximately 12.7 h of sunshine per day.

3.2.4. Rainfall

Precipitation in Seville shows a marked seasonal pattern:

- Winter: The wettest months are October through December, with rainfall reaching up to 77 mm in December.
- Summer: The driest period is between July and August, with almost negligible rainfall.

3.3. Building Skin (Epidermis)

Due to the importance of implementing passive measures in this research, it is essential to know and describe the building’s complete envelope. Given its heritage nature, it is crucial to maintain and complement it with non-invasive intervention measures.

The building has a star-shaped form with several entrances, although currently, only one is operational for daily use, as shown in Figure 6. There is another direct access to the basement that connects the auditorium with the exterior plaza where some events take place.

It is a building of high artistic and craftsmanship value, both in its exterior and interior. This greatly limits our possibilities for intervention without sacrificing artistic elements, whether acting on the envelope or the interior.

Regarding exterior enclosures, there are primarily two types. On the ground floor and first floor, the entire building features a curtain wall envelope with some external lattice
elements adorning certain corners, interspersed with non-functional fountains. Although from the outside it may appear that a percentage of the façades are on the ground floor and first floor, from inside, we can observe that everything is external to the curtain wall, which serves as the element separating the interior from the exterior, as shown in Figure 6.

3.4. Energy Performance Evaluation

3.4.1. Energy Audit of the Moroccan Pavilion to Assess Its Current Energy Performance

A comprehensive energy assessment has been conducted, documenting various features of the building’s envelope, including its walls, ceilings, floors, doors, windows, and skylights. For each of these elements, the area and thermal resistance (R-value) have been measured and estimated. Additionally, the rate of air leakage or infiltration through the building envelope has been examined, with particular attention paid to the quality of windows and doors. The aim of this study was to quantify the building’s overall thermal performance. The assessment also evaluated the efficiency, physical condition, and programmatic features of the building’s envelope, including its walls, ceilings, floors, doors, windows, and skylights.

3.4.2. Integrated Model Decision

The integrated model proposed in Figure 7 consists of two distinct phases, each with specifically selected decision factors [34–36]. The first phase is the analysis phase, followed by the simulation and materialization phase, which is supported by a decision support system. This approach can also be effectively applied to any other building requiring intervention and climate control, particularly in the context of new scenarios.

![Figure 7. Integrated model, Decision Support System.](image)

3.4.3. Conceptual Phase

In previous studies, during what can be seen as a conceptual phase, the following improvement measures were considered:

- Lighting control in the perimeter zone of exposure.
- Inclusion of heat recovery units in the ventilation system.
- New heat pump and replacement of Air Handling Units (UTAs).
- Replacement of the curtain wall.
- Roof insulation (including the cost of demolishing the slope formation and adding new waterproofing).
- Perimeter shading element in the exterior area to reduce solar incidence on the curtain wall.

In conclusion, all these measures alone have not been sufficient to achieve the objectives in the simulation.

3.5. Virtual Simulation and Data

An integrated sustainable model concept has been developed from advancements in different fields such as modelling, simulation, computer networking, image processing, and multimedia representation [37]. This audit has explored these areas within the architectural process to address the growing complexity in collecting data, including the architectural
CAD model, prototypical systems, and the modelling of the building according to all gathered information [38–40]. Ultimately, the sustainable integrated environment has become a key framework for achieving sustainable development goals in heritage building conservation [41]. Sustainable design renovations, a relatively new concept, aim to improve the quality of obsolete constructions by minimizing the negative impacts and optimizing the use of natural resources.

3.5.1. The 3D Model

The geometric model of the building has been constructed directly from the TeKton3D TK-CEEP modeler, based on the CAD model created from the original building plans executed in AutoCad software by Autodesk. Once the 3D geometry is defined, the monthly demand data are obtained through the simulation of the building model using specific software [42,43]. For generating the model, the data collected in phases 1 and 2 of the audit (preliminary information and data measured during the building visit) are used, estimating and calculating some of the variables when necessary [44,45]. The following sections list the data required for the construction of the thermal model; see Table 1.

Table 1. Thermal model data.

<table>
<thead>
<tr>
<th>Data</th>
<th>Main Façade</th>
<th>Basement Wall</th>
<th>Building Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Resistance (m²·K/W)</td>
<td>0.384</td>
<td>0.179</td>
<td>0.573</td>
</tr>
<tr>
<td>Overall Mass (kg)</td>
<td>311.20</td>
<td>611.24</td>
<td>407.50</td>
</tr>
<tr>
<td>Total Thickness (m)</td>
<td>0.1856</td>
<td>0.2628</td>
<td>0.3451</td>
</tr>
<tr>
<td>Thermal Transmittance (W/m²·C)</td>
<td>1.804</td>
<td>0.753</td>
<td>1.403</td>
</tr>
<tr>
<td>Colour</td>
<td>Medium</td>
<td>–</td>
<td>Medium</td>
</tr>
</tbody>
</table>

The main openings of the building are:

- Doors: Their thermal transmittance has been introduced according to the material they are made of, and their absorption coefficient based on their colour (light, medium, dark, or black). This information has been estimated based on observations during the building visit.
- Glazed openings (windows): The total energy transmittance of the opening, with mobile shading devices (blinds, curtains, etc.) activated, is obtained through the program using values collected in the Building Technical Code (CTE) based on observations and data gathered during the building visit.

Assumed from the information provided by the property and on-site inspections, the HVAC systems are responsible for generating heat transfer fluids for room climate control. The following systems have been defined:

- Direct expansion systems (using refrigerant fluids), such as VRF (Variable Refrigerant Flow) or multi-split systems.
- Air conditioning systems: These are air handlers that discharge into an air duct network, such as UTAs or Rooftops.
- Water condensation systems: Used to temper water from chiller condensers or heat pumps.

3.5.2. Energy Consumption

Once constructed, the model is validated with the actual consumption of the building by comparing the model’s results with the measurements taken from historical invoices. The total annual energy consumption of the building is 162,116 kWh, of which 60,244 kWh is allocated to “other uses”. Therefore, the remaining consumption (101,872 kWh) is allocated to heating, lighting, ventilation, and Domestic Hot Water (DHW), in the proportions shown in Figure 8.
This breakdown of consumption is an estimate based on the distribution provided by the energy certification software, which does not account for the consumption of “other uses”; see Table 2.

### Table 2. Energy consumption model.

<table>
<thead>
<tr>
<th>Specific Use</th>
<th>Total Energy Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>23,805</td>
</tr>
<tr>
<td>Cooling</td>
<td>39,787</td>
</tr>
<tr>
<td>Ventilation</td>
<td>23,163</td>
</tr>
<tr>
<td>Lighting</td>
<td>13,788</td>
</tr>
<tr>
<td>DHW</td>
<td>1300</td>
</tr>
</tbody>
</table>

### 4. Results and Discussion

This research underscores the importance of the continuous monitoring and adaptation of both active and passive measures for this unique pavilion. By addressing current inefficiencies and preparing for future climate scenarios, it aims to maintain the pavilion’s functionality and heritage value while minimizing energy consumption.

#### 4.1. Monthly Energy Consumption

The energy consumption data have been represented in Figure 9 to compare the values in winter and summer for the months of January to September. The maximum value occurs in July and the minimum value occurs in August, due to reduced building usage.

#### 4.2. Zones and Data Monitoring

For accurate data monitoring, different thermal zones within the building have been defined. These zones may or may not correspond to physically delineated rooms. A zone can include multiple spaces that share similar thermal conditions (e.g., orientation, climate control). In this case, zoning has been carried out by floor, and each floor is further defined by usage area (e.g., office, restroom, hallways, technical room).

To align the model’s consumption with the actual consumption, a setpoint temperature of 20 °C for heating and 22 °C for cooling is established. A sufficient number of temperature and humidity measurements have been taken to define the environmental conditions of...
the building. Measurements were taken in five thermal zones with different climate control requirements to realistically characterize the building, yielding consistent results across all zones. Thus, a total of five measurement points were used in this model.

The maximum temperature measured was 31.6 °C, and the minimum was 30.4 °C. It was generally found that the comfort conditions regarding indoor temperatures, as established by current regulations and energy-saving recommendations, are not met.

4.3. Materials and Procedures

4.3.1. Building Envelope

- Exterior enclosure: On the ground floor and the first floor, the entire building features a curtain wall with some external latticework elements adorning certain corners, alternating with non-functioning fountains. The curtain wall is composed of double glass with an air chamber, covering approximately 1133 m$^2$. This makes it a significant element for thermal performance and potential intervention. The opaque enclosure consists of a wall made of perforate brick masonry, an air chamber of approximately 40 cm used for installations, and an interior partition. These elements are heavily adorned with detailed Arab craftsmanship, making them a distinctive feature of the building and crucial when analyzing possible interventions.

- Roofs: This building features three types of roofs: two are flat and sloped. The two flat roofs are walkable and lack insulation, distinguished only by their flooring finish. Additionally, the building has a wooden dome that crowns the interior courtyard. The exact composition of the dome is unknown, but it is mobile, allowing it to uncover the courtyard for ventilation and cooling.

- Exterior Carpentry (doors and windows): The doors have double glazing with an air cavity. There are only four windows, located on the second floor, which are not significant in terms of the building’s envelope.

All technical data required for the construction of the thermal model are listed in Table 1.

4.3.2. Decreasing Energy Consumption Procedures Suggested

According to the study conducted during the measurement period and various virtual evaluations using the TeKton3D TK-CEEP modeler CAD software and local regulations, the following actions are recommended:

- Reducing Heating and Cooling Loads: To reduce the demand for heating and cooling, it is essential to minimize the amount of solar heat that enters the building and obtain natural air currents for cooling indoor spaces [46,47]. This can be effectively achieved by utilizing the central courtyard for passive cooling through natural ventilation.

- Optimizing Lighting Systems: Select an optimal combination of light fixtures and lamps to achieve necessary lighting levels while saving electricity [48].

- Implementing Climate-Responsive Façades: Climate-responsive building façades can be achieved through various strategies [49]. These include shading the building’s walls, incorporating insulation or building envelopes where feasible, using reflective glass windows to bounce daylight, and allowing for natural ventilation. These strategies help to regulate the building’s temperature and reduce reliance on artificial cooling and heating.

- Using Heat Insulation Envelopes: Properly designed heat insulation envelopes can significantly reduce dependence on mechanical heating and cooling systems [50]. A high-quality envelope is not solely determined by the amount of insulation, but also by its ability to control air infiltration. A low infiltration rate means less air leakage, leading to better temperature regulation and reduced energy usage.

- Employing Occupancy and Light Sensors: Occupancy sensors can be used to automatically switch lights on and off based on room usage, and light sensors can be
incorporated to adjust artificial lighting according to the amount of natural daylight, achieving an efficient balance between sufficient lighting and energy savings.

4.4. Analysis and Results

The conducted research study highlights the critical importance of energy expenditure related to air conditioning, particularly cooling, within the context of building management. This finding underscores the necessity for substantial investment in upgrading outdated building systems, which promises a high return on investment.

4.4.1. Glazing and Curtain Wall Systems

This study identifies that the curtain wall systems are a major source of energy loss. Improving these systems can lead to significant reductions in energy consumption. However, these improvements involve substantial investment in new insulation materials, which are costly and have a long payback period with an unreachable return and a high cost. At this point, a deep reflection is necessary to minimize energy consumption in a sustainable matter.

4.4.2. Proposed Approach: Passive Measures and Façade Redesign

Therefore, bringing back the concept of the envelope and passive measures as the most suitable answer to this problem, this approach involves the redesign and reconfiguration of the main building’s façade from an architectural point of view, leading to the consideration of passive design strategies as the more viable answer.

The building’s clear and balanced architectural language must not hinder further interventions. Consequently, measures are proposed to reinforce the pavilion’s architectural language, making it viable and coherent for its everyday use. By focusing on the envelope, the ventilation and air conditioning systems (as seen in Section 4.3.2) will support the redesign of a new passive façade. A key recommendation is the replacement of the current curtain wall with a new passive façade that offers improved performance. This redesign is analysed in the study with an emphasis on achieving a total transmittance of \( U = 1.76 \text{ W/m}^2\text{K} \) and a solar factor of 0.49. These metrics aim to maximize the energy-saving impact of the façade improvements.

Regarding the types of latticework (mashrabiyas) proposed in this work, they have been equated with the data and improvements obtained from the energy study through a new curtain wall that complies with the requirements set by current regulations. Therefore, we emphasize the replacement of an expensive envelope with one that meets the required qualities, already mentioned in this study. The simulation of this passive façade indicates significant potential for energy savings. By focusing on passive design measures and façade improvements, reliance on mechanical ventilation and air conditioning systems can be reduced. The passive measures become the primary means of enhancing energy efficiency, with mechanical systems serving as additional support.

The research underscores the importance of addressing energy consumption in buildings through a combination of modernizing outdated systems and adopting passive design strategies. While the initial investment in new insulation and passive measures is substantial, the long-term benefits in terms of energy savings and return on investment are clear. The proposed redesign of the building’s façade not only aligns with its architectural language but also significantly improves its energy performance, paving the way for more sustainable building practices and coherence with everyday use.

4.5. Implementation of Intervention Strategies

A proposal for a set of passive measures tailored to the building has been made, and this includes shading elements, thermal insulation improvements, and the use of locally sourced materials.

- Insulation in opaque enclosures: This addresses actions from the interior on vertical walls that maintain existing ornamentation and reinforce thermal inertia. On
Heritage 2024, 7 3863

... roofs, interventions should focus on the sloping structure with insulation over the waterproofing (inverted roof).

- Analysis of the ensemble of lattices versus glazing, with special emphasis on solar arch façades. Reducing the incidence on curtain walls should help to avoid the need to replace glass and should drastically reduce economic investment (using vinyl where necessary). The architectural design of this new skin is the foundation of this research concept, as shown in Figure 10a,b.

![Figure 10. (a) Intervention areas. Low level. Moroccan Pavilion. Isla de la Cartuja (Seville, Spain); (b) Section view of curtain wall. Moroccan Pavilion. Isla de la Cartuja (Seville, Spain).](image)

- Improving the ventilation and air conditioning systems: These systems are now sized for the building’s new behaviour.
- Other actions: The building will be used responsibly, with the controlled application of lighting, presence detection, and the regulation of light intensities.

The results of this study shed light on various factors that could influence the indoor temperature of this architecture. The proper handling of these values and data is crucial for preserving these structures, which still serve their original purpose today. Additionally, regarding the design process and preservation, industrial heritage buildings are currently and will continue to be affected by climate change. Their ongoing preservation necessitates understanding these impacts on their exceptional universal value and addressing them appropriately.

5. Conclusions

The importance of sustainable architecture practices has increased over time due to the rising environmental concerns. Sustainable design integrates energy-efficient systems, renewable energy, and eco-friendly materials to protect the environment and enhance living spaces by improving the air quality, natural lighting, and thermal comfort. This comprehensive approach makes sustainable architecture essential, not just a passing trend.

This research emphasizes the need for the continuous monitoring and adaptation of active (HVAC systems, smart technologies) and passive (natural ventilation, thermal insulation, shading) measures to maintain the indoor climate of architectural heritage, ensuring energy efficiency and conservation. Establishing a feedback mechanism to refine and adjust interventions based on the observed performance and emerging climatic trends is crucial for the long-term sustainability of these structures.

A case study on the Morocco Pavilion in Seville demonstrates how passive measures, like the use of mashrabiya for solar control and natural ventilation, enhance thermal comfort and energy efficiency while preserving historical value. This research shows how the
mashrabiya, a traditional architectural element, can serve as an effective solution for solar control and natural ventilation in buildings during hot summers. The mashrabiya’s lattice design reduces heat gain while allowing air circulation, significantly enhancing the building’s thermal comfort. This demonstrates that traditional design principles can be relevant in modern architecture. Thus, respecting heritage can be compatible with modern sustainability. By utilizing passive design strategies such as natural ventilation, strategic shading, and thermal mass, and combining them with modern materials and technologies, the renovation can achieve significant energy savings while preserving the building’s historical and cultural significance. The Morocco Pavilion’s renovation, utilizing passive design strategies and modern materials, achieves energy savings and preserves cultural significance. This approach ensures that heritage buildings meet contemporary sustainability standards and local regulations.

The application of such hybrid techniques ensures that architectural heritage can meet contemporary sustainability standards without compromising its integrity in an area as sensitive as the heritage of a Universal Exhibition, The Expo’92. Comprehensive evaluations of thermal comfort, energy consumption, and existing passive measures are essential. In this research, CAD and specific software for the modelling of a virtual twin in terms of the skin of the Pavilion have been used as advanced simulation tools to represent the building’s energy performance under various scenarios, allowing for the development of targeted strategies for improvement. These strategies include enhancing insulation, optimizing natural ventilation, integrating renewable energy sources, and retrofitting the building envelope with high-performance materials.

Equally important is understanding climate variability factors of the city of Seville. Holistic approaches considering immediate and long-term climate impacts are vital for preserving architectural heritage. Continuous monitoring, data collection, and smart building technologies (IoT sensors, automated climate control) enable proactive maintenance and timely interventions. This includes assessing the potential effects of extreme weather events, such as heatwaves, that occur more frequently each year in Seville, with maximum temperatures above 40.0 °C and reaching over 45.0 °C according to the Spanish State Meteorological Agency (AEMET). Implementing adaptive measures, such as responsive shading systems and phase-change materials for thermal regulation, can enhance the building’s resilience.

Based on the results obtained and subsequent analysis, it is clear that intervention in the Pavilion’s envelope is necessary. This paper highlights and emphasizes this necessity, recognizing and appreciating the importance of improvements that align with the heritage value of the property. This need for intervention serves as a reflection on actions taken regarding historical heritage, underscoring the need to be subtle and delicate in such endeavours and to recognize a set of measures that align with the quality of the construction and historical knowledge from which we must learn. The intervention itself will result from a future study of this catalogue, whose implementation will require further analyses deserving of specific studies.

This research contributes to the growing body of knowledge on sustainable architecture and provides a framework for future projects aiming to balance heritage conservation with modern sustainability goals, ensuring resilience and adaptability to the future.

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