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Expressions of Arab Influence on the Brazilian Architecture: The Case of Solar Control Elements

Egon Vettorazzi [1,2], Filipe Rebelo [2], António Figueiredo [2], Romeu Vicente [2,*], Marcelo Langner [3] and Gabriel Feiertag [1]

[1] ILATIT—Latin American Institute of Technology, Infrastructure, and Territory of UNILA, Foz do Iguaçu 85870-650, Brazil; egon.vettorazzi@unila.edu.br (E.V.); ga.feiertag.2022@aluno.unila.edu.br (G.F.)
[2] RISCO—Civil Engineering Department, University of Aveiro, 3810-193 Aveiro, Portugal; filiperebelo@ua.pt (F.R.); ajfigueiredo@ua.pt (A.F.)
[3] Architecture and Urbanism Course at UDC—Dinâmica das Cataratas University Center, Foz do Iguaçu 85852-010, Brazil; marcelolangner@gmail.com
* Correspondence: romvic@ua.pt

Abstract: Over the centuries, architects have distanced themselves from the accumulated architectural knowledge, which often provided constructive solutions highly connected to the climatic context and cultural characteristics. With utmost expression from the 20th century on, building designers have assumed a somewhat negligent attitude towards the architectural project, essentially relying on active mechanical systems, to achieve indoor environmental comfort conditions. This paper overviews the current knowledge of solar control elements adopted and developed by Brazilian architecture, tracing its origin to the influence of Arab and Moorish architecture, with the objective of valuing passive solutions. Arab influence in Brazilian architecture began in the 17th century when Portuguese settlers felt the need to adapt the colonial buildings to the climatic constraints, particularly with regard to excessive solar radiation, leading to indoor thermal discomfort and excess natural light. Arab influence in Brazilian architecture remains present until the current day with the same objectives; however, it has been reinterpreted and appropriated by the Brazilian architectural school. Among the most used construction elements during the colonial period were the *muxarabis*, *rótulas*, and *gelosias*. Throughout the 20th century, these elements were culturally appropriated and served as inspiration for the development of the *cobogó* and the pioneering use of *brise-soleis* in Brazilian architecture. These elements have spread throughout global architecture, accompanied by the adoption of computer-controlled dynamic solar protection systems. Therefore, it is important to promote traditional solutions and encourage new architects to adopt passive approaches, aiming for energy efficiency and reducing environmental impacts.

Keywords: solar control element; thermal comfort; lighting comfort; Arab architecture; passive strategies

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1. Introduction

The evolution of humankind has relied on shelter for comfort and protection, especially from hostile climate conditions. Intense solar radiation, excess daylight admittance, and extreme temperatures have long been amongst the most significant environmental factors responsible for leading innumerous generations to iteratively develop specific construction techniques and architectural solutions, based on the different climate particularities and geographic characteristics. These anthropic manifestations materialized in the various constructive approaches and architectural solutions, have slowly become one of the most relevant cultural expressions of identity and ideology of the world's diverse human populations.

Over the last century, architecture has progressively distanced itself from traditional knowledge which often evolved over millennia to become perfectly adapted to the surrounding environment, as well as to be highly representative of local cultural identity, and to perform correctly according to the regional climate conditions thus assuring indoor thermal and lighting comfort. Brazilian traditional architecture has evolved under various cultural influences that have defined its architectural elements according to the local climatic context and cultural identities. Brought by the Portuguese settlers in the 16th and 17th centuries, Arab architecture has been ever since one of the most influential cultural expressions in Brazilian architecture, with special regard to solar protection solutions. Nevertheless, during the 18th and 19th centuries throughout the Industrial Revolution, new materials, mass production together with constructive techniques appeared in the global architectural scenario, along with the development of artificial means for lighting and indoor thermal sources, leading traditional climate-adapted (bioclimatic [1,2]) architecture to gradually be abandoned towards energy dependent standardized architectural solutions. More recently, the 1970's energy crisis raised a significant alert and highlighted the importance of rethinking the architectural design to become once again adapted to the local climatic constraints, aiming to reduce energy dependency, therefore mitigating negative environmental impacts such as greenhouse gas (GHG) emissions. On the other hand, the standardization of architectural forms and practices, due to the internationalization of European architectural expression throughout the 19th century, inspired a young generation of Brazilian architects during the first half of the 20th century to pursue the lost identity of the traditional Brazilian architectural elements, construction materials, forms, and techniques. Therefore, an uprising of organic architecture again arose, not only to express a specific cultural language but to perfectly adapt the architectural design to the local geography, climate conditions, and cultural constructive traditions as well, thus passively assuring thermal and lighting comfort, together with cultural identity.

To enhance the design possibilities repertoire in terms of passive architectural solutions that promote buildings' energy efficiency whilst reducing its energy demand, aiming for indoor environmental comfort, it is of paramount importance to know and understand the past architectural experiences as well as the obstacles faced and overcome by the past generations.

Brazilian climatic regions are predominantly characterized by intense solar radiation, high temperatures, and high levels of natural lighting [3,4]. In this sense, the first Portuguese settlers turned to the Arab and Moorish (the term *Moors* refers to the Muslim populations that occupied the southern territory of the Iberian Peninsula from A.D. 712 until A.D. 1492, often, but not exclusively, of North African origin. The terms Arab and Moorish will be used hereafter undifferentiated, without any territorial meanings, solely referring to a shared architectural expression) traditional elements, deeply rooted in the Portuguese architectural practice, in order to overcome these climatic challenges.

During the last few decades, Brazil has faced various environmental and energy crises, which generated a growing concern with energy efficiency in contemporary architecture. Between 2001 and 2002, the blackouts (in Portuguese—*apagões*) occurred due to a crisis in the supply and distribution of electric energy, that resulted in a campaign of energy rationing [5]. On 21 March 2018, a blackout left 70 million people without electric power, in over 14 Brazilian states [3]. More recently, in 2021, the most severe hydrological crisis in more than 90 years came with consequences, with the lowest levels in the hydroelectric reservoirs, Brazil was forced to use thermoelectric power plants to avoid the risk of blackouts or energy rationing. Considering that residential buildings are responsible for the consumption of 31.2% of energy [6], it is essential to think of passive architectural solutions to increase buildings' energy efficiency. In this sense, revalue techniques that are perfectly adapted to the local climate and architectural culture, can be an adequate alternative to minimize energy-related problems.

Aiman and Fausto analyzed traditional Arab architectural patterns and building types aimed at natural climate control. Therefore, several traditional techniques were analyzed to be improved and adapted with new materials and knowledge. The studied parameters are building orientation, design philosophy, building envelope and materials, building components, natural ventilation, shading, and passive cooling [7].

Various authors have focused their studies on controlling excess daylight admittance and the use of blinds to provide visual privacy [8]. Concerning this matter, historically, certain cultural groups, including the Arabs, incorporated architectural designs that prioritize the privacy of occupants and view, often featuring openings with veiled windows known as *Mashrabiya* [9–11]. Sahar et al. [11] found in the performed research that one key factor with influences some aspects of the Arab architecture is the need to guarantee thermal comfort as a prominent reason for closing their window shades while opening them for natural ventilation.

In another study, Fabio Pollice [12] highlighted the role of the architects in the building's design, which is key to promoting more sustainable solutions to mitigate climate change. Police, [12] studied Masdar City, and regarding the residential buildings, the solution was defined using red sand-colored, undulating glass-reinforced concrete screens, having the same purpose as the traditional Arab mashrabiya screens. They provide shade, thus preventing solar gain on the indoor spaces and they allow residents to look out at the street below while maintaining their privacy. This strategy also allows air to pass through these elements to cool the balconies.

The Arab influence, brought by the Portuguese to Brazil, helped transform Brazilian architecture [13]. While the literature has adequately addressed different cultural expectations namely the Arab, it remains unclear how these shifts, when expressed in building design, impact a broader spectrum of solar control elements into the Brazilian architecture. Therefore, this paper is focused on the solar control architectural elements present in the Brazilian architectural tradition, whose origin is the result of the Arab and Moorish architectural influence, brought in the 17th century by the Portuguese settlers. An overview of the influence of solar control elements of Arab origin in Brazilian architecture is presented. A specific objective of this paper is to recollect, study, and revalue the traditional cultural solutions that passively promote indoor thermal and lighting comfort in contemporary Brazilian architecture, to inspire younger generations of architects and engineers, giving these professionals organized and technical information, relevant to the local climate conditions, decreasing energy dependency of buildings whilst increasing indoor environmental comfort, and beyond the standardized formal glazed prismatic patterns.

2. Materials and Methods

The adopted methodology is based on literature and real examples collected, to investigate, according to historical events and cultural movements, the influence of Arab and Moorish architecture in the adoption and acculturation of architectural solutions for solar control elements and natural ventilation by Brazilian architecture.

Controlling solar radiation incidents in the building, while allowing natural ventilation, are examples of architectural solutions that can contribute to reducing energy demand in current buildings. The main elements studied in this work are the *rótulas*, *gelosias*, and *muxarabis*. Their main similarities and differences are presented in Table 1.

Table 1. The main characteristics of the solar control elements are influenced by Arab architecture.

	Rótulas	*Gelosias*	*Muxarabi*
Common features	Composed of a wooden latticework they are arranged on the facades in front of windows or window doors.		
Different features	The presence of joints to open and close the element, either in a vertical or horizontal axis [14]	Box superimposed on the outside of the window doors, above the level of the ground floor, structures that take advantage of the windows' balconies [15]	Very protruding balcony, covering more than one window up to the entire façade [16]
Natural ventilation and solar protection	The wooden latticework, according to its arrangement and spacing, allows greater or lesser air circulation in the environments while maintaining privacy. Likewise, it controls the direct incidence of solar radiation inside environments, increasing the shading of buildings.		
Privacy	The wooden latticework allows people inside the buildings to observe the outside without being noticed.		
Energy efficiency	Protecting the building from solar radiation, while allowing air circulation, allows buildings to need less energy demand for thermal comfort (cooling).		

Field research was also carried out through a photographic survey of architectural typologies representing the use of solar control elements Arab-based, located in historic Brazilian cities, such as Olinda, Diamantina, Mariana, and Rio de Janeiro. To synthesize important characteristics of solar control elements with Arab influence, explanatory graphic representations of such elements were created through digital drawings and presented to improve the information from the photographic survey. Figure 1 summarizes the adopted methodology.

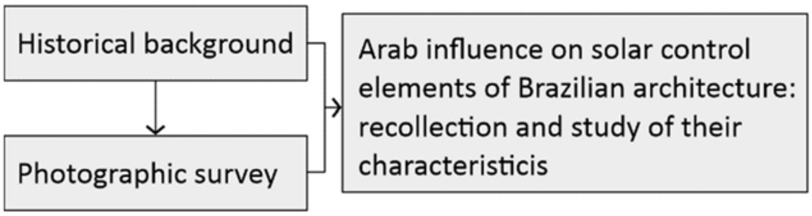


Figure 1. Scheme of the adopted methodology.

3. Historical Context

The first Portuguese settlers arrived on the Brazilian shores during the first half of the 16th century, originating from different regions and comprising various backgrounds, several areas of expertise, and technical knowledge, but unaware of the climatic challenges to be faced and required to be overcome, conditioning the construction of buildings in the new territory. The different Brazilian climate profiles, the extensive territory, and the natural resources were significantly different from those to which the Portuguese settlers were accustomed [13]. Therefore, during the entire 16th century, the settlers relied on indigenous experience to solve these architectural challenges [14].

Climate has undoubtedly been the most challenging physical factor that interfered with the development of Brazilian architecture during the settlement period [17]. Given the high temperatures during the summer season associated with intense solar radiation, indoor overheating, and excessive lighting were the first major problems in need to be solved through architectural solutions [18]. In this sense, the influence of Arab and Moorish architectural heritage rooted in the Portuguese construction tradition from the 16th century, appeared naturally as the adequate solution to overcome the climatic challenges faced in the new territory. Architectural elements of Arab inspiration were extensively used throughout the 17th and 18th centuries in Brazilian construction scenarios, and according to Marianno Filho [14], its origin is believed to have occurred in the regions of Bahia and Pernambuco, as early as the beginning of the 17th century. These construction elements of Arab architectural inspiration gradually became deeply connected with local indigenous and popular themes, considered therefore as non-erudite architecture executed by local populations to fulfill rudimentary needs, and detached from the influence of the official principles of Portuguese architectural practice. At that time, popular architecture became widely spread across the Brazilian territory, becoming more common than official Portuguese architecture, constituting a true endogenous Brazilian identity expression, allowing the wide dissemination of the Arab architectural elements due to its natural suitability to the new territory climate demands [14].

While in Portuguese and Spanish traditional architectures, external elements of Arab origin were commonly used largely with ornamental character instead of functional purposes [14], for the Brazilian reality on the other hand, the application of these architectural elements was perfectly justified given the climate constraints, especially regarding intense solar radiation. The architectural challenge was overcome by the Brazilian people themselves, applying Arab construction principles according to the solar protections needed for the different Brazilian regions, combined with local identity, thus resulting in a multitude of different and adapted architectural solutions [14]. In this context, the Portuguese architecture originally performed by the early settlers, slowly reached for solutions suitable to be adapted to the local climatic realities, finding in the Arab architectural inheritance the adequate answer to passively reduce the buildings' indoor temperatures and intense lighting, as a consequence of the high external temperatures and solar radiation. Arab architectural elements proved efficient for that purpose and became frequently adopted, being used in the buildings' envelope openings as solar protection elements composed of hollow wooden latticework, designated as *rótulas*, *muxarabis*, and *gelosias* (Portuguese expressions with no known translation), solutions further explained throughout Section 4.

In the year 1809, the use of oriental-inspired elements in Brazilian architecture was prohibited by the regime, in particular the *muxarabis*, which were replaced by industrialized technical solutions recurring to glass and guillotine type windows, and later to solar protections of Venetian blind type [14,15,19]. More than a century later, following the revaluation of Brazilian's national architecture, a movement deepened within the search for its own identity, Brazilian architecture invents the *cobogó* [20,21] and appropriates the use of the *brise-soleil* [18], architectural elements for solar protection and control inherited from the Arab architecture influence [21].

4. The Portuguese Settlement and the Solar Control Elements of Traditional Arab Architecture Influence

Brazilian intense solar radiation obliged the Portuguese settlers to widely adopt, from the beginning of the 17th century until the early years of the 19th century, solar control elements of Arab architectural inspiration. The adopted elements were, as referred to in Section 3, the *rótulas*, the *muxarabis*, and the *gelosias*, as further detailed. These elements comprise similar constructive characteristics, being composed of wooden slates diagonally arranged in latticework, whose main function is to act as a solar filter, reducing solar radiation and excessive lighting, thus allowing natural ventilation while protecting from the rain, whilst ensuring privacy and security for the buildings' inhabitants. Indirectly, through the influence of these elements on the parameters described, various characteristics relating to the indoor environment can be controlled, such as relative humidity, and indoor air quality, among others. For instance, Abdelsalam and Rihan [22] provided insights relating to the building features and the ventilation. The relationship between several construction methods, such as domes, wind towers, *muxarabi*, and others was analyzed in terms of maximizing the effectiveness of natural ventilation.

Furthermore, these architectural elements can be interpreted as a materialized border between public and private spaces, the external environment versus the security of the indoor space. These architectural elements may as well be installed after the building is constructed, most of the time comprehending intricate details and complex geometric patterns which provides additional value to the architectural composition of the building itself. A detailed description of each element is presented in the following subsections, with a more detailed characterization.

4.1. *Rótulas*

From the 17th century until the early 19th century, urban houses frequently integrated *rótulas* and *gelosias* in the windows. The term *rótula* comprises different designations, diverging between architects and historians. However, its origin may be related to the human knee joint as is the Portuguese translation of the word which means the kneecap articulation allowing the movement of the knee, given the presence of articulations (joints) in the architectural element letting it to open and close [14]. In every designation, the architectural element is composed of a wooden latticework (wooden slates diagonally arranged), forming a non-orthogonal mesh (or grid) pattern, which effectively controls sunlight and natural ventilation, allowing indoor privacy and protection from the rain. As mentioned, one of its main characteristics is the presence of joints to open and close the element, either on a vertical or horizontal axis.

These solar control elements, *rótulas*, were located at the external surface of the openings and windows [14]. In the case of existing windows, these maintained their original characteristics of the double wooden pane, opening to the interior of the compartment [23].

The architectural element *rótula* allowed an adequate and effective control of natural lighting and ventilation, paramount for hot climate conditions, whilst providing privacy by protecting the interior of the dwelling from external viewing. It was an architectural element complementary to the external windows, which could be easily applied in retrofit actions.

Windows equipped with *rótulas* were usually horizontally divided between two or more parts, with similar functions although comprising different aesthetics (Figures 2 and 3). The moving part of the *rótula* was composed of a wooden latticework at the occupants' level, allowing natural ventilation and sunlight control, while guaranteeing privacy at the same time, as people inside the dwelling were able to observe the exterior environment without being noticed. The *rótula's* upper component was fixed (not moveable), usually balustraded or with geometric patterns referring to the Arab culture and design. This fixed part of the *rótula*, by being distanced from the outdoor eyesight, guaranteed privacy despite having a larger opening area, thus allowing increased natural ventilation and lighting. Besides its functionality, the result from the different compositions of opening areas and geometries, patterns, and configurations, enhanced the architectural aesthetic of the building. The example of *rótula* presented in Figure 2 has a fixed and a movable element. The fixed upper part corresponds to 30% of the element (larger openings for air circulation) and the movable lower part corresponds to 70% of the element.

Figure 2. Example of *rótulas*. (**a**) House of *Rótulas*, Pilar de Goiás—GO, Brazil. Edited from [24]. (**b**) Details of the *rótula*.

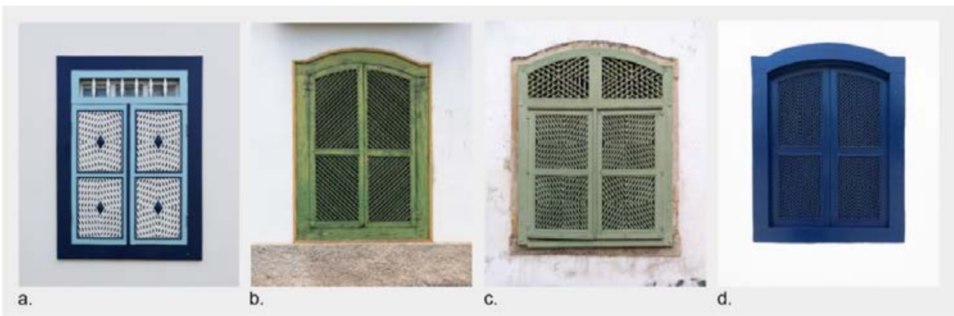


Figure 3. Example of different types of window configurations with *rótulas* in different Brazilian cities. (**a**) e (**b**) Diamantina—MG. (**c**) Ouro Preto—MG. (**d**) Paraty—RJ.

4.2. Gelosias

The etymological meaning of the term *gelosias* does not have a consensus between the architectural and historical communities, similar to the referred for the *rótulas* in Section 4.1.

The origin of the Brazilian word *gelosia* may derive from the French word *jalousies* or the English *jealous*. This hypothesis is based on the specific functionality of the architectural element as a barrier, preventing the person inside the dwelling (behind the window) from being seen from the outside environment, as this architectural element would be predominantly used in the women's bedrooms, not to be observed from the environment external to the family. The *gelosias*, according to Miotto [15], are architectural elements similar to a box superimposed on the outside of the window doors, above the level of the ground floor, forming structures that take advantage of the windows' balconies for support. It consists of a wooden latticework, similar to the *rótulas*. The upper section of the "box" is composed of opening sheets, fixed to its upper part. This architectural element allows a constant flow of natural ventilation to the indoor environments with little sunlight penetration, whilst protecting the indoor environment from outdoor viewing, guaranteeing privacy. Figure 4 presents a photograph from the 18th-century *gelosia* present in a building located at Rua da Quitanda, Diamantina/MG, Brazil. The example of *gelosia* presented in Figure 4 has two fixed elements and one movable. The fixed parts correspond to 60% of the window and the movable part corresponds to 40% of the element.

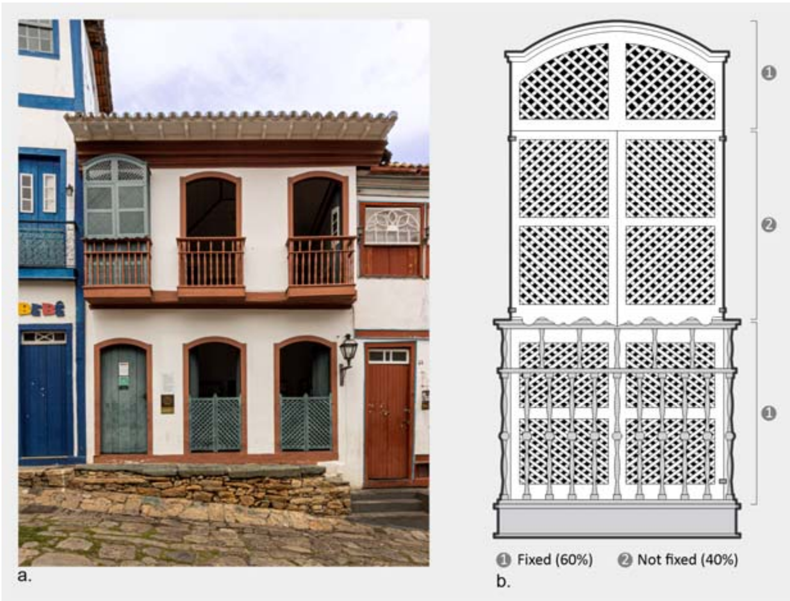


Figure 4. Example of *gelosia*. (**a**) *Gelosia* from the building located at Rua da Quitanda, 48, Diamantina/MG, 18th century. (**b**) Details of the *gelosia*.

Similar to the *rótulas*, the *gelosias* were applied in front of a single opening (on the external surface), although not on the windows as the *rótulas* but in front of the window doors instead, covering a larger area for natural ventilation and lighting.

4.3. Muxarabi

An interesting architectural element, similar to the *rótulas* and *gelosias* in its form and function, is the *muxarabi*. The word *muxarabi* according to El-Shorbargy [25] and Ficarelli [26] originates from the Arab word for "drink" (*sharab* in Arabic), referring to "a place to drink" or "a place to store drinks". On the other hand, Lemos [27] states that the original term has the meaning of "a place where the water pot is refreshed". According to Pinto [16], the word *muxarabi* means "place of drinks", referring to the place where the water pots were stored to refresh their content. *Maxrab* is the Arabic word for "fountain" and the original etymological meaning of *maxrabia* refers to a type of traditional ceramic jar in which water is served (the Brazilian words for these types of ceramic jars, comprising that specific function, are *moringa* or *quartinha*). The common origin for all these terms is the Arabic verb *xariba* which means "to drink". Different variations occur in the Portuguese language, such as *muxarabi*, *mucharabi,* or *muxarabiê*. Fletcher [28] suggests a different origin for the word *muxarabi*, proposing its origin from the Arabic word *sharâb*, suggesting the idea of a chess pattern.

The main difference between *gelosia* and *muxarabi* is initially proposed by Pinto [16], suggesting that the first would consist of a slightly protruding balcony (as observed in Figure 4), while the latter (*muxarabi*) would consist of a very protruding balcony, almost in every case supported on stone corbels, covering more than one window up to the entire façade, which would support the roof of the building with its upper part. For Mariano Filho [14], the *muxarabi* emerged as a pronounced cantilever/overhang element from the second level of the two-story buildings (usually houses), which despite its functional qualities, often shaded the stores of the ground level and hindered the traffic (see Figure 5). Pinto [16] identifies the *muxarabis* as the coolest place in the house, providing protection and security, while promoting well-being and tranquility for the occupants of the dwelling. The example of *muxarabi* presented in Figure 5 has two fixed elements and one movable. In this case, the percentage of fixed and movable elements is equivalent (approximately 50% each).

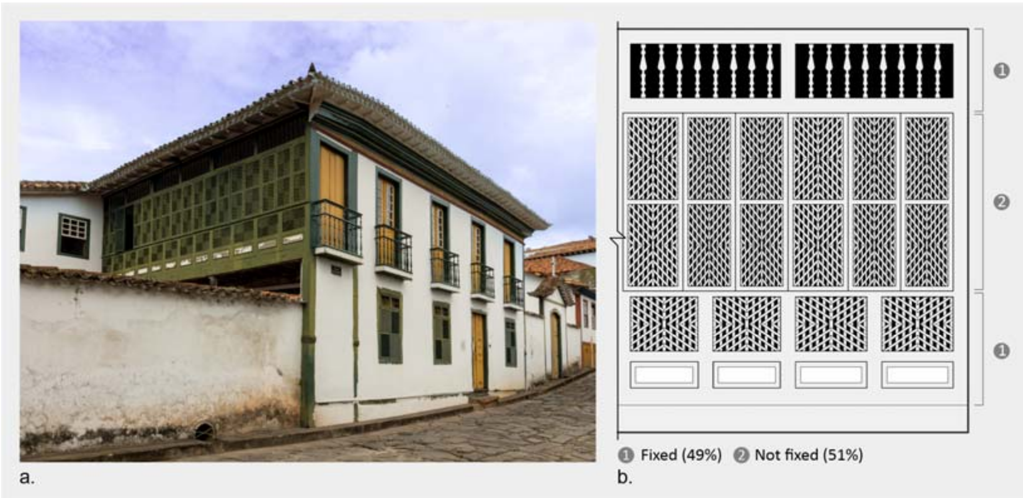


Figure 5. Example of *Muxarabi*. (**a**) *Muxarabi* from Casa Chica da Silva, Diamantina MG, Brazil (17th century). (**b**) Details of the *Muxarabi*.

The function of the *muxarabi* was to act as an element of solar protection to reduce excessive exposure to the sunlight and airflow, to diminish indoor air temperature while guaranteeing privacy, as it allowed visibility from the indoor environment to the outdoor and prevented visibility from the outside. *Muxarabis* are considered one of the utmost relevant expressions of influence from the Arab architecture in Portuguese architecture, further transferred to colonial Brazil. The *muxarabi* as an architectural solution is highlighted by Mariano Filho [14] and Pinto [16] given its importance as an element of ecological housing in a country with a hot climate and excessive sunlight. The authors suggest that the *muxarabi* brings the idea of adaptation to the environment, as it was mainly used in narrower streets and especially in houses without patios or gardens, being the architectural solution to allow natural ventilation from the outdoor environment through its wooden latticework, to reduce indoor air temperature fostering thermal comfort. Additionally, the *muxarabi* filtered the excess of natural lighting, ensuring indoor natural lighting comfort as well.

This architectural element, the *muxarabi*, was identified in a variety of locations throughout the Brazilian territory: Minas Gerais, São Paulo, Rio de Janeiro, Pernambuco, and Bahia. In the northeast of Brazil, in the cities of Recife, Olinda, and Salvador, these were widely used until the end of the 18th century, when local authorities ordered its removal from the architectural practice [29], for reasons further detailed (see Section 5). Over the years, the word/term *muxarabi* became generally applied to describe wooden latticework or panels constituted by slats arranged at regular intervals, that cover the buildings' openings, often applied to *rótulas* and *gelosias*.

4.4. Urupemas

The owners of the humblest houses who were not able to build solar protection elements such as *rótulas*, *gelosias,* or *muxarabis* using wooden slats, recurred to the indigenous solutions to overcome the absence of noble materials. Thus, these populations applied local plant materials such as *taquara*, *uru,* or any other materials of easy access and low acquisition cost [14,27]. The resulting latticework became popularly known throughout the Brazilian territory as *urupemas*, an architectural solution widely used until the early 20th century in north-eastern Brazilian rural houses. These local rural houses with *urupemas* as solar protection elements became known as *mocambos*.

The word *urupemas* derives from the indigenous term *uru* which means "straw latticework". These were also designated as "sieves" by the common people, as highlighted by Marianno Filho, given the similar construction technique of *urupemas* and sieves [14]. Lima and Albernaz [30] define *urupemas* as a mat manufactured with plant fibers, mainly used to cover openings of doors, windows, and balconies, similar to the previously detailed solar protection elements. According to these authors, the used plants to manufacture the *urupemas* have varied over time and geographic regions, such as straw, *taquara* (a bamboo-like plant), and *cipó* (a vine-like plant), although maintaining the same characteristics that allowed adequate natural indoor ventilation and protection from solar radiation. This architectural solution was mainly applied to old constructions in the North and Northeast regions of Brazil and may still be used today in these regions, in the humblest dwellings of the inland territory.

Urupema can be described as a simplified version of the *gelosias* and *rótulas*, applied to rural and less sophisticated houses [15]. Generally, *urupemas* are composed of a guillotine-type panel, made of straw latticework, assembled on the outer surface of the opening, covering half of the window, and leaving the other half without any solar protection, as illustrated in Figure 6. Similarly, to the *rótulas* and *gelosias*, the *urupemas* allow natural ventilation and solar radiation to be controlled, while protecting the indoor space from the outdoor view. Since this system is generally used in rural areas and is constituted of compostable material, no emblematic buildings have been identified with this technology. Therefore, Figure 6 presents an illustration of the system.

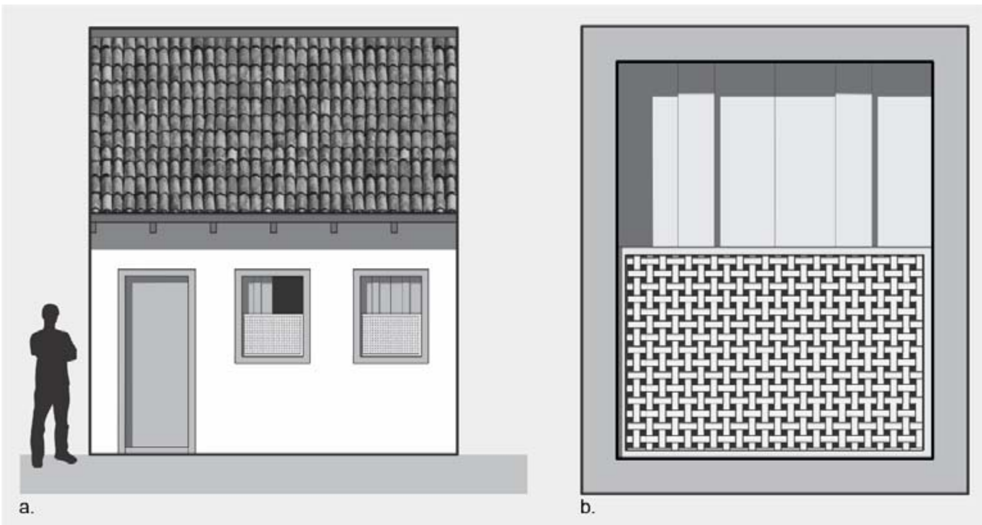


Figure 6. Illustration of a window with *urupema* applied as solar protection element: (**a**) Element applied in the context of residential construction. (**b**) Element detail.

5. Early 19th Century: Prohibition of Arab Elements in Brazilian Architecture

In the year 1809, one year after the Portuguese Royal Family arrived in Brazil, Regent D. João VI ordered the removal of all architectural elements of Arab influence, such as the *muxarabis*, as considered these architectural elements to be an offense to the Portuguese kingdom [19]. The population was given 8 days to remove the *muxarabis* from the buildings, and those who opposed the removal of the then-designated "gothic customs" (a designation to define what was considered to be a barbaric or primitive costume) were labeled as retrograde, anti-progressive and uncivilized [14]. Security reasons could have also been at the origin of this prohibition, given the possibility of firearms being used from inside the small openings of the wooden latticework of the *muxarabis*, being unnoticed for malicious use [16].

England had a special interest in the architectural reforms carried out by D. João VI in Brazil, able to exclusively supply plane glass for the windows [15]. The commerce of glass with England would have justified the aesthetic and architectural hygienic shift, often recurring to the police force, to substitute the wooden latticework with the so-called "modern" industrialized glass windows [27,31].

Brazilian architecture began to incorporate industrialized elements and construction materials, such as ceramic bricks, and glass, among others, leading to a systematic extinction of architectural elements of popular (endogenous) origin and unofficial characters such as the wooden latticework of *muxarabis*, *rótulas,* and *gelosias*. The aim was to bring Brazilian architecture closer to European tradition, valuing neoclassical aesthetics and the culture of industrial society. The use of industrial bricks allowed a smaller thickness of walls, larger spans, and a standardized production of doors and windows. The traditional wooden latticework, which ensured indoor protection and privacy, was replaced by small glass windows, invading the intimacy of homes, compromising natural cross ventilation, and flooding indoor spaces with excessive natural light, often undesired, resulting in indoor environmental discomfort [32].

Every advantage provided by the traditional latticework (*gelosias*, *rótulas,* and *muxarabis*) gradually disappeared, originating architectural elements that did not allow for adequate natural ventilation levels nor controlled natural lighting in indoor environments [33]. Privacy however was able to be maintained using embroidery textiles in the internal face of the guillotine-type windows, to protect indoor spaces of the dwellings from the outside environment, which in urban areas had become increasingly busy. The adoption of guillotine-type windows corresponds, according to Marianno Filho [14], to the historical milestone of the definite decline of Arab influence in Brazilian architecture, during the first decades of 19th century Brazil.

6. 20th Century: Expressions of Arab Influence on the Brazilian Modern Architecture

In the early years of the 20th century, modern Brazilian architecture found itself in a search for an identity of its own, looking for elements that would integrate the industrialization era within a current aesthetic language, deeply rooted in the tropical climate characteristics. The increasing spans and the excessive use of glass were two major challenges that Tropical Architecture should be able to solve and overcome. Most visionary Brazilian architects from the beginning of the 20th century turned to colonial-period architecture to seek solutions to these problems, particularly with regard to solar control elements of Arab influence. From that moment on, the Arab-inspired solar control elements, prohibited in the 19th century, became assimilated once more by the Brazilian architects and assumed as architectural elements connected with the Brazilian cultural identity. Thus, elements such as the wooden latticework, widely used during the colonial period, were again revisited, and reinterpreted to be adapted to a modern architectural language from the tropical climate. Examples of the use of Arab-inspired wooden latticework by modern Brazilian architecture can be found in the works of: Lucio Costa (Saavedra/RJ residence, 1942; Casa Hungria Machado/RJ, 1942); the Roberto Brothers (vacation camp IRB/RJ, 1943); Luiz Fernando Corona and Carlos Fayet (Residence Cândido Norberto/Porto Alegre, 1952).

Industrialization and mass production together with the search for a new architectural language, combined with the need to provide Brazilian architecture with solar protection solutions and sustained by the presence and availability of new construction materials such as concrete led to the development of original solar control elements, inspired by the influence of Arab architecture, such as what became known as *cobogó*. *Cobogó* is the solar control element, which was patented in 1929 [19], before the wide dissemination by Le Corbusier of the *brise-soleils* in 1933, and first applied in 1935 by the Brazilian architect Luis Nunes, in the building designated as *Caixa d'Água de Olinda*, constructed in concrete (Figure 7).

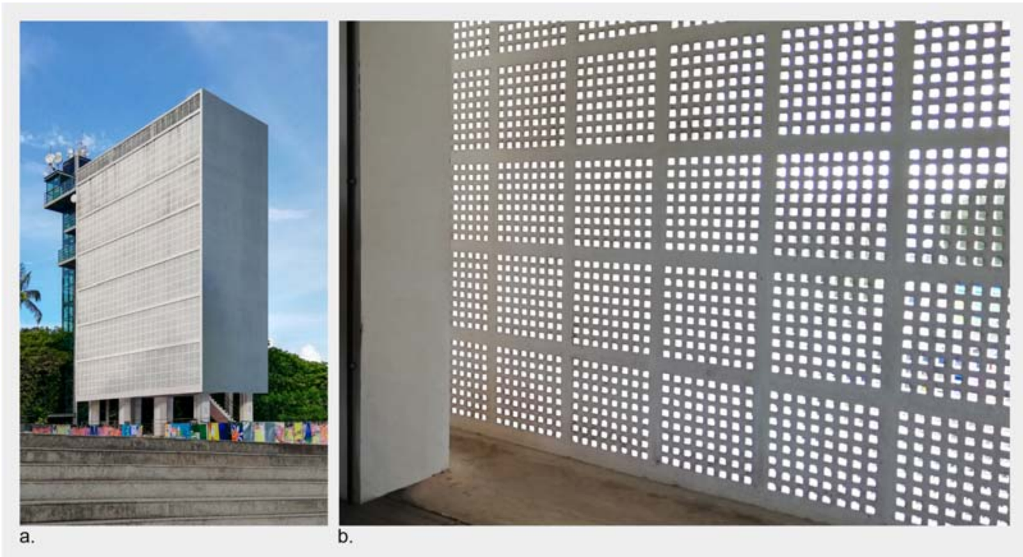


Figure 7. Example of a *cobogó*. (**a**) Building *Caixa d'Água de Olinda*, 1935. (**b**) *Cobogó* detail from the interior environment of the building *Caixa d'Água de Olinda*.

The name *cobogó* derives from the initials of the surnames of its inventors: Amadeu Oliveira Coimbra, Ernest August Boeckmann, and António de Góis [20]. However, some architects such as Oscar Niemeyer refer to this element as *combogó*, a name also present in the product patent registration from 1929. Additional designations are found in the literature, such as *cambogé*. The *cobogó* differs from the *brise-soleil* in two main aspects: it is a solar control element composed of modular units; and besides its function of controlling solar radiation, light, rain, and strong wind protection, it is the sealing element itself. The year 1929 may be considered the date of the resumption of the influence of Arab architecture in the definition of solar control elements in Brazilian architecture.

Cobogó is a prefabricated hollow element, inspired by colonial wooden latticework such as *muxarabis*, *rótulas*, and *gelosias*. It provides natural lighting and ventilation while ensuring indoor privacy. Originally made of concrete and later in ceramic and other materials, it consists of modular units assembled to form a panel.

Le Corbusier valued the concept of opening buildings to the outside environment, fostering the entrance of natural light, air, and nature itself [18]. However, the wide use of glass as the buildings' façades skin in modern architecture, has utterly changed the relation between indoor environment and outdoor climate, emphasizing overheating as a major issue resulting from the excessive use of glass as construction material for the external envelope [34]. Thus, in 1933, shortly after the development of Brazilian *cobogó*, Le Corbusier systematized the use of the *brise-soleil* in architecture [5]. The name *brise-soleil* refers to a French expression describing the function of solar protection. Other terms used to translate the French expression *brise-soleil* in architecture are "light-breakers", "sun-breakers", "external shading devices", or as commonly used in Brazil in a shortened version, simply *brise*. Maragno [35] refers to its origin as being related to traditional Arab architecture.

Although Le Corbusier has systematized the *brise-soleils* as a solar control solution, the Brazilian architects were those responsible for the practical application, widespread, and final definition of the *brise-soleil* architectural concept [17,18]. The *brise-soleil* solutions used in Brazil were so ingenious and varied, that they extrapolated the purely functional purpose of that solar control solution, transforming it into a means of expression that profoundly marked the Brazilian architecture of its period [18].

Below, information on landmark buildings using *brise-soleil* is presented. Considering that the date on which these buildings began their construction practically coincides, it is important to provide the start and completion dates of each construction, to understand some degree of influence between the buildings. The building designated as the *ABI* building (Figure 8a), constructed by the Robertos Brothers between 1936 and 1938 is considered the first building in the world to be equipped with a modern *brise-soleil* solution [36]. Additionally, Oscar Niemeyer's *Obra do Berço* (Figure 8b) (1937–1939) was the first building to integrate the mobile *brise-soleil* into architecture. The building of Education and Health Ministry (Figure 8c), was built between 1937 and 1945 and designed by a group of eminent architects including Oscar Niemeyer, Affonso Reidy, Jorge Moreira, Carlos Leão, and Ernani Vasconcelos, under the consultancy of Le Corbusier and led by Lucio Costa, comprehended the first application of a *brise soleil* in a large-scale building [37]. All these innovative and flagship buildings for their use of *brise-soleil* were designed and constructed in Rio de Janeiro, Brazil, during essentially the same timeframe.

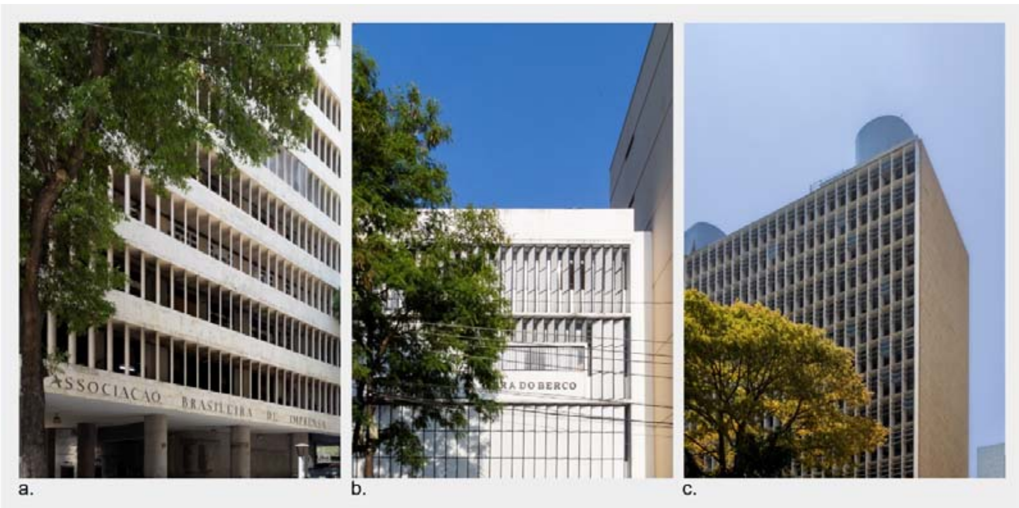


Figure 8. Example of a *brise-soleil*. (**a**) ABI building (1936–1938). (**b**) *Obra do Berço* (1937–1939). (**c**) Education and Health Ministry, built from 1937 to 1945.

The experiments with the use of solar control architectural elements continued enthusiastically until the end of the 1950s. Some of the utmost relevant architects of this period along with some of their most emblematic works comprehending solar control elements are listed as follows and shown in Figure 9: Robertos Brothers office designed Santos Dumont International Airport (1944), *IRB* building (1944), *Seguradoras* building (1943), and *Marquês de Herval* building (1955), all located in Rio de Janeiro (Brazil); Oscar Niemeyer designed the building *Grande Hotel* (1940) in Ouro Preto (Brazil), the building *Copan* (1951–1952) in São Paulo (Brazil), the *Pampulha complex* (1943) and a *Niemeyer* Building (1954–1960) in Belo Horizonte (Brazil); Lucio Costa was responsible for the design of *Barão Saavedra's* house (1943) in Petrópolis-RJ (Brazil), the *Parque São Clemente* hotel (1944) in Nova Friburgo-RJ (Brazil), and the buildings from *Parque Guinle* (1954) in Rio de Janeiro (Brazil). It is also worth mentioning the Brazilian Pavilion' developed by Lucio Costa and Oscar Niemeyer for the 1939 New York World's Fair. The building showcases the innovations of Brazilian architecture to the world, such as the use of *brise-soleil* for solar protection, another suitable example of components with Moorish origins of Iberian descent, functioning as a fixed modern *muxarabi*. Other renowned architects who resourced the use of solar control elements in the Brazilian national scenario are Affonso Reidy, Rino Levi, Vilanova Artigas, and Oswaldo Bratke. Until the 1960s, numerous works from Brazilian architects unveiled an effective and creative use of *brise-soleils* and *cobogós*, influencing the international architecture scenario.

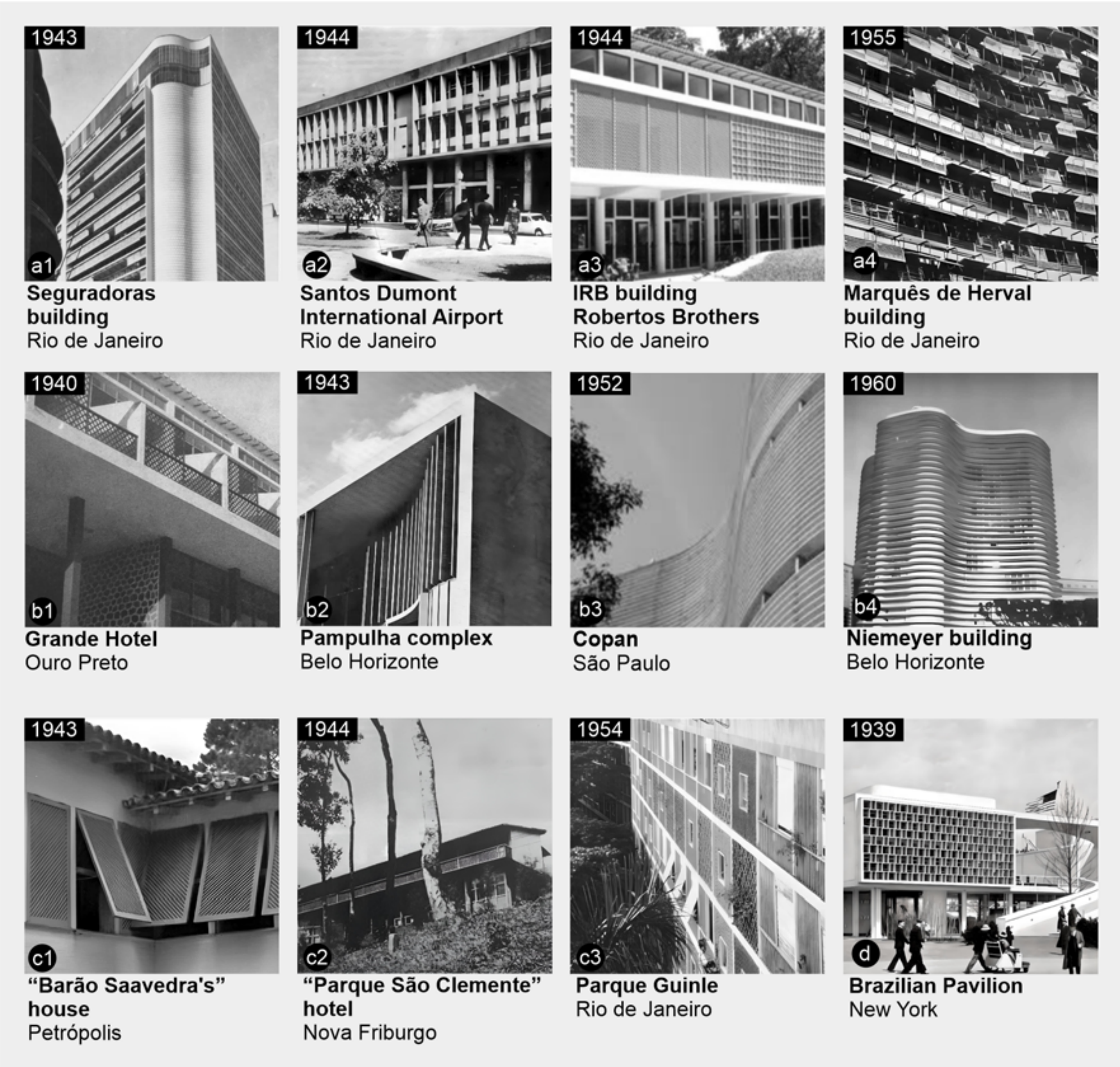


Figure 9. Some emblematic Brazilian buildings used solar control elements until the end of the 1950s. (**a1**–**a4**) Robertos Brothers [18,38]; (**b1**–**b4**) Oscar Niemeyer [17,18,38,39]; (**c1**–**c3**) Lucio Costa [18,37,40]; (**d**) Lucio Costa & Oscar Niemeyer [17].

The search for national identity affirmation resulted in the production of architectural works of distinctively Brazilian character. Instead of subjecting the interior of the building to relentless tropical solar radiation exposure, the external wall does not excuse itself from the task of intermediating two conflicting environments: indoor and outdoor. Thus, the massive use of glazed areas must be combined with adequate protection strategies, preferably recurring to the available (and local) resources and relying on architecture itself as the solution. Instead of active mechanical systems, indoor environmental comfort can be achieved through passive design solutions as the solar control elements are applied as façade's solar protection [36].

7. Analysis and Discussion

A graphical synthesis highlighting the differences between the various solar control protections addressed throughout this paper (*rótulas*, *gelosias*, and *muxarabis*) is presented in Figure 10. Generally, all these architectural elements are composed of a wooden latticework with similar functions; however, some differences stand out: the *rótula* is usually applied to ground-floor windows, as *gelosias* and *muxarabis* are exclusively applied to upper-level openings given the presence of overhangs in these elements. The *gelosia* advance in front of the façade is usually reduced and is applied (usually added) to window-doors individually. The *muxarabi* on the other hand, comprehends a much greater frontal extension, expanding through several façade openings (windows or window doors). A common feature between the three elements is that they are all composed of a fixed and moveable part, with vertical or horizontal joint axes. The moving components are located at the eye level of the inhabitants of the building, that is, the area where privacy is to be controlled. The upper element of the three solutions is above the eye level of those outside the building (external environment), and therefore, these components are usually fixed, often comprehending a larger opening area, since privacy is no longer an issue.

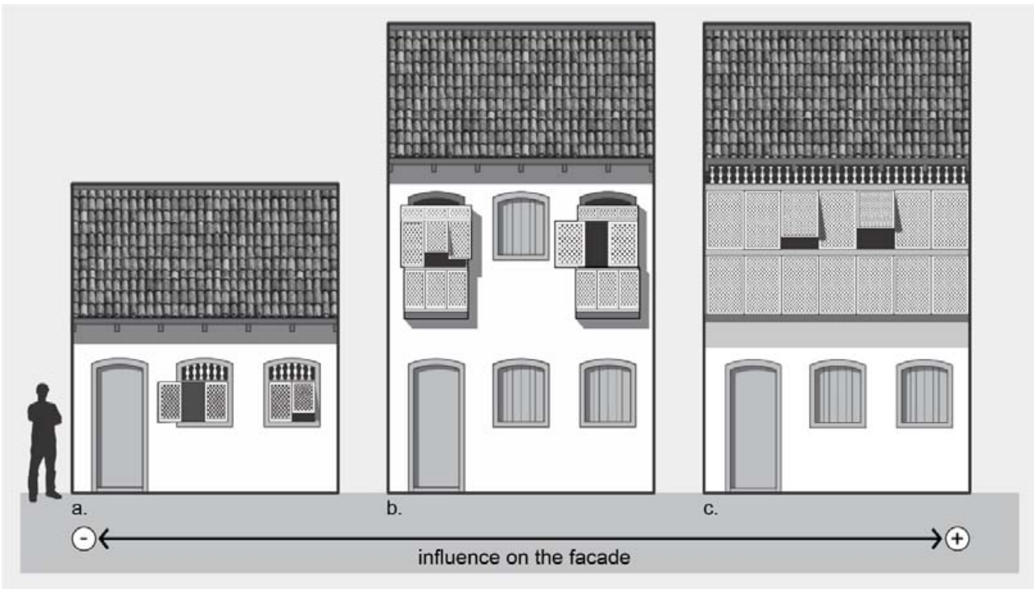


Figure 10. Differences between the various solar control elements: (**a**) *rótula*, (**b**) *gelosia*, and (**c**) *muxarabi*.

The expressions of Arab influence in Brazilian architecture in what concerns solar control elements are summarized in Table 2 and chronologically depicted in the timeline of Figure 11. A chronological demonstration from the beginning of the influence of the Arab architectural elements in the early 17th century, until the beginning of the 19th century, where these elements were prohibited, is provided. The increasing industrialization led these wooden latticework elements to be replaced by glazed windows of guillotine-type, together with Venetian solar protections. Nevertheless, these elements combined were not able to achieve the benefits of the previous solutions, particularly regarding the integration of natural light and ventilation, view of the outside environment, and privacy at the same time. At the beginning of the 20th century, as industrialization influenced society, including architecture development, new solar control elements such as *cobogó* and *brise-soleil* were developed to adequate modern architecture to the tropical climate. Although with very few records, given their fragile nature, *urupemas* were also an architectural solution used during this period for solar control.

Table 2. Historical synthesis of the expressions of Arab influence into Brazilian architecture, focusing on the development of solar control elements.

Period	Analysis of Relevant Events			
XVI Century	European arrival to Brazil. European adaptation to indigenous technological solutions. Use of indigenous technology for building adaptation to climate conditions [13].			
XVII Century and XVIII Century	Search for architectural elements able to promote adaptation to tropical climate, particularly with regard to intense solar radiation and luminosity. Period of great influence from Arab architectural elements of solar control [13]. Architectural elements for controlling solar radiation while allowing natural ventilation ensuring indoor privacy: *rótulas*; *gelosias*; *muxarabi*; *urupemas*.			
XIX Century	1808	Portuguese Royal Family arrives in Brazil.	Decrease (almost to extinction) of Arab influence in Brazilian architecture due to the Portuguese Royal Family decree. Beginning of the influence of international industrialization on Brazilian architecture (use of glass, iron, and ceramic bricks). Architectural elements of Arab influence are replaced by glazed windows of guillotine type and Venetian solar control solutions.	
	1809	Prohibition of using architectural elements of Arab origin in Brazilian territory. [13,15,18,26,30]		
XX Century	1929	*Cobogó* is patented [19]	Amadeu Oliveira Coimbra, Ernest August Boeckmann and Antônio de Góis	Architecture searches for its national identity, suited to the local climate conditions. Revalue and reinterpretation of elements and solutions from the colonial architecture of Arab inspiration, however influenced by industrialization. Use of solar control elements: *brise-soleil* (vertical, horizontal, combined, fixed, and mobile) and *cobogós*.
	1933	Systematization of *brise-soleil* [14,17]	Le Corbusier	
	1935	First application of *cobogó*: Caixa d'Água de Olinda [19]	Luis Nunes	
	1936–1938	The first application of *brise-soleil* in the world: ABI/RJ (Brazilian Press Association), (vertical) [35]	Roberto Brothers (Marcelo and Milton)	
	1937–1939	First application of mobile *brise-soleil* in architecture: Obra do Berço/RJ [5]	Oscar Niemeyer	
	1937–1945	First application of *brise-soleil* in a large-scale building: Education and Health Ministry/RJ [36]	Oscar Niemeyer, Affonso Reidy, Jorge Moreira, Carlos Leão e Ernani Vasconcelos, consultancy by Le Corbusier, project leader Lucio Costa.	

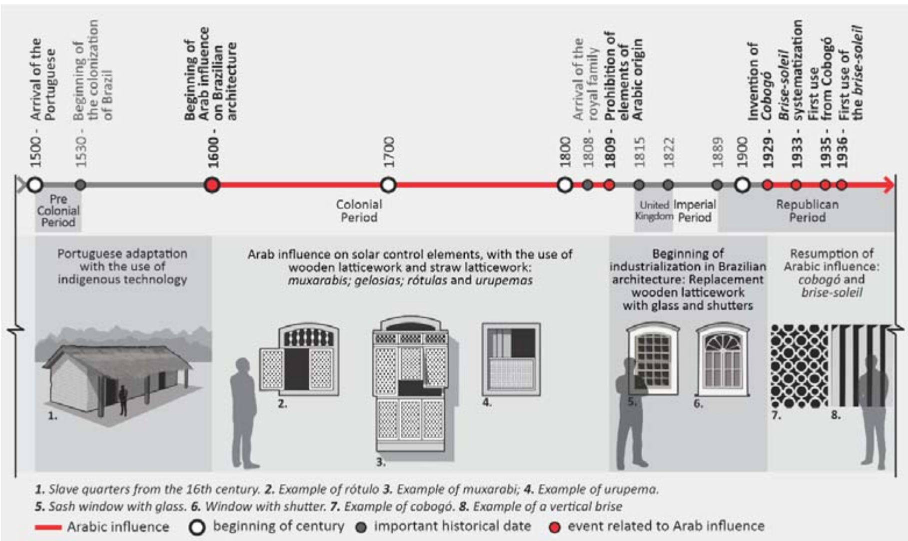
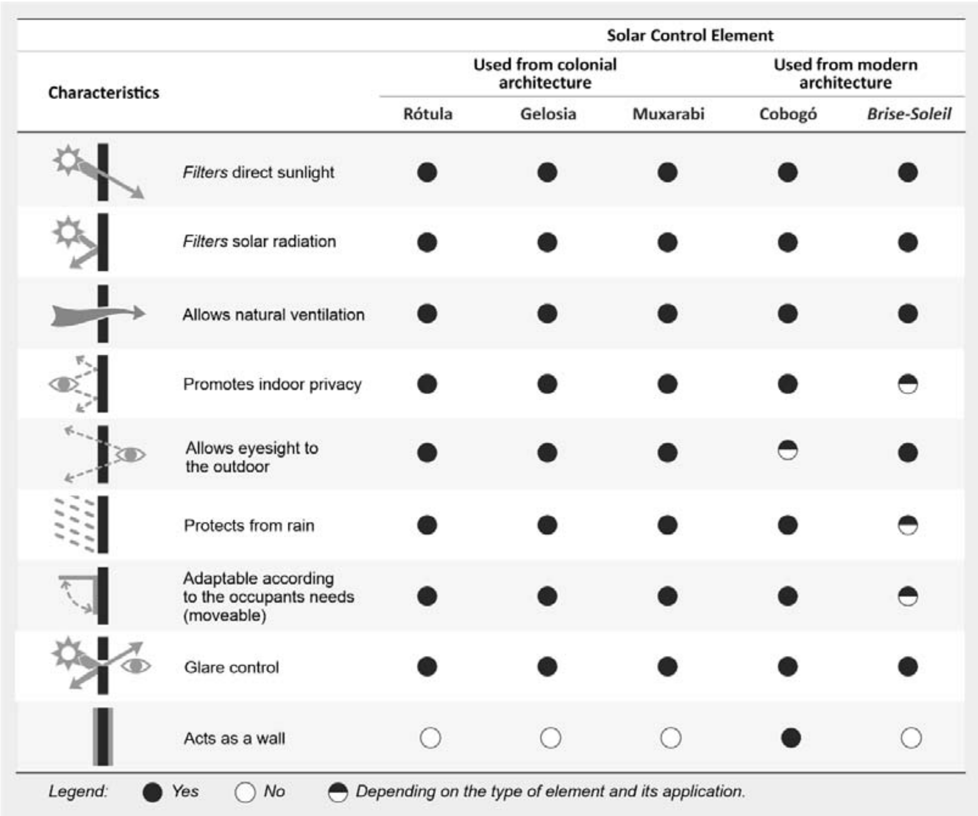


Figure 11. Timeline: influence of solar control elements of Arab origin on Brazilian architecture.

The functional characteristics of the studied solar control elements are summarized in Figure 12. Eight relevant characteristics of the different architectural solutions are highlighted.



Characteristics	Solar Control Element: Used from colonial architecture			Used from modern architecture	
	Rótula	Gelosia	Muxarabi	Cobogó	*Brise-Soleil*
Filters direct sunlight	●	●	●	●	●
Filters solar radiation	●	●	●	●	●
Allows natural ventilation	●	●	●	●	●
Promotes indoor privacy	●	●	●	●	◒
Allows eyesight to the outdoor	●	●	●	◒	●
Protects from rain	●	●	●	●	◒
Adaptable according to the occupants needs (moveable)	●	●	●	●	◒
Glare control	●	●	●	●	●
Acts as a wall	○	○	○	●	○

Legend: ● *Yes* ○ *No* ◒ *Depending on the type of element and its application.*

Figure 12. Analysis of the most relevant characteristics of the solar control elements of Arab architecture influence.

As observed, the practical characteristics of traditional elements in Brazilian colonial architecture of Arab origin are practically identical to those of modern architectural solar control elements. All these elements work as climatic filters, controlling sunlight, solar radiation, and natural ventilation, with the possibility of rain protection and exterior visualization, assisting, to a greater or lesser extent, in the privacy of indoor spaces. *Cobogó* stands out for also serving the function of exterior closure, performing the same function as a wall. Furthermore, the aesthetic features between traditional and modern elements are also quite similar, although with a new interpretation as industrial materials, especially concrete, metal, and ceramics become into use, in contrast to traditional wooden elements.

8. Final Remarks

Throughout the history of Brazilian architecture, the influence of Arab and Moorish architecture has played a crucial role in the search for solutions that provide thermal and luminous comfort in tropical climates. The rediscovery and reinterpretation of these Arab influences by a generation of Brazilian architects in the 20th century highlighted the resilience and relevance of these elements, integrating them into the architectural identity of the country.

Cobogós, brises, and traditional Arabic elements such as *rótulas*, *gelosias*, and *muxarabis* serve as climatic filters. They control solar radiation and natural ventilation, provide protection against rain, and allow external visibility, contributing to the privacy of internal spaces to varying degrees. It is noteworthy that *cobogós* function as exterior enclosures, equivalent to walls, while some brises can be manually adjusted. Elements such as *cobogó* and *brise-soleil*, pioneered by Brazilian architecture, were globally disseminated in the 20th century, contributing to more sustainable buildings by increasing thermal and luminous comfort, and reducing energy consumption.

Currently, society faces increased energy dependency and environmental crises, not only in Brazil but worldwide. Buildings play a significant role in global energy consumption and related greenhouse gas emissions. Effectively controlling solar radiation in buildings, filtering excessive radiation during hot periods, and allowing adequate radiation during cold ones, is an impactful and necessary design strategy. In this context, reinterpreting and adapting traditional architectural elements can contribute to shaping a more sustainable future. The new generations of architects need to value traditional cultural solutions that passively promote thermal and luminous comfort in buildings, thereby reducing the environmental impact associated with energy consumption.

Emerging applications are gaining prominence, such as the use of dynamic solar control facades with adaptable elements able to autonomously manage solar incidence. These systems typically operate with sensors monitoring environmental conditions, allowing automated computer systems to adjust elements as needed. Examples of automation can be found in the Arab World Institute, designed in Paris at the end of the 20th century, and the Bahar Towers, designed in 2012 in Abu Dhabi. These advancements represent a significant step towards more efficient and sustainable buildings.

The use of passive techniques promotes harmony between the building and its context while fostering the connection between inhabitants and their surrounding environment, establishing a relationship with the local climate and culture, resulting in indoor comfort as it reduces the environmental impact associated with energy consumption.

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