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Architecture and the climate: An analysis from a bioclimatic point of view of the Solaris Building project by architect Ken Yeang

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ABSTRACT
The works of Ken Yeang, an architect widely recognized for his work in what is known as "green architecture", stand out for the fact that they are designed taking into account the climatic conditions of the places where his projects are implemented. In this sense, his works are aligned with the concept of bioclimatic architecture, which aims to design buildings adapted to the climate of each region. This article aims to characterize the climate of the city of Singapore and analyze the bioclimatic strategies applied to the Solaris building, evaluating whether these strategies meet local climate needs. The analysis methodology consisted of reviewing project documents, descriptive documents and images available on the website of the architects responsible for the work. The research results reveal the conscious use of certain elements in the building, corroborating the principles of bioclimatic architecture.

KEY-WORDS: Bioclimatic architecture. Thermal comfort. Energy efficiency.

1 INTRODUCTION

With the increase in discussions about global climatic conditions and the impacts they have on humanity, it becomes essential to consider architecture, relating it to the specific needs of each location. Taking advantage of these climate indicators has proven crucial in seeking to create a more sustainable, economical and efficient architecture for users. In this context, the concept of bioclimatic architecture emerges, whose objective is to propose architectural solutions suited to the climatic particularities of each region. (MELLO; SANTOS; DORNELES, 2017).

Bioclimatology, which studies how weather conditions and effects affect the environment and people, has been the subject of research since 1963, when Victor Olgyay and his brother Aladar Olgyay first collaborated in this field. The first work that addressed this topic was the book entitled "Design and Climate: Bioclimatic Approach to Architectural Regionalism", written by the Olgyay brothers, which made them pioneers in this field (OLGYAY, 1998). According to Olgyay (1998), bioclimatology gained greater focus from the 1970s onwards at a time when society began to realize the unrestrained use of energy resources in a way that made these resources exhaustible. From this panorama, buildings became objects of study, in order to make them more efficient from an energy and thermal point of view, thus reducing the use of cooling equipment that requires greater energy use in the building.

It is clear that, due to climate change and the threat it poses to life on the planet, the construction sector is progressively adapting to sustainability concepts, which includes incorporating the concept of bioclimatic architecture into buildings. One of the main supporters of this concept in civil construction is the Malaysian architect Ken Yeang, graduated from the Faculdade Architectural Association and considered a pioneer in the practice of ecological architecture (HAMZAH & YEANG, 2023 a). His works stand out for the use of natural lighting and ventilation, the capture of rainwater and the use of vegetation to provide more efficient buildings, both from a thermal and economic point of view. This contributes to a more sustainable and environmentally responsible construction (RODRIGUES, 2018).

One of the main places where Yeang operates is the city-state of Singapore. This island, which was once part of Malaysia, is one of the most important economic centers in Asia. According to analysis on the World Bank website, the global average GDP (Gross Domestic Product) in 2022 was US$12,647 per capita, while Singapore's average exceeded US$82,800, surpassing even major world powers, such as the United States. United States, for example (BANK MUNDIAL, 2023).

Contrary to what is generally imagined in relation to civil construction, which often grows in a disorderly manner, especially in rapid development scenarios, Singapore has adopted a more responsible approach. The sector is committed to increasing the number of green areas within the city and conserving forest areas. The city, internationally recognized as the "city of nature," plays a significant role in discussions about increasing green areas, both in public and private spaces, controlling heat islands, sustainable management and promoting urban biodiversity (JOSON, 2022).

In this context is the Solaris Building, the object of study in this research. The project was designed by T.R. Hamzah & Yeang Design Team, one of whose partners is architect Ken Yeang, in collaboration with other professionals in the city of Singapore. Construction was carried out between 2008 and 2010, covering a total area of more than 51,000m², including a garden area of 8,363m². In relation to the land area (7,734m²), the green areas of the building represent 108%, highlighting one of the fundamental guidelines adopted by the architect: the intensive use of vegetation (HAMZAH & YEANG, 2023, b).

Additionally, the Solaris Building boasts the BCA Green Mark Platinum Certification, widely recognized as one of the most significant certifications in the field of sustainable construction. This certification evaluates the solutions implemented in construction that meet the criteria of energy efficiency, sustainability and low environmental impact (ECOLOGICAL ARCHITECT, 2016). The purpose of this article is to examine the main bioclimatic strategies adopted in the Solaris Building and understand whether these strategies are aligned with the climatic conditions that characterize the city of Singapore.

2. ANALYSIS METHODS

The analyzes carried out on the Solaris building project, by architect Ken Yeang, will be focused on the aspect of bioclimatic strategies applied to the building, using as a basis documentary analysis through technical drawings, schematic sections and images of the building and its implementation, in order to understand the environment in which it operates and how bioclimatic strategies interact in this scenario.

With regard to climate characterization analysis and recommended bioclimatic strategies based on climatic conditions, two tools will be employed: Clima Date, which performs a comprehensive climate analysis of Singapore using data collected by the Singapore Meteorological Station, and ProjetEEE (Designing Energy Efficient Buildings), which offers the main recommendations for each type of climate.

The ProjetEEE tool, which was developed in collaboration between PROCEL/Eletrobrás and the Federal University of Santa Catarina, has the main purpose of helping students and construction professionals understand local climate factors in the main Brazilian cities. Furthermore, the tool also provides the main bioclimatic strategies recommended for each city, according to the climate results presented (PROJETEEE, 2023).

It is important to highlight that the ProjetEEE tool is a Brazilian platform and, therefore, exclusively covers data and analyzes within Brazilian territory. For this reason, it was decided to use a Brazilian municipality as a reference point for bioclimatic analyses. In this context, the city

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of Belém-PA was chosen, which, in addition to being located in the same climatic zone as the city of Singapore, also has similar climatic characteristics to the city-state.

3. SINGAPORE AND THE CLIMATE

Authors such as Lamberts, Dutra and Pereira (2014) debate the relevance of conducting prior studies on the climatic conditions and location of a new building, anticipating the start of the project. This aims to design an architecture that appropriately and sustainably meets user requirements while promoting an energy-efficient architecture.

To analyze design decisions for the Solaris Building, it is essential to understand the weather conditions that affect Singapore. The city-state is located in a region close to the Equator, therefore, it is subject to the influences of the Equatorial climate. Cities located in this climate zone are known for their hot and humid climate, with a high level of rainfall that is distributed regularly throughout the year and high and constant temperatures. In the Equatorial climate, there is no distinction between the seasons, with an average annual temperature of 26°C. Furthermore, there are no significant variations in temperature between day and night (PINHEIRO, 2013).

For the general characterization of Singapore's specific climate, the Clima Date tool was used, which presents a general table (figure 1) composed of the city-state's main climatic variants.

Figure 1 – Compiled from the main climate data for the city of Singapore.

	Janeiro	Fevereiro	Março	Abril	Maio	Junho	Julho	Agosto	Setembro	Outubro	Novem-bro	Dezembro
Temperatura média (°C)	25.8	26.2	26.7	27.1	27.4	27.3	27	26.9	26.9	26.7	26.3	26
Temperatura mínima (°C)	24.3	24.5	25	25.4	25.7	25.7	25.5	25.4	25.3	25.1	24.8	24.6
Temperatura máxima (°C)	27.9	28.7	29.1	29.2	29.1	29	28.5	28.5	28.6	28.7	28.3	28
Chuva (mm)	168	97	152	198	232	200	199	185	164	214	280	277
Umidade(%)	84%	82%	83%	85%	85%	84%	83%	83%	84%	85%	86%	86%
Dias chuvosos (d)	14	10	16	19	20	18	18	18	16	19	20	18
Horas de sol (h)	8.8	9.1	9.1	8.9	8.8	9.1	9.1	9.1	9.2	9.2	8.7	8.7

Source: ClimaDate, 2023.

The data depicted in Figure 1 demonstrates the absence of significant variations in temperatures throughout the year. Monthly average temperatures remain in the range between 24.3°C and 27.4°C, which confirms a predominantly hot climate. Furthermore, in relation to temperature, it is noted that the number of hours of natural light also remains constant throughout the year. Average hours of sunshine throughout the year vary from 8.7 hours per day to 9.2 hours, indicating a high incidence of sunlight and likely intense exposure to solar radiation. Additionally, the regularity of precipitation can also be seen throughout the months, with emphasis on November and December, which stand out as the rainiest months, while February is the least rainy.

A highly relevant issue to be considered is the relative humidity of the air, which is directly related to the feeling of comfort in relation to temperature. When relative humidity is

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high, even at high temperatures, the sensation is cool. On the other hand, the lower the percentage of relative humidity in the air, the greater the feeling of discomfort and stuffiness (LAMBERTS, 2016).

In the case of Singapore, the relative humidity percentages are within a range that varies from 82% (in February) to 86% (in November and December). Despite the considerably high temperatures in the region, the constant presence of rain, combined with the geographical location of Singapore, which is at the end of a portion of land and is bathed by the Singapore Strait, contributes to maintaining the relative humidity at high levels. This, in turn, helps maintain a more pleasant thermal sensation.

From the climate characterization, it is possible to identify the main bioclimatic strategies recommended to meet the specific demands of each region. Using the ProjetEEE tool and focusing the climate analysis on the city of Belém (PA), which shares similar climatic characteristics to those found in Singapore, we can verify the most suitable bioclimatic strategies for the situation in Belém, which are also applicable to Singapore. Figure 2 represents the main bioclimatic strategies recommended for Belém.

Figure 2 – Main bioclimatic strategies recommended for the city of Belém (PA), also applicable to Singapore.

Source: ProjetEEE, 2023.

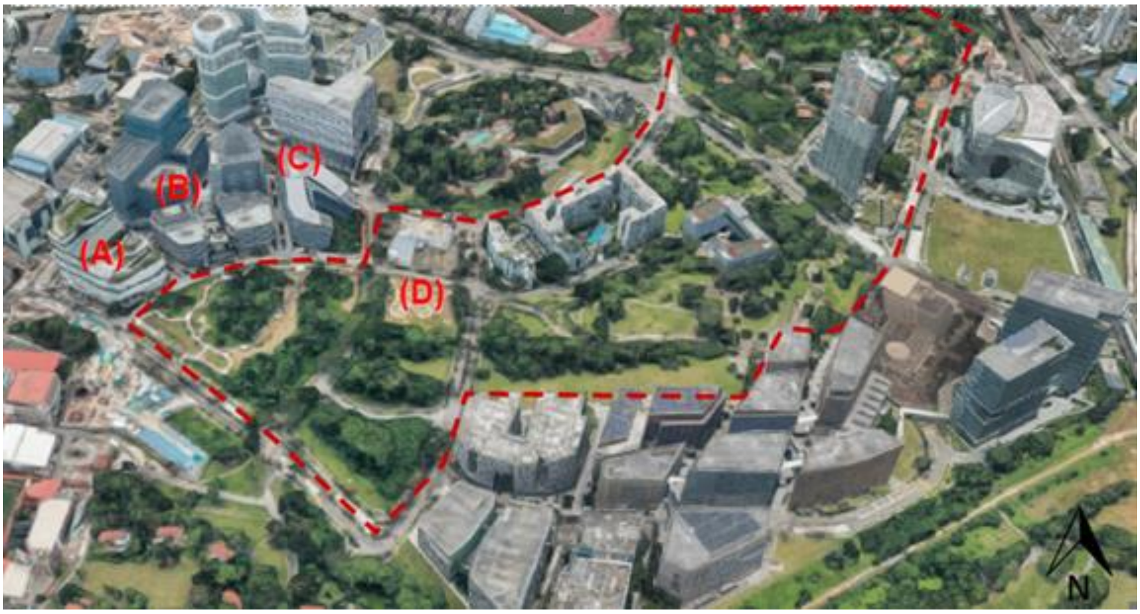
Based on the climate analysis carried out by the tool for the city of Belém, the platform identifies that the city experiences thermal discomfort due to heat during 97% of the year. Therefore, the tool lists the main bioclimatic strategies to be used in buildings subject to these same climatic conditions, following three principles: strategies that promote natural ventilation of environments, shading of buildings and approaches that aim at thermal inertia with a focus on cooling buildings.

Therefore, it is recommended to incorporate elements that promote solar protection as one of the main strategies in building design. It is also essential to consider natural ventilation as a means of renewing air in internal spaces, taking into account strategies that facilitate air circulation, such as cross ventilation and chimney effect ventilation. Furthermore, it is extremely important to consider the properties of materials and elements that contribute to the thermal insulation of buildings, in order to maintain lower internal temperatures compared to external temperatures.

4. THE SOLARIS BUILDING AND BIOCLIMATIC STRATEGIES

The Solaris Building is located in an urban context with notable ecological and technological potential. The buildings neighboring the building house a variety of commercial uses, with companies in the technology sector standing out, and their architecture stands out for the abundant presence of green elements, as well as the adoption of strategies aimed at controlling solar incidence and the use of alternative energy through photovoltaic systems (Figure 3).

Figure 3 - - Implementation scheme for the Solaris Building. (A) Solaris Building; (B) and (C) neighboring buildings being (B) Nexus One-North Space For Rent, which houses several companies; (C) Eclipsi Building which features a kind of internal forest in its entrance hall; (D) One Forest North Park, an important green area present in the region.



Source: Google Earth, adapted by the author (2023).

Another significant aspect related to the construction of the building is the proximity to an urban park, One Forest North Park (Figure 3, d), which covers an extensive green area. This provides users with an interesting integration between the urban environment and nature. In certain sections, visitors can walk along walkways suspended high in the treetops, while at other times, they have the option of walking at level public sidewalks or paths between buildings. The presence of this park contributes to the creation of an urban microclimate that can mitigate the effects of heat islands due to the abundant presence of vegetation.

Regarding the construction characteristics of Solaris, the building consists of two towers, the tallest tower with 15 floors and the lowest tower with 9 floors. The configuration of the towers allows the creation of garden terraces on the roofs, which contributes to increasing the thermal inertia of the building. Furthermore, these towers are connected by a central atrium

(Figure 4), which serves not only the function of connecting these two elements, but also of providing natural lighting and ventilation to the interior of the building.

Figure 4 – External view of the building with an indication of the towers and the connecting element between them, the central atrium.

Source: HAMZAH & YEANG, adapted by the author (2023).

The main guidelines adopted in the building's design aimed to preserve the surrounding ecosystem, with the aim of increasing the region's biodiversity and creating a building that required minimal use of cooling equipment, such as air conditioners, in order to promote efficiency. energy. To meet these guidelines, the architect incorporated elements to control solar radiation, such as the use of horizontal brises, combined with abundant vegetation, transforming the building into a natural habitat that encourages connection with nature, an approach known as biophilia. Figure 5 presents, through a schematic section, the main strategies that not only meet the project guidelines, but also incorporate bioclimatic strategies appropriate for the Equatorial climate zone.

Figure 5 - Schematic section indicating the main bioclimatic strategies used by architect Ken Yeang.

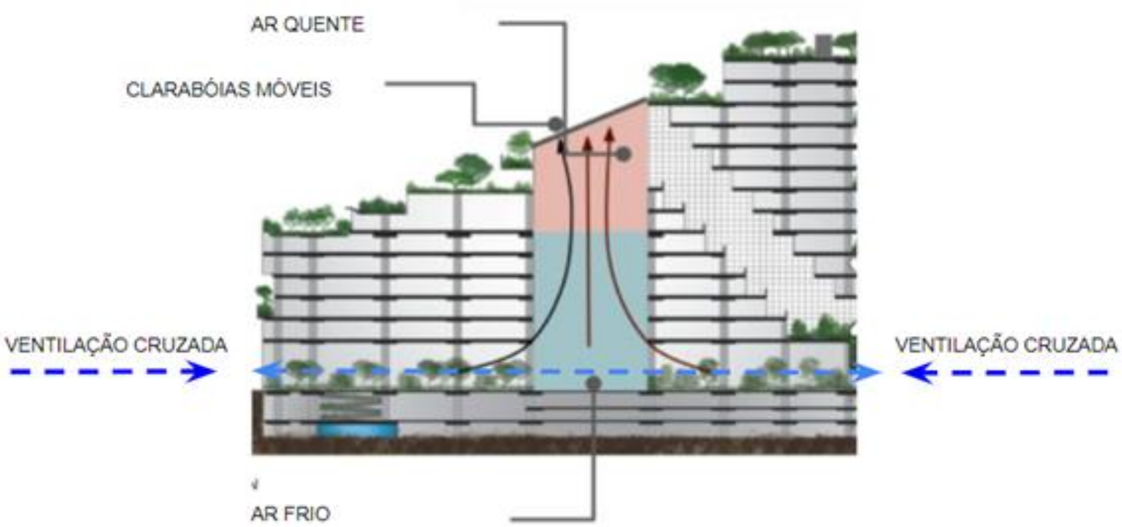
Source: HAMZAH & YEANG, adapted by the author (2023).

When analyzing the strategies used in the Solaris Building, it is evident that most of them have solar protection as their main objective, at the same time as they make use of natural lighting as a resource that promotes energy savings inside the building. Figure 5 illustrates the creation of a kind of light well that crosses the main tower of the building. This strategy allows the tower's internal environments, which, due to its typology, would not have access to natural lighting due to the distance from the building's openings, to be covered by this lighting and also by natural ventilation. Inside this light gap, small balconies were created that not only receive vegetation, contributing to the concept of biophilia, but also open up the environments to this space.

In addition to the implementation of the light well to save electricity, the building is also equipped with integrated sensor systems that use technology to evaluate the luminosity of environments according to their specific demands. In this way, the sensors activate the luminaires when they identify the need for lighting and turn them off when they realize that it is no longer necessary.

Just like the light well, the project has a central atrium, which in addition to connecting the two towers of the project, also serves as an element to carry out internal air exchange through the chimney effect. In this sense, the cross ventilation promoted on the ground floor together with the presence of abundant vegetation, produce a pleasant microclimate and thermal sensation for users. However, as the internal air mass remains in the space, the air tends to heat up, which in turn increases the feeling of discomfort and stuffiness inside. To avoid this issue, the central atrium works with a chimney, designed to remove hot air from inside the building. Figure 6 schematically illustrates how this air exchange works.

Figure 6 – Ventilation change diagram. Cold air enters and hot air is removed, keeping the building at comfortable thermal levels.



Source: HAMZAH & YEANG, adapted by the author (2023).

The upper part of the atrium has several skylights that are controlled by automatic systems capable of detecting the building's internal temperature. They open to eliminate hot air, keeping only the cooler air inside the building. Furthermore, the skylight system is also sensitive to the presence of rain, automatically activating itself to close its openings when necessary.

Another feature that stands out, not only in the Solaris project, but also in other buildings designed by Ken Yeang (Figure 7), is the notable presence of vegetation around the building. This vegetation plays a fundamental role in the thermal inertia cooling strategy and in the formation of a natural shading barrier. According to a report on the Ecological Architect website (2016), the use of vegetation in the project results in a 36% reduction in electricity consumption compared to other buildings of similar size located in the same region where the Solaris Building is located and which do not They feature expressive vegetation in their design. This reduction in consumption is attributed to the reduction in the building's thermal transmittance, which is only 39W/m², in significant contrast to, for example, the use of 8mm laminated glass, which has a thermal transmittance of 5,700 W/m², of according to simulations carried out by the ProjetEEE platform (2023). In this aspect, it is possible to understand that vegetation plays a role that goes beyond aesthetics in Yeang's projects, actively contributing to reducing the energy consumption of his buildings.

In addition to low thermal transmittance, vegetation plays a crucial role in Ken Yeang's works, contributing to improving air quality, reducing CO2 emissions (carbon dioxide, a gas harmful to the ozone layer), stimulating evapotranspiration , mitigating the negative effects of urban heat islands, controlling the propagation of urban noise into buildings, creating a natural habitat for animal species that already inhabit the region and the use of plant mass as a living system for air filtration.

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Figure 7 – Projects by architect Ken Yeang that emphasize the use of vegetation in their composition. (A) Shenzhen Complex (China) in the implementation phase. (B) Editt Tower (Singapore) under construction.

Source: HAMZAH & YEANG, 2023.

Vegetation is integrated into the Solaris design through the creation of a continuous external ramp. This ramp extends the ecosystem already present in the region, which originates in the park adjacent to the building, One Forest North Park. The ramp is three meters wide, intended for planting native plant species and offering a passage between the building and the flower beds, thus facilitating the maintenance of vegetation without the need to access internal commercial spaces (Figure 8). Due to its width, this structure generates overhangs that provide double shading. At the height of the ramp, the shading is provided by the vegetation cover, while, at the level below the ramp, the shadow is projected by the ramp structure itself.

Figure 8 – Ecological ramp. (A) Operation of the ecological ramp with the space dedicated to vegetation and the maintenance walkway. (B) General panorama of the ecological ramp that runs along the building.

Source: HAMZAH & YEANG, 2023.

Regarding solar protection, the building has horizontal brise systems around the entire building (Figure 9). The system is designed to provide shading to the internal environment as needed both at the equinox (solar position perpendicular to the Earth) and at the solstice (solar position with greater inclination), indicating the total control that the architect has over the path that the solar projection has in relation to the building and the importance of computer simulations in this process.

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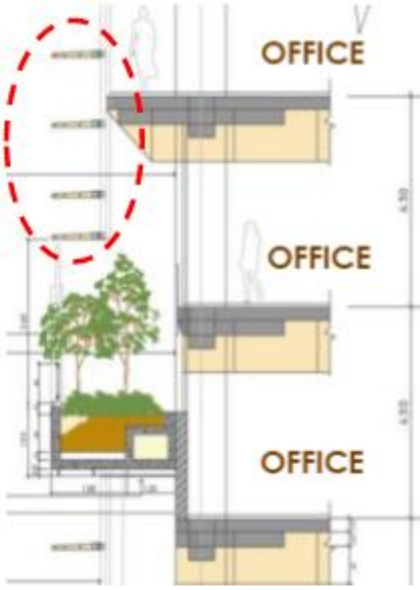
Figure 9 – Schematic section and location indication of the horizontal brises present in the project to control solar incidence.



Source: HAMZAH & YEANG, 2023.

Proving once again the importance of understanding all the climatic variations of each region, the Solaris Building was designed to take advantage of the constant rainfall to which the city-state of Singapore is subject throughout the year. In this sense, the building has systems that allow the collection and reuse of rainwater. This strategy is used both to capture rainwater through garden terraces and through pipes present in the ecological ramp's beds. The water is carried through pipes to a system called by the architect an "eco cell" (Figure 10).

Figure 10 – Eco-cell system created by Ken Yeang as a way of reusing rainwater. From the images, you can see the path taken by the waters that are carried from the ramps and vegetated terraces by pipes to the eco-cell,

Source: <https://www.architectsjournal.co.uk/archive/llewelyn-davies-yeang-goes-out-of-business>. Acess: set. 2023.

The eco cell is located at the beginning of the ecological ramp, where there is a vertical garden that camouflages the pipe system that directs rainwater to spiral ramps that take these waters to a reservoir located underground. This space is reused both as a water receptacle and as an opening in the structure that provides natural lighting and ventilation to the basement floors, which for the most part do not receive this type of treatment. The water is redirected through pumping systems to the vegetation beds, where they feed the plants, thus reducing the building's water consumption in maintaining the abundant vegetation present in the project. This strategy is also used in other buildings created by the architect. One of these projects is the Suasana PJH building, located in Putrajaya, where the eco cell is implemented in a similar way to the Solaris Building, integrating the open space and the basement floors.

4. CONCLUSION

Both the analysis of the Solaris project and the research into other works by architect Ken Yeang show the uniqueness that the professional presents with regard to the sensitivity of creating responsible architecture from an environmental, ecological and sustainable point of view. His works demonstrate the care in considering the particularities imposed by the conditions of each location as a starting point for his projects. Furthermore, it can be stated that, in the case of the Solaris Building, the bioclimatic strategies considered appropriate for the city of Belém (PA), used as a reference city due to its climatic conditions similar to those of Singapore, are adopted in several aspects and in different elements of construction.

However, some questions are necessary regarding the design choices in the case of the Solaris Building. Although the building proposal has unquestionable relevance from a thermal, ecological, sustainable and climate-friendly point of view, it is important to note that the project still demands a large energy consumption, especially due to its use, which houses companies focused on technology, which, par excellence, require large machines that, in turn, consume a significant amount of electrical energy.

In this sense, it is clear that the project did not include strategies that would contribute to the generation of alternative energy. For example, there is no use of solar energy, as can be seen in the surrounding buildings. According to a report on the website Pensar Contemporâneo (2021), the city-state has limited resources for generating energy through wind or hydroelectric systems, with the natural gas system being the main source of energy generation, representing 95% of the matrix energy. However, there are increasing investments in the area of energy generation considered clean, such as photovoltaic systems. Due to the limitation of its territorial extension, a solution found for the generation of photovoltaic energy was the creation of floating solar parks. These parks generate energy by capturing sunlight and taking advantage of the electrical currents created by friction between the panels and the movement of waves (PENSAR CONTEMPORÂNEO, 2021).

Relating the region's energy matrix and the importance of generating alternative energy in this scenario, it is up to future studies to carry out an investigation that seeks to justify the lack of strategies aimed at generating renewable energy in buildings, especially considering the surroundings in which the building is located. where these systems are present in neighboring buildings and considering the high energy demand that the uses present in the building end up requiring.

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