INFLUENCE OF PAVING SURFACES ON THERMAL COMFORT

INFLUÊNCIA DAS SUPERFÍCIES DE PAVIMENTAÇÃO NO CONFORTO TÉRMICO

LA INFLUENCIA DE LAS SUPERFICIES DE PAVIMENTACIÓN EN EL CONFORT TÉRMICO

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ABSTRACT
Constructive densification, increased asphalt paving, lack of vegetation, and climate change are factors contributing to the formation of heat islands in urban centers. This study aimed to investigate the characteristics of different pavement surfaces in the vicinity of the University of Contestado and their influence on thermal comfort. It is an applied research with a predominantly qualitative approach, a case study type, using a thermo-hygrometer for data collection at points distributed in the surroundings of the Concórdia and Mafra campi of the University of Contestado. The results show that surfaces covered with asphalt have the worst indices, with higher temperature and lower air humidity, while surfaces with vegetation have the best indices with lower temperature and higher air humidity. The study allows the conclusion that the presence of vegetation in the vicinity of the University can directly influence the reduction of heat island effects in urban areas, as it acts on the control of air temperature and humidity, as observed in both study environments.

KEYWORDS
Urban surfaces. Constructive densification. Microclimate control. Heat islands. Asphalt paving.

RESUMO
O adensamento construtivo, aumento da pavimentação asfáltica, ausência de vegetação e mudanças climáticas são fatores que contribuem para a formação das ilhas de calor nos centros urbanos. Este estudo teve como objetivo investigar as características das diferentes superfícies de pavimentação nos entornos da Universidade do Contestado e sua influência no conforto térmico. Se trata de uma pesquisa de natureza aplicada, com abordagem predominantemente qualitativa, do tipo estudo de caso, com uso de termo higrômetro para a coleta de dados em pontos distribuídos nas vizinhanças do campus de Concórdia e Mafra da Universidade do Contestado. Os resultados mostram que a superfície com cobertura asfáltica apresenta os piores índices, com maior temperatura e menor umidade no ar e as superfícies com vegetação apresenta os melhores índices com menor temperatura e maior umidade no ar. O estudo possibilita concluir que a presença de vegetação nos entornos da Universidade pode influenciar diretamente na redução dos efeitos das ilhas de calor em áreas urbanas, pois atua no controle da temperatura e umidade do ar, como observado em ambos os ambientes de estudo.

PALAVRAS-CHAVE
Adensamento construtivo. Controle do microclima. Ilhas de calor. Pavimentação asfáltica.

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RESUMEN

La densidad de construcción, el aumento de pavimentación asfáltica, la falta de vegetación y el cambio climático son factores que contribuyen a la formación de islas de calor en los centros urbanos. Este estudio tuvo como objetivo investigar las características de diferentes superficies de pavimento alrededor de la Universidad de Contestado y su influencia en el confort térmico. Se trata de una investigación de carácter aplicado, con enfoque predominantemente cualitativo, del tipo estudio de caso, utilizando un termohigrómetro para la recolección de datos en puntos distribuidos en las cercanías de los campus de Concordia y Mafra de la Universidad del Contestado. Los resultados muestran que la superficie con cobertura asfáltica presenta los peores índices, con mayor temperatura y menor humedad en el aire y las superficies con vegetación presentan los mejores índices con menor temperatura y mayor humedad en el aire. El estudio permite concluir que la presencia de vegetación alrededor de la Universidad puede influir directamente en la reducción de los efectos de las islas de calor en las zonas urbanas, ya que actúa controlando la temperatura y la humedad del aire, como se observa en ambos ambientes de estudio.

PALABRAS CLAVE

Superficies urbanas. Densificación constructiva. Control del microclima. Islas de calor. Pavimentación asfáltica.

1. INTRODUCTION

The increase in building density in Brazilian cities occurs without due attention to the effects on microclimates, which enhances the creation of thermally uncomfortable open spaces (MACHADO DOS SANTOS *et al.*, 2023). Climate change is causing environmental, social, and economic impacts due to extreme weather events, such as heavy rainfall and flooding (VASCONCELLOS *et al.*, 2023).

These and other events associated with climate change affect people's quality of life, especially in subtropical cities (SANTAMOURIS, 2020). As a solution, studies indicate the need to recognize the history, social and material relations, and trajectories that shape people's lives in any urban governance process aimed at combating climate change (CASTÁN BROTO, 2017).

The increase in temperatures in heat islands is more pronounced in areas with higher intensity of human occupation and less pronounced in areas covered by vegetation (KRÜGER; PEREIRA, N. H. G., 2020). Hence, the characteristics of the city serve as a barometer of urban climate, whereby its impermeabilization with paved areas and the reduction of green spaces lead to an increase in temperature levels and a decrease in air humidity, causing discomfort to its inhabitants (NERES; SILVA; PEREIRA, M. A. B., 2021).

Climate change can also be a significant factor when studying urban microclimates and their impacts on the quality of life of the population. Sustainable construction and the quality of surroundings can mitigate the effect of the urban heat island (ZIMMERMANN *et al.*, 2019). The characteristics of surfaces surrounding buildings can also impact urban microclimates. Trees are considered the best natural climate regulators, acting to balance the microclimate. Therefore, cities need to incorporate tree-planting programs into their projects (MARTINI; BIONDI; BATISTA, 2022; PINHEIRO; SOUZA, 2017; VASCONCELLOS *et al.*, 2023).

In the presented context, this study aims to investigate the characteristics of different paving surfaces in the surroundings of the University of Contestado (Concórdia and Mafra campi) and their influence on thermal comfort. To achieve this objective, an evaluation of temperature and humidity characteristics, important factors in urban microclimates, was conducted. The study presents the results of the evaluation of 10 points located on the Concórdia campus and 10 points located on the Mafra campus, using the same method and instruments, with data collection performed at a one-week interval between collections at each campus.

This study stands out by focusing on the specific characteristics of paved surfaces near the University of Contestado and their impact on thermal comfort. While many studies address heat islands broadly, this applied and qualitative research uses a case study to directly analyze how different types of pavement influence air temperature and humidity in specific urban areas. The novelty of the study lies in the detailed analysis of paved and vegetated surfaces around the University of Contestado, providing concrete data that highlight the importance of vegetation in controlling the urban microclimate, something that may not be as thoroughly addressed in other studies.

2. INTELLIGENT AND SUSTAINABLE

Smart cities should integrate cutting-edge technological solutions to tackle air quality issues, which can affect temperature and other microclimate factors. Cities can reduce their carbon footprint by measuring the reduction in emissions of pollutants resulting from technology use. Therefore, urban sustainability in smart cities can be impacted through the utilization of control Technologies (AHAD *et al.*, 2020). However, the use of technologies for smart cities can have both positive and negative impacts on urban microclimate, depending on how they are designed and implemented (MARTIN; EVANS; KARVONEN, 2018).

The impacts of climate change on urban microclimates can already be observed in various locations around the planet, often resulting in mortality related to socioeconomic and demographic factors, as well as specific health problems, especially in subtropical cities (SANTAMOURIS, 2020). In this circumstance, studies show that climate change can be an important factor to consider when studying urban microclimates, as well as their impacts on the quality of life of the population.

In San Francisco, California, measurements were taken at 26 points within a 250-meter radius, where it was observed that temperature and air humidity are important factors in urban microclimates and can significantly affect building energy usage and environmental comfort (HONG *et al.*, 2021).

In India, satellite data collection revealed critical heat zones in the summer in the central areas of two megacities (New Delhi and Kolkata), showing temperature variations between vegetated and built-up regions, with a difference of 8.76°C on one night (DUTTA; BASU; AGRAWAL, 2022). Based on the distribution of area, location, thermal amplitude, and contribution to the formation of heat islands, sustainable planning strategies were developed for each local climatic zone.

In Brazil, a study analyzes the impact of building characteristics, such as building height, on thermal comfort and energy balance, after analyzing variables such as temperature, humidity, solar radiation, wind speed, and direction. The study concludes that in taller buildings, temperatures are higher, and wind speeds are lower in the surrounding area (CARFAN; GALVANI; NERY, 2012).

In the city of Bagé (RS), another study of urban microclimate shows that shading caused by the verticalization of buildings can favor thermal comfort in hot climates but tends to be unfavorable to the climate during winter periods due to shading in open spaces (MACHADO DOS SANTOS *et al.*, 2023).

The studies cited demonstrate that sustainable construction practices can help mitigate the urban heat island effect, which is a phenomenon where urban areas experience higher temperatures than surrounding rural areas due to the absorption and retention of heat by buildings and other infrastructure (ZIMMERMANN *et al.*, 2019). Furthermore, sustainable buildings can help promote more sustainable lifestyles and reduce the overall environmental impact of human activities.

Urban Heat Islands (UHI) is a microclimatic phenomenon affecting urban areas, causing temperature increases that amplify heat waves and reduce quality of life. A review of studies in 14 cities across 13 countries showed that specific urban characteristics present different challenges. The study suggests that maintaining and expanding urban green spaces can reduce the impacts of heat islands. (LEAL FILHO *et al.*, 2021).

The presence of vegetation can directly influence urban heat islands and help reduce temperatures in urban areas. Studies on morphological classification reveal a relationship between local climatic zones and the resulting thermal field (KRÜGER; PEREIRA, 2020).

According to Martini, Biondi, and Batista (2022), trees are considered the best-existing climate regulators, acting naturally to stabilize the microclimate. They can help mitigate the effects of urban heat islands, heat stress, extreme precipitation, coastal flooding, soil erosion, air pollution, drought, and water scarcity, which are some of the global risks resulting from climate change concentrated in urban areas.

Regarding thermal performance, data collection in urban spaces is important for the calibration and validation of climatic models, which can be used to assess different urban scenarios and their microclimatic conditions (NOVAES; MONTEIRO, 2022).

3. MATERIALS AND METHODS

The present study was conducted during the course "Sustainable Technologies Applied to Engineering," offered by the Professional Master's Program in Sanitary and Environmental Civil Engineering (PMPECSA) in the first semester of 2023. It is an applied research, with a predominant qualitative approach, of the case study type. The case study entails a few objects with extensive and detailed knowledge, a task practically impossible through other considered designs, with results for the convergence or divergence of observations obtained from different procedures (GIL, 2002).

3.1 Study Area

The chosen location was the University of Contestado, at the Concórdia Campus (Figure 1, left), at the geographic coordinates (-27.217626311866873, -51.99542929565719), and at the Mafra Campus (Figure 01, right) at coordinates (-26.132242727948107, -49.80873483918057), in the state of Santa Catarina, Southern Brazil. In both locations, the terrain is relatively flat, with an average altitude of 690 m at the Concórdia campus and 815 m at the Mafra campus.

In Concórdia, throughout the year, the temperature ranged from 8°C to 32°C and rarely fell below 1°C or exceeded 37°C. In Mafra, the temperature ranged from 9°C to 28°C and rarely fell below 4°C or exceeded 31°C. In both locations, summers are hot and humid, and winters are cold and dry, with June and July being the coldest months (SPARK, [s.d.]).

3.2 Data Collection, Recording, and Analysis Method

Initially, 10 collection points were determined (Figure 01), using criteria such as surface characteristics (concrete, asphalt pavement, vegetation, soil), surroundings (presence of vegetation or buildings), and the distance between consecutive points, as in previous studies (GRIGOLETTI; LAZAROTTO; WOLLMANN, 2018; MARTINI; BIONDI; BATISTA, 2022), the developed method involved the use of geotagged photos, direct observation, and in-situ measurements of temperature and air humidity.

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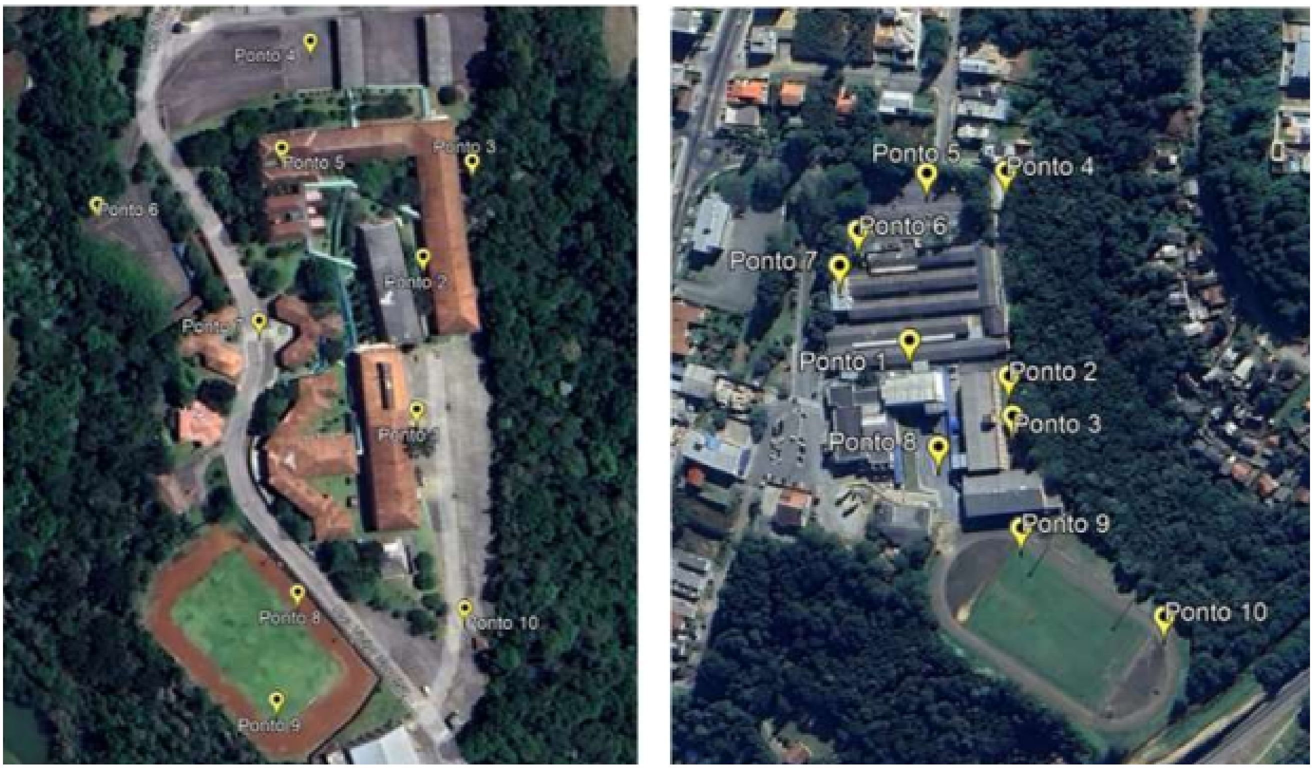

Figure 01: Data collection points location for Concordia campus (left) and Mafra (right).
Source: Adapted from Google Earth.

For each point, 10 measurements of temperature and relative air humidity were taken, with a 1-minute interval between each measurement. At each point, the equipment was allowed to stabilize in temperature and relative air humidity values, and simultaneously, geotagged photographic records were taken, along with notes regarding observations of the environment and its surroundings.

The observation (Figure 02) of the surroundings at the points was considered, as previous studies "demonstrate that increased building density limited to three-story buildings during the hottest period of the day (at 2:00 p.m.) minimally alters the microclimate in the analyzed block [...] (MACHADO DOS SANTOS *et al.*, 2023, p. 8). In addition to buildings, forests, ground cover, orientation, and street width influence microclimatic variables due to the amount of solar radiation received (MARTINI; BIONDI; BATISTA, 2022).

Data collection at the Mafra campus took place on July 1, 2023, from 2:00 p.m. to 5:00 p.m. And at the Concórdia campus, it was on July 7, 2023, at the same time, under sunny weather conditions. A term-hygrometer with a sensor installed on a tripod 25 cm from the surface was used as the data collection instrument. The data recording and analysis were conducted in spreadsheets using Microsoft Excel.

Figure 02: Characteristics and physical conditions of the studied points.
Source: Authors.

4. RESULTS AND DISCUSSIONS

Ten collections were conducted with a 1-minute interval for each of the 10 points. The results indicate similarities in surface conditions when comparing the Mafra and Concórdia campi. The data show that there was solar incidence at most points, with surfaces including concrete, asphalt, and soil being considered.

The table below (Table 1) shows the characteristics of the surface and solar conditions of the collection environment. Data analysis reveals variations in temperature averages and relative air humidity indices at both the Mafra and Concórdia campi. At the Concórdia campus, the best indices (higher values for air humidity and lower values for air temperature) were at point 3 (68% and 23°C) and point 9 (60% and 24°C), both with surfaces covered by grass.

In a previous study (MARTINI; BIONDI, 2015), For all seasons, the statistics demonstrate the influence of vegetation on meteorological variables (temperature and air humidity) and on the thermal comfort index. Point 5, which has a surface covered with basalt gravel, also showed good results (57% and 24°C).

At the Mafra campus, the points with the best indices, higher relative air humidity, and lower temperature were points 1 (77% and 20°C), 4 (69% and 21°C), and 10 (76% and 21°C). The surface of points 1 and 4 is smooth concrete, located between the campus buildings, both with tree presence and solar incidence. The hypothesis is that the presence of buildings contributed to heat loss in the concrete, considering that low temperatures were recorded on previous dates.

Another factor that may have contributed was the presence of green areas near the evaluated site, as the literature emphasizes the importance of forests for environmental comfort (MARTINI; BIONDI; BATISTA, 2022). Therefore, these two points (points 1 and 4) in the summer period may be influenced differently (temperature gain and humidity loss). Point 10, with a gravel surface, near the sports field, with vegetation presence (grass) near the point.

Campus	Point	Surface Characteristics	Solar Condition
Concordia	1	Smooth concrete floor	Without sun
	2	Concrete blocks (hexagonal)	With Sun
	3	With grass	Without sun
	4	Asphalt pavement	With Sun
	5	Gravel surface	Without sun
	6	Concrete blocks (hexagonal)	With Sun
	7	Concrete blocks (hexagonal)	With Sun
	8	Gravel surface	With Sun
	9	With grass	With Sun
	10	Concrete blocks (hexagonal)	Without sun
Mafra	1	Smooth concrete floor	With Sun
	2	Gravel surface	With and without sun
	3	Asphalt pavement	With Sun
	4	Smooth concrete floor	Without sun
	5	Asphalt pavement	With Sun
	6	Asphalt pavement	With Sun
	7	Asphalt pavement	With Sun
	8	Concrete blocks (interlocking)	With Sun
	9	With grass	With Sun
	10	Gravel surface	With Sun

Table 1: Characteristics and physical conditions of the studied points
Source: Authors.

At the Mafra campus (Figure 03), the point with the worst comfort condition was point 5 (54% and 28°C), with an asphalt surface and close to the masonry building. The initial and final collection points were close to green areas with tree presence, a factor that may have contributed to thermal comfort.

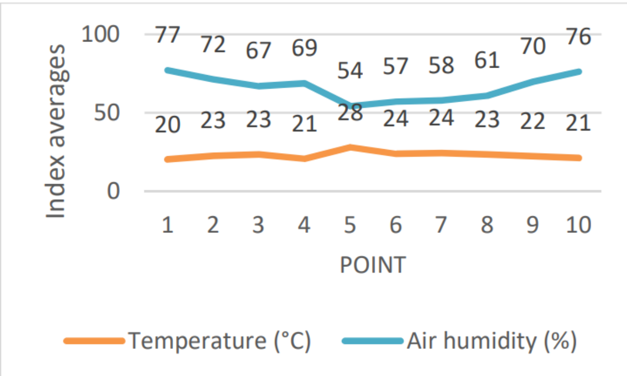

Figure 3: Mean temperature and humidity indices of the points at Mafra Campus.
Source: Authors.

At the Concórdia campus, the worst air humidity and temperature indices observed were recorded at points 4 (45% and 30°C) and 7 (45% and 31°C), both with asphalt and hexagonal concrete surface, exposed to solar incidence (Figure 04). Callejas, Durante, and Rosseti (2015) consider asphalt as "one of the main contributors to the formation of heat islands in cities" (p. 64). The results of the data collected in this study corroborate the assertion of these authors.

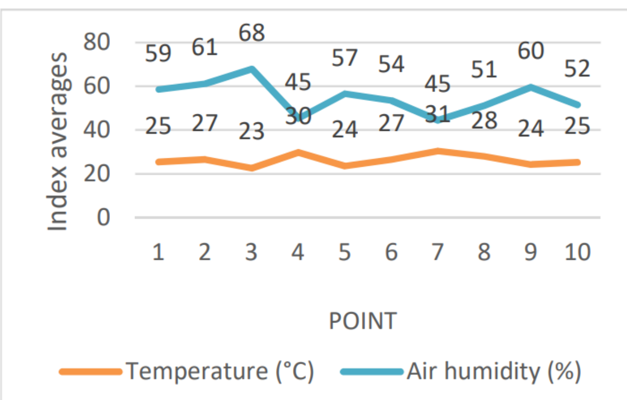

Figure 4: Mean temperature and humidity indices of the points at Concórdia Campus.
Source: Authors.

High levels of air humidity can exacerbate the perception of thermal discomfort in urban areas, affecting the body's ability to cool itself through the evaporation of sweat, leading to a higher perceived temperature and reduced thermal comfort. Likewise, higher temperatures can cause heat stress and discomfort among residents, especially during heat waves or prolonged periods of hot weather. Therefore, the combination of air temperature, humidity, wind speed, and radiation influence thermal comfort levels in urban environments. (ZHAO *et al*., 2021). The results of measurements carried out on different surfaces show the points where there is greater or lesser comfort when observing the humidity and air temperature levels.

The temperature data collection took place during July 2023, corresponding to the winter period in the study region. It was observed that the average temperatures recorded during this period ranged between 24°C and 31°C in Concórdia and 20°C to 28°C in Mafra, exceeding historical averages for the winter season. These elevated temperatures may have significant implications for understanding seasonal climate variations and for activities dependent on thermal conditions in this specific region.

In Oslo (Paris), temperatures in the hottest month are expected to increase by more than 5°C by 2050. Satellite measurements showed that on one of the hottest days in 2018, areas with paved buildings reached 39°C, while areas with vegetation maintained between 29 and 32 °C. The results indicate that the maintenance and restoration of tree cover reduces urban heat (VENTER; KROG; BARTON, 2020). This result observed in Oslo agrees with the results obtained in our study.

Understanding seasonal climate variations is crucial for assessing their impact on thermal comfort and energy demands, as thermal comfort directly influences heating and cooling needs. Understanding seasonal climate variations is crucial for assessing their impact on thermal comfort and energy demands, as thermal comfort directly influences heating and cooling needs, as evidenced by a study conducted on 505 residential buildings in six cities located in China's Hot Summer and Cold Winter zone (LIU *et al*., 2017). However, these variations were not a relevant variable for this research.

5. CONCLUSION

The study aimed to assess the influence of surfaces on thermal comfort by evaluating temperature and relative air humidity indices at different points located in outdoor areas of the University of Contestado. The research, conducted in the course "Sustainable Technologies Applied to Engineering," was a case study at the Concórdia and Mafra campi. The analyzed surfaces included concrete pavement (smooth and in hexagonal blocks and interlocking pavers), asphalt-covered surface, grass, and soil and gravel surface.

The collected and analyzed data show that surfaces with vegetation and stone (gravel or pebble) were the ones that presented the best thermal comfort conditions. The data also provide evidence of the importance of urban vegetation for good thermal comfort conditions. The presence of vegetation can directly influence the reduction of heat islands and temperature control in urban areas, as observed in both study environments on the Concórdia campus (figure 05) and the Mafra campus (Figure 06).

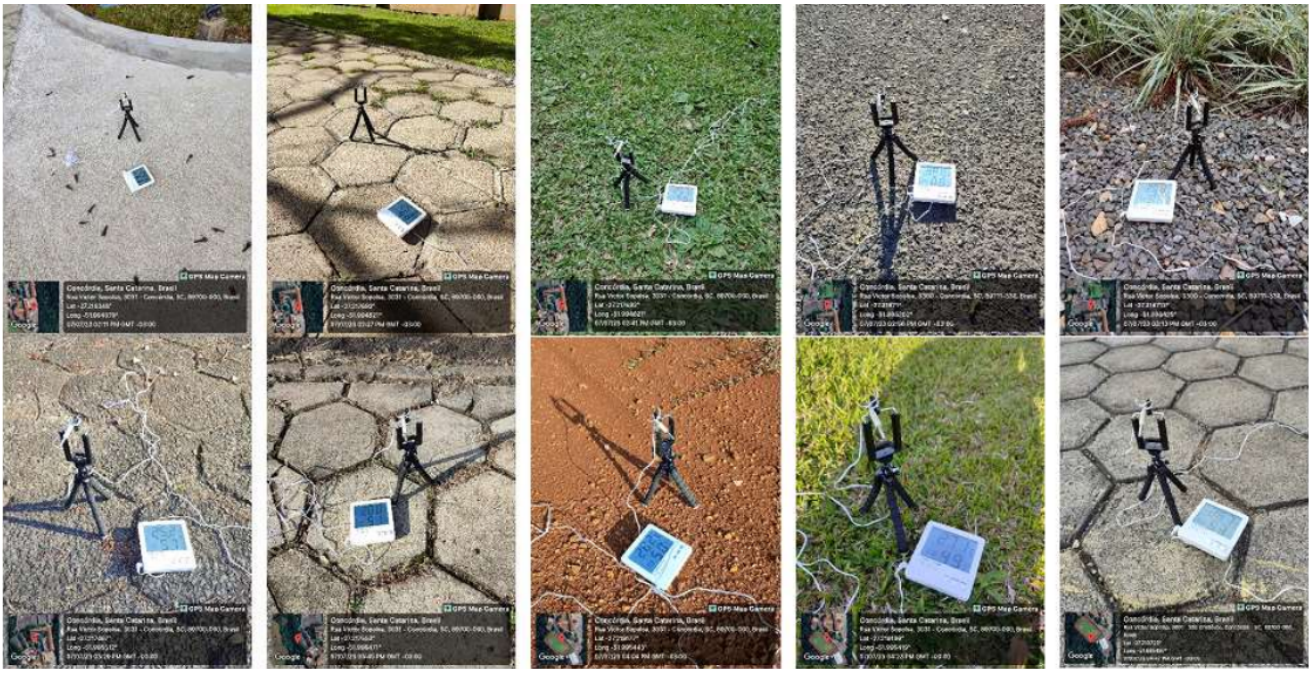

Figure 5: Characteristics of the surfaces analyzed on the Concórdia campus.
Source: Authors.

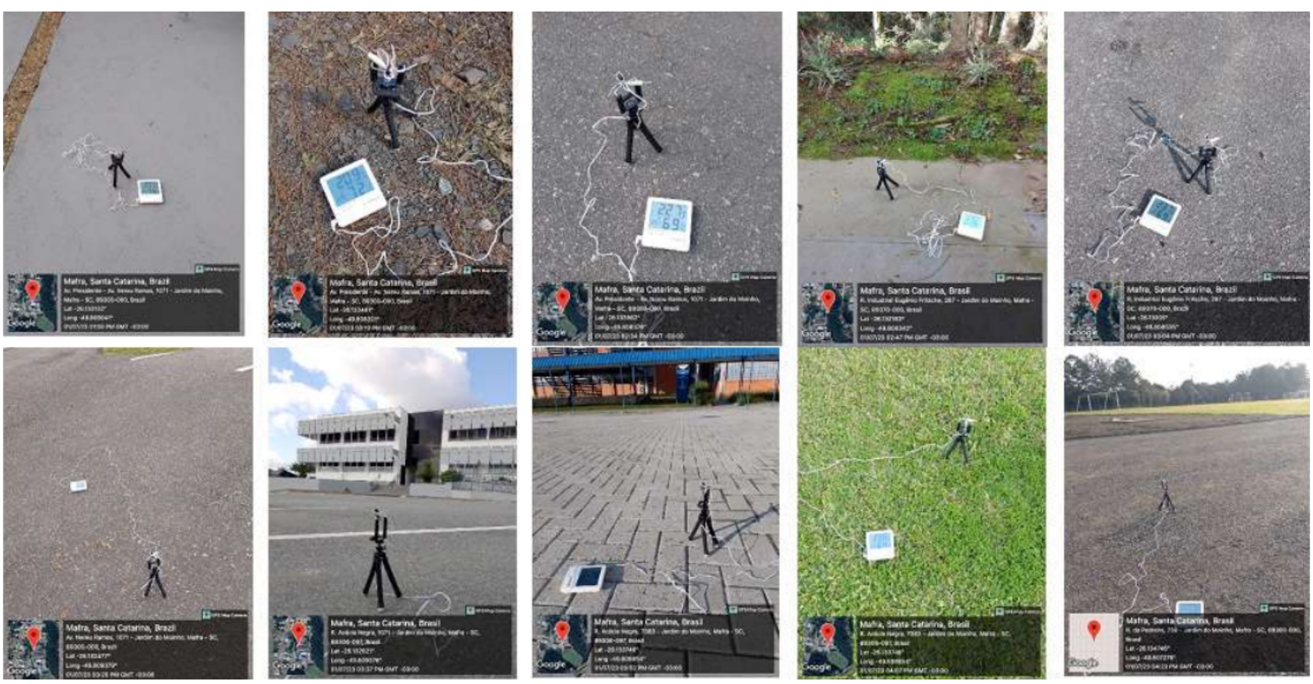

Figure 6: Characteristics of the surfaces analyzed on the Mafra campus.
Source: Authors.

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