



Impact of heat on the deterioration of facades of the industrial heritage of the Peruvian Sierra

Impacto del calor en el deterioro en fachadas del patrimonio industrial de la Sierra Peruana

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ABSTRACT Urban heat and environmental pollution contribute to the deterioration of architectural heritage. Therefore, this research aims to analyze the impact of climatic, social, and environmental urban variables on heritage façade materials in three phases: identification of damage indexes based on materiality, observational flow analysis, and analysis of climate variability and wind chill using a thermographic camera and hygrometer. The results show that wood and ignimbrite are the materials most affected by heat and pedestrian behavior influences pedestrian traffic, choosing alternative routes to avoid discomfort caused by wind chill. This study aims to contribute to material analysis and develop conservation strategies for these types of heritage façades, addressing current environmental challenges and ensuring their durability over time.

RESUMEN El calor urbano y la contaminación ambiental contribuyen al deterioro del patrimonio arquitectónico. Debido a ello, esta investigación tiene por objetivo analizar el impacto de variables climáticas y variables sociales urbanas y ambientales, en los materiales de las fachadas patrimoniales, en tres fases: identificación del índice de daños según materialidad, análisis de flujo por observación y análisis de la variabilidad climática y sensación térmica con el uso de cámara termográfica e higrómetro. Los resultados evidencian que la madera y la ignimbrita son los materiales más afectados por el impacto de calor y el comportamiento de los peatones influye en su afluencia escogiendo vías alternas a fin de evitar molestias a causa de la sensación térmica. Este estudio tiene como propósito contribuir con el análisis material, para formular estrategias de conservación en fachadas patrimoniales de este tipo, frente a los desafíos ambientales de la actualidad, asegurando su durabilidad en el tiempo.

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PALABRAS CLAVE patrimonio arquitectónico, sensación térmica, impacto de calor, fachadas, variabilidad climática



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1. Introduction

Urban heat, characterized by rising temperatures in urban environments (Aguilar, 2021; Wonorahardjo et al., 2022), along with other factors such as environmental pollution, contributes to the deterioration of local architecture (Resende et al., 2022), affecting the preservation of heritage buildings. Climatic factors such as temperature, precipitation, wind, and solar radiation directly affect facade cladding, causing materials to expand, contract, and shrink, which can result in structural damage (Falcão et al., 2023) and impact maintenance and associated costs (Barrelas et al., 2024). This adverse impact of heat, which is interrelated with the heat-absorption properties of the built environment and anthropogenic heat sources, affects public health (Tabatabaei and Fayaz, 2023).

According to Zeballos (2021), the 2018 surface temperature map of Arequipa shows that temperatures in the buffer zone of the Historic Center (the location of our study area) range between 26°C and 30°C starting at 9:00 a.m., compared to other areas within the city limits, where temperatures typically range from 21°C to 25°C. This variation is due to the color and material of the buildings, which cause greater absorption of solar radiation and thus contribute to urban heat islands (UHI) (Candanedo and Villarreal, 2020).

For this reason, the objective of this research is to evaluate the relationship between climatic variables and the deterioration of facades, while accounting for human activities, natural elements, and pedestrian and vehicular traffic, all of which can significantly impact the preservation of architecture. To this end, three phases of analysis were established: (1) Identification of the damage index by material type, (2) Flow analysis through observation, and (3) Analysis of climate variability and heat-induced thermal sensation.

To address this issue, some studies have employed experimental methodologies (Ornam et al., 2023), combining field measurements and simulations to analyze the effects of different facade types on reducing ICU. Similarly, Wonorahardjo et al. (2022) conducted their research using field and laboratory measurements to analyze the impact of indoor and outdoor temperatures on buildings. On the other hand, Gunawardena et al. (2019) used urban climate simulations to examine the influence of UHI on space conditioning loads in urban and suburban environments.

Recognizing the harm caused by UHI, practical mitigation strategies were proposed, such as increasing green spaces and bodies of water in urban environments. However, this approach is limited by the physiological characteristics of each location (Xiang et al., 2023).

In addition, the study by Jang et al. (2024) focused on mitigating UHI through green infrastructure to improve thermal comfort in urban environments, evaluating the impact of urban vegetation and water bodies on UHI reduction related to Outdoor Thermal Comfort (OTC). Similarly, Zhuo et al. (2024) proposed another strategy to reduce surface temperatures and energy consumption in buildings, using high-reflectance pearlescent cool coatings.

The software used in these studies was ENVI-met, which employed a 3D building model to simulate the urban climate and the interaction between the land surface (Ornam et al., 2023), to evaluate the cooling and heating effects in the area, and the effectiveness of technological facade concepts. Another simulation was conducted using EnergyPlus software to evaluate energy consumption in different climate zones (Zhuo et al., 2024).

Furthermore, satellite platforms such as Landsat have been used to analyze land use and its relationship with UICs, based on studies that used Google Earth Engine/Images, ArcGIS, and MODIS software to analyze meteorological conditions (Rajagopal et al., 2023). However, in the case of Gunawardena et al. (2019) and Palme et al. (2019), both used the *Urban Weather Generator* (UWG) V4.1.0 software, as simulations were conducted using a framework prepared with rural meteorological data.

The results of the research reveal that, during the day, building materials, such as hard, dark-colored pavements, as well as roof finishing materials like asphalt, cement, concrete, and brick, among others, absorb heat and release this heat into the environment at night, generating surface urban heat (Ravelo, 2011).

Furthermore, research by Alarcón (2020) highlights the influence of vegetation color and density as heat mitigators on building surfaces, noting that light colors absorb less radiation when exposed to sunlight; likewise, vegetation on surfaces can reduce their temperature by up to 10°C.

Finally, Jang et al. (2024) highlight the importance of incorporating green spaces and bodies of water into urban planning to mitigate UHI effects. The presence of these features was shown to reduce outdoor thermal discomfort during both the day and the night, underscoring the need for effective urban planning strategies.

2. Methods

The methodology employs a mixed-methods, non-experimental approach, consisting of three phases: The first phase consisted of identifying the damage index by material type, based on the research by Sullón (2017) to weight each structural element,

following the delineation of the study area and a graphical survey of the physical properties of the components of heritage facades along a street section selected for the composition of its structural elements, materials, and colors.

The second phase involved flow analysis through observation, specifically counting vehicle and pedestrian traffic. Data collection took place from May 16 to 22, 2024. The analysis was conducted in phases corresponding to different times of the day, with pedestrian traffic assessed by counting pedestrians passing through three analysis points. Data collection took place for three hours each day over one week, yielding a total of 63 measurements; for vehicle composition, measurements were taken at a single general analysis point, yielding a total of 21 measurements.

Finally, in the third phase, a non-invasive analysis of climatic variability was conducted using a KJT digital thermohygrometer with an external TA 318 sensor designed for environmental use, with an outdoor temperature range of -50 °C to 70 °C (resolution of 0.1 °C and accuracy of ± 1.0 °C) and a relative humidity range from 25 to 98%RH (resolution of 1%RH and accuracy of ± 5 %RH).

In addition, a thermal inspection of the facades was conducted using a Guide Sensmart P120V pocket-sized thermal imaging camera, with an IR resolution of 120×90 @17 μ m, a measurement range of 20°C–150°C (100°C–400°C for automatic switching) and an accuracy of ± 2 °C or ± 2 % (whichever is greater), and Revit software was used to analyze solar exposure during the following time periods: 8:00–9:00, 12:00–13:00, and 17:00–18:00, which was then processed into a temperature map of the facades.

The methodology employed does not aim to track the historical progression of heat-induced deterioration, but rather to verify, through non-invasive analyses such as IR image analysis, whether heat has a greater impact on areas with greater deterioration and how it may affect people's behavior as they walk along this street.

3. Results

The study area is located on a section of a street in the historic center of Arequipa, Peru, where the facades of the former Museum of Contemporary Art (EM-1 and EM-2) and the Casona del Tranvía (CT-1) are located (Figure 1).

These mansions feature an eclectic architectural style characteristic of the late 19th and early 20th centuries; opposite these architectural landmarks is a park, which is an important environmental factor to evaluate, as it would allow for determining its influence on heat impact mitigation.

3.1. Identification of the damage index based on materiality

The architectural elements relevant to the study were coded according to their material composition and color (Table 1). This highlighted the importance of the building's setback from the road, as well as the level of reflectance derived from color and its influence on thermal behavior.

Regarding the materials used in the facades, ignimbrite accounts for 43.2% of the facades of the EM-1 and EM-2 mansions, where it is used for walls. The second most prevalent material is concrete, at 22.69%, primarily used for structural elements such as foundations and columns in the mansions. This is followed by steel, which accounts for 19.1% and is found in the details of the railings on the perimeter fences of the EM-1 and CT-1 mansions. Finally, wood accounts for 15.1% of the entire street, all of which is found in the CT-1 mansion.

Furthermore, the use of yellow paint on the walls of the EM-1 and CT-1 mansions has a reflectance of 60%. This means that sunlight hitting these walls is reflected, reducing the amount of heat absorbed, preventing the material from overheating, and helping maintain a cooler temperature.

On the other hand, the use of darker shades such as red, blue, brown, and black has the opposite effect, since they have a lower reflectance of 15%. This means that most of the solar radiation is absorbed rather than reflected, trapping heat in the material and raising its internal temperature. Consequently, the heat accelerates the material's deterioration, leading to cracks, spalling, discoloration, and loss of structural integrity.

Based on the pathological damage observed on the EM-1 facade, the ignimbrite showed deterioration of the perimeter pillar elements, with dirt and spalling observed; however, the most severe damage was detected at points P2 and P8 (Table 2).

The concrete exhibited the same pathologies, but in this case, the most affected element was sidewalk PV1, which sustained very severe damage due to its horizontal exposure, unlike the vertical elements (Figure 2). On the other hand, all four defects were evident in the steel, with the R1 and R7 railing elements being the most affected, as well as the T1, T2, and T3 gable roofs.

At point EM-2, the ignimbrite exhibited dirt accumulation and spalling, with severe damage to walls MS1 and MS2. These defects were also present in the concrete, but only with minor damage. In contrast, the wood at point EM-2 exhibited soiling, deformation, and flaking on door PA1, which was the most affected element at this location (Table 2).

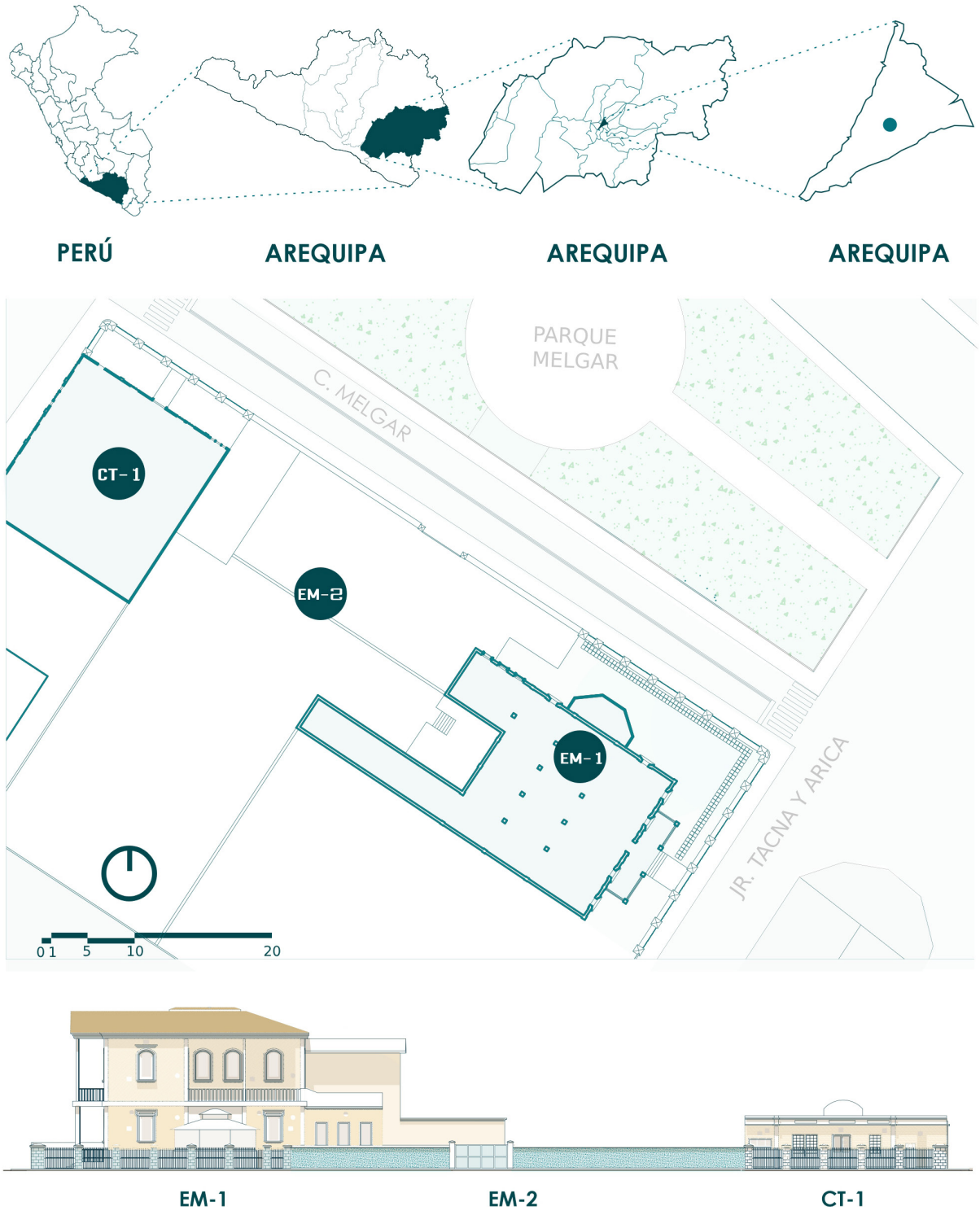


Figure 1: Survey and segmentation of analysis points. (2024)

Facade coding	Perimeter setback	Architectural elements	Material coding	Color	Color reflection (%)	Material
EM-1	4.00 m	Walls	M	Yellow	60%	Concrete
		Baseboards	Z			Concrete
		Railings	B			Wood
		Capital	CAP	White	75%	Ignimbrite
		Cornice	CA			Concrete
		Perimeter columns	P			Ignimbrite
		Doors	PA			Wood
		Sidewalk	PV	Gray	20%	Paving
		Gable roof	T	Dark red	10%	Corrugated metal
		Columns	C	Black	0–3%	Concrete
EM-2	-	Perimeter Fences	R	Dark green	10%	Steel
		Columns	C	Blue	10%	Ignimbrite
		Walls	M			Ignimbrite
		Capital	CAP	White	75%	Ignimbrite
		Sidewalk	PV	Gray	20%	Paving
		Baseboards	Z			Concrete
CT-1	4.00 m	Doors	PA	Green	10%	Wood
		Capital	CAP	White	75%	Ignimbrite
		Perimeter columns	P			Ignimbrite
		Walls	M			Wood
		Sidewalk	PV	Gray	20%	Paving
		Columns	C	Brown	10%	Steel
		Cornice	CA			Wood
		Doors	PA			Wood
		Baseboards	Z			Wood
		Perimeter Fences	R	Dark green	10%	Steel

Table 1: Physical characteristics of the facades. Authors (2024) based on Mendoza and Aguillón (2021)

At point CT-1, the ignimbrite exhibited damage, including soiling and spalling, with perimeter columns P1, P2, and P5 most affected. The concrete exhibited the same pathologies, with sidewalk PV1 being the most affected, similar to the previous facade. In contrast, the wood exhibited an additional pathology—deformation—along with those mentioned above; the most affected elements were door PA1, walls M1, M2, and M3, and columns C1 and C2. Finally, regarding the steel, all four pathologies were present, with railing R1 being the most affected.

Figure 3 shows the locations of these pathologies at the points EM-1, EM-2, and CT-1, which are in the lower areas near the roadway, where pollution is more direct; likewise, in the upper sections, only pathologies related to dirt and oxidation are observed, due to the environment. This allows for the identification and prioritization of areas requiring urgent repair.

Therefore, the material most prone to these heat-related issues is steel, which ranges from corrosion and deformation to dirt accumulation and, in some places, spalling. Second, wood is the most affected

material, followed by concrete and ignimbrite, which are also damaged but to a lesser extent, as they tend to suffer issues such as dirt accumulation and flaking, particularly due to sudden temperature changes.

3.2. Flow analysis by observation

Data collection on pedestrian and vehicular traffic composition was conducted from May 16 to 22, 2024. The method used to assess pedestrian traffic involved counting pedestrians passing through the three analysis points (data collection lasted 3 hours each day over 1 week).

It was observed that most pedestrians avoid passing through point EM-2, choosing instead to use the road in front; this behavior is more pronounced in the morning and afternoon (Figure 4). It can also be determined that pedestrians tend to use both sides of the street, with tree-lined areas being the most heavily trafficked.

The average pedestrian flow indicated a lower volume near the street fronting the studied facades than along the alternate route near the park.

Casona	Material	Element	Code	Dirt	Rust/corrosion	Deformations	Detachment	Total damage	
EM-1	ignimbrite	perimeter columns	P1	2	-	-	1	3	
			P2	2	-	-	2	4	
			P3	2	-	-	1	3	
			P4	1	-	-	1	2	
			P5	1	-	-	1	2	
			P6	1	-	-	1	2	
			P7	1	-	-	1	2	
			P8	3	-	-	2	5	
		walls	M1	1	-	-	-	1	
			M2	1	-	-	-	1	
			M3	1	-	-	-	1	
			M4	1	-	-	-	1	
			M5	1	-	-	-	1	
		concrete	columns	C1	1	-	-	1	2
				C2	1	-	-	1	2
	C3			1	-	-	1	2	
	C4			1	-	-	1	2	
	C5			1	-	-	1	2	
	C6			1	-	-	1	2	
	baseboards		C7	2	-	-	1	3	
			Z1	1	-	-	-	1	
			Z2	1	-	-	-	1	
			Z3	1	-	-	1	2	
	cornice		CA1	1	-	-	-	1	
			CA2	1	-	-	-	1	
			CA3	1	-	-	-	1	
			CA4	2	-	-	-	2	
	sidewalk		PV1	2	-	2	2	6	
	steel	windows	V1	1	1	-	-	2	
			V2	1	1	-	-	2	
			V3	1	1	-	-	2	
			V4	1	1	-	-	2	
			V5	1	1	-	-	2	
			V6	1	1	-	-	2	
			V7	1	1	-	-	2	
			V8	1	1	-	-	2	
			V9	1	1	-	-	2	
			V10	1	1	-	-	2	
			V11	1	1	-	-	2	
			V12	1	1	-	-	2	
		bars	R1	1	2	1	-	4	
			R2	1	1	1	-	3	
			R3	1	1	1	-	3	
			R4	1	1	1	-	3	
			R5	1	1	1	-	3	
			R6	1	1	1	-	3	
			R7	1	2	2	-	5	
		railing	B1	1	1	-	-	2	
			B2	1	1	-	-	2	
		gable roof	T1	1	3	-	1	5	
			T2	1	3	-	1	5	
		EM-2	ignimbrite	walls	MS1	2	-	-	2
MS2					2	-	2	1	4
wood			door	PA1	2	-	3	3	7
				P1	3	-	-	1	4
CT-1		ignimbrite	perimeter pillars	P2	2	-	-	2	4
				P3	2	-	-	1	3
				P4	2	-	-	3	5
				P5	2	-	-	1	3
	P6			2	-	-	1	3	
	Z1			1	-	-	1	2	
	concrete	baseboards	Z2	1	-	-	-	1	
			Z3	1	-	-	1	2	
			CA1	1	-	-	1	2	
		cornice	CA2	1	-	-	-	2	
			CA3	1	-	-	-	1	
		sidewalk	PV1	2	-	-	2	6	
	wood	door	PA1	1	-	2	1	4	
			PA2	1	-	1	1	3	
		walls	M1	2	-	2	1	5	
			M2	2	-	2	1	5	
			M3	2	-	2	1	5	
			C1	2	-	2	3	7	
		columns	C2	2	-	2	3	7	
			C3	2	-	2	3	7	
		steel	windows	V1	1	1	-	-	2
				V2	1	1	-	-	2
	V3			1	1	-	-	2	
	V4			1	1	-	-	2	
	bars		R1	1	2	1	-	4	
			R2	1	1	1	-	3	
			R3	1	1	1	-	3	
			R4	1	1	1	-	3	
			R5	1	1	1	-	3	
			R6	1	1	1	-	3	
			R7	1	1	1	-	3	

Table 2: Sampling of damage to structural elements.

Authors (2024) based on the National Institute of Educational Physical Infrastructure (2022); Sullón (2017)

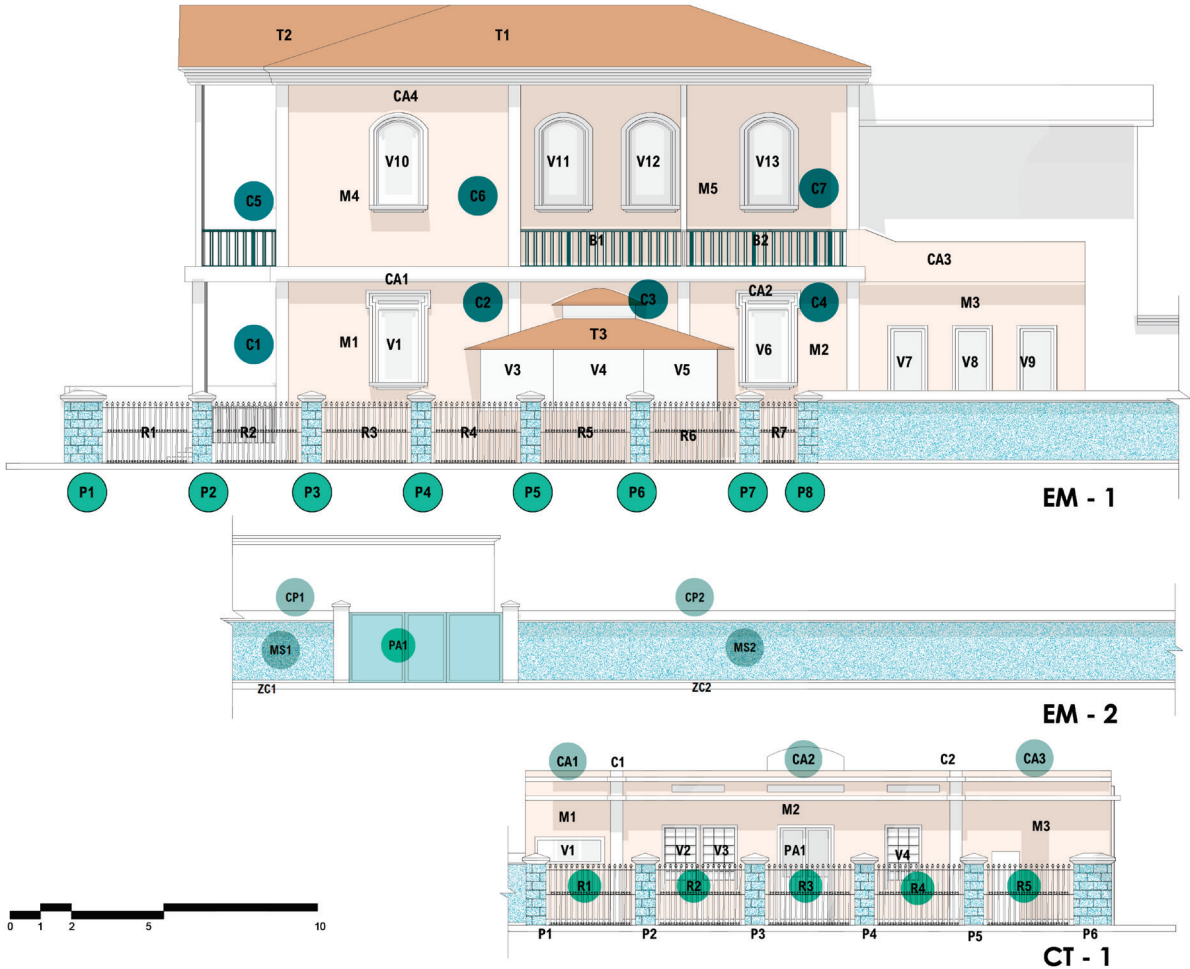


Figure 2: Coding of facade structural elements. (2024)

This suggests that the difference may be due to the lack of green spaces and increased perceived temperature. Furthermore, the deteriorated condition of these heritage buildings creates an impression of neglect that does not enhance their appeal to passersby, leading to their being ignored.

Unlike the pedestrian count, the vehicle traffic data collection consisted of counting vehicles traveling along Melgar Street for three hours a day, throughout the week; this enabled determining the high volume of traffic, which results in higher carbon emissions. This situation contributes to rising temperatures in the area and negatively affects the appearance of the historic mansions, making them dirty and deteriorated.

It was determined that an average of 447 vehicles per hour travel along the street in question each day. Finally, the analysis of vehicle and pedestrian count data revealed that Monday, Thursday, and Friday are

the days with the highest traffic flow and, therefore, have the greatest influence on the rise in temperature in the area.

3.3. Analysis of climate variability and heat index

For this stage, temperature and solar radiation data were collected from May through July 2024. According to Peru's National Meteorological and Hydrological Service (SENAMHI, 2024), temperatures were forecast to range from 19 °C to 23 °C, with ambient humidity generally between 29% and 35%. Based on this, along with the week's highest traffic volume, it was deemed appropriate to collect data on Monday, May 20, to evaluate how the forecast varied with respect to user presence and modes of transportation. Temperature and humidity samples were collected at each analysis point at two different times (8:00–9:00 a.m. and 12:00–1:00 p.m.), revealing the following:

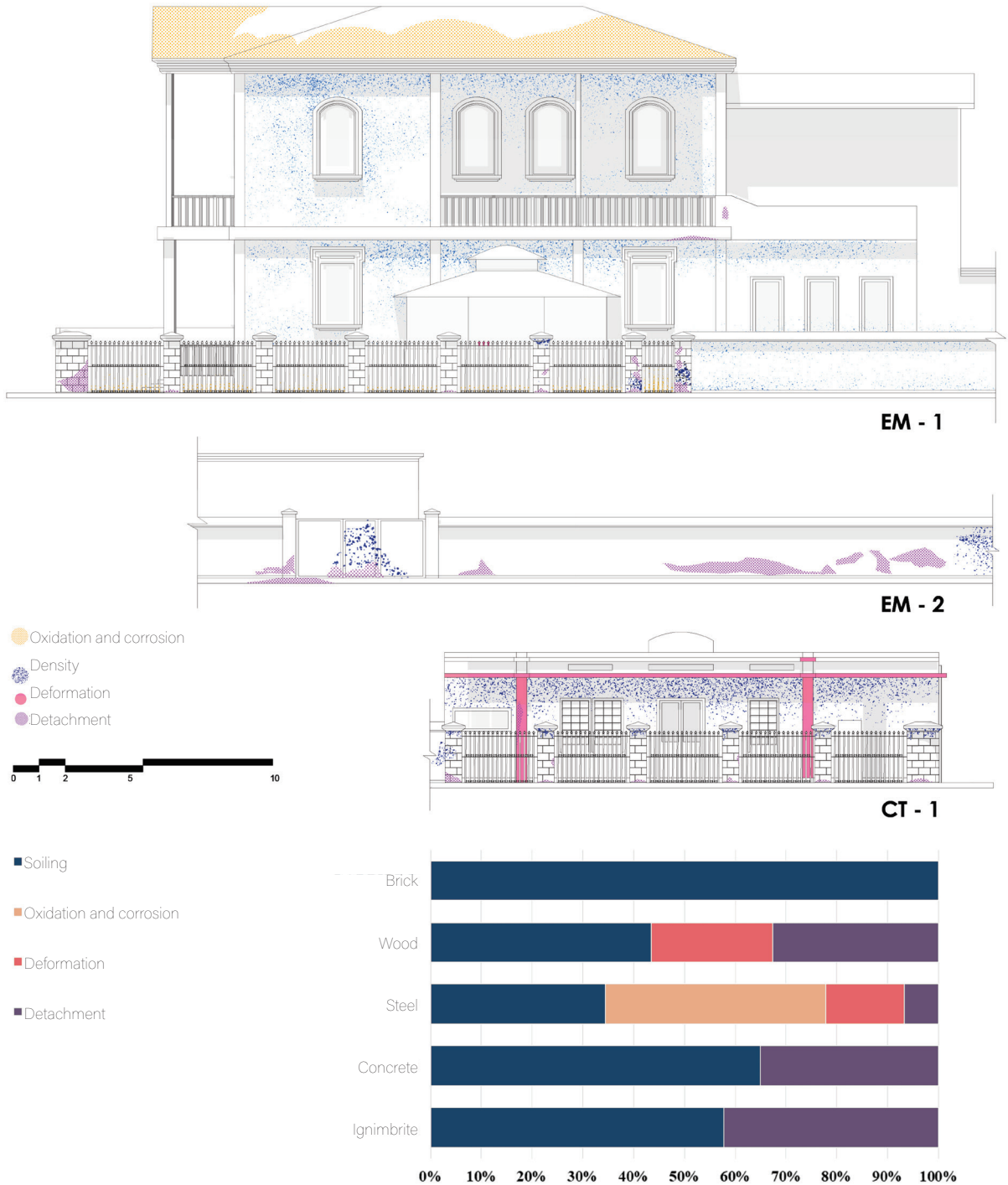


Figure 3: Damage Index for Historic Facades. (2024)

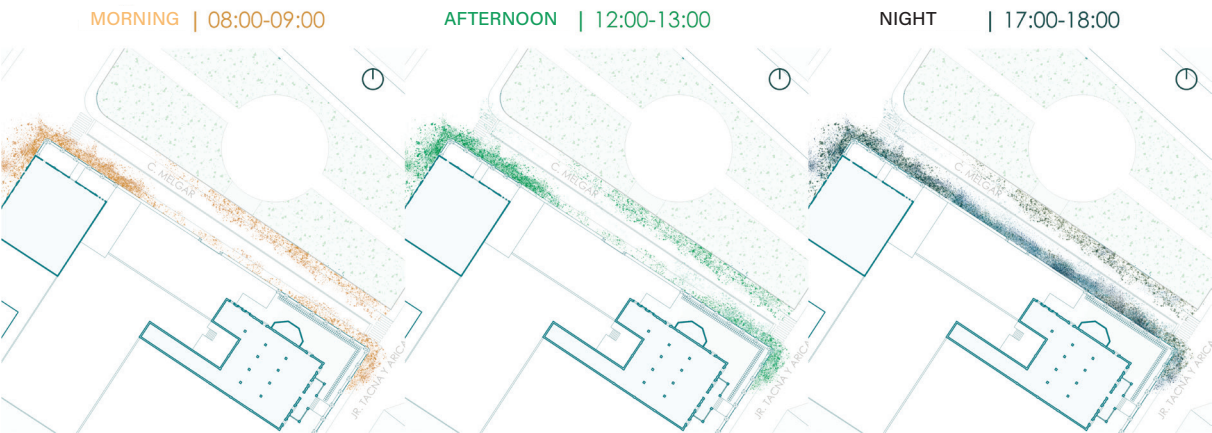


Figure 4: Diagram of pedestrian flows during the day. (2024)

			Humidity (%)					
			CT-1		EM-1		EM-2	
			24.5 °C	31.3 °C	28.5 °C	28.3 °C	29.4 °C	24.5 °C
Temperature (°C)	CT-1	27%	23.7 °C					
		10%		28.9 °C				
	EM-1	19%			27.1 °C			
		14%				26.9 °C		
	EM-2	21%					27.8 °C	
		10%						23.3 °C

Table 3: Wind Chill. Authors (2024) based on the Heat Index (National Oceanic and Atmospheric Administration, n.d.)

CT-1:

- **8:00–9:00 a.m.:** The temperature is 24.5 °C and the humidity is 27%.
- **12:00–13:00:** The temperature rises to 31.3 °C and the humidity drops to 10%.

EM-1:

- **8:00–9:00 a.m.:** The temperature is 28.5 °C and the humidity is 19%.
- **12:00–13:00:** The temperature drops slightly to 28.3 °C, and the humidity drops to 14%.

EM-2:

- **08:00–09:00:** The temperature is 29.4 °C and the humidity is 21%.
- **12:00–13:00:** The temperature drops to 24.5 °C and the humidity falls to 10%.

The collected data allow us to determine the heat index and, thereby, evaluate the Thermal Sensation (TS) perceived in the study area. To determine the TS, we use the parameters provided by the U.S. National Oceanic and Atmospheric Administration (NOAA) as a reference; these parameters are also used by SENAMHI for the general calculation of meteorological data in the study area. The information is presented in this cross-tabulation table (Table 3), which correlates ambient temperature in °C with relative humidity (%) to calculate the TH.

Each value obtained corresponds to one of four categories:

C ≤ ST < 32 °C: Category I: Caution (Possible fatigue due to prolonged exposure or physical activity).



Figure 5: Solar exposure at three times of day in the fall. (2024)

$C \leq ST < 40^\circ\text{C}$: Category II: Extreme Caution (Sunstroke, heatstroke, cramps. These effects are possible with prolonged exposure or physical activity).

$C \leq ST < 55^\circ\text{C}$: Category III: Danger (Sunstroke, heatstroke, cramps. These effects are very likely with prolonged exposure or physical activity).

$ST \geq 55^\circ\text{C}$: Category IV: Extreme Danger (Imminent heatstroke and sunstroke). According to the findings, in the mornings, the facades with the highest ambient ST are EM-1 and EM-2, with values of 27°C ; however, at midday, the situation changes for the CT-1 facade, since as its ambient temperature rises to 31.3°C , the heat index reaches a value of 28, triggering the first level of caution. This is related to pedestrian traffic in the area; pedestrians experience fatigue when walking along CT-1 and EM-2 and opt to use the alternate route near the park instead.

Furthermore, the solar study showed that at 9 a.m., the sun is rising, and the east- and southeast-facing facades receive the greatest amount of direct solar radiation. However, at 2 p.m., the sun reaches its highest point in the sky, and solar radiation is at its peak. Facades directly exposed to the sun receive an intense amount of radiation. Conversely, at 5:00 p.m., the sun begins to set, and solar radiation decreases. Therefore, west-facing facades receive the greatest amount of solar radiation at this time, which

contributes to the heating of the western facades, keeping surface temperatures high until late afternoon. The accumulation of heat during the day can delay the nighttime cooling of buildings, prolonging the heat island effect (Figure 5).

Finally, thermographic images were taken at three time intervals for each location: 8–9 a.m., 12–1 p.m., and 5–6 p.m. These are represented on the elevations by shades of yellow, orange, red, and purple, corresponding to temperature ranges from highest to lowest, respectively (Figure 6).

This data shows that, in the morning, the CT-1 section of the facade has the highest material temperatures, with the steel in columns C1 and C2 and the wood reaching temperatures above 70°C (Figure 7); this, combined with the absence of vegetation around the historic mansion, intensifies the thermal sensation experienced by pedestrians passing by.

For the EM-1 section, the material with the highest heat level is ignimbrite, which makes up the entirety of its walls, followed by the stone found in columns C1, C2, C3, and C4.

On the other hand, on the EM-2 section, PA1 recorded the highest temperature in the morning, at 81.7° , reaffirming the signs of structural damage previously identified. The rest of the materials maintained an average temperature ranging from 30 to 50°C .



Figure 6: Temperature map of facades. (2024)

In the afternoon, although the maximum temperature on both facades dropped by 3°C, the temperature of the concrete, steel, stone, and pavement rose, exceeding 70°C (Figure 7). The temperature of the ignimbrite material on the EM-2 facade rose by 30°C. This significant increase may be related to the low traffic volume in that area.

The high temperatures observed in the steel correspond to the columns of CT1, differing from the steel in the perimeter enclosures, where wind flow causes temperatures to decrease in that area, making it less uncomfortable to walk along those facades. Furthermore, the average temperature ranges from 40–70°C, intensifying the heat sensation on the facades.

On the other hand, at night, temperatures drop to as low as 40°C. Furthermore, it was observed that the materials that stored the most heat were the ignimbrite and the pavement on the EM-1 and EM-2 facades, which also show the most signs of spalling.

The dirt accumulated on the capitals of the pillars, as well as on parts of the walls and the ignimbrite ornamentation, indicates higher detected temperature levels, causing greater damage to the infrastructure.

Door PA1, which shows greater wear in the lower area, is associated with the high temperature detected at the horizontal level, as well as its proximity to the pavement, which also maintains a constant heat level.

Elements painted in dark tones compromise the integrity of the large houses, as they cause temperature variations on any material, such as the columns and ornamentation of CT1 and EM1, as well as on the pillars.

4. Discussion

This research reaffirms the position of de Ornam (2023), who, in his study on stereotomic wall facades, found that these absorb solar thermal energy in the morning, accumulate heat, and warm the surrounding spaces, thereby increasing the heat index and exacerbating heat stress.

Regarding the influence of vegetation on slowing the degradation of materials, Alarcón (2020) highlights a reduction in temperature levels of up to 10°C; this reinforces the comparison made between the two facades of the mansions studied, which vary in their level of degradation and thermal sensation due to the influence of natural elements such as trees.

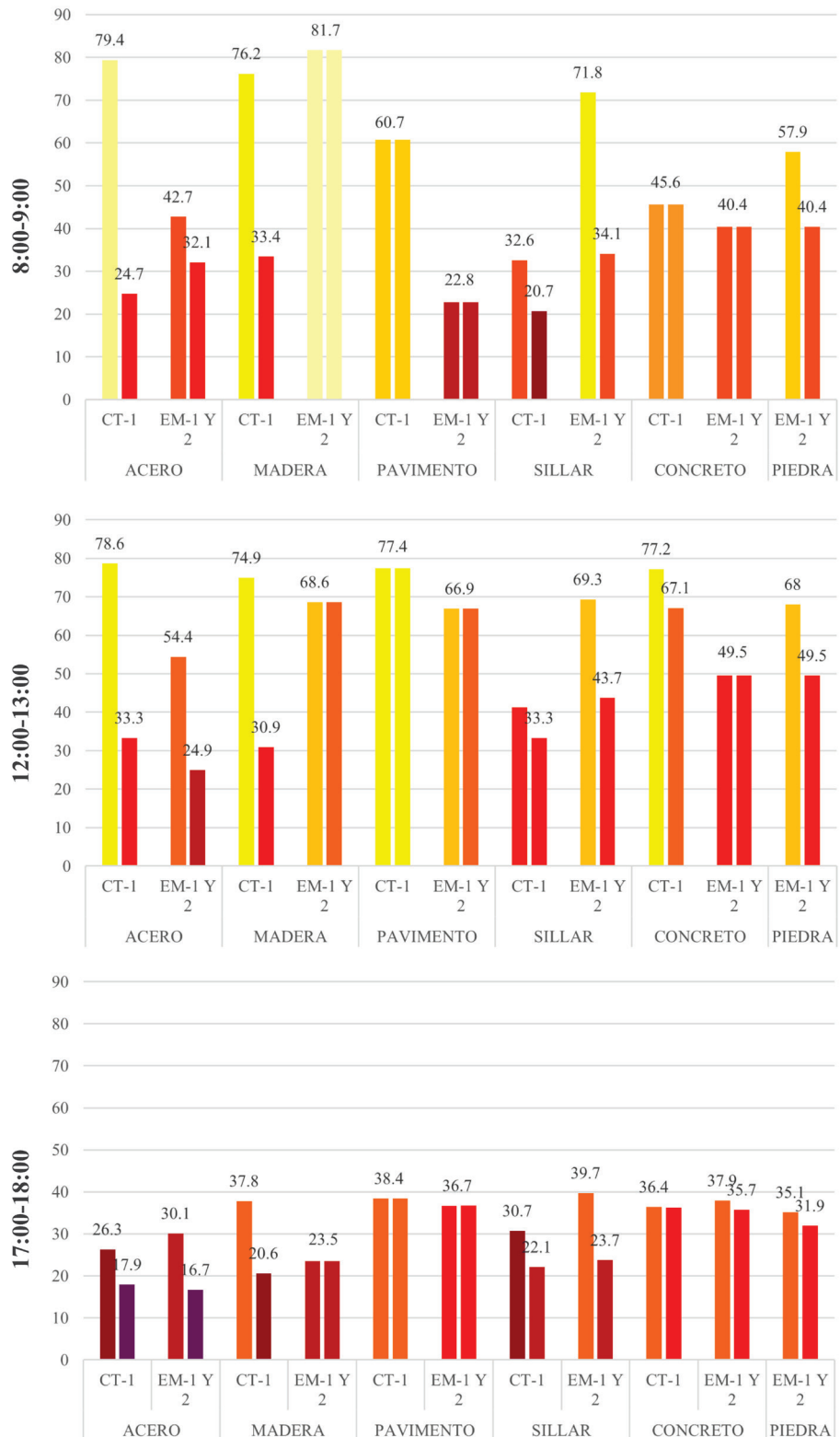


Figure 7: Comparison of maximum and minimum temperatures of materials at three times of day. (2024)

According to Herrera-Sosa et al. (2020), although ignimbrite has a thermal conductivity of 0.16 W/m °C, this suggests that heat is retained on the exterior, causing the heat index on days with high temperatures to be higher at points where this material is most prevalent; this, combined with the thermal conductivity of the pavement due to greater contact, leads to the expected fatigue experienced during the day.

Likewise, according to the study by Xi et al. (2023), the temperature on sidewalks or non-motorized pathways can be reduced by up to 1.05°C compared to non-tree-lined streets. Over time, this temperature variation has a significant impact on the materials that make up the mansions' facades, especially those closest to the street, since that part of the sidewalk lacks trees compared to the opposite side.

Considering that, as noted in the analysis of ignimbrite and steel, temperatures can rise further in the presence of darker colors; this is corroborated by Alarcón's (2020) study, which highlighted heat absorption in darker-colored gravel materials.

Studies such as Ornam et al. (2023) conducted their research during the months with the highest solar radiation. In contrast, this study was carried out between the fall and winter seasons, which correspond to the months with the lowest solar radiation in the city under study. However, the trend of high daytime temperatures persisted, reflecting the challenges facing the area and the urgency of future research on heat mitigation strategies, particularly during extreme heat, when the degradation of heritage facades accelerates.

5. Conclusions

In conclusion, the mansion most affected by heat was CT-1. This is because the construction system used, "Balloon Frame," is more susceptible to the pathologies detected throughout the mansion, which is primarily wood, where peeling and dirt were observed. Furthermore, in the thermal analysis, this material reached the highest temperatures—80°C during the day—and, because all the walls are light in color, heat reflection did not help mitigate the damage this facade suffered from the heat.

The study demonstrates the significant impact of heat on the materials that make up the facades of heritage mansions. A variety of problems were identified, some caused by anthropogenic factors such as pollution and others by natural factors related to solar radiation. Although there is no historical data set, the data collected on the day with the highest predicted temperatures suggest a cumulative effect that, in the long term, threatens the most vulnerable materials in these buildings.

By overlaying the maps of detected pathologies and heat, the deformations located in C1 and C2 of the CT-1 mansion are those with the highest heat levels; likewise, the areas with spalling in PA1 of the EM-2 mansion mostly exhibit high temperature levels; however, this does not necessarily indicate that these pathologies were caused strictly by heat, since spalling in other areas—such as the ignimbrite walls and pillars—may have been caused by unintended wear and tear or human activity. However, these structural defects create thermal bridges in vulnerable areas, leading to temperature variations within these large houses. Furthermore, it was observed that the pillars of EM-1 exhibit higher temperatures than those of CT-1; this is evident when overlaid with the map of structural defects, as the EM-1 pillars show a higher degree of soiling, primarily caused by vehicular pollution in the area.

The materials most vulnerable to heat were wood and ignimbrite, which showed significant deterioration, including spalling and dirt accumulation, especially in the perimeter columns and wooden structures. Steel, affected by rust and deformation, and concrete, with minor damage to the sidewalks, also showed signs of deterioration, although less severe. The damage was concentrated in the lower sections of the facades, near the roadway, suggesting a significant impact from vehicle pollution. In the upper sections, the predominant issues were soiling and oxidation.

The data collected indicate that heat generated by vehicular traffic significantly contributes to the deterioration of facade materials. Areas with the highest rates of thermal damage—especially the ignimbrite elements in the lower sections—require

urgent intervention. This demonstrates that the impact of heat not only compromises the integrity of the materials but can also influence people's behavior as they walk along the street.

It is essential to implement specific maintenance measures for materials with the highest damage rates, such as wood and ignimbrite; of these, wood forms part of the primary structural system of the EM-1 mansion, which is currently the most neglected building on the street. Likewise, a comprehensive assessment of traffic flow in this area should be conducted, with a view to integrating more comfortable spaces for people passing through, since the area's highest foot traffic is composed of college students.

Local policies aimed at preventing damage have shown significant limitations, as they have failed to adapt to the specific characteristics of the historical context. Therefore, it is necessary to implement specific management tools to preserve architectural heritage.

Conflict of interest. The author declares no conflicts of interest.

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