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Impact of Environmental Pollution in the Sustainability of Architectural Heritage: Case Study from Cartagena of India, Colombia

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Abstract: Limited studies have been carried out in emerging nations on the correlation among the environmental pollution, economic factors, and architectural heritage. For this reason, this research presents an assessment of environmental parameter values on materials deterioration used in architectural heritage in Cartagena de Indias; furthermore, it depicts the effect of heritage degradation on socioeconomic aspects of people whose livelihood depends on trade, tourism, and service activities. Dose-response functions were used for estimating of deterioration of carbon steel, copper, and zinc caused by relative humidity (RH), temperature (T), sulphur dioxide deposition (DSO_2), and chloride deposition (DCl^-). In addition, socioeconomic impact on architectural heritage was studied using a Socioeconomic Impact Survey (SEIS), with the sample of 174 individuals who work in areas of great architectural value in the city. The results show a corrosion rate (Vcorr) in the range of 80 < Vcorr < 200, 2.8 < Vcorr < 5.6 and 4.2 < Vcorr < 8.4 μm/year for carbon steel, copper, and zinc, respectively, due to the high level of pollutants. The high deterioration jointly with the lack of citizen culture affect the architectural heritage monuments causing a negative impact in several economic aspects. The establishment of public programs is essential for the conservation of the heritage monuments of the city.

Keywords: environmental pollution; architectural heritage; sustainability; economic aspects

1. Introduction

Among the variables that cause architectural heritage deterioration are climate change, pollution, and environmental factors. The impact of environmental pollution is a sensible issue for both the city and the surroundings [1,2].

Sustainability is a concept that helps establish resilient systems and increases adaptability to change, durability, and the possibility to remain diverse and productive over time. It also explains the means for stabilizing human needs across time [3], and requires economic efficiency [4], a socio-ecological perspective [5], and strong environmental protection policies [6].

Historical city sites that have the UNESCO World Heritage status are significant for their impact on the economic growth of the region and contribution to the achievement

of an inclusive and sustainable development. These sites are also an important factor for enhancing social capital and environmental protection [7].

The deterioration of different materials due to air pollution [3] seriously affects the cultural wealth of the architectural heritage [8,9]. Protection and conservation must be a responsibility of each state, city, or municipality [9–11]. The aggressive pollutants that increase the deterioration processes of materials are gases such as SO_2, NOx, O_3, atmospheric particles (PM) [12,13], salt spray, organic acids, and polycyclic aromatic hydrocarbons—PAHs [9,14–16]. Additionally, the effect of climate (temperature, relative humidity, (RH), precipitation and wind) [17] has a significant influence in the deterioration of materials in coastal areas [18].

Deterioration of materials caused by atmospheric corrosion is an irreversible process [19] due to different reactions that occur in the surface of materials (carbon steel, copper, bronze, limestone, etc.), and this situation has been a subject of study for different research projects in Europe. CULT-STRAT Project or Noah's Ark Project studied the strong correlation between climate and air pollution in architectural heritage in different scenarios [20–23]. These correlations can be addressed in terms of modelling and predicting as in the case of dose-response functions [20]. Dose-response functions use multivariate models for estimating the dynamics of change of the materials in terms of corrosion rate(rcorr,). Several investigations [24–26] define dose-response functions as the measure of the level of concentration, deposition of the pollutants, and meteorological parameter values to the corrosion rate of materials, represented by Equation (1):

$$r_{corr,it} = f\ (RH_{it},\ T_{it},\ D_{SO2it},\ DPM_{it},\ \tau) \tag{1}$$

where DPM is the particulate matter (PM), D_{SO2} deposition in (mg $*$ m^{-2}day^{-1}, and τ is the exposure time (months); i corresponds to the i-th corrosion station and t is the time period in which data were collected [27]. Some research has been established using this function, as [28–32].

Atmospheric contamination and natural processes may generate depreciation of historical monuments [16] and economic or social losses due to continuous maintenance [31,33]. Currently, The World Heritage Committee has a list of structures damaged or deteriorated, making their sustainable development extremely urgent [34]. In Italy, the corrosion risk is due to the levels of limestone (34%) and copper (97%) that are higher than the tolerable level, [19]; in Madrid, the corrosion due to pollution is lower compared to cities of Central and North Europe, [32], but it is necessary to carry out constant maintenance and restoration processes considering the concepts of sustainability and conservation [24].

Furthermore, the preservation and sustainability of material assets are necessary for the success of an economic model and can provide sustainable economic growth for the local people. This situation, however, might harm their heritage value [35]. The evaluation of economic aspects obtained by cultural heritage indicates the need for implementing a policy for cultural tourism [36].

Cultural tourism includes all activities done by tourists. They could be visits to museums, exhibitions, events, and fairs, among the most important [37], where the visitors want to discover new experiences and enjoy cultural attractions and products [38]. Tourism and culture are closely linked [39] and they are considered as the key elements of tourism and industry [40]. Some authors establish that cultural heritage and attractions are integrated under the concept of environmental sustainability. One of them highlights the contribution of cultural tourism towards the improvement of the quality of life in a community [41,42]. Tunbridge et al. [43] establishes that tourism as an economic source in heritage places receives little attention by Graham et al. [44] and the economic aspect around heritage has been researched little, but currently the increase of studies of heritage in business schools indicates the economic potential of heritage. This last is considered fundamental for cultural tourism [45] and can be an input to the economy of each country if properly managed [46]. In 2019, the Travel and Tourism sector contributed to 10.4% of the global GDP; a share which decreased to 5.5% in 2020 due to ongoing restrictions to mobility [47].

The recognition of cultural tourism as a constituent element is essential for social and economic development, and the preservation of it also improves the historical significance of a social group. Moreover, it recognizes its importance in building and developing a city regarding the social, economic, environmental, and cultural aspects [48]. The architecture of historical sites attracts more tourists and provides them with new cultural experiences. It presents the architectural heritage as an opportunity to promote several economic activities in these regions where high levels of poverty and unemployment prevail. Architectural heritage is associated with tourism development for both inhabitants and visitors [49]. There has to be a balanced relationship between those variables to protect society's culture between tradition and modernity [50]. The importance of sustainable architectural heritage depends on the basic economic aspects necessary for its valuation and preservation. The economic approach denominates heritage as a public asset. The architectural heritage presents several aspects that generate externalities, e.g., it is a fact that these sites are visited in high levels, making their maintenance and preservation difficult. This situation involves many people who get income from many indirect jobs whereas the private sectors or government contribute to the conservation. Thus, the private owners are less likely to invest in heritage.

Historical urban heritage represents a clear case of a public good with positive externalities. It indicates that the enjoyment of the assets representing this heritage is non-exclusive and allows a beneficial experience for other people or institutions [51]. Thus, it is recurrent that institutions and individuals take advantage of it without investing or financing its sustainability. High demand of this heritage, in contrast, could guarantee its preservation. Many heritages are, thus, threatened by obsolescence of their historic building and modern urban growth. Dynamic economic activities and high-income status result emigrating from these environments [52]. However, the issue estimates the potential spillover effects in the local economy, as stated by Bowitz and Ibenholt, but does not estimate the true value of culture [53]. For example, in an informal market, people generally depend on the architectural heritage and monuments for their livelihood. The low levels of formal employment for most of the unemployed urban population becomes a source of informal employment. It has less productivity, stability, and wages than formal sector employment. Several studies recommend different approaches regarding generated revenues and employment, in terms of the effects of heritage on the regional economy.

In this case, this paper focuses on the Cartagena UNESCO World Heritage, which is considered a historical city to be visited, especially for the architectural value of its buildings and urbanism. About 2.7 million national and foreign tourists arrive annually in the city to benefit from the city's integral heritage route [54]. This implies that the lack of employment in the city and the number of street vendors of varying socioeconomic levels, especially the lower class, increases mainly in the historical center of Cartagena. Since it has a high concentration of tourists, informal vendors can generate an income from selling products such as traditional handicrafts, among other consumer products or services. For example, Colombian studies on the economic impact of the historical city of Cartagena [55] list the most common products bought by tourists and locals, including arts and crafts, lodging, natural and cultural attractions, and complimentary services. The latter relates to tours, typical meals, souvenirs, brochures, and so on. There are several dynamic economic opportunities with visits to cultural heritage like museums, historical monuments, and ancient buildings. It also includes the constructions without historical content used to provide commercial services to tourists. They are public swimming pools, sports courts, viewpoints, etc. Cartagena is promoted as a city with a mixture of sun and beach with many cultural attractions. This counteracts the comparative disadvantage of its exotic beaches in comparison to other tourist sites of the Caribbean [56]. Zuleta, as cited [57], found that the architectural and cultural goods (36% of total attractions), ethnography (25%), scheduled events (19%), and natural sites (16%) represented the city's main tourist attractions. This gives Cartagena the significant potential to become a tourist city with a highly established capacity to attend to those seeking alternative attractions.

The Tourism Corporation's report from the Coastal Airport Society SA's study (SACSA) shows the growth of national and international travelers going to this city. In 2016 there were 1,931,511 visitors, 2,201,923 in 2017, and more than 2,700,000 in 2018 [54]. This form of tourism generates direct, indirect, and induced economic impact on revenue and employment [58] as cited in [59], depending on the large percentage of tourists visiting the preserved heritage [60]. Thus, it is the city that the media presents: idealized, careful and beautiful, but internally fragmented with processes of exclusion. An informal city where spontaneous settlements are part of the hidden Cartagena. It represents the Colombian city with significant social, structural, functional, economic, and political problems [61]. Its significant historical heritage is a potential environmental asset, including its socio-cultural traditions and colorful colonial-style buildings, which bring economic and social recovery opportunities.

A study indicates that the majority of people in Cartagena consider the Historic Center's heritage as an instrument for economic development. It also indicates that a quarter of the tourists' expenses are from the attractions of the historic heritage of Cartagena.

"The study establishes that for each peso a tourist spends in the commerce sector, the city generates an additional 3.6 pesos of production. Thus, Cartagena's attractive assets represent an added value and employment generation accountable for 3.8% and 5.0%, respectively of the city's figures. The historic zone creates 11.2% of the city's added value and 8.4% of its workforce" [55]. The Historical Center, its plazas, and its several museums become sufficient attractions to mobilize diverse groups of tourists from different places. Most of the economy grows as a result of these tourist attractions. It becomes risky, from an architectural heritage viewpoint, in regard to how many citizens support their economies with numerous activities like hotels, travel agencies, restaurants, and commerce in general. It also brings the potential for developing informal work in the absence of other opportunities. Historical heritage is a source of economic wealth that increases the level and quality of life for locals [62].

This study aims to determine the impact of environmental pollution in the sustainability of architectural heritage in Cartagena, Colombia. It also determines the relevant risks related to economic aspects and heritage degradation with indicators of socioeconomic impact due to the degradation of the Cartagena architectural heritage. The results can help propose effective public policies with a scientific basis to conserve the site.

2. Materials and Methods

2.1. Area of Study

Cartagena is located at 10°25' N, 75°32' W (10.41667, −75.5333), covering an area of 609.1 km^2 (see Figure 1).

Figure 1. Map of Cartagena and the location of research sites.

It is one of the most popular Colombian cities with rich architectural value and is a national and international tourist destination. The city was declared a Historical and Cultural Heritage of Humanity in 1984 because of its representative architectural set of the colonial period. It includes churches, streets, civil buildings, and squares that give it a unique character worldwide, making it a tourist attraction for locals and visitors.

2.2. Meteorological and Pollutions Database

The values of relative humidity (RH%), temperature (T, °C), and precipitation (P, mm) in the city were recorded in monthly average values from the year 2008 to 2020, according to the data collected by the Centro de Investigaciones Oceanográficas e Hidrográficas in the city of Cartagena (CIOH) [63]. The pollution database was collected from the diagnosis environmental report [64]. In addition, in the sites of the study (S1, S2, S3, and S4, see Figure 1) pollution was measured according to the standard [65]. Figure 2 shows the behavior of relative humidity (RH), temperature (T), and precipitation in the period between 2008 to 2020.
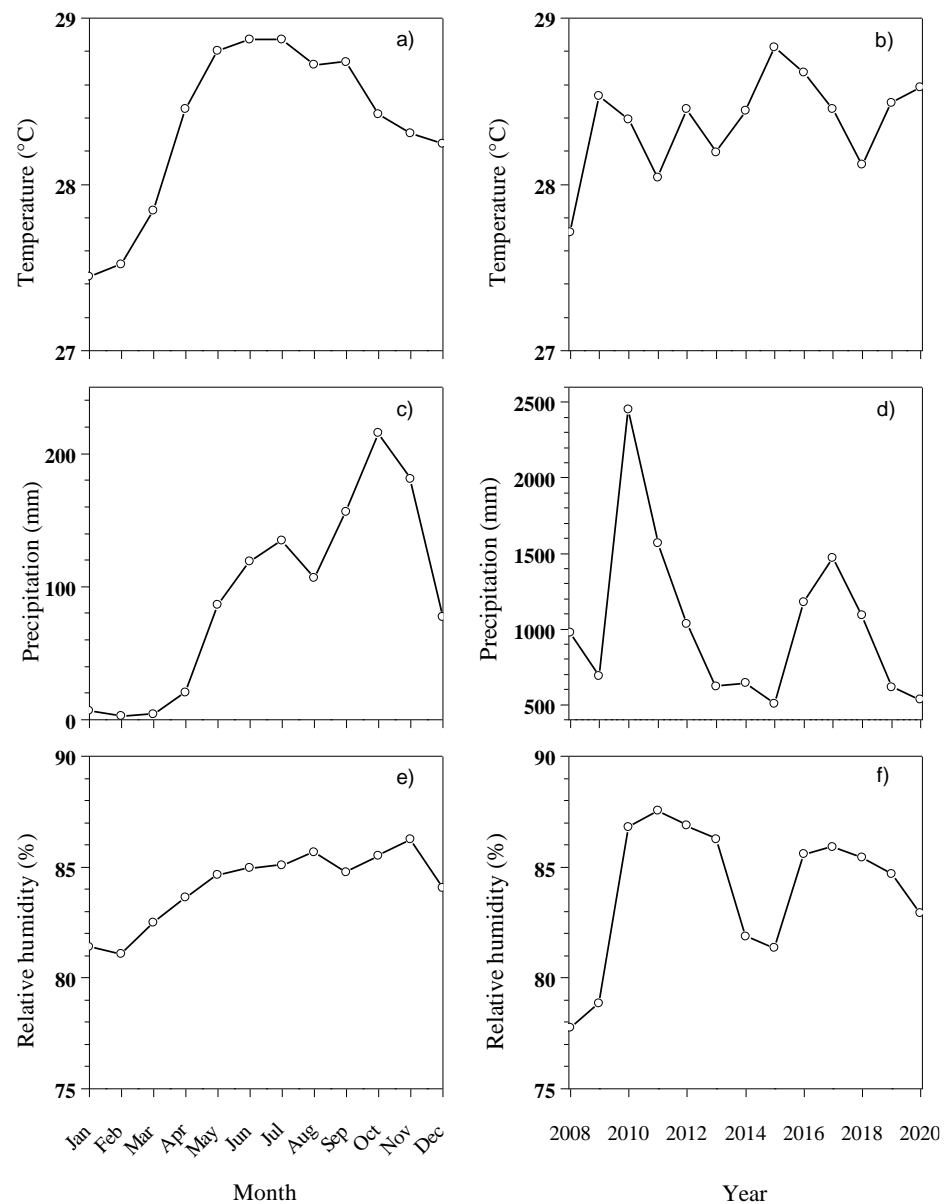

Figure 2. Meteorological parameters in Cartagena between 2008–2020. (**a**,**b**) Temperature; (**c**,**d**) precipitation; and (**e**,**f**) relative humidity.

The average monthly temperature (Figure 2a) increases in the first semester, where the highest values are recorded in the months of June and July, followed by a decreasing trend until the month of December, which is associated with the influence of north-south displacements of the Intertropical Convergence Zone. The average annual temperature (Figure 2b) fluctuates between 27.7 and 28.8 °C. A slight increase of temperature is observed, probably due to the urban heat island effect. Figure 2c shows the average monthly precipitation. The precipitation increases during the year, with very low values in the months of January, February, and March reaching higher values in the period between May and November, with October being the month with a higher average precipitation (215 mm). In relation to annual average precipitation (Figure 2d), the highest precipitation is recorded between 2010 and 2011, due to the effect of the "La Niña" phenomenon [66], characterized by the considerable increase in rainfall in some areas of the country such as the Caribbean region [67]. The RH is observed in Figure 2e,f and the average are in a range of 78% and 88%. The higher value was reported in the period 2010–2012 due to "La Niña" phenomenon. In the months of May to November, the RH was high because it is the winter period.

Levels of PM_{10} and SO_2 near of the sites of study are observed in Table 1. The most critical pollutant is PM10 because in some sites (see Table 1), the value is higher than the annual permissible value of 50 $\mu m/m^3$ [68]. On the other hand, the SO_2 observed in the Table 1 shows a higher value near at avenue Pedro de Heredia (5.37 $\mu g/m^3$) and in industrial zone (3.4 $\mu g/m^3$).

Table 1. Level of PM_{10} and SO_2 reported near the sites of study.

Sites of the Study	Data Reports [64]	Parameters PM_{10} ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)
S1	CAI Pasacaballos	37	3.4
	Interception Socorro, Jardines, la Victoria	51	1.27
	School Juan José Nieto	33	1.27
S2	Station Texaco Ternera	24	5.37
	School Gustavo Pulecio—Flor del Campo	13	1.75
	Average	30	2.4
	Zone Bascule Corredor de carga	26	0.78
	CAI Bosque	104	1.68
S3	Zaragocilla	83	3.02
	C. San Juan de Dios	43	2.54
	Station of service Bazurto	49	0.43
	Average	61	1.7
	CAI Lemaitre	31	0.86
	CAI Santa Rita	29	0.87
S4	Society Mejoras Publicas	20	0
	School La Candelaria	67	0.4
	Average	37	0.5

Table 2 describes the deposition rate of SO_2 and Cl^- in the sites of study. For the SO_2, the deposition rate is higher in S3 and S4 and the classification according to ISO 9223 [23] is P3 (90 < Pd ≤ 250). The chloride is higher in sites S1 and S4 with a classification ISO 9223 [23] of S_2 (60 < S ≤ 300) and for station S2 and S3 the classification is S_1 (3 < S ≤ 60).

Table 2. Annual deposition rate of SO_2, Cl^- in the sites of study.

Sites of the Study	Deposition Rate (mg/m² .day)	
	SO_2	Cl^-
S1	66.60	67.48
S2	71.78	44.66
S3	90.78	53.46
S4	87.24	96.27

2.3. Dose-Response Function

In this research the degradation of materials of architectural heritage was estimated with dose-response function showed in the Equations (2)–(4) for carbon steel, copper, and zinc respectively; where Vcorr is the corrosion rate (μm/year), the pollution parameters are D_{SO2} (mg/(m^2.day) and D_{Cl-} (mg/(m^2.day). The climatic parameters are temperature (T, °C), and relative humidity (RH, %).

$$\text{Vcorr} = 1.77 D_{SO2}{}^{0.52} e^{[0.020RH-0.054(T-10)]} + 0.102 D_{Cl}{}^{0.62} e^{[0.033RH+0.040T]} \tag{2}$$

$$\text{Vcorr} = 0.0053 D_{SO2}{}^{0.26} e^{[0.059RH-0.080(T-10)]} + 0.0125 D_{Cl}{}^{0.27} e^{[0.036RH+0.049T]} \tag{3}$$

$$\text{Vcorr} = 0.0129 D_{SO2}{}^{0.44} e^{[0.046RH-0.071(T-10)]} + 0.0175 D_{Cl}{}^{0.57} e^{[0.008RH+0.085T]} \tag{4}$$

2.4. Architectural Heritage as a Livelihood: Socioeconomic Characterization

Figure 3 shows the location of the research sites for the socioeconomic characterization. Different representative sites of the city of Cartagena within the limited area of the research project: Plaza de Armas, Plaza Santo Domingo, Plaza los Coches, Castillo de San Felipe de Barajas, and las Bóvedas. Tourism in Cartagena represents one of the city's main economic activities and depends on its historical and cultural heritage. These places are the most significant in tourism and business and most popular among tourists due to their historical monuments, old buildings, luxurious restaurants, warehouses by renowned designers, and entertaining places including bars and nightclubs. Its beautiful churches and cathedrals are significant daily tourist attractions.

Figure 3. Delimited area of the socioeconomic characterization.

2.4.1. Sampling and Design

The SEIS's design complies with several factors including socio-demographic data, current housing conditions, family, education, health access, income generation, and architectural heritage. The factors studied to conduct the socioeconomic characterization of the population that derived their livelihood from the interaction of the architectural heritage as tourism were extracted from a documentary review and from previously designed tools to which adaptations were made according to research needs [69]. In order to analyze the different quantitative and qualitative conditions of the socio-economic dynamics generated in the most influential sites due to the architectural, patrimonial, and cultural content, the research was carried out, on the one hand as a basis for the detailed analysis of the literature

on the demand of the historical zone, the perception of the homes of Cartagena de Indias and the arriving tourists [59] from which the dimensions of the perception of aspects of demand related to the economic impact. On the other hand, the factor related with the analysis of cultural heritage in a multi-attribute framework microeconomic perspectives [70]. Participants are economically active, employed, or independent workers, and their main source of income is tourism. Sample size is 174 people from different economic activities of the sector. This sample is taken from the total population with a confidence ratio of 95%. The interviews were conducted in October 2016 across a descriptive study based on a structured questionnaire. The instrument contained 65 items that were grouped in 6 dimensions: (1) housing, (2) family, (3) education, (4) social security, (5) income generation, and (6) architectural heritage. The aim was to characterize the population's conditions in social and economic aspects. The information was obtained through an interview of approximately 25 min long. People gave their consent in which they were explicitly indicated that aggregate use of the data would be used exclusively for research purposes. The interviewers were students from the industrial engineering program at Antonio Nariño University who received 20 h of intensive training to apply the SEIS.

2.4.2. Variables and Measures

The details of the factors analyzed in this investigation are as follows:

- Demographics factors

The age variable was introduced in the research to classify socioeconomic information by groups from younger to older, dividing them into five groups (15–26, 27–39, 40–51, 52–64, and 65+) for statistical analysis. Gender is considered for the distribution of the population pyramid with the age variable. Other variables recognize the group as special or vulnerable groups, including Indigenous, Raizal or islander, Gypsy, Mulatto, Palenquero, or Afro-Colombians. Several variables even included the marital status, indicating married or not married, common-law marriage, separated, widowed, and unmarried.

- Dwelling factors

Housing refers to the physical place where the interviewees live. These variables are dichotomous between houses and apartments. As Tupėnaite, Naimavičienė, Bagdonavičius, and Sabaliauskas [71] mention in their report, the housing tenure is an owner-occupied home without any outstanding loans or mortgages or living in rented dwellings. The housing quality relates to the construction materials for wall, floor, ceiling, and furnishings. It also includes information on the number of rooms available and their socioeconomic level. Housing in Cartagena de Indias might be categorized as being low level (1–2), middle level (3–4), or upper level (5).

- Family factors

Some determining factors are the sizes of families, the number of people in the family within the dwelling, and kinship with the head of household. It also includes the identification of any family member belonging to the LGBTQ community.

- Education factors

The levels of education had the following variables: illiterate, primary, intermediate, or more according to the years of education.

- Health factors

Social security coverage gets classified into three categories among private, public, and no coverage. It also considers people with physical and mental limitations.

- Household income factors

Household income is the combined income of all people in the household. Variables like economic activity, work formality, job location, time and training in the trade, the sale of souvenirs, trade association, language proficiency, primary clients, generated jobs, economic dependence, family economy, and savings culture were analyzed.

- Architectural heritage factors

This variable included the state of degradation, responsibility for monuments conservation, condition of architectural monuments, and impact of the economy and heritage conservation proposal.

2.4.3. Characteristics of the Population

Figure 4 shows the characteristics of the population pyramid. It indicates that of the 174 people included in the sample, half were male, and the highest representation was from the age group between 15–26 (26.79%). The population distribution related to gender shows that 36% were females and 64% were males.
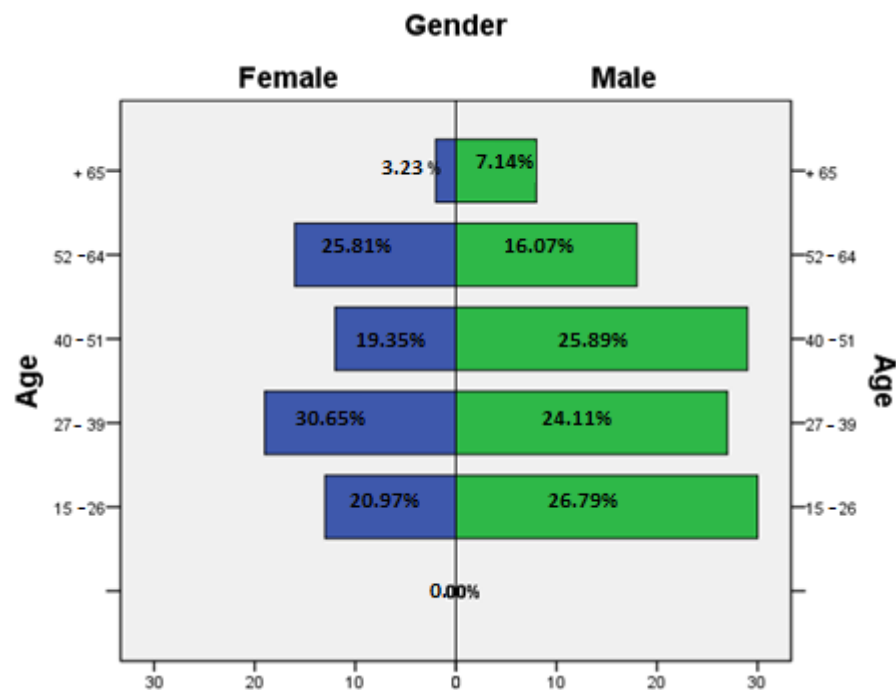

Figure 4. Population pyramid according to the age group of the 174 people included in the sample: SEIS, 2016.

Table 3 shows the characteristics of the population by gender and age group. According to the demographic factors, approximately 12.6% of the sample was composed by afro-descendants, and 10.9% was by indigenous people.

Among all the ethnic groups included, 71.3% of the population did not include vulnerable groups. The marital status also estimated that the highest proportion of the people were in common-law marriage (42%), with a significant gender differential (29% among male and 13% among female). According to the housing type, the youngest age group (15–26 years) lived at home while the age ranging 27–39 years old commonly lived in apartments. The resident distribution sector changed by age, so the youngest individuals were highly concentrated in the tourism sector compared to the oldest age group (15–26). The ages ranging between 27–39 and 40–51 lived in a residential sector of the city. It implied that 94% of the sample used their home as a dwelling place, and the other 6% used their housing for productive businesses. The age group 40–51 (12%) has a similar tendency to live in rental homes, while the youngest age group (12.9%) lived in owner-occupied homes. Furthermore, 94% of the sample had quality services, and their homes were constructed of masonry materials. The houses, especially from the group aged 27 to 39, had more than two rooms. In addition, 83.9% of the population belonged to the lower socioeconomic level, where the difference for both genders had approximately 20% of the men (53.3%) above the women (31.6%). The percentage of subjects belonging to the lower, middle, or upper classes also decreased slightly from age 27–39 (23.6%) to age 65 or older (4%).

Table 3. Characteristics of the population by gender and age groups: SEIS, 2017.

Factors	All Sample	Gender		Age Group				
		Male	Female	15–26	27–39	40–51	52–64	65+
No. (%)	174 (100)	112 (64)	62 (36)	43 (24.7)	46 (26.4)	41 (23.6)	34 (19.5)	10 (5.7)
Demography								
Ethnic group (%)								
Indigenous	10.9	8.6	2.3	1.7	5.7	3.4		
Raizal/Islander	2.3	2.3		1.1		1.1		
Mulatto	1.7	0	1.1		1.7			
Palenquero	1.1	1.1		0.6			0.6	
Afro-descendants	12.6	7.5	5.2	1.7	2.9	1.1	4.6	2.3
None of them	71.3	44.3	27	19.5	16.1	17.8	14.4	14.4
Status Marital								
Married	15	9.8	5.2		3.4	3.4	6.5	1.7
Not married	85.	54.7	30.3	24.7	23	20.0	13.3	4.0
Dwelling								
house	65.0	41.4	23.6	17.8	13.2	15.5	14.4	4.0
Apartment	35.0	23	7.5	6.9	13.2	8.0	5.2	1.7
Status tenure								
Owner-occupied home/outstanding loan	46.0	30.5	15.5	12.6	6.9	10.3	11.5	4.6
Owner-occupied home/without outstanding loan	2.9	1.7	1.1	1.1	0.6	1.1		
Rent home	51.2	32.2	18.9	10.9	19	12.1	8.1	1.2
Housing quality (%)								
Public services	94.3	59.8	34.5	24.1	24.7	20.7	19.0	5.7
Construction materials	94.3	59.2	35.1	24.1	24.7	20.7	19.0	5.7
Rooms available ≤2	87.4	56.9	30.5	22.4	23.0	20.1	16.6	5.1
Socio-economic status (%)								
Upper class (≥5)	1.7	1.7			0.6	0.6		0.6
Middle class (4–3)	14.3	10.3	4.0	5.2	2.3	2.3	3.5	1.2
Lower class (2–1)	83.9	53.3	31.6	19.6	23.6	20.7	16.1	4.0
Family								
Number of households (%)								
1	71.2	43.1	28.1	17.3	18.4	17.8	13.2	4.6
≥1	28.8	21.3	7.5	7.4	8	5.8	6.3	1.1
Number of people (%)								
4	52.8	29.9	22.9	10.3	13.2	13.2	12.6	3.6
≥4	47.2	17.3	29.9	14.4	13.2	10.4	6.9	6.4
LGBTI	1.7		1.7	1.7				
Education								
Illiterate/informal	0.6		0.6				0.6	
Primary	27.0	18.4	8.6	3.4	6.3	7.5	6.3	3.4
Intermediate or more	72.4	46	26.4	21.3	20.1	16.1	12.6	2.3
Health								
Coverage (%)								
Private	19.5	13.8	5.7	4.6	3.4	2.9	6.3	2.3
Public	68.4	40.8	27.6	15.5	20.1	17.3	12.1	3.4
No coverage	21.3	16.7	4.6	5.2	5.2	6.3	4.5	
Limited capacity	9.2	6.9	2.3	0.6	2.3	2.9	3.4	

Family distribution differentiates according to age. The younger individuals lived in one dwelling as compared to the age group of above 65. However, the family's size was homogeneous where 52.8% of the sample had four members and 47% had more than four members. This proportion increased with age but it is similar to gender. Furthermore, 1.7% of the sample population belonging to the LGBTI community was female. Of the sample, 72% had intermediate education or more, with separate results between genders (46% among males vs. 26.4% among females). Of the sample, 88% had health insurance, out of which 19% was private, and 68% was public, and 9.2% of them had mental or physical

disabilities. This value increases with age and range by gender (6.9% among males vs. 2.3% among females).

2.4.4. Statistical Analysis

All variables used descriptive frequencies as primary sample units that serve as the first reference frame of this baseline. These analyses use SPSS version 23. Bivariate analyses were performed between the exposure variables with the variables of age and gender. It establishes the tendency of the population surveyed in social and economic terms in comparison to the activities they develop around monuments with historical and cultural value.

3. Results

3.1. Estimation of the Deterioration of Materials

Table 4 show the annual material deterioration estimated with a dose-response function. The corrosion rate for carbon steel, copper and zinc were calculated using the Equations (2)–(4). In general, the atmospheric corrosion of the sites S1 and S4 are categorized as very high for all materials studied, corresponding to 80 < Vcorr < 200 μm/year for carbon steels; 2.8 < Vcorr < 5.6 μm/year for copper, and 4.2 < Vcorr < 8.4 μm/year for zinc, after the first year of exposure. The stations S2 and S3 are categorized as high, with corrosion rate of 50 < Vcorr < 80 μm/year para el carbon steel; 1.3 < Vcorr < 2.8 μm/year for copper and 2.1 < Vcorr < 4.2 μm/year for zinc.

Table 4. Annual material deterioration estimated.

Sites of the Study	Corrosion Rate (μm/Year)		
	Carbon Steel	**Copper**	**Zinc**
S1	102.49	3.26	5.38
S2	87.67	2.98	4.51
S3	98.41	3.13	5.0
S4	124.74	3.57	6.48
Level acceptable [1]	20	0.8	1.1
Report Data	26.5 [2]	1.19 [3]	3.55 [2]

[1] [72] [2] [73] [3] [74].

3.2. Socioeconomic Characterization

3.2.1. Socioeconomic Incomes vs. Physical State of Architectural Heritage

Table 5 identifies the percentage of variables as household incomes include the influence of architectural heritage and the perception on the monuments' physical state.

The primary variable of the main economic activities of the population is trading (50%) which is prevalent between the ages 27–39 and 40–51 (14.9% and 13.2%, respectively). After this, it appears tourism (36%) and services (13%) involved the youngest age group (15–26) but decreased from 6.3 to 0.6% among ages 52–64. Furthermore, 87% of those activities are informal labor as 49% of the sample are business owners located in the parks and squares in public spaces. The ages 27–39 were dominant in these sites, followed by the ages 52–64 due to the largest tourist visits. Additionally, 40% of the items sold were handicrafts as they are significant sources for the tourists who appreciate the cultural expressions of the architectural heritage with various objects. These articles were sold more by the age group from 52 to 64, followed by the ages 27 to 39. The language was also determined, where 38% of the subjects speak English, Portuguese, and French. This is more common among the younger age groups. The population sample sold their products to national tourists (56%), foreign tourists (35%), and only 8.6% were local customers. Finally, the years of experience that the respondent, who remained in the surroundings of the architectural patrimonies, which is reflected in the population with a permanence of more than 10 years (48%), 16.1% belonging to the ages between 40–51, followed by the ages 52–64 (16.1%). Furthermore, 72% of the subjects stated that the patrimonial monuments degraded due to environmental

conditions, but they did not have a maintenance plan to protect them against it. In total, 63% of the sample stated that the responsibility for conservation lies with the government. The proportion between the ages 40–51 increasingly held citizens responsible for heritage conservation. There is also a significant proportion (51%) of the subjects, mostly males (35%) instead of females (16%), whose income would be affected by the degradation of the architectural heritage because they could disappear along with the area's tourism. The proportion of conservation availability varies with age, where the younger individuals contribute more than the older age group (65+ years). The segment with the protection measures increased with gender while age differentials decreased significantly. This also includes the area's security, social control, and condemning were the measures proposed by the subjects.

Table 5. The baseline of the population's economic study by gender and age group: SEIS, 2017.

Characteristics	All Sample	Gender		Age Group				
		Male	Female	15–26	27–39	40–51	52–64	65+
No. (%)	174 (100)	112 (64)	62 (36)	43 (24.7)	46 (26.4)	41 (23.6)	34 (19.5)	10 (5.7)
Household incomes factors (%)								
Main economic activities	98.8							
Trade	50.0	31.6	18.4	7.5	14.9	13.2	11.5	2.9
Tourism	36.2	23.0	13.2	10.9	9.2	6.3	6.9	2.9
Services	12.6	9.2	3.4	6.3	2.3	3.4	0.6	
Workplace	98.4							
Historic Center	18.4	13.2	5.2	7.5	5.2	4.0	1.7	
San Felipe Castle	23.6	20.1	3.4	3.4	3.4	8.2	6.3	2.3
Parks and squares	48.9	25.3	23.6	10.9	13.9	10.3	11.5	2.3
Monuments	7.5	4.0	3.4	2.4	3.4	0.6		1.1
Labor								
Formal	12.6	9.2	3.4	5.7	1.7	2.9	1.1	1.1
Informal	87.4	55.2	32.2	19.0	24.7	20.7	18.4	4.6
Language	38.5	27.6	10.9	9.7	9.2	8.1	8.1	2.8
Main customer								
Local tourism	8.6	5.1	3.4	2.3	1.7	2.3	1.7	0.6
National tourism	56.3	38.5	17.8	12.6	16.1	14.4	9.2	4.0
Foreign tourism	35.1	20.7	14.4	9.8	8.6	6.9	8.6	1.1
Time worked								
<1 year	12.6	5.2	7.5	8	2.9	0.6	1.1	
1–5 years	21.8	12.6	9.2	9.2	8	2.3	1.7	0.6
5–10 years	16.7	9.8	6.9	4	5.7	4.6	2.3	
>10 years	48.8	36.7	12.1	3.4	9.8	16.1	14.4	5.1
Income								
<US220	32.8	17.2	15.6	8.6	11.5	5.3	6.3	1.1
US220–US660	66.1	45.5	20.6	16.0	14.9	17.2	13.2	4.6
>660	1.1	1.1		0.6		0.5		
Heritage monuments factors								
Degradation	72.4	46.6	25.9	13.8	22.4	19.0	13.2	4.0
Good conditions	26.4	17.2	9.2	10.4	4.0	4.0	6.3	1.7
Responsibility for conservation								
Government	63,2	39.1	24.1	14.9	12.1	18.4	12.6	5.2
Private enterprises	8.0	6.3	1.7	1.1	1.1	1.7	4	
Citizens	27	17.8	9.2	24.7	26.4	23.6	19.5	5.7
Income allocated	50.6	34.5	16.1	13.2	10.3	12.6	12.1	2.3
Conservation Availability	92.0	59.2	32.8	22.4	24.7	20.7	18.4	5.7
Protection measures	98.0	62.4	35.6	24.7	26.4	23.0	18.9	5.0

3.2.2. Bivariate Correlation Analysis

The bivariate correlation, according to economic and architectural heritage factors, is presented in Table 6. The negative incidence of some economic factors is also observed

(income, type of work, workplace, main economic activities, time worked). The negative value shows that the state of heritage has a negative incidence in the economy, especially in the cultural tourism. Furthermore, the heritage factors (state of heritage monuments, income impact, protection measure) evidence a negative value. This generates high incidence in the economic factors, producing a possible effect in the sustainability, especially in the income. The higher negative values (-0.167, -0.185, and -0.184) show that the type of work and main economic activities exceed the normal value (0.05), indicating a possible alarm over sustainability of the heritage.

Table 6. Pearson's Correlation results according to economic and architectural heritage factors. SEIS, 2016.

		Heritage Factors			
		State of Heritage Monuments	Income Impact	Economic Impact	Protection Measure
Economic factors	Income	−0.029	−0.047	0.034	−0.038
	Type of work	−0.167 *	0.030	0.135	0.035
	Work place	−0.119	0.123	0.002	0.025
	Main economic activities	−0.057	−0.034	−0.184 *	−0.185 *
	Main customers	0.069	0.189 *	0.109	
	Time worked	−0.160 *	−0.020	−0.108	

* The correlation is significant at the 0.05 level (bilateral).

The adverse incidence of degradation of architectural heritage remaining on type of work was 0.167 ($p < 0.05$). The responsibility for architectural heritage conservation had a heavy negative incidence on household income. The protective measures for area security, social control, or denouncement negatively affected the modality of work and the sold products. The continued deterioration of architectural heritage could affect the income so adversely that its main clients (tourists) stop visiting these monuments.

4. Discussion

4.1. Influence of Pollution and Climate in the Deterioration of Architectural Materials

Atmospheric corrosion is a natural phenomenon that causes damages or destruction in the materials due to reaction with the pollutants (SO_2, Cl^-, NOx, O_3, etc.) and climate parameters (T, RH, precipitations, and winds). In the case of Cartagena de Indias, the concentration of SO_2 in the different research sites originated due to use of fossil fuels with high level of sulphur [75]. It is observed that the high value (see Table 1) is present near avenues or streets with heavy traffic. It is highlighted that motorized vehicles are a source of harmful pollutants (NOX, SO_2 and PM) [76] and in 2020 the 56% of vehicles were motorized [77]. The classification as P3 is considered extreme due to accelerator effect in the corrosion process of metallic materials and limestones, generating reactions that produce dissolved acids. Results by Oliveira et al. [9] establishes that vehicular traffic near The Walled City of Cartagena de Indias probably damages the surface of the building materials.

In the marine environment, the chloride ion is another accelerator factor of corrosion and degradation of materials [78]. The chloride ion accelerated the corrosion when metal surface was wet. Ambler and Bain [79] said that a RH of 78% in equilibrium with a saturated solution of NaCl generated a strong acceleration of corrosion of carbon steel. In this case, the values reported for RH in the Figure 3e,f are higher than cited by Ambler and Bain. It is well-known that the salinity in the marine atmospheres changes according to the winds (directions and velocity), distance from the coast, topographic, altitude, among others [80]. These factors have a strong influence in the deterioration of materials due to the salts, acid gases, particles, and carbonation and sulfation reactions contribute to the formation of crusts [18]. The results observed in the Table 3 show high deterioration degree for these materials, generated by high level of pollutants (SO_2, Cl^-) and climate conditions; it is observed that sites of study are located near the sea and the industrial zone. These results compared with the tolerable corrosion rate reported by [24] are extremely high; for example, for cooper monument it is 1.0 μm/year and for zinc is 1.6 μm/year, with tolerable time

between maintenance of 50 years. In another study, it is shown that the corrosion rate of copper is 0.8 µm, for carbon steel 20 µm, and for zinc 1.1 µm, exceeding in all cases the maximum level recommended for 2020 [33].

According to the results obtained [9,81,82], contaminants, salts, moisture, and poor drainage maintenance trigger the deterioration of the material alongside the absence of public institutions dedicated to its preservation. For future scenarios in Cartagena de Indias, it is advisable the installation and/or updating of Meteorological Data Acquisition System and pollution, since both parameters have influence in the materials degradation [24] affecting the Outstanding Universal Value (OUV) of World Heritage properties [83]. It is important to know the sites in Cartagena de Indias that need special attention as a result of being in areas where anthropogenic activity is relevant, such as S1 and S4, located in the industrial zone and the historical center respectively. The preservation of historical heritage is important as it has a cultural, economic, and developmental impact on the city.

4.2. Sustainability of Architectural Heritage

Historical centers like the one in Cartagena de Indias have a close connection with national citizens and foreigners. Tourism in historical cities may contribute to economic growth and generation of employment, as Timothy [45] states in his research. This improves the social development (quality of life) of the population dedicated to several activities such as tourism, services, and trade [6]. The cultural tourism makes notable contributions to the economic dynamics of the city and helps develop the tourism and leisure industry. The results show that the socio-economic development of the architectural heritage is inadequate since 48% of the sample interviewed had established their informal businesses for more than 10 years (see Table 5) for two reasons. First, the lack of institutional offers for the formalization of jobs and businesses in this sector, and second the measures restricting the development of those activities in streets that affect direct businesses that pay the taxes in compensation for the valuation and conservation of heritage. According to the study results, the interviewees argue that the lack of culture and citizen awareness in the community generates a negative impact on the area's economy. Artal-tur et al. [40] report that the characteristics (level of studies, income, gender, young people, etc.) of the visitor are important to increase the level of economic sustainability.

The correlation results (see Table 6) show that tourist visits decrease with the increase in deterioration of the architectural heritage. The economic impact generated by the heritage deterioration establishes a negative correlation with the main economic activities of the sector including commerce, hotels, guest houses, and restaurants. The tourism in the region depends mostly on the quality of heritage sites and availability of them [84]. Economic assessment of business benefits from the heritage is so significant that it is impossible to urge direct and indirect goods and services if it is non-existent on the site [85]. The formal jobs might be more affected, according to the results [60], whereas the informal jobs will only shift from one place to another. McLoughlin, Kaminski, and Sodagar [85] establish that the increased business benefits from heritage may include more tourists, a higher hotel occupancy rates, restaurant demand and public transport, and increase of sales of traditional craft that reflect the culture. In other words, increase of culture tourism recognized by four elements as tourism, cultural assets, the consumption and the tourist [41]. There is a negative correlation of protection measures for architectural heritage with economic activities, restricting land usage. It implies that informal businesses cannot be inactive, and they should promote association to formalize its businesses within the city's historical center. It would instead limit the developing activities that are incompatible with land usage. It would also endanger heritage conservation, like horse-drawn cars, discotheques, bars, and those informal sales people invading the public space. They might be a potential business for local's economic development but unsustainable for architectural heritage [53,86].

There are also positive factors related to socio-economic development from the architectural heritage, like the restoration of historical buildings and their provision of services

promotes compatibility and sustainability in the long term. The participation of residents in the use of heritage to adopt and implement the Master Plan for Heritage Management and Protection would attract more tourism and produce more complementary goods and services. The public participation and cooperation among stakeholders reflects the positive impact in the conservation processes [87]. The latter will be possible according to the procedure of several economic activities and the responsibility of the heritage conservation. According to the study conducted by Yung et al. [88], heritage conservation is essential for both the historic buildings and the sustainable development of the regions.

According to the results obtained (see Table 6), the economic impacts of cultural tourism show that the 66.6% of interviewees have an income between US 220–US 660. Grazuleviciute and Urbonas [89] say that the influence of the architectural heritage and household income are beneficial due to increase of visitors, the creation of additional household income, and an improvement in the quality of life of the local population. In general, economic impacts of cultural tourism are direct, (individual benefits by selling products), indirect (are benefits obtained by other tourism holders), and induced (result of direct and indirect effects) [90].

5. Conclusions

This study highlights the impact of environmental pollution in the sustainability of architectural heritage in Cartagena de Indias, Colombia. The potential risk of deterioration of architectural heritage of the city deriving from air pollution and climate changes are high, with estimating corrosion rate (Vcorr) between $80 < Vcorr < 200$ μm/year for carbon steels; $2.8 < Vcorr < 5.6$ μm/year for copper and $4.2 < Vcorr < 8.4$ μm/year for zinc. The contaminants (Cl^- and SO_2) are an important factor in the corrosion process, as well as RH and temperature. The results can serve to prompt additional studies and highlight the need of public policies for air pollution reduction in Cartagena de Indias, especially in the historic center to prevent further damage.

Regarding sustainability of architectural heritage, also in this paper the relevant risks between economic aspects and heritage degradation with indicators of socioeconomic impact were determined. The economic impacts generated by the heritage deterioration establish a negative correlation; it is possible that this result is originated due to the lack of culture and citizens' awareness. The economic factor of the population has been influenced by the employment generated in its historical areas. This is exclusively due to the attractive history and culture of the architectural heritage of Cartagena de Indias for locals and visitors. The value of the architectural heritage perceived by the interviewees is low because of the area's structural problems including the lack of institutional supply, the invasion of the public space, economic activities incompatible with land usage, and tourists and locals' attitude towards the protection and conservation of heritage. Investment is also insufficient for the development and renovation of the buildings and/or potential monuments of the historic center to attract visitors and increase other tourism benefits. Despite the efforts to manage the conservation and maintenance of the architectural heritage, in some cases, the market supply and demand mechanisms allow the private sector investment; However, more government involvement is required for increased social value. Promoting incentives, e.g., real estate sectors, also strengthens the process and ensures sustainability over time.

Finally, it is important to reinforce the quality education of future generations to develop entrepreneurial skills and innovation in those who feel attracted to the dynamics of tourism from the architectural heritage. The creation of tourism workers' associations in the historical area would be possible by adopting inclusive public policies, concentrating efforts in the economic development, to optimize investment in the conservation, maintenance, and administration of the historical and cultural heritage. This will improve the quality of life for these individuals as they meet their basic social and economic needs.

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