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Integration of georeferenced informed system and digital image analysis to asses the effect of cars pollution on historical buildings

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HIGHLIGHTS

- Risk analysis for decision making for traffic control measures in historical cities.
- A new multidisciplinary approach based on SIG, modeling maps and digital image.
- A cost-effective methodology to analyse pollution in cities to improve building conservation.

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ABSTRACT

The blackening of buildings in historic cities due to air pollution is common. In historic urban centres, pollution from traffic negatively affects the preservation of monuments and results in the appearance of black crusts and/or deposits. The cleaning procedures for restoring or rehabilitating these building to remove these deposits are expensive and require continuous effort. Thus, it is necessary to monitor and control the effects of traffic on buildings. The objective of this study was to develop a new analytical methodology to assess and evaluate the continued risk of traffic pollution due to the circulation of vehicles near monument facades. This methodology combines geographic information systems (GIS) and digital image analysis (DIA) to evaluate the effect of traffic on the facades of stone buildings, which will enable more informed decisions regarding the reorganisation of traffic and the pedestrianisation of streets near monuments.

1. Introduction

The current developmental model of society has resulted in large cities with increasing numbers of vehicles and industrial zones. Due to air pollution, many monuments and historic buildings have begun to deteriorate [1,2].

Motor vehicles are the largest source of air pollution in urban areas. Carbon monoxide (CO) is the most common pollutant emitted by vehicles. Vehicles are also a significant source of particulate emissions, NO_x, and SO_2. The negative effects of air pollution on the building materials of monuments are well-known; particles may accumulate on the building surface, affecting its outward aspect, in addition to chemical reactions of pollutants with building materials [3]. Deposits and crusts on buildings are basically generated by two phenomena: dry and wet deposition. In dry deposition, pollutants adhere directly to the stone surface. In wet deposition, blackening is produced by oxidation of gas, such as SO_2 or NO_x, in the presence of catalysers resulting in the formation of different acids (principally H_2SO_4 and HNO_3) that begin to dissolve the stone surface. This phenomenon occurs extensively with materials composed of carbonates, such as marble, limestone, and calcarenite. Several investigations have been completed on the impact of air pollution on cultural heritage [4–6] and the appearance of mechanical damage [7] or black crust due to traffic and atmospheric SO_2 [8,9]. These studies demonstrate that walls directly exposed to traffic have higher concentrations of sulphate, nitrate, and organic carbon.

The damage layers in blackening and black crust [6] are a record of the environmental changes over time, and some differences in thickness exist [10] from different exposures to vehicular traffic.

Black crusts generated by pollution should be periodically removed from buildings using lasers, superficial cleaning, pressure washing, or chemical products, which may tangibly or intangibly damage these sites of historical significance. The expense associated with these restoration projects varies based on the costs of

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amortization of the instrumentation, consumable products required for cleaning, and operation time [11]. The costs are already high and must be incurred periodically in cities due to increases in pollution.

For these reasons, European legislation has been concerned with the effects of air quality on populations, ecosystems and, more recently, cultural heritage. Regarding risk assessment and the vulnerability of historical buildings to pollution, the basic texts of the Council of Europe [12] explicitly address physical deterioration due to pollution and refer to risks as the damages or foreseeable losses of cultural heritage that are caused by deterioration and accentuated by pollution and poor preservation. As in many developed countries, legislation in Spain addresses the exposure of historical buildings to pollutants as one of the factors guiding the establishment of air quality objectives and alert thresholds [13]. However, analysis of the actual risk of pollution in the environment and evaluation of the damages to historical buildings are rare.

In the cities and historical centres of Spain, local governments have jurisdiction in measures relating to urban traffic and are included in air quality improvement plans under Decree 239/2011 [14], by which the quality of atmospheric air is regulated. In this decree, a classification of traffic levels as a function of number of vehicles is found. A high volume of traffic represents more than 10,000 vehicles/day, medium volume represents between 3000 and 10,000 vehicles/day, and low volume represents between 500 and 3000 vehicles/day. The aforementioned decree is also connected to the guidelines established in Directive 2008/50/CE [15] to promote better environmental air quality and a cleaner atmosphere for Europe.

One of the guidelines for action in the National Plan of Climate Change Adaptation (Plan Nacional de Adaptación al Cambio Climático) [16] contemplates the evaluation of the potential impacts of climate change on cultural heritage (tangible or intangible) and its repercussions for tourism. However, no defined methodology exists for analysing the effects of air pollution on historical centres or on sites destined for preservation. For this reason, a new methodology is proposed in this article to combine geographic information systems (GIS) and digital image analysis (DIA) at the street level, considering sources of pollution, the flow of traffic, and the dispersion of pollutants, as well as the geographical location of monuments in the historical centre.

GIS is a tool used in different fields, such as in architectural inventories of rammed earth construction projects, which include the historical context, topographical data, and architectural characteristics and details of buildings [17], studies of rural construction projects [18], hazard evaluations [19] integrated with satellite remote sensing systems to assess flood risks [20–22], and in combination with RAMAN and SEM-EDX to study the pollutants on walls [23].

DIA may be combined with other techniques or used on its own, and it represents a useful methodology for the identification of different types of materials [24–26], weathering forms [27], signs, and drawings [28–30] or lichens, as well as for the analysis of the effectiveness of biocides [31] or the study of black crusts that have formed on buildings [32,33]. As a complement to other techniques, DIA is a non-destructive technique that also serves to evaluate salt damp on walls [34,35] and provides detailed materials mapping for the evaluation of the compatibility of conservation interventions [36]. In combination with remote sensing techniques, DIA of mural paintings allows for an understanding of the interactions of the different elements in a system that has diverse spatial positions [37]. Thus, this method is extensive and has several applications, and its results may guide decisions concerning the rehabilitation, cleaning, and consolidation of historical buildings. For these reasons, this method was selected to quantify damage to stone facades due to air pollution.

2. Methods

2.1. Study area

To demonstrate the application of the methodology, the city of Seville in the southern Spain was selected. The study area is approximately 3.7 km^2, and 16 facades of the most emblematic and ancient churches were considered (Table 1). These churches were built in the Gothic-Mudejar, Renaissance, and Baroque styles between the XIIIth and XVIIIth century.

2.2. Study of weathering forms on the facades of monuments

According to ICOMOS-ISCS [38], we describe the effects of pollution on the facades of monuments using visual inspections; these inspections allow to evaluate the frequency of weathering forms in different streets, and to carry out the analysis of frequency of weathering forms at the studied churches according to level of traffic (Fig. 2). In Fig. 2, a direct relationship is observed between the level of traffic and the weathering form by black deposits. For this result we have carried out the GIS map.

Visual inspections also allow to evaluate the thickness and blackish of black crusts and deposits in order to decide the number of samples.

Samples of black crusts and deposits were taken from the facades of the buildings at different heights (Table 1) in order to have enough samples that could be representative of the differences that were observed but trying to minimize the number of samples according to the recommendations of the technical commission CNR-ICR NORMAL 3/80 [39]. At least 4 samples have been taken of each monument studied by digital image analysis.

To characterise the black crusts and deposits on church facades, the following techniques were used:

a) The black crusts and/or deposits of samples were described with the aid of a ZARBECO 2000 magnifying lens. The front and back surfaces of the samples were viewed under visible, ultraviolet, and infrared light. A cut perpendicular to the surface was viewed with a KYOWA transmitted light petrographic microscope attached to a digital camera, a Leica 5400 LV optical microscope attached to a digital camera, and JEOL JSM-5400 and Zeiss Gemini 300 scanning electron microscopes with energy dispersive X-ray spectroscopy (SEM-EDX).
b) The building materials and the content of newly formed crusts and deposits were characterised using X-ray diffraction with a Bruker model D8C system and X-ray fluorescence using PANalytical Axios and Epsilon 5 spectrometers.
c) For samples from facades with different degrees of alteration, the rate of blackening and the thickness of the crusts and/or deposits was evaluated with a ZARBECO 2000 magnifying lens, and the digital analysis of images was completed for a 4 mm^2 surface area.

2.3. Construction of a pollution map by geographic information system (GIS)

ArcGIS was employed to evaluate the traffic of vehicles on all streets in the centre of Seville (Spain).

Air pollution data were provided by the Environmental Information Network of the Council of Andalucia (Red de información Ambiental de la Junta de Andalucía; REDIAM), this Network was