The environmental risk assessment applied to cultural heritage. A methodological approach

Emilio Galán, Patricia Aparicio
University of Seville, Departamento de Cristalografía, Mineralogía y Q. Agrícola, Sevilla, Spain

1. Introduction
Alteration of a fresh rock used as a building stone is an unstabilizer process by the combination of atmosphere, hydrosphere and biosphere (including man). This alteration usually means a modification in physical properties, texture and chemical-mineralogical composition of the rock. But, in general, stone degradation is slow if the action of atmospheric pollutants is not considered. Pollution accelerates stone degradation rate to near exponentially. As it is known, stone deterioration is more and more increasing mainly due to industrial and urban pollution since the final of XIX Century. Along the XX Century different stages (at least three) can be considered according to the scientific approach used in the stone research. In the first half of the XX Century a stone macroscopic observation and visual descriptions of alteration indicators, together the historical documentation, were mainly the base for conservation and restoration works. Since the 60’s basic research was developed to understand the stone behaviour in the monument, according to: petrography, physical and physic-chemical properties and environmental conditions. Also the research was focused on three topics: 1) simulation of environmental conditions (ageing tests), 2) location of original quarries and 3) conservation products. For those proposes, all the classic and new techniques used in mineralogy, geochemistry, building materials, civil engineering, and material science were applied to the diagnosis of monument stone and its conservation. Later, since the 80’s the most interesting research in this period concerns to cartography of lithology and degradation forms (mapping), the use of new techniques for diagnosis and control of conservation treatments (mainly non-destructive techniques), biological activity studies (biodeterioration), and new approach on atmospheric pollution and climatic modeling effects.
Because of stone degradation is more and more seen as a concern with the environment, an environmental risk assessment, adapted to cultural heritage could be very useful to know the present state of conservation, degradation causes, and environmental risks. The hazard is defined as the probability that a phenomenon, of an established intensity, may occur in a defined area during a given period of time. Vulnerability can be defined as the degree of loss of elements as a consequence of the occurrence of a natural phenomenon of a given intensity. The risk corresponds to the expected value of loss of elements due to hazards and it can be expressed as the product of hazard and vulnerability.
Many methodologies and integrated tools have been developed for hazard assessment and risk analysis [Rinaldi et al.1992, Luria and Aspinall, 2003]. In this paper a proposal to assess the environmental risk that presently supports
a monument is presented, and applied to evaluate the environmental risk supported by a Spanish case study.

2. Methodology

The methodological proposal follows the previous approaches developed by Galan et al (2006) and Antúnez et al. (2010). The methodology implies the knowledge of the monuments, the hazard assessment, and the vulnerability analysis. For hazard assessment the static-structural, environmental-air and anthropogenic factors should be evaluated in the site under study. Finally to determine the vulnerability of each monument, a vulnerability matrix (VM) must be adapted to the nature of Cultural Heritage conservation problem (Fig. 1).

Therefore, the degradation of building materials, evaluated by means of the vulnerability index (VI %), is mainly due to the deterioration effects of static-structural damage, weather and pollution agents and anthropogenic damage. The VM is prepared by inserting in the rows the hazards of the particular environment and in the columns the building material characteristics, the structural conservation degree and aesthetic properties. The vulnerability index for each monument is quantified by a visual study of the buildings, where the frequency and weathering degree of the deterioration patterns is taking into account. The frequency of appearance is set between 1 and 3; if it is difficult to detect the presence of the weathering form the frequency would be 1, if the weathering form is identified easily, the frequency would be 2 and the frequency would be 3 if it occurs at a high rate.

![An example of vulnerability matrix (VM) adapted to assess the environmental risk for a monument](image-url)
Once all weathering forms for each monument have been obtained, the vulnerability index (VI) is calculated dividing the total value of the deterioration patterns (Vx) for each monument by the sum of total value of deterioration patterns (∑vdp), that in the case that their frequencies would be the maximum value (3 or 10), it would be:

\[ VI = \frac{V_x}{\sum_{j=1}^{vdp}} \times 100 \]

Vulnerability index (VI%) is classified into vulnerability degrees using ordinal classes (Table 2)

<table>
<thead>
<tr>
<th>VI (%)</th>
<th>Vulnerability degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 %</td>
<td>Low</td>
</tr>
<tr>
<td>10-25 %</td>
<td>Moderate</td>
</tr>
<tr>
<td>25-50 %</td>
<td>High</td>
</tr>
<tr>
<td>50-75 %</td>
<td>Very high</td>
</tr>
<tr>
<td>&gt;75 %</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

Table 2. Vulnerability degrees classification

3. Case study: the Torre del Oro (Seville)
Seville’s Torre del Oro is a defensive tower built in the 13th Century by the Almohads (Figure 2). It is located on the bank on the Guadalquivir River, and is set back from an avenue with intense urban traffic flow. The tower has three bodies. The fabric of the first body is built of biocalcarenite and calcareous sandstone, mortar and brick. The second and third bodies are of mortar and brick. Principal weathering forms are biological patinas, dark deposits and/or crusts. Anthropic alterations are gouging, graffiti and effects of the open-air mass by-night bottle parties. Alteration forms of stone are mainly pitting, alveolar weathering, cavities, grain disaggregation and loss of material. Alteration forms in mortar are swelling and associated fractures, cracking and loss of material, efflorescence and sub-efflorescence. In the part of the Tower base facing the river, the rising dup affect the iron reinforcements causing loss of material as contour scaling. Brick presents scaling, exfoliation pitting and loss of material [Leguey 2000, Leguey et al. 2001, Galán et al. 2002, 2003]. Gypsum and microcrystalline carbonates generally form the crusts. In some cases traces of halite and smooth spheres resulting from fuel combustion have been also found. The efflorescences are predominantly formed by sodium sulphate (tenardite).

Other pollution sources affecting the Tower can be the industry located in the outskirts of the city (iron foundry brick factories, pottery, chemical and fertilizer plants, etc.). Seville belongs to a climatic region known as “attenuated southern continental area” (Font Tullot, 1983), characterized by temperate winter. Seville presents a low average wind speed and frequent anticyclonic situation with little rainfall, ideal conditions for producing a thermal inversion which impedes the diffusion and dispersion of pollutant emitted. Furthermore the relative high humidity creates favourable conditions for the production of secondary chemical reactions. Because of these climatic conditions the pollution derived from the industry can affect the Tower.
On the other hand, many flooding historically affected the city and tower, and also frequent earthquakes produced important structural damages.

Taking into account all those data the following matrix was proposed (Fig.3). The vulnerability degree for the Torre del Oro, Seville is moderate (23%).

4. Conclusion
This paper presents an easy and cheap methodology that allows to know the main risks that can affect to a monument in a particular site and the conservation conditions. It provides a tool for helping to decide which factors should be considered more important in preservation efforts for a monument and the intervention planning.

References
Fig. 3 - The vulnerability degree for the Torre del Oro, Seville. The VD is 23% (moderate)


