Monitoring the performance of stone conservation treatments: Technical and economic aspects
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1. Introduction
Maintenance is one of the key words in the field of conservation of cultural property; this is especially important for monuments exposed outdoors, such as architectural surfaces, and it is also needed following conservation treatments of natural and artificial stones to check their performance and durability. All those working in the fields of Material Science and of Conservation of tangible Cultural Heritage know very well that materials are prone to decay as a consequence of their interaction with the environment they are exposed to. The severity, rate and morphology of such decay, depend upon the intrinsic properties of each material (or of each composite) as well as upon the environmental factors and their synergic effects. Since 1980s standard glossaries were proposed for the description and mapping of the numerous decay forms evidenced in natural and artificial stones [Aa.Vv., 1980]. More recently the ICOMOS-ISCS (International Scientific Committee for Stone) issued an “Illustrated Glossary on Stone Deterioration Patterns”, originally in English and French and now translated into several other languages [Aa.Vv., 2008]. Today, an accurate description of the morphology of decay is the first, inevitable step of any diagnostic investigation of the condition of stone monuments, in view of their conservation.

Unfortunately, materials and products used for conservation treatments also tend to deteriorate and cannot last forever, even if the treatments were done to the best of conservators’ knowledge. For this reason it is necessary to carry out periodical maintenance even after extensive and accurate conservation works.

The evaluation in advance of the efficacy of products and of the suitability of stone treatments is rather complicate and time consuming [M. Laurenzi Tabasso, S. Simon, 2006]; this is due not only to the different properties of the products used and on the environmental conditions, but also on the past “conservation history” of the monument, the methodology used to apply the product and the accuracy during the application.

Different approaches can be adopted for such an assessment [M. Laurenzi Tabasso, 2004]: 1) to survey the condition of monuments treated in the past, for which reasonably good documentation exists on products and methods used; 2) to carry out ad hoc tests (either in the laboratory or in situ or in both contexts).

Studying the condition of monuments that have been treated in the past, after a known time interval and under known environmental conditions is the closest way to assess the performance of products and methods. The sine qua non condition is the availability of exhaustive, or at least sufficient, documentation of the works which were carried out, concerning not only the various products and treatments but also the conditions of the stone both before and after treatment. The information collected through these surveys is very useful
for setting up databases for first level knowledge on the performance of products used for stone conservation and for rough forecast of the durability of any conservation treatment.

However, even when surveys have been carried out, evaluating the long-term performance of products still remains very difficult because of the influence of many partly unknown factors, related to the complexity of the conservation treatments themselves. While consensus on the need and usefulness of maintenance is quite general and available techniques for solving specific maintenance problems are rather well established, the frequency of each maintenance intervention cannot be established in advance as it depends on the local condition (stone quality, environmental and climatic data, etc.). Moreover, at least in some countries, maintenance frequency often depends more upon budget conditions and limitations rather than upon real conservation needs. The risk is to carry out “emergency maintenance”, when irreversible losses have already occurred.

To avoid such risk, effective maintenance programmes should be based on the real needs of each monument and could take advantage of the results of accurate and regular monitoring of its conditions.

Ideally, each conservation project for any given monument or art object should include a plan of regular monitoring and of maintenance. Timing and technical contents of the latter should depend on the results of the former. Since several years, basic criteria for implementing monitoring campaigns on monuments after stone conservation treatments were proposed. In Italy, at least in the specific case of several Baroque monuments in Lecce, monitoring is being carried out regularly since the late 1990s (even though this does not seem to have very much influence on the policy of the concerned Authorities!) [A. Calia, 2005]. However, in the majority of cases, one of the main problems to overcome when planning monitoring comes from budget restrictions and it is generally considered that regular monitoring of stone conditions is more a luxury than a real need.

The present study is aimed at evaluating the sustainability of regular monitoring in monuments and sculptures both from the technical and (especially) the economic standpoint. The study was the object of a Master Thesis on “Science Applied to Cultural Property”, Sapienza University, Rome [S. Sestini, 2010].

2. Experimental
In order to collect elements useful for the proposed evaluation, the following path was adopted:
1. Selection of a recent case study where the different conservation treatments and their costs are well known;
2. Selection of suitable techniques to monitor the stone condition and estimation of their costs;
3. Selection and economic evaluation of three different maintenance strategies.

2.1. The conservation treatment of the “Mostra dell’Acqua Felice”
The “Mostra dell’Acqua Felice”, also known as “Fontana del Mosè”, is the
monument selected as case study. It was built in 1586-1589 by the Pope Sisto-V to celebrate the accomplishment of a new aqueduct to bring water to the Quirinale and Viminale hills. Travertine, various types of marble (Carrara, Cipollino, Bardiglio and Africano), stuccoes and plaster were used to build the monument.

The fountain is located in one of the busiest cross-roads of Rome town centre (Figs. 1, 2).

When the Fountain was restored in 1988, the stone surfaces were covered by heavy dust deposits and black crusts (Figs. 3, 4, 5), due to the heavy pollution in the area.

Twenty years later, the monument was again in strong need of conservation and an extensive intervention was planned by the Municipality Superintendency (Figs. 5, 6). The works started at the end of 2008.

Figs.6,7 - The same details as in -Figs. 3, 4, and 5, before the conservation treatment carried out in 2009 -2010
Cleaning, gap filling, re-pointing, biocide treatments, localized consolidation and surface protection by a water repellent product were the most important treatments included in the project. The authors of the present study were allowed to examine the different items of the contract and could be informed on the economic aspects of the project.

2.2. The monitoring of stone condition after the conservation treatment

A limited number of parameters, indicative of the condition of the stone surfaces, were measured with non-destructive and low cost techniques: low tech methods were selected on purpose, on the basis of previous experiences [A. Calia, 2005] and being aware that sophisticate (and more expensive) techniques could probably be used only episodically but not on a regular time scale, as it is needed with monitoring.

The measured parameters and the techniques and methods adopted are listed in Table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Analytical technique</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface colour</td>
<td>Reflectance spectroscopy</td>
<td>NORMAL 43/93</td>
</tr>
<tr>
<td>Surface water absorption</td>
<td>Contact absorbing sponge</td>
<td>[P. Tiano, 2004]</td>
</tr>
<tr>
<td>Qual-quantitative content of water soluble salts</td>
<td>Ionic chromatography</td>
<td>Extraction of salts by Japanese paper</td>
</tr>
</tbody>
</table>

Just as an example, Fig. 8 shows a map of the points where surface water absorption was measured.

All the monitoring measures were carried out at the conclusion of the conservation treatment, safe in the case of the lions at the ground level, near the water basin, where the measures were carried out before and after the cleaning and after the application of a water repellent protection, at the conclusion of the treatment. Despite the simplicity and low cost of, the chosen methods, the measured parameters proved significant enough to highlight the difference among the materials and to characterise their condition. The obtained results can be therefore considered as a reference, a “zero point”, for the future monitoring to assess the condition of the stone.

All the technical details and the experimental results of the monitoring are given in [S. Sestini, 2010].

The cost of the monitoring carried out for the preparation of the Master thesis, was evaluated on the basis of market costs of the different measurements (including the photographic documentation) and of the time needed for each operation and for the elaboration of the experimental results.
2.3. The maintenance alternatives

For the overall economic evaluation of monitoring, three different conservation strategies were considered and compared. The selection of the three alternatives was based on the concepts of Vulnerability and Dangerousness as defined by the “Risk Map” (http://www.cartadelrischio.it/ita/info.asp), established by the Istituto Superiore per la Conservazione e il Restauro (ISCR), of the Ministry of Cultural Property and Environment. To evaluate the Risk of Fontana dell’Acqua Felice, archival and bibliographic data were consulted, both concerning the climatic data and the condition of the monument in the 1980s and just before the 2010 conservation treatment. The selection of the parameters to monitor, listed in Table 1, was based on the results achieved for the evaluation of the risk of the Fountain.

The three alternatives considered for the study are:

1. To carry out only emergency treatments (if needed) and plan a thorough conservation intervention after a rather long period of time as it occurred in 2010 and as it frequently occurs for many other monuments, where a "project-less policy" is adopted.
2. To establish an ordinary maintenance programme, whose time intervals are fixed “a priori”.
3. To carry out regular monitoring and to use the information provided by the measured parameters for planning and implementing targeted maintenance interventions.

This last alternative is compatible with the strategy of planned conservation and with the idea that only through prevention is possible to assure the material authenticity of a work of art.

The three alternatives, in the case of the Fontana, can be illustrated by the following Table 2, where TM = total maintenance (as in 2010); MO = important maintenance; M1 = light maintenance

<table>
<thead>
<tr>
<th>Year</th>
<th>A1 1st hypothesis</th>
<th>A2 2nd hypothesis</th>
<th>A3 3rd hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td></td>
<td>Total Maintenance</td>
<td>Total Maintenance</td>
<td>Total Maintenance</td>
</tr>
<tr>
<td></td>
<td>TM TM TM</td>
<td>TM TM</td>
<td>TM TM</td>
</tr>
</tbody>
</table>

Table 2
The details of the different operations budgeted for MO, M1 and for monitoring are given in [S. Sestini, 2010].

2.4. The economic analysis of the three alternatives
The Multi-Criteria Analysis (MCA) was chosen for the economic evaluation of the three conservation strategies also with the support of the S.W.O.T analysis.

S.W.O.T. analysis is a tool which helps the identification of the main strategic guidelines in a decision making process considering four aspects of an examined project: its Strengths, Weaknesses, Opportunities and Threats.

In the case of Alternative N.1 (Total Maintenance after 20 years), we considered:
Strengths = no investments are needed at a short date; Weaknesses = Increased risk for the monument and lack of data on the monument condition; Opportunities = with the saved investments, other different projects can be budgeted; Threats: risk of irreversible damage for the monument; risk of lack of funds when needed.

In the case of Alternative N.2 (Important Maintenance every ten years) we considered:
Strengths = no investments are needed at a short date; Weaknesses = Increased risk for the monument and lack of data on the monument condition; Opportunities = possibility of changing conservation strategy on the basis of the information achieved during the maintenance intervention; Threats: risk of planning unnecessary operations, due to the lack of data on the monument condition.

In the case of Alternative N.3 (Yearly monitoring and light maintenance every five years) we considered:
Strengths = Frequent control of the monument condition, set up of a data base useful for scientific studies on stone conservation, improved “quality of use” of the monument; Weaknesses = Need of constant investments; Opportunities = Creation of employment; possibility of changing conservation strategy on the basis of the monitoring results, better use of the available resources, creation of a targeted economy; Threats: suspension of the program due to political-financial reasons, frequent presence of conservation yard which could interfere with the local commercial activities.

The above description of the three alternatives stresses how the simple financial cost is inadequate to evaluate them from an economic point of view. For that reason a multi-criteria analysis (MCA) was adopted whose main steps are: 1) definition of criteria that are relevant to reach a decision; 2) allocation of suitable weight to each criterion.

MCA then uses mathematical matrix models to analyze qualitative and quantitative data in function of the criterion typology: each criterion is evaluated on the basis of the most suitable unit of measurement.

In the present study the criteria adopted for the evaluation of the three alternatives are illustrated in Table 3:
Table 3
Vulnerability was defined according to the above-mentioned Italian Risk Map. The Costs of the different activities included in the three alternatives were evaluated on the basis of the budget of the 2009-2010 treatment and on market analyses for all those items not specified or not included in that budget. For the definition of the Employment criterion, the number of persons and the number of contracts needed for the activities included in each alternative were estimated on the basis of the situation of the 2009-2010 treatment and on the related monitoring experience; all the details are given in [S. Sestini, 2010].

In order to establish a ranking order of the different criteria for each of the considered hypotheses, each criterion had to be compared to the two others and have a weight assigned. For this purpose, a discrete number of specialists with different cultural background, either directly involved in the field of architectural conservation or interested, at a more general level, in the management of cultural property, were requested to give weights to each criterion for the three alternatives. They were requested to fill the following Table 5 on the basis of the fundamental Saaty Scale, illustrated in Table 4 [B. Roy, 1981] where each criterion is compared with a second one:

Table 4
<table>
<thead>
<tr>
<th>Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>The two elements have the same importance to reach the aim</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>The evaluation is slightly in favour of one of the two elements</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>The evaluation is strongly in favour of one element</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>The predominance of one element is clearly demonstrated</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>There is the highest evidence in favour of one element</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values between two close evaluations</td>
<td>A compromise is needed for the final evaluation</td>
</tr>
</tbody>
</table>

Table 5
3. Results
The results of the interviews to the experts were further elaborated mathematically in order to define the final normalized matrix. MCA is strongly influenced by uncertainty due to the subjectivity of each decision maker's point of view. For this reason, a sensitivity analysis has been carried out to investigate the results of the weight attribution process. The aim is to determine which variations in the proposed model could have a substantial impact on the final ranking of the evaluated alternatives. In this work, the sensitivity analysis was carried out starting from the assumption that the cost criterion is the one with more influence on the two others and it studies the effects of an increase in
its weight with respect to the weights of the employment and vulnerability criteria. The same evaluation process described in 2.4 was therefore reiterated supposing that the cost of the different alternatives could increase by 10, 20 and by 30%.

The results confirmed that even in this case the ranking order of the alternatives did not change. Table 6 gives the final results of the multi-criteria analysis and Fig.9 illustrates the trend, in the next 20 years, of the Vulnerability Criterion for the three alternatives described in Table 2.

4. Conclusive remarks
The Multi Criteria Analysis proved to be a useful tool in the decision-making processes related to conservation of built architecture. It allowed discussing advantages and drawbacks of different alternatives starting from the recent case study of the conservation treatment of the Fontana dell’Acqua Felice, in Rome. The three alternatives, their timing and technical content, were selected on the basis of the Italian “Risk Map” and on authors’ personal experience on monitoring techniques. The Risk Map also served as a guideline for the selection of the criteria needed for the economic evaluation of the proposed alternatives.

The subjectivity in the evaluation of the criteria by a group of experts was mitigated on the one hand by their different cultural background, and, on the other hand, by the “sensitivity analysis” carried out on the results.

Fig.8 shows the great advantage that can be offered to the good conservation of the monument by regular monitoring, followed by light maintenance, when needed.

For the sake of space it is impossible to show here the trend of the Employment Variability, which is more regular for A3 than for A2 and A1. Even the Cost Variability follows the same pattern, considering that heavy maintenance carried out after a long period (20 years) requires much more work to do and therefore much higher budget.

The last point to stress concerns the analytical techniques adopted for monitoring the monument: simple and cheap methods were adopted, which however resulted to be useful to distinguish among different materials and different conditions. The fast evolution and development of Non-Destructive Techniques useful to measure other physical and chemical parameters allows to hope that monitoring will become in the next future more and more sustainable from the economic point of view and, provided the concerned Authorities
will pay due attention, a “routine” part of the conservation strategy.

Authors wish to thank Dr. Rossella Motta, of the Superintendence of Cultural Property, Rome Municipality, responsible for the 2009-2010 project on the Fontana dell’Acqua Felice, for the precious information provided and moral support.

References
NORMAL 43/93, Misure colorimetriche di superfici opache, CNR/ICR, Roma.