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A Method for Risk Maps in Archaeological Sites: The Case Study of the Domus Tiberii on the Palatine Hill in Rome

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ABSTRACT: The paper presents a pilot application, on one of the most important archaeological sites in Rome, The Palatine hill, where an attempt to formulate the risk is carried out. This target is achieved by taking in exam the major possible causes of alterations which a monument can be subjected to: from the decay to the structural damage. The application is carried out on the North West side façade of the roman Domus Tiberii which was covered, in the 16th century by a system of retaining walls built up by the Farnese Family, and known as *Farnesian bastion*. In 19th century these walls partially ruined, leaving a complex situation under the point of view of historical and archaeological stratification and consequently of design choices, strategies of conservation and structural safety. The results of this preliminary screening yielded to highlight which area can be considered as the most vulnerable, requiring more detailed surveys, structural investigations and archaeological excavations. Finally a restoration and strengthening design was developed by the Archaeological Superintendence of Rome.

1 INTRODUCTION

1.1 Policies for cultural preservation in Italy

One of the major issues in countries with a consistent presence of historic architecture is the management of its conservation.
This problem is particularly crucial in Italy, due to the extensive historic heritage present, a notable part of which is represented by archaeological remains.
Moreover, economic funds available for Conservation are usually inadequate for safeguarding the whole heritage.

When dealing with archaeological sites this condition becomes particularly complex as the potential value of the site under a historic, constructive or archaeological point of view can be definitively assessed only after accurate surveys and investigations. So that operative choices within the archeologically heritage are strongly featured by a level of uncertainty: possible discoveries during excavation campaigns can yield to completely change the value of that site, and hence its priorities. Therefore, the strengthening or conservation project, represents just the last step of an articulate process aimed at achieving a deep knowledge of the monument, under the point of view of its cultural value, as well as of its preservation conditions. As a matter of fact, the past experience on many archaeological sites in Italy (among which the same Palatine Hill) suggests that archaeological excavations, structural investigations and architectonic surveys are necessary to highlight the real state of the monument.

So far the conservation and the restoration policy of archaeological sites in Italy has been afforded without a general planning tool, so that local Institutions involved in this sector (leaded by the Ministry of Cultural Heritage) usually operate independently from each other. The result of this situation is that the management of economic funds is often left to the decisions of single technicians operating in the sector, and this can yield to a non optimal allocation of available resources.

1.2 The Risk analysis as management tool

The above considerations clearly stress that appropriate tools for managing the Cultural Heritage are needed in order to identify those sites mostly requiring more accurate investigations and urgent interventions. One powerful method for analysing the problem under a general point of view is represented by the Risk analysis, aimed at examining all possible risks associated with historic or archeological sites. The risk refers to all possible causes of decay or structural damage which an historic structure can undergoes over the centuries, and hence includes the lack of maintenance, the presence of inadequate constructions criteria, the lack of strengthens, as far as the seismic vulnerability when the monument under exam lays on a seismic prone area.
Over the last ten years, an approach for determining the risk of the cultural heritage in Italy has been carried out by the ICR (Central Institute for Restoration), focusing on the architectonic, decorative features, and with some attempts even in defining the structural behaviour (Accardo, 1997).

The method is developed at territorial scale, as to highlight over the whole Country the most jeopardised areas. The so called method MARIS (from Map-risk), also implemented in a Territorial Informative System, is capable to store data sets of different types of protected sites, including historic architecture, archaeological sites, archaeological remains, as far as decorative and museum articles. The data collected are then processed for the final calculation of the risk. This is mainly based on the *observed vulnerability*, and hence based on extension and level of the damage observed. One of the limits of this approach is that it is much more accurate for describing damage produced by superficial decay than for the one due to structural problems. The final risk is defined as a function respectively of the vulnerability and of the *hazard*, defined as potential level of aggression (for the different aspects to which the risk is defined), in a given territorial area. As to territorial data, the hazard is assumed constant when analysing more sites in the same area, and hence the only factor influencing the risk is the vulnerability, formulated as combination of three indices (superficial decay, structural performance, type of use and global safety). However, this criterion is undoubtedly useful for compare and observe the distribution of risks at large scale, but when focusing on more restricted areas, some more parameters are needed. The above considerations have been implemented in a new experimental method, clearly inspired to the ICR criterion, and applied to a significant test site: North West side façade of the roman Domus Tiberii, on the Palatino hill in Rome.

2 THE RISK MAP OF THE NORTH WEST SIDE OF THE PALATINO HILL

2.1 Introduction to the test site: the north west side of the Palatino hill

The Palatino hill in the very centre of Rome, is one of the most important archaeological sites in Italy, as here the Roman Emperors built up their Palaces, in Latin “Palatium”. The old structure, whose ruins still highlight the magnificence of roman architecture, covered approximately a squared surface of 1000 metres per side, with height on top of 30 mt. above the Tiber river.
The Palace was founded on a basement of (from top to bottom) red and grey volcanic lithoid tuff, pleistocenic sands and gravels, and plio-pleistocenic clays; and its construction was carried out in different stages over the centuries.

Natural calamities, as seismic events, meteoric agents, latter alteration of the structure (as its use as quarry until 18th century), produced serious damage, with collapse of structural elements, and high level of decay of surface and materials.

In 16th century, the north-west and north-east sides of the hill, characterised by the presence of the so-called “Domus Tiberii” buildings, was covered by a system of retaining walls for better supporting the Gardens of the Farnese family, known as Horti Farnesiani. Over the last 30 years these walls have undergone local and global failures, bringing to the light the roman structures behind. Since then, the area has been closed and forbidden to tourists.

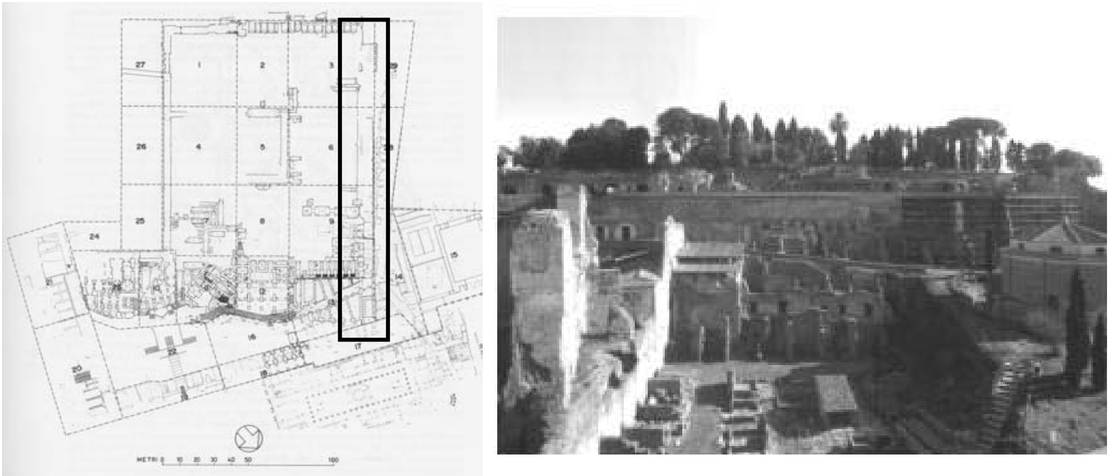


Figure 1 : Map of the Domus Tiberii, with highlighted the front taken in exam (left); global view of the Northwest side of the hill (right).

The wall collapse which occurred in the west side of the front in the 19th century, enabled the discovery of archaeological remains and caves, testifying the archaic life on this area, used for storage or recovery. These cavities can be one of the possible causes of damage and collapse of the overhanging Roman structures.
The front under exam, illustrated in Fig.2, is approximately 30 m in height and 150 m in length, and shows different problems, from advanced material decay as far as geotechnical and structural aspects.

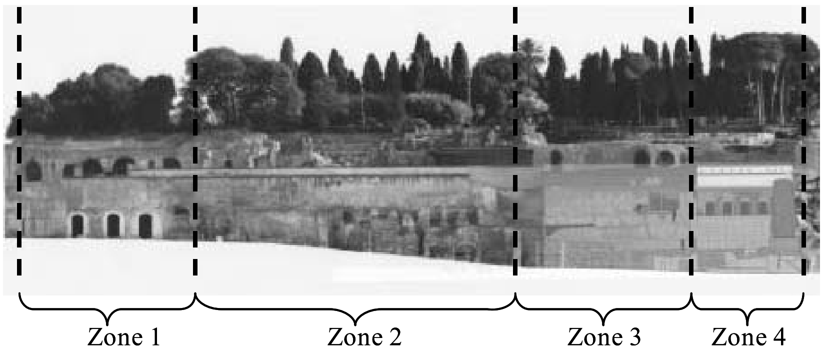


Figure 2 : View of the nort-west front under exam

The front has been divided in four partitions, each characterised by different situations. While the decay of material (concrete, brickwork, tuff blocks, remains of decorations as mosaics, etc.) is uniformly very high over the whole surface, because of the total lack of maintenance, the structural damage is more concentrated on few zones.
A typical situation of decay, outlining the state of abandon, is the decohesion of roman mosaics of Fig.3 (left), taken in the zone 1. Similarly Fig.3 (centre and right) illustrates the masonry and mortar erosion of external walls of zone 2 and 3.
Zone 1 is featured by a system of repeated arches, getting into internal spaces, where the original concrete vaults get lost. The internal partitions are seriously cracked, requiring structural propping for avoiding further collapses. This situation jeopardizes also the external front, subjected to high thrusts weakly balanced.

Figure 3 : Typical examples of material decay (zone 1, zone 2, zone 3)

The second zone, is characterised by an extensive decay of the surface, and conversely by a more contained structural damage. However the structure has lost its original configuration, featured by a system of tuff buttresses thrusting against the wall and hence contributing to the global stability. Moreover the upper part of the wall, filled of earth, debris and vegetations, represents a very high risk for the global safety.

The third zone is the one collapsed in the 19th century, when the ruined Farnesian retaining walls of 16th century, brought to light a complex situation. The hill is realised by a basement of grey tuff and red lithoid tuff on top, with an intermediate layer of sands, 2 mt thick. The tuff is deeply cracked, and vertical cracks, filled by earth, run the risk to fall down. In this case also, the roman buttresses are partially ruined, without contributing to stabilize the rest of the hill.

The zone 4 (Fig. 4 right), represents the west edge of the Farnesian Bastion, which ends with a sort of bulk buttress, known as Rivellino. This zone is featured by a system of Imperial time arches, walled up in 16th century, in order to fill up the internal vaults of earth, and hence creating the upper garden. Similarly to other situations, here the safety level is particularly low, running the risk of structural failures.

Figure 4 : Examples of structural damage of zone 1 (left), 3 (two in the middle) and 4 (right).

2.2 Map of vulnerability factors

Once outlined the major alterations of the front under exam, following a checklist preliminarily formulated, these have been ordered according to progressively pejorative situations. In total 13 vulnerability factors have been recognised and labelled. The first 3 concern features, which simply represent an exposure to decay (from V_1 to V_3), while the remaining 2 are associated with evident decay, as follows:

V_1Occluded sewers
V_2Water erosion
V_3Sediments (or growth)
V_4Loss of superficial cohesion
V_5Material crack and fall of fragments
The remaining 8 factors include structural problems, as listed below:
V_6Partial collapse of arches, lintels

V_7Partial collapse of caves/vaults
V_8Walls subjected to earth thrust
V_9Lack of material
V_{10} Ineffective structural elements
V_{11} Instability due to clay
V_{12} Risk of collapse of wall portions
V_{13} Instability of tuff fragments

Factors from V_6 to V_9 concern features representing a simple exposure to structural vulnerability, while the remaining 4 (from V_{10} to V_{13}) include very serious structural problems.
The 13 vulnerability factors have been surveyed over the whole surface, and mapped in Fig.5. One can note that while the superficial decay, in the five different alterations listed above, is associated with very extensive surface, the structural damage is concentrated in more restricted areas or structural partitions. The map has been further processed in order to achieve a final assessment of the vulnerability and of the associated risk.

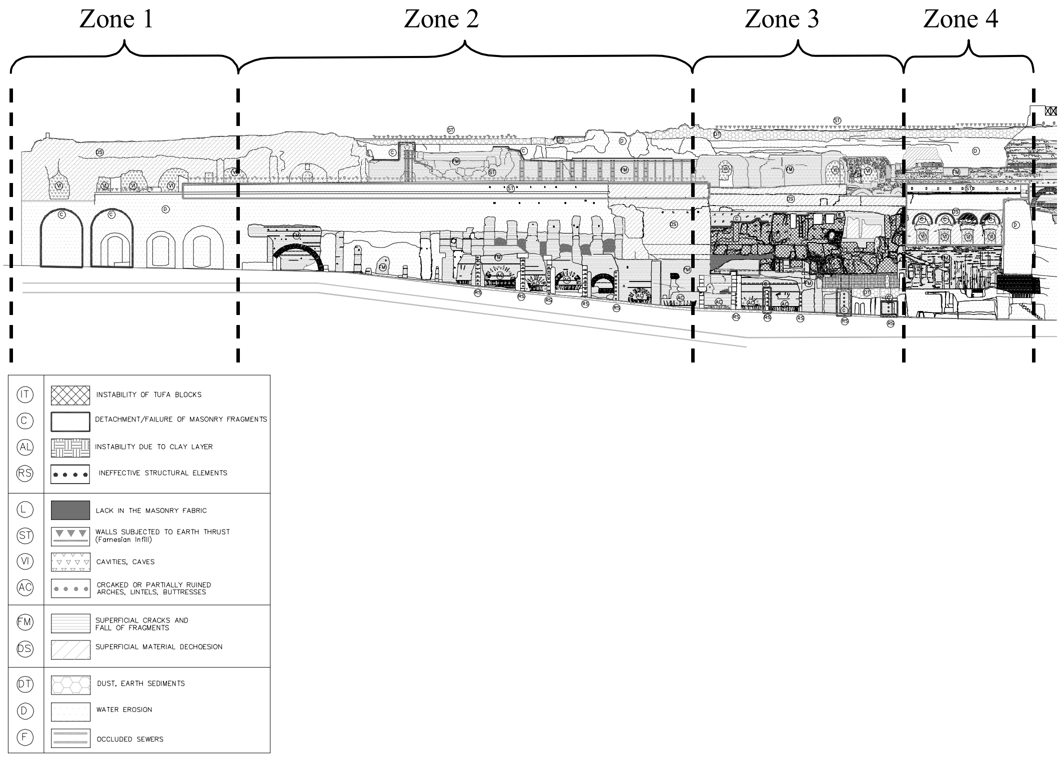


Figure 5 : Map of the vulnerability factors surveyed over the whole facade

2.3 *Distribution of vulnerability factors*

The distribution of the alteration types featuring the front, is clearly outlined by the two histograms of Fig.6. The one on the left refers to the vulnerability associated with superficial damage and decay, while the one on the right refers to the structural damage.

The above percentages are related to the total surface of the wall under examination, in order to enable correlations among the different zones in terms of surface extension.

It is worth noticing that the decay is present in a massive percentage, covering almost the whole wall. As uniformly distributed, the histogram on the left also shows the dimensional ratios among the 4 areas. The pick of decay is in the second zone, as this covers an extension of almost 50% of the total surface. However, the most serious decay, represented by material cracks with loss of fragments, is clearly recognisable only in zones 2 and 4 (with 17% and 10% respectively), being the remaining ones featured by more light alterations.

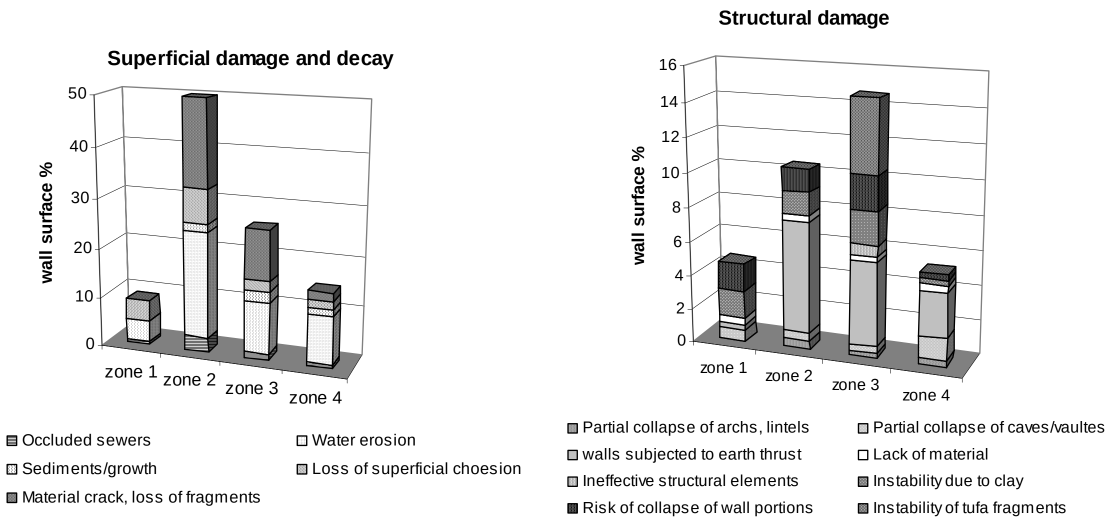


Figure 6 : Distribution of vulnerability factors

When taking in exam the structural damage, the distribution totally changes. First of all, the structural vulnerability (from V_6 to V_{13}) affects the surface in a smaller percentage of 30% of the total surface. Secondary, the most vulnerable zone becomes the third, showing a consistent percentage of instable wall portions (V_{12}). Moreover, zone 2, 3 and 4 are characterised by high percentage of walls subjected to earth thrust (V_8), ranging among 3% and 7%.

2.4 Vulnerability and risk assessment

In order to achieve a final assessment of the seismic vulnerability, a speedy method has been assumed in order to compare each other the 4 zones into which the wall surface has been divided. As a matter of fact, the damage types considered in the analysis cannot be directly correlated, being very different from each other. So, while the surface extent can be considered suitable for analysing all situations connected with decay, this method becomes less appropriate when passing to the structural damage.

Consequently, different weights have been assigned to the 13 factors considered; such to establish a pejorative scale from lighter to most serious alterations, and finally enable their comparison. In particular, progressively higher weights have been assigned to structural damage, from V_6 to V_{13} with associated weights varying from 1.2 to 2, while weight 1 has been assigned to the first 5 factors, related to decay.

The 13 indicators (from V_1 to V_{13}) each associated with a surface extent and with a specific weight, have been grouped in two indices, related to decay vulnerability (V_{Dj}) and structural vulnerability (V_{Sj}) respectively, defined as follows:

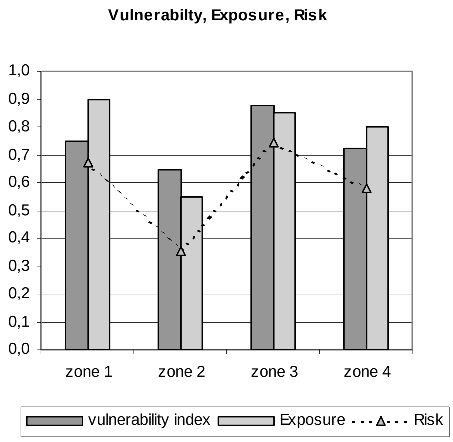
$$V_{Dj} = \sum_{i=1}^{i=5} \left(V_{i,j} \cdot w_i\right) ; \qquad V_{Sj} = \sum_{i=6}^{i=13} \left(V_{i,j} \cdot w_i\right); \tag{1,2}$$

where $V_{i,j}$ is the percentage in zone *j*, of surface affected by alteration *i*, and w_i is the weight assigned to this variable. The final vulnerability index (V*j*), for each zone *j*, is defined by the average between V_{Dj} and V_{Sj}.

Finally, the evaluation of the total risk of each zone is function of the vulnerability index (V_j), and of a further variable, i.e. the *exposure*. This has been introduced in order to take into account features (as accessibility in emergency conditions, economic loss following a given damage, loss of historical-archaeological value) which do not depend strictly on the monument itself but which can interfere with its risk. The hazard, in terms of geothecnical, hydrological, seismic, environmental features, has been neglected as constant over the whole facade.

Conversely the exposure (E_j), normalised to 1, exerts an important role in each zone. In particular, it has been assumed highest in zone 1, by considering that eventual failures would not allow the access to the area. Zones 3 and 4 have been assimilated, with exposure 0.9, by considering the economic loss (waste of economic resources previously invested, and loss of archaeological remains) consequent to a possible failure. Zone 4 represents the one where a possible collapse, or decay increase, could produce more moderated consequences, for what concerns the usability of the area and the loss of economic/historic value.

The resulting distribution of vulnerability, exposure and associated risk is shown in Fig.7, left. The histogram also highlights the order according to which the four zones can be ordered hierarchically. By dividing the total risk in four ranges (very high, high, medium, low), the distribution of the surface extent in risk levels is highlighted in Fig. 7, right. One can note that the risk is very high in zone 3, followed by high risk in zones 1 and 4 respectively, and finally a medium risk is obtained for zone 2.



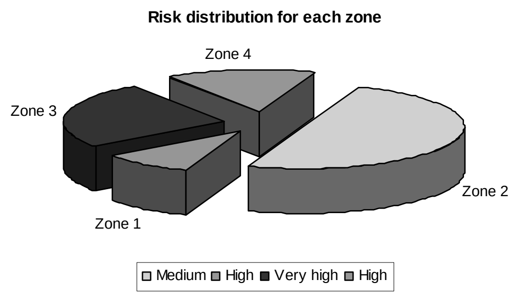


Figure 7 : Indices of vulnerability, exposure and risk for each of the 4 zones (left); percentual distribution of the risk over the wall surface under examination (right).

To sum up one half of the surface is associated with very high and high risk, and consequently the priority for further investigations and strengthening works has been given to zones 1, 3 and 4.

3 CONCLUSIONS

The method applied to the Farnesian Bastion on the Palatine Hill, represents ant attempt to assess the global risk on an archaeological site. The method lays in the fact that vulnerability, and the associated risk, are formulated through several factors, basically governed by two major alterations represented by *decay* and *structural damage*. These factors are weighted in order to take into account the severity of each alteration and hence enable their correlation. The final risk is defined as function of the exposure, such to consider external features, which can strongly influence the safety of the site. Finally, the application of the method to the Farnesian Bastion enables the four zones, into which it has been shared, to be ranked according their respective risk level.

The most jeopardised zones resulting from this process were then subjected to more careful investigations and checks, most of which based on the forecast and calculations of failure mechanisms which cracked tuffs elements could undergone following a seismic event. These further checks were very helpful to focus in detail the major structural vulnerabilities of the chosen zones, and hence draw a strengthening and restoration design.

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