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How to evaluate shelters for archaeological sites: some recommendations based on the use of exposure trials

Cristina Cabello Briones

Abstract: Shelters are commonly considered effective preventive conservation methods for excavated archaeological sites. However, archaeological remains covered with shelters are still deteriorating in many cases, and the shelters can even exacerbate the damage. Therefore, regular evaluations of the shelter behaviour are extremely important. This paper presents a summary of the main approaches to shelter performance assessment carried out to date. In addition, the application of geomorphological methods to heritage conservation has been reviewed. The objective is to determine their suitability for the evaluation of shelters. This paper also presents the main results from the study on the shelters at the Bishop´s Palace (Witney, England) and Hagar Qim (Malta) on limestone conservation using exposure trials. To conclude, recommendations based on the case-study sites have been made to improve the effectiveness of future approaches.

Key words: shelters, archaeological sites, preventive conservation, limestone, exposure trials, the Bishop´s Palace, and Hagar Qim.

Cómo evaluar las cubiertas para yacimientos arqueológicos: algunas recomendaciones basadas en ensayos de exposición de probetas

Resumen: Las cubiertas son frecuentemente consideradas métodos efectivos de conservación preventiva para yacimientos arqueológicos excavados. Sin embargo, los restos arqueológicos cubiertos siguen deteriorándose en muchos casos, y las cubiertas pueden incluso exacerbar el daño. Por lo tanto, inspecciones regulares del comportamiento de la cubierta son extremadamente importantes. Este artículo resume los principales enfoques en la evaluación de la actuación de las cubiertas hasta la fecha. Además, la aplicación de métodos geomorfológicos para la conservación de patrimonio ha sido revisada. El objetivo es determinar su idoneidad para la evaluación de las cubiertas. Este artículo también presenta los resultados principales del estudio sobre las cubiertas del Palacio del Arzobispo (Witney, Inglaterra) y Hagar Qim (Malta) en la conservación de piedra caliza usando probetas. Para concluir, se han incluido recomendaciones basadas en los casos de estudio para mejorar la efectividad de futuras estrategias.

Palabras clave: cubiertas, yacimientos arqueológicos, conservación preventiva, piedra caliza, exposición de probetas, el Palacio del Arzobispo y Hagar Qim.

Introduction to shelters for archaeological sites

Shelters are commonly considered one of the most effective methods of preventive conservation for excavated archaeological sites (Roby, 2006). They attempt to provide optimum conditions for the preservation of the remains. They are also considered to be less intrusive than remedial treatments.

It is generally agreed that the main criteria for shelter design are long-term maintenance, cost efficiency, materials and design, public access, and non-intrusion into archaeological deposits (Rivero Weber, 2011, Zanelli, 2015). In this respect, the visual interaction of the shelter with the landscape is especially emphasised (Pesaresi and Rizzi, 2007, Michaelides and Savvides, 2008). However, all of these values must be balanced with the necessity of physical protection for the archaeological materials when a shelter is designed (Cassar et al., 2001, Aslan, 2007).

As shelters can provide a physical barrier to rain and direct sunlight, appraisals of shelters in the literature have generally been based on the idea that covering a site will always be better than leaving it exposed to the environment. However, shelters do not reduce environmental damaging factors and/or keep the microclimate stable in most cases (Demas, 2013). For example, the open shelters made of metal panels over adobe remains in Joya de Cerén (El Salvador) were found to be affected by excessive air infiltration and strong winds from outside (Maekawa, 2006). Another example is the glass enclosure over the mosaics at Villa del Casale (Italy) characterized by frequent temperature and relative humidity fluctuations and extreme values (Ministero per i Beni e le Attività Culturali and Instituto Centrale per il Restauro, 2006). Furthermore, shelters may have a negative impact on archaeological features. In a survey conducted by the Israel Antiquities Authority, it was found that half of the 106 mosaics covered with shelters were still deteriorating deteriorating and that, in some cases, the shelters were exacerbating the damage due to insufficient roofing and lack of drainage or maintenance (Neguer and Alef, 2008).

Shelter effectiveness has been commonly evaluated by a qualitative point factor system (Cacace et al. 2006). More than 100 sheltered archaeological sites in Italy were evaluated with this system (Laurenti, 2001). Aspects such as the morphology of the archaeological area, materials used for shelter construction, state of building components, and functionality were studied. It was found that only 38.7% of the shelters were considered efficient. For example, the transparent roofs of the House of Ariadne at Pompeii were classified with a score of 5.5 (intermediate protection). However, a study on the murals paintings in 2008 demonstrated that the shelters were enhancing excessive temperatures, particularly in summer and, as a result, a new shelter made of opaque sheets of cement was constructed the following year (Merello et al., 2013). This second assessment was determined after undertaking microclimatic monitoring. This demonstrates that visual assessments rarely provide a complete understanding of the problems affecting a site when used on their own. Although some other publications gathered the results of extensive environmental monitoring programmes (Stewart et al., 2004, Siegesmund et al., 2012, Becherini et al., 2016), most of the studies on shelters are merely descriptive (Demas, 2013), and a more critical review of the effectiveness of the shelters is required (Zanelli, 2015).

Assessments of shelter behaviour should be based on the identification of possible decay factors and analysis of environmental data, but also an evaluation of the material decay and shelter condition (Tringham and Stewart, 2008). However, to date, few studies that have provided a scientific explanation of the decay processes affecting a site based on these aspects (Getty Conservation Institute and Instituto Hondureño de Antropología e Historia, 2006). This could be the result of project limitations such as those related to budget and duration. An alternative could be found in the use of geomorphological approaches (Cabello Briones, 2013).

Introduction to geomorphological methods

The main geomorphological approaches to studying stone weathering at heritage sites are in situ investigations, laboratory tests and on site exposure trials. In situ assessments are based on direct measurements and analyses on materials from the site. For example, micro-erosion measurements to monitor surface recession rates (Trudgill et al., 2001) or analyses of decay products to evaluate the conservation state of ruins (Doehne, 1991, Moropoulou and Bisbikou, 1995). Some authors, such as Siedel (2011), believe that in situ investigations may provide more reliable information about weathering than exposure trials or laboratory tests. However, original materials are usually altered by past interventions or deterioration patterns, which can change the response under current weathering conditions (Viles, 2013). This makes observed weathering phenomena difficult to extrapolate to other cases or even to other parts of the same site. In addition, sampling using invasive techniques may compromise the structural integrity and aesthetic quality of original surfaces, and destructive analysis causes material loss. Therefore, they have been criticised in the conservation field (Carson and Giacomo Chiari, 2010).

Laboratory tests simulate the impact of certain degradation factors on specially prepared specimens under controlled conditions. For this purpose, it is frequent to use environmental cabinets, where samples are subjected to conditions in excess of the magnitude and/or frequency that would be expected in real-life situations. For example, Laycock et al. (2008) used accelerated laboratory tests to select a replacement stone for Truro Cathedral, England. To test their suitability, several stone types were subjected to sodium sulphate crystallization and freeze-thaw tests, following national standards. Laboratory tests are designed to measure decay in a replicable way so results benefit from comparison with other studies, but they have been criticised for their lack of representativeness of historic buildings (Viles, 2013). Although results can be obtained in months, these tests do not reproduce natural conditions and it may be unrealistic to transfer the results to real monuments, where diverse combinations of factors might be acting (Trudgill and Viles, 1998).

Exposure trials consist of placing stone samples (discs, tablets or blocks) in real-life conditions. Their behaviour may be employed as an indicative 'sensor' of decay under complex environmental conditions. The specimens can be brought into the laboratory at intervals for evaluation, which can provide a link between laboratory simulations and field observations (Trudgill and Viles, 1998). Exposure trials last from a few months to determine early stages of decay (Viles, 1990) to several decades to establish dose-response functions (Tidblad et al., 2001). Although there have been some attempts to implement this approach to the study of shelters, the result is of limited success because shelters are not similar in typology (Ministero per i Beni e le Attività Culturali and Instituto Centrale per il Restauro, 2006).

Materials & methods

The shelter assessment at Hagar Qim (Malta) and the Bishop's Palace (Witney, England) [figure 1] was based on the use of exposure trials. The objective was to determine their suitability for the evaluation of shelters and draw some recommendations to improve the effectiveness of future approaches. Analytical investigations of the exposed stones samples were complemented with visual surveys of stone remains and shelters, and environmental assessments. The methodology was intended to be simple and low-cost so it could be applied widely (Cabello Briones, 2016a).

Four replicates (90x90x30 mm) of Portland, Cotswold, Chalk, Globigerina and Coralline limestones were placed outside, on the periphery and inside the shelters [figure 2]; Portland, Cotswold and Chalk stones were used at the Bishop´s Palace between August 2012 and July 2013, and Globigerina and Coralline stones at the Bishop´s Palace and Hagar Qim for a comparative study between August 2013 and July 2014. The samples were cut from fresh quarried limestone, and their different types were chosen to represent different degrees of vulnerability to decay [table1].

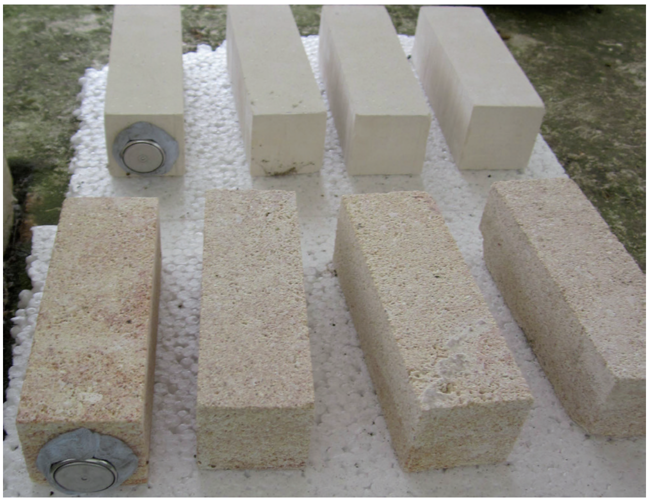

Figure 2.- Globigerina and Coralline limestone blocks with hygrochrons attached with synthetic rubber in a ring-shape (Cabello Briones, in press).

Changes in the following stone properties were documented periodically at regular intervals: weight (Sartorius AG Göttingen balance), elasticity (M-K5, Grindosonic), hardness (Equotip 3, Proceq), ultrasonic pulse velocity (UPV) (Pundit Lab, Proceq), colour (CM-700d, Konica Minolta) and general appearance (USB optical microscope VMS-001, Veho). The results were compared with control samples that were stored

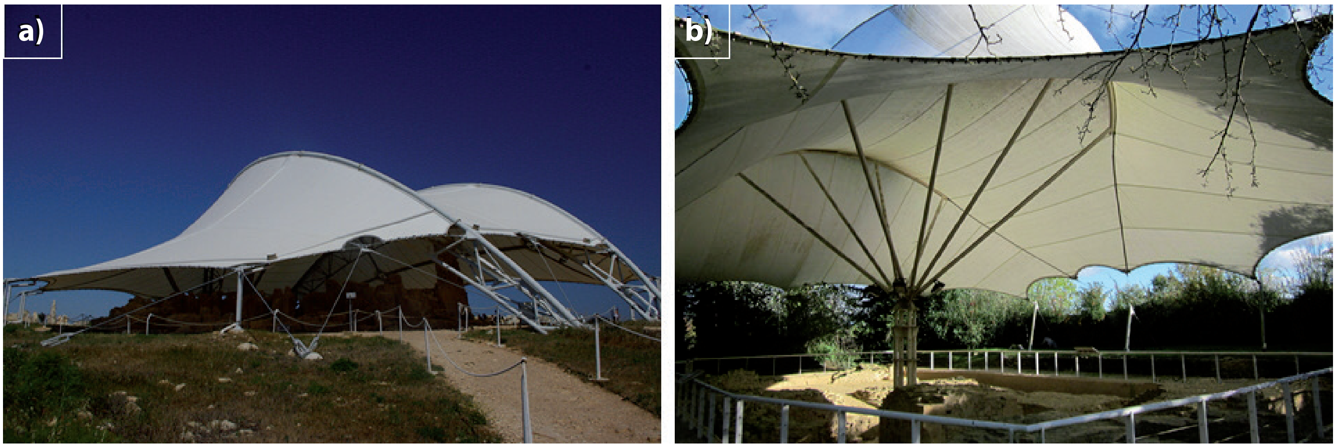

Figure 1.- Hagar Qim (Malta) and b) the Bishop´s Palace (Witney, England), both covered with glass fiber and PTFE open shelters (Cabello Briones, in press).

Table 1.- Physical properties of the stones used in this study (Cabello Briones, in press).

		Portland	Cotswold	Chalk	Globigerina	Coralline
BS EN 3755:2008	Water absorption at atmospheric pressure (Ab)	6.96%	12.52%	18.51%	14.75%	3.36%
BS EN 1936:2006	Open porosity (Po)	14.46%	22.02%	31.17%	31.18%	11.01%
BS EN 1936:2006	Apparent density (ρb)	2100 Kg/m3	2375 Kg/m3	1773 Kg/m3	1789.72 Kg/m3	2356.52 Kg/m3

in the laboratory for the duration of the study period. These techniques have been extensively used to measure a wide range of decay processes (Nicholson, 2002). Additionally, low-cost and non-destructive equipment was selected to reduce costs and minimise the need for many replicates. Temperature, relative humidity and wetting events were measured using dataloggers (i-button® hygrochrons, and Tinytag® leaf wetness logger). The number of NaCl crystallisation cycles and frost events were derived from temperature and relative humidity RH data (Sabbioni et al., 2010).

Additionally, twelve Portland limestone tablets (50x50x20 mm) were attached to freely rotated carousels inside and outside the shelter at Bishop's Palace for 18 months in 2014 [figure 3]. Carousels allow more equal exposure of all faces, in addition to preventing samples from standing in water when it rains (Moses, 2000). Tablets were used to compare results on stone dissolution with those obtained from the NMEP project (Butlin et al., 1993). Examination by scanning electron microscope (JSM 5910 SEM, Jeol) was complemented with a study on salt ion content (Dionex ion chromatograph), pH of the rain (pH meter, Orion Model 410A) and NO_2 and SO_2 concentrations (Gradko® combined diffusion tubes).

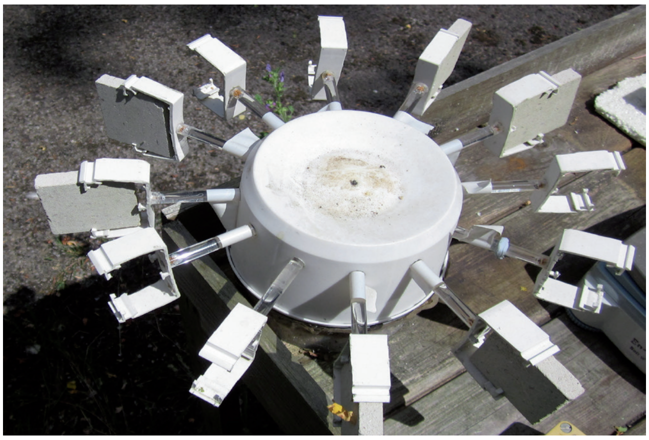

Figure 3.- Free rotating carousel used in this study (Cabello Briones, in press).

Results

All stone blocks located outside the shelter at the Bishop's Palace lost more weight than those located inside, but particularly the Chalk and Globigerina. The outside blocks also changed colour to a greater degree and showed an increase in surface roughness. These samples were wetter for longer and were exposed to lower temperatures. Additionally, higher temperatures, temperature fluctuations and freezing events were reduced inside the shelter. On the other hand, the periphery tended to have higher RH values than the centre, and outside and an increase in temperatures in early afternoon during summer could be seen as a sign of a fault in the shelter design (Cabello Briones, 2014). Higher levels of RH on the periphery and outside the shelter are most probably responsible for biological growth observed at the site during the visual assessment and likely explain the observed discolouration.

Portland limestone tablets outside the shelter at Witney lost more weight due to the different microenvironmental conditions. These also changed significantly more in colour. As this is a relatively unpolluted site, the colour change could be of biological origin due to higher water availability. Salts tended to accumulate in sheltered tablets but, in comparison with the sites of the NMEP, the concentrations of sulphates, nitrates and chlorides were lower than expected due to a change in pollution regime since the 1980s (Butlin et al., 1993).

At Hagar Qim, temperature and RH outside the shelter fluctuated more than in the centre and on the periphery. Additionally, the temperature was higher outside the shelter than in the other two positions, especially in summer. However, a fault in the shelter design made temperatures increase on the periphery when the sun reached the ruins at specific times of the day in winter. The shelter was effective in reducing wetting events and subsequently, the possibility of biological growth on the ruins. However, alveolisation, often related to the action of salts, was found to be the main decay mechanism at the site after the preliminary visual assessment. Results in the weight changes indicate that limestone blocks could be affected by a combination of physical weathering due to temperature fluctuations and accumulation of salts, with the samples outside the shelter the most affected (Cabello Briones, 2016b). Globigerina blocks placed outside were more discoloured than those inside, but there was no significant difference for the Coralline blocks, which could indicate a natural weathering process.

In contrast to colour and weight changes, results for UPV, elasticity and hardness were consistently non-significant statistically, although this may change with a longer period of exposure.

Discussion & conclusions

Exposure trials are an established technique in the field of geomorphology but can be adapted to determine the effectiveness of open shelters on the preservation of limestone remains at archaeological sites. Short to medium term exposure trials provide evidence of early stages of decay and represent a compromise between the time available for a project and the time necessary to obtain indicative results. They are especially useful for projects with low budgets and/or with a limited time for research. This approach should always be accompanied by a visual inspection of the condition state of the remains and shelters, as well as environmental monitoring.

Exposure trials are not destructive for ruins themselves and allow a wide variety of techniques to be employed. In addition, replicates can strengthen statistical confidence because they minimise the influence of stone heterogeneities and differences in mineralogical and chemical composition. However, it may be difficult to match decay mechanisms seen in stone samples with those on the ruins themselves because of, for example, differences in the stone types and the influence of past interventions [table2].

Table 2.- Advantages and disadvantages of the methodology used in this study (Cabello Briones, in press).

Advantages	• Non-destructive for the ruins • More information than studying the ruins directly • Rapid results (early-warning method to detect decay) • Greater variety of techniques (destructive and non-destructive) • Stable conditions for measurements if taken to a laboratory • Possibility of having replicates for strong statistical results • Suitable for sites with low budgets • Suitable to be undertaken by non-experts • Adaptable by choosing different stone types or analytical techniques • Different positions can be studied with simultaneous monitoring of decay • No necessity to close the site to the public (samples are small and discreet) • Comparisons of sites/environments possible through the use of the same materials
Disadvantages	• May be difficult to match decay mechanisms seen in the stone samples with those on the ruins • Sample size could be too small to accurately represent conditions of the ruins • Samples can be stolen/lost

Table 3.- Summary of the techniques used in this study for the monitoring of stone property changes and observations based on the experience of the author (Cabello Briones, in press).

	Equipment and purpose	**Advantages**	**Disadvantages**	**Overall**
Weight	Balance: material loss/ deposition	Precise, easy to use, low cost, can detect changes in short time periods, non-destructive	Highly affected by handling errors, laboratory conditions and dried samples needed	X
Elasticity	Grindosonic: change in EMOD (increase in pores and inner cracks)	Easy to use, non-destruc-tive	Only good for homogenous stones, more than 1 year of exposure may be needed for significant results, influenced by environmental conditions, samples of specific shape needed, high variability between replicates	
Hardness	Equotip: change in surface hard-ness (weathering /deposition)	Easy to use, field work equipment	Many measurements needed (large sample surfaces), micro-destructive, more than 1 year of exposure may be needed for significant results, influenced by environmen-tal conditions, high variability between replicates	
UPV	Pundit: change in UPV (increase in pores and inner cracks)	Easy to use, field work equipment, non-destruc-tive	Stain samples, no good for samples with irregular surfa-ces, more than 1 year of exposure may be needed for sig-nificant results, influenced by environmental conditions, dried samples needed, high variability between replicates	
Colour	Spectrophoto-meter: colour change (soiling/ biofilms)	Precise, easy to use, field work equipment, non-destructive	Influenced by environmental conditions	X
Visual changes	DSLR camera and USB microscope: surface erosion/ soiling	Easy to use, good for field work, non-destructive, good for before/after mea-surements	Only visible changes, low magnification	X
Salts	Ion chromatogra-phy: salt content (amount and type)	Precise	Requires preparation of samples (time consuming and expertise required), micro-destructive	X

Stones with low apparent density, high water absorption and high open porosity, such as Chalk and Globigerina, are likely to weather after only a short time in situ (a year in the case of this study). Stones with higher apparent density but which are fine-grained, such as Portland limestone, are also good indicators of decay but the time of exposure needed to obtain significant results may be longer. On the other hand, stone samples with very rough surfaces and a heterogeneous surface colour, such as Coralline and Cotswold, increase the variability of baseline data and are, in comparison, not good indicators of decay.

The techniques used in this study were selected to monitor a wide variety of physical, chemical and biological weathering processes. Weight loss, elasticity, hardness and UPV detect physical weathering in terms of loss of material (cracks, erosion and increase in porosity). In addition, analyses of salt content and weight gain can provide information about chemical weathering processes. Colour and visual changes (by macroscopic and microscopic imaging) can be used to corroborate the presence of biological films as well as signs of physical weathering and soiling. A summary of the techniques used to determine stone decay is presented in Table 3. The advantages and disadvantages are based on the experience of the author. An overall evaluation refers to the recommendations of the author after taking into consideration their simplicity of use and the results obtained.

Stone blocks and tablets provide an indication of the relative aggressiveness of different environments across the sites. Therefore, their use has been found to be a suitable option for monitoring the effects of shelters on archaeological sites mainly when comparisons are required and/or direct tests on original surfaces need to be avoided.

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