The Concept of Acceptable Technology in Architectural Conservation

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1. Introduction

In the year 1931 the most eminent international experts in conservation of architectural heritage met for a conference in Athens and approved a document, later known as the Athens Charter, in which it was written that "they approved the judicious use of all resources at the disposal of modern technique and more especially of reinforced concrete". During one of the days of the conference, the morning of Sunday October 25, the experts visited the Acropolis where they had the opportunity to observe and discuss with the director of the intervention the use of cement and metal cramps. Although these decisions may appear strange to us today, knowing the poor durability and behaviour that common cement based products have, it may have seem irresistible at that time to have a material as hard as Portland stone (and implicitly with a similar durability) that could be easily shaped in the most complex ways. The case of the Acropolis is an extreme, and it took many years to realize the damages induced by the use of cement and to correct the restorations carried out in the period of 30 years[1]. This historical situation should always be remembered since it includes several powerful lessons.

In the light of the knowledge we actually have on the performance of cement based materials it may look strange how it was possible in the beginning of the 20th century to produce such a peremptory statement as the one in the Athens Charter and to begin a wide use of technologies of similar nature in so many monuments all over the world, without any prudent consideration about the periods of useful life and the types of degradation they may suffer and induce. This fact was later understood and included in 1964 in the Venice Charter, where it is clearly referred that Awhere traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacity of which has been shown by scientific data and proved by experience@. This common sense statement constitutes, then, the framework in which the use of modern technologies can be envisaged. But, as it shall be seen, it does not solve all the real situations with which conservation is faced on a daily basis.

Nowadays the effectiveness of modern technology tends to be justified with the help of an extensive list of laboratory tests, whose full understanding is confined to the very few working in applied scientific research. For the common practitioner these data are seldom relevant and very often what prevails is the marketing associated with the product or the technology. Once use(s) of this technology or product has been made, and assuming that no problems occur, it is likely that case study papers may be submitted to some of the several conservation conferences that take place regularly. Given the fact that in most of these meetings there is no tradition of critical review of the papers, some of them will inevitably appear in some of the most important meetings. Once published they will tend to be considered as absolutely reliable information by many readers.

Even in the case of sound scientific research it may not be easy to fully extrapolate the medium or long term performance of these techniques or products based on short term tests, even if artificial ageing procedures are used. In fact, these artificial ageing tests can easily be

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[1] See L. Lambrinou "*State of the art: Parthenon of Athens. A challenge throughout history*", in Workshop Ariadne 9 "Historic materials and their diagnostic", (http://www.arcchip.cz/w09/w09_lambrinou.pdf) February 2002 and J. Jokilehto "*A history of architectural conservation*", Oxford, Butterworth-Heinemann, 1999.

misleading, since there are not adequate correlations between the periods used in those tests and the corresponding durabilities. Even if this was possible, the product would be tested in conditions that are frequently far from those occurring in real buildings. The issue raised in the Venice Charter about the use of experience as a way to guarantee the efficiency is in fact very difficult, since this experience is only relevant after a long period of time that no longer corresponds to the concept of Amodern@ material or technology.

The key point in the evaluation of modern technologies or products should always include the comparison of their expected durability and harmfulness with the life expectancy and character of the architectural heritage in question. By definition, an historical monument is an object whose cultural value is so relevant that society accepts the obligation of conserving it, even if it no longer can provide Auseful@ practical use. Therefore, although its life expectancy may not be indefinite, it should be as long as possible. Hence the justification for all required conservation efforts. This is the framework in which all interventions should be analysed and, consequently, all technologies be evaluated. So, in the end, the question of the use of modern technologies is mainly based on the interpretation made by each applier of the existing data, experience and context, which can either lead to acceptable or to totally unacceptable interventions.

The strong point about traditional materials and technologies is that their performance and durability are known from centuries of use and although sometimes they may be far from ideal, they will hardly confront us with unexpected surprises. The experience gathered over several centuries of regular use allow us today to understand reasonably well what can be expected from their use. However, surprises do occur particularly when the traditional ways of application have been lost and they are replace by modern practices, e.g., the use of lime-based mortars is a good example.

2. The concept of acceptable technology

Perhaps one of the best ways to evaluate the potential and the risks of any particular technology is by the analysis of previous failures, since this can provide invaluable information. But one should always be aware that either the success or the failure of a given technology may be strictly related to particular conditions of application and to specific situations and types of construction. A frequent error consists in extrapolating information from a case study, which may not be applicable in other circumstances. So much care should be taken when analysing previous examples.

There is no such thing as Agood@ or Abad@ materials or technologies. In fact, materials and technologies that are either compatible or incompatible for a given situation. So these issues should be looked at from a relative point a view. Consider, for instance, reinforced concrete. Although it is widely considered as something to be avoided, there are plenty of situations where present technology has no alternative solutions and, in the end the question is either to use it, or to let the building perish. In the following paragraphs some situations of the use (or non-use) of modern technologies are analysed, trying to highlight the challenges that arise from this rather complex issue.

The National Palace of Sintra, located some 30 km to the West of Lisbon, is a historic building whose first references appear in 1281. The building is characterised by extensive rendered walls, with stone and mortar simulating stone pilasters in the angles. The most characteristic aspect of the building are the two large conical chimneys, that constitute the landmark for the palace (fig. 1). The damp climate of Sintra creates excellent conditions for biological development, resulting in the existence of extensive grey areas produced by vast biological colonization on most facades, creating a negative visual impact. For that reason an intervention aimed at replacing all the existing renders by new cement based mortars, considered more durable and efficient, was developed in 1995.

Fig. 1 – The National Palace of Sintra

At a time the work was to start, it was possible by the above referred methodology, to develop an entirely different approach based on the use of traditional technologies[2]. Based on philosophical principles and on the fact that the existing renders were in very good condition, there are several layers of superimposed mortars applied throughout the centuries, a simple operation of removal of the biological colonisation by brushing and the application of a fungicide was envisaged, thus allowing to achieve the main objective: the conservation of the existing materials and the removal of the poor aspect of the building. For all the areas requiring the application of new mortars a mix of 1.5 parts of pure lime to 3 parts of pit sand and 1 part of river sand showed a very satisfactory performance in terms of adhesion, strength, dimensional stability and absence of significant cracking.

The solutions for surface finishes were basically two: a "marmorino", a fine layer of lime putty and marble powder mortar (1:2) serving to give the final colour of the surface and a limewash, intended to correct any minor cracking that could occur. These solutions were applied together, except for some areas where the existing final coating was in such good condition in which the limewash was applied for aesthetic reasons.

Thus, this intervention served to establish a new concept in Portugal, as far as the conservation of renders is concerned. For the first time in a building of such magnitude it was possible both to maintain the existing mortars, while only using traditional repair solutions. The vicious circle of Portland cement mortars was finally discontinued, in an intervention that constituted a landmark and assumed a pedagogic role for future projects of this nature.

Some years before, in 1993, the intervention on the exterior of the Tower of Belém had been started. The Tower (fig. 2), a landmark of the discoveries period, is included in the World Heritage List of UNESCO. This intervention, lead by the association World Monuments Fund (Portugal), faced the need for the treatment of a considerable amount of joints with missing mortars (totalizing some 8000 linear metres).

The tower is located by the river Tagus, in the city of Lisbon, surrounded by water and very exposed to environmental conditions. The project began in 1993, but was interrupted the following year and not resumed till 1997[3]. This large interval of time allowed the evaluation of the mortar applications that were used in an experimental area during the first intervention period. Given the very harsh environmental conditions that the building faces, such as the presence of considerable

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[2] Henriques, F.A. - The conservation of the rendered walls of the national palace of Sintra (Portugal). Internationale Zeitschrift für Bauinstandsetzen, 5, Jahrgang, Heft 5, 1999.

[3] The international prize *Europa Nostra* 1999 was awarded to this intervention.

amounts of chlorides (the tower is located in the mouth of the river close to the sea, so the winds always carry sea salt) and the primordial importance of keeping rainwater out of the masonries, suggested the use of special new mortar formulations rather then traditional compositions[4].

Fig. 2 – The Belem tower

For this purpose special Italian binders LEDAN C30 an MTX were used, the latter for internal injections and the former for more surface finish, i.e. pointing (since it has much better behaviour). The mortars were prepared with mono-granulated sands, adequately chosen and mixed, resulting in very good mechanical behaviour and salt resistance. Although the compressive resistance of C30 was too high, the formulations were worked in order to decrease significantly their values to a more satisfactory level. Furthermore, the very hard limestone used in the monument allowed the application of such a product. Although the exact formulation of these binders are not known, X-Ray powder diffraction analysis allowed the identification of the following crystalline materials:

C30 major: alite [C3S] and belite [C2S];

minor: tricalcium aluminate [C3A], calcite [CaCO3], gypsum [CaSO4.2H2O] and anhydrite [CaSO4]

traces: calcium sulphate hemihydrate [CaSO4.2H2O]

MTX major: alite [C3S] and belite [C2S];

minor components: portlandite [Ca(OH)2]; gypsum [CaSO4.2H2O]; anhydrite [CaSO4]; quartz [SiO2] and calcium sulphate hemihydrate [2CaSO4.H2O]

No organic material was found in the C30 when analysed by FTIR spectroscopy.

The very impressive behaviour of this type of mortar, particularly in what concerns adhesion, resistance to salts, water absorption and dimensional stability, lead to their use in the new project of the conservation of the cloister of Jeronimos monastery (close to the Tower of Belem), also included in UNESCO's World Heritage List (fig. 3). The work on this project began in1999 and was completed by the beginning of 2002, given the considerable extension of the monument. In this case again, the extensive amount of joints requiring repointing, totalizing some 20.000 linear

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[4] Henriques, F. *et al.* - The Masonry of the Tower of Belem and its Repointing. Internationale Zeitschrift für Bauinstandsetzen, 6/1998.

metres, was one of the main problems. The same type of mortar was used although, since this building is considerably less exposed then the tower, most of the work was done with MTX (the weaker of the two binders), and C30 was used only in the very surface layer just as a measure of colour correction.

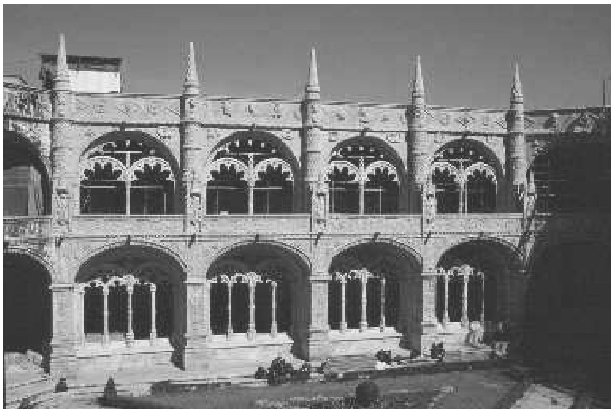

Fig. 3 – The cloister of Jeronimos monastery

In mid-1999,US/ICOMOS invited five international experts to analyse the situation of the city walls and forts of San Juan, in Puerto Rico, included in the World Heritage List. The massive walls are made of stone masonry that was initially rendered (fig. 4). However, most of the renders were missing at the time, so the critical conservation issue raised by the Puerto Rico Historic Preservation Office and the National Park Service was the identification of appropriate technologies for conserving the walls. After a week of work on site, the experts[5] decided that the best approach was to apply pure lime mortars, following formulations that had to be evaluated locally with the help of small experimental applications.

Fig. 4 – View of the walls of S. Juan, Puerto Rico

The previous four situations described required the use of mortars, either for renders or for repointing, and serve to illustrate the concept that each situation is different from any previous one, requiring the evaluation of the pros and cons of each available technology so that the most adequate can be selected. We cannot in fact refer to Athe best@ technology or material but only to the one that is best suited to a given project in very specific circumstances.

[5] A. Elena Charola (USA), Fernando Henriques (Portugal), Jeanne Marie Teutonico (USA), Luiz Torres (Mexico) and Luz Angela Useche (Colombia); see US/ICOMOS Newsletter nº 3, May-June 1999.

Technologies are not intrinsically good or bad. Everything will depend on the use made and the particular conditions of a given project. Take for instance the case of stone cleaning. Abrasive methods are in general considered negative. But even in high quality projects micro-abrasion is used on specific objects as a complement of other cleaning methods. Another interesting example is laser cleaning. Nowadays it is considered as one of the most efficient cleaning methods with virtually no risks associated. Yet, the first generation of laser devices conducting light through articulated arms with interior mirrors (i.e., most of the devices in use and for sale) can seriously damage the stone, given the way the energy is released. In those machines the energy has a gaussian distribution as opposed to the flat top distribution of the new devices based on the use of optic fibres[6]. The principle associated with laser cleaning is based on the different absorptions presented by dirt layers and the underlying stone. The former, having a darker colour, absorb more energy then the latter, so small amounts of energy are sufficient to pulverise these dark layers but insufficient to harm the stone substrate. The problem presented by lasers with the gaussian distribution (fig. 5) is that either a very small spot size is used for cleaning (corresponding to the maximum values of the energy), resulting in a situation that does not induce any damage but with very low cleaning effectiveness - or a larger spot size is chosen resulting in a peak having enough energy to damage the substrate. In this case, corresponding to applications too close to the surface, a pitting effect will occur, as has been observed in some interventions[7]. This effect does not occur with optic fibre laser, no matter how close the laser head is held given the flat profile of the energy that can be kept below the damaging level.

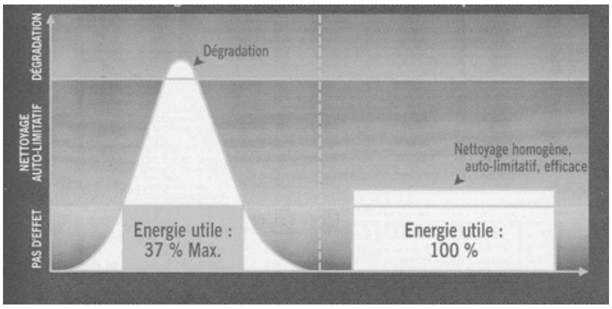

Fig. 5 – Gaussian and flat profiles of two types of laser cleaning devices

For many years the effectiveness of consolidants was evaluated by means of indirect laboratory tests. There are plenty of situations all over the world in which such products were applied based either on direct laboratory evaluations or on previous experience. Recently a new device[8] was created that allows an *in situ* evaluation of the real efficiency of this family of products. The apparatus measures the drilling resistance in relation to the depth of drilling, therefore allowing the creation of graphs in which the drilling force or torque is plotted against depth. Thus, it is possible to evaluate the depth of penetration of the products under real application conditions and their consolidation action compared with the resistance of the substrate. This technique allows to select the most appropriate consolidant for each particular case. Fig. 6 shows an example of the use of this technique to evaluate the performance of a consolidant applied on a calcareous stone.

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[6] The recently concluded conservation project of the cloister of Jeronimos monastery in Lisbon included an area of about 1.500 m^2 cleaned with optic fibre laser.

[7] See photo 1 of Maravelaki, P. *et al.* - Investigation on surface alteration of limestone related to cleaning processes, *in* Rodrigues, J., Henriques, F., Jeremias, T. (edit.) 7[th] International Congress on Deterioration and Conservation of Stone, Lisbon, 1992.

[8] See "DRILLMORE Drilling methodoligies for monuments restoration. Proceeedings of the Workshop. BLfD, Munich, March 2000.

The darker line represents the stone without treatment , while the lighter a treated area where the hardness increase produced by the consolidant can be observed in the first 2 mm of the exterior surface, after which no consolidation is noticeable (since the two lines converge)[9].

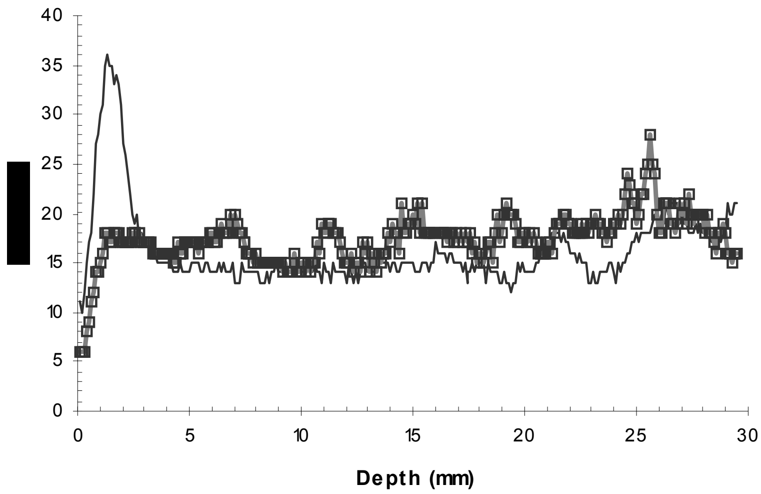

Fig. 6 – Drilling profile of a stone with and without consolidant

Although some of the new materials and technologies may be questionable in certain cases, inappropriate in some and quite defensible in others, the recently developed techniques of non destructive testing (NDT) are a considerable improvement of those that were in use sometime ago. The use of these techniques allows the modern conservator to enter a new field of knowledge in building characteristics and behaviour. NDT is a generic designation that covers a considerable number of techniques, such as thermography and sonic tomography, whose analysis goes beyond the scope of this paper. Nevertheless it may be interesting to focus on some of the most relevant procedures that constitute a group specially aimed at assisting the structural evaluation of historical buildings.

Among the several tasks involved in architectural conservation, structural evaluation is one of the most delicate, both on account of the difficulties associated with the process and the direct implication for the survival of the building. One of the most serious concerns when dealing with this sort of questions is to know the internal make-up of walls, piers, vaults, etc., and especially the mechanical properties that can be assigned to them. In fact any analysis performed without a thorough knowledge of these factors cannot be but a preliminary approach, no matter how sophisticated the analysis may be.

In the case of old buildings the first problem to be faced is the correct definition of its geometry, since it is unlikely to find similar dimensions in two apparently equal elements as they were built with pre-industrial techniques, non-standardized materials with considerable properties variations and often over extended periods of time (frequently several generations). Photogrammetry and rectified photography have been in used for quite some time even though these had considerable costs. Nowadays the new families of computational rectified photography and 3D re-constitution constitute a mean of reducing considerably the costs and enhancing speed and precision. The software involved allows the use of chosen photographs taken with a pre-specified matrix to be computed together and to render rectified and measurable surfaces (and in some cases the creation of 3D models).

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[9] Graphic reproduced by kind permission of J. Delgado Rodrigues, Laboratório Nacional de Engenharia Civil, Lisbon, Portugal.

After a good knowledge of the geometry of the building, the key issue is determining the properties of the masonries. For this purpose a multi-approach strategy may be envisaged. First an infrared thermography analysis can be conducted to identify non-homogeneous surface areas, therefore allowing the selection of specific locations where other ND methods could be used.

Infrared thermography is based on the evaluation of surface temperatures at long distance, using optical capability of infrared spectra analysis. The technique allows to evaluate the presence of heterogeneities near the surface. Given the fact that in these locations the heat absorption varies with the type of material and with its depth it is possible to render visible several construction features that otherwise would be invisible. Situations as covered doors or windows, stone, brick or metal reinforcements or, in general, all those in which discontinuities are present can easily be identified and taken into account.

This preliminary approach is the basis for the use of sonic tomography, which does not replace thermography because it is a hard time consuming technique that should only be performed in pre-determined locations. In fact, in many circumstances sonic tomography cannot be performed adequately due to the need of having access to both sides of the element to be evaluated. Hence thermography is an important first approach and, in many cases, the only possible (namely in all those locations that do not have easy access).

Having a first knowledge of the masonry properties, the next step is to select adequate locations in which sonic tomography can be performed. This technique is actually the most important non-destructive technology since it allows to evaluate the degree of compactness of masonries. Based on the characteristics of propagation of elastic waves, the process consists in the evaluation of the time necessary for a sonic wave to cross the masonry, which is a function of the type of material and its compactness. Having previously determined the geometric locations of the impact points for the percussion hammer and of the receiving points on the opposite side, it is straightforward to calculate the different speed between the several points, which are computed with a specific software allowing the definition of tomographs. These tomographs can be considered as an analysis carried out slice by slice at selected points of the masonry. If measurements are taken both on horizontal and vertical plans, the whole can be computed together generating 3D tomographs.

Sonic tomography thus serves to obtain a general knowledge of the situation of the internal constitution of masonries, allowing the identification of voids, multiple layers, different materials and diverse degrees of compactness. This type of information is crucial for identifying the locations where slightly destructive quantitative tests should be performed.

After this selection process, flatjack techniques are used to determine the existing stresses and to evaluate important mechanical properties such as the modulus of elasticity, coefficient of Poison and peak compressive stresses. These techniques are covered by appropriate ASTM standards[10], and are currently and successfully used for this purpose. The technique is based on the use of one or two flat jacks, carefully introduced inside the masonry, in a slight destructive process, in conjunction with deflectometers. The one flatjack technique allows the determination of *in situ* stresses. The displacements between points located at two levels are measured, after which the masonry is cut at a point in between for the introduction of the jack (therefore decreasing the distances between those points). Once the flatjack is in place, pressure is increased until the deformations come to zero, at which point the measured pressure can be related to the stress level of the masonry.

The two flatjack technique allows the evaluation of *in situ* deformability. In this case the flatjacks are positioned outside the location of the points used for displacement measurement (as

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[10] ASTM C1196 "Standard test method for in situ compressive stress within solid unit masonry estimated using the flat-jack method"; ASTM C1197 "Test method for in situ measurement of masonry deformability properties using the flat-jack method".

in a sandwich). The increase of pressure in both jacks simultaneously induces an increase of stress in the masonry and a decrease of the displacements between the measuring points. By gradually increasing the pressure, a stress strain relationship can be determined allowing to obtain an experimental curve from which the Young modulus or Poison coefficient can be determined. When the load-displacement diagram becomes highly non linear, indicating imminent failure, the peak compressive strength can be estimated by extrapolation of the stress-strain curve. The data obtained in this way can be used with any computer structural analysis software.

It is often necessary to check visually the interior of masonries for problematic areas, such as those in which sonic tomography cannot be applied or when unclear results are obtained. In these circumstances a core drill should be used. This can serve both to extract material for laboratory mechanical and physical tests as well as to allow the examination of the interior masonry with an endoscope. Endoscopy is a very powerful technique that permits optical confirmation of peculiar locations and has been in use in Portugal for almost ten years. It should be noted that endoscopy can also be used without a core drill, making smaller bores or taking advantage of eventual voids that may exist in the analysed locations - which constitutes a considerable advantage over standard boroscopes.

The core drills obtained serve to confirm some of the properties measured with flat jacks, allowing the tentative definition of methods for the calculation of mechanical characteristics of masonries based on individual values of their constituents (stones, mortars, bricks, earth, etc.).

This last aspect is crucial for future less destructive interventions and are presently at a very initial stage for all buildings made with irregular and variable materials. Although there are formulas in the masonry Eurocode allowing the calculation of mechanical characteristics for masonries based on those of their constituents, most international experts consider that they do not apply - and should not be applied - to old buildings. Hence there is still a long effort to be made in order to achieve reliable formulations.

The experimental techniques referred to above can also be used to monitor the effectiveness of eventual reinforcements that may be considered necessary for the safety of the building. All these techniques can also prove to be indispensable in this context.

Recent developments in non-linear computer analysis allowed commercial packages to be developed that facilitate the use of the information acquired with NDT in a quantified process. But, on the other hand, the use of this type of software without the previous knowledge of the properties and characteristics of the actual building being analysed may conduct to misleading conclusions. Therefore, when cultural values are to be taken into account, all care should be taken to prevent undue or unsuitable reinforcement approaches.

As with any technique, even NDT can be misused. Situations where only partial approaches are conducted and from which relevant data is to be extracted are a simple example of the wrong use that can be made of an apparently inoffensive technique. This question may lead to another interesting point. The increasing amount of analytical technologies and conservation treatments makes it virtually impossible for anyone to fully know and understand them, at least in such a way as to allow critical evaluation of their possibilities and limitations. Therefore, it is possible for someone to reach wrong assumptions based on insufficient knowledge of the field, emphasizing the pros without duly considering the cons (these situations are not in general intentional and are rather due to insufficient information). Thus, caution should always prevail and the advice of experts should be sought.

3. Conclusions

In the previous section a brief analysis was made on the use of modern technologies in architectural conservation (many of which can also be used in the conservation of movable heritage). The main problem associated with their use is what can be called the shining effect. In these technological times it is common for the modern man to be amazed by all the modern