Defining the Structural Risk at the Archaeological Site of Baalbek

PIERRE SMARS[1], ASSAAD SEIF[2]
AND
MARIO SANTANA[3]

[1]National Yunlin University of Science & Technology (Taiwan)
smars@yuntech.edu.tw
[2] Directorate of General of Antiquities (Lebanon)
assaad.seif@dga.culture.gov.lb
[3] Carleton University (Canada)
mario_santana@carleton.ca

Abstract. The archaeological site of Baalbek is exposed to both natural hazards (mainly earthquakes) and human-induced hazards (armed conflicts, tourism...). Between March and July 2010, an international team prepared guidelines for the establishment of a 'Risk Preparedness Strategy (RPS)'; a work done in the framework of the UNESCO programme 'Capacity building of human resources for digital documentation of World Heritage Sites affected by the 2006 war in Lebanon'. This paper will discuss questions related to structural risks.

In an ideal situation, it would be possible to precisely quantify the hazards affecting the site, the vulnerability of its parts and the expected losses in case of disaster. The resulting knowledge about risks would form a sound base for the decisions of the managers. This is certainly a good target, but in reality, the process is not so straightforward. The data is incomplete and the process of gathering and improving knowledge requires time and resources. The RPS aims to address these requirements. The models used to estimate the vulnerability of the structures are far from perfect. Their use is not always innocent. It is always beneficial to multiply the points of view. Examples are given of the use of data from a laser scanner survey to better understand the effect of past earthquakes on the structure. The values to protect also require a better definition. Life is certainly of paramount importance, but what about the other values (heritage values, integrity of the buildings, costs of interventions). How can their often contradictory requirements be balanced?

1 Site

Situated in the centre of the fertile Beqaa valley, between the ranges of Mount Lebanon to the west and the anti-Lebanon to the east, Baalbek Temple complex was on the crossroad of two main historic trade routes, one between the Mediterranean coast and the Syrian interior and the other between northern Syria and northern Palestine. It lies around 90km northeast of Beirut. [FIGURE 2]

Figure 1. Great court from the platform of the Jupiter Temple

The site has been occupied since the Neolithic (Van Ess 2008). During the Roman era, Baalbek was the major construction project of Emperor Augustus – the founder of the Roman Empire – and his successors ever made in the East. It was then transformed into an important cultural and pilgrimage place in addition to an essential meeting point for all the caravans crossing the Beqaa from the interior to the south (Palestine) or to the Mediterranean coast. Consequently, Baalbek was transformed into a central place for the dissemination of the Roman civilization and to show the power of Rome to the inhabitants of the region.

The main construction campaign in the complex lasted from the first to the third century AD. The construction of the Jupiter Temple, the largest Roman temple of its time of which six huge columns are still standing [FIGURES 4 and 8], began around the year 15 AD and was almost completed around 55 AD; an inscription from this date was discovered on one of its columns. The building of the Bacchus Temple began around 60 AD and was completed around the mid-second century AD. The construction of the Great Courtyard [FIGURES 1 and 3] began around the end of the 1st century and the beginning of the 2nd century AD. As for the Venus Temple, its construction began during the middle of the 3rd century AD shortly before the Propylaea [FIGURE 7] and the Jupiter temple construction were completed under the reign of Emperor Philippus Arabs in 244-249 AD (Chéhab 1970).

This site was inscribed on the UNESCO World Heritage List in 1984 (ICOMOS 1984). This inscription was based on the site's outstanding universal value; therefore it belongs to all humanity and to future generations.

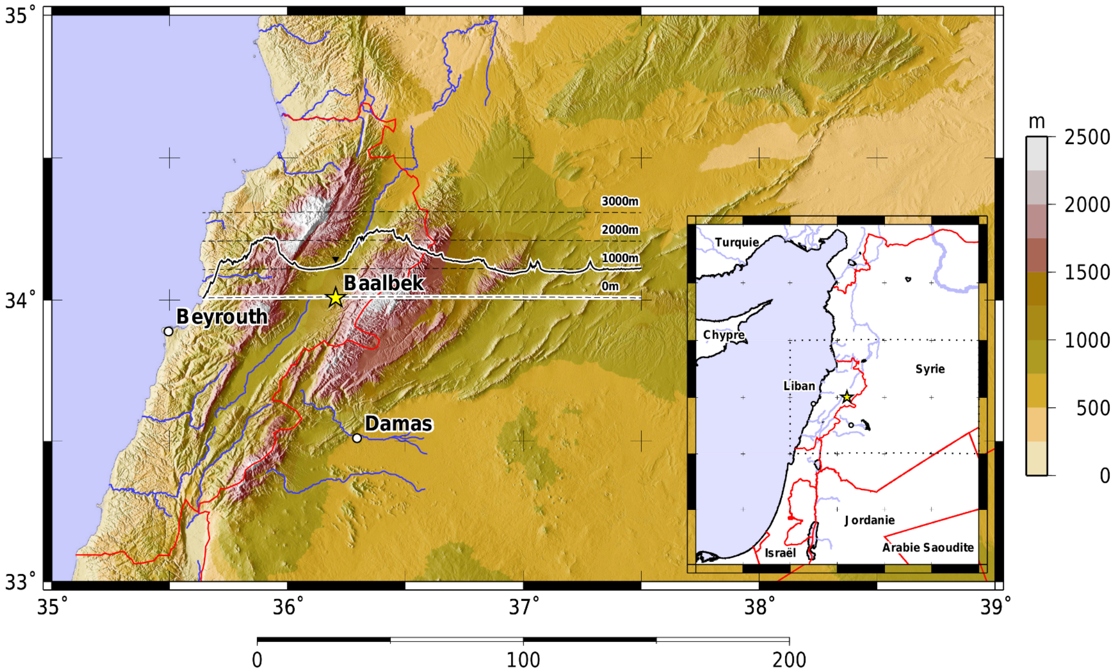

Figure 2. Situation of Baalbek, at the centre of the fertile Beqaa valley,
between the chain of Mount Lebanon to the west and the anti-Lebanon to the east

2 Risk

To decide in the presence of uncertainty is perhaps the most fundamental act human agents have to perform. Knowledge is always imperfect (neither accurate nor complete, and perhaps not even adequate) and decisions have to be taken at heartbeat pace.

Intuitively, we may state that: 'A responsible line of action is to do what we believe is best'.

But who is the 'we' in the above statement? What makes us 'believe' and how do we assess that some course of action is the 'best'? When should actions take place and how will they influence the future? Are the actions chosen responsibly? Rationally? Answers to those questions will have a shaping influence on the definition of a strategy. Answering them is actually a key part of the whole process.

Decision making is intimately related to the question of risk, i.e. the 'effect of uncertainty on objectives' (ISO 31000: 2009). The awareness of risks influences our actions. A good knowledge of them hopefully leads to better decisions, taken on rational ground. The World Heritage Committee 'recommends that States Parties include risk preparedness as an element in their World Heritage site management plans and training strategies' (UNESCO 2011).

In a first attempt to clarify the situation, the problem can be approached from a partial 'engineering perspective' using a so-called 'risk-based' approach. PEER, the Pacific Earthquake Engineering Research Center has, for example, developed a very complete framework for a scientific evaluation of seismic performance of buildings: performance-based earthquake engineering (Porter 2003). A requirement of this approach is to be able to characterise precisely hazard (earthquake occurrence), vulnerability (physical effect of a given earthquake on the building) and expected losses (consequence of deterioration on the values).

If those parameters are known - most likely in a probabilistic sense - the risk of a loss can be evaluated. ISCARSAH, the International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage of ICOMOS, also sees this evaluation as a *prerequisite to any intervention*: 'No action should be undertaken without having ascertained the achievable benefit and harm to the architectural heritage, except in cases where urgent' (ICOMOS 2003). Uncertainty in the data will obviously propagate to the conclusions.

Apart from the inherent randomness (i.e. the statistical uncertainty present in the definition of seismic hazard for instance), there is another type of uncertainty not directly addressed in this approach: epistemic uncertainty, the kind of uncertainty related to things that we could theoretically know but that, in practice, we do not know.

A long-term strategy will try to reduce all kind of uncertainty and hopefully transform some epistemic uncertainty to statistical uncertainty. 'Turning uncertainty into opportunity is critical' (Vujicic-Lugassy 2010). At this stage, when the level of knowledge is low, it is arguably more efficient to work on reducing uncertainty before attempting to quantify risk (Klinke 2002, Smars 2010).

Clearly, it will be necessary to look outside the realm of civil engineering to define values and losses and a way to measure them. In the case of new constructions, it may be relatively straightforward to give them a monetary equivalent, but in the case of cultural heritage, it is clearly more complex. Those problems will be discussed in section 5.

3 Hazard

Figure 3. Great Court from the Northern side. The columns of the Temple of Jupiter and the Temple of Baachus are visible in the background

The values of the site of Baalbek are threatened by various hazards, natural and human-induced.

From the structural point of view, the seismic hazard is the most critical. The risk of flood and landslides are, for instance, low in the area (WHO 2011).

Lebanon is situated in a seismic zone. It is traversed by the Levant fault system separating the African and Arabian plates. At the level of Lebanon, the fault system is divided into three major branches. The first two are left-lateral strike-slip faults: the Yammouneh fault (the most active), bordering the Eastern flank of the range of Mount Lebanon, and the system of faults of Rachaya-Serghaya which crosses the Anti-Lebanon mountain range. The third is the East-dipping Mount Lebanon thrust, forming an arch offshore, between Tripoli and Saida.

Baalbek is situated in the Beeka valley, at approximately 7km away from the Serghaya fault and 25km from the Yammouneh fault.

In the past, various earthquakes affected the site (Daëron 2005): July 9th 551 (estimated Mw: 7.5), January 749, in 1170, May 20th 1202 (estimated Mw: 7.5), October 30th and November 25th 1759 (estimated Mw: 6.7 and 7.4) and more recently, September 29th 1918 (estimated Mw: 6.8) and March 16th 1956 (Mw: 6.3).

Earthquakes contributed to the progressive degradation of the site. Just considering the most emblematic of its monuments, the Temple of Jupiter, mention is made of two fallen columns in 565, one in 991, eleven in the 12th century, thirty one in 1202, and three in 1789 (last major earthquake) (Daëron 2005). Today, six columns are still standing. [FIGURE 8]

Hazard is probably the element of the risk-based approach which is best known. Seismic hazard maps of Lebanon exist. According to Huijer et al. (2011), the expected peak ground acceleration is 0.25g for a return period of 475 years and 0.35g for a return period of 950 years.

Improvements are nevertheless still possible. If site factors were studied (source mechanisms, local geology and topography, determination of the foundation levels), the local amplification factors of the Peak Ground Acceleration (pga) and the frequency content of potential earthquakes would be better known. Time-history representations of the earthquake motion (synthetic accelerograms) could then be prepared. A more accurate definition of the hazard would lead to better risk evaluations and a more effective intervention policy.

4 Vulnerability

The vulnerability of a structure is a measure of the effect of structural actions on its physical condition. As actions increase, new types of damage progressively appear: cracks, permanent deformations, local collapses, total collapse. Models should allow studying and quantifying this relation (many models commonly used by practitioners do not produce this kind of result/information, Smars et al. 2010).

A reliable assessment of the vulnerability requires a good knowledge of the solicitations (as discussed in Section 3), of the structures and suitable models.

In the present situation, structures are not yet sufficiently characterised. ‘A full understanding of the structural and material characteristics is required in conservation practice. Information is essential on the structure in its original and earlier states, on the techniques that were used in the construction, on the alterations and their effects, on the phenomena that have occurred, and, finally, on its present state’ (ICOMOS 2003).

The geometry is the aspect of the constructions which is best defined. The recent laser scanner documentation of the site provided accurate measurements of the buildings (Santana et al. 2010, Seif and Santana 2011). This is a clear and substantial asset, but before this data can be used for structural modelling, the geometrical models have to be completed. Most of the upper parts of the buildings were indeed not measured, as those areas are not visible from any potential laser scanner station. Finally, the data should be transformed to a form more suitable to structural analysis.

The construction techniques and material structure of the fabric (hidden inside the walls and below the ground) is not as well-known as the outside surface of the buildings (shapes). Most buildings on the site are built with large stone blocks. Metallic and concrete reinforcements are also common. Some are original (hooks, bolts) and some were placed during the various restoration campaigns (steel bars). Those reinforcements modify the connections between blocks and can significantly influence the behaviour of the structure. A precise documentation of past interventions and reinforcements is still missing. Reinforcements were, for instance, introduced in the architrave of the Temple of Jupiter. [FIGURE 4]

Figure 4. Temple of Jupiter. On the left: situation at the end of the 19th century (Source: Félix Bonfils (1831-1885), Service des collections de l’École Nationale Supérieure des Beaux-Arts). On the right, situation in March 2010

Past earthquakes destroyed many structures on the site and left numerous traces on the buildings left standing. This fact demonstrates well enough that future earthquakes could bring more destruction. An analysis of traces can help in understanding the potential effect of disasters (ICOMOS 2003). Laser scanner measurements can be used to study deformations and understand the damage [FIGURES 5 and 6] (Smars et al. 2010). Some caution is nevertheless necessary. All deformations are not the results of past earthquakes. Comparison of the current situation with ancient photographs demonstrates that some important deformations only appeared after anastylosis, probably to accommodate non-fitting elements.

Modelling such constructions is not easy. Even for a structure as simple as a column made of a single block, perfectly defined, studies have shown that similar dynamic solicitations (earthquakes with identical pga and frequency content) can lead to significantly different outcome (DeJong 2009). Behaviour is very sensitive to initial conditions. Ideally, vulnerability should also be expressed in probabilistic terms.

In practice, a progressive approach is necessary (ISO 31000: 2009, ICOMOS 2003). The site is very large. Priority should be given to a more detailed analysis of the structures of high value (see below) and structures identified on the basis of a qualitative assessment of the vulnerability.

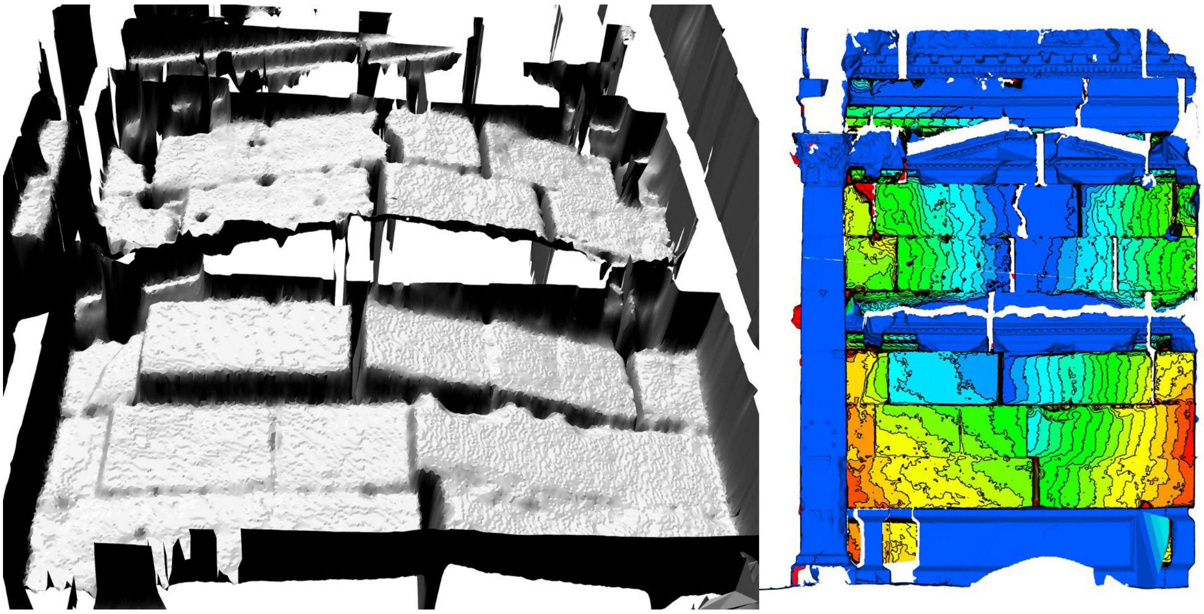

Figure 5. Eastern Wall of the northwestern semi-circular chamber of the Great Court.Left: exaggerated (10x) deformations of the wall. Right: elevation where colours indicate the distance to a vertical reference plane. The two figures were created with Points&Forces software using the data of the laser scanning documentation of the site

5 Values

The existence of risk is contingent on the existence of hazard. If nothing may vary, there is no risk. To reduce it, changes are necessary.

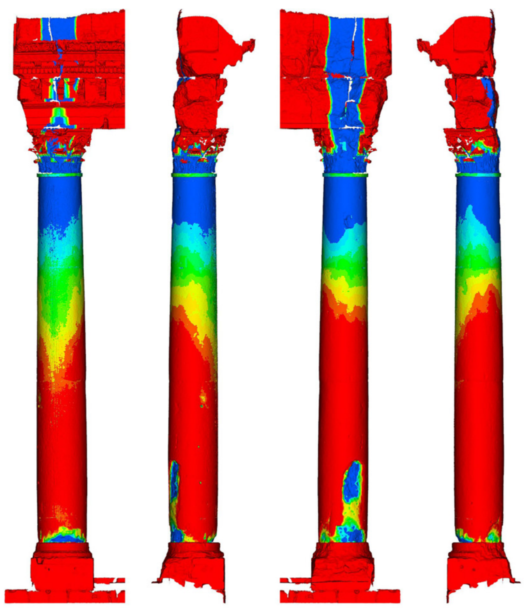

Figure 6. Analysis of the deformations on column of the Temple of Jupiter. Colours indicate the distance between the surface of the column and a vertical reference cylinder

Considering life value and safety of the visitors, the previous statement does not pose a conceptual hurdle. Structures can be reinforced, retrofitted and the risk on persons mitigated (within cost limitations).

Heritage values (under their various guises) introduce specific challenges. Professionals in the protection of architectural and archaeological heritage typically define their field using words like 'conservation' or 'preservation', which clearly do not fit with the idea of change. Those words may be misnomers but they certainly do not point obviously in the direction of retrofitting or structural reinforcement.

As already clear from the analysis of Riegl (1903), values are multiple; they often have contradictory protection requirements; they are not weighted equally by the stakeholders; and they will change with time and the evolution of society. Various cultures also see them in another light (Nara conference on Authenticity). Newer studies (like in Avrami et al. 2000) may have a different interpretation of Riegl but arguably do not alter fundamentally this vision.

But how can vulnerability actually be decreased? That can certainly be achieved by changing the object (structural mitigation), but also by changing its context (non-structural mitigation) and/or the perception of the problem by stakeholders. The question to answer will be: 'How much are we ready to change to be confident that what we value will be preserved?'

Structural mitigation reduces vulnerability by introducing new structural elements in the building: anchors, tie-rods, concrete beams, fibre-reinforced plastic reinforcements, injections, etc. If the intervention is properly designed, the object will be more resistant to disasters, and the chance to transmit some of its values to the future generations will be increased. As stated above, this is often the most straightforward and effective solution to protect life and 'use value'. Unfortunately, in the case of cultural heritage conservation, this type of mitigation may endanger other values.

Figure 7. Columns of the propylaea

Whatever the set of heritage values considered and their precise definition, some of them will nevertheless be negatively affected by changes to the fabric. For Riegl, it would probably be the 'historic value'. ISCARSAH (ICOMOS 2003) emphasise the importance of protecting buildings behind their surface: 'the value of architectural heritage is not only in its appearance, but also in the integrity of all its components as a unique product of the specific building technology of its time', 'the distinguishing qualities of the structure and its environment, in their original or earlier states, should not be destroyed' and 'each intervention should, as far as possible, respect the concept, techniques and historical value of the original or earlier states of the structure and leave evidence that can be recognised in the future'. The so-called 'principle of minimum intervention' is meant to protect those values. Finally, it may be argued that, in order to let to the future generations apply some new social-constructed values to the fabric, it is a good idea not to burn too much of its essence.

In past restorations, metallic bars were intensively used in Baalbek to give continuity to the block structures which were reconstructed (sometimes giving them a somewhat surrealist appearance) [FIGURE 7]. In that way, the 'integrity' of the structure was restored but without much consideration for 'the specific building technology of [the] time' and 'the concept, techniques and historical value of the original'. This is a case where values are conflicting – a typical problem with conservation issues. The major weight given to integrity may fit with a growing tendency towards reducing objects to the iconic value of their image (Adorno 1991) or towards seeing heritage solely as a means of economic development, a tendency well illustrated by the discussion surrounding the possibility of reconstruction of the statues of Buddha in Bamiyan. It is the opinion of the authors that it is important to have clear ideas about values and their relative weight before attempting to evaluate risks and certainly before deciding about future interventions. Those ideas should be developed, stated and publicised in dialogue with the representatives of the numerous stakeholders. Issues related transparency will be developed below. Furthermore, structural mitigation is not the only way.


Figure 8. Temple of Jupiter seen from the South

Non-structural mitigation decreases vulnerability indirectly, without changing the object or building. Smaller fragile objects may be moved to safer environments, like museums. Buildings and building elements, clearly, cannot receive the same treatment. But, for some of them, collapse may be anticipated and the environment prepared to limit damages and facilitate retreatability (Van Balen et al. 1999). Preventive measures can be taken to mitigate the effect of potential disasters: precise documentation of current condition, preparation of ground surfaces, and protocols of post-disaster intervention. This is not a solution to apply *indiscriminately,* but it is an option worth considering. Various factors may help deciding its suitability.

- A difference must be made between structures still standing in what we imagine was their original condition, structures still standing and retrofitted (like the columns of the Temple of Jupiter) [FIGURES 4 and 8] or modified (with some of their blocks moved); structures which collapsed and were rebuilt trying to keep the original structural concept; structures which collapsed, were rebuilt and retrofitted; and remains lying on the ground. Many blocks, often on the top of walls, are currently not exactly in their original position, some for many years.
- The expected damage in case of collapse and its impact on the other values, considering the possibility of a new anastylosis.
- The increased risk for the visitors must also to be taken into account. This risk may be decreased by controlling access and circulation. Some areas may become inaccessible.

Non-structural mitigation techniques have the clear advantage of keeping the historical document intact, but that does not mean that this approach does not affect other values: context and perception will be modified.

To improve the documentation of the site (photographs, surveys, analysis, scientific studies...) is also a non-structural mitigation technique. It reduces the risk to loose information, even if the risk of losing its material support is not changed.

To clarify the process of defining and measuring values, it is worth returning to the sentence 'a responsible line of action is to do what we believe is best' and discussing its parts.

'Responsible'. Baalbek is inscribed on the UNESCO World Heritage List. As such, it is recognised that it has Outstanding Universal Value, i.e. that it is of 'common importance for present and future generations of all humanity' (UNESCO 2011). Decisions makers have therefore a huge responsibility. It is a truism to say that they should follow a responsible line of action.

'We'. Who decides what course of actions should be followed? Who influences the decisions? Who should benefit from the action of the deciders? Those are classic questions related to governments and ethics. It is certainly beneficial to recognise this similitude and use it as an inspiration to state principles of good governance at the various levels (strategic and management).

The existence of a risk management strategy will improve the stakeholders' confidence and trust (ISO 31000: 2009). In Baalbek, the stakeholder, i.e. 'person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity' (ISO GUIDE 73:2009) is 'humanity of today and of the future' (UNESCO 2003): many people indeed!

Trust will also benefit from an understanding of the context. The formal as well as the practical or actual decision-making procedure should be studied, improved, laid out and publicised with deciders, influencers (technical, financial, political) and other stakeholders identified and their interaction clarified.

Participation and transparency contribute to the fulfilment of accountability to stakeholders. Questions of values should not be discussed in isolation at a decisional or at a technical level. They result from the manifold vision of the numerous stakeholders on the archaeological site. Stakeholder representatives could help raise awareness about values at stake. They may help define them or more likely help weighing the effect of practical decisions, 'courses of actions' or 'type of interaction' on values. Stakeholders should therefore have a place somewhere in the decision-making organization. Mechanisms should be implemented to let them exert influence both a-priori and a-posteriori. They should be given the possibility to complain and the assurance of getting responses. This is another guarantee of good governance; risk management benefits of negative feedback (ISO 31000:2009), it improves its robustness. This dialogue or 'participatory discourse' is part of the discourse-based management strategy discussed by Klinke and Rena (2002), a strategy which suits well situations combining low probability of occurrence, high stakes, and large uncertainty.

Another way to improve transparency is to give access to data (open data). Thanks to the implementation of this policy by many institutions, there is already a lot of information available on Baalbek. Numerous ancient photographs and documents are accessible in various open internet archives (E-corpus, Europeana, Gallica, INHA, Internet archives, Library of Congress (also stereoscopic images), etc.). Some UNESCO reports are also accessible online. It may be a good idea to investigate the possibility and conditions to go further and offer access to other types of data: results of measurements, monitoring, reports of experts, etc.

This policy would present various advantages:

- Improving transparency of the actions decided concerning a site 'important for all humanity', possibly mobilising new stakeholders.
- Facilitating 'peer review' of actions and studies.
- Facilitating new contributions to the understanding of a World Heritage Site, possibly offering new perspectives on complex issues. For instance, evaluation of the vulnerability can always be improved or done on the basis of other premises.
- Putting an organised repository in place (i.e. aggregating data coming from difference sources) to make it easier to identify gaps in the knowledge and in the strategy. A repository may become a tool of the risk-management strategy, facilitating monitoring (ISO 31000:2009).

Of course, the possibility of new threats has to be considered.

'believe'. Some epistemic uncertainty will always remain. This is particularly true when dealing with vulnerability assessment. Some assumptions cannot be verified without destroying the objects that are to be protected. Conservation is dealing with the unique; meaningful experiments are not reproducible ('einmal ist keinmal'). In such a context, it is beneficial to keep a critical eye on hypotheses, possibly test the sensibility of results to them, and multiply points of views which can, somehow, improve belief (ICOMOS 2003, Smars 2010).

'best'. What is the 'best' course of action? To answer this question, it is necessary to agree:

On the values to protect.

- To prepare a set of tentative options (possible course of actions). It is not possible to consider all options.
- To evaluate the influence of an option on the individual values. Some options will favour the protection of some values and be detrimental to others.
- On a measure to evaluate the options. This is certainly the most critical point. It requires compromises (Riegl 1903) and dialogue.

This agreement should be the result of a dialogue between deciders, influencers and stakeholders. Elements useful to this dialogue were presented above.

The preparation of a set of options is probably the point which will be left in the hands of technicians (a category of influencers). This may also be a critical point. Choices are made in the space defined by the options offered, but better solutions may lie outside this space. Structural engineers have bias. They are firstly trained to deal with new constructions, using a limited set of materials and techniques, and their ideas are influenced by the framework given by structural standards. They may also have the propensity to think only in terms of structural-mitigation.

For new constructions, the key values to protect are the safety of the occupants and the financial value of the construction. Their protection is guaranteed by requirements imposed by construction standards like the Eurocodes. Requirements are of two kinds: principles, which have to be followed in any circumstances, and application rules, which do not have necessarily to be followed if the designer can prove that the problem addressed can be solved using another approach, compatible with the relevant principle. This framework is interesting and its relevance extends beyond its legal limits. However, some principles are inappropriate for architectural heritage and even more for archaeological heritage. 'Often the application of the same safety levels as in the design of new buildings requires excessive, if not impossible, measures. In these cases, specific analyses and appropriate considerations may justify different approaches to safety' (ICOMOS 2003). One of the principles states that the structure should not collapse during its designed working life. But what is the designed working life of the archaeological site of Baalbek? And is it always necessary that structures will not collapse? For new buildings, it is certainly an effective way to protect the safety of occupants but for an archaeological site it is probably better to refer to higher principles: the life of the visitors and the protection of the heritage values and to let the designers find a suitable way to ensure their protection.

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