TECHNICAL ASSISTANCE WORKSHOP
FOR THE WORLD HERITAGE SITES OF
THE CRAC DES CHEVALIERS, PALMYRA
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SITE OF PALMYRA
- Citadel
- Museum
- Archaeological site

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Pierre-André LABLAUDE
Salvatore RUSSO
Historic and geographic context of the monument

Originally built in the 13th century and then reinforced in the 16th century by Fakhr ed-Din al Maany, the Qalat Ibn Maany castle, also known as the "Mamluk citadel", is located on a rocky peak overlooking the Ancient city of Palmyra to the East.

Following a common construction system at that time, it was surrounded by a defensive ditch dug in the rock. The materials extracted from the digging were used for the construction of the citadel itself. The shape of the wall of the citadel is roughly triangular and is punctuated at its periphery by a series of rectangular towers which are not very prominent. Most of them are crenellated, which provides the monument a particular grandness.

The wall appears to have foundations built alternately by roughly squared rock blocks and layers of smaller fragments. All being connected by a mortar made of plaster and lime. The fight that took place on 25 March 2016 for regaining control over the city resulted in major destruction and mainly affected the eastern front of the citadel, where the sole entrance is located. The monument was inaccessible between 25 March and 11 December 2016 due to the destruction of its access bridge and possible mining. Thus, no pictures showing destruction from the inside are available and pictures from the outside are limited.

The reports of the previous missions carried out on this monument under the direction of Professor Giorgio Croci and the request of UNESCO and DGAM, in 2003, 2006 and 2007, are the most valuable sources of information on the configuration of the monument and its state of conservation prior to the recent destructions.
Diagnostics and recommendations from previous studies

The reports of the previous missions carried out highlight a number of important data:

- The surveys of the monument, drawn up in plans, sections and elevations, with a significant amount of pictures, highlight the exceptional density of the citadel. They give a precise idea of the distribution of the interior spaces and of the constructive principles implemented, overlaying several levels of vaulted rooms and galleries that are supporting terraces. These terraces were once ensuring the autonomy of the citadel, collecting the rare rainwater stored in a central group of three cisterns.

- A historical approach leads to the identification, in this imposing ensemble which appears homogeneous, of four successive campaigns of works, conducted between the 13th and the 18th centuries. An initial triangular enclosure, comprising 8 towers (No. 1 to 8 in the above plan), was doubled externally on the eastern front by a new curtain punctuated by 5 towers (No. 14 to 18) and then, to the west, by a curtain punctuated by 3 towers (N ° 9, 10 and 11) later completed with 2 last towers (N ° 12 and 13) and a new gallery, thus creating a uniform level of towers. The narrow voids between these different interlocking enclosures were simultaneously filled by several overlaying levels of vaulted rooms and galleries and formed the massive construction that we know today.
The analysis of the various pathologies carried out and described in the previous reports, as well as the diagnostics produced, allows the clear identification at this stage of the following critical conservation issues:

- A variable but very marked slope of geological layers made limestone rock forming the base of the monument, showing the friability of this material largely cracked on the surface, a physical alteration due to climatic phenomena (thermal shock, water ingress, winter frost, etc.).

- The supports of the various foundations of the monument are established at varying levels according to the morphology of the rocky base. Most of the time they are built without any embedding in the more or less inclined and fractured rocky layers. Thus in some places and from a static point of view, the load is more under friction than compression.

- As previously mentioned, the structures are vertical elevations successively added to the core monument without any effective solidarization among the different parts. The junctions present potential disruptions.

- The interstitial spaces (halls and galleries) between the initial core enclosure (towers 1 to 8) and the outer enclosure (towers 9 to 18) are covered, at the eastern and western sides, by a series of vaults. Their horizontal thrusts load the masonry of the outer enclosure, insufficiently dimensioned to ensure an effective support, causing a more or less marked slope of the outer curtains and towers. Numerous fractures that are parallel to the facades are noticed on the pictures showing the vaults and other internal masonry. The crack records are also reported on the drawings in planes, sections and facades.

- The construction materials were rather poor: the mortars used contain gypsum (a moisture-expansive material), the stone extracted on site was externally sealed and protected by a covering that disappeared since, exposing the joints to water ingress and the stone cladding to weathering, wind in particular, which induces physical or chemical alteration.

- Former and recurring defects in the irregularly maintained sealing of the upper terraces result in water ingress into the upper masonry, including interior mortars, thereby weakening these very exposed physical works.

The documents and reports highlight the fragility of three elements constituting the monument: fragility of the foundation soil, of the built structures and of the materials of the monument.
The Citadel’s rock base (2006)

Dip and alteration of the rock (2006)

Instable blocs supporting the walls (2006)

Degradation of walls’ basis and foundations
Disbonding of masonries built in different periods of time (2006)

Vertical cracks in a room built between the outer and inner enclosures (2006)

Alteration of stones and connecting mortars (2006)
Third floor plan - 2007 surveys
Note the numerous cracks identified on the towers of the outer curtain and vaulted spaces in junction with the inner enclosure.

The 2007 reports by Professor Croci and his team also mention that during its history, the citadel has already been damaged by war and reconstructed. In this seismic area, several earthquakes have weakened the structures, resulting in the numerous cracks indicated above.

In particular, in 1759 an earthquake destroyed Towers No.10 and 11 (rebuilt afterwards) and in 1996 an earthquake damaged Towers No. 17 and 18, which resulted in an important restauration campaign carried out by the DGAM.

The history of the monument testifies to the succession of several phases of partial destruction and reconstruction. These phases, including latest restauration works at the end of twentieth century, repeat identically the same forms, uses the same materials and the same techniques, maintaining the aesthetic and formal coherence of the citadel which appears immutable at first sight.

The pictures of the May 2007 report show the pre- and post-reconstruction of Towers NO. 17 and 18, as well as the masonry work being carried out by the DGAM in 2007 for the repair of various vaults, terraces or superstructures.
Towers of the eastern outer curtain in 2003: No. 14, 15, 16, 17 (already partially reassembled in the lower section but still destroyed in the upper section), and No. 18 (right wing destroyed).

Note the setting of the towers on the altered slope.

Ongoing reconstruction work on Tower No. 17 in 2006-2007.

Towers No. 17 and 18 in 2007, after the reconstruction of their lower parts previously destroyed.
Various phases of the reconstruction of a vault by the DGAM teams (2007):
- Bending and formwork
- Setting joining up
- Casting of gypsum and lime mortar joints
- Smoothing coatings beneath the vault
Terraces and crenellated towers being restored in 2007. Overlooking view on the city of Tadmor, the oases and the Antique site.
The 2007 recommendations were unfortunately not implemented.

This same 2007 report concludes by advocating a dual action of conservation and consolidation of the monument, including:

- on the one hand, a series of local interventions aiming at continuing and developing the operation for the recovery of the most fragile masonry in various areas of the monument,
- on the other hand, for static purposes and seismic prevention, a general reinforcement of the citadel as a whole, by installing several levels of tie rods designed to ensure the deep anchoring of the partially destabilized facades (mainly at the eastern and western fronts) and also in the opposite facades, in internal thick masonries or in its rocky core, depending on the configuration of the structures as the latter recommendation requires the installation of scaffolds on the peripheral facades of the citadel, which is particularly delicate and expensive, given the escarpment of the site.
Towers No.17, 18 and 7 in 2007

Side view of Tower No.18 (reconstructed side façade) and No.7 in 2007

Eastern facade of Tower No.7 in 2007

Northern side facade of Tower No.7 in 2007
Eastern front in 2007, before 2016 destructions (Towers No. 4, 14, 15, 16, 17, 18 and 7)
State of the citadel after the 2016 destructions

The detailed review of the few pictures available after the destruction resulting from the fights in early 2016, which mainly damaged the eastern side of the monument, confirms the previous diagnostics and highlights four significant issues:

• A very clear natural inclination towards the east of the overall geological stratification of the bedrock of the citadel on this area,
• A significant natural fragmentation of the rock layers by a network of cracks perpendicular to their stratification planes,
• The wall seems to stand on the inclined top of the rocky layer, without any embedding
• Finally, the wall of this eastern facade in particular is grounded immediately above the inner crest of the ditch dug in the rock mass surrounding the citadel.
Collapse of Towers No.17, 18 and 7 (picture: Iconem/DGAM)
The frontal impact and concentration of explosions at the entrance to the citadel, whose initial design was already lacking anchorage in the rock and has been weakened by former structural movements, resulted in vibrations that led the foundation to slide on the inclined bedrock and the base of the wall to move forward, until they collapsed. The backward inclination of the few remains of Tower No.17 seen on the eastern facade illustrates perfectly the phenomenon of sliding of the base of the wall along the slope, corresponding to the geological dip of the bedrock.
The two north towers of the eastern facade (No.17 and 18) nearly collapsed, as well as the eastern face of the north-east corner Tower No.7, showing through the damaged vaulted rooms of the two upper levels. In the 2007 report, a picture dated 17 February 2003, was showing Towers No.17 and 18 partially in ruin. Several other views were showing the assembling of the upper half of the eastern facade of Tower No.17 and of the entire northern side of Tower No.18.

The destruction at the beginning of year 2016 mainly concerns parts of the citadel that were rebuilt some fifteen years ago.

![Diagram of Palmyra Citadel Elevation of the Eastern Front of the Outer Enclosure](image)

The findings of the 2016 destructions fully confirm the relevance of the structural diagnostics previously issued by Professor Croci in his 2007 report and the necessity to implement the recommended linkage by tie rods to "hook" the towers and curtain walls of the outer enclosure together with the mass of the inner enclosure and its inner built and rocky cores.

A number of secondary disorders can also be identified at the eastern side, on the crenellations of Tower No.15, the small outer wall defending the entrance door, the pillars and supporting masses of the destroyed access bridge crossing the ditch and the parapet of the counterscarp.

The other facades seem to show only few breaches in the crenellation of walls. However, given the current inaccessibility of the site and monument, it is impossible today to assess more precisely the extent and severity of the destruction inside the citadel.
The monument is currently particularly at risk due to the alarming instability of the largely cracked remains of Tower No.17, of the northeastern corner Tower No.7, of the eastern bed of the bridge. The instability of the rubble of collapsed towers’ at the foot of the wall overhanging the ditch is also alarming, as this rubble is temporarily contributing to the stabilization of the remains on which it is leaning.

In view of this particularly alarming situation, it is necessary to set quickly the strategy for the emergency interventions to be implemented in the field, as soon as the situation allows.
This strategy could be organized based on the following recommendations:

1. Anticipate field interventions, by collecting and gathering all the existing documentation and studies on the monument (old and new), as well as archive documents on the various restauration campaigns carried out.

2. Ensure the demining of the citadel, its accesses and surroundings in order to guarantee the safety of the personnel involved and, as far as possible, close the access to the monument.

3. Re-establish the access to the gateway, either temporarily by scaffolding, or if possible by reconstructing damaged pillars and supports. Access is absolutely essential to the implementation of the following phases of work.

4. Ensure to maintain in its place the collapsed material at the feet of Towers No. 7, 17 and 18, which is undoubtedly contributing to their precarious stability at the moment and preventing further collapse of residual remains.

5. Simultaneously inspect the interior of the citadel, which damage remains totally unknown at this time, in order to identify any structures affected by the destruction and to implement emergency measures and urgent shoring, thus neutralizing imminent risks.

6. With extreme caution and after the installation of belts and temporary reinforcements, carefully dismantle the last remains of Tower No. 17, dumped backwards in a disorganized manner that cannot be stabilized as it is. Assess and survey damages, number and record the stones before storing them in an organized manner, flat and in an area outside the enclosure, awaiting their possible reassembly by anastylosis in the framework of a future project.

7. Tower No. 7 was cut in half over its entire height by the collapse and therefore has an even riskier stability. For security reasons, give priority to the installation of shoring implemented by the inside (bending of the vaults), then, if possible, fix external belts made of reinforced polymer fiber horizontally at different levels. Finally, set scaffolding in front of the eastern side of the tower to undertake first consolidation work on the masonry pulled out from the vertical plane (see diagram below) and set a temporary closure system on the façade, awaiting further work.

AXIAL SECTION ON TOWER No. 7
PRINCIPLE FOR THE PROVISIONAL CONSOLIDATION
(To be confirmed after an on-site analysis)

- On both levels, create inside the rooms temporary floors that are able to support shoring for the vaults;
- Progressive implementation from the inside of shoring, made of wooden arches or preferably of cement blocks (filled with mortar at the junction with the vaults);
- In heights, install and put progressively in tension several reinforced polymer fiber belts, in order to ensure the strapping of the vestiges, if possible without mounting any scaffolds;
- In order to allow waiting for restoration works, after completion of the inner arches and the clearing of the rubble at the foot of the tower, assemble a scaffolding and proceed with the temporary consolidation by roughcasting (mortar projected with a trowel in broad strokes to cover the wall surface with a thin 5mm layer) all the pulled-out masonry,
- Cover temporarily the facade.
Despite the first impression of the spectacular damages to the citadel, and after a thorough analysis of the detailed plans of the monument, it seems difficult to exclude a priori the option of a future identical reconstruction of the collapsed structures, for the following reasons:

1. A first approximate calculation on plans shows that the impact of the 2016 destruction represents about 720 cu. m (mass + internal voids) for a monument whose total volume (mass + internal voids) amounts to about 23 300 cu. m. This gives a 3.2% destruction ratio for a monument that still totalizes 96.8% of the shape and material it had before 2016.

2. The analysis of the previous studies that synthetize an amount of information given by DGAM site managers, gives a clearer idea of the authenticity of the various constitutive structures of the citadel. It highlights in particular the important reconstruction previously carried out on the façades of the outer enclosure, including those of the Towers No. 17 and 18, recently destroyed again.

3. As reported for the campaigns carried out over the last fifteen years, notably through pictures taken at worksites, the DGAM teams demonstrated their good ability to carry out the same type of reconstruction, using the original forms and techniques, as well as materials derived from the substance of the monument itself, in order to ensure a harmonious and discreetly visible integration of these rebuilt parts in the silhouette and general presentation of the citadel.

However, in view of the ancient disorders preceding the last destruction, including permanent seismic risk, and the state of conservation and structural stability of the citadel as a whole, the feasibility of a possible stabilization and healing process for the citadel, is to be queried. Indeed, this process might transfer the risk to the structures adjacent to the ones recently destroyed.

In conclusion, in the medium term, the objective would be to carry out the identical reconstruction of the destroyed structures re-using the original materials. However, the latter must be imperatively envisaged as the first step to the implementation of the program of global consolidation - static and seismic - of the monument, with the installation of a complete network of horizontal tie rods and bonding anchors link ties, as defined by the 2007 study.

Consequently, in the short-term, it is recommended to design and implement as soon as possible, the various first interim interventions mentioned above, integrating the provisional objective of reconstruction and related execution constrains, so that the transition from such temporary work to final work can be efficient, coordinated and well programmed.
Palmyra Citadel

DAMAGE ASSESSMENT (through images, after 2016 destructions)

- Masonry destroyed at the level of the plan
- Masonry destroyed at the level below
Palmyra Citadel
DAMAGE ASSESSMENT (through images, after 2016 destructions)

- Masonry destroyed at the level of the plan
- Masonry destroyed at the level below

Plan Nivo 3

Plan Nivo 1
PALMYRA MUSEUM

Main facade and destruction to the terrace

Overview of the situation

Built by an Egyptian architect in 1958 at the time of the United Arab Republic, the Palmyra Museum is a modern building, incomparable in terms of architectural and patrimonial interest with the various monumental components of the antique site and the property inscribed on the World Heritage List. It is not currently included within the limits of the latter. Its interest is based on the remarkable collections rather than on its architecture, on the content rather than on the container.

This report will not consider the issue of evacuated or damaged collections, which relates to a museum issue that should be the subject of parallel reflections.

The rectangular two-story building is built with a reinforced concrete frame and a veneer of local limestone covering the main façade. It was damaged during fighting. In particular, three projectiles broke through the upper terrace and floors and two others damaged the rear façade overlooking the garden (See map below). The photos available prior to 11 December 2016 testify to this state of destruction, spectacular in some points.

Confirming the assessments previously carried out, the detailed examination of the damage does not reveal any secondary disorders threatening the overall stability of the building. At this stage, it is possible to conclude that it can be repaired with a view to a future re-use.
View of a gallery after the destruction and before the evacuation of large-scale works of art.

Peroration of the central terrace.

Cracking on the inner slab of the terrace.
Destruction of the superstructures of the terrace

Destruction in the inside and facade
Principles of the repair of the building

As soon as the building is accessible to the DGAM, the following measures should be implemented:
- Remove and evacuate the interior and exterior rubbles (ensure that no fragments of collections are left in the rubbles);
- Establish a detailed record of damages (pathology records) and identify any structure likely to present risks of displacement or collapse;
- According to the diagnostic’s results, install the shoring needed to secure the unstable elements.

For final works, two technical approaches could be envisaged (also detailed in the report in annex, by the engineer Salvatore Russo):
1. Retain as much as possible the structures directly impacted by explosive charges, pillars in particular, reinforcing them through specific techniques and materials (sheets of Carbon Fibre Reinforced Polymers (CFRP) bonded to the epoxy resins)
2. Demolish the damaged parts and rebuild them identically, with reinforced concrete, in connection with the sound structures.

The option, one of “healing” being more complex and technically innovative or the other of common "surgery" being more conventional, should be chosen in due course, depending on the respective costs of the two solutions but also taking into account the technical implementation skills actually available on the ground.
Adaptation of the building to the evolution of its use

Considering the extent of the damage suffered by the building and its collections, it seems apparent that the future museum cannot and could not be restored exactly as it was before.

The museum conceptions and practices at the international level have evolved and the public visiting of these institutions are expecting settings that are more contemporary. In addition, the notion of "museum of collections" evolved to the one of "site museum". Despite some recent adaptations, this still raises the issue of the adaptability of a museum built and designed almost 60 years ago. The rigidity of the current partitioning which shows a repetitive succession of identical rooms, the multiplicity of the windows that reduces the linearity of available rails, as well as the lack of fluidity of the visitors' itineraries, highlight the need for the reorganization of the museum's interior spaces.

First, it is recommended to complete the diagnostic of pathologies mentioned above, and to this end, carry out a series of localized holes that will allow identifying the types of masonry and clarifying the bearing or non-bearing role of the inner walls of the masonry at the two levels of the building. This study will clarify the feasibility of decompartmentalising the interior spaces in order to propose a more innovative museum design.

In addition to the option of a functional evolution of the museum within its current envelope, the option of an extension to the building can also be considered. Given the relatively small size of the parcel allocated to the museum owned by DGAM, such an extension might be envisaged at the back of the present building. This proposal would need further studies, however it would present the advantage of keeping the main façade of the building facing the antique site side, though this might also present the disadvantage of proposing a more or less hybrid architectural ensemble that is not fully functional.
The actual location of the museum overlooking the ancient site appears a priori ideal. It could possibly be the ‘entrance gate’ to the site. No other neighboring or remote plot (given it is made available) would seem as appropriate as this location for a "site museum".

Finally, a third option could be considered and studied with the demolition of the existing building that is of modest architectural interest, and does not respond to the evolution of museum practices and norms. This would be the reconstruction at the same place of a new building that would better respond to this evolution. A contemporary could offer a skillfully staged direct visual connection with the ancient site, while integrating subtly and discretely into the cultural landscape.

The available options could resume in four avenues of action:

- Option 1: Repair and reuse the museum in its current provisions.
- Option 2: Repair and reuse the museum, modifying its interior spaces (Subject to verification of the structural feasibility of the project).
- Option 3: Extension of the museum on its current site (with or without modification of its internal partitions).
- Option 4: Demolition of the existing building and construction of a new building.
By the time the situation at the site allows works to begin, it is recommended to anticipate and start as soon as possible two types of reflections:

- A collegial discussion on the scientific content and functional program desired for the future restored museum, in order to deduce the needs in terms of surfaces and spatial organization:
  - Evaluation of the museum collections after the destruction;
  - Possible enrichment of the collections;
  - Development of a concept for the museum as a ‘site museum’ (models, multimedia, etc. ...);
  - Spaces for temporary exhibitions,
  - Pedagogic workshops,
  - Storages, restoration workshops and laboratories (possibly relocated to a neighboring site to be identified);
  - Offices for conservation services;
  - Reception of the public, cloakrooms and sanitary facilities;
  - Eventual ticketing, control and security rooms (assuming the access to the site is given at the museum);
  - Shop, bookshop, souvenirs;
  - Cafeteria and fast food, outdoor terrace;
  - Technical rooms.

- Once the programme is defined in terms of content and induced surfaces, assess in terms of container the functional and economic feasibility of the various architectural options 1 to 4 mentioned above, in order to judge the ability of each of them to respond optimally to that programme and those needs, and then assess their respective advantages and disadvantages before deciding on a final option.

In conclusion, it should be stressed that the current period of difficulty in accessing the situation at the site in Palmyra can benefit a sound reflection on the programme elements of the future museum, with the choice of the option that responds optimally to the programme.

In Annex, the report by the engineer Salvatore Russo gives specifications and prescriptions for the technical diagnostic of the museum, allowing the technical definition of the restoration project to be refined.
THE WORLD HERITAGE SITE OF PALMYRA

Previous Recommendations

The UNESCO Rapid Assessment Mission held at the site of Palmyra site from 23 to 27 April 2016 assessed the overall state of conservation of Palmyra after the intentional destruction of the main archaeological and monumental components of the ancient site by extremist armed groups, since 21 May 2015.

The mission was able to access the demined parts of the site and noted the destruction of the following:

- The Cella of the Temple of Baalshamin (destroyed on 23 August 2015),
- The Cella of the Temple of Bel and its peripheral columns (30 August 2015),
- The Central part of the Arch of Triumph (4 October 2015),
- Three columns of the main colonnade (26 October 2015).

The 2016 mission established that the following components had not been destroyed:

- The Colonnade
- The Tetrapylon (since then largely destroyed on 20 January 2017),
- The Theater (whose central part of the stage wall was also destroyed on 20 January 2017),
- The Agora,
- The baths,
- The Camp of Diocletian,
- The Decumanus with columns

However, the mission was unable to access the funerary towers of the Valley of the Tombs, where 6 main towers have been destroyed. It also noted the presence of numerous military installations on the site and their possible impact on the Archaeological remains.
For the three main monuments destroyed in 2015, the mission estimated that “a certain percentage of the stones after intentional explosions (to be detailed in future studies and extensive field work) were in fairly good shape, in view of future consideration related to potential anastylosis projects”. It reiterated the principle, already emphasized by several successive decisions of the World Heritage Committee, that “only damage assessment, first aid and emergency measures can be conducted in Palmyra”.

The technical mission foreseen by UNESCO to be organized in December 2016 aimed at assessing further damages to the site of Palmyra and at proposing the technical emergency measures to be implemented.

The security situation did not ultimately allow the mission to take place on the site of Palmyra, which was taken back by the extremist groups on 11 December 2016. It has been decided that the issues of emergency measures to be implemented would be discussed with the heads of the Directorate General of Antiquities and Museums of Syria (DGAM) based off of a first collection of archival documents and recent pictures taken after the destruction of 2015, within the framework of the Technical Assistance Workshop on World Heritage sites held in Beirut on 13 and 14 December 2016.

The expertise on the documents leads to the following observations and recommendations:

**Assessment of damages to the destroyed elements**

Unlike the other destruction of heritage monuments by collateral damage, those that devastated the site of Palmyra are primarily intentional destructions, targeting deliberately and symbolically the universally celebrated masterpieces of architecture and archeology of Palmyra. Intentionally planned and executed, they were extremely effective.

Prior to the destruction of 2015, the site of Palmyra had a configuration resulting jointly from:
- From 1929, the evacuation and complete demolition of the village of Palmyra, which had developed in the archaeological area during the previous centuries,
- Excavations and archaeological clearing subsequently undertaken on some of its monumental components,
- Finally, numerous campaigns of restoration and anastylosis works conducted since the French mandate in Syria, later and until 2010, by various national or international teams.

The architectural remains (preserved above the ground and exclusive of underground remains) could be divided into four material categories:
- Structures preserved in elevation (colonnades, cella of various temples, Arch of Triumph, etc.),
- Structures in elevation but partially assembled by anastylosis, in various proportions (Tetrapylon, stage wall of the Theater etc ...),
- Materials kept on the ground, in their places of origin and in their positions of collapse,
- Materials, originating from previous collapses or dismantling, preserved and categorized in ground storage fields, to anticipate future anastylosis of the original structures.

The intentional destruction, which took place at the end of 2015, added here a fifth category of remains: the more or less diffused rubble resulting from the blasting of structures. It created an additional layer, particularly chaotic, on some of the other categories of architectural remains.

The analysis of recent pictures, enriched by the testimonies of the rare persons who have been able to visit the site after the destructions, allowed the identification of important differences in the nature and diffusion of the residual materials resulting from various type of destructive devices used for the blasting of the monuments.
THE TEMPLE OF BEL

Plan of the Temple of Bel, its cela, its peristyle and its peribolos

The cela and its peristyle, before their destruction in 2015

Southeastern corner of the Temple of Bel and the remains of its peristyle, before their destruction in 2015
West facade of the Temple of Bel and its lateral portico (note the more recent stones at its base)

Interior view of the cela before its destruction in 2015
The Temple of Bel has apparently been mined with a peripheral belt of explosives displaced on the external face of the wall of the cella, in the lower part of the walls and directly in contact with its underlying foundation. The stones were "pulverized," which resulted in the breaking in innumerable fragments of small dimensions, which scattered around with the deflagration.

At first sight, only the west side portico is preserved, presumably spared from destruction due to its relative distance from explosive charges, but also because of the presence of reinforced concrete structures at its base and at the level of the lintels, implemented during the restoration works in the 1930s.

At first sight, the visible inclination of the portico towards the West could be attributed to the breath of the explosion; however, the examination of the old pictures shows that the inclination towards the outside of the temple existed previous to the destruction. It certainly resulted from the longstanding degradation of the portico's low-lying stones due to the rising damp, which justified the consolidation works carried out in the 1930s.

However, it seems that most of the base of the temple lying under the rubble might be still preserved on a height of approximately 1 to 1.20 meters.

It is very likely that the first two or three lower layers of the walls of the cella that were in direct contact with the charge of explosives must have been more or less pulverized during the deflagration. However, although they collapsed, it seems that the stones of higher layers (Elevations, entablatures, cornices and acroterion), as well as the remaining vestiges of the peristyle, are less damaged, with sharp breaks, broken corners and edges. These are the characteristics of a "classic" collapse of structures made of stone.

The 3D drone and 3D scan of the Temple of Bel made by ICONEM after its destruction clearly show two types of materials. The widely extended lower layer is made of small fragments resulting from the lower part of the cella. The other above layer is more concentrated in the area of the temple and is made of identifiable blocks, resulting from the collapse of the superstructures and remains of the peristyle.

Plan of restitution for the sanctuary of the Temple of Bel
The enclosure of the Temple of Bel, after the destruction of its cella, view from the East.
The only remain in elevation is the western portico remain.
Note the presence of previous in-ground storage fields in the temple area.

West portico after the destruction of the cella.
The explosion uncovered underpinning works in reinforced concrete at the base of the structure.
South facade of the Temple of Bel.
Old picture showing the former inclination of the west portico towards the outside

Shoring for the temporary consolidation of the portico and the execution of the reinforced concrete underpinning carried out in the 1930s

Scheme of the upper consolidation by reinforced concrete lintels
Digital survey by 3D scan of the remains of the Temple of the cella
Note the portico preserved at the West (Iconem/DGAM document)

Digital reconstruction of the destroyed parts of the Temple of Bel (Iconem/DGAM document)
The Temple of Baalshamin

This is a monument of similar structure but of much smaller dimensions than the previous one. Logically, the mining techniques used for its destruction seem to have been proportioned accordingly. Unlike for the Temple of Bel, the explosive charges used seem less powerful, but also placed inside the cella itself. The reduced blast of the explosion towards the outside of the cella resulted in a tilting of its lower parts and a collapse of the upper parts. The images taken by drones show a mass of collapsed stones, predominantly large blocks of stone clearly recognizable, many being broken at corners and edges as a result of the collapse. The shattered parts are limited to the crater of the explosion where the charges were placed, resulting from the destruction at that place of the pavement and interior floor of the sanctuary.

The use of an explosive charge placed and concentrated at the heart of the cella resulted in a very strong radial deflagration, nevertheless allowing to easily identify the position of the origin of each block due to their radial displacement away from this central blasting point. There also, a part of the low elevation of the temple of approximately 1 to 1.50 meters height seems to be more or less preserved under the heap of the rubble.
TEMPLE OF BAALSHAMIN

Mining principle for the destruction

Section

Plan

- Radiation of the deflagration
- Displacement of elements

Aerial view by drone of the temple of Baalshamin after its destruction in 2015
Note the central crater corresponding to the location of the explosives
The Arch of Triumph

In view of the currently available graphic infographic and photographic documents and in the absence of precise information, the modality for the destruction element varies from the others and may lead to questioning the use of explosives. The vertical collapse of superstructures and the absence of explosive traces on the lateral elements remaining in place indicate that the Arch might have been destroyed because it was shaken by heavy equipment, either an excavator or a bulldozer. The blocks of stone that fell on the ground are relatively intact, some presenting easily identifiable breaks and impacts, as demonstrated by the virtual simulation by ICONEM of the reassembly of the remains, based on a 3D scan.
Materials resulting from the collapse of the Arch of Triumph

Identification of destruction: Destroyed parts / preserved parts (Iconem/DGAM document)
The information and the elements for the assessment of the funerary towers of the Valley of the Tombs are extremely limited for this inaccessible area. They have been dynamited and the elements in elevation destroyed. We have no information on the underground parts.

Funeral tour of Elabel and Atanatan after destruction

Beyond this intentional destruction of the structures of these monuments, the use of explosives for this purpose may also generate a serious pathology on their original constructive materials. The potential micro-cracks are likely to weaken the stone that becomes physically or chemically less resistant to weathering, including by thermal dilations and shocks, exposure to rain and frost or alteration by risings loaded in soluble salts (sulfates, nitrates, chlorides, etc.).

The presence of numerous natural alterations seen on most of the monumental stone structures of the site of Palmyra, including on the monuments before their destruction, testifies to this phenomenon in time. In the long term, it might affect the preservation of stones fallen to the ground, likely weakened by the explosion.
Stabilization of the remaining vestiges

From the elements destroyed, the western portico of the temple of Bel reaching 12 meters height and the remaining lateral pillars of the Arch of Triumph reaching 10 meters height are the only elements left higher than 1 to 2 meters.

Undoubtedly, these remains require a provisional consolidation that would guarantee their stability. The technical design of the shoring used for the consolidation should also anticipate future restoration needs. The annex by engineer Salvatore Russo refers to this point, formulating technical recommendations.

In the case of the portico of the Temple of Bel, apparently strongly shaken by the deflagrations but fortunately standing, it is important to establish an accurate diagnostic, not mistaking the pre-existing inclination of the structure towards the West with the new disorders resulting from destructions. According to the few pictures available, the destruction seems to have affected the junctions between old and new stones and the reinforced concrete added in the 1930s rather than the verticality of the structure. The portico might be remaining thanks to this reinforced concrete structure.

The consolidation of the remains of the Arch of Triumph does not raise any real technical difficulty but will probably require the provisional dismounting of the two instable upper layers of the southwestern lateral pillar of the monument (at the left on the above pictures).
Emergency interventions

Although the situation and the actual state of conservation of the main monuments are still uncertain (limited documentation is available further to the destruction of the Tetrapylon and the stage of the theater in January 2017), future conservation and restoration choices can to be considered already.

The range of possible options for all monuments could theoretically range from a minimal option – keeping the monuments as they are after their destruction between 2015 and 2017 – to a maximal option, with a complete restoration of the monumental ensemble as it was at the beginning of 2015.

The first option is not sustainable because of the fragility and exposure of the rubble that will gradually decompose. The maximal option remains illusory, since a restoration to an "original" state prior destruction could only be achieved by the introduction of an excessive proportion of new materials, yet still unknown today, to replace the fragmented or degraded old material. An intermediate (or even median) option could be a possible choice.

The Venice Charter (1964) shed light on the point of view that is still valid today. As specified in Article 15, "all reconstruction work should be ruled out “a priori”. Only anastylosis, that is to say, the reassembling of existing but dismembered parts, can be permitted. The material used for integration should always be recognizable and its use should be the least that will ensure the conservation of a monument and the reinstatement of its form”.

Applied to recent destructions, such a principle of reassembling the monuments from the collapsed fragments, supplemented by a minor contribution of new materials needed for the stability of the works and the harmony of their forms, would fully reflect the continuity of practices implemented in Palmyra by various archaeological missions for nearly 90 years. If we take into consideration the loss of a part of the original materials, this practice applied to the recent remains would necessarily result in reassembled structures below the volumes of the monuments, prior to their destruction. However, in view of the numerous old material stored on the ground carefully categorized by previous archaeological missions, other ancient ruins of the same site could be reassembled by anastylosis (colonnades, peribolos, walls of enclosures etc ...), creating an overall volume size over the previous volume that existed prior to 2015.
The range of potential options remains open today: 1/refusal of any anastylosis (possibly compensated by virtual 3D restitution), 2/partial anastylosis or complete, 3/anastylosis on different elements. It is among these varied options that the final choices can be made.

Whilst remaining in line with the ethical framework of international standards for the conservation and restoration of monumental heritage, this issue takes a particular theoretical and memorial dimension in the context of the martyred site of Palmyra. What memory do we want to preserve, give, or restore to this site?

- The memory of destruction (and along the one of the destroyers, whether it is wanted or not) or, to the greatest extent possible, the memory of the site prior to the destruction?

- To what extent do we want to erase the memory of the martyrdom (and the martyrs) of Palmyra and to what extent do we want to preserve it?

This theoretical and memorial debate is an emotional, identity, historical, scientific and aesthetic debate. It can also take a touristic dimension according to the heritage message that one may wish to deliver to future visitors of the site.

This debate certainly goes beyond the responsibilities and competences of the authors of this report, who focus on technical recommendations and emergency conservation measures. Nonetheless, all future options need to be considered.

This debate and reflection must be undertaken as soon as possible, and would need to be done in collegial manner, involving all stakeholders, including the knowledgeable national and international experts of the site. This consultation could also extend to the experts of other World Heritage sites that have experienced such situations of conflict and post-conflict, as their experience can benefit the debate.

Moreover, this debate should not be carried out in a purely theoretical, doctrinal, or even philosophical manner. The practical action should be first based on a thorough evaluation, diagnostic and detailed scientific and technical, quantitative and qualitative analysis of the remains of the recent destructions:

- What is the proportion of the more or less preserved or irretrievably lost material in the present debris?
- To what extent can we identify the exact provenance of the different parts of the monument destroyed, looking at the available documentation?
- What is the state of conservation looking at the structure of the material, possibly weakened by explosions?
- What would be the consequent proportion of re-use of the material?
- What would be the feasibility of reassembly by means of limited or more complete anastylosis?
- What would be the proportion of new materials to be introduced with a maximum re-use of the usable materials?

These are the most important concrete questions to nourish the reflection and guide the choice of future decisions.

In order to provide answers to these different open questions, it will be necessary to initiate, as soon as possible, a methodological process which must imperatively follow the following steps:
1. A detailed survey of the totality of the monumental remains and their rubble, in their current position, and without any displacement of materials.

2. Inventory of the remains, number and record, stone by stone, on the basis of a typology to be defined beforehand (flat-faced stones, molded stones, carved stones, provenances according to the different parts of the monument, etc.).

3. First diagnostic of the state of the material, stone by stone, and immediate conservation measures before removal (summary reassembly, etc.).

4. Removal, stone by stone, of the top layers of the collapsed material.

5. Storage of the various stones and fragments in a sheltered area, to be implemented in the vicinity of the sites and locked when possible.

6. Additional detailed graphic and photographic inventory for each stone or fragment.

7. Consolidation and restoration, stone by stone, of each block or fragment stored: reassembly, broaching and bonding, using appropriate techniques and products, consolidation of porous, cracked or powdering cladding and decorations, etc.

Note: for monuments left with a pile of rubble, the work of survey, inventory, removal and restoration of the collapse materials will be carried out by stratigraphy, layer by layer, following a methodology similar to the one used in archaeological excavation, until reaching the base of the monument remains is reached. The work should be carried out by specialized teams specifically trained for this purpose.

It is only at the end of this work that virtual anastylosis can be studied by numerical simulations showing the materials that are preserved and re-used. The on-site implementation of the selected option of anastylosis could be implemented afterwards.

**Recommendations**

In conclusion of this analysis and in light of the experience gathered on similar issues encountered on other sites and monuments inscribed on the World Heritage List, at this stage, the following recommendations can be made:

**Immediate measures that can be implemented without accessing the site:**

1. Gather and analyze all scientific, ancient or recent, written or graphic, photographic or digital, documentation available on the site of Palmyra in Syria or abroad. In particular, for the recently destroyed monuments, as a matter of priority, gather architectural records, reports, photographic backgrounds, publications, inventories, archives of previous work campaigns, etc. This documentation may seem to be numerous, extremely rich and precise for certain monuments such as the Temple of Bel. This work constitutes the indispensable preliminary intervention for the effectiveness of any concrete intervention implemented at the site.

This collecting work, to which all national and international institutions and teams have to be associated, needs to be supplemented by a task of harmonization of documents and a widespread dissemination to all stakeholders contributing to the safeguarding of the site.

**Immediate measures to be implemented when the access to the site is secured:**

2. Ensure, as far as possible, the guarding and surveillance of the archaeological site, in order to avoid looting of carved and decorated fragments as well as illegal excavations. Engage in parallel in the demining of the site, but gradually along with the guarding of the site. Keep mines in place in clearly delineated and marked areas can temporarily contribute to the security of the site before the situation gets back to normal.
3. **Urgently prohibit any hasty intervention of clearing the rubble**s of the recently destroyed monuments, because:
   - their accumulation can now contribute to the more or less precarious stability and preservation of the remaining covered or surrounded structures,
   - their distribution on the ground after the explosions testifies in one way or another to the original position of each block in the monument, thus allowing a sound identification.

Despite the “a priori” chaotic appearance at the Temple of Bel or the Temple of Baalshamin, the pile of rubble represents a precious and significant part of the formal memory of the monument destroyed and guarantees the traceability of the origin of each fragment. A hasty intervention of clearing the site that is not precisely documented would be a permanent loss.

4. For the three major elements (the Temple of Bel, the Temple of Baalshamin and the Arch of Triumph), the survey, inventory and precise recording of all apparent blocks and fragments in place should be established on-site prior to any intervention and preferably by 3D digitization as an extension to the work already undertaken by Iconem, **without moving any of them** and pending the development of a scientific methodology of processing.

5. **Guarantee temporarily the protection and stability of the monuments remains**, implementing appropriate measure for the partial shoring or dismantling (as mentioned above) of the structures, and in particular, the west portico of the Temple of Bel and the remains of the side pillars of the Arch of Triumph.

6. **With a view to addressing the technical problems related to the destruction of the monuments**, conduct, with the support of UNESCO and international partners, training courses for national teams on methodologies and techniques of anastylosis, as well as on stone conservation and restoration.

7. **Extend all approaches described and recommendations to the emergency safeguarding of other destroyed components of the site**, in particular those that took place at the Tetrapylon and Theater in January 2017.

8. Finally, with a view to ensuring in the future the safeguarding of the World Heritage site of Palmyra and its reopening to visitors, invite UNESCO to contribute to the establishment of a permanent structure or committee to address the issues of documentation, conservation, restoration and future management of the site, which would include all stakeholders as well as competent national and international potential partners likely to contribute to the reflection, to the selection of restauration options and to the implementation of the projects.

   Pierre-André Lablaude
   Chief Architect
   Historical monuments
   Expert of Unesco
ANNEX

FINAL REPORT -

Technical assistance workshop for the emergency safeguarding of the world heritage sites of Palmyra, Crac de Chevalier and Damascus

13-15 December 2016, Beirut

Extracts concerning the site of Palmyre

- Citadel
- Museum
- Temple of Bel
- Arch of Triumph

by

Prof. Eng. Salvatore Russo

Professor of Structural Engineering, Iuav University of Venice, Italy

Venice, January 6, 2017
4. Site of Palmyra (14/12/16)

4.1 Technical Issues raised

Palmyra Citadel
As for the citadel Palmyra, the issues raised relate mainly to the impossibility of an analysis of the structural damage inside, especially due to the possible presence of unexploded bombs, the incompatibility between drawings and photographs as well as the absence of structural drawings.

Palmyra Museum
The structure is column-beam framed made by reinforced concrete (RC) and characterized - as testified by the DGAM and the views – by structural masonry walls.

The biggest technical issue presented - within a broader conceptual issue that concerns the recovery or demolition of the building as a whole - refers to rehabilitation mode of the structural damage, in particular the rehabilitation or renovation of four RC pillars and, consequential, the overlying RC floors.

Structural damage, overall, appears broad and widespread, but does not undermined the structural system as a whole.

Temple of Bel (Complex Masonry wall and Portal)
With reference to the structure called Complex Masonry (Annex 15) - as it was not covered by a specific technical discussion during the meeting - it is considered appropriate to provide rapidly at a static shoring that reduces head rotations of the walls indicated with “β” in the Annex 15.

As regards the Portal, its structural state of conservation seems threatened, by a displacement in the plane δy (Annex 14) and a horizontal rotation αxy (Annex 14). The analysis of both displacement and causes that generated them would need further study.

Arch of Triumph
Major technical issues are related to the structural safety and the safeguard-approach to the two vertical elements left standing (Annex 17 and Annex 18) at the edge of the three arches that collapsed (Annex 16) Consequently, the reconstruction mode of the three arches originally placed between the aforementioned elements left standing, will be sensitive.
4.2 Proposals for technical solutions

Citadel of Palmyra

The monumental complex - according to DGAM reports - as a whole does not appear to be affected by any recent intervention of structural restoration. The overall response of the Citadel to the explosion of the projectiles and its related damage, appears acceptable (Annex 10) – even if some areas have suffered severe damage (Annex 10a and 11) - due to their predominant massiveness.

Indeed, it seems relevant to note, with particular reference to the images shown, that elements from the front of the Citadel have totally collapsed and that parts of elements are still at risk of imminent collapse (Annex 10a and Annex 11).

Palmyra Museum

The technical proposal focused on the necessary procedures for the stabilization of structures in order to protect stakeholders from major injuries. In particular, four RC pillars, which have, respectively, a major shear-fracture (Annex 20), and an important disconnection break in the upper beam with a partial ejection of the reinforcing steel bars (Annex 20). In other places, there was a warping of the pillar at its connection with the beam, with a partial expulsion of a section-part of the pillar. The RC pillars will be reinforced, in a first structural hypothesis, or demolished and rebuilt with a modification of the shape of the yard, in a second structural hypothesis.

Temple of Bel (Complex Masonry Wall and Portal)

As regards the Complex Masonry Wall, it is suggested as an emergency for the urgent affixing of two lattice triangular wood shoring along the plane of the masonry (Annex 15), reducing the existing rotations which are evident at the top of the walls. This reticular shoring will be designed as an active shoring.

As regards the Portal, the loss of material and damages are evident. An ad hoc adequately designed shoring should be installed. An in-situ analysis of the situation is recommended prior to intervention. –due to the structural and symbolic importance of the monument and, not least, to its external dimensions of about 4-5 meters by 13-14 meters in height.

Arch of Triumph

It is proposed to address the stabilization of the two vertical elements left standing (Annex 17), by considering the priority of preventing the fall of the remaining stones at the top level (Annex 18, on the left) and ensuring the security of the entire vertical structure-element (Annex18, on the right).
If the choice of reconstructing the three arches is taken, it should be reconstructed with appropriate shoring and special formwork – specifically designed - following the instructions and methodology of the architect/archaeologist in charge.

4.3 Technical recommendations for the future

Citadel of Palmyra

With reference to the stabilization procedures of the structural parts analyzed in the above paragraph 4.2, the following technical recommendations are made, strictly sorted from a chronological point of view:

1. Complete an in-depth analysis of the structural damage, both internally and externally, taking care of identifying, where applicable, the categories of damage (DC) mentioned in Chapter 3;
2. With reference to the potential rubble’s removal, apply the recommendation 8 of Chapter 3;
3. Organize specific scaffolding in order to safely apply the stabilization measures that will be induced by wood elements or FRP(Fiber Reinforced Polymer) band/strip (see Annex 10a and 11);
4. Based on the analysis of structural damage and, above all, on the basis of an estimated analysis of crisis mechanisms and expected collapse, decide where to apply crossed tie rods in wood or FRP in order to contain the damage and stabilizing structural parts (see Annex 10a and 11);
5. Decide if the shoring will be active or passive;
6. Design and set the shoring so that they could also contribute to the consolidation and restoration processes;
7. If complex decisions should be taken - both for the design of shoring or for the permanent structural reinforcement interventions - do not exclude the use of closed formulas related to the rigid bodies theory or/and a 3D FEA.

Palmyra Museum

The choice of the structural rehabilitation of the RC pillars and overhanging beams, intended as structural hypotheses 1, or the demolition and reconstruction choice, intended as structural hypotheses 2, depends primarily on the following aspects:

- Analysis of the costs related to the two different technical options;
- local ability to demolish and reconstruct or to rehabilitate the building with the option of changing the related yard.

- In the case of the rehabilitation of the existing RC pillars, regardless of the potential new loads or changes in the property, it is suggested – after the straightening/stirrup of the pillars – to clean the pillar, use a primer and apply low modulus FRP carbon sheet (as reinforcement) glued with epoxy resin, which will generate a 1 mm thick only. This procedure will be applied after the proper calculation, made with different configuration, for the shear fracture as well as the curved parts referred to (see Annex 20). The structural rehabilitation procedure must take place, as stated, only after the realignment of the pillars and a suitable support created for the overlying beams.

- In the case of demolition and rebuilding of the RC pillars, please note that any greater static loads that will be borne on the floors in relation to new or different destinations of the functions of the building, will have to be accounted using high-performance concrete, with or without fibers.

Temple of Bel (Complex Masonry Wall and Portal)

As regards the Complex Masonry Wall, it is suggested as an emergency measure to install in plane, a triangular shape wooden shoring and internal struts, adequately calculated and fixed to the ground in a reasonable way; in order to reduce head rotations (Annex 15). We recommend an intervention with active shoring. Alternatively it can be designed as a double belting with active FRP bands.

For the Portal, we propose the following recommendations/actions which also include the design of an adequate shoring. Given the complexity, sensitivity and importance of the monumental structure, it should also be designed to contribute to the final restoration of the portal. The following recommendations gives the work phases succession

1. Survey and accurate verification of the presence (or absence) of foundations for each of the two pillars; the survey must be carried out without causing any damage to the portal and without removing the existing stones rubble at the portal (see Annex 13). It is strongly recommended to undertake a non-destructive campaign of diagnostic tests in situ, such as endoscopy, sonic tests, rebound hammer and tromograph and, before any operations involving the insertion of a special and dedicated shoring. The analysis and interpretation of the results will give the accurate state of damage and highlight the needs for the structural conservation of the portal;
2. With reference to the potential removal of rubble, apply Recommendation 8 of Chapter 3;
3. Calculation of the masses that characterize the structure of the portal;
4. On the basis of the calculation of the masses and of the results of the application of the rigid bodies theory, you will be able to design and install 2 triangular wooden shoring - such as triangular lattice working in their own plan - placed on each side of the portal along the major inertia plan (Annex 13a). The structural cross section of each wooden element of the triangular shoring should not be less than 900 cm$^2$. The shoring will be adequately placed on the ground;
5. The two wooden shoring, identical to each other, will be passive at the beginning - because they will be in contact with the monument and therefore should not produce any force, but act as supports in case new displacement (see Annex 13a). However the mentioned wooden shorings will then become active, according to the restoration’s methodology approach decided and in relation to the reduction, or not, of the displacements showed in Annex 14;
6. Design at the same time an internal shoring - thus in the central part of the door – as triple “S.Andrea Cross” system (Annex 13a) with structural wooden elements (larch or oak or local structural wood) having indicatively a smaller side section of not less than 30 cm, due to the very massive structure; the shoring will be anchored to the ground and build up until contact with the portal;
7. Make two additional orthogonal shoring to support the major inertia axis of the portal - one for each of the two sides, in correspondence with the center line of the portal - to reduce the potential horizontal rotation (Annex 13b) and to support the heavy weight of the monument during its restoration;
8. This installation will totalize five parts of wooden shoring, four of which are arranged on the outside of the portal and one inside and will allow to check in detail the condition and stability of the stones laying overhead;
9. The shoring will be allocated as little as possible by moving the collapsed stones and falls at the basis of the portal itself, in order not to alter the framework of the forces acting around of the same pillars and potentially induced also by them (see Recommendation 2);
10. check by visual inspection and with the rebound hammer device the state of conservation and the mechanical characteristics of reinforced concrete at the basis of the pillars;
11. The history and interpretation of the results obtained from non-destructive diagnostics in situ (Recommendation 11) will be useful for the restoration of the monument;
12. the shoring system as a whole can also be used for the restoration;
13. If complex decisions should be taken – both for the dimensioning of the shoring or for the final restoration - it is suggested to use a closed formula related to the rigid bodies theory or/and a 3D numerical FEA, in order to scientifically guide decisions.

The feasibility of recommendation 1 to 15 needs to be confirmed by an in-situ analysis of the situation.

Arch of Triumph

The Arch of Triumph has been severely damaged and the three arches collapsed. At the top of one the remaining column element (see Annex 17 and 18 to the left) stand two important stones (in terms of weight), at risk of falling. The two stones should be removed to the ground using appropriate light equipment (cranes/scaffolding) in order to intervene without touching the structure,

It should be possible to intervene in situ on the other column element (see Annex 17 and 18 on the right) - which apparently seems to have a better state of conservation than the above-mentioned column - with an empirical non-destructive acoustic investigation in order to check if there are any risk of stone fall.

The acoustic empirical investigation may be conducted applying an external non destructive excitation by means of a common hammer made by polymer, which will induce the acoustic emission reflecting the structural state of the stones. The survey will proceed from the base upwards and data will be regularly compared. The absence of noise or in any case the presence of a deaf noise will correspond to a good connection between the stones and/or to a good consistency of the examined stones; the presence of a easily perceptible noise may correspond to the state of a stone poorly clamped, damaged or partially damaged.

Once the empirical investigation is conducted and the intact and/or well clamped stones as well as the stones at greater risk of falling are defined) it will be possible to understand if the state of the connections between the stones at the top level is reliable and whether they should also be removed to the ground.

In the case of this column, the use of an endoscope device will allow to verify the connection between stones and the potential risk of imminent collapse.

In either cases, this safeguarding procedure is intended to for the safety of the workers in this area.
The reconstruction of the three arches (see Annex 19), should start with the reconstruction of the two central columns, which were of particular importance before the damage (Annex 16). They will be the basis for building up the three wooden formwork-shoring arches, which in turn will support the construction of the stone arches, according to the instructions and methodology decided by the architect/archaeologist in charge.

It suggested proceeding with a preliminary numerical 3D FEA to define the structural design and type of the formwork-shoring for the reconstruction of the Arch of Triumph. Note that it is quite easy to find documentation on numerous examples of formwork-shoring-arch for the reconstruction of in line stone arches.

The meeting did not focus on the reconstruction of the destroyed Temple of Baalshamin Temple and tower Tombs.
Need of stabilization even if in presence of dry and dry
ETAT DE SYRIE
RUINES DE PALMYRE

PLANCHE II
ANNEX 19

PROJETS DE RESTAURATION DE L'ARC MONUMENTAL

FILE À RECONSTRUIRE

SOL ACTUEL

SOL PRÉCÉDENT

ÉCHELLE : 2 cent. par mètre - 1.