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THE ANCIENT DRAINAGE SYSTEM OF PETRA: ANALYSIS AND RESTORATION FOR CULTURAL HERITAGE CONSERVATION *METHODOLOGIES APPLIED TO THE CONSERVATION OF THE MONUMENTAL PALACE TOMB.*

R. GABRIELLI [1], B. LANDINI[1], N. AMICO[1], A. ANGELINI[1], R. FRANCHI[2], L. MENCI[3]
[1] *Institute for Technologies Applied to Cultural Heritage (ITABC), CNR, Rome, Italy.*
[2] *Institute of Human Sciences, Environment and Nature.*
[3] *Mencisoftware, Arezzo, Italy.*

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1. INTRODUCTION

The Institute for Technologies Applied to the Cultural Heritage (ITABC) belongs to the Department of Cultural Heritage of the CNR (National Council Research of Italy). It deals with experimentation and application of integrated methodologies and multidisciplinary techniques for the knowledge, management, fruition and safeguard of Cultural Heritage. The main goal of the research line, which deals with the presented project, is to develop integrated techniques minimally invasive and quickly but at the same time very reliable and precise, applied to the Cultural Heritage. The aim of the works is the understanding and knowledge of the archaeological features and buildings. The activities are referred to archaeological and topographical fields, developing new methodologies that allow the contemporary proceeding of the excavations.
In the following paper we are presenting the interesting case study of the Palace Tomb in Petra. This case study belongs to two important international projects both in agreement with the Department of Antiquities of Jordan directed from Dr. Fawaz Alkhraysheh:

- The ancient drainage system of Petra: analysis and restoration for cultural heritage conservation. Project financed by Ministry of Foreign Affairs (MAE) and directed by Prof. Roberto Franchi of the University of Urbino.

- 3D spatial reconstruction of the ancient drainage system of Petra. A CNR research project directed by Dr. Roberto Gabrielli.

Both the projects are finalized to develop specific methodological applications for the monumental area of Petra in order to help the conservation and restoration of the ancient buildings and the analysis and recovery of the ancient nabatean drainage system.
The projects concern therefore different fields from the geology to the topography, the 3D photogrammetry, the GIS and restoration studies. In this case, these applied methodologies give us the chance to contextualize the ancient structures to get a better interpretation and to record the present day situation of the monuments. The final step will be the drafting of a restoration program of the area.

2. HISTORICAL BACKGROUND

The monumental area of Petra locates itself on the left edge of the Rift Valley of the Dead Sea, this region presents a particular tectonic environment because of the high rise between the eastern *plateau* and the Rift bottom. The site lies on the slope of the Mount Hor in a basin among the mountains which form the eastern flank of Arabah (Wadi Araba), the large valley running from the Dead Sea to the Gulf of Aqaba. It has been declared World Heritage Site by the UNESCO since 1985.
Petra, described even by ancient authors such as Pliny the Elder, Strabo and Diodoro Siculo, has been identified as the capital of the Nabateans. We can recognize some different settlement phases in the area:

- Pre-pottery neolithic period (natufian layers): X-VIII millenium B.C in the site of Beidha.

- Edomite Phase: VIII-VII century B.C. This edomite occupation is identified in the site of Umm al Beira and on the hills near Petra. Probably the Edomites moved to the Hebron region after the Babylonian exile.

- Nabatean Phase: from the VI century B.C. The origin of the nabatean is a debated issue. The Nabateans based their economy mainly on the trade activity. Petra became a crossroad, controlling the main commercial routes which passed through it Gaza, Bosra, Damascus, Aqaba and across the desert to the Persian Gulf.

- Hellenistic Phase. It was in the Hellenistic period that the major monuments have been realized due to a particular flowering of the city.
- Roman Phase. The Romans made some attempts to control the city but they succeeded to conquer it only in the 106 A.D (Trajan period). The roman govern caused a decay of the city in its role of crossroad of the commercial routes.
- Byzantine Phase. During this phase some ancient building were reused and some others new were realized.
- Islamic-Crusader Phase. The city was progressive abandoned and in the VIII century a.D. It was reduced to a village. The coming of the Crusaders leads to the building of castles and fortresses like Al Wuay'ra and Al Habis.

3. THE PROJECT

The ancient drainage system of Petra is dated to the nabatean period and it is composed by some water channels and collection tanks located in the nearby of the monuments. With the high probability this complex work of hydraulic engineering had the double purpose both to assure the water supply for the city and canalize the water flows to protect and preserve the monuments from the runoff, the major degradation reason of the façade of the tombs. This hydraulic system, with its complex net of hydraulic devices, had strongly characterized the organization of the city and its natural morphology. Another function of the system was to protect the central area of Petra from the floodings of the Wadi Mousa river. It is composed by a great amount of different hydraulic structures typologies: channels carved in the rocks, acqueducts, pottery channels, tanks and cisterns, basins of decantation, waterfalls, pools, flood traps and even sophisticated hydraulic elements similar to the persian *qanat*, with wells of aeration and some other devices to aid the correct flowing of the water. Telluric movements, burials and collapses had currently damaged the drainage system and it doesn't solve its primary function anymore (Fig.1).

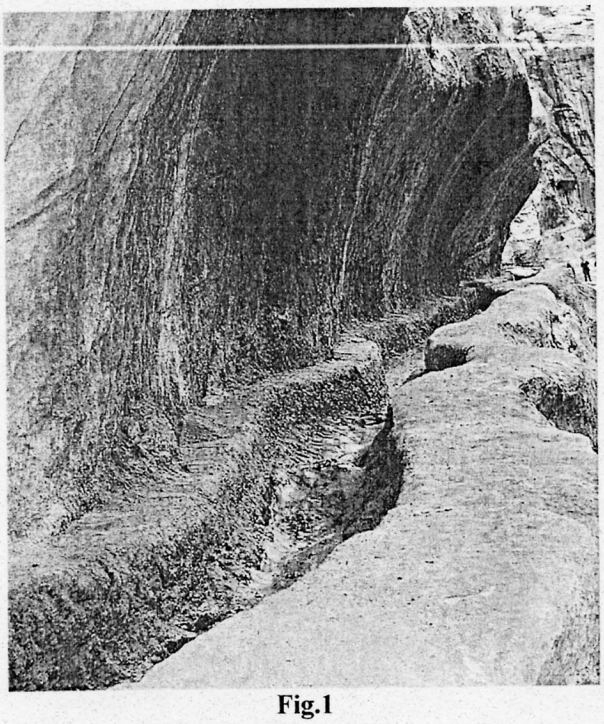

Fig.1

The projects have been organized and planned with a series of steps, some of them already accomplished, the others currently carried on:

- Preliminary test on the area of the Al-Habis hill inside the Petra Archaeological Park. This test concerned the use of different survey techniques (topography, photogrammetry) in order to obtain a 3D model of the morphology of the area to get a precise visualization of the channel system and define the level of the decay. That allowed the checking of the precision of the model obtained both in the morphological result and in the quantization of the data.
- Archaeological, geological and topographical survey of the valley, especially in the area of the royal tombs.
- Photogrammetric survey with high definition shots from an aerostatic gas balloon in order to realize a tridimensional model of the Palace Tomb façade.
- Integration of the data and spatial mapping of the decay areas.

- Realization of a restoration plan of the Palace Tomb with the technical aid of the Department of Antiquities of Jordan.
- Territorial photogrammetric survey of the details of the water channel system, quantification and localization of the lacking parts of the hydraulic system.
- Creation of a GIS to get integrated information about the channels and the decay status of the monuments. This is going to be a valid support to draft the restoration project of the hydraulic system.
- Restoration of the hydraulic net in order to get the canalization back to their original functions. In this way it will be possible to accumulate and use the rain water.

3.1 GEOLOGICAL AND PETROGRAPHIC RESEARCH.

The Petra monumental area is located on the left rim of the Rift Valley in the central-southern Jordan. The whole valley, originally tectonic, verges on late Cambrian quartzarenite rock formations of continental origin. These sandstones are composed principally of quartz (in percentages up to 95%), and of caolinite, ematite, goethite and, rarely, calcite cement rock. These different types of cement rocks often coexist arranged in districts which are generally made up of a single mineral.

The physical characteristics of these sandstones are extremely changeable related to the granulometry of the rocks, and to the type and quantity of the cements.

The only part of the whole valley still visible consists of a series of tombs and temples dating back to the Nabataean period, chiseled out of the rock walls.

The members of the project, after having led the preliminary studies, they have pointed out the following main causes of the degradation of the monuments. These causes are due synthetically to these physical phenomena:

- The phenomena of expansion and contraction of the rocks, caused by the great daily temperature ranges, breaks down the quartz grains leading to rock disruption. This phenomena has turned out to be active at least at a depth of approximately 20cm. The effect of gravity is one of the principal factors contributing to removing single grains of quartz or grained aggregates more or less solid from the rock surfaces. Heavy rainfall (rainstorms are not unusual in these areas and tend to be violent) and the running waters contribute significantly to carrying away superficial material (Fig. 2);

- Further forms of degradation, locally intense, are due to the presence of salts (halite, silvie, polyhalite) along fractures and diaclase.

Both fieldwork and laboratory analyses carried out with the help of climatic rooms, have underlined how the customary products used in standard preservative restoration works are not very effective due to the extreme weather conditions and the chemical-physical characteristics of the rocks. Moreover, the immensity of the surfaces requiring restoration would make this process extremely expensive. Indeed, past inspections carried out during surveys on the site have pointed out the key role played by rainwater flowing down the front of the monuments in causing their advanced deterioration (Fig. 3).

Fig.2

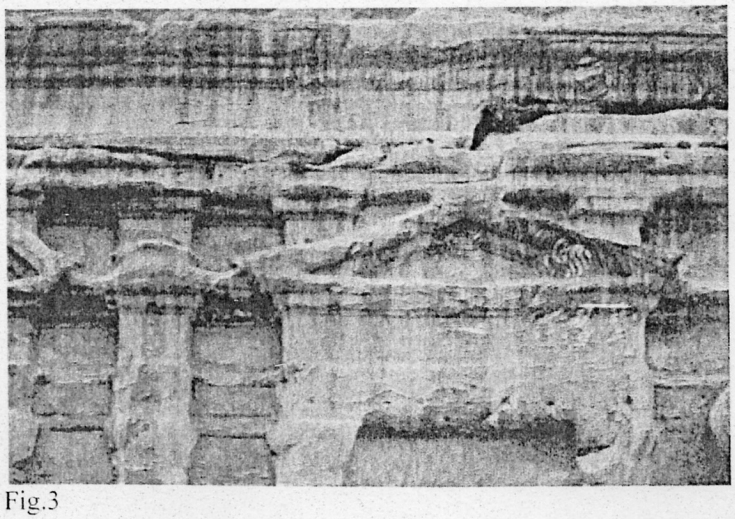

Fig.3

3.2. THE SURVEY

During the past missions we have decided to apply the methodologies of the project to a specific case study: the Palace Tomb monument (Fig. 4). Indeed the Palace Tomb, especially its façade, presents one of the main examples of the decay due to the water flowing and chemical deterioration. It is one of the most important buildings inside the PAP, probably the greater one. The monument was built by the nabatean genius during the Hellenistic period and it is the only one that presents two construction typologies: in fact it was both carved in the rock (in the middle and lower part) and free standing (in the upper part). At the present day the façade measures 49 meters wide and 46 height and it is possible to recognize five different architectural orders. The building presents at the ground floor four inner square chambers.

Actually we can't define the specific function of the monument because its structure is different from all the other royal tombs.

In the backside of the building there is an area buried with collapsed blocks of the ancient upper part. This sediments are causing cracks and damages because they are pushing the façade from the back.

The work carried out on the Palace Tomb leads to three main results:

- The realization of a 3D model finalized to the documentation of the present day situation and for a virtual reconstruction and fruition.
- The production of a GIS concerning the archaeological features of the monument (for instance the drainage system), the deterioration of the façade and the cracks of the sandstone. This GIS is finalized to be a valid support for the restoration project of the monument.
- The production of some layouts concerning decay maps of the facade.

In order to explain the methodological approach to the research, it's important to underline the particular geo-morphology (deep wadi, narrow paths, steep rocks), the hugeness of the monument investigated and the complex climatic conditions (high temperature, daily temperature ranges, strong blasts of wind, great amount of sand and dust) that don't allow a survey through standard techniques as laser scanner.

As a matter of fact , to carry out such a huge and difficult survey it had been necessary to develop innovative devices, with the collaboration of the Menci Software of Arezzo, in order to make an archaeological-topographical survey both manual and automatic aerial photogrammetry in a fast and reliable way. The purpose is to get a 3D model that allows to obtain planimetries, prospects, sections, DEM, ortho-photo and so on (Fig. 5).

A fundamental step that let us to carry out the survey is the integrated use of data acquired with different instruments in order to obtain homogeneous results. It has been possible through the use of the total station and the DGPS (Differential Global Positioning System). Acquiring ground control points (GCP), all the data have been georeferenced in the same reference system becoming comparable together.

The photogrammetric process (manual and automatic) is based on the identification on the images of homologous points, through a special mathematic algorithm the software is able then to generate the 3D point clouds. The fiducial points taken with the total station ensure the correct position in the 3D space of each datum.

All the data set has been imported in a specific GIS to obtain some important information that will be useful for the safeguard and consolidation of the monument. The construction of the GIS is a work in progress and the results will be different kind of maps of the decay. All the data acquired during the project will be inserted in a wider territorial GIS in order to contribute to a better contextualization of the tombs and of all the archaeological features. This is going to lead to a better historical knowledge and will help the interpretation of the monuments

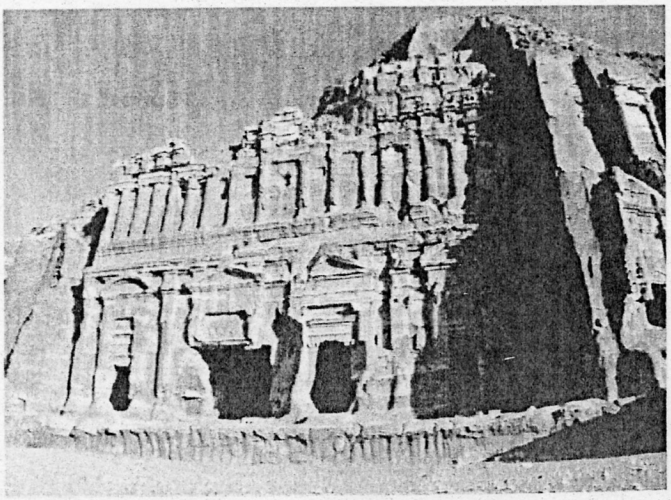

Fig. 4

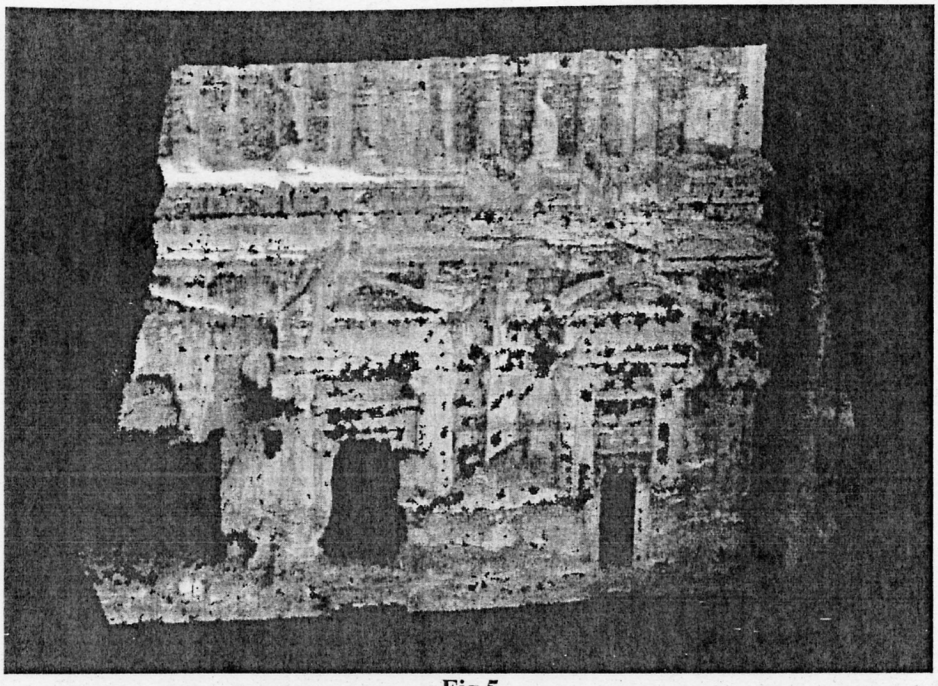

Fig.5

4. CONCLUSION

As described in the previous paragraphs, the entire hydraulic system is in a complete state of abandonment. The repercussions on the territorial system and the archeological and architectonic emergencies are devastating. The destruction and the progressive abandonment of the drainage network along with the complete loss of the terracing and urban gardens is leading to a slow but progressive process of erosion that involves the entire system, both the constructed parts and the territory.

The interventions, that are proposed in the projects, fit into a larger plan of territorial systematization that will subsequently involve the entire territory. On what was stated, it appears in fact that the wealth of hydraulic archeology described is really valuable, not only for the witness that it furnishes of a culture of advanced technological skills, but even for the control that it can have on the dynamics of restoration and protection of the entire enviro-constructed system. The possible recovery of the hydraulic system, considering the water a social item, could led to a better comprehension of the ancient development and settlement in relation to the modern one. Besides, the tridimensional models and the all the data set could be used for touristic purposes in a virtual path usable through the web. In this way the visitor could virtually visit the Petra Archaeological Park and enjoy the monuments both inside and outside

The plan of interventions is set in a larger program of integrated archeological-environmental recovery that extends from the conservation of ruins to the architectonic restoration, and from the archeological restoration to the territorial restoration, and will be developed consequently in four phases:

- A first phase of conservative restoration of the hydraulic structures.

- A second phase of restoration and rehabilitation of the hydraulic system that puts back in operation the circuit of drainage and canalization of the water.

- A third phase utilizes these systems to pass knowledge to visitors through the revitalization of the courses, secures the more delicate passageways, and creates an informative and descriptive system of proposed routes.

- A transversal phase finalizes the compiling of a continuous maintenance plan of the drainage canals and control of water flow.

Considering the advanced state of deterioration of the structures and the limited interventions carried out to this point, it is regarded as particularly urgent the elaboration of a project of conservation formulated by a multidisciplinary group of scholars. Some aspects of either technical or logistical-functional character require an infrastructure for the execution of the works of restoration which are water tanks, an electrical system powered by solar energy, workshops and storage sheds, and a technical-scientific office to protect, work on, and control the works as well as carry out analysis and studies on the development of the whole intervention.

The descriptive graphic renderings compiled during the phase of the mapping of the degradation and also their distribution in qualitative terms on the system will serve to identify the areas that need urgent treatment and, as such, will be those in which to start the works.

In conclusion it is necessary to emphasize the importance of an accurate survey to record the present day situation. This record show us how to reconstruct and understand the past, and that's the base to construct our future.

The obtained results will help the understanding and the knowledge of the hydraulic system of the buildings and will deal with the protection, conservation and safeguard of the cultural heritage.

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