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Risk Assessment and Structural Restoration of Roman Cisterns at the Regional Theatre of Skikda, Algeria

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ABSTRACT

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This study is part of a comprehensive initiative focused on the restoration and adaptive reuse of Roman cisterns located beneath the Regional Theatre of Skikda, Algeria. As a key component of a broader heritage conservation strategy, the project supports the structural rehabilitation and functional reintegration of historical infrastructure, while prioritizing public safety and the preservation of architectural heritage. The primary objective is to implement a comprehensive structural diagnostic assessment, using non-invasive and semi-invasive techniques to detect and map pathologies in the load-bearing elements, fixed installations, joints, and historical construction materials. Key issues, such as material degradation, cracking, fractures, and aging, are examined, with a focus on identifying root causes through systematic analysis. The diagnostic process integrates traditional surveying with modern techniques, including visual inspection, material sampling, and structural behavior modeling, to ensure accurate evaluation and informed decision-making. A secondary objective of the project is the adaptive reuse of the cisterns as a secure cultural facility specifically, an art gallery meeting contemporary safety standards. This transformation prioritizes structural stability, visitor safety, and long-term sustainability, while preserving the site's historical integrity. The project demonstrates a replicable approach to combining heritage preservation with modern safety and usability requirements.

1. INTRODUCTION

All built structures exhibit a finite service life, during which they must maintain functional performance, aesthetic qualities, and structural safety. In this context, the disciplines of rehabilitation, restoration, and renovation are essential for extending the lifespan of civil engineering assets. A restoration project involves a systematic, multidisciplinary approach aimed at conserving, repairing, and revitalizing heritage structures or buildings, while preserving their original materiality and architectural authenticity [1].

The primary objective is to safeguard both the historical and aesthetic integrity of the structure, while ensuring enhanced durability and structural reliability under current and future environmental conditions. Restoration works typically include the assessment and diagnosis of deterioration mechanisms, with particular emphasis on moisture ingress, which is a major cause of material degradation and crack development [2]. The evaluation of

damage involves non-destructive testing (NDT) methods, such as infrared thermography, ultrasonic pulse velocity, and moisture mapping, to identify hidden defects and quantify degradation levels [3]. Subsequent interventions focus on the repair and consolidation of deteriorated materials—such as masonry, concrete, and timber—using compatible repair mortars, consolidants, and reinforcement systems. Structural stabilization may involve the application of advanced strengthening techniques aimed at mitigating existing pathologies and preventing further structural deterioration [4], [5], [6]. Finally, damaged architectural elements are carefully reinstated through the use of traditional craftsmanship, complemented by modern conservation materials, to ensure both material compatibility and long-term durability [7].

The restoration and adaptive reuse project of the Roman cisterns beneath the Regional Theatre of Skikda reflects a broader global movement toward the preservation and functional reintegration of subterranean heritage

structures. When compared to analogous initiatives—such as the Basilica Cistern in Istanbul, the La Malga cisterns in Carthage, and the Laeken cisterns in Brussels—this project shares several key objectives: the implementation of non-destructive diagnostic methods, a strong emphasis on public safety, and a long-term vision for cultural and social sustainability. However, the Skikda initiative is distinguished by its pioneering character in the Algerian context and its holistic methodology, which integrates scientific conservation, adaptive reuse, and compliance with contemporary safety standards. As such, it presents a transferable model for the adaptive reuse of historic infrastructure in comparable settings.

2. CASE STUDY: THE ROMAN CISTERNS PAGE SETUP

2.1 Project Location and Context

The Roman cisterns are located in the heart of downtown Skikda, in the area historically known as "Place des Calèches," situated between Didouche Mourad Street (main entrance) and Mekki Ourtilani Street (artist entrance) (Figure 1). A striking white structure with blue slate roofing along its sides occupies the site, notable for its architectural presence and refined elegance [8].

Constructed atop the ancient substructures of the Temple of Venus—the tutelary goddess of Roman Rusicade—a wooden theatre was built in the mid-19th century (1854). This original structure was later demolished and replaced by the current theatre building, as part of the preparations for the centennial celebrations of the French colonization of Algeria.



Figure. 1 Location Map of the Roman Cisterns.

2.2 Project Overview

This project forms part of a broader initiative aimed at the enhancement and preservation of historical monuments, seeking to protect, restore, and promote cultural heritage within the Wilaya of Skikda. The objective is to ensure the sustainability and transmission of this heritage to future generations, thereby reinforcing the recognition of historical structures as tangible witnesses of the past.

The Roman cisterns, which constitute the foundational substructures of the current Regional Theatre, consist of

seven compartments. These compartments are constructed using load-bearing masonry walls made from stone (Figure 3).

The vault construction system employed during the Roman period represented a significant architectural innovation. It enabled the development of larger and more complex structures through the use of the arch—a curved form capable of efficiently distributing heavy loads.

Roman builders commonly used brick and Roman concrete, a highly durable composite material composed of lime, sand, gravel, and stone fragments. In this particular case, the vaults are of the barrel vault type—a continuous, semi-cylindrical structure made of brick, characteristic of Roman engineering.

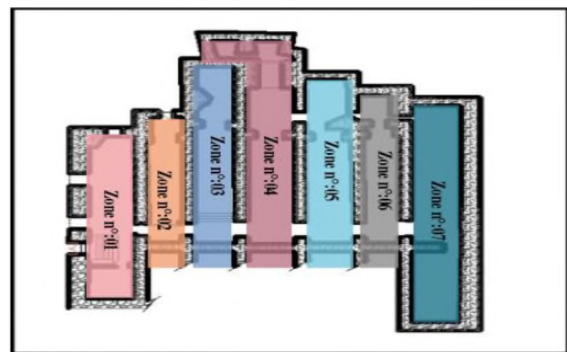


Figure. 2 Plan view showing the seven component sections of the vault system.

2.3 Historical Background

Many public buildings constructed during the colonial era were built upon substructures or foundations originating from Roman-era edifices. Among these is the Municipal Theatre, erected on the regular small-stone masonry substructures of the Temple of Venus. This temple itself was built over a complex of Roman cisterns, which constitute the primary subject of the present study.

3. CONSERVATION STATE AND DIAGNOSTIC ANALYSIS

An on-site inspection was conducted to assess the current condition of the Roman cistern structures. The initial phase of the study involved the development of detailed graphical and metric documentation, based on a comprehensive architectural survey of the vaults, both interior and exterior. This documentation was carried out using precise instruments and appropriate surveying equipment—particularly essential given the numerous constraints and limited accessibility encountered on site.

A damage-mapping campaign was then performed to systematically identify and locate visible pathologies throughout the structure. This process enabled clear visualization of degradation types, such as structural cracks and areas affected by moisture.

Each observed pathology was classified and coded using standardized color schemes and symbolic notations, in accordance with best practices in structural diagnostics. This visual coding system facilitates both the interpretation and communication of findings among specialists.

The primary objective of this diagnostic phase was to evaluate the nature, extent, and probable causes of deterioration, in order to propose appropriate restoration measures. Emphasis was placed on preserving the architectural and structural integrity of the cistern system while ensuring long-term durability.

The following major forms of deterioration were recorded during the survey:

- Cracking in the masonry vaults and walls (Figure 3).
- Moisture infiltration and humidity-related damage (Figure 4).

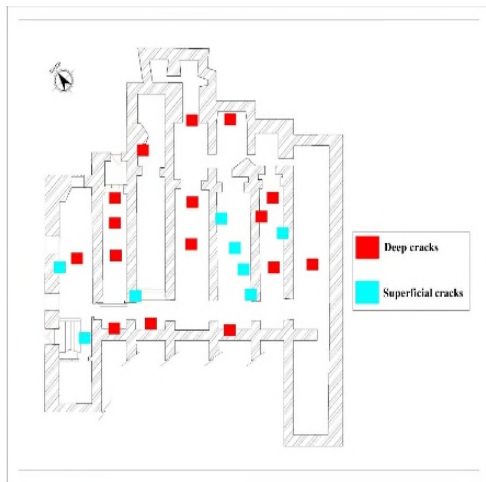


Figure. 3 Mapped Structural Pathologies – Cracking

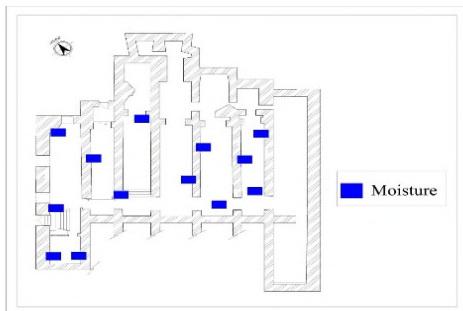


Figure. 4 Moisture Pathology Map – Identification of Humidity-Affected Zones.

4. TREATMENT OF DEGRADATION IN ANCIENT ROMAN CISTERNS

Following the diagnostic phase, it was observed that the structure is affected by a range of adverse phenomena that compromise the building’s functionality and occupant comfort. These issues necessitate permanent repair

interventions aimed at restoring structural integrity and enhancing the comfort levels required for the building’s intended use.

4.1 Crack Treatments

Significant cracking was observed across multiple interior wall segments (Figure 5).

For the treatment of oblique and linear cracks on the interior walls, the following measures are recommended:

- Filling the cracks in the affected walls using appropriate repair materials.
- Reconstructing severely deteriorated sections to restore structural integrity.
- Eliminating sources of rainwater infiltration to prevent further damage and moisture-related issues.



Figure. 5 Crack observed on the interior wall.

4.2 Treatment of Black Mold

Black mold was observed on the vault surface (Figure 6). The recommended treatment procedure includes:

- Washing the affected areas with a suitable façade cleaner, followed by thorough rinsing.
- Applying a fungicidal treatment to eliminate mold spores and prevent recurrence.
- Coating the surface with an acrylic insulating paint to protect against moisture penetration and future biological growth.



Figure. 6 Black mold growth on the vault surface.

4.3 Moisture treatment

Moisture-related deterioration is evident on the vaults and walls, characterized by visible moisture stains (Figure 7). The remediation measures include:

- Partial replacement of stones or bricks exhibiting significant damage.
- Identification and elimination of all sources of water infiltration to prevent recurrence [9], [10].



Figure. 7 Moisture stains on vaults and walls.

4.4 Treatment of Interior Finishes

Figure 8 illustrates the condition of the interior finishes. The treatment procedure includes:

- Removal of existing overlays, followed by excavation down to the desired floor level.
- Installation of a new stone flooring finish.



Figure. 8 Condition of the interior finishes.

4.5 Carpentry Works Treatment

Figure 9 shows the deteriorated state of the carpentry elements. The proposed treatment includes:

- Replacement of damaged doors and windows.
- Installation of new doors in accordance with the proposed layout plan.
- Repainting of severely deteriorated metal elements using moisture- and corrosion-resistant paint.



Figure. 9 Damaged carpentry elements.

4.6 Wall Treatment

As illustrated in Figure 10, the masonry walls exhibit signs of stone deterioration. The proposed restoration procedure comprises the following actions:

- Material Condition Survey: Conduct a detailed assessment to identify various forms of degradation, including cracks, surface erosion, biological colonization

(such as moss or algae), and general soiling.

- Non-Aggressive Cleaning: Perform gentle surface cleaning using soft-bristle brushes or low-pressure water systems to remove contaminants without altering or damaging the original stone texture.
- Structural Consolidation and Surface Repair: Stabilize weakened zones through appropriate methods. This may include resin injection to improve internal cohesion or the application of compatible repair mortars to seal cracks. Severely degraded stone elements can be reconstituted using specialized stone patching techniques [11], [12].
- Selective Replacement: Elements that are too deteriorated to be salvaged should be replaced using

materials that are physically and aesthetically compatible with the original masonry, in order to preserve structural integrity and visual coherence [13], [14].

- **Protective Finishing:** Apply a breathable hydrophobic treatment or protective coating to enhance durability and water resistance, ensuring moisture vapor can still escape from the masonry to prevent internal condensation or decay.



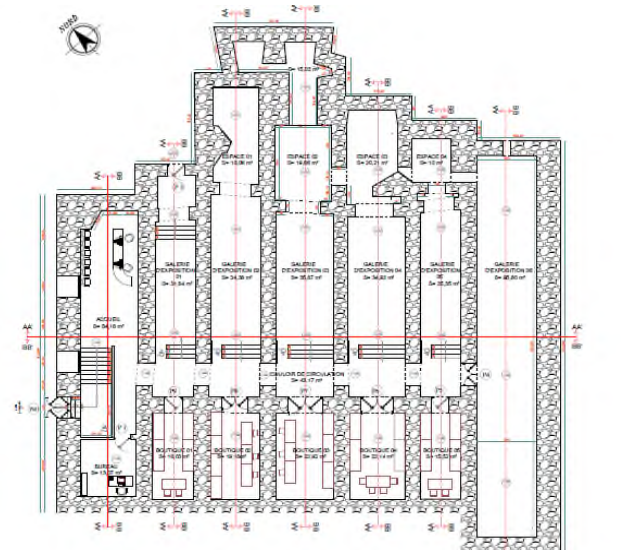
Figure. 10 Degraded masonry observed on wall surfaces.

5. INTERVENTION ON THE BUILDING

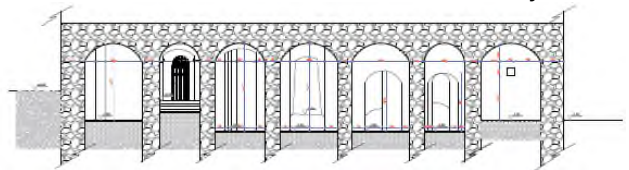
The objective of this intervention is to repurpose the space, transforming its original function as Roman cisterns into a contemporary art gallery. The proposed works include the following components:

5.1 Spatial Reconfiguration

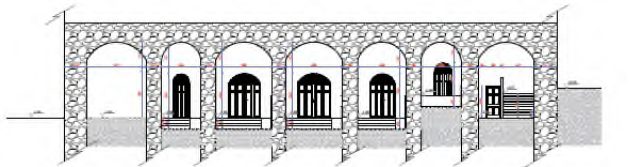
- Conversion of the vaulted spaces into exhibition galleries [15].
- Allocation of dedicated areas for creative workshops.
- Extension of the vaults to incorporate new art retail spaces (Art Shops) (Figure 11).



Plan View – Cisterns Converted into Gallery



Section AA – Modified



Section BB – Modified

Figure. 11 Roman Cisterns Converted into Art Gallery

5.2 Façade Intervention

The façade in question is located to the right of the theater’s main entrance and shares a service courtyard with the adjacent courthouse, providing vehicular access for service vehicles and delivery vans. The façade is composed of two levels: upper and lower. The lower level includes two main access points: one leading to the library, and the other providing entry to the theater’s basement level, where the Roman cisterns are located (Figure 12).

Given that this façade mirrors that of the theater’s garden side, the proposal includes the addition of architectural details aimed at enhancing its visual quality and clearly marking the entrance to the new art gallery (Figure 13).

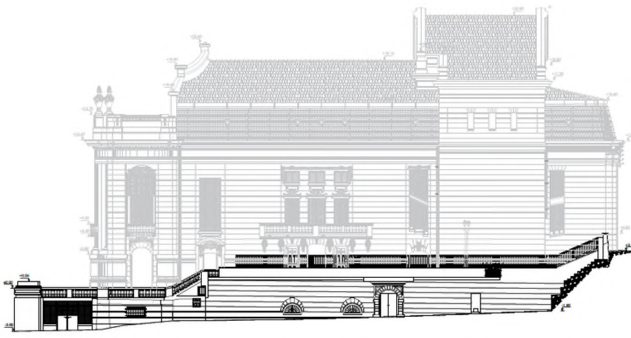


Figure. 12 Upgraded Main Façade

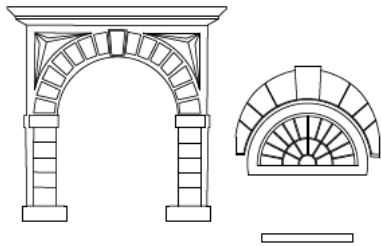


Figure. 13 Façade Detail

5.3 Fenestration Modifications

The existing woodwork should be replaced with glazed doors to improve visual permeability and optimize daylight penetration. Incorporating glass elements enhances spatial continuity between interior and exterior environments, thereby increasing natural illumination levels. This intervention not only contributes to the architectural clarity of the design but also improves energy performance by reducing reliance on artificial lighting and fostering a brighter, more open spatial experience.

6. CONCLUSIONS

The detailed study conducted in accordance with established standards has led to the identification of the following key findings:

- The Roman cisterns exhibit persistently high levels of moisture.
- The structure shows the presence of both superficial and deep cracks within the cistern walls.
- All restoration and intervention works must be carried out with full respect for the original materials and architectural character of the building, ensuring minimal intrusion and reversibility wherever possible.
- Converting a historic space into an art gallery requires a careful balance between heritage preservation and the functional and spatial needs of a contemporary cultural venue. This transformation creates a unique setting where history and modernity converge to elevate the experience of art.

- Adequate environmental controls must be implemented to mitigate moisture-related risks and preserve both the structure and the artworks housed within the gallery.
- Structural reinforcements should prioritize non-invasive techniques that maintain the integrity of the original fabric.
- Accessibility improvements must be sensitively integrated to ensure inclusivity without compromising the building's historic value.
- Ongoing monitoring and maintenance are essential to address emerging issues promptly and extend the lifespan of the restored site.
- Stakeholder collaboration—including conservation specialists, architects, and cultural managers—is critical to the successful adaptive reuse of the cisterns.

While this study provides a comprehensive assessment of the physical state and potential adaptive reuse of the Roman cisterns, it is important to acknowledge certain limitations. The investigation was constrained by the accessibility of some cistern sections, potentially limiting the full assessment of structural integrity and moisture conditions. Moreover, climatic variations over time may influence moisture levels and structural behavior beyond the study period.

Despite these constraints, the methodology and findings offer a valuable framework that can be adapted and replicated for the conservation and reuse of similar Roman subterranean structures elsewhere. This contributes to the broader field of heritage conservation by demonstrating how historic engineering works can be sensitively transformed to serve modern cultural purposes. Future research should focus on long-term monitoring of environmental conditions and structural behavior post-intervention to evaluate the effectiveness of the restoration strategies. Additionally, developing innovative materials and techniques tailored for subterranean heritage sites could enhance durability and sustainability. Further interdisciplinary studies combining architectural conservation, environmental science, and cultural management are recommended to optimize the balance between preservation and adaptive reuse.

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