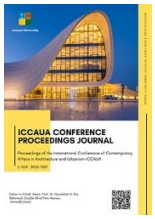

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Resilience Strategies of Ottoman Architecture between the 15th and 16th Centuries. Case Study of the Restoration of the Columns at the Bardo National Museum in Algiers

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A b s t r a c t

This article examines the intersection of cultural and architectural history in Algeria during the Ottoman period, with the Bardo Museum in Algiers as a key example. The National Bardo Museum is a significant symbol of Algeria's cultural and historical identity, having undergone various architectural changes that mirror the evolution of Algerian society and culture. Notable features, such as the architraves and columns, serve as silent witnesses to the nation's turbulent history. Restoring these elements is vital for preserving this unique heritage and ensuring its legacy for future generations. This research aims to deepen understanding of professional practices related to both material and immaterial heritage restoration. Specifically, it examines the restoration process of the museum's architraves and columns, detailing the methodologies employed, the challenges faced, and the outcomes achieved throughout the restoration efforts.

K e y w o r d s : Column, Heritage, Restoration, The Bardo Museum of Algiers.

1. Introduction:

1.1 The Bardo, a restoration project

The restoration project of the Bardo National Museum marks the Ministry of Culture's commitment to promoting the preservation of tangible and intangible heritage. The Bardo National Museum has been listed as a historic monument since 1985. It was completely closed to visitors in 2010, when work on the lower part of the monument began. The Bardo Museum features a remarkable decoration characterized by its enameled ceramics, as well as outdoor spaces with the presence of columns and busts with Tuscan columns from the Ottoman era, in addition to its splendid mural decorations adorning the domes, decorations and various wall spaces.

The Bardo Palace presents two types of columns depending on their size and morphology. In the first portico, there are columns made of very porous calcareous tuffeau stone with a creamy yellowish color, approximately 1.70 m high, supporting arches from the era of the caliphs, which feature bands decorated with enameled ceramics. The columns made with a semi-bust stereotomy, with a hexagonal lower elaboration, present a series of deteriorations, which require an intervention based on a reintegration of volume as well as the elimination of additions that must be replaced by other structures more suitable for architectural restoration.

The preservation of tuffeau has been one of the major interventions in the restoration. The columns and doorways dating from the 15th and 16th centuries are indeed subject to a stone disease, "scaling in plates": more permeable than their granite and stone neighbors, they have indeed deteriorated more quickly. The restoration operation launched by the management of the Bardo National Museum is intended on the one hand to develop protection methods, and on the other hand to improve and restore the stone elements to their potential unity, in cases where they have been lost or damaged by reinsertion operations, cleaning, removal of harmful added elements, producing negative effects on the physical or aesthetic masterpiece.

The tufa columns and door frames underwent a meticulous restoration, entrusted to an Algerian-Spanish company (Restaur-arte) specialized in monument restoration. The restoration aims to improve the stone elements and restore their potential, in cases where they have been damaged or lost, through reintegration operations, cleaning, and the

removal of harmful elements that were added in previous interventions, in order to mitigate any negative effects on the physical or aesthetic integrity of the work. This operation was carried out with the participation of an in-house museum team composed of archaeologists and architects that I represented.

1.2 The Bardo: an emblematic architectural heritage in a charged historical context

The Bardo National Museum (المتحف الوطني باردو), located at the top of the main boulevard in downtown Algiers, Didouche Mourad Boulevard (formerly Rue Michelet), overlooking the Ghermoul and Mustapha Pacha Hospital neighborhoods, is an Algerian museum. It was previously simply called the "Bardo Museum" before taking its current name in 1985.

The palace that houses the museum, called a "Djenane", was reportedly built in the late 18th century by a wealthy Tunisian exile, Hadj Ben Omar, to serve as a summer residence and host notable figures of the time.

In 1879, its last owner added an extension, a Frenchman named Joret, which was meant to serve as stables and outbuildings. Today, this historic building houses the exceptional collections of the Bardo National Museum, making this cultural institution one of the most important in Algeria.

The palace was constructed on two floors (Figure 1), above vast vaulted halls lit by small dormers. The exterior architecture was typical of the traditional Algiers style, with façade offsets and powerful buttresses supporting the tall walls. These featured a few rare rectangular windows, secured by bars. According to E. VALLOIS, 1951: "the Bardo Palace has a vast courtyard, the two entrances face each other, the galleries are arranged according to the same principle. Vegetation is present in reference to the cosmetic paradise, even the ceramic wall coverings of the facades are inspired by the floral register."

Figure 1. The Marble Courtyard (www.museebardo.dz).

This description highlights the architectural characteristics of the palace, namely its organization on two levels, its vaulted and sparingly lit interior spaces, as well as its exterior appearance marked by the local architectural style with its projections and massive buttresses. Life revolved around the beautiful interior "Moorish courtyard". The walls of this inner courtyard were paneled up to about a meter and a half high with magnificent tiles that rivaled the beauty of the black and white marble, as well as the ochre of the eight-tufa columns.

Among these columns, the shafts of the corner columns were twisted, while the others were octagonal in shape. This refined architectural arrangement, combining noble materials and elaborate forms, attests to the high standard of this aristocratic residence.

As for the exterior facades of the palace, they present a more defensive style, with powerful stonewalls pierced by rare and narrow windows. Massive buttresses that follow the different volumes of the building reinforce these walls. Thus, the interior architecture of the palace combines highly refined decorative elements with a more austere exterior envelope, reflecting the dual residential and representative functions of this aristocratic residence.

The lower courtyard is paved with marble, and in the middle rises a basin just in front of the ogival doorway. Two floors of beautiful tiled rooms, an interior walkway, a Hamman and a large terrace.

To access the patio, one had to climb the splendid honor staircase of the main entrance, steps of black slate, walls enameled with geometric patterns, ceiling decorated with cedar beams, before stopping on a small landing, closed by a massive carved cedar door.

The restoration of the columns at the Bardo National Museum provides a valuable case study for examining resilience strategies in Ottoman architecture. This analysis raises several important questions: How does the restoration of the columns illustrate the principles of resilience in Ottoman architecture? What materials were traditionally used in this architectural style, and how did they contribute to the longevity of structures? Additionally, how have modern restoration interventions integrated or modified traditional Ottoman construction techniques? Understanding the

lessons learned from the Bardo restoration can inform future conservation projects within the realm of historical architecture. Furthermore, how did the interaction between local cultural influences and Ottoman practices shape resilience strategies during this period? It is also crucial to explore the specific challenges encountered during the restoration of the columns and how these challenges were overcome. Finally, how can the resilience strategies of Ottoman architecture inform contemporary conservation and restoration practices? This study ultimately contributes to our understanding of the cultural and historical dynamics of the region.

It can be hypothesized that this restoration illustrates resilience by employing traditional techniques that prioritize both structural integrity and aesthetic continuity, reflecting the adaptive strategies used by Ottoman builders to withstand various environmental and cultural changes. Traditionally, materials such as limestone, marble, and specific types of mortar contributed to the longevity of these structures due to their availability, thermal properties, and resistance to weathering. Furthermore, modern restoration interventions likely integrated traditional techniques with contemporary materials that mimic original properties while enhancing structural performance, thereby bridging the gap between historical authenticity and modern engineering practices.

Lessons learned from the Bardo restoration may emphasize the importance of thorough historical research and community involvement, suggesting that successful conservation requires a balance between preserving historical integrity and adapting to current needs. The interaction between local cultural influences and Ottoman practices likely led to a hybrid architectural style that incorporated local materials and techniques, enhancing structural resilience by making buildings more suited to their specific environmental and cultural contexts. Specific challenges encountered during the restoration, such as structural instability and material degradation, were likely overcome through innovative engineering solutions and advanced materials that complemented traditional methods without compromising authenticity.

Additionally, the resilience strategies of Ottoman architecture can inform contemporary conservation practices by highlighting the significance of sustainable materials, adaptive reuse, and the integration of traditional techniques with modern technology. Ultimately, studying Ottoman architectural resilience contributes to a deeper understanding of the socio-political and cultural dynamics of the region, revealing how architecture served as a means of expressing identity, power, and adaptability in the face of changing circumstances.

The main objectives for this research are:

- **To Assess the Impact of Traditional Materials**: Evaluate how the use of traditional materials and techniques in the restoration contributes to the architectural resilience of the columns, ensuring their preservation against environmental challenges.
- **To Analyze the Effect on Historical Integrity**: Investigate whether the integration of authenticity and historical integrity in the restoration process enhances the overall cultural significance of the columns at the National Museum of Bardo.
- **To Evaluate Restoration Techniques**: Analyze the specific restoration techniques used for the tuff columns and assess their effectiveness in mitigating current degradation and addressing future risks.
- **To Measure Visitor Engagement**: Examine how the restoration of the tuff columns influences visitor appreciation and understanding of the cultural heritage, thereby fostering a stronger connection to the museum's historical narrative.

2. Material and Methods

The methodology adopted for this study primarily involved a qualitative approach. This included a thorough documentary analysis, where reports on the restoration, academic articles, and publications related to architectural heritage were examined. Additionally, semi-structured interviews were conducted with restorers and conservation experts to gather insights on their experiences and methodologies. Specific case studies of interventions carried out on the columns were also analyzed to provide context and depth to the findings.

Data collection involved field observations through visits to the museum, allowing for direct observation of the ongoing restoration techniques. Furthermore, questionnaires were distributed to visitors to collect data on their perceptions of the heritage and the effectiveness of the restoration efforts. This combination of qualitative methods aimed to provide a comprehensive understanding of both the technical aspects of restoration and the public's engagement with the cultural heritage.

The restoration team creates detailed graphic documentation in order to develop a comprehensive mapping of the various interventions, before, during, and after the implementation of the works. This approach allows for the identification and tracking of the history of actions taken on the structure, which is essential for its long-term monitoring and preservation. Similarly, a complete dossier is established, reflecting the entire process. It includes a detailed description of the operations, tests, and inspection methods used to identify the origin of the damage. This documentation compiles the conclusions drawn from the various analyses, such as samples and visual observations in hard-to-access areas.

All this constructive and morphological information, as well as the structural aspects, are recorded in a way that constitutes a comprehensive reference for future stakeholders.

The study began with a thorough examination of the conservation condition of the tuffeau columns in the museum. The main analysis techniques used were:

- 3D photogrammetric surveys to precisely map the damage and deformations of the columns

- Petrographic analyses in the laboratory to identify the mineralogical composition and alterations of the stone
- In-situ tests of mechanical resistance and porosity to evaluate the fragility of the material
- These in-depth analyses allowed the identification of the main degradation mechanisms affecting the tuffeau columns. Specifically, flaking in plates and powdering were identified as severely weakening certain columns.

This detailed understanding of the material pathologies was crucial to guide the most appropriate restoration interventions, aimed at stabilizing and preserving these emblematic architectural elements of the Bardo Museum.
The main success criteria used to evaluate the effectiveness and quality of the restoration of the columns and door frames at the Bardo National Museum are:

- Compliance with international standards for heritage conservation
- Respect for the fundamental principles of the Venice Charter on the conservation and restoration of historic monuments
- Application of best practices recommended by ICOMOS (International Council on Monuments and Sites)
- Use of restoration materials and techniques compatible with the nature of the original materials
- Respecting these criteria makes it possible to guarantee the quality and sustainability of the restoration, while ensuring the preservation of the historical and cultural integrity of the Bardo National Museum.

3. Results and Discussions

3.1. Restoration Approach: Presentation of Key Findings

3.1.1. The causes of stone deterioration

Deterioration symptoms arise from human, chemical, physical, mechanical, or biological factors. We can consider these factors as natural, and the changes in the stones under their influence represent a normal aging process. Their effects remain permanent, but it is important to emphasize that both their intensity and the processes of stone deterioration increase over time.
The main factors in the deterioration of historic stone monuments are water, temperature variations, and human action, which leads to the need to preserve cultural heritage.
This section addresses the main forms of alteration that have an impact on the architectural appearance, in connection with the ornamental envelopes. We will focus mainly on these types of alterations, without addressing those related to other factors such as the quality of materials, the constraints of modifications, thermal impacts, or structural pathologies.

3.1.1.1. Causes by human action

In this case, the alterations resulting from previous interventions have led to unfortunate consequences, sensitive to variability, which caused increased degradation. These alterations include cleanings with abrasive methods that seriously damaged the material and even removed patinas or protective layers from earlier periods.
These interventions involved testing gaps to assess the state of alteration, resulting in a gradual aesthetic change in the stone. Additionally, using Portland cements with the incorporation of mineral earths has contributed to this issue.

3.1.1.2. Loss of intergranular cohesion

The cracking of the material, caused by "umbrella" type micro-phenomena, contributes to the loss of intergranular cohesion. This loss leads to the progressive release of the minerals that make up the support, either spontaneously or due to mechanical stresses.

3.1.1.3. Application of paints on architectural stone

In this case, we are referring to the widespread application of paints on architectural stone supports. Although this intervention may be perceived as a measure of protection and embellishment, it is in fact highly debatable.
Indeed, these paints are often very recent additions, devoid of any sufficiently relevant historical value to justify their restoration.
From an aesthetic point of view, these paints generally have a poor quality appearance.
Furthermore, the presence of different layers of paint, with variable thicknesses and uneven degrees of conservation, makes their appearance heterogeneous and inharmonious. Overall, the application of these paints on architectural stone raises questions about their relevance, both historically and aesthetically, with regard to the conservation of heritage.

3.1.2. Strengthening and consolidation measures for the columns

3.1.2.1. Consolidation of the structure

Restoring the columns required specific technical skills. A conservator supervised the process and first conducted an in-depth diagnosis of the pathologies affecting these elements to define the appropriate criteria and methods for their restoration. During the restoration work at the Bardo Palace, the team identified structural disorders. The columns of the patio of the Bardo Palace were in a very worrying state of conservation, victims of the ravages of time and past neglect.

The signs of deterioration were evident: deep cracks, deformation of the column system Image 8, erosion of the stone, discoloration due to air pollution, as well as significant accumulations of dirt over the decades. Although these damages were foreseeable given the age of the architectural elements, they required urgent intervention. The aim was indeed to avoid irreversible degradation and to preserve the artistic and historical integrity of these columns.
To remedy this, a bracing operation was carried out. This consisted of relieving the load on the columns, in order to be able to realign the entire load-bearing structure vertically and perfectly plumb.

3.1.2.2. Surface Consolidation

The surface consolidation carried out by Restaur-ARTE on the material has improved the cohesion of the grains and the preservation of this cohesion. To do this, the company used a siliceous consolidant-based component, applied using soft brushes to facilitate its penetration into the rock.
As a product developed by Restaur-ARTE for siliceous rocks, a compound of ethyl silicic acid esters dissolved in white spirit was applied in order to obtain the optimal degree of absorption in the heart of the stone. The gel formed thanks to the strong chemical bond produced on the treated surface confers new mechanical properties based on silica.
Studies carried out in collaboration with the Department of Materials Engineering at the University of Trento have made it possible to verify that the Estel 1100 consolidant meets the following requirements:

- A sample of 1100 ESTEL products solidified after 28 days was analyzed using a Cambridge Stereoscan electron microscope (Photo D/1).
- The photomicrograph reproduced here shows clear cracking of the material.

The electron microscope examination made it possible to observe in more detail the internal structure of the consolidated ESTEL 1100 sample after 28 days.
Beyond the clearly visible cracks in the previous micrograph, the analysis also reveals the presence of microcracks and weak zones in the material matrix. This suggests that the consolidation process did not allow for homogeneous and stable cohesion within the sample. Areas of decohesion and delamination between the different components of the consolidant are notable. This raises questions about the sustainability and long-term performance of this product when applied to mineral surfaces.
These microscopic observations highlight structural weaknesses that could result in lower mechanical strength and poorer long-term adhesion of the consolidant. Further tests would be necessary to more accurately assess the performance and durability of this product under real-use conditions.

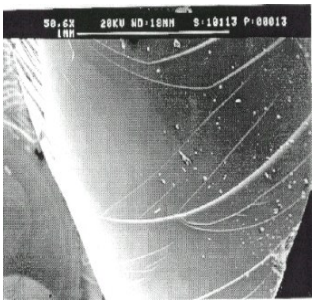

Figure 2. Scanning electron microscope (SEM) micrograph, 50.6x. (E, Javier, 2012).

This result indicates that the consolidating product, when applied in excess beyond the amount that can penetrate the support, can be easily removed from the surface in the form of powder, probably by simple blowing or brushing. This is a typical characteristic of solidified products obtained from silicic esters, after hydrolysis and subsequent condensation.
This phenomenon is related to the surface tension between the consolidated material and the support (5.6). The presence of these surface stresses is remarkably reduced when the thickness of the solidified gel is low. In this case, thanks to a modulus of elasticity much lower than that of the consolidated material (= 5GPa) and a strong chemical bond between the gel and the support, the gel is able to withstand small deformations of the structure, thus exerting a significant consolidating agent action.
Finally, the simultaneous presence of hydrophobic siloxane gel units in the polymer chain makes it possible to obtain an effective water-repellent treatment, protecting the surfaces against the action of atmospheric agents.

3.2. Techniques and intervention

The Wast Al-Dar (patio) level is surrounded by eight (08) twisted columns, and semi-twisted columns (Figure 3). This type of column has a low octagonal base that allows the maintenance of the woodwork of the balustrade.

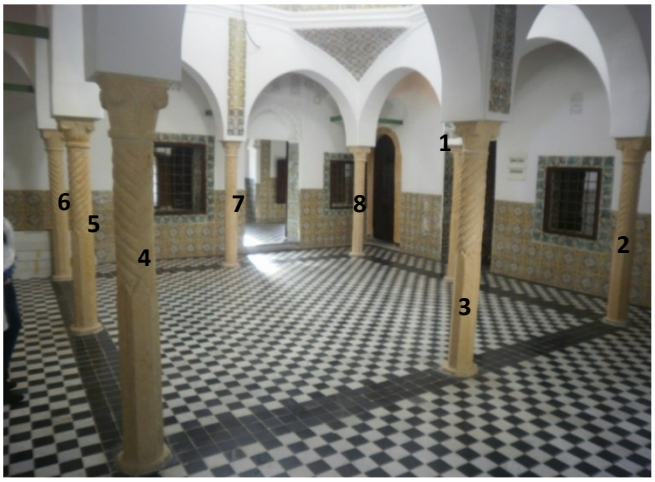

Figure 1.The eight columns of the patio intended for restoration (Bardo Museum, 2012).

The restoration technique used for these interventions is extremely homogeneous, which makes it possible to postulate that they belong to a single repair phase.
The principle of the treatment is to give the altered superficial part of the stone a cohesion equivalent to that of its unaltered part in depth. The treatment of the patio columns is carried out in situ.
A diagnosis is also essential to determine the main properties of the column and its state of degradation: depth, nature of the degradation (micro-cracking, granular disintegration, etc.). This diagnosis made it possible to adjust the treatment more precisely (depth of penetration, amount of product, type of product, etc.). The diagnosis of the alterations at the scale of the columns and the material was carried out upstream, as part of a preliminary study that also made it possible to study the feasibility of the treatment, its effectiveness, as well as its effect on the other properties of the stone necessary for its conservation.
Before applying a consolidation treatment, it was necessary to answer certain general questions:

- Is it necessary to consider consolidation (what is the desired goal)?
- What are the properties of the material that we want to consolidate?
- What are the causes of its degradation? Do we have the means to eliminate these causes?
- How to apply the treatment? What product to select? What consumption to choose so that the treatment is as effective and durable as possible?
- What methods are likely to control the effects of the treatment?
- What will be the durability of the treatment? When will the stone need to be retreated?

3.2.1. Cleaning the tuff elements.

This first phase consisted in deeply cleaning the columns made of tuff stone, in order to prepare them for the following steps of the restoration. The techniques used were carefully selected for their ability to delicately remove the various deposits and dirt accumulated on these fragile architectural elements, without damaging them. Different types of cleaning were necessary to give the columns their original appearance and balance.

3.2.1.1. Removal of deposits using brushes or suction (Dry cleaning)

Starting with a dry cleaning type, with soft hair brushes and controlled suction to eliminate surface dust. This initial step was applied to all eight (08) columns taken care of.
This phase consisted in using two complementary methods to gently remove the accumulated deposits on the surfaces of the tuff columns:

- Brushing using soft brushes made it possible to mechanically remove part of the deposits Image 4.
- Controlled suction complemented this work by capturing the residual particles, without exerting excessive pressure on the stone.

These techniques, applied with care, have optimally prepared the surfaces for the next steps in the process of restoring the architectural elements in tuff.

Figure 4. Use of the soft brush and the vacuum cleaner (column 1) (Bardo Museum).

3.1.2.2. Removal of deposits using steel brushes (Mechanical cleaning)

Steel brushes can only move aside thin layers of dirt and impurities, loosely packed deposits and encrustations. With a soft brush, we move aside, with the deposits, the thin layer of stone to which they are strongly adhered, or we tear them off, revealing the powdery inner parts of the stone. Other instruments are also used to remove concretions and mortar remains on the ceramic support, such as scalpels (Figure 6), vibro-incisors (Figure 7), microtones, fiberglass pencils, etc.

The use of these mechanical cleaning methods has proven effective in deeply cleaning these delicate architectural details in tuff. This made it possible to optimally prepare their surfaces for the following steps of the overall restoration process. This meticulous preparatory phase was therefore essential to ensure the success of the overall restoration of the columns and frames, while preserving their integrity. The expertise and knowledge of the team made it possible to obtain remarkable results at this key stage of the process.

Figure 6. Use of scalpels (column 5).

3.1.2.3. Removal of damage using organic solvents

The physicochemical and chemical methods of removing deposits involve the use of chemical compounds acting by dilation or dissolution of the deposits, as well as by chemical transformation. The chemical methods are based on the chemical reactions that occur between the substances used and the components of the deposits or the stone.

An experimental treatment of a strongly degraded tufa stone by exfoliation. Carried out with a spray bottle, the treatment corresponds to the application of a solvent-phase water-repellent, harmful by inhalation, which justifies special precautions during application (mask).

After the initial cleaning of the surface dust, the restoration team proceeded to remove the more significant damage using appropriate organic solvents. This method makes it possible to gently dissolve and extract the altered or damaged areas, without further damaging the fragile tufa stone. The controlled use of these solvents is an essential tool for restoring the original condition of the architectural elements while preserving their integrity.

The expertise and precautions taken by the restoration team were crucial to successfully carrying out this delicate step, while avoiding any further damage to the tufa surfaces.

3.2.2. Consolidation treatments applied to the tufa stone columns

3.2.2.1 Properties of the resins used for the conservation of the column stone

The resins used for the conservation of the stone depend on the type of action one wants to perform on the stone object. In general, resins are used for the following functions: consolidation, bonding, filling of stone losses and hydrophilization. The cleaning was mainly done by micro-abrasion, which consists of projecting a very fine powder

using a compressor, in order to remove the soot film. Poultices and laser are two other techniques used on the sculptural parts.
This phase of the restoration process involved the application of resins specifically formulated for the conservation of tufa stone elements, such as columns and frames. The selected resins had particular properties that made them suitable for this type of intervention:
• Compatibility with tufa stone, avoiding any risk of incompatibility or damage
• Ability to penetrate deeply into the porous structure of the stone
• Long-term stability to ensure durable consolidation
• Transparency and aesthetic appearance preserving the original appearance
The careful application of these resins has made it possible to gently consolidate the architectural elements while maintaining their aesthetic and structural qualities. This treatment played an essential role in the long-term preservation of these tufa heritage details.

Figure 7. The loss of stone at the level of columns 5, 6 and 7.

3.2.2.2. Reinsertion and restitution of the stone
The work carried out involved a series of volumes of ornaments and restitution materials to maintain the same characteristics as the original building materials. In case of restitution of the stone, the coping and the bases of the jambs were made with stones of the same origin, in this case Tuba stone.
The reconstructions of the material have become more effective on the disconnected material, with the formation of voids or significant losses. The reintegration operations involved:
• The extraction of the eroded part to reach a sound substrate
• The cleaning of the previously well-defined areas to remove the adhering dust
• The insertion, in some cases, of stainless steel cores or fiberglass rods for bonding with an epoxy resin.
The team filled the joint surfaces with lime mortars and then applied an appropriate chromatic treatment, considering the previous interventions to achieve a base color that could be modified later.

Figure 8. Insertion of stainless steel cores (columns 1-5 and 7).
By wetting the treated surfaces with water, a white superficial veil is revealed, betraying the presence of the resin on the surface. These irreversible disorders are attributed to a "product return" phenomenon, due to uncontrolled environmental conditions and a lack of protection of the surfaces during the days following the treatment.

3.2.2.3. Properties of the mortars used for the conservation of the column stone
The choice of mortars was paramount to ensure the compatibility and durability of the consolidation of the columns. The specialists selected mineral formulations specifically adapted to the nature of the tuff, thus avoiding any risk of adverse chemical reaction or incompatibility with the stone.

These mortars had a fine grain size allowing them to penetrate deeply into the porous and cracked structure of the columns. This ensured a solid and lasting consolidation of the entire stone, and not just the surface. On a mechanical level, the chosen mortars offered high resistance, while retaining a certain flexibility.
This property was essential to accompany the natural movements and slight deformations of the stone, without risking further weakening of the columns.
Finally, the selected mortars were permeable to air and water, thus allowing good breathability of the stone and avoiding any risk of moisture trapping, a potential source of future deterioration.
The team filled the already articulated surfaces with lime mortars and then applied an appropriate chromatic treatment, considering previous interventions to achieve a base color that could be modified later.
The meticulous and controlled application of these consolidation mortars has thus made it possible to restore the full solidity of the tuff columns, while preserving their original characteristics. This treatment played a decisive role in the long-term stabilization of these heritage architectural elements.
The evaluation of the authenticity of the restored tuff columns at the National Museum of Bardo revealed that the materials used for the interventions strictly adhered to those of the original columns. Geotechnical analyses confirmed that the restored tuff came from a geological source similar to that of the historical columns, thus ensuring material continuity. Additionally, the construction techniques applied during the restoration respected traditional methods, as evidenced by the photographic documentation and reports from the artisans involved. Aesthetic fidelity was also maintained, with precise reproduction of the carved motifs, corroborated by comparisons with historical photographs. This attention to detail and choice of materials helped preserve the authenticity of the columns, thereby enhancing their heritage value.
The historical integrity of the tuff columns was carefully preserved throughout the restoration process. Results indicate that the columns were reintegrated into their original environment in a way that respected the museum's historical configuration. Adjacent elements, such as bases and capitals, were also restored or conserved, contributing to the maintenance of architectural harmony. Analysis of historical archives revealed that the interventions respected the original context of the columns, supported by old plans and descriptions. By preserving not only the columns themselves but also their architectural context, the restoration successfully maintained historical integrity, allowing for a better understanding of the Ottoman heritage.
The interpretation of the results obtained highlights the effectiveness of the restoration of the tuff columns in terms of authenticity and historical integrity. The use of original materials and traditional techniques allowed for the preservation of the columns' heritage value while respecting their history. These results confirm that thoughtful and respectful interventions can strengthen cultural identity and appreciation of heritage within the community. Furthermore, the engagement of skilled artisans was crucial to achieving these goals, illustrating the importance of passing down traditional knowledge. The findings also show that the restoration can serve as a model for other similar projects, emphasizing the significance of authenticity and integrity in the conservation of architectural heritage.

4. Perspectives and Challenges of the Restoration of the Columns at the National Museum of Bardo

4.1. Significance and Impact of the Restoration

The restoration of the columns at the Bardo National Museum carries significant implications for both cultural heritage preservation and architectural practice. Successfully restoring these historical elements not only enhances the aesthetic value of the museum but also reinforces the importance of maintaining cultural identity. By employing traditional techniques alongside modern conservation methods, the project sets a benchmark for future restorations, emphasizing the need for a balanced approach that respects historical integrity while ensuring structural stability. This initiative also highlights the role of interdisciplinary collaboration, bringing together conservators, architects, and historians to create a comprehensive strategy for preserving cultural landmarks.

4.2. Pathways for Future Conservation Efforts

Looking ahead, the restoration efforts at the Bardo National Museum can inform future conservation projects across similar historical sites. Continued research into the materials and techniques used will enhance our understanding of effective restoration practices. Additionally, engaging the local community and stakeholders in future projects can foster a deeper appreciation for cultural heritage and encourage sustainable tourism. As the museum continues to evolve, ongoing monitoring and maintenance of restored elements will be essential to safeguard their longevity. Ultimately, the lessons learned from this restoration can guide future initiatives, ensuring that cultural treasures remain vibrant for generations to come.

5. Conclusions

In conclusion, the restoration work carried out on the tuff stone columns in the courtyard of the National Bardo Museum has successfully preserved these architectural heritage elements of great historical and artistic value. Thanks to the expertise and state-of-the-art techniques implemented by the restoration team, each step of the process was carried out with the utmost care, while fully respecting the integrity of the tuff stone.
The meticulous cleaning first revealed the authentic beauty of these columns, gently removing the various dirt accumulated over time. The consolidation treatments by applying specially formulated mortars and the judicious

choice of resins used have then ensured the stability and sustainability of these fragile elements, without altering their original characteristics.

This restoration demonstrates the commitment of the authorities and experts to the safeguarding of Algerian cultural heritage. It also illustrates the importance of expertise and scientific rigor when it comes to preserving architectural elements as precious and fragile as tuff stone columns. However, many questions remain about the future of these restored columns. What monitoring and maintenance measures will be put in place to ensure the sustainability of this restoration?

The National Bardo Museum houses many other architectural treasures in tuff stone, which would undoubtedly deserve similar attention and treatments. What priorities and resources will be allocated to the preservation of this fragile heritage as a whole? How does the National Bardo Museum intend to further enhance these restored columns for the public? What educational or cultural initiatives could allow better understanding and greater appropriation of this heritage by visitors?

These are all questions that underline the importance of continuing efforts and maintaining constant vigilance to ensure the transmission of this exceptional architectural legacy to future generations. The restoration of the tuff columns is only a first step, paving the way for new reflections and new actions for the sustainable preservation of the Bardo Museum's heritage.

The sustainability of this restoration is indeed an essential issue. Beyond the consolidation and protection treatments carried out, regular monitoring and maintenance programs will have to be put in place to ensure that the columns remain in optimal condition. This will involve periodic inspections, preventive maintenance actions and, if necessary, rapid corrective measures in the event of deterioration.

The allocation of sustainable financial and human resources will be crucial to successfully carry out these long-term actions. The Museum authorities will have to ensure that the necessary budgets are allocated and that the required technical skills are maintained within their teams. Beyond these practical considerations, the reflection must also focus on the preservation of the entire tuff stone heritage of the Museum.

A comprehensive mapping of these architectural elements, as well as an assessment of their state of conservation, would make it possible to establish a global and coherent action plan. This plan should prioritize actions based on the identified risks and the historical and cultural importance of each piece. Thus, other restoration projects could be strategically scheduled, building on the lessons learned from this first successful experience.

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