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Modern Technological Approaches to the Preservation of Rock Art: The Zaccar Site in Djelfa in Light of the Spanish Experience

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Astract:
Rock art is one of the most significant material testimonies reflecting the lifestyles and symbolic practices of ancient societies. However, these sites face multiple threats that endanger their survival, whether due to natural factors or human activities. In this context, the preservation of rock art gains considerable importance, particularly with the development of modern technological approaches that provide accurate and effective tools for safeguarding such heritage. This study examines the Zaccar site in Djelfa as a case study, drawing upon the Spanish pioneering experience in the use of digital technologies for documentation and protection. The main research issue addresses how these modern technological approaches can be employed to preserve rock art and ensure its sustainability while maintaining its symbolic and cultural value. The study adopts an analytical-comparative method, relying on archaeological studies, field reports, and specialized publications on cultural heritage preservation

Key words: : Rock Art; Zaccar; Cultural Heritage Preservation; Technological Approaches; Spanish Experience

الملخص:
يعد الفن الصخري أحد أبرز الشواهد المادية التي تعكس أنماط الحياة والممارسات الرمزية للمجتمعات البدائية ، غير أن هذه المواقع تواجه تحديات متعددة تهدد استمراريتها، سواء بفعل العوامل الطبيعية أو الممارسات البشرية. ومن هذا المنطلق، يكتسب موضوع صون الفن الصخري أهمية بالغة في ظل تطور المقاربات التكنولوجية الحديثة التي باتت توفر أدوات دقيقة وفعالة للحفاظ على هذا التراث. يتناول هذا البحث بالدراسة موقع زكار بولاية الجلفة كنموذج تطبيقي، مع الاستفادة من التجربة الإسبانية الرائدة في مجال توظيف التقنيات الرقمية في التوثيق والحماية. تتبنى إشكالية البحث على التساؤل حول كيفية توظيف هذه المقاربات التكنولوجية الحديثة في حفظ الفن الصخري وضمان استدامته مع الحفاظ على قيمته الرمزية والثقافية. اعتمدت الدراسة المنهج التحليلي–المقارن، من خلال تحليل التجربة الإسبانية ومقارنتها بالواقع المحلي، بالاستناد إلى مصادر متنوعة شملت دراسات أثرية وتقارير ميدانية وإصدارات متخصصة في صون التراث الثقافي.

الكلمات المفتاحية: الفن الصخري – زكار– صون التراث الثقافي – المقاربات التكنولوجية – التجربة الإسبانية

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1. INTRODUCTION:

In light of the technological advancements witnessed worldwide today, the preservation of both tangible and intangible cultural heritage has emerged as one of the most pressing challenges facing researchers and institutions concerned with human identity. Rock art stands as one of the most significant civilizational testimonies, reflecting the lifestyles and cultural symbols of ancient societies. It represents an open archive for understanding the earliest stages of humanity and its interaction with the surrounding environment. However, this heritage faces increasing threats due to natural and human factors, such as climatic erosion, human vandalism, and the weakness of protection mechanisms. These challenges necessitate the search for innovative solutions capable of ensuring the safeguarding of such sites. Within this context, the Spanish experience has emerged as a pioneering model in employing modern technology to protect rock art sites, relying on advanced techniques such as 3D modeling, high-resolution laser scanning, multispectral imaging, and drones. These tools have provided unprecedented opportunities for documentation and protection without compromising the originality of the sites.

Accordingly, this research raises its central problematic question: How can the Spanish experience in employing such advanced technologies be utilized to contribute to the preservation of rock art sites in Djelfa Province, particularly the Zaccar site, and ensure the transmission of its cultural value to future generations?

The aim of this study is to highlight the importance of integrating digital technologies into strategies for preserving rock art, while analyzing the extent to which these experiences can be transferred to the Algerian context and evaluating the challenges that may arise in the adaptation process, whether technical, logistical, or institutional. The research will rely on multiple methodologies, including the analytical approach to compare the methods used in the Spanish experience with the realities of Djelfa's sites, the descriptive approach to assess the current preservation status, and the historical approach to understand the civilizational continuity of these sites and their cultural significance. This integrative vision seeks to establish a connection between the deep-rooted past and contemporary technologies...

2. Rock Art: Value and Challenges

Prehistoric rock art refers to engravings or paintings executed on natural rock surfaces dating back to the prehistoric era. It represents one of the earliest forms of

human visual expression and is employed to reveal the symbolic and cultural patterns of societies that existed before the advent of writing.[1]

It is also regarded as a means of communication and documentation among primitive communities, reflecting their social environments and daily practices within a spiritual or ritual framework.[2]

Moreover, it constitutes a fundamental reference for the study of early human heritage, as it provides evidence on the development of artistic representations in ancient humans and the evolution of their symbolic cognition over time.[3]

1.1. Its Place within Cultural Heritage:

Prehistoric rock art is regarded as one of the earliest tangible components of humanity's cultural heritage, as it embodies a collective memory deeply rooted in antiquity and bridges the gap between distant pasts and present cultural identity. It is not merely a set of drawings or engravings on cave walls or exposed rock surfaces, but rather a visual document that stands as a living testimony to the intellectual, religious, and social practices of early societies. This makes it a fundamental part of world heritage that warrants both protection and scholarly investigation.[4]

Its value also lies in its role as a mirror of the earliest symbolic systems employed by humans to interact with their environment and spiritual world. Rock engravings reveal diverse patterns of rituals and practices associated with hunting, fertility, and social relations. Today, they are considered part of humanity's "shared cultural memory," as they do not belong to a single group or region but to the collective heritage of humankind, testifying to the unity of human experience despite environmental and cultural differences[5].

Furthermore, rock art has received increasing recognition from international organizations such as UNESCO, which has categorized it as both tangible and intangible cultural heritage, given its connection to the identities of local communities and its capacity to reflect the spirit of early human creativity. Consequently, safeguarding and documenting this art form is not only a scientific

[1] Clottes, J. (2002). *World Rock Art*. Los Angeles: Getty Publications.
[2] Lewis-Williams, J. D. (1984). "Ideological Continuities in Prehistoric Rock Art: The Case of Southern Africa." *African Archaeological Review*, 2(2), pp. 147-174. Springer.
[3] Whitley, D. S. (1999). *The Archaeology of Rock Art*. Cambridge: Cambridge University Press
[4] Conkey, Margaret, and Christine Hastorf. *The Uses of Style in Archaeology*. Cambridge: Cambridge University Press, 1993
[5] Whitley, David S. Introduction to Rock Art Research. Walnut Creek, CA: Left Coast Press, 2011.

task but also an ethical and legal responsibility towards future generations, as it carries aesthetic, anthropological, and archaeological value simultaneously.[6]

1.2. The Importance of Rock Art in the Zaccar Area of Djelfa

The Djelfa region belongs to the Great Saharan Atlas Mountains, which cover vast areas north of the Sahara, stretching from east to west, and forming a natural barrier between the desert and the Tellian cities. Since ancient times, this barrier constituted a distinctive habitat for prehistoric man, as it provided a suitable environment for settlement before human life trajectories evolved due to climatic changes that forced him to migrate to different places. Consequently, the duration of his stay allowed for the emergence of his art, through which he expressed scenes of his daily life and the details of his existence.



Fig. :01 -02 Rock engravings in the Zaccar area carry rich artistic meanings**.**

Source: Author, personal research

Rock art in the Djelfa region is considered particularly significant, as it documented numerous aspects such as ways of life, the types of animals that prevailed at the time, scenes of hunting, predation, wars, and battles that occurred between primitive human groups, as well as the types of weapons they employed.

The province of Djelfa abounds with a wide system of rock art sites that constitute the general framework in which the Zaccar area is included; around 325 stations distributed across approximately 50 sites have been recorded throughout the province, highlighting the density and temporal as well as spatial diversity of the

[6] Smith, Claire, ed. *Encyclopedia of Global Archaeology*. New York: Springer, 201

visual representations at the scale of the entire region. Within this whole, Zaccar represents one of the most prominent centers, where more than 326 engravings and over 17 paintings have been documented on large rock surfaces such as Hajrat Sidi Boubakr, making it a key documentary hub within the Djelfa network. Zaccar itself is divided into multiple field stations (including Dir Digaouine, Kef Ennacer, and the eastern/western Zaccar facades)[7].

Interspersed with natural rock shelters on mountain slopes and valley foothills, which explains the variation in viewing fields and the differing preservation conditions, ranging from medium to poor, from one station to another. From a classificatory perspective, the murals and panels at Zaccar display a thematic spectrum that includes large animals (elephant, ancient buffalo, rhinoceros, cattle, antelope, ostrich, lion) and human scenes (hunters, bowmen, armed groups), in addition to symbols such as circular discs and painted handprints, allowing the distinction of categories: zoomorphic, anthropomorphic, and symbolic/geometric. On the technical level, rough and polished engraving techniques coexist with red pigment and charcoal painting, while differences in line quality and incision thickness indicate successive artistic hands or distinct chronological phases.Chronologically, a significant number of scenes are attributed to the "ancient buffalo period", characterized by large-scale dimensions and a naturalistic tendency in representation, which is a distinctive feature of the Saharan Atlas. Artistically, the compositional relations—such as the superimposition of elements, direction of movement, and distribution of spaces—reveal a narrative dimension that organizes the pictorial field around axes of hunting, predation, and human processions. This provides a "visual archive" that transcends aesthetics to nourish anthropological and ecological readings (patterns of life, armament, and migratory seasons). Nevertheless, deterioration factors—including cracks, erosion, and human vandalism—remain present, which necessitates a methodological conservation sequence beginning with diagnosis and assessment, followed by recording and documentation, then restoration and rehabilitation, in order to ensure the sustainability of the site within the Djelfa rock art system as a whole.[8]

[7] Khaled Kacemi, Maintenance and Rehabilitation of Classified Archaeological Sites in Djelfa Province, Master's Thesis, Institute of Archaeology – University of Algiers, Specialization: Conservation and Restoration, Academic Year 2012/2013, p. 116.

[8] Khoudiri, K., & Aberkane, K. (2023), "The Role of the DStretch Program in the Study of Rock Art: The Case of Deir AD-Djaqawin Site (Zaccar, Djelfa)", Athar Journal of Archaeological Heritage, vol.12, no.1, pp.147–164.

2. Digital Preservation and Photogrammetric Recording: Safeguarding the Heritage of Levantine Rock Art at La Joquera:

The Levantine rock art, recognized as UNESCO World Heritage since 1998 and protected as an Asset of Cultural Interest under the Spanish Heritage Act since 1985, represents a fragile yet invaluable component of global cultural heritage. Its vulnerability necessitates continuous initiatives for revisiting and monitoring sites and updating existing records, including descriptions, tracings, and photographs. This need is particularly urgent for long-documented sites such as La Joquera, first discovered and graphically recorded in 1930, but without substantial updates for decades. Revisiting these sites serves three primary purposes: first, to assess the integrity of the finds since their discovery or last revision; second, to evaluate how modern digital technologies can enhance previous interpretations and reproductions; and third, to generate accurate three-dimensional photorealistic models that better capture the materiality of the heritage and improve the visualization of motifs. Such comprehensive approaches are vital not only for the qualitative and quantitative study of rock art but also for its long-term preservation and for building digital archives that ensure a sustainable virtual future for Levantine art. The case study of La Joquera demonstrates both the potential and challenges of these methods. Technical limitations, such as restricted space, lighting constraints, and the visual interference of protective fencing, complicated the digital documentation process. Nonetheless, significant results were achieved, including the identification of previously invisible details such as weaponry and adornments associated with the site's only preserved archer, along with other incomplete remains. Furthermore, the production of a photorealistic model with color-enhanced tracings has facilitated the recognition of motifs now heavily faded, offering a closer approximation of the site's original appearance. Overall, the integration of digital enhancement and photogrammetric recording not only advances archaeological interpretation but also ensures that this fragile heritage can be preserved, studied, and disseminated with unprecedented accuracy and accessibility.[9]

[9] Domingo, I., Javadi, P., & Román, D. (2024). Digital enhancement and photogrammetric recording of La Joquera Levantine rock art (Borriol, Castelló). Virtual Archaeology Review.



Fig. 03 digital enhancement and photogrammetric recording of la joquera levantine rock art (borriol, castelló).

Source : Domingo, I., Javadi, P., & Román, D., 2024, p. .114

1.2 Digital and Preventive Strategies for Safeguarding the Zaccar Rock Art Sites

The protection and conservation of the Zaccar rock art sites in Djelfa Province require a comprehensive approach that integrates both advanced digital technologies and preventive management strategies. Drawing on lessons from international experiences, including the Spanish model at Altamira Cave, the pioneering outcomes of the 4D · arte rupestre project, and the methodological innovations highlighted by Carrero-Pazos et al. (2018) in Galicia, a combination of Geographic Information Systems (GIS), photogrammetry, 2D and 3D scanning, and hyperspectral imaging can be employed to document and analyze fragile engravings without physical contact. These technologies allow for the creation of accurate digital archives and virtual replicas, facilitating public access, research, and educational activities while minimizing physical risks to the original works. Additionally, spatial modelling and decision-support tools can help identify the most vulnerable areas, guiding targeted conservation interventions. Preventive strategies, such as environmental monitoring, controlled visitor access, and regulated movement between different stations, have proven effective in reducing deterioration caused by human presence and environmental fluctuations. Institutional coordination, including training programs for local researchers and community stakeholders, ensures sustainable management and strengthens protective practices. Implementing this integrated methodology at Zaccar would safeguard over 326 engravings and 17 painted motifs, enhance archaeological interpretation, support tourism and education, and secure the long-term preservation of Algeria's rich prehistoric heritage. By combining digital documentation with preventive conservation measures, Zaccar can serve as a national model for sustainable

rock art management, reflecting global best practices while addressing local challenges.[10]

Based on the outcomes of the "4D · arte rupestre" project and its associated field applications, we present here a synthesis of practical approaches and how they can be directly adapted to the Zaccar sites in Djelfa. The strategy begins with a comprehensive site diagnosis that includes physico-chemical characterization of the rock substrates and biological surface films, detailed visual inspection of decay processes and products, as well as thermal imaging where required; thus establishing a multi-dimensional reference baseline for the condition of each panel and engraving. At the documentation level, we recommend a standardized protocol combining close-range photogrammetry to produce highly accurate 3D models, and gigapixel imaging enhanced with techniques such as DStretch to reveal faint or invisible motifs; these outputs are later used for diachronic comparison and volumetric surface change analysis via point cloud comparison software (Cloud Compare), allowing for the early detection of millimetric losses. On the non-invasive analytical side, we suggest repeated in situ measurements with portable µ-Raman spectroscopy and pXRF to monitor pigment and substrate evolution, complemented by systematic colorimetric assessments to track fading over time.[11]

For Zaccar (326 engravings and around 17 painted motifs), these approaches are crucial to defining conservation priorities: beginning with a comprehensive diagnosis of the most at-risk panels, followed by the design of a graduated periodic monitoring plan balancing cost and efficiency, and the training of a local team to manage data and field visits. Furthermore, the digital archive should be transformed into public-facing digital outputs that enhance local awareness and tourism without exposing the sites to physical stress. Finally, we emphasize an integrated preventive approach that merges science with community-based management—technology provides predictive and diagnostic power, while local engagement ensures the long-term sustainability of preservation efforts.In light of the fragility and scientific significance of the Zaccar rock art in Djelfa, applying such advanced methods is both urgent and essential. These technologies can ensure the safeguarding of this heritage against the accelerating threats posed by environmental and climatic changes, while also supporting its inclusion in broader frameworks of world heritage recognition. Furthermore, integrating digital documentation and non-invasive analysis at Zaccar would promote

[10] Carrero-Pazos, J., Rodríguez-Rellán, C. & Vilas-Estévez, B. (2018), Digital imaging techniques for recording and analysing prehistoric rock art panels in Galicia (NW Iberia), detailed website: https://doi.org/10.1016/j.daach.2018.e00085

[11] Carrero-Pazos, M., Vilas-Estévez, B. & Vázquez-Martínez, A. (2018), Digital imaging techniques for recording and analysing prehistoric rock art panels in Galicia (NW Iberia), detailed website: https://doi.org/10.1016/j.daach.2017.11.003

its visibility in international academic research and highlight Algeria's contribution to global cultural memory. Preserving such irreplaceable heritage is, therefore, both a local responsibility and a global challenge requiring collaborative scientific and institutional efforts.

3. Altamira Cave and Preventive Conservation Plans :

The Altamira Cave in Cantabria, northern Spain, is regarded as one of the most significant rock art sites worldwide, containing paintings and engravings dating back to the Upper Paleolithic, especially from the Magdalenian and Solutrean periods. Its outstanding value led to its inscription on the UNESCO World Heritage List in 1985, making it a global symbol of prehistoric art.[12] Since its discovery in the nineteenth century, the cave has attracted considerable attention from both visitors and researchers, but the growing tourist pressure posed a direct threat to the preservation of its paintings, particularly due to the rise in carbon dioxide and humidity levels caused by large numbers of visitors.[13]

To address this risk, Spanish authorities took decisive measures, closing the cave completely to the public for several years and conducting detailed biological and environmental studies to assess the impact of visits on the stability of the rock art.[14] Based on these studies, a strict plan was implemented, setting the maximum environmental carrying capacity that the cave could sustain. As a result, only a very limited number of visitors were allowed to enter under controlled conditions, usually in small groups accompanied by specialized guides.[15]

In 2001, an exact replica known as the "Neocave" was inaugurated. This reconstruction reproduced the main paintings and panels with scientific accuracy using advanced three-dimensional scanning and digital simulation techniques, offering an educational and touristic alternative without affecting the original site.[16] This replica has become an effective substitute, enabling the continuation of cultural promotion and tourism while significantly reducing the pressure on the authentic cave.

Authorities also relied on precise environmental monitoring systems to measure humidity, temperature, and CO_2 levels inside the cave, allowing for early

[12] Paleolithic Art in Peril: Policy and Science Collide at Altamira Cave. Science, 2010.
[13] Ontañón, R., Bayarri, V., Herrera, J., & Gutiérrez, R. (2014). The Conservation of Prehistoric Caves in Cantabria, Spain. In: The Conservation of Subterranean Cultural Heritage. CRC Press.
[14] Ibid.
[15] Ministry of Culture of Spain. Plan de Conservación Preventiva de la Cueva d'Altamira, 2012.
[16] Building a New Prehistoric Cave. Wired Magazine, March 2001.

interventions whenever risk indicators appeared.[17] Results showed that visitor management based on scientific parameters, combined with the use of replicas, is an effective strategy to balance heritage preservation with touristic demand.

The Altamira experience demonstrates how political decisions supported by scientific research can make a decisive difference in heritage conservation. It represents a comprehensive model of preventive protection that combines partial closure, digital documentation, replica creation, and restricted visitation—measures that have since become a global reference in managing endangered rock art sites.[18]

Recent studies indicate that precise environmental factors within the Altamira Cave play a critical role in either preserving or accelerating the deterioration of its rock art. Periodic monitoring of the ceilings in the Polychrome Hall has revealed direct alterations in the paintings caused by washing and partial erosion of the limestone's mineral components, while scanning electron microscopy (SEM) has shown flaking and loss of pigment adhesion. Water is identified as the primary agent driving these processes, as it transports carbon dioxide and nutrients from the soil through the outer soil cover to the ceiling surface, resulting in partial dissolution of the limestone and pigment detachment. Geophysical studies, including ground-penetrating radar (GPR) surveys, have highlighted central fractures that constitute direct pathways for water infiltration, exacerbating deterioration. The Spanish experience underscores the importance of developing scientific and systematic conservation strategies, which can be applied to the Zkar region by studying local environmental dynamics and implementing indirect preventive interventions to safeguard prehistoric rock art and mitigate degradation risks.[19]

3.1 The Applicability of the Spanish Model for the Protection of Rock Art to the Zaccar Sites in Djelfa Province:

The Spanish experience in the protection of rock art offers a comprehensive model that can inspire practical approaches to safeguarding the Zaccar sites in Djelfa, where archaeological richness intersects with challenges of preservation and conservation. Since the inscription of Altamira Cave in Cantabria on the UNESCO World Heritage List in 1985, Spanish authorities have implemented a preventive conservation policy that balanced strict protection with cultural and touristic

[17] World Monuments Fund (WMF). New Project Launched to Document the Cave Art of Altamira, 2022.
[18] Clottes, J. (2008). Cave Art. Phaidon Press.
[19] Bayarri, V., Prada, A., & García, F. (2023), A Multimodal Research Approach to Assessing the Karst Structural Conditions of the Ceiling of a Cave with Palaeolithic Cave Art Paintings: Polychrome Hall at Altamira Cave (Spain), Sensors (Basel, Switzerland): https://doi.org/10.3390/s23229153

demands. This began with the temporary closure of the cave after studies showed that uncontrolled tourist pressure led to dangerous increases in humidity and CO_2 levels, threatening the Upper Paleolithic paintings. To avoid further deterioration, a comprehensive plan was introduced, allowing only a very limited number of visitors under controlled environmental conditions, while at the same time creating an exact replica known as the "Neocave", produced using three-dimensional scanning and digital simulation technologies. This replica offered an alternative educational and touristic experience without endangering the original site. In the case of Zaccar, a similar approach could be adopted by establishing periodic environmental monitoring using simple sensor devices to track microclimatic changes, and by developing a digital or even virtual exhibition space that would make the engravings accessible without exposing them to physical risks.[20]



Fig. 04 Cave of Altamira

Source: https://whc.unesco.org/en/list/310

In terms of documentation, Spain has been a pioneer in the use of non-contact technologies, notably multispectral and hyperspectral imaging applied at El Castillo Cave. These methods revealed color layers invisible to the naked eye, enabling researchers to reconstruct the chronological sequence of paintings and deepen their symbolic interpretations.[3] For Zaccar—which contains more than 326 engravings and over 17 painted motifs distributed across multiple stations such as Dir Digaouine, Kef Ennacer, and Hajrat Sidi Boubakr—introducing such technologies would be invaluable for identifying chronological and stylistic phases of its rich iconography. These include zoomorphic representations (elephants, ancient buffalo, rhinoceroses), anthropomorphic scenes (hunters, archers, armed groups), and geometric or symbolic motifs.[4] Photogrammetry and drone-based surveys could

[20] Cave of Altamira and Paleolithic Cave Art of Northern Spain; https://whc.unesco.org/en/list/310

also be applied to document large and inaccessible rock surfaces, creating a comprehensive three-dimensional database for future research and conservation planning.

Another crucial lesson from the Spanish model is the management of tourist visits and environmental carrying capacity. Studies showed that uncontrolled access to Altamira not only altered humidity levels but also facilitated the growth of harmful microorganisms such as fungi and algae, directly endangering the paintings.[5] To address this, Spanish authorities enforced strict visitor limits, required advance booking, and imposed guided tours in small groups along predefined routes.[6] For Zaccar, a comparable system could be designed by regulating visitor numbers and structuring movement between its various stations, supported by the development of a visitor reception center. This center could feature interactive screens, 3D models, and high-resolution images, thereby enriching the visitor experience while reducing direct contact with the original engravings.[21]

Preventive conservation has also been central to the Spanish strategy. A structured methodology was developed, beginning with diagnosis and monitoring, followed by systematic recording and documentation, limited restoration where necessary, and finally environmental and touristic rehabilitation of the sites. This sequence proved highly effective in ensuring sustainability, as it enabled timely interventions without compromising the authenticity of the prehistoric art.[7] For Zaccar, where many panels suffer from surface cracking, erosion, and vandalism, the adoption of this methodological framework could provide a roadmap for targeted interventions—starting with precise documentation, followed by controlled stabilization of major fractures, while avoiding intrusive restoration that might distort the original works.[22]

On the institutional level, Spain demonstrated the importance of multidisciplinary coordination, particularly through the Spanish Cultural Heritage Institute (IPCE), which oversaw national conservation plans, standardized procedures, and organized specialized training programs that brought together experts in geology, anthropology, and digital conservation.[8] For Zaccar, success depends on embedding the site within national or regional heritage protection initiatives, with active collaboration between Algeria's Ministry of Culture,

[21] Bayarri, V., et al. (2024). A multisensory analysis of the moisture course of the Cave of Altamira (Spain): Implications for its conservation. Remote Sensing, 16(1), 197. https://doi.org/10.3390/rs16010197

[22] Ministerio de Cultura d'España. (n.d.). Plan de conservación preventiva de la Cueva de Altamira. Retrieved from https://www.cultura.gob.es/libro-verde-patrimonio/en/buenas-practicas-todas/cuevaltamira.html

universities—especially archaeology and conservation institutes—and the local community. Training programs for students and researchers, designed in cooperation with international experts, would be essential to build technical capacity, while local engagement would strengthen protective behavior and reduce accidental or deliberate damage.[23]

From an artistic and anthropological perspective, Spain's adoption of digital imaging and advanced analytical tools has also enriched interpretations of prehistoric art. At El Castillo, hyperspectral imaging helped to uncover details about prehistoric lifeways, ritual practices, and seasonal environmental patterns, thus connecting rock art more directly with anthropological and ecological research.[9] A similar application in Zaccar could open new avenues for understanding the relationship between its engravings and the daily practices, spiritual life, and ecological adaptations of prehistoric communities in the Saharan Atlas.

Taken together, the Spanish model outlines a coherent roadmap that can be adapted to the specific context of Zaccar: precise environmental diagnostics, advanced non-contact digital documentation, regulated visitor management, sequential preventive conservation, and institutional coordination. Implemented in synergy, these measures would not only safeguard Zaccar from further deterioration but also position it as a national reference site for the sustainable management of rock art in Algeria, echoing the global role played by Altamira as a benchmark for the preservation of humanity's earliest visual heritage.

4. General Conclusions:

The examination of the Spanish experience in the protection of rock art, particularly at Altamira and El Castillo, has yielded several key findings that can inform a local strategy for the Zaccar site in Djelfa Province. The success of the Spanish model rests on a set of interrelated elements. The first is precise environmental monitoring, which enabled the regulation of climatic and biological factors affecting the paintings; this opens the possibility of adopting simplified sensor devices at Zaccar for regular monitoring of environmental changes. The second is non-contact digital documentation, as applications of hyperspectral imaging and photogrammetry in Spain have demonstrated a remarkable capacity to reveal hidden details while safeguarding the original data, underscoring the need to introduce such tools at Zaccar to establish a comprehensive digital database of

[23] De Las Heras, C., et al. (2012). Conservation and Management of the Altamira Cave: The Preventive Strategy. In Proceedings of the International Conference on the Conservation of Heritage Sites. Madrid: Ministerio de Cultura.

engravings. The third concerns tourist management, whereby the regulation of carrying capacity has proven effective in balancing conservation and promotion; this approach could be adapted in Zaccar through structured pathways and a visitor center equipped with digital alternatives. The fourth is the sequential preventive conservation methodology, combining diagnosis, documentation, limited restoration, and rehabilitation—an approach well-suited to the site's local realities. Finally, the Spanish case highlighted the pivotal role of institutional frameworks, particularly through the Spanish Cultural Heritage Institute (IPCE), demonstrating that Zaccar's protection will depend on its integration into national policies and effective academic and community collaboration. Based on these findings, it is evident that adapting the Spanish model to local specificities could transform Zaccar into a leading national reference for the safeguarding of rock art heritage.

5. Conclusion

This study has demonstrated that rock art is not merely a silent archaeological witness to human life in prehistoric times but rather a comprehensive visual document that embodies anthropological, cultural, and ecological dimensions, making every rock site an open archive of early human history. In this context, the Spanish experience, particularly at Altamira, El Castillo, and the Levantine rock art complex, has shown that safeguarding this heritage requires moving beyond traditional approaches toward integrated scientific and institutional strategies. These strategies combine precise environmental diagnostics, non-contact digital documentation, strict visitor management, and multidisciplinary institutional frameworks.

When projecting this experience onto the reality of the Zaccar site in Djelfa Province, the urgent need emerges to adapt the Spanish model within a local framework that accounts for available resources and existing challenges. Djelfa hosts around 325 rock art stations, making it one of the richest regions of Algeria in this type of heritage. However, this density is counterbalanced by significant fragility in conservation conditions and the spread of natural and anthropogenic deterioration. Here lies the value of the Spanish model as a reference capable of guiding national policies toward the effective safeguarding of this heritage, while recognizing the geographical and social particularities of the Algerian context.

The importance of drawing inspiration from the Spanish model resides in its success in solving a complex equation: protecting archaeological authenticity while promoting tourism and cultural value. The use of 3D scanning and hyperspectral imaging provided highly accurate scientific documentation, while the creation of

replicas (such as the Neocave) helped to relieve tourist pressure without depriving the public of interaction with the heritage. At Zaccar, such approaches could provide innovative solutions, including the creation of digital platforms and alternative educational spaces that highlight the site's significance while protecting its original engravings.

The Spanish case also underlined the central role of institutional frameworks, embodied by the Spanish Cultural Heritage Institute (IPCE), which provided a strong basis for coordination, standardization of procedures, and the training of specialized personnel. In Algeria, the success of any conservation plan for Zaccar depends on integrating the site into clear national programs that complement academic and university efforts, while also involving the local community in protection and valorization processes to ensure sustainability and efficiency.

Furthermore, this study reveals that the protection of rock art is not merely a technical issue but also one of community awareness and strategic vision. Just as Spain demonstrated early awareness of the significance of this heritage in shaping cultural identity and human memory, Algeria is now called upon to adopt a similar vision, positioning sites such as Zaccar as essential pillars of national identity and as cultural, touristic, and even economic resources.

Accordingly, it can be affirmed that adapting the Spanish model to the specific context of Zaccar is not simply a methodological option but an urgent necessity to ensure that this heritage remains alive for future generations. The Spanish experience has not only demonstrated the feasibility of protecting rock engravings from deterioration but has also provided a model for transforming these sites into spaces of education, valorization, and scientific research. Thus, the future challenge lies in turning Zaccar from a site at risk of disappearance into a national reference model that harmonizes authenticity with modernity, and conservation with valorization, thereby opening new horizons for scientific research and cultural tourism in Algeria.

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