# Documenting to preserve: archaeological recording as a tool for risk mitigation in coastal heritage sites

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**Abstract**
The article explores how systematic documentation functions as an active strategy for risk mitigation in coastal heritage contexts increasingly exposed to climate change. Focusing on a case study from southern Oman, it examines how high-resolution photogrammetry and 3D laser scanning supported the assessment and restoration of the citadel of the Islamic site of Al Baleed, severely damaged by cyclone Mekunu in 2018. The experience demonstrates the role of digital recording as a tool for resilience and long-term preservation.

**Keywords**
Digital documentation, archaeology of Oman, climate change, risk mitigation, restoration of cultural heritage

## Introduction

Cultural heritage sites around the world are increasingly recognised as endangered under multiple and often interconnected forms of pressure, including conflicts, urban development, mass tourism, environmental degradation, and the accelerating effects of climate change. Among these threats, climate-related hazards have become some of the most pervasive and least predictable.

Archaeological documentation plays a fundamental role in all research contexts, but its importance becomes truly vital when dealing with sites exposed to severe environmental stress. This priority is also reflected in international guidelines: both UNESCO and ICOMOS emphasise the need for systematic, accurate, and accessible recording as a core component of heritage protection, as stated in the UNESCO *Recommendation Concerning the Preservation of, and Access to, Documentary Heritage including in Digital Form* (2015) and in the ICOMOS *Principles for the Recording of Monuments, Groups of Buildings and Sites* (1996).

Along both the Mediterranean (Andreou *et al.* 2020; Westley *et al.* 2023; Gkaifyllia *et al.* 2025) and the Indian Ocean coasts (Andreou *et al.* 2022, see also for further references), settlements are increasingly affected by the combined effects of climate change, sea-level rise, and extreme weather events, including tropical cyclones in the Indian Ocean, capable of compromising, within a few hours, structures that have survived for centuries.

A recent analysis conducted by UNESCO and the World Resources Institute (WRI) revealed that 73% of World Heritage sites are highly exposed to water-related hazards, including drought, water stress, and riverine or coastal flooding. This alarming figure highlights the scale of the threat faced by cultural heritage worldwide and the urgent need to integrate risk assessment and mitigation into heritage management practices.

As recent studies have shown (Andreou *et al.* 2022), Oman ranks among the regions of the Arabian Peninsula most vulnerable to these events. In particular, the southernmost region of the country, the Dhofar Governorate, is struck by cyclones with a frequency, on average, every five to seven years, with a documented intensification of storm surges and precipitation expected in the coming decades. Such environmental pressures pose a direct threat to the cultural heritage of the country, and particularly to its maritime dimension which reflects the long interaction between Omani people and the sea, as documented by numerous coastal settlements whose occupation spans from prehistory to the Islamic period (MoHT 2021).

Within this fragile framework, the documentation of archaeological sites emerges not only as a scientific tool for recording but as a key strategy for risk management and resilience. Systematic recording through high-resolution photogrammetry, 3D laser scanning, and geospatial mapping (Remondino and Campana 2014; Bertocci and Parrinello 2015; Galeazzi 2016; Bosco 2022) provides a metrically accurate archive that serves not only as documentation, but also as a resource that can be mobilized in the event of damage, ensuring that both knowledge and material form are preserved even when the physical fabric of a monument is severely damaged or lost.

The site discussed in this paper, located on the southern coast of Oman, clearly illustrates this condition. The ancient town of Al Baleed (Figure 1) lies in fact in an area identified as highly vulnerable to storm surges and coastal erosion, where the effects of climate variability have been compounded by repeated cyclonic events.

In May 2018, Cyclone Mekunu, one of the most intense storms ever recorded in Oman, caused extensive flooding and severe structural damage to the site, particularly to the citadel, which at the time was the focus of an ongoing excavation and conservation project under the direction of the author (Figures 2-3).

Fortunately, a comprehensive digital documentation campaign had been completed only a few days before the cyclone. This pre-event dataset, acquired through advanced recording methods, made it possible to assess the extent of the damage with exceptional precision and to guide the reconstruction of the affected portions of the monument.

This experience demonstrates that digital documentation is not a secondary aspect of archaeological research and conservation projects, but a proactive and interpretative process capable of generating new knowledge about building materials, construction techniques, and the structural response of heritage sites to environmental stress and gradual decay.

In regions where instability is an intrinsic feature of the landscape, as along the Indian Ocean coasts, extreme phenomena often occur with little or no warning, leaving no time for preventive measures. Similar coastal World Heritage sites face comparable challenges. Recent work at Kilwa Kisiwani in Tanzania (Pollard *et al.* 2025) has shown how digital documentation can support climate-change adaptation, guide conservation planning, and strengthen community engagement in environments exposed to coastal erosion, intense humidity, and extreme weather events. These international experiences highlight the growing relevance of integrated digital workflows for the long-term protection of vulnerable coastal heritage.

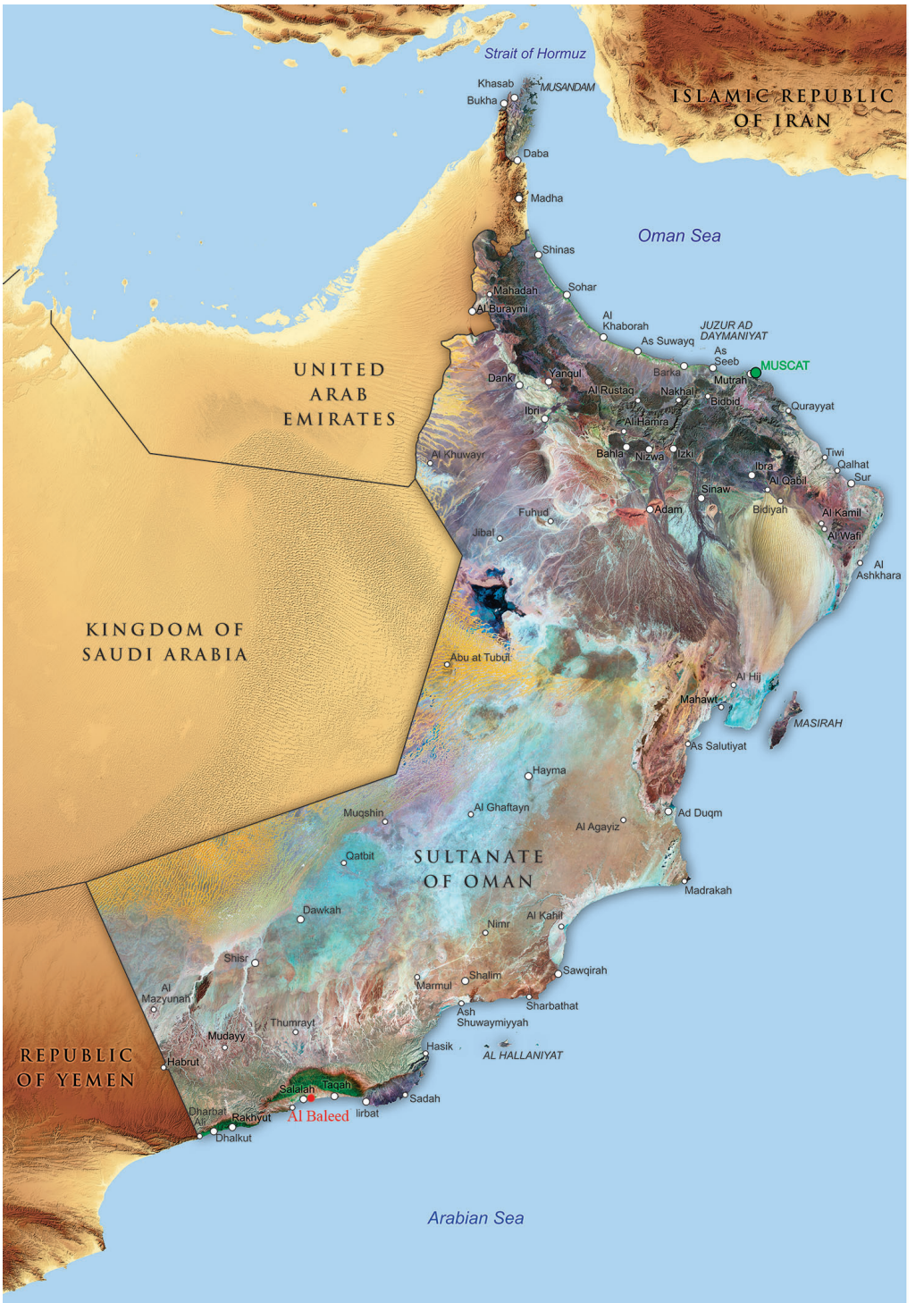



*Figure 1. Map of the Sultanate of Oman with the location of Al Baleed in red (©IAMOB).*



*Figure 2. Orthophoto of the citadel of Al Baleed before the cyclone Mekunu (22/05/2018, photo by A. Massa, Esplorativa Architetti).*



*Figure 3. Orthophoto of the citadel of Al Baleed after the cyclone (01/06/2018, photo by A. Massa).*

Within this broader framework, the case of Al Baleed offers a further example of how digital documentation can function as a proactive strategy for safeguarding an archaeological site exposed to cyclical climatic stress.

Building on this premise, the research addressed a set of key issues: the extent to which systematic documentation can help identify and understand the structural and material vulnerabilities of a historic building; how pre-event and post-event datasets can be compared to support evidence-based restoration after extreme weather events; and the ways in which the integration of archaeological, architectural, and digital data can inform long-term maintenance strategies in fragile environments.

The following section does not aim to provide an exhaustive technical report of the survey parameters. Instead, it outlines the documentation workflow as applied in this case study, with the purpose of illustrating its methodological implications for risk assessment and post-event analysis.

## 1. The Site and its Environmental History

The site of Al Baleed, known in antiquity as Zafar, lies along the southern coast of Oman, in the southeastern area of the present-day city of Salalah, within the Governorate of Dhofar (Figure 4).

Strategically located at the mouth of Wadi Garziz and bordered by a natural lagoon partially shaped through human management, the city was one of the principal commercial hubs of the Indian Ocean, renowned for the trade of frankincense, Arabian horses, and other valuable resins and aromatics such as myrrh, benzoin, liquid storax and dragon's blood (Pavan 2020).

Founded around the eleventh century, Al Baleed reached its peak under the Rasulid dynasty, between the thirteenth and fifteenth centuries, when it became a major node in the maritime trade networks connecting southern Arabia with East Africa, India, and the Persian Gulf, and as far as China (Newton and Zarins 2017; Giunta 2021). Archaeological evidence indicates that the city was abandoned around the eighteenth century (Pavan *et al.* 2020; Pavan 2021).

Since 2000, the site has been inscribed on the UNESCO World Heritage List as part of the *Land of Frankincense* complex and today forms part of an Archaeological Park that also hosts the Museum of the Frankincense Land, one of the most visited cultural landmarks in Oman.

The architecture of Al Baleed is characterised by the use of locally available materials and construction techniques adapted to the coastal environment. The primary building material is a porous, shelly limestone (beach rock), extracted from nearby quarries and shaped into masonry blocks arranged in both regular and irregular courses. Two main construction techniques are attested: rubble masonry with internal filling ("a sacco") and a more regular ashlar construction based on cut-to-fit blocks arranged according to the header–stretcher method. Fired bricks were occasionally used for specific architectural elements such as partition walls, basins, and cisterns, while wooden reinforcements, sometimes reused from ship timbers, were embedded within the masonry to improve structural cohesion. The



*Figure 4. Aerial view of the site of Al Baleed (photo by B. Isenberger).*

structures were originally coated with lime-based plaster, now only partially preserved (Pavan *et al*. 2019).

These construction characteristics, while well adapted to the local environment, also make the architectural remains particularly vulnerable to erosion processes and extreme climatic events in a coastal context exposed to seasonal monsoons and cyclones. This vulnerability has repeatedly shaped the history of the site, threatening both its continuity and its preservation.

In his account of Dhofar, based on visits to the region in 1883 and in 1884 (Marshall 1989), S.B. Miles, a British political officer who served as a diplomat in several Arab countries, reported a series of destructive episodes that had affected the ancient town of Al Baleed. Among them, he referred to a particularly catastrophic event that had taken place roughly thirty years before his arrival, ~~that is,~~ around the mid-nineteenth century. Miles (1919, 545) wrote: *"The Arabs here assured me that in a hurricane that had occurred some thirty years before, the plain had been flooded, sweeping camels, goats, and cattle out to sea and scouring the creek and clearing away the bar."* He also mentioned other violent cyclones that hit the Dhofari coast and caused serious damage to the city in 1286 (Miles 1919, 507) and in 1325 (Miles 1919, 508) although he did not specify the nature or origin of the provided information.

While these earlier episodes cannot be verified due to the absence of historical or archaeological evidence, the account of Miles about the mid-nineteenth-century event finds strong support in recent paleoenvironmental research.

Geoarchaeological and palynological studies have in fact demonstrated that the environmental evolution of the Salalah plain is closely linked to the variability of the Indian Ocean monsoon. Research by C. Hoorn and M. Cremaschi published in 2004 showed that, during the Late Holocene, the *khors* (lagoons) of southern Oman, including Khor Al Baleed and Khor Rori both associated with ancient settlements respectively in Islamic and pre-Islamic period, gradually transformed from open estuaries into barrier-dominated lagoons. This transformation

resulted from a progressive reduction in freshwater discharge from the mountains, associated with a weakening of the southwest monsoon and an overall trend toward aridification.

The formation of coastal sand barriers and the consequent silting of the lagoons directly affected the harbour function of these sites, leading to the decline of urban centres such as Sumhuram/Khor Rori, which experienced a major contraction in the third century CE, was abandoned in the fifth century, and subsequently reoccupied only sporadically (Pavan 2023). A similar pattern can be observed at Zafar/Al Baleed, which remained partially inhabited during its final centuries before its definitive abandonment in the eighteenth century (Pavan *et al.* 2020).

More recent sedimentary analyses (Steele *et al.* 2024), relying on the sedimentological studies conducted by E. Reinhardt (2000) have provided new evidence for a massive marine overwash event dated between the late eighteenth and early nineteenth centuries CE. The cores from Khor Al Baleed reveal a layer of marine sands and foraminifera deposited far inland, indicating a violent marine intrusion likely caused either by a powerful tropical cyclone, such as those documented in the Gulf of Aden in 1885 and 1898, or by a distant tsunami generated along the Sunda–Sumatra subduction zone (Steele *et al.* 2024, 9). Whatever its origin, the event had a profound geomorphological and archaeological impact, accelerating the silting of the lagoon and contributing to the final decline of the harbour. This episode, combined with the long-term processes of barrier formation and monsoon weakening already described by Hoorn and Cremaschi (2004), marked a decisive phase in the transformation of the coastal landscape. In this light, the observations recorded by Miles at the end of the nineteenth century acquire renewed significance as they reflect the tangible effects of catastrophic phenomena now confirmed by paleoenvironmental and sedimentological evidence.

The convergence of historical testimony and scientific data underscores the vulnerability of Al Baleed to recurrent natural events and highlights the importance of integrating archaeological, documentary, and environmental research in reconstructing the long-term history of the site.

## 2. Documentation Strategy and Methods

The archaeological site of Al Baleed covers an area of approximately 64 hectares. Although archaeological investigations have been conducted since the mid-1950s, only about 15% of the total area has been excavated to date. Research has focused on several key complexes, such as the Great Mosque, the Funerary Mosque, the harbour and customs house, a series of smaller mosques, and the citadel, which was the political and symbolic centre of ancient Zafar (Albright 1982; Costa 1979; Jansen 2015; Newton and Zarins 2017; Pavan 2021). A productive area is currently being investigated by the University of Naples L'Orientale.

During the excavation campaigns directed by Juris Zarins and Lynne Newton (2005-2011), several structures of the ancient town, including the citadel and the city walls, were also the object of conservation and restoration works carried out in collaboration with the Department of Structural Engineering of the University of Pisa (Andreini *et al.* 2008; Sassu *et al.* 2017). These interventions aimed to stabilise some fragile portions of the site while preserving the authenticity of the masonry fabric and enhancing the overall legibility of the ruins. The team,

coordinated by M. Sassu, developed a set of best practices inspired by UNESCO and ICOMOS principles, promoting interventions that were recognizable, reversible, and respectful (Sassu *et al.* 2017).

The consolidation of the citadel followed these guidelines through the reconstruction of collapsed masonry sections and the installation of stone blocks laid transversely to connect the two wall faces and improve their cohesion. The intervention also included the replacement of the compacted earth filling between the two faces of the wall with a drainage layer of mixed gravel and small stones selected on site to restore permeability and ensure efficient water runoff during the rainy season (Andreini *et al.* 2008). The use of geotextile films to distinguish reconstructed areas reflected a methodological awareness consistent with international conservation standards while ensuring low cost, minimal visual impact, and the advantage of not requiring specialised labour.

These conservation practices laid the groundwork for the subsequent phase of research and management at the site. Between 2016 and 2020, the citadel became the focus of a multidisciplinary programme combining excavation, material studies, conservation, and site enhancement (Pavan *et al.* 2020; Pavan 2021). Directed by the author within the framework of the Office of the Adviser to His Majesty the Sultan for Cultural Affairs, later incorporated into the Ministry of Heritage and Culture and subsequently into the Ministry of Heritage and Tourism of the Sultanate of Oman, the project was suspended in July 2020 following the outbreak of the COVID-19 pandemic. Activities resumed in other sectors of the site in December 2021 under the direction of R. Giunta, University of Naples L'Orientale. During this phase, particular attention was given to systematic documentation, integrating photogrammetry, topographic survey, and detailed recording of materials and construction techniques to support both conservation and interpretation.

The restoration principles established in the earlier campaigns were further developed during this phase, maintaining the same criteria of material compatibility, minimal intervention, and clear recognisability of new additions, while ensuring that the restored structures maintained their visual integrity and remained fully comprehensible to visitors, in line with the vocation of the site as an archaeological park.

The core of the work consisted of a stratigraphic excavation, supported by the study of artefacts and ecofacts conducted by specialists in various fields (D'Andrea *et al.* 2021).

The building, shaped like a *tell,* was investigated both from the top of the mound in order to expose the sequence of building phases through a horizontal stratigraphic excavation and along its sides, to reconstruct the succession of interventions on the curtain walls through a vertical stratigraphic approach (Pavan et al. 2019). In the uppermost levels removed at the beginning of the excavation, it was possible to recognise the same sequence previously uncovered by J. Zarins and L. Newton, although their work relied on a level-excavation method using arbitrary 10 cm spits rather than stratigraphic criteria.

The investigation methodology included the recording of Stratigraphic Units (SU) and Masonry Stratigraphic Units (MSU). Record sheets were designed to document definition, position, relationships, components, measurements, and descriptions, following and adapting

the standards of the Italian *Istituto Centrale per il Catalogo e la Documentazione (ICCD)*. Specific forms were also developed for different categories of findings: artefacts, raw materials, samples, pottery, coins and ship timbers. A dedicated form for wall recording was moreover designed, including fields such as building element, binding, and masonry type, with the aim of creating an atlas of masonry (Pavan *et al.* 2019). Bones and shells were collected from selected, stratigraphically secure contexts for future palaeofaunal and malacological analyses, in order to provide data on subsistence strategies, environmental conditions, and resource use in the area. All finds from the citadel excavation were entered into a database that integrates materials recovered between 2016 and 2020, items stored in the Museum Collection related to the site of Al Baleed, and artefacts excavated by the University of Naples L'Orientale since 2021.

The documentation of the citadel was conceived as an integral part of the archaeological investigation, aiming to produce a comprehensive and metrically reliable record of the site, capable of supporting both scientific interpretation and long-term conservation.

In 2018 and 2019, two multidisciplinary survey campaigns were conducted respectively in collaboration with the architectural team Esplorativa Architetti (Turin, Italy), directed by architect A. Massa (Amadio 2019), and with A. Tilia (Rome, Italy), who was responsible for topography and site documentation during the restoration works carried out in 2019 under the supervision of architects A. Borgese and A. Gratteri (Borgese *et al.* 2019). The latter were engaged to restore and stabilise portions of the building that had been severely damaged by Cyclone Mekunu. Because of the exceptional intensity of the storm which brought, within a few hours, rainfall equivalent to several years, the soil became completely saturated, forming water basins that caused collapses and rendered the structure inaccessible for months.

Both campaigns included terrestrial topographic measurements using a total station, close-range photogrammetry, and aerial photogrammetry carried out with unmanned aerial vehicles (UAVs).

The terrestrial survey conducted in 2018 began with the establishment of ground control points and the materialisation of the reference network. The mapping of the building followed the 50 × 50 m grid system originally designed by P.M. Costa and his team during the excavations carried out between 1977 and 1981 (Costa 1979). To provide a more precise spatial definition of the archaeological contexts within the citadel, an additional 5 × 5 m grid was later implemented by the surveyor B. Isenberger during the excavations directed by J. Zarins and L. Newton, in which each square was assigned a numeric code. This system was revised and updated in 2018 by A. Massa, who introduced an alphanumerical version of the grid, facilitating a clearer and more consistent reading of the excavated surfaces (Figure 5). Known reference points already established in and around the citadel of Al Baleed were identified, and a new control network was created based on them.

The photogrammetric survey was carried out on all the external facades of the citadel and in selected internal areas that required detailed photographic documentation for subsequent processing. Two complementary approaches were adopted: close-range terrestrial photogrammetry and aerial photogrammetry using a drone.

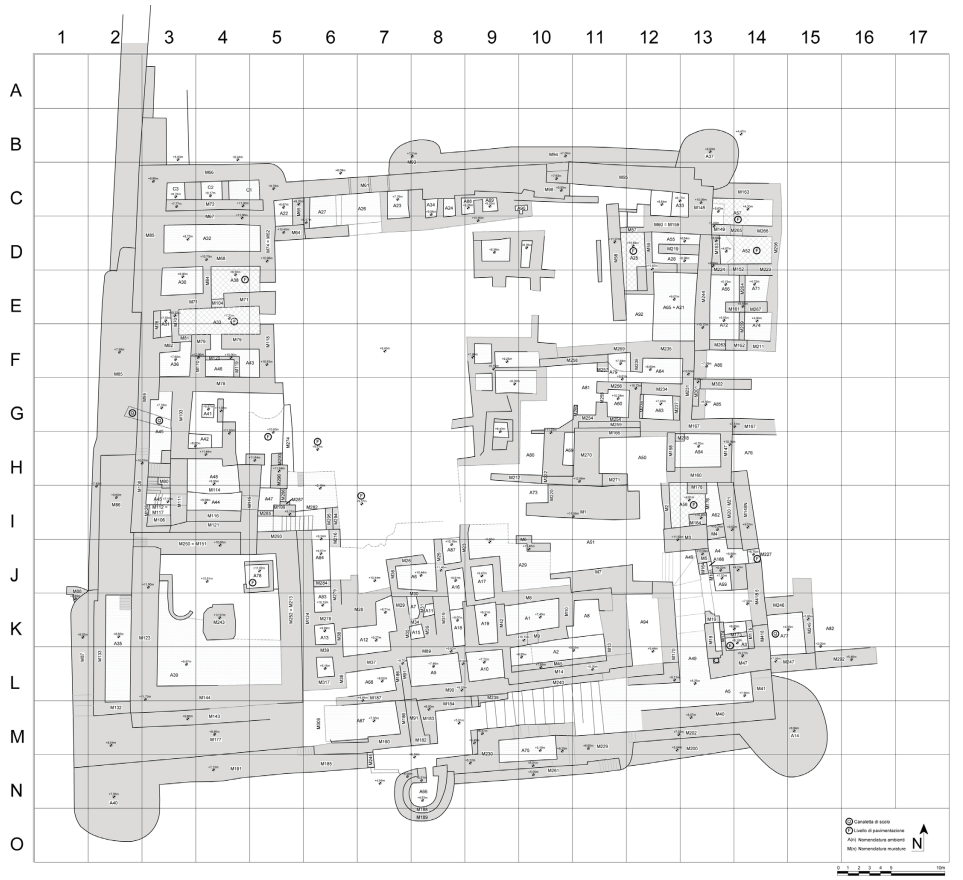



*Figure 5. Map of the citadel showing grid layout, elevation points and structure names (map by Esplorativa Architetti).*

The close-range survey was conducted using a Canon EOS 550D camera equipped with a Canon 18–55 mm lens fixed at a focal length of 55 mm. This operation mainly focused on the lower portions of the external walls along the entire perimeter of the structure, as well as on internal areas. During the acquisition of the images, the camera was kept as orthogonal as possible to the surfaces being recorded, ensuring a minimum overlap of 60% between consecutive photographs. In confined or architecturally complex spaces, additional images were taken with the camera inclined at approximately 45° to the surface, in order to improve spatial information and achieve greater accuracy in the third dimension. For certain shots, the camera was mounted on a telescopic rigid pole to reach higher or otherwise inaccessible points. Particular care was taken to include all available topographic targets within the frames of the analysed areas.

For the documentation of elevated and otherwise inaccessible parts of the monument, as well as for the acquisition of nadiral images of the ground, a quadcopter drone was employed.



*Figure 6. General view of the dense cloud of points (acquisition and elaboration by Esplorativa Architetti in Amadio 2019, 26, fig. 27).*

The processing of the images began with their import into photogrammetric software, where each photograph was aligned through the identification of pre-marked targets. The photogrammetric processing was georeferenced using the previously established topographic network, ensuring metric consistency and improving the overall accuracy of the final model (Figure 6).

The 2018 campaign also included terrestrial laser scanning, performed with a Faro Focus 3D phase-shift laser scanner. The data collected during this campaign were later partly processed by A. Tilia in 2019, who produced 3D models of the area (Figure 7).

Because several parts of the citadel were affected by structural instability and at risk of collapse, direct access was limited, and traditional surveying methods could not be safely applied (Figure 8).

In this context, laser scanning proved particularly effective, enabling the documentation of otherwise inaccessible structures and the reconstruction of the internal layout with high metric precision. The instrument, equipped with a bi-axial compensator, height sensor, and electronic compass, ensured accurate alignment and reliable elevation data and operating without the mandatory use of targets.

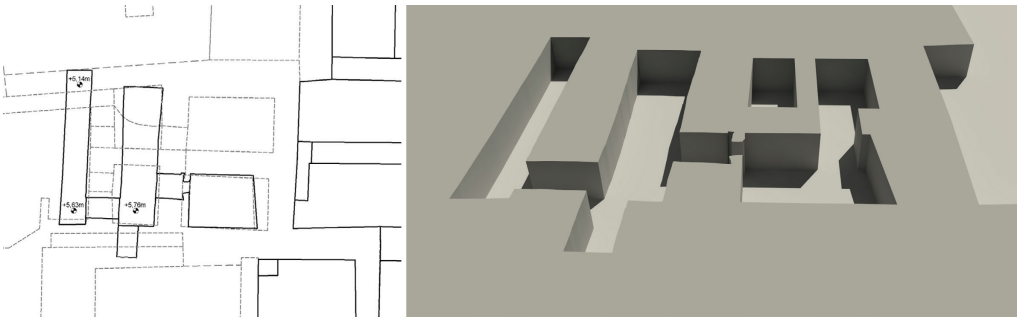



*Figure 7. Plan and 3D rendering of the rooms individuated at the second storey of the citadel (plan and 3D by A. Tilia in Pavan 2021, 69, figs. 13, 14).*



*Figure 8. Preliminary laser-scanning acquisition of the second-floor rooms prior to debris removal (Photo by A. Massa, Esplorativa Architetti).*

The analysis of the scans, integrated with excavation data, made it possible to examine the construction and preservation of the floor slabs, elements rarely surviving in medieval citadels but crucial for understanding structural design and building techniques.

The data revealed that the second floor was composed of a series of elongated rooms connected by narrow passages, forming a compact and enclosed architectural unit partly isolated from the rest of the complex (see above, Figure 7).

The recorded elevations, ranging between +5.14 m and +5.76 m, reflect both original differences in floor height and the accumulation of sediments that could not be removed for safety reasons. This spatial configuration, with its controlled circulation and restricted access points, suggests that the sector was intentionally designed as a self-contained and possibly secure area within the citadel, where movement between rooms was deliberately limited.

The integrated use of these instruments resulted in a highly accurate 3D dataset of the monument and its surroundings, forming the basis for subsequent photogrammetric processing, metric verification, and integration with archaeological data. Each technique was selected according to scale and purpose: LiDAR ensured full coverage of the architectural remains, while high-resolution photogrammetry provided detailed orthophotos, 3D models, and textured surfaces for structural analysis and condition mapping.

The integrated survey resulted in a dense and multi-source dataset, including UAV photogrammetry acquired at an average altitude of approximately 20 m, 143 terrestrial laser scans, and a series of vector drawings in CAD at scales of 1:50 and, for selected areas, 1:20.

All datasets were georeferenced within a common spatial framework to enable precise integration with excavation data, topographic mapping, and archival documentation.

The resulting 3D models were not limited to visualisation purposes but were used as analytical tools to study masonry typologies, construction techniques, and patterns of structural instability. This approach created a digital archive of the state of preservation of the monument immediately prior to the 2018 cyclone and documented in detail the areas later restored in 2019.

## 3. Cyclone Mekunu and the Use of Pre-Event Data

On 25 May 2018, cyclone Mekunu made landfall on the Dhofar coast, causing unprecedented rainfall, flooding, and wind damage, with severe destruction along the shoreline and the loss of human lives. At Al Baleed, several sections of the citadel walls and upper structures collapsed or were heavily eroded (Figure 9).

The pre-event 3D models, orthophotos, and elevation drawings produced only a few days earlier became an essential reference for the post-disaster assessment. By overlaying new aerial and terrestrial images onto the existing 3D base, it was possible to map with high precision the areas affected by collapse and erosion.



*Figure 9. Damages along the eastern curtain wall of the citadel (photo by A. Pavan).*

The most extensive damage occurred along the outer curtain walls, which had already been the subject of partial restoration during the campaigns directed by J. Zarins and L. Newton, and were again under conservation and maintenance at the time of the cyclone. The elevation drawings obtained through photogrammetric documentation (Figure 10) proved fundamental for the reconstruction of these areas, enabling the restoration teams to reproduce the original geometry and masonry texture with full scientific accuracy (Figure 11).

In this context, documentation also played a key role as a training tool, supporting restoration activities carried out by locally available labour that was not always specialised, and ensuring consistency in the execution of interventions (Figure 12).

The comparison between the pre- and post-event datasets, based on 3D alignment and orthophoto analysis, revealed not only the volumetric loss of masonry, but also structural vulnerabilities and weaknesses in earlier restoration work.

These insights directly informed the subsequent conservation strategy, leading, for example, to an increase in the number of transverse stone sections used to improve bonding between wall faces, as well as to targeted maintenance of wall-tops to reduce water infiltration and seasonal decay.

This demonstrates how the combined analysis of pre- and post-event datasets can effectively support evidence-based restoration and also highlight the importance of digital curation, understood as the long-term management, preservation, and accessibility of digital records,

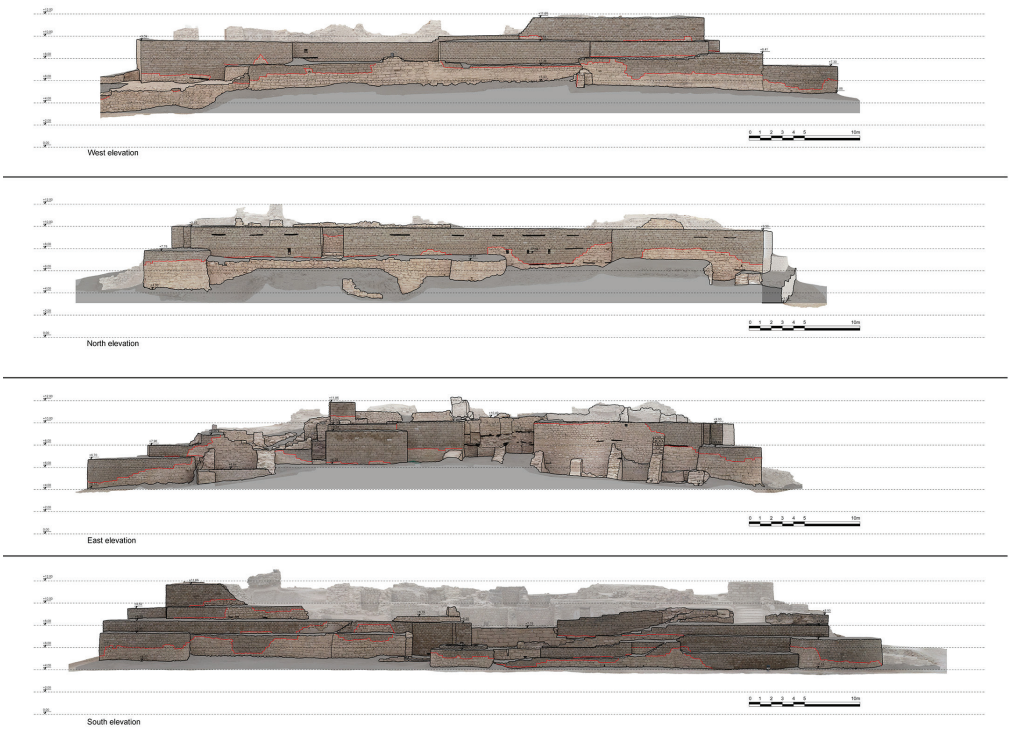



*Figure 10. Elevation drawings of the sides of the citadel before the cyclone Mekunu (drawings by Esplorativa Architetti).*



*Figure 11. Aerial view of the citadel after the completion of the restoration works (8/05/2020, photo by S.M Al Shahri).*



*Figure 12. Example of conservation interventions carried out on the masonry structures of Al Baleed (photo by A. Pavan).*

an essential condition for ensuring that pre-event datasets remain usable and comparable when new emergencies arise.

This aspect is closely linked to data management and long-term preservation strategies. The datasets were organised using standard formats and a georeferenced framework, allowing their integration, comparison, and reuse over time. Particular attention was given to data organisation and consistency in order to support future accessibility. The long-term objective is to make these datasets accessible through an online repository, in line with current practices in digital heritage and open data.

## 4. Documentation as a Tool for Resilience

The experience of Al Baleed highlights the role of documentation as a proactive strategy for heritage resilience in environments exposed to climate extremes. In this context, recording is not a passive act of registration but a preventive measure which anticipates loss by creating a durable, shareable, and verifiable digital record. Rather than constituting only a fully integrated heritage digital twin in the HBIM/ABIM sense, this approach produces a high-resolution digital replica of the citadel, suitable for monitoring, temporal comparison, and evidence-based decision-making. By providing a reliable virtual surrogate of the monument, the ~~digital twin~~ 3D model also reduces the need for repeated technical inspections and direct physical access to structurally fragile areas, an essential strategy for safeguarding vulnerable archaeological contexts (McKenna *et al.* 2025).

At the same time, the citadel is once again accessible to visitors (Figure 13), although with certain restrictions due to structural issues inherent in its original construction techniques. These include the use of perishable materials such as wood, the absence of protective roofing



*Figure 13. Visit to the citadel in July 2025 with a delegation accompanied by the author (photo by S. Al AAmri).*

and wall cappings, and the considerable height of the standing walls, which in some areas exceed 5 metres.

While exceptional events such as tropical cyclones can cause sudden and devastating damage, the most persistent threats to the site are linked to the *khareef*, the southwest monsoon that affects Dhofar every year, from June to September. During this period, continuous humidity, rains, and seasonal vegetation growth profoundly alter the local environment, accelerating the decay of exposed masonry and destabilising the masonry of the citadel.

In this respect, the recording campaigns did not simply preserve the visible state of the structure, but revealed underlying structural vulnerabilities, clarifying how the monument responds to environmental stress. This diagnostic knowledge has direct implications for conservation planning, particularly at a site where the combined effects of humidity, exposed dry-stone masonry, and the absence of protective coverings generate recurrent instability.

When integrated with high-resolution digital data, such insights support a shift from emergency-driven restoration to knowledge-based, preventive maintenance, where documentation becomes the foundation for planning and monitoring conservation works over time.

This approach confirms the importance of interdisciplinary collaboration, a key principle in contemporary digital heritage research. The integration of archaeological, architectural, structural, and information-technology perspectives not only strengthens the reliability of documentation but also enhances its capacity to support sustainable, long-term conservation strategies (Elmas and Altin 2023).

The resilience of a heritage site like Al Baleed lies not in its immunity to decay, but in the ability to preserve, interpret, and manage it through knowledge-based approaches. Such integrated workflows, combining archaeological, architectural, structural and environmental data, can serve as a model for other coastal heritage sites along the Indian Ocean, where the increasing frequency of cyclones, low-pressure systems and sea-level rise poses similar threats. While the workflow presented here demonstrates the potential of integrated digital documentation for heritage resilience, its direct applicability to other contexts may depend on the availability of technical expertise, equipment, and financial resources. However, the underlying methodological approach, based on systematic and multi-scale recording, remains transferable and adaptable to different operational conditions.

The experience of Al Baleed ultimately shows that digital documentation can sustain the continuity of heritage knowledge even when the material fabric is fragile: in this perspective, resilience relies as much on the ability to record as on the ability to restore.

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