# 2024 Season of the University of Naples L'Orientale at Wādī Banī Khālid. From the Excavation to Conservation and Valorisation

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*Abstract*
Since 2019, the University of Naples L'Orientale project at Wādī Banī Khālid has been conducting archaeological research under the patronage of the Italian Ministry of Foreign Affairs and International Cooperation and the Oman Ministry of Heritage and Tourism (MHT). The main research topics focus on mapping archaeological evidence dating from the prehistory to the Late Iron Age and examining its relationship with the coastal environment, particularly the coastal strip between Bamah and Tīwī. Furthermore, archaeological excavations are focused on the main Iron Age settlement (WBK1) and the newly discovered secondary fort (WBK49). Finally, a conservation and valorisation project, within the framework of the MHT's efforts to foster a local economy based on sustainable tourism, was launched in 2022, beginning with initial conservation measures and progressing toward the digital valorisation of the archaeological sites.

*Keyword:* Conservation, Valorisation, Wādī Banī Khālid, Sultanate of Oman, Iron Age, Gamification, Digital Humanities
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## *Introduction*

The project in Wādī Banī Khālid, in the eastern Hajar Mountains, follows 9 years (2014-2022) of research along the coast between Quriyat and Sur (Bamah) and the mountainous areas of al-Hajar, to investigate the relationship between the coastal sites of the region and the larger agricultural oases in the interior, in order to reconstruct the socio-economic dynamics and settlement strategies of the 1st millennium BCE - 1st millennium CE, which are known only through Classical Greek and Roman sources (Loreto in press). This scientific approach proved particularly suited to the renewed Omani ministerial framework following the establishment of the MHT. In fact, on 19 November 2024, the Wakil (Deputy Minister) for the MHT, and subsequently, on 2 December 2024, the team of the Director General for Antiquities, during a field visit, approved the implementation of the conservation and enhancement strategy for the fortified site of WBK1 (4th century BCE - 2nd century CE) within the framework of the 2023-2027 agreement between the University of Naples L'Orientale and the MHT. Therefore, the project proceeded not only with the systematic excavation of the urban sites of Wādī Banī Khālid (WBK1 and the newly discovered WBK49) (Fig. 1), but also with the immediate restoration (consolidation) of the excavated structures, the creation of the first access routes within the WBK1 area, and the preliminary design of both a local museum (Antiquarium) and a digital dissemination system, including a virtual museum supported by a gaming platform. The physical and digital museums are conceived as complementary spaces: the former as a

tangible repository of the material culture unearthed in WBK, and the latter as an interactive environment enabling remote audiences to explore the archaeological landscape through immersive narratives and gamified experiences. In agreement with the MHT, the access staircase to WBK1 was inspected and certified and the first 160m of the visitors' pathways were built.

*Remote sensing and field surveys*

As usual, the project includes remote sensing activities for the complete mapping of the Wādī Banī Khālid catchment area, in order to produce a geoarchaeological remote sensing map as a preparatory tool for field exploration and to serve as reference documentation for the Omani Ministry of Heritage and Tourism (Loreto, Marcolongo 2023, 151-161). The 2024 campaign focused on the outermost stretches of the long watercourse, to the north, intercepting around a dozen structures that could be identified as shelters and referred to the Iron Age; and towards the south, where the results obtained were rather striking. Near the eastern alluvial conoid of the wadi, i.e. immediately at the foot of the mountains from where the wadi inundates the innermost areas of the al-Hajar, near Kamil wal Wafi, a substantial number of mound or turret-type tombs were identified, all of which are deployed on the foothills or on elevations (inselbergs) that stand out on the alluvial plain. The tombs are organised in clusters (i.e. necropolises) and there are at least 1.900 of them. A visit was conducted on 30/11/2024 and it was noted that the number of tombs is higher than what can be detected from satellite imagery, since numerous smaller examples cannot be detected through remote sensing. Given the location of this huge burial field, it is plausible that it was connected to Wādī Banī Khālid environment.

*Excavations in WBK1*

The excavations of 2024 confirm the results observed in 2023, i.e. that the northern wall sector presents the deepest stratigraphy: the newly identified building G/A, visible on surface (a circular structure 12m in diameter), is only the later dwelling phase, datable to the 2nd century CE; it is followed by at least a second phase still datable to the Late Iron Age (2nd century BCE - 1st century CE) and a further occupation phase datable to the Early Iron Age (6th century BCE). The excavation shed light on the nature of the fortifications. Indeed, the earliest phases do not include dwellings but rather a series of quadrangular casemates filled with ceramic (tableware and storage vessels) and chlorite artefacts. Approximately 6.000 ceramic fragments have emerged from the excavation of the lower levels, many of which can be reconstructed; during the campaign, four specimens were restored to provide reference material for the digital dissemination currently in preparation.

*Excavation of WBK49*

WBK49 (sector D), discovered in the 2023 campaign (Loreto in press), appears as a mighty fortress of approximately 80 x 40m protected by casemate walls and characterised by dwelling structures arranged in the centre and along the southern front, where the original access to the site is preserved (Figs. 1, 2). It was decided to start excavations in the vicinity of the dwelling structures (building A/D - 8×9 m – in the centre of the site and buildings B/D and C/D – a total of 24×8 m – on the southern front), while for the casemates that circumscribe the site it was decided to collect any material visible on the surface. The excavations lasted 10 days: the buildings present material that can be dated to the Late Iron Age, in particular to the 2nd century BCE - 2nd century CE, with many comparisons to WBK1 and referable to the Samad horizon.

In light of the number of materials collected (over 5.000 ceramic sherds), we are once again facing with a particularly rich habitation site that, together with WBK1, demonstrates the predominant role of Wādī Banī Khālid in the economy of eastern Oman during the Iron Age.


Fig. 1 - Plan of WBK1 and WBK49 (©University of Naples L'Orientale)

Fig. 2 - Aerial view of WBK1, from the east (©University of Naples L'Orientale)

*Conservation and fruition strategies at WBK1*

In the settlement landscape of the Iron Age in eastern Oman, the fortified site of Wādī Banī Khālid 1 (WBK1) represents one of the most complex and monumental examples identified so far. The settlement is located in the middle section of the wadi course, on a wide limestone terrace overlooking the underlying alluvial plain, in a strategic position for the control of water and agricultural resources. The geomorphological setting, already defined through geoarchaeological analyses and remote sensing, corresponds to a valley basin of about 250 km², structured in terraces and alluvial fans that, since the Iron Age, have supported the development of an "oasis-urban" economy based on the complementarity between agriculture and water management (*falağ*), pastoralism, and territorial control (Loreto, Marcolongo 2023, 150-160).

The fortified site of WBK1 covers an area of approximately c. 1.5 ha (c. 200×100 m) and features a regular layout enclosed by a defensive wall about 650 m long, punctuated by eleven towers set at regular intervals. The wall was built using large wadi cobbles, some up to 1 m in diameter, arranged in a double facing and filled internally with gravel and soil (Loreto 2020, 7-8). The preserved height reaches up to two meters on the northern side, where the natural slope ensures greater stability; by contrast, on the western side, vulnerable to talus erosion, the fortification is partially collapsed. The towers display alternating circular and quadrangular plans; some are integrated within the main wall, while others were added later, indicating at least two main construction phases.

The first corresponds to the original building phase, including the corner and main sectoral towers (T1, T4-T6); the second phase strengthened the defenses by adding new towers along the northwestern side and inserting an additional double curtain on the northern front.

The internal organization of the site, characterized by a "saddle-shaped" profile, shows a clear distinction between the northern sector, densely built-up, and the southern sector, more sparsely occupied and less compact (Fig. 1). In the northern area, numerous domestic units with rectangular or sub-circular plans can be identified, built using the same masonry techniques as the fortifications and directly resting on the rocky substrate, following a construction model common to Late Iron Age sites in central Oman, such as al-Moyassar M34 (Yule 1999, 129, fig. 7), Ṭīwī, Jabal Ṣunsunah (Yule 2016, 61, figs. 22-23), and Lizq (Kroll 2013, 38, fig. 33). The absence of true road axes or an orthogonal layout suggests an organic and incremental development of the "urban" plan, in which domestic spaces gradually adapted to the natural morphology of the slope and to the changing defensive requirements of the site.

*Consolidation of excavated structures*

The activities, initiated in 2019, adopted an integrated methodological approach aimed at combining the consolidation of archaeological structures with landscape enhancement and the preparation of the site for public access. Twelve architectural units, including towers, domestic areas, and partially collapsed wall sectors, were subjected to systematic excavation and conservation interventions. The entire process was preceded by a preliminary diagnostic phase and a degradation mapping, conducted in accordance with international guidelines for the conservation of porous materials (Torraca 2005, 83). During this phase, altimetric elevations, planimetric layouts, and damage maps were accurately recorded in order to document the pre-intervention state of preservation and to provide a reference framework for subsequent phases of intervention and monitoring.

The analysis of degradation phenomena revealed the widespread presence of collapses, superficial detachments, and loss of cohesion in the earthen binder, caused both by surface runoff from rainwater and by the abrasive action of wind and seasonal thermo-hygrometric fluctuations. This condition of fragility is

typical of the arid and semi-arid contexts of eastern Oman, where the clay component of sediments tends to disintegrate due to cyclical expansion and contraction. The construction technique at WBK1, based on unworked river cobbles laid dry and on beaten-earth floors, therefore required targeted action to protect both foundation levels and walking surfaces, following principles of minimal intervention and material compatibility, in accordance with the general ICCROM and ICOMOS guidelines.[1]

The initial intervention strategies focused on protecting the foundation walls through the construction of low retaining structures. These were designed to respect the original geometry of the architecture, using only local cobbles collected from the wadi bed, with the aim of minimizing both the visual and mechanical impact on the ancient structures. The use of modern high-rigidity mortars was avoided and replaced with loose materials compatible with the original construction system.

For the beaten-earth floors, subject to pulverization and disintegration, a procedure successfully tested at the site of Dūmat al-Jandal (Saudi Arabia) was adopted (Loreto 2017). This involved the application of a natural 10% gum arabic solution diluted in water, applied in three consecutive cycles. Gum arabic, chosen for its low salt solubility,[2] its ability to form a breathable protective film,[3] and its full reversibility,[4] proved to be perfectly compatible with the physical and chemical characteristics of WBK1's building materials. Thanks to the soil's natural porosity, the organic substance was deeply absorbed, generating a stable and natural cohesive effect.

Tests conducted in 2022 and verified in 2024 approximately one centimeter and the continued activity of the consolidant, thus confirming both the durability of the treatment and its long-term compatibility with the original materials (Fig. 3).

In line with the principles of preventive conservation, the project included the implementation of a systematic monitoring and maintenance plan. All interventions were thoroughly documented through high-resolution metric and photogrammetric surveys, processed using *Agisoft Metashape* software to generate high-density, georeferenced 3D models. This approach allowed precise recording of the geometry of the consolidated structures, the detection of micro-volumetric variations, and the monitoring of possible deformations or material losses over time. The photogrammetric acquisition, integrated with close-range photography and aerial drone imagery, produced detailed documentation of the consolidation areas and treated surfaces, providing a comparative baseline for future stability assessments and evaluations of the conservation treatments' effectiveness.

A scheduled maintenance plan was also established, including the periodic cleaning of surfaces, control of salt efflorescence and superficial disintegration, localized filling of sediments in correspondence with gaps or erosions, as well as systematic photographic surveys at the end of each excavation season.

Conservation, in this perspective, is conceived as a dynamic and continuous process rather than a definitive intervention. The awareness that every consolidation action represents a temporary phase within a cycle of monitoring and periodic review constitutes one of the most innovative aspects of the WBK1 protection plan. In this sense, the intervention forms part of a broader strategy of landscape protection and integrated site management, in which the material safeguarding of structures is interwoven with visitor planning, risk mitigation, and environmental enhancement. This approach, consistent with international guidelines, recognizes that conservation is never "once and for all," but requires continuity, adaptability, and shared responsibility over time.

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[1] Si vedano ICOMOS 1990, art. 3 e art. 5; Feilden, Jokilehto 1987, 61-66.

[2] For further details on the composition and properties of the Arabic gum, see Masschelein-Kleiner 1995, pp. 49-50.

[3] *Ibidem*.

[4] Regarding its characteristics and reversibility, see also the text *Adhesives* (Albro *et al.* 1989, 14-16).

Fig. 3 - The result of the 2022 test in 2024. Up, consolidated floor; down, not excavated floor (©University of Naples L'Orientale)

*Access to the site*

After identifying an appropriate solution to keep the residential areas clear and facilitate visitor accessibility, in 2023 the project initiated the construction of a stable and safe access system that would allow controlled entry to the site in harmony with the site's natural morphology (Fig. 4). The intervention area, located on the northwestern slope, features a steep incline covered with loose deposits, showing clear signs of surface instability and erosion caused by seasonal runoff. The geometric alignment of the staircase was defined through slope analysis and hydrological modeling, ensuring minimal interference with existing drainage lines. The intervention followed a principle of morphological compatibility, adopting gradients that respect the natural runoff to prevent future erosion and water stagnation.

The layout of the new pathway was defined following a topographic and photogrammetric survey, conducted to analyze the slope gradients and the configuration of the rocky substrate. Based on this analysis, a 45-metre-long access staircase was designed and positioned along the most stable portion of the slope. The structure is entirely built with medium- and large-sized local river cobbles, laid dry and laterally reinforced with gravel and wadi sand, ensuring effective drainage and adaptability to minor ground movements.

Each step was shaped according to the natural contour of the terrain, avoiding any cutting into the bedrock or the use of invasive anchoring. The intervention, fully reversible in nature, allows visitors to ascend comfortably to the western edge of the defensive wall, where the pathway directly connects to the internal walkways arranged for the exploration of the domestic and defensive structures.

Particular attention was also devoted to the visual integration of the staircase within the surrounding landscape: the materials, selected from those collected on site, replicate the natural hues of the soil and are almost indistinguishable from a distance. In this case as well, progressive photographic documentation was undertaken during construction, serving both for geometric verification and for the long-term monitoring of structural conditions.

Today, the pathway provides safe access to the site, reducing human impact and limiting uncontrolled visitor movement. This solution, simple yet technically refined, has made possible the direct enjoyment of the archaeological area without altering its original perception or interfering with the legibility of the ancient structures.

Fig. 4 - The access staircase, view from the west (©University of Naples L'Orientale)

*Visitor pathways*

Once the main access to the site had been secured, the planning of visitor circulation focused on defining internal walkways conceived as interpretive routes within the archaeological landscape. Their design goes beyond the mere logistical function of circulation, assuming the role of a narrative and interpretive "corridor" intended to convey to the visitors the spatial and topographical perception of the site as it may have appeared during its Iron Age occupation.

The system of walkways, structured as a "continuous network," connects the various sectors of the settlement, towers, residential quarters, storage areas, and the edges of the defensive perimeter, thus enabling a gradual understanding that progresses from the architectural to the territorial scale (Fig. 5). At present, the pathways extend for a total length of about 160 meters, distributed across four main routes: two aligned along the internal axis of the settlement, one tangent to the eastern defensive wall, and another newly designed path leading toward the area designated for the Wādī Banī Khālid *Antiquarium*, located downstream of the site and near a potential visitor parking area.

This latter route serves as the concluding axis of the visitor experience, an itinerary guiding visitor from the ancient residential fabric to the contemporary museum context. The dual function of these walkways ensures, on the one hand, physical and visual continuity between the site and the museum, and on the other, translates into museographical terms the principle of the knowledge circularity, according to which the understanding of archaeological data arises both through direct observation in situ and through

its interpretive display. Along these routes, rest points are marked by interpretive stations, small areas paved with stabilized cobbles and bordered by low stone curbs, designed to host permanent informational panels.[5]

The layout of the pathways is based on two parallel rows of small river cobbles, once again selected for their color and grain size consistent with the surrounding soil. This solution, devoid of anchors or artificial substructures, makes it possible to visually indicate the path without interfering with archaeological stratigraphy. The surface is leveled with a light layer of sand and gravel, sufficient to stabilize walking while remaining permeable to rainwater, thus reducing surface runoff. The average width of the corridors varies between 80 cm and 1.2 m, depending on soil conditions and the need for wider circulation near rest areas.

From a perceptual standpoint, the internal walkways were conceived as a sequence of panoramic viewpoints. The alignment of the paths, often tangent to the wall structures, allows visitors to closely observe the construction details of towers and dwellings, while also perceiving the volumetric relationship between the buildings and the surrounding landscape (Fig. 6). The progression from the central residential sector toward the outer wall leads to natural terraces overlooking the wadi valley, offering a comprehensive view of the entire complex and its strategic position.

Particular attention has been devoted to reversibility and maintenance. The pathways can be removed without leaving permanent traces, while the information panels can be anchored to shallow stone bases. An annual maintenance plan has been established, including leveling checks, sediment removal, and verification of the legibility of the informational supports, in order to maintain consistent perceptual quality and visitor safety.

The functional integration with the *Antiquarium* enhances the value of the visitor experience, establishing WBK1 as a unified center for territorial interpretation: the site and the museum are conceived not as separate entities, but as complementary parts of a single narrative system. The physical connection between the two spaces transforms the visitor experience into a circular journey in which scientific understanding and sensory perception mutually reinforce one another. The *Antiquarium* is envisioned as part of a wider landscape system. Its spatial layout draws on the morphology of the wadi and the stratigraphic logic of excavation, translating the archaeological section into an inhabitable narrative sequence.[6] The design thus aims to restore a continuity between architecture, terrain, and memory, acting as trait de union between history and territory

Looking ahead, the internal pathway network and its connection with the *Antiquarium* will form the foundation for future programs of heritage education and sustainable cultural tourism, integrating WBK1 into the network of visitable sites in the eastern Hajar and strengthening the relationship between archaeological research, the local community, and territorial enhancement.

[5] The display panels, conceived during a preliminary design phase that prioritizes structural longevity and minimal perceptual interference with the surrounding archaeological landscape, are based on a load-bearing frame made of satin-finished stainless steel, treated with a matte surface finish to reduce light reflection, and on a multilayer fiberglass didactic cladding whose composite profile ensures effective protection against prolonged exposure to climatic variations. Each element will feature bilingual texts (Arabic-English) accompanied by site plans, excavation photographs, and reconstructive drawings.

[6] "The city is the locus of the collective memory. [...] The relationship between the *locus* and the events that take place within it determines the image of the city." (Rossi 1982, 30).

Fig. 5 - The building of the visitor pathways, from the wall's perimeter leading toward the inner part of the site (©University of Naples L'Orientale)

Fig. 6 - The building of the visitor pathways following the wall's perimeter (©University of Naples L'Orientale)

*A digital valorisation for Wādī Banī Khālid*

In line with the Ministry's strategic planning, the creation of a local museum (*Antiquarium*) intended to house and showcase the artefacts unearthed during the WBK excavations is currently under evaluation.

Alongside the material conservation interventions, a digital valorization strategy has been developed, envisioning the development of a dedicated web portal and, in the longer term, the establishment of an integrated digital museum. This museum will include both a virtual reconstruction of the archaeological site and a three-dimensional representation of the future physical museum.[7]

This dual infrastructure, both physical and digital, reflects the strategic vision of the Ministry of Heritage and Tourism, which regards the heritage digitalization as a means of ensuring the continuity of knowledge and promoting collective participation (Al-Raee 2022) by combining digital humanities (Mehta, Hemmy 2021, 56-58), methodological rigor, public engagement, and technological management. In architectural terms, the physical and digital dimensions are conceived as complementary spatial experiences. The built *Antiquarium* defines a material continuity with the stone and sediment of WBK1, while the virtual counterpart extends its perceptual horizon, reconfiguring the notion of place through augmented spatial narratives (Pallasmaa 2012, 44-50).

In the specific case of Wādī Banī Khālid, digitalization transcends the role of a simple educational or dissemination tool, taking on an epistemic function that extends the scope of archaeological research. It links the material dimension of archaeological data to its digital representation, establishing a continuum between observation, modeling, and interpretation. Within this framework, digital valorization becomes an integral part of the cognitive process, as it transforms archaeological data into a shared communicative and analytical language.[8] This approach, already successfully tested in Oman, has proved particularly effective

[7] A precedent is represented by the Virtual Museum of Salūt project, which was the first to translate the three-dimensional documentation of an Omani archaeological site into a museum format, experimenting with an interactive model of engagement based on the integration between digital reconstruction and the physical exhibition space (Tagliamonte 2019, 174-176).

[8] An effective digitalization process cannot exclude the participation of local communities, since the authenticity of heritage does not reside solely in the geometric accuracy of its representation, but in the capacity to reflect the values, memories, and practices embedded within it. Digital documentation of heritage, especially in the contexts of the Arabian Peninsula, cannot be conceived as a mere technical operation of surveying and modeling, but rather as a complex cultural practice that encompasses material,

in educational contexts, fostering active learning ("learning by doing"; See Mortara *et al.* 2014, 319) and encouraging positive engagement with archaeology among school-age students (Ambusaidi, Al-Rabaani 2019, 499-500).

Through digital applications, from 3D surveying to modeling, a form of active preservation is thus established, capable of ensuring the continuity of knowledge even in the absence of direct physical contact with the site. In this perspective, digital documentation of heritage should not be understood as a mere replica of the object, but rather as an ecosystem (Forte 2004, 424) of relationships among data, context, and interpretation (Buragohain et al. 2024, 4-5), in which cultural value emerges through the interconnection of multiple informational layers. Such an approach draws on the epistemology of *designing for experience* (Wright, McCarthy 2010), in which the visitor's embodied interaction becomes the primary medium for learning and interpretation (*ibid.*, 17-24).

The theoretical framework underpinning the site's digital enhancement site is grounded in the idea that playful mechanisms and interactive participation serve as key drivers for knowledge construction and cultural mediation. Digital engagement is not conceived as a passive consumption of content, but as a situated learning experience in which users are invited to explore, interpret, and connect information through a process of action and response.[9] In this dynamic, play, understood in its anthropological sense as a tool for the symbolic re-elaboration of reality, becomes the cognitive paradigm through which the virtual environment transforms into a shared space of knowledge. This convergence between play and learning also aligns with current research in *game-based design for cultural heritage*, which explores how immersive environments can extend interpretive depth and foster empathy through spatial storytelling. Here, design operates not as a static display mechanism but as a dynamic medium for speculative reconstruction and critical imagination (Champion 2019, 34-52).

It is precisely within these dynamics that continuity emerges between popular and vernacular arts (of which the *Antiquarium* will host a dedicated section) and digital media. The virtual dimension thus stands out as a "living art form," capable of evoking emotion, identification, and a sense of belonging, not through contemplation, but through action (Jenkins 2005, 23). Within this same perspective, a video game has been conceived, grounded in interaction[10] and the aesthetic-cognitive response model (MDA),[11] capable of

symbolic, and participatory dimensions. As Thompson (2016, 211-226) has pointed out, the process of digital preservation in Gulf sites, particularly in the case of Al Jazeera Al Hamra, must be interpreted as an act of mediation between memory and representation, in which technology does not replace heritage but translates its historical and semantic depth into a new language. From this perspective, digitalization is not limited to reproducing the visible image of an object; it becomes a tool of cultural continuity, capable of preserving not only the architectural form but also the social memory and lived experiences that gave rise to it.

[9] Digital engagement is not conceived as the passive consumption of content, but as a situated learning experience in which the user is invited to explore, interpret, and connect information through a process of action and response, within a regulated environment that suspends ordinary reality to create new forms of meaning. For the concept of play as a cultural act and generator of meaning, see *Homo Ludens* by Huizinga (1949).

[10] Interaction, in fact, is the essential condition of its effectiveness: the player acts, experiments, and transforms, becoming an integral part of the aesthetic and cognitive process. The contemporary game designer, as observed by Crawford (Crawford 1984, preface XI-XIV), is an artist capable of anticipating and orchestrating the user's reactions, shaping a narrative system that generates surprise, tension, and emotional engagement.

[11] The structural formalization of these processes can be interpreted through the Mechanics-Dynamics-Aesthetics (MDA) model, formulated by Hunicke, LeBlanc, and Zubek (2004) and later reinterpreted within participatory and museological frameworks (Junior, Silva 2021; Bunt *et al.* 2024). This model provides a valuable conceptual framework for understanding how digital engagement can be conceived as an act of cognitive interaction rather than as mere visual consumption or entertainment activity. The model describes games, and, by extension, any interactive system, as a process articulated across three complementary levels: *mechanics*, that is, the rules and structures that define possible actions; dynamics, the ways in which those rules generate emergent behaviors and responses; and *aesthetics*, the emotional, perceptual, and intellectual experience produced in the player. From this

translating archaeological complexity into a narrative system where discovery and learning unfold through experimentation, hypothesis, and verification. The visitor, assuming an active role in the process, does not merely observe the reconstruction but inhabits and questions it, personally reconstructing the meaning of the data and material traces. The ludic dimension, in this sense, does not diminish the scientific value of representation but rather expands its communicative potential, making archaeological knowledge accessible, experiential, and reflective. This approach, chosen for WBK, aligns with the most recent museological reflections (Hooper-Greenhill 2007, 25-26) that conceive the museum, whether physical or virtual, as a place of active learning. The contemporary visitor is no longer a passive recipient of content[12] but an active co-author of interpretive experience. In this view, the virtual museum does not merely reproduce the archaeological site but translates its cognitive structure: exploration replaces guided tours, discovery takes the place of explanation, and learning arises from direct engagement with data and its complexity.[13]

The digital valorization of Wādī Banī Khālid thus presents itself as a model of immersive and reflective education, in which technology enhances the cognitive relationship between individuals and heritage. The virtual museum becomes an epistemological laboratory where material culture, perception, and memory interact in real time, transforming the act of visiting into a critical practice of learning. The adoption of these principles goes beyond the educational sphere and reflects a broader museological conception of the museum as a communicative space: digital museography redesigns the conditions of spatial experience, transforming navigation into a process of knowledge construction. At the same time, digital valorization fully integrates into the paradigm of the digital humanities applied to archaeology, in which technology assumes an analytical and reflexive role. WBK1 thus stands as an exemplary case of transdisciplinary research, where archaeology opens itself to new languages of investigation and communication. The project aims to demonstrate how digital design methodologies as parametric modeling, real-time rendering, and spatial interface prototyping, can serve as epistemic instruments in archaeological research.

It should be emphasized that the digital strategy adopted at Wādī Banī Khālid responds to a clear political and cultural vision of heritage as a shared good, consistent with the directives of *Oman Vision 2040*, which identifies digital culture as a central pillar of national sustainability. The creation of an integrated system of valorization, both physical and virtual, local and global, represents a step toward defining a replicable model for the management of Omani archaeological sites, capable of uniting scientific research, conservation, and social participation. In this sense, digital valorization does not mark the conclusion of the WBK1 project, but its natural continuation within the immaterial domain of knowledge.

perspective, the virtual museum is not conceived as a closed space but as a modular learning environment in which knowledge is constructed through the interaction of rules, freedom, and narrative. The user, moving within a system of defined but non-prescriptive possibilities, exercises a form of cognitive autonomy that symbolically reproduces the inferential logic of archaeological research: observing, hypothesizing, and verifying.

[12] According to Eilean Hooper-Greenhill (2007), the contemporary museum no longer communicates in a unidirectional way but operates through interpretive processes in which the audience actively constructs the meaning of the experience. The visitor, therefore, does not receive a predefined message but participates in the negotiation of meaning within the exhibition and its contents.

[13] Antinucci (2014, 82) defines the museum as "a system of cognitive communication," in which knowledge is constructed through perception and interaction. As he observes, cultural transmission in the contemporary museum can no longer rely on the static display of objects but must activate a network of signs and relationships that enables the audience to reconstruct the meaning of an artefact or context autonomously.

*The Digital Museum as Gaming Platform*

The design of the virtual museum of Wādī Banī Khālid represents the operational synthesis of the documentation, modeling, and communication processes that have accompanied the archaeological field research activities. The primary objective was not merely the production of a visual artifact, but the creation of an interactive knowledge system grounded in the empirical verification of data and the controlled reproduction of the landscape and architectural context. The workflow was structured in a sequence of integrated phases. First, the previously mentioned photogrammetric and topographic surveys conducted on the site enabled the creation of digital terrain models (DTM), which provided the metric and morphological foundation of the project. These models, processed and optimized in *World Machine*, underwent a geomorphological simulation process that faithfully reproduced the natural landforms of the area, the alluvial slopes and depositional zones, yielding a scientifically coherent and highly realistic representation of the archaeological landscape. The terrain and morphological data were processed through a hybrid GIS–3D workflow. The digital terrain model (DTM) was imported into Unreal Engine to reconstruct the topography in 3D, where material shaders were applied to enhance visual realism and maintain consistency with the morphological data.

For many of the architectural features, modeling was carried out in *Blender* (Corrado 2020, 132), an open-source software selected for its ability to handle large amounts of geometric data and its compatibility with major 3D interchange formats. All structures, walls, towers, domestic units, and service areas, were reconstructed to scale; during this phase, digital models of selected artifacts were also integrated, derived from photogrammetric surveys of diagnostic materials and reprocessed as optimized meshes for interactive visualization. The digital modeling phase was approached emphasizing the material legibility of surfaces and volumes. Polygonal density, texture fidelity, and light response were calibrated to reproduce the sensorial experience of mass, lightness, and depth typical of the site's lithic architecture.

The texturing process combined original photogrammetric materials with digital resources chromatically to correspond to actual surface tones. This stage, essential for both perceptual rendering and model legibility, was conceived as a *data fusion* operation, in which high-resolution textures were mapped with physical properties closely corresponding to the actual archaeological materials. The use of open-source resources and the adoption of interoperable standards respond to the need to ensure transparency, replicability, and long-term preservation of digital data, core principles of research within the digital humanities.

The subsequent phase of rendering and immersive simulation was carried out in *Unreal Engine* 5, selected for its ability to handle high-polygon environments in real time. The *Nanite* technology enabled the visualization of models with high geometric density without the need for mesh reduction or baking, thus preserving the full detail of structural elements. The integration of Nanite virtualized geometry allowed polygon counts to be processed without compromising frame rate performance, maintaining the full-resolution geometry.

Nevertheless, the increase in the number of three-dimensional assets posed performance optimization challenges, since each landscape element (stones, fragments, debris) was assigned was assigned specific physical and collision properties. To mitigate the computational load, a multilayer *Level of Detail* (LOD) system and *occlusion culling* strategies were implemented, dynamically managing visibility based on the observer's distance.

Global illumination was handled through the *Lumen* system, which allows for the simulation of indirect light propagation and ensures photometric accuracy consistent with real environmental conditions. The atmospheric context was further refined through the calibration of dynamic parameters, such as

variations in brightness, air density, and dust particle distribution, adjusted to values closely matching real-world conditions. This approach aimed to reproduce the perceptual quality of the landscape, balancing realistic fidelity with immersive plausibility.

Within this framework, the interactive component was designed to encourage active visitor participation. A controllable avatar (Fig. 7) was developed, equipped with third-person navigation controls and the option to switch to first-person view during exploration phases. The walking system follows the actual topography of the site and integrates the dynamic resistance of the terrain, simulating friction and slope gradients. The interactive system was designed with a performative logic, parameters such as acceleration, gravity, and terrain feedback were fine-tuned to induce a bodily awareness of spatial resistance. These design choices do not pursue playability in a strict sense but rather aim to generate a cognitive experience grounded in the bodily perception of the archaeological space.

Fig. 7 - The avatar inside WBK1 is looking at the Digital Museum (©University of Naples L'Orientale)

A second level of the digital environment hosts the virtual museum (Fig. 8), conceived as an interpretive extension of the site. Within it, visitors can interact with 3D models of the artefacts, rotating, zooming, and examining them in detail, while accessing their technical descriptions, excavation photographs, and related site plans. A *virtual photography* mode has been implemented, allowing visitors to document their exploration and create personal archives. Free from the physical constraints of space and conservation, the museum can potentially host an unlimited number of objects, functioning as an expandable, multilayered archive. The notion of the museum as a dynamic database extends the concept of spatial design beyond its material boundaries. Here, data curation and interface design become architectural operations that shape the visitor's spatial and cognitive experience. The architecture of information thus mirrors the architecture of the site, maintaining a formal and conceptual continuity between the physical and digital realms. The structuring of the database follows the same logic as the architectural project: modular, hierarchical, and relational. In both cases, the design process constructs systems of spatial meaning, whether material or informational, capable of being navigated, expanded, and interpreted. The architecture of information thus operates as an invisible infrastructure of place-making, bridging computational logic and architectural form.

The platform has been optimized for execution on Windows systems to ensure maximum compatibility and accessibility with standard IT infrastructures. At the same time, a prototype *augmented reality* (AR) module is under development, designed to project portions of the virtual museum into the physical context, thereby integrating remote experience with on-site presence. This extension, in line with the most recent developments in *augmented, virtual, and mixed reality* (Bekele *et al.* 2018, 1-30), aims to establish a model of hybrid engagement in which digital interaction does not replace the real experience but enhances it and extends its persistence over time.

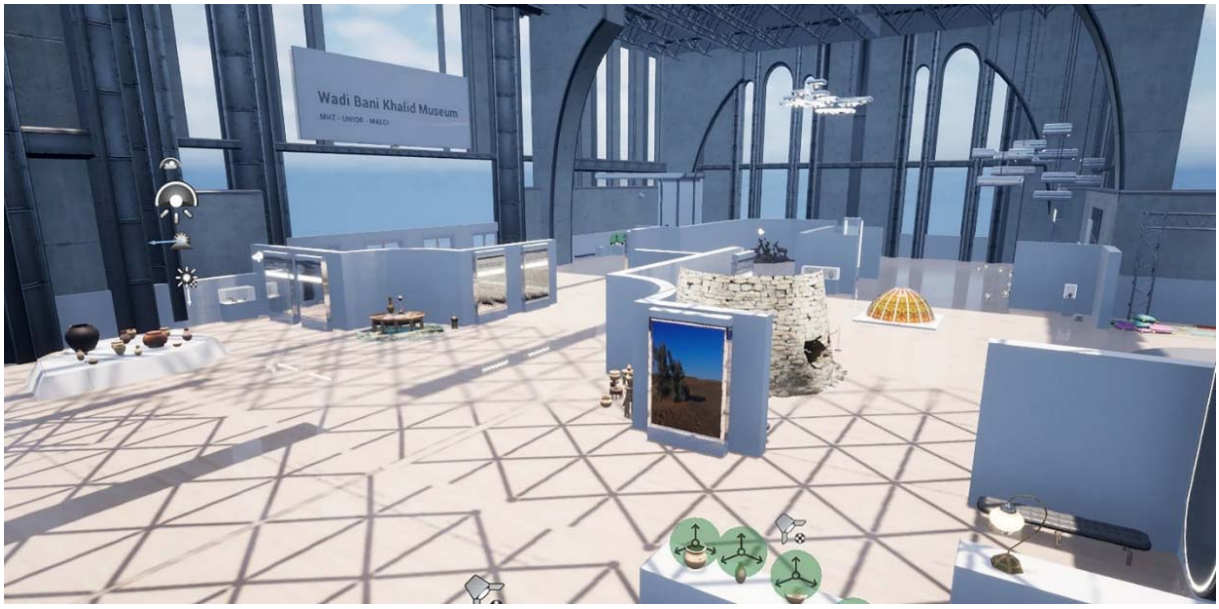


Fig. 8 - A scene inside the Digital Museum in standpoint visual navigation (©University of Naples L'Orientale)

From a methodological standpoint, the creation of the Wādī Banī Khālid virtual museum demonstrates that the technological workflow is an integral component of the scientific construction of heritage. Modeling, simulation, and interactivity become stages of a unified process of mediation, where metric accuracy converges with perceptual understanding and knowledge transmission. In this perspective, the virtual museum constitutes a continuously evolving research environment, open to future updates and reinterpretations

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REFERENCES

Albro, S.R., S. Bertalan, A. Dwan, H. Krueger, E.C. Leslie, K. Nicholson, K. Schenck, A. Seibert, D. van der Reyden, T.B. Wallis (1989) Adhesives, in C.I. Maynor (ed.), *Paper Conservation Catalog, 6th edn*. (American Institute for Conservation) Washington D.C.

Al-Raee, A.A. (2022) *Displaying the Nation: The Role of Museums in the Expression of National Identity in the Sultanate of Oman*. [Phd. Thesis, University of Birmingham].

Ambusaidi, N.A., A.H. Al-Rabaani (2019) The Efficiency of Virtual Museum in Development of Grade Eight Students' Achievements and Attitudes towards Archaeology in Oman, *International Journal of Educational Research Review* 4, pp. 496-503.

Antinucci, F. (2014) *Comunicare nel museo*. Roma.

Bekele, M.K., R. Pierdicca, E. Frontoni, E.S. Malinverni, J. Gain (2018) A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage, *Journal on Computing and Cultural Heritage* 11/2, pp. 1-36.

Bunt, L., J. Greeff, E. Taylor (2024) Enhancing Serious Game Design: Expert-Reviewed, Stakeholder-Centered Framework for Serious Games, *JMIR Serious Games* 12, pp. 1-22.

Buragohain, D., Y. Meng, C. Deng., Q. Li, S. Chaudhary (2024) Digitalizing cultural heritage through metaverse applications: challenges, opportunities, and strategies, *Heritage Science* 12, pp. 1-16.

Champion, E. (2019) *Critical Gaming: Interactive History and Virtual Heritage*. London.

Corrado, L.A. (2020) Il vasellame in pietra dagli scavi italiani de "L'Orientale" di Napoli a Bimah, Sultanato dell'Oman, *Newsletter di Archeologia CISA* 11, pp. 125-146.

Crawford, C. (1984) *The art of computer game design: reflections of a master game designer*. Berkeley, California, USA.

Feilden, B.M., J. Jokilehto (1987) *Management Guidelines for World Cultural Heritage Sites* (ICCROM). Roma.

Forte, M. (2004) Dal reale al virtuale verso una comunicazione arricchita?, *Archeologia e Calcolatori* 15, pp. 423-448.

Hooper-Greenhill, E. (2007) *Museums and Education: Purpose, Pedagogy, Performance*. London.

Huizinga, J. (1949) *Homo Ludens. A Study of the Play-Element in Culture*. London.

Hunicke, R., M. LeBlanc, R. Zubek (2004) MDA: A Formal Approach to Game Design and Game Research, *Proceedings of the AAAI Workshop, Challenges in Game AI* 4, pp. 1-5.

Jenkins, H. (2005) Games, the New Lively Art, in J. Hartley (ed.), *Creative Industries*, pp. 175-189. London.

Junior, R., G.M. Silva (2021) Redefining the MDA Framework. The Pursuit of a Game Ontology, *Information* 12, pp. 1-19.

Kroll, S. (2013) The Early Iron Age Fort at Lizq. Sultanate of Oman, *Zeitschrift für Archäologie Außereuropäischer Kulturen* 5, pp. 159-220.

Loreto, R. (2017) Note on the Fourth Season of the Italian Restoration Project in Kingdom Saudi Arabia, Dūmat al-Jandal, *Newsletter di Archeologia CISA* 8, pp. 123-133.

Loreto, R. (2020) A Late Iron Age settlement in Wādī Banī Ḫālid: First season of the joint Omani-Italian archaeological project, *Arabian Archaeology and Epigraphy* 31, pp. 365-392.

Loreto, R. (in press) *Ichthyophagoi*: their culture and economy. 10 years of archaeological activities along the River Ocean shores within the northern Oman Iron Age, *Proceedings of the Conference Egitto e Vicino Oriente Antichi*, Turin, Eothen.

Loreto, R., B. Marcolongo (2023) *Manuale di geoarcheologia. Un approccio geomorfologico da remoto*. Napoli.

Masschelein-Kleiner, L. (1995) *Ancient Binding Media, Varnishes and Adhesives* (ICCROM) Roma.

Mehta, R.A., K. Hemmy (2021) Digital Humanities in Oman: Logistics, Challenges and Opportunities, *Knowledge Cultures* 9, pp. 56-74.

Mortara, M., C.E. Catalano, F. Bellotti, G. Fiucci, M. Houry-Panchetti (2014) Learning cultural heritage by serious games, *Journal of Cultural Heritage*, *Elsevier* 15, pp. 318-325.

Pallasmaa, J. (2012) *The Eyes of the Skin: Architecture and the Senses.* Chichester.

Rossi, A. (1982) *The Architecture of the City*. Cambridge.

Tagliamonte, E. (2019) Il Museo Virtuale di Salut. Alla Scoperta del Cuore dell'Oman, in D. Frenez, M. Cattani (eds), *Dreamers, 40 Anni di Ricerche Archeologiche Italiane in Oman* (BraDypUS Communicating Cultural Heritage), pp. 174-176. Roma.

Thompson, S. (2016) Digitally Preserving the Heritage of the Arabian Peninsula: Al Jazeera Al Hamra Considered, in G. Katodrytis, S. Syed (eds), *Gulf Cities as Interfaces* (Gulf Research Centre Cambridge), pp. 211-228. Cambridge UK.

Torraca, G. (2005) *Porous Building materials. Materials Science for Architectural Conservation* (ICCROM). Roma.

Yule, P. (1999) The Samad period in the Sultanate of Oman, *Iraq* 61, pp. 121-146.

Yule, P. (2016) Valorising the Samad Late Iron Age, *Arabian Archaeology and Epigraphy* 27, pp. 31-71.

Wright, P., J. McCarthy (2010) *Experience-Centered Design: Designers, Users, and Communities in Dialogue*. San Rafael.