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For a Perception of Monumentality in Eastern Arabia from the Neolithic to the Bronze Age: 3D Reconstruction and Multidimensional Simulations of Monuments and Landscapes

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Figure 1: Dhabtiyah archaeological site, Saudi Arabia

ABSTRACT

The monumentality of Neolithic and Early Bronze Age (6th to 3rd millennium BC) structures in the Arabian Peninsula has never been approached through a comprehensive approach of simulations and reconstructions. As a result, its perception remains understudied. By combining archaeological and paleoenvironmental data, 3D reconstruction, 4D simulations, virtual reality and generative AI, this PhD research project proposes to analyse the perception of monuments, exploring their spatial, visual and temporal dimensions, in order to answer to the following question: how can we reconstruct and analyse the perception of monumentality in Eastern Arabia through 4D simulations, and how can the study of this perception influence our understanding of monumentality and territories?

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This article presents a work in progress, after three months of research of which one month on the Dhabtiyah archaeological site (Saudi Arabia, Eastern Province).

Index terms: Monumentality, Virtual Reality, 3D reconstruction, 4D simulations, Eastern Arabia

1 INTRODUCTION

Neolithic and Bronze Age were marked in the Arabian Peninsula by the emergence of monumentalism, a crucial stage in social changes. These large structures seem to have played a role in territorial organisation and spatial orientation, perhaps marking routes of circulation, resources and gathering places [9]. However, in the absence of written documents, studying monumentality and territories requires considering the visual links between monuments, their locations, architecture, lighting and, more generally, their perception within their environmental context.

The 4D simulation of archaeological sites and the use of generative Artificial Intelligence (AI) open up new perspectives for understanding this monumentality. This project focuses on the perception of monumental structures, particularly in Saudi Arabia, through their 3D reconstruction and that of their environments, using archaeological data and digital tools. The multi-dimensional

space also incorporates the fourth dimension, time, through the observation of environmental changes, light exposure and the simulation of human activities associated with these monuments. This involves the development of an innovative methodology that can be applied to different environmental and cultural contexts.

In order to achieve these goals, this PhD research project aims to fulfil several objectives:

- Create 3D representations of monumental structures within their reconstructed hypothetical environments, based on excavation and paleoenvironmental data.
- Examine monument architecture to study their impact, especially the influence of materials, on the perception.
- Simulate varying vegetation covers to document their influence on the perception of structures.
- Conduct lighting simulations to understand the role of light in perception.
- Simulate hypotheses of ceremonial processions or deposits when archaeological data are sufficient.
- Study general perception of structures and analyse relationships between visibility, monumentality, and territory through virtual reality immersion.
- Propose an enhancement of archaeological heritage through 3D reconstructions and 4D simulations, *in situ* (museums) or online supports.

2 CONTEXT AND STATE OF ART

The Neolithic and Bronze Age (6th-3rd millennium BCE) are characterized by a wide variety of megalithic structures in both northern and southern Arabia. Interpreted as cenotaphs, sanctuaries, or ceremonial gathering places, these structures reflect the impact of communities on their environment and a strong territorial marking [8]. These structures include long alignments of stones (such as *mustatils* or pendants [12]), trapezoidal or rectangular platforms [7, 9], dolmens [11, 13], and steles and stone circles.

From the Bronze Age (3rd millennium BCE) onwards, tens of thousands of monumental megalithic tombs, shaped like towers or igloos, mark the entire Arabian Peninsula. Often grouped in necropolises, these tombs are located on high points of the landscape or form true "funerary avenues" [2, 8]. They exhibit various morphological types and are sometimes associated with alignments of standing stones (trains), triangular structures, circular enclosures, or stacked stone structures (caissons) [8].

These dry-stone monuments, known but understudied until the 1970s, have only recently become the focus of extensive research, particularly through aerial and satellite surveys. They reflect the increasing complexity of societies and their practices, seemingly indicating a desire to mark territory and legitimize the ancestral authority of communities. To shed light on these and other aspects, attention has now turned to their perception within landscapes, opening new research avenues. This perception will be analysed using 3D reconstruction and 4D simulation methods, integrated in virtual reality, enabling a multidimensional study.

Virtual Reality (VR), as defined by Philippe Fuchs in 2006, provides a sensorimotor and cognitive experience within a virtual environment [4]. It relies on technical and computational devices that simulate and immerse the user in real-time. This definition is based on two key and intrinsically linked concepts: immersion and interaction. Immersion stimulates and isolates the user's senses, particularly vision and hearing, while interaction is based on the user's ability to act and react within the environment. Thus, the use of virtual reality allows for an enhanced perception experience by immersing users within 4D simulations.

However, before it can be fully utilized, it is necessary to begin with an essential step: the 3D modeling of virtual environments. The use of 3D in archaeology dates back to the 1990s. During this

period, it primarily concerned the 3D digitization of archaeological sites and artifacts. Notable examples include the 3D model of the Lascaux Cave (Périgord) and others projects such as *Rome Reborn* [3]. While these 3D reconstructions were often carried out with conservation or promotion goals, research interest has developed in recent decades, particularly with the integration of 4D. For instance, the restitution of the awning of the Theatre of Pompey, which allows for solar simulations, or various projects involving the study of objects in action, such as the operation of a Roman ballista, are noteworthy. Nevertheless, 4D is still used marginally in archaeological research, just like generative artificial intelligence. In this regard, the work of Maurizio Forte, which enables the reconstruction of Etruscan tombs and their environments in images and videos [5], is a notable example.

VR is used in a differentiated manner, either for promotion, research, or both. Several projects have been carried out with a concrete research goal, such as those by Valérie Gouranton and Jean-Baptiste Barreau, who have also highlighted the value of VR for archaeological and historical research by focusing on the professional applications that could be made of it [6, 10]. For example, in the context of a study on the 18th-century ship *Le Boullongne*, virtual reality was used to create a 1:1 scale immersive reconstruction of this East India Company ship based on historical data. This approach enabled a better understanding of life on board and stimulated new reflections [1].

In this PhD research project, the integration of monuments and their environments in virtual reality appears as the most suitable means of studying the perception of monumentality, defined as the way in which monuments were seen, understood, and used by past societies. This involves, for example, the impact of their architectural design, the materials used, lighting, the environment, or their positioning within the landscape on these elements. Perception is thus partly based on what our senses perceive and how it is interpreted by the individual. It is therefore subjective. However, by allowing the researcher to immerse themselves in reconstructed past environments, while isolating them from the real world, virtual reality enables the exploration and analysis of how these structures may have been perceived in an immersive and interactive way, allowing the researcher to get as close as possible to the sensorimotor experience that individuals from the relevant periods may have experienced.

This research is based on methodological foundations drawn from various studies, particularly in the field of heritage. However, it stands out due to the combination of different approaches, notably 4D simulations in virtual reality and generative artificial intelligence, as well as its object of study: monumental structures' perception. It also aims to propose a methodological framework that can be reproduced by the archaeological community, enabling the exploration of this complex and subjective concept and opening new perspectives.

3 METHODOLOGY

The methodology primarily relies on the analysis of paleoenvironmental and architectural data obtained from archaeological excavations, combined with the use of digital tools, some of which are still relatively underutilized in archaeology. Bibliographic research, discussions with archaeologists and geoarchaeologists, and data collection in the field constitute an essential first step help establish the specifications for the 3D modeling of structures and the environmental reconstructions to be carried out.

Subsequently, the monumental structures will be modeled in 3D using Blender software, allowing for a more detailed study of their architecture. With the help of generative AI tools such as Stable Diffusion, images and videos that inspire improvements to

the 3D models can be generated. This will enable an assessment of the limitations and advantages of this tool for the study of archaeological sites.

Next, several projects will be developed using the Unreal Engine 5 game engine to create virtual simulations. The terrain in these simulations will be based on a Digital Terrain Model (DTM) for each relevant area, ensuring that subsequent geographic information is accurately incorporated. Multiple environmental hypotheses will be reconstructed after discussions with paleoenvironmental specialists. For example, hydrography or vegetation cover may vary depending on the hypotheses and periods. This is crucial for better understanding the impact of changing vegetation cover in Eastern Arabia on the environment and perception. Furthermore, it will help address the lack of paleoenvironmental data for certain sites by proposing several possibilities. Generative AI tools will again be used to inspire plausible environmental reconstructions. At this stage, the 3D models of the structures will be positioned in their locations. By positioning themselves within these reconstructed environments, spatial studies, especially visibility analyses, can be conducted, taking into account the effects of materials (colors), vegetation, and lighting on perception.

The temporal (4D) dimension will be integrated at multiple timescales (short, medium, and long) through simulations of natural light and internal lighting, the day/night cycle, weather conditions, and ceremonial activities (including the integration of virtual humans). For the long timescale, the study will focus on the evolution of necropolises, including the addition of new monuments and changes in vegetation cover over time.

Immersion in virtual reality within these environments will enable an in-depth analysis of perception and the various axes discussed. Perception, inherently subjective, is influenced by complex factors such as vegetation, architecture, employed materials, lighting, and spatial interactions. By providing researchers with the ability to explore a 4D virtual environment, virtual reality allows for a dynamic study of the influences of these elements, thereby opening new avenues for research and interpretation. The system used will be a virtual reality headset. This choice was made considering the low cost and practicality of this device, which can be easily used in archaeology laboratories, universities, and museums, facilitating the sharing of the simulation with others.

The interpretation of the results will be guided by an analytical framework based on existing studies on the concept of monumentality and the perception of monumental structures according to socio-cultural contexts. Spatial relationships, visual perception, or temporal evolution will serve as key analytical criteria. This framework will be refined throughout the research, based on the initial results obtained.

4 DHABTIYAH (SAUDI ARABIA): A MULTIMILLENNIAL MONUMENTAL SITE

The Dhahabiyah site is an exceptional case study for furthering our understanding of long-term monumentality in Saudi Arabia. Located in the Eastern Province of Saudi Arabia, near Hanidh, it is a diachronic site with remains dating from the 6th millennium BCE to the 1st millennium CE. Positioned on rocky terraces, it overlooks a *sebkha*. Various types of structures have been observed, including many presumed tombs identified through satellite, aerial, and ground surveys in 2021 during the Franco-Saudi mission at Thaj.

The site is now being explored as part of a French-Saudi cooperation between the CNRS and the Saudi Heritage Commission, through the Dhahabiyah Archaeological Mission of the French Ministry for Europe and Foreign Affairs. It is also

integrated into the ANR ArabianCairns project (#ANR-22-CE27-0001), which focuses on monumental protohistoric tombs in the Arabian Peninsula. Currently, over a thousand dry-stone structures of various types have been identified, including:

- *Mustatils*: These rectangular structures are formed by two long, more or less parallel walls, connected by two shorter walls. They feature a platform at one end, which may include niches where deposits have been observed.
- Circular cairns/tower tombs: Various types and sizes of cairns are found in large numbers on the site. They may be associated with circular, triangular, trapezoidal, or rectangular enclosures or platforms. They feature a corbelled roof chamber surrounded by several structured concentric walls and an external facing.
- Several elongated “cuneiform” structures are also present on the site.

While the *mustatils* are dated to the Neolithic, most of the other structures are attributed to the 3rd and 2nd millennia BCE, with possible re-uses until the modern times.

The 3D modelling of these structures and their repositioning in their environmental context, reconstituted thanks to the geoarchaeological data collected during the mission, will enable us to analyse their perception, in particular by modelling several hypotheses for environments and lighting and by simulating various scenarios of use.

The first excavation campaign at Dhahabiyah, from November to December 2024, allowed for the excavation of four structures (two circular cairns, one *mustatil* and one cairn with sub trapezoidal enclosure). Two tombs and one cuneiform structure had also been excavated in 2021. Additionally, sampling for ¹⁴C dating has been conducted on all the excavated structures and on several surveyed tombs.

5 MODELING OF STRUCTURES THROUGH PHOTOGRAMMETRY

15 structures were modelled in 3D using photogrammetry scanning, some excavated and others not. The acquisition was carried out using a drone (for the excavated structures) or a camera mounted on a pole. The 3D models created have various benefits for this project.

They allow for 3D documentation of all the observed types of structures, especially cairns of varying sizes, more or less collapsed, some looted ones, and sometimes featuring slabs still in place.

Scaling the models will enable measurements of the stones and provide dimensions of the modules used. This will facilitate the modelling of typical stones that can be added to the 3D models created via photogrammetry to restore architectural elements, as well as aid in the full modelling of certain structures, supported by data from the excavations. Several modules of slabs were also modelled by photogrammetry. These can serve as models or bases for the modelling of the slabs of circular cairns, with textures that can be extracted.

The external appearance of these structures, now recorded, which will help determine the textures to use to best represent the materials employed, as well as how they may have appeared following natural or anthropogenic degradation (looting, sand accumulation, collapse). Indeed, since the necropolis spans millennia, newly built structures must have coexisted with older and more or less degraded or looted ones.

Thus, by cross-referencing excavation data of this site and similar sites, photogrammetry models, and the information they provide (dimensions, texture, modules), we will be able to model structures of different types and varying degrees of degradation and add them to the 3D and 4D reconstruction of the necropolis. While hypothetical, these reconstructions will be informed by

multiple data sources to reduce the margin of error as much as possible.

Plants observed on-site were also digitized. A palaeobotanical study will determine whether their integration into the reconstructed environment is relevant.

We are still considering whether to directly integrate the photogrammetry 3D models into the hypothetical reconstructed environments. From a technical perspective, we still need to determine whether it is more practical to remodel the structures directly using the information gathered, allowing for better control over mesh optimization and texture consistency, or to integrate them as they are.

All the pictures taken, whether for photogrammetry modelling or not, will be used to feed the image database provided to the generative AI, Stable Diffusion, to create images offering reconstructions of the structures and environments.

6 FUTURE DIRECTIONS AND DEVELOPMENTS OF THE RESEARCH

The next steps of this PhD research project will be to model in 3D several structures of the Dhahbiyah site from the photogrammetry 3D models (enabling to obtain measurements, textures, examples of degradation, etc.). These models will be able to be integrated into a hypothetical environment created in Unreal Engine 5, using geoarchaeological data and a DEM.

Afterward, a first trial in virtual reality can be conducted. Early testing of the 3D environment in virtual reality will ensure its proper functionality within the first year of research, allowing for the optimization of its various components, and adjustments where necessary. By incorporating temporal and environmental changes and enabling movement and interactions, 4D and VR go beyond the limitations of static approaches. They will allow for dynamic and interactive analyses of monumental structures, providing a unique way to study key aspects of the monuments that could influence their perception within landscapes (e.g., light, materials, etc.). This experimental method, through immersion, should further engage the researcher in the virtual environment and in simulations of the structures' use. This will allow us to determine whether the use of VR enhances the perception experience and thus facilitates its study.

7 CONCLUSION

This research aims to provide a new understanding of monumentality in Eastern Arabia from the Neolithic to the Bronze Age, through 3D reconstructions and 4D simulations integrated in virtual reality. The results will shed light the role of these structures as territorial markers, particularly through visual relationships and the impact of materials, architectures, and environments on visibility. They will also reveal how individuals perceived these monuments and the potential objectives behind certain choices (e.g., architecture, positioning). The creation of multiple environmental reconstructions will allow to observe how environmental changes influenced the visual perception of monuments. Simulations of ceremonial processions and deposits will add another layer to the study of how individuals perceived monuments within ritual contexts at the time of their use.

Thus, this PhD research project relies on an innovative methodology to study monumentality and its perception within landscapes, offering immersive virtual reality reconstructions that are unprecedented in the study of the Neolithic and Bronze Age, allowing for the overcoming of the limitations of traditional methods of studying monumentality.

FIGURE CREDITS

[Figure 1](#) image credit: Dhahbiyah Archaeological Mission / Kaïna Rointru, 2024.

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