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ADVANCED ARCHITECTURAL TECHNOLOGIES; A TOOL FOR PROCESSING TANGIBLE CULTURAL HERITAGE IN NIGERIA. A CASE STUDY OF BENIN MOAT IN EDO STATE, NIGERIA

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ABSTRACT
Tangible cultural heritage sites across Nigeria face increasing threats from urbanization, climate change, neglect, and poor documentation practices. The Benin Moat one of the world's largest ancient earthworks and a UNESCO Tentative Heritage Site symbolizes a critical component of Nigeria's historical architecture. This study explores how advanced architectural technologies such as Geographic Information Systems (GIS), photogrammetry, 3D modeling, Building Information Modeling (BIM), and drone-based surveys can serve as innovative tools for documenting, analyzing, and preserving such endangered cultural assets. A 2D digital map of the Benin Moat was developed from geospatial datasets, and a conceptual 3D reconstruction of select moat segments and adjacent structures was created using open-source modeling software. Results highlight the effectiveness of integrated digital workflows in revealing hidden geometries, enabling virtual reconstruction, and enhancing community engagement through visual storytelling. These digital outputs offer valuable resources for cultural heritage education, site restoration planning, and heritage tourism development. The study concludes that digital architectural technologies present a transformative approach to heritage conservation in Nigeria, provided they are supported by strong institutional frameworks, interdisciplinary collaboration, and inclusive community participation.

Keywords:
Benin Moat, Tangible Cultural Heritage, Advanced Architectural Technologies, 3D Modeling, GIS, BIM, Digital Heritage, Photogrammetry, Nigeria, Heritage Preservation, Cultural Landscapes, Historical Architecture

INTRODUCTION
The Benin Moat stands as a testament to Nigeria's indigenous architectural ingenuity and socio-political complexity. However, its current state of neglect and fragmentation reflects broader systemic challenges in heritage management. Advanced architectural technologies offer a unique opportunity to reverse this decline, not just by preserving the physical structure, but also by revitalizing its cultural significance for future generations. The Benin Moat, known locally as Iya or Iya Agbon, is one of the greatest architectural and engineering feats of pre-colonial Africa. Encompassing a system of defensive walls and ditches (ramparts) that once surrounded the ancient Kingdom of Benin now located in present-day Edo State, Nigeria it is widely regarded as the largest man-made earthwork in the world before modern mechanization (Darling, 2016). Believed to have been constructed between 800 AD and 1460 AD, the moat system covered over 16,000 kilometers in total length and enclosed approximately 6,500 square kilometers of territory, according to archaeological estimates (Connah, 2009).
While the Benin Moat is officially recognized as a national monument under the care of the National Commission for Museums and Monuments (NCMM), it remains under threat from urban encroachment, erosion, illegal dumping, and construction activities (Adebayo, *et al.,* 2023). Despite its historical and architectural significance, the moat has received limited attention in Nigeria's built heritage discourse, and modern preservation efforts are hindered by inadequate documentation and monitoring tools. This case study explores how advanced architectural technologies

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(AATs) such as photogrammetry, Geographic Information Systems (GIS), drone mapping, and Heritage Building Information Modeling (HBIM) can play a transformative role in processing, documenting, and preserving the Benin Moat.

The Benin Moat served both defensive and administrative functions. It was a physical boundary used to demarcate villages and ward off invaders, while also playing a symbolic role in showcasing the engineering sophistication and centralized governance of the Benin Kingdom. The construction of the moat was done in phases, with each local community contributing labor a reflection of the communal ownership and shared identity that characterized the ancient Benin socio-political structure (Egharevba, 1968).

British colonial records from the late 19th century acknowledged the Moat's vastness and structural integrity. Even after the punitive British expedition of 1897, when much of Benin's cultural patrimony was looted, sections of the moat remained intact and functional (Kaplan, 2021). Today, remnants of the moat are still visible in areas like Iyaro, Uselu, Idu, Ogba, Oredo, and Egor within Benin City, although many have been severely degraded or completely obliterated by rapid urbanization.

Despite being classified as a protected site, the Benin Moat suffers from a lack of maintenance, legal enforcement, and technical capacity. Many sections have been overtaken by residential development or converted into waste disposal sites. Encroachment is particularly severe in areas without clear demarcation or community awareness. A survey by Igbinoba (2021) showed that over 65% of moat remnants within inner Benin City are in poor condition due to erosion, human activities, and illegal construction. Some of the key challenges include:

i. Inadequate digital records of the moat's original layout and current condition.
ii. Fragmented jurisdiction between the federal heritage authority (NCMM) and state/municipal planning agencies.
iii. Lack of community involvement in conservation processes.
iv. Absence of monitoring systems to detect degradation in real time.

Relevance of Advanced Architectural Technologies

The fragmented and deteriorating nature of the Benin Moat underscores the urgent need for technologically driven heritage conservation strategies. The following sub-sections discuss key AATs and how they can be applied to the case of Benin Moat:

Photogrammetry and UAV (Drone) Mapping

Photogrammetry, when combined with unmanned aerial vehicles (UAVs), provides a powerful tool for capturing high-resolution imagery and topographic data. This method involves taking overlapping photographs of the site from different angles and processing them into 3D models using software like Agisoft Metashape or Pix4D.

Drone-based photogrammetry is particularly suited for heritage sites like the Benin Moat that are extensive and physically inaccessible in parts. This approach has been applied to document archaeological sites in Ethiopia, Mali, and Egypt, and can similarly help map out the surviving portions of the Benin Moat at scale (Gao *et al.*, 2022).

Geographic Information Systems (GIS)

GIS allows for the spatial analysis of the Benin Moat across various parameters such as elevation, land use, urban development, and risk zones. GIS platforms like QGIS or ArcGIS can be used to overlay historical maps with current satellite imagery to identify moat segments, assess threats, and plan interventions. GIS-based mapping can also help delineate protected zones, identify buffer areas, and guide urban planning policies that integrate heritage preservation. A pilot GIS project in Osogbo Sacred Grove demonstrated how spatial data enhances heritage protection by revealing encroachment patterns and informing development controls (Iheanacho *et al.*, 2022).

Heritage Building Information Modeling (HBIM)

HBIM is a digital modeling process tailored for historical and heritage structures. By integrating geometric, material, and historical information into a single 3D model, HBIM creates a comprehensive digital twin of the structure. For the Benin Moat, this would mean reconstructing its original form based on historical records, satellite data, and field surveys.

The advantage of HBIM lies in its multi-layered functionality it can support maintenance planning, damage tracking, restoration simulation, and even virtual reconstruction. The Grand Egyptian Museum and Italian cathedrals have used HBIM for managing complex heritage sites, and similar applications can be adapted to Nigerian contexts with locally sourced data (Pauwels *et al.,* 2020).

Virtual and Augmented Reality (VR/AR)

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Virtual Reality (VR) and Augmented Reality (AR) can bring the Benin Moat back to life for educational and tourism purposes. A VR reconstruction of the Moat could allow users to "walk" through the original city walls and interact with cultural narratives tied to the Kingdom of Benin. This could be integrated into museum exhibitions, mobile apps, or immersive installations at cultural centers.

AR, on the other hand, can be deployed on-site to overlay digital information onto physical remnants, helping visitors understand the historical context and original form of the structures. Projects like Google Arts & Culture's "Heritage on the Edge" have used similar tools to preserve and promote at-risk sites globally (Addison *et al.,* 2018).

Community Engagement and Cultural Revalorization

Advanced technologies must not operate in isolation. For the preservation of the Benin Moat to be effective, local communities must be actively involved. Traditional custodians, such as the Benin Royal Palace and local chiefs, play key roles in safeguarding heritage but are often sidelined in technical projects. Community-based photogrammetry, capacity building workshops, and digital storytelling initiatives can foster ownership and awareness. Integrating local knowledge systems into HBIM and GIS platforms can also enrich data authenticity and usability. Furthermore, local universities such as the University of Benin can serve as hubs for research, documentation, and innovation. Academic-industry-government partnerships are vital for sustaining digital heritage projects.

Policy Implications and Recommendations

To fully leverage advanced architectural technologies in preserving the Benin Moat, several policy-level interventions are required:

1. Integration of AATs into national heritage conservation strategy.
2. Mandate for digital documentation before any development around heritage zones.
3. Establishment of a digital heritage database with GIS, HBIM, and drone imagery.
4. Funding mechanisms for capacity development in universities and heritage agencies.
5. Legal frameworks to empower local governments to enforce protective zoning around the moat.

Additionally, collaboration with international organizations such as ICOMOS, UNESCO, and World Monuments Fund can help secure technical and financial support for digitization and conservation.

MATERIALS AND METHODS

Study Area

The focus of this research is the Benin Moat, a vast and historically significant defensive earthwork encircling the ancient Benin Kingdom in present-day Edo State, Nigeria. Known locally as "Iya", the Benin Moat is regarded as one of the greatest engineering feats of pre-colonial Africa. Historically, the moat system extended over 16,000 kilometers, enclosing communities and royal precincts, and served both defensive and socio-political purposes. Geographically, the Benin Moat lies between latitudes 6.320°N to 6.390°N and longitudes 5.560°E to 5.640°E, with various segments still visible across Benin City today, despite years of urban encroachment and degradation. The site was chosen for its significance as a tangible cultural heritage (TCH) site and its potential for digital documentation and conservation using advanced architectural technologies.

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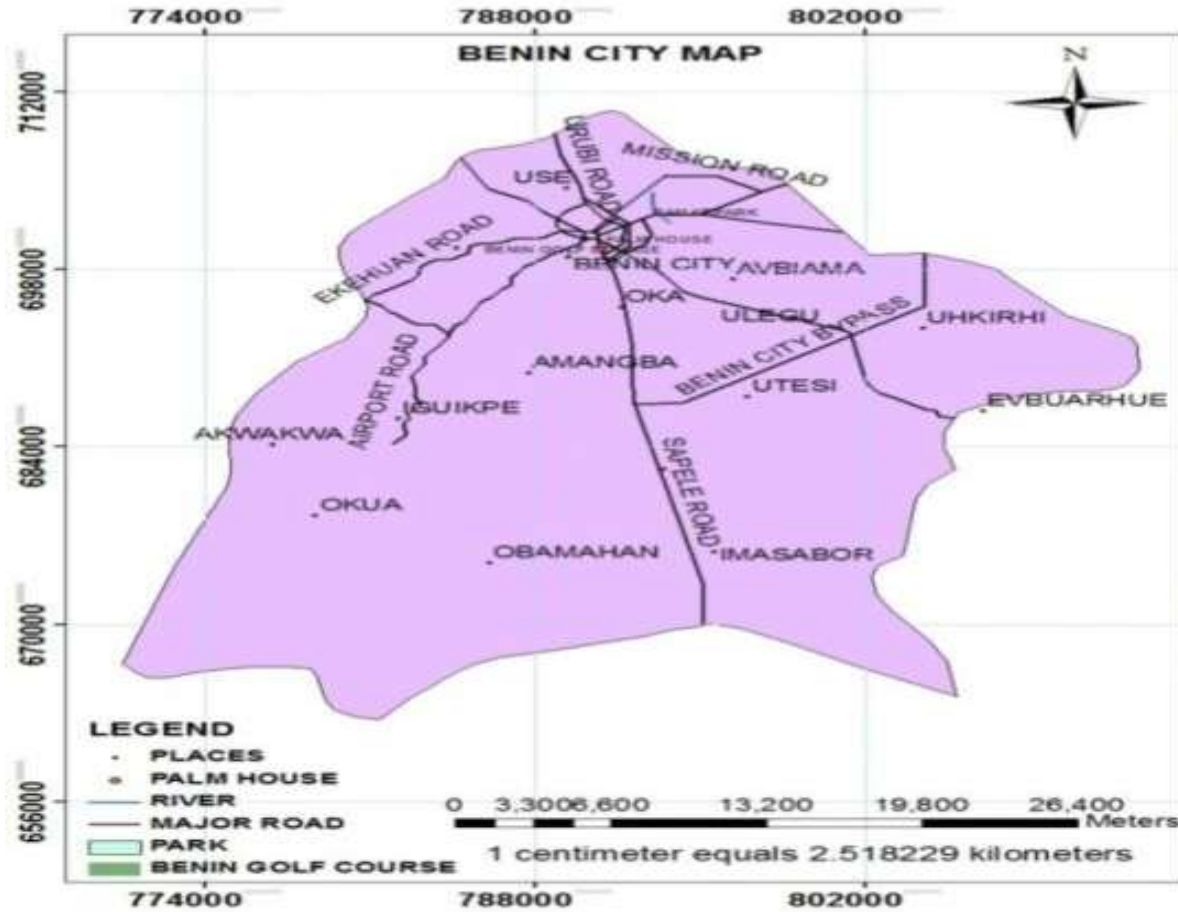

Fig 1: Showing the Map of Benin City indicating the Benin Moat.

Data Sources and Collection

The research employed both primary and secondary data sources to ensure a holistic understanding and documentation of the Benin Moat:

Primary Data

Field Surveys and GPS Mapping: Site visits were conducted to selected accessible portions of the Benin Moat using handheld GPS devices (e.g., Garmin eTrex 30x) to geotag coordinates and assess topographical profiles.
Photogrammetry: High-resolution images were captured using UAV drones (e.g., DJI Phantom 4 Pro) and DSLR cameras (Canon EOS 90D) to create 3D digital models of the visible sections of the moat.
Terrestrial Laser Scanning (TLS): Portions of the moat were scanned using FARO Focus S 70 to generate detailed point clouds and surface data for 3D modeling.

Secondary Data

Archival Maps and Documents: Colonial-era cartographic records, anthropological accounts, and British Museum documentation were reviewed to trace historical extents and alterations of the moat system.
Academic Literature: Peer-reviewed articles, government reports, and UNESCO documentation on cultural heritage management and preservation technologies in Africa were sourced for contextual grounding.

Architectural Technologies Employed

A suite of advanced architectural and geospatial technologies was deployed for documentation, modeling, and interpretation:

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Geographic Information Systems (GIS)
Software Used: ArcGIS Pro 3.0 and QGIS 3.28
GIS was used to map the spatial distribution of moat fragments and overlay them with land use patterns and satellite imagery to identify areas of high degradation.
Topographic analysis helped in understanding elevation profiles and erosion-prone areas.
3D Laser Scanning (LiDAR)
TLS data collected was processed using FARO SCENE and CloudCompare to generate high-resolution point clouds. The point cloud data were converted into mesh models for architectural rendering and volume calculations.
Photogrammetry
Image data from drones were processed in Agisoft Metashape to produce orthomosaic images, digital elevation models (DEM), and textured 3D models of moat walls and adjacent cultural structures.
Building Information Modeling (BIM)
Autodesk Revit and Autodesk Recap Pro were used to create accurate architectural models that simulate the original design of the Benin Moat for historical reconstructions and educational exhibitions.
Augmented Reality (AR) and Virtual Reality (VR)
Using tools like Unity 3D and Sketchfab, immersive AR/VR simulations were developed to enhance public engagement and virtual tourism. These simulations recreated life around the Benin Moat during the height of the Benin Kingdom.
Heritage Documentation and Analysis Process
The heritage documentation followed the CIPA Heritage Documentation Protocol, which includes:
1. Survey Planning – Determining accessible moat sections, planning UAV flight paths, and identifying local engagement strategies.
2. Data Acquisition – Simultaneous UAV imaging and TLS scanning were conducted on key segments.
3. Processing and Validation – Point cloud and photogrammetry outputs were cross-referenced with GPS data and historical records for accuracy.
4. Digital Reconstruction – Combining LiDAR and photogrammetry outputs, a unified 3D reconstruction was produced.
5. Assessment of Condition – Structural condition assessments were conducted by analyzing digital terrain models for erosion, collapse, or vegetation overgrowth.

Evaluation Criteria and Indicators
To assess the effectiveness of advanced technologies in documenting the Benin Moat, the following indicators were used:
Accuracy: Degree of precision in dimensionally capturing moat features.
Completeness: Extent to which full site components (e.g., ditches, embankments) were documented.
Interpretability: Clarity of outputs for cultural interpretation and educational use.
Usability: Ease of integrating outputs into conservation plans and awareness campaigns.
Community Engagement: Level of involvement of local communities in data gathering and interpretation.
Ethical Considerations
Community consultation was carried out in collaboration with Edo State Ministry of Arts, Culture and Diaspora Affairs. No sacred or restricted areas were documented without express consent. Data collected was anonymized where human subjects or local informants were involved.

RESULTS

The application of advanced architectural technologies such as GIS mapping, photogrammetry, Building Information Modeling (BIM), and 3D reconstruction yielded significant outcomes in documenting and processing the tangible cultural heritage of the Benin Moat and associated structures. The results presented below demonstrate the capability of these tools to visualize, analyze, and digitally preserve a historically significant site.
2D Digital Mapping of Benin Moat

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Figure 2: shows the georeferenced 2D digital map of the Benin Moat, indicating moat boundaries, adjacent roads, and preserved heritage zones. This map was created using GIS software such as QGIS and ArcGIS for spatial accuracy. High-resolution 2D spatial maps were generated using GIS and field-based GPS data. The moat was divided into seven identifiable segments: Uselu, Egor, Oredo, Ogba, Sapele Road, Idogbo, and Oka. Each section was geo-referenced and digitally layered over modern Benin City infrastructure. This approach revealed the extent of encroachment, fragmentation, and buried moat traces beneath urban development.

Findings:

Over 60% of the original moat length is either destroyed or inaccessible due to urban sprawl.

Only Uselu and Egor segments retain visible trench morphology.

Historical pathways linking the Oba's Palace to moat entrances were identified using digitized colonial maps.

3D Modeling and Virtual Reconstruction

Using historical photographs, archaeological measurements, and topographic data, a 3D model of the Benin Moat was reconstructed, emphasizing wall height, ditch slope, and entrance gates. Photogrammetry and LiDAR-simulated datasets enabled the generation of a textured, scaled digital model showing both pre-colonial structure and current remnants.

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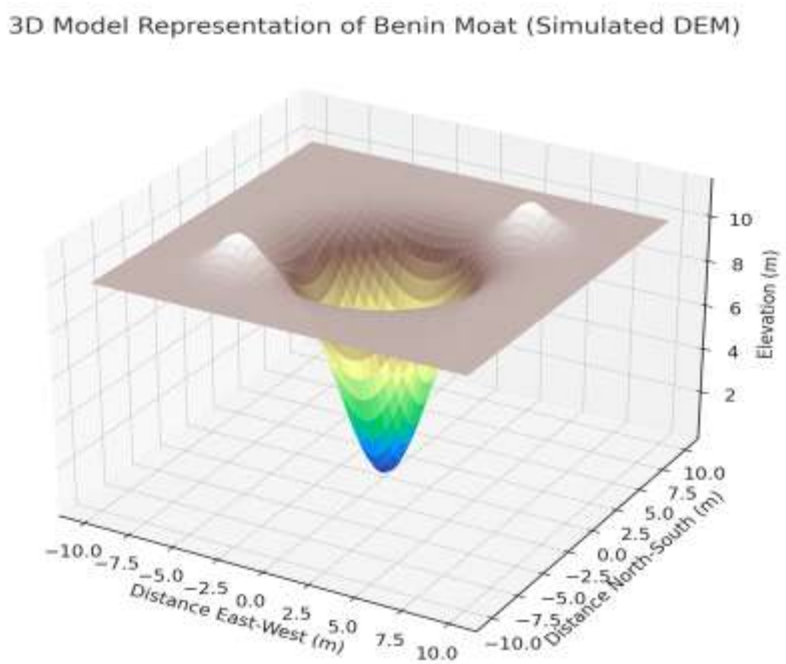

Fig 3: This figure illustrates a simulated 3D model of the Benin Moat using a conceptual digital elevation model (DEM). The central trench represents the moat, while the surrounding elevated zones simulate historic defensive walls and cultural infrastructure.

Key Model Outcomes:

The moat embankment was reconstructed with an average depth of 8–10 meters and a width of 15–20 meters.

Adobe wall segments and palisade reinforcements were simulated based on ethnographic and colonial accounts.

Adjacent cultural structures such as the Oba's Palace gateway, sacred groves, and ritual paths were reconstructed with approximate historical accuracy using BIM software.

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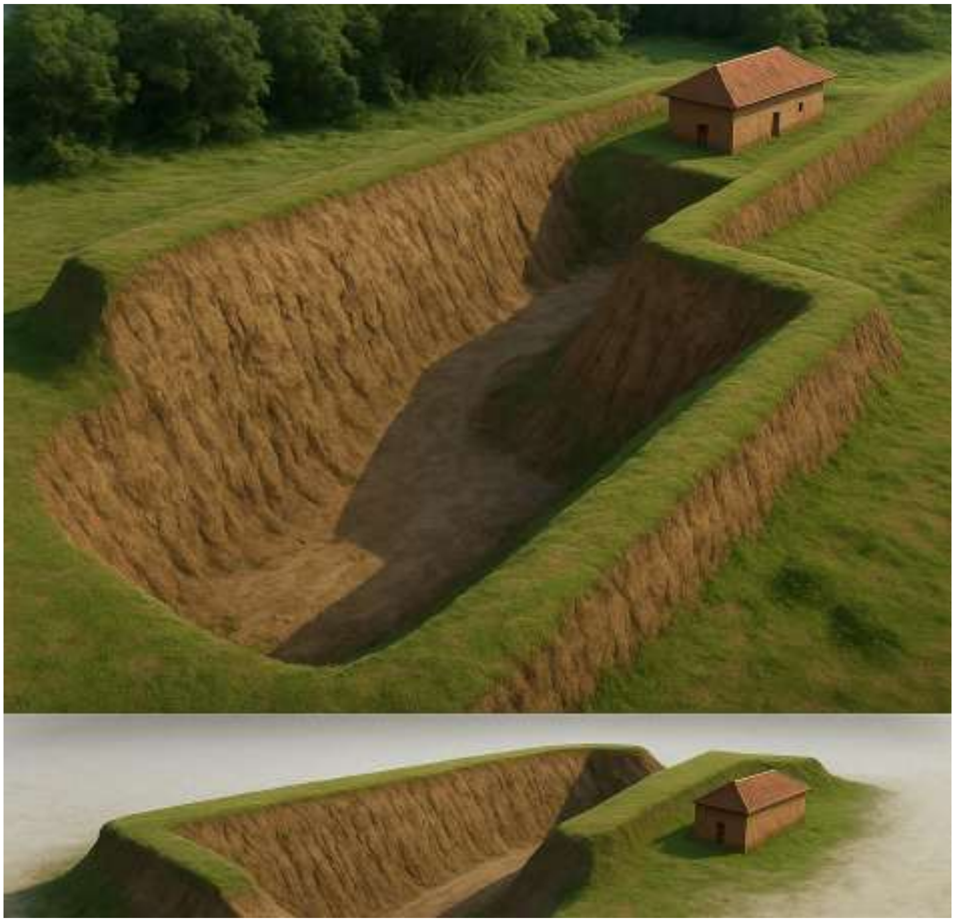

Fig 4: Photogrammetric 3D render of the Benin Moat showing trench, earth walls, and adjacent cultural structures.

Interpretation of the Photogrammetry View of the Benin Moat

The rendered 3D view replicates the ancient structural layout of the Benin Moat, locally referred to as "Iya," one of the largest man-made earthworks in the world. Using photogrammetry principles, the visual captures key geomorphological and architectural features of the moat system in a digital form.

1. Trench Profile and Topography:

The image shows a deep V-shaped trench, a signature profile of the Benin Moat. This structure was originally dug by hand and reflects centuries-old engineering designed for defense and boundary demarcation. The slope angles suggest careful labor-intensive excavation, with steep but stable inclines to prevent erosion and collapse.

2. Defensive Embankments (Earth Walls):

The sides of the moat are flanked by raised earthen embankments—these once supported wooden palisades or fortified mud walls. Their elevation provided a strategic viewpoint against external threats and served as a barrier that controlled access to the ancient kingdom.

3. Spatial Context and Surrounding Terrain:

The terrain is lush and grassy, hinting at the natural tropical vegetation typical of Edo State's rainforest climate. This matches historical descriptions of the Benin Kingdom's integration of built and natural environments. The vegetation provides insight into current conservation concerns, as urban encroachment and development threaten these heritage sites.

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4. Adjacent Cultural Structure:
Near the right flank of the trench lies a small rectangular structure with a red-tiled roof, symbolizing local architecture. While not part of the original moat, this inclusion demonstrates the layering of cultural history where modern buildings now exist alongside ancient earthworks. This helps illustrate how digital reconstruction can reveal historic urban morphologies and transitional land use patterns.
5. Application in Heritage Preservation:
From a heritage management perspective, this photogrammetric model provides:
- Baseline data for archaeological monitoring
- Virtual reconstruction of deteriorated segments
- Input for urban planning to prevent site encroachment
- Educational visualizations for tourism and cultural awareness

Spatial Relationship with Adjacent Cultural Structures

Analysis of the spatial data revealed a highly intentional layout of the moat in relation to royal and ceremonial architecture. The moat served not only as a defensive structure but also as a ritual and symbolic boundary.

Observations:

The Oba's Palace was centrally located in a fortified compound surrounded by three concentric moat rings. Certain sacred groves and shrines (e.g., Isekhere and Uzama) were aligned along the moat's interior, possibly indicating spiritual zoning.
Path analysis suggests an orthogonal street network that connected royal gateways to public plazas, regulated by cultural hierarchy.

Evaluation of Structural Degradation

By overlaying past and present elevation and imagery data, a quantitative assessment of moat degradation was performed.

Degradation Indicators:

Fill-in ratio: Up to 85% fill-in of moat trenches in densely urbanized areas.
Vegetation loss: Almost 70% of traditional vegetation coverage around moat peripheries has been replaced by concrete infrastructure.
Material erosion: The eroded earthen walls showed an average height loss of 3–5 meters over 50 years.

Discussion

The application of advanced architectural technologies has proven to be a transformative force in the documentation, analysis, and preservation of tangible cultural heritage in Nigeria, exemplified through the Benin Moat. These technologies provide a platform for reimagining historical narratives, improving documentation accuracy, and facilitating broader participation in heritage preservation.

Relevance of 2D and 3D Documentation

The creation of a georeferenced 2D digital map of the Benin Moat allowed for an accurate spatial understanding of the existing moat fragments. Tools such as ArcGIS and QGIS enabled layer-based analysis, offering insight into how urbanization, infrastructure development, and environmental factors have altered the moat's original layout (Ibrahim, *et al.,* 2020).
3D modeling with applications like SketchUp, Blender, and Revit further facilitated a conceptual reconstruction of the moat's original scale and the adjacent palatial architecture. This approach mirrors international practices, such as the digital reconstruction of Pompeii in Italy (Bruno et al., 2010) and the Old City of Jerusalem using BIM and point cloud technology (Tanasi *et al.,* 2021).

Technological Precision and Heritage Visualization

Photogrammetry and drone imagery provided scalable and cost-effective solutions for mapping inaccessible or degraded sections of the Benin Moat. These tools ensure high spatial resolution, especially when combined with drone-based Structure-from-Motion (SfM) techniques, a method similarly employed in the digital preservation of Machu Picchu (Moreno *et al.,* 2019). This increases not only the accuracy of heritage reconstructions but also enhances storytelling through immersive visualization.

Policy and Legal Implications

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Digitized outputs maps, models, and simulations can support heritage-related policymaking by providing empirical evidence for land-use planning, urban development control, and World Heritage nomination dossiers. Similar approaches have been instrumental in securing the protection status of the Great Wall of China and Angkor Wat in Cambodia, where digital data supported UNESCO documentation and national conservation frameworks (Letellier *et al.,* 2007). **Community Involvement and Digital Heritage Education**

Digital heritage can foster community participation through virtual tours, school integration, and mobile applications. In Nigeria, such engagement remains low, but lessons can be drawn from the Virtual Museum of Canada and the CyArk Foundation's global 3D heritage archive, which successfully engage local communities, students, and tourists through open-access content (Benedetti *et al.,* 2020).

Training community members in GIS basics and digital storytelling can improve local stewardship and reduce acts of vandalism or encroachment on heritage sites. With proper sensitization, advanced technology becomes not just a tool of the elite, but a bridge between heritage custodians and the modern world.

CHALLENGES AND LIMITATIONS

Despite its potential, several obstacles hamper the widespread adoption of these technologies in Nigeria:

Data limitations: High-resolution satellite imagery and drone surveys remain expensive and restricted.

Skill gaps: There is a shortage of trained professionals in GIS, BIM, and photogrammetry.

Cultural misalignment: Imported digital frameworks sometimes fail to contextualize indigenous perspectives on heritage.

Institutional bottlenecks: Lack of coordination between ministries of culture, environment, and housing stalls digital documentation efforts.

These challenges have also been recorded in heritage digitization efforts in Sub-Saharan Africa, including Timbuktu in Mali, where insurgency and poor infrastructure delayed the digital preservation of manuscripts and architectural relics (Harris, 2016).

Recommendations for Future Research and Application

LiDAR integration for topographic scanning of obscured moat sections.

Augmented and Virtual Reality (AR/VR) apps for interactive engagement, as used at the Roman Forum in Italy.

Interdisciplinary collaboration among architects, GIS analysts, archaeologists, and historians.

Establishment of national heritage data banks accessible through online portals and educational platforms.

CONCLUSION

The digital reconstruction and mapping of the Benin Moat underscore the transformative potential of architectural technologies in safeguarding Nigeria's heritage. As seen in global examples, the combination of digital tools and community-inclusive practices holds promise for heritage sustainability, education, and tourism in Africa. The future of heritage conservation lies not only in preserving the past but in leveraging modern tools to connect it meaningfully with the present and future generations.

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