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Chapter 5

The Potential of Drones in Documenting and Preserving Cultural Heritage in Bahrain

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Introduction

Cultural heritage sites reflect important links in the history, identity, and legacy of a country (Qadir et al., 2022). There are old settlements, forts, and mosques in Bahrain which, if maintained well, could continue the long history of those countries. At the same time, most heritage sites face severe risks brought about by environmental impacts, urban growth, and neglect (Qadir et al., 2022). Traditional methods of documentation and conservation of such sites very often become limited in capacity, are extremely costly, and carry risks due to the hazards of working in declining structures.

In the last years, drone technology has been well highlighted to solve such problems in the domain of cultural heritage preservation (Zheng et al., 2024). The utilization of drones offers non-destructive, inexpensive ways to capture high-resolution images and generate 3D models of ancient sites, including those that are challenging to access. They allow for fast and accurate documentation, thus giving valuable support to conservation and creating a digital record for future generations (Samadzadegan et al., 2023). These gains in the said fields notwithstanding, the cultural heritage in Bahrain remains restricted to the legal, technical, and operational obstacles of using drones.

This will seek to show the potential of drones in the preservation of Bahrain's cultural heritage. Significant opportunities and challenges regarding the implementation of drones in heritage documentation will be underlined using drone usage in a variety of successful case studies and interview analyses with local architects. Additionally, this paper will also propose a workable framework in Bahrain that could help overcome regulatory obstacles toward further improved drone technology and stakeholder collaboration.the housing units of under 60 m^2 and with no views of green areas, as their households are more prone to depression (Amerio et al., 2020) and, on the other hand, those located in community blocks and with aligned façades, given the difficulties to carry out extensions or alterations. This paper stresses three aspects for this type of housing: the need to consider the orientation of the housing to improve the quality of the indoor and outdoor space; the need for public housing policies for a greater number of rooms to facilitate remote working; and, finally, the importance of functional terraces overlooking green areas.

The importance of Cultural Preservation

Cultural preservation is the protection of cultural heritage for future use. Cultural heritage in itself consists of the tangible and intangible elements that manifest in historical buildings and monuments, traditional practices, languages, forms of knowledge identifying a community-as identified by (Okoli et al., 2023) It is the preservation of these elements that helps to further the sustenance of cultural values and consolidates national identities confronting challenges emanating from globalization, modernization, and urbanization.

The connection to heritage ties the individual with the past and strengthens the sense of belonging, making it also a promoter of social cohesion. According to (Sigmund, 2016), heritage is not necessary but even understood as a symbolic meaning of collective history and identity. Moreover, Cultural heritages play a strong role in both economic and social life even though the majority remains informal, without public protection and without explicit

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management as they are the main institutions that connect history, territory and society, defining the cultural context of social life (Sigmund, 2016).
A vital component of cultural preservation involves the implementation of architectural methodologies aimed at protecting historical edifices and monuments. Such methodologies encompass adaptive reuse, restoration, and conservation, which are essential in preserving the structural integrity and significance of heritage sites. The utilization of architectural strategies is instrumental in confronting the difficulties presented by modernity, particularly the necessity of reconciling preservation efforts with urban development (Okoli et al., 2023). This will help in the conservation of the environment as well as retain the original characteristics of the building, according to (Sigmund, 2016). Adaptive reuse generally involves converting heritage structures to modern use while retaining their historical significance and hence securing a place in current society (Okoli et al., 2023).

Methods of Heritage Preservation

Basic methods of protection of the constructed cultural heritage are restoration and conservation. As explained by (Besana, 2019), it is pointed out that restoration focuses on returning a cultural property to a previous, already defined state by removing alterations or rebuilding missing parts. The early theoretical assumptions initiated by Viollet-le-Duc in the 19th century underlined that restoration works needed paying close attention to preserving at least the initial goals of the authors. The aim of restoration is to preserve the monuments' aesthetic and historical integrity; thus, it considers their stability.

Conservation, on the other hand, means the preservation of the material integrity of heritage sites without any further deterioration of the site itself, without reconstruction or major alteration. The Charter of Venice (1964) and the European Charter of Architectural Heritage (1975) underscore the significance of comprehensive conservation, which combines both the preservation of physical structures and meticulous urban planning (Besana, 2019). Efforts in conservation are founded upon diagnostic methods, encompassing non-invasive assessments to evaluate material composition, identify structural vulnerabilities, and ascertain the historical importance of locations (Besana, 2019). It means restoration and conservation differ in their approach to deal with change and deterioration to retain the spoken historical narration of each heritage site for its being.

The digitization of cultural heritage became one of the current means for preserving tangible and intangible heritage in recent years. With regard to this, (Goussos, 2022) underlines that digitization-3D scanning, virtual reality tours, and digital mapping-provides such a possibility in terms of detailed and accurate documentation and preservation of historical sites and artifacts. It not only preserves a digital archive of inestimable historical and contemporary value for future generations, but also allows for access to cultural heritage on the part of a worldwide community when physical access to sites is severely limited by political, natural, and other obstacles.

Furthermore, digital preservation methodologies protect fragile or deteriorating materials by creating virtual copies that reduce the need to handle the physical material. For instance, digital collections of manuscripts, art, and oral traditions have become crucial to the preservation of cultural heritage (France, 2010). In this regard, digitization has become an integral part of modern preservation strategies, since it allows better access while reducing the possibility of loss due to physical decay or natural disasters (Goussos, 2022).

Drones technology

Most of the common techniques, through which drones realize highly accurate 3D models, involve several shots taken from different angles. (Febro, 2020) has presented how drones are able to deliver highly detailed 3D replicas of the Philippine Baroque churches, hence giving a very effective and non-destructive means of documenting cultural heritage. This is important in the creation of digital recordings that preserve the physical features of the sites, which are very vital for restorations in the future.

1. LiDAR for High Performance

Mounted on unmanned aerial vehicles, LiDAR (Light Detection and Ranging) is a remote sensing method used to examine the surface of the Earth (National Oceanic and Atmospheric Administration, 2024). This provides a finer alternative to photogrammetry, particularly for areas covered with vegetation. (Themistocleous, n.d.) highlighted how LiDAR could cut through vegetative cover and create detailed digital terrain models, which is very critical for archaeological sites. LiDAR provides topographical data with a great deal of accuracy that would otherwise not be achievable with photogrammetry.

2. Affordability and Accessibility

It is cost-effective compared to other documentation tools. (Febro, 2020) proved that even small-scale organizations can have easy access to drones for wide usage in faraway or not-well-endowed areas with resources. Affordability by ease of use makes cultural preservation possible to a wide range of users.

3. Supervision and Conservation

Drones have increasingly great importance in the continuous monitoring of heritage sites, enabling the immediate estimation of changes due to various environmental or anthropogenic causes. Quite often, the flights of drones lead to underpinning data for conservation effort and manage the degradation at sites more easily.

4. Limitations and Barriers

Coupled with the innumerable benefits of drones, some of the disadvantages comprise but are not restricted to dependence on the environment. Weather, light, and topography constitute those environmental factors that seriously impart an impact on quality. (Febro, 2020) further indicated that poor weather conditions that involved high wind amidst unfavorable light might result in poor accuracy in the photogrammetric model. Also, LiDAR manages to cut through vegetation, yet it is quite costlier than photogrammetry and hence cannot be applied to all projects.

Materials and Methods

This research adopts a qualitative approach into finding the potential of using Drones in documenting and preserving cultural heritage in Bahrain. Data will be collected through interviews using open ended questions with participants who are involved in general building documentations in Bahrain. This will provide insights into how building documentation is conducted locally and what challenges might face. The interviews were conducted via phone calls for convenience and accessibility.

Additionally, case studies will be collected on successful applications of drones in building documentation, one local case study that have been conducted on Bahrain Fort additionally will be comparing two international case studies for Santo Stefano Church in Italy, and The Deir-e-Kaj caravanserai, located in Qom, Iran. The study considers the technical aspects, the out come achieved and the challenges faced.

This analysis helps to highlight both, the strategies gained from international practices and the local challenges. Throughout the whole study, ethical guidelines were closely followed, including gaining informed consent and protecting participant privacy.

key limitation of this study and its methodology has to do with the relatively low level of access and application of drone technology in Bahrain because of its rather restrictive regulations, hence limiting the number of practical case studies relevant to a local context. In addition, this research is heavy on the interviews with architects and may not fully deliver the technical or operational challenges faced by drone fliers.

Case Study - Santo Stefano Church in Italy

In this study by (Lin et al., 2024), the employment of UAVs integrated with HBIM (Heritage Building Information Management) for recording and rehabilitation of the architectural heritage will be considered for the Santo Stefano Church in Volterra, Italy. Acquisition was made using a DJI Mavic 3 Pro equipped with a Hasselblad high-resolution camera, taking 200 images in low-altitude photogrammetry. Subsequent image processing was made by means of software such as Pix4Dmapper and Photoshop to deliver highly detailed 3D models. It also involves GPS to provide support for measuring the control points with high accuracy. The integration of drone-captured data within the comprehensive 3D model of HBIM was further extended by VR technology for the virtual restitution of the original appearance of the Church.

Results Obtained The accuracy in the flown paths allowed for the realization of a 3D point cloud and virtual reconstruction of Santo Stefano Church for its digital preservation in that state of deterioration. Further immersive VR experiences were possible with this 3D model, thus providing a visual reference both for conservators and the public.

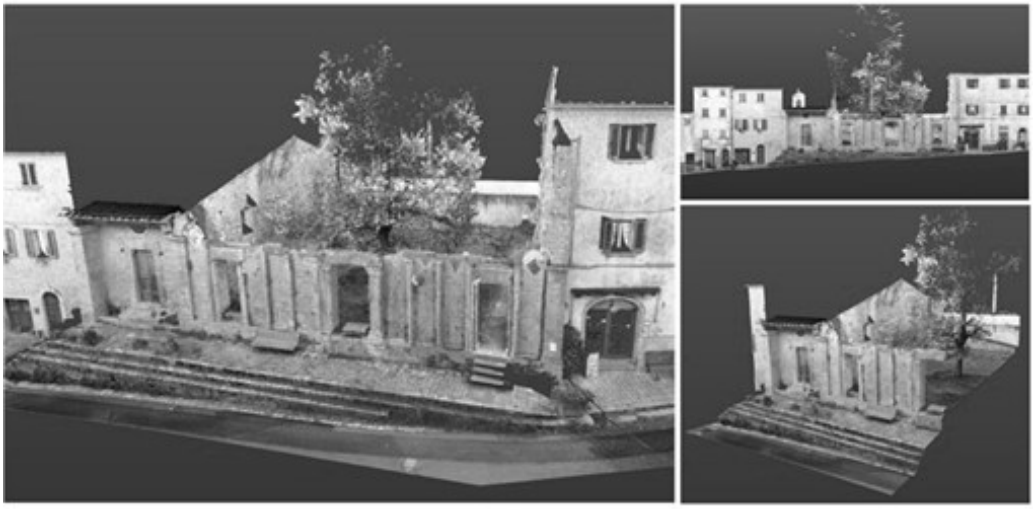

Figure 1. The point cloud of the Santo Stefano Church. (Lin et al., 2024).

Further, integrating the HBIM model allowed the analysis of such structural issues as wall tilting and foundation subsidence, which also supported both current and future restoration efforts. Another output was the development of a family library in HBIM by recording key architectural elements useful in heritage conservation.

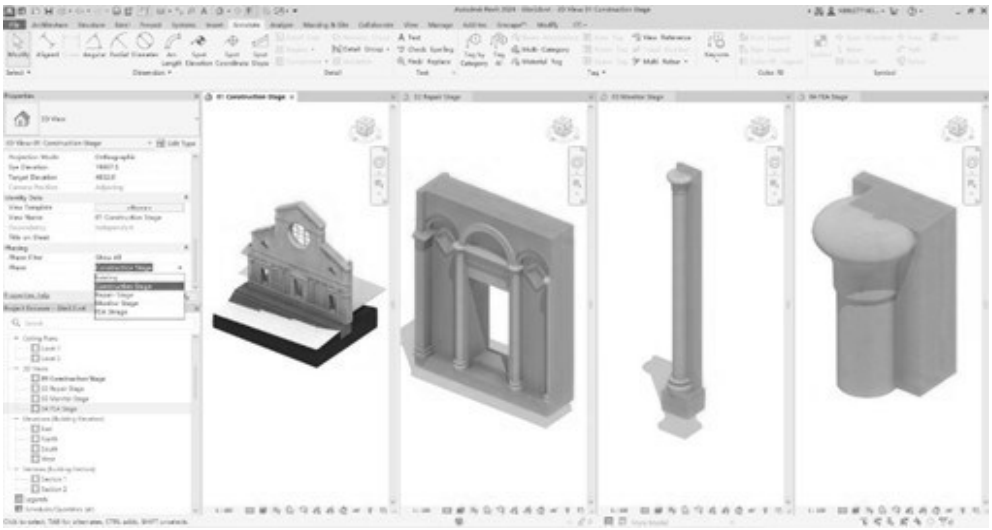

Figure 2. Family library in BIM for Santo Stefano Church made by (Lin et al., 2024).

Challenges Encountered The project has to face big difficulties: from the scarcity of historical records which compelled the research group to rely very much on data derived from drones and to make partial compensation with archetypes known for the period concerned, to the very bad conditions of weather and light that made the photogrammetric process very complicated, demanding heavy planning and correction of images. One more technical problem has been about the precision of the 3D model, partially solved by the integration of GPS technology with uncertain adjustment of point clouds.

Case Study - Deir-e-Kaj caravanserai in Qom, Iran

In a study of the Deir-e-Kaj caravanserai in Qom, Iran by (Samadzadegan et al., 2023) , a combination of UAV-based photogrammetry and multi-view imaging techniques was employed for 3D documentation. The quadcopter drone used was equipped with a 12-megapixel camera, mounted on a three-axis gimbal. The drone captured nadir, horizontal, and oblique images, allowing for comprehensive data acquisition of the site. The data processing was carried out using Structure from Motion (SfM) techniques in Zephyr software to generate a dense point cloud and create a detailed 3D model. The use of Ground Control Points (GCPs) ensured that the model achieved high precision with a ±1 cm accuracy.

Figure 3. Approximate position of targets on the caravanserai`s enclosure used by the Drone(Samadzadegan et al., 2023)

Outcomes Achieved, The use of drones in this study led to the creation of a highly accurate and textured 3D model of the caravanserai, which could be used for conservation and restoration planning. The multi-view imaging approach allowed for the documentation of both the exterior and interior spaces, including areas that were inaccessible due to physical damage and illegal excavations. The 3D model preserved metric and geometric data, which are crucial for long-term preservation and research. Additionally, this model can be integrated into Geographic Information Systems (GIS) and used in virtual reality applications, expanding the potential for heritage documentation and public engagement.

Figure 4. Bird's eye view of the textured 3D model (Samadzadegan et al., 2023)

Several challenges were encountered during the documentation process. First, the site's physical deterioration and the presence of illegal excavations made it impossible to use traditional survey methods. UAV-based surveys were necessary to overcome these physical barriers. Additionally, there were technical issues related to ensuring adequate image coverage, particularly in areas with shadows or complex structures. To address this, oblique imaging was introduced to reduce gaps in the data and avoid dark spots in the 3D model. Another challenge was ensuring the precision of the model, which was tackled by employing GCPs and using software to fine - tune the accuracy of the reconstruction.

Case Study – Bahrain Fort

The Bahrain Fort study by (Chiabrando et al., 2022)introduced a state-of-the-art solution for the 3D documentation of the site with the help of UAV photogrammetry, SLAM-based MMS, and TLS. The photogrammetry by UAV had to do with flying the so-called drone-aspect sensor, the DJI Phantom 4 Pro, in nadiral and oblique images at different altitudes with regards to documenting the surroundings and structure of the fort. The proposed system used close-range photogrammetry for minute detail capture, SLAM indoors, and provided dense point clouds from both techniques, processed in Agisoft Metashape and Geoslam Hub, respectively, with GCPs in each for ensuring the accuracy of point cloud.

Results Achieved Only by integrating various imaging techniques could a very accurate high-resolution 3D model of the Qal'at al-Bahrain fort be obtained. Data supplied valuable metric information for the conservation project with very accurate documentation of the structural details and relief of the fort. The obtained model showed a good level of accuracy (±2 cm) for applications in future restorations.
Besides this, the multi-sensor approach overcame various documentation challenges due to inaccessible or internally complex structures while providing further support to archaeological analyses and virtual heritage applications.

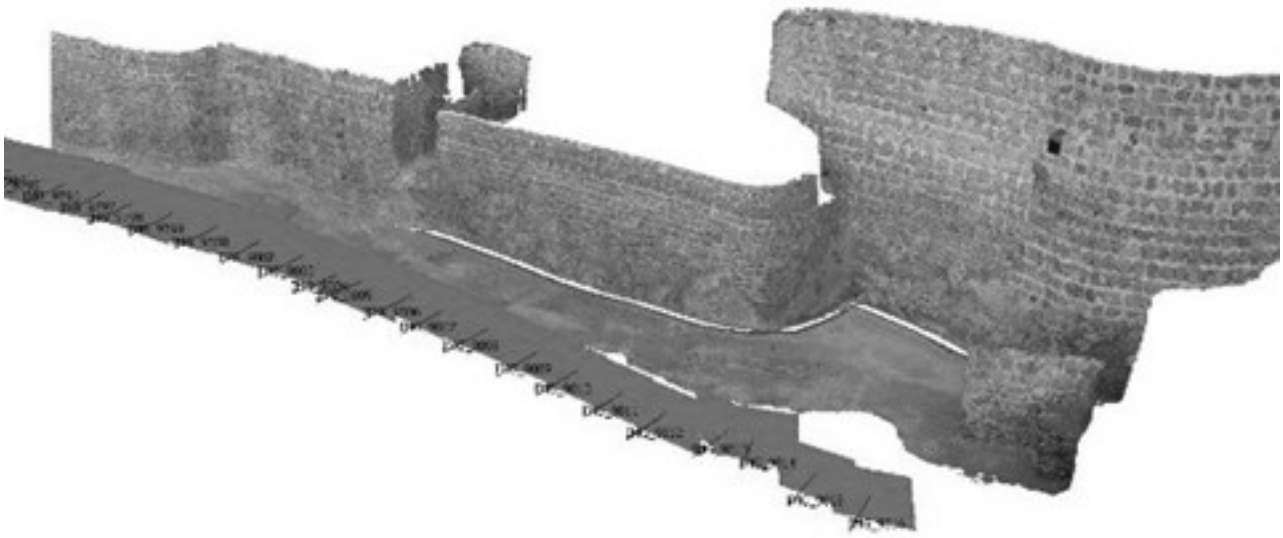

Figure 5. Close-range photogrammetric point cloud model, interior wall of Qal'at al-Bahrain.
(Chiabrando et al., 2022)

Challenges Presented The project faced many technical and environmental challenges. Under ideal situations of severe illuminations, high temperatures, wind, and humidity, the possible time to capture the data was greatly reduced, limiting activities to early morning. Moreover, the variety of surface types and the ever-changing lighting situations developed a critical situation for image acquisition, especially regarding photogrammetric purposes. Radiometric quality problems and shadowing effects also caused additional problems, affecting the homogeneity of UAV photogrammetry data. There were also complications on how to merge and consolidate some data from several sources to ensure consistency and integrity.

Discussion and Conclusion

interviews with architects shows how these professionals view the application of drones for documentation purposes in building practices, particularly those dealing with heritage sites.

Architects also comprehend the possibilities of drones in supporting and enhancing the accuracy and speed of the processes of building documentation. Most traditional methods include laser measurements and manual mapping, which tend to be way off the mark consistently in terms of accuracy, as this comment reveals.
Meanwhile, drones provide an overview from above, giving much more contextual understanding of the building in its setting, and allowing highly accurate 3D modeling. "Drones will make it possible to shoot over a building, and view and measure things that it's difficult to measure," said one architect. Moreover, drones make it possible to capture regions that are difficult to reach, including rooftops or old buildings with safety risks for a surveyor. The capability of acquiring accurate images of difficult-to-access locations is very useful in heritage documentation, where structural fragility often reduces accessibility.

Despite acknowledging that drones are useful tools for documentation, interviews revealed quite a number of practical difficulties.
One of the respondents reflected that from drones, one can get very high-quality 3D models, but often the files are big and heavy to handle with software and hardware. Another interviewee mentioned that during big projects, at the moment when 3D scanning was performed with the help of drones, all that usually "caused problems in the treatment of data and opening big files, less reliable, and more difficult to use in certain cases".
However, one interviewer suggested that we could use similar approach that Google uses when constructing 3d models for their google maps. They use 3d images that gathered from drones GPS data to construct depth maps in the photos (Brent Daniel, 2022).
Besides that, privacy and legal restrictions become substantial barriers in Bahrain. For flying drones, special permissions are needed, but it faces a limit because of considering the implications on privacy and safety, especially during capturing images of buildings around important areas, like a police station or congested residential areas. The existence of these kinds of regulations also makes practical implementation complicated despite the acknowledged technical benefits. Notwithstanding, everyone agrees that the drones bring added value to the documentation of buildings.

The architects said that drones could present an entirely new view and collect quite different data that would have been impossible or risky to acquire. One of the interviewees underlined that, especially in cases when assessment of the structure's condition is performed with drones before direct human involvement, it enhances safety during site inspections. It allows the enhancement of 3D models, enriching values into a dataset that will be demanded by an architect in restoration planning, primarily when such works become indispensable at historic sites.

Conclusion

The process of utilizing drones for documentation and conservation can be divided into four key stages.

First is the phase of Planning & Regulatory Compliance, underlining that a drone should be flown legally and safely. Permission from the relevant authorities must be granted while addressing issues on privacy and consultancy with various government and heritage stakeholders. The deliverables expected from the said stage are legal clearance for the use of drones and well-defined operational guidelines, while challenges involve delays in getting permits and restricted flying areas.

Second Stage is Data Acquisition, which Capture the site data in detail through drones fitted with photogrammetry and LiDAR. Use of drones to fly over areas inaccessible, coupled with safety operations, assured. This would be foreseen to yield high-resolution 3D models with full site coverage, though it might suffer the same drawbacks regarding bad weather conditions or issues of handling very large files.

Third stage is data process, the captured data must be processed with specialized software, like Pix4D (Lin et al., 2024) and Agisoft (Samadzadegan et al., 2023) (Chiabrando et al., 2022), and data must be integrated into Historic Building Information Modelling, or HBIM (Lin et al., 2024), with the optimization of file size. The expected deliverables are detailed and accurate 3D models for restoration and digital archiving. Handling of large datasets and specific expertise have been a challenge in this phase.

Finally, the stage of Monitoring & Conservation consists of long-term monitoring, publicity outreach through drone surveys, real-time data feedback for conservation, virtual tours, and simulation development. While the goal of this phase is to allow for further documentation with active public involvement via virtual models (Goussos, 2022), a number of disadvantages are seen with this method, including increased operational and continuous technological upgrade costs.

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Conflict of Interests

The author(s) declare(s) no conflict of interest.

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