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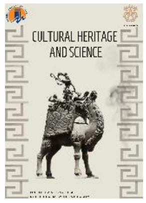

Exploring structural deterioration at historical buildings with UAV photogrammetry

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Abstract
The preservation and transmission of cultural heritage to future generations are crucial in today's rapidly advancing world. This study focuses on the application of Unmanned Aerial Vehicle (UAV) technology and photogrammetric techniques in the modeling and documentation of Germus Church, a significant cultural heritage site. The research aims to create a high-fidelity 3D model of the church, capturing its architectural intricacies and deformations caused by time and damage. The fieldwork involved capturing aerial photographs using a DJI Mavic 2 Pro UAV system, followed by image processing with Structure-from-Motion (S*f*M) software. The generated 3D model revealed extensive deformations, including cracks, collapses, and loss of religious figures and decorations. The findings emphasize the importance of preserving and restoring Germus Church for tourism promotion. The study showcases the effectiveness of UAV technology in documenting cultural heritage and highlights its potential for future applications. The 3D model serves as a valuable resource for researchers, historians, and the public, fostering a deeper understanding and appreciation of our rich cultural heritage.

1. Introduction

In today's rapidly advancing world, the preservation and transmission of historical artifacts and cultural heritage to future generations have become not only possible but also necessary. The documentation of these invaluable treasures plays a vital role in ensuring their preservation and providing us with valuable insights into our history [1-3]. By capturing and recording every clue related to history, we can create a comprehensive repository of knowledge for future exploration.

Traditionally, terrestrial observation systems have been widely employed for documenting cultural heritage. However, in recent decades, the advent of satellite technologies with higher spatial resolution has revolutionized the field of modeling efforts on a global scale. Furthermore, the advancements in aviation and remote sensing technologies have opened new avenues for more effective utilization of photogrammetry and Unmanned Aerial Vehicle (UAV) systems in the documentation process.

Unmanned aerial vehicles are frequently used in different areas such as agriculture, mining, construction, natural disaster monitoring, meteorology, archeology, imdustry especially cartography [4-16].

The application of photogrammetry techniques using photographs captured by cameras integrated into UAVs is commonly known as UAV photogrammetry [16,17]. This innovative approach has gained significant attention in the literature, particularly in the field of 3D modeling of cultural heritage, due to its inherent advantages in terms of time efficiency, cost-effectiveness, and data collection capabilities [17,18].

The development of unmanned aerial vehicles in various shapes, sizes, and features has significantly contributed to the advancement of 3D modeling techniques [18,19].

These technological advancements have made it easier than ever before to accurately assess the current state of historical structures and identify any deformations or changes over time. Leveraging the advantages of UAV photogrammetry, this study aims to create a high-fidelity 3D model of the Germus Church, a remarkable cultural heritage site.

By harnessing the power of UAVs and photogrammetric techniques, this research endeavors to

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provide a comprehensive and detailed representation of the Germus Church, capturing its architectural intricacies and preserving its historical significance. The resulting 3D model will serve as a valuable resource for researchers, historians, and the general public, fostering a deeper understanding and appreciation of our rich cultural heritage. Moreover, this study aims to showcase the immense potential of UAV photogrammetry in the documentation and preservation of cultural heritage sites, paving the way for future applications and advancements in the field.

2. Study area

The selected study area, Germuş Church, is located in the Dagetegi near at the foothills of Germus Mountain, which is situated 10 kilometers northeast of the city center of Sanliurfa. The historical church is positioned at coordinates 37°12'06.0" latitude and 38°51'04.2" longitude and is located 5 kilometers away from Göbekli Tepe, which is known as the "zero point" of history. The location information for the study area is depicted in Figure 1.

Figure 1. The study area

It is rumored that Germus Church, presumed to have been built in the 19th century, was constructed over seven years using cut stones brought from the surrounding mountains. It has been reported that within the village where the church is located, there are underground markets, tunnels, and various structures [20]. In 2011, the Ministry of Culture and Tourism of the Republic of Turkey designated the vicinity of Germuş Church as a "tourism development center." However, due to years of neglect, the structure has suffered significant deterioration over time. As part of the restoration and preservation efforts, a 3D model of the church's current condition was created using UAV technology. This has enabled the necessary preliminary preparations for restoration and conservation work.

3. Method

The production of the model consists of two stages: fieldwork and office work.

During the fieldwork stage, data acquisition takes place. This involves capturing aerial photographs or images of the Germus Church using the unmanned aerial vehicle (UAV) equipped with a camera. The UAV is flown over the site, and high-resolution images are taken from different angles and positions. The purpose of this stage is to collect visual data that will be used for the subsequent modeling process.

In this study, the DJI Mavic 2 Pro, a UAV system from the DJI brand, was used to generate a 3D model of the historical church. The DJI Mavic 2 Pro is a successful system with features such as an effective range of 8 km, a maximum flight time of 31 minutes, 4K recording with a Hasselblad camera, a 1" CMOS sensor, GPS sensor, 4-way obstacle sensing, automatic return to home, and a weight of approximately 1 kg [20]. The UAV used in the study is depicted in Figure 2.

Figure 2. DJI Mavic 2 Pro UAV system used in the study

For the photo capture a circular flight plan was prepared with *6 °.* Once the fieldwork is completed, the collected images are transferred to the office for processing. This is where the office work stage begins. In this stage, specialized software is used to process the images and create a 3D model by using Structure from Motion (SfM).

The acquired aerial images underwent processing using the Structure-from-Motion (SfM) approach, which has emerged as a revolutionary and cost-effective photogrammetric technique widely employed in recent years [22].

Unlike traditional photogrammetry, SfM introduces mathematical and statistical differences. While traditional photogrammetry aims for global consistency, model validity, accurate measurements, and compatibility through a global mathematical model, SfM is an image-based modeling technique that automatically arranges camera parameters, positions, and object 3D geometries to create a three-dimensional (3D) model. *Sf*M achieves this by aligning corresponding features in images captured from different locations, ensuring an appropriate overlap rate in accordance with photogrammetric measurement processes [23].

The establishment of image relationships requires the identification of features such as corners and edges within the images. By directly aiming to reconstruct the 3D object, *Sf*M generates a local solution and model through photogrammetric bundle block adjustment, utilizing all available data. Nowadays, there are numerous commercial and free software applications available that operate based on the *Sf*M approach, offering versatile capabilities [22,24,25,26].

The software analyzes the images, identifies common points and features, and reconstructs the three-dimensional structure of the Germuş Church based on these data points. The acquired images from the unmanned aerial vehicle were processed using Agisoft

Photoscan, an independent software that offers significant capabilities for performing photogrammetric operations on digital images. A point cloud and a 3D model were created based on the evaluation of the images.

4. Results and Discussion

Circular flight is when an UAV (Unmanned Aerial Vehicle) flies by following a circular path around a specific target. In this study, the Germuş Church was selected as the target, and a 6-degree flight plan was prepared for the circular flight from a 25 meter height. The flight duration and efficiency were increased through circular flight. In our case the circular flight is performed in approximately 5 minutes in May 2022**.** The camera angel is automatically arranges as 75 degree from nadir. In total, 40 aerial images were obtained. The flight plan is depicted in Figure 3.

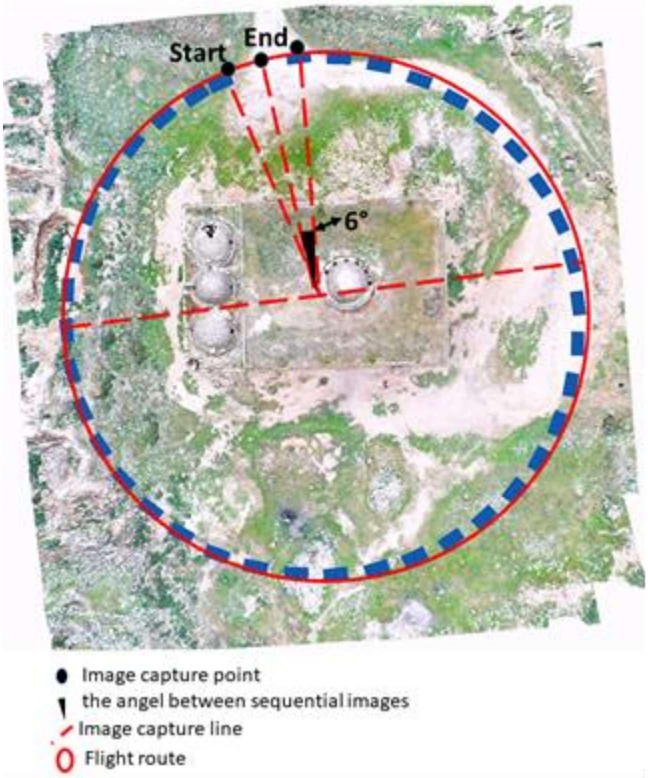

Figure 3. Photogrammetric flight plan

In this study, UAV-based 3D modeling of the historical heritage site known as Germus Church, located in the Haliliye district of Sanliurfa province, has been successfully accomplished. All photogrammetric process was performed in Agisoft software in high quality parameters.

The use of UAVs was employed to contribute to the surface investigation prior to the planned restoration of the historical church and to produce topographic products that could serve as a basis for the restoration works. The findings and processes involved in the production of the 3D model reveal that the UAV-based capture, which is overlapping, precise, and highly accurate, plays a significant role in generating the point cloud. The generated dense point cloud contains 7,800,413 points. The colorless and colored form of the generated point cloud is given Figure 4.

Figure 4. The generated point cloud

The obtained point cloud allows us to obtain both 3D position and color information from all surfaces of the structure. Using this data, it is possible to produce a 3D solid model of the structure. Within the scope of the study, the 3D solid model of the Germus church was produced both in colorless (Figure 5) and colored (Figure 6).

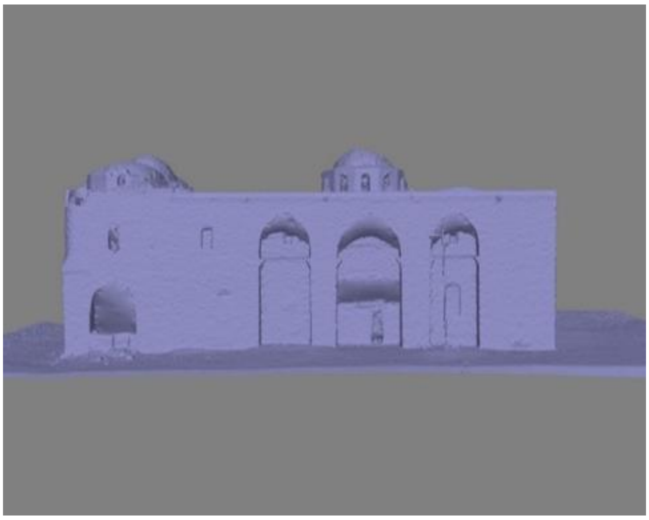

Figure 5. Colorless 3D solid model of Germus Church

When evaluating the Agisoft software used for image processing, it can be observed that photos with regular overlap rates are processed accurately, resulting in a 3D model that closely resembles reality. However, it is noted that as the number of added photos increases for the purpose of achieving greater accuracy, the processing time of the model also increases. Therefore, it is important to aim for an optimal balance between image input parameters and processing time [27].

Figure 6. Colored 3D solid model of Germus Church

When evaluating the generated 3D model and the fieldwork, it is clearly visible that the domes of the historical church have collapsed and the side facades have suffered damage. The deformed parts of the historical church are indicated on the 3D model.

The damaged domes made of knitted stone pose a high risk due to falling stones. Figure 7 shows extensive damage to the dome, completely opening it up and causing stones to fall. The unstable structure increases the danger, as each dislodged stone increases the chance of further collapse. Urgent action is needed to stabilize the remaining sections, ensure safety, and restore the domes to their former glory.

Figure 7. The deformed dome.

The building's exterior walls exhibit significant wear, a result of aging, decay, and human-induced damage. Over time, the elements have taken a toll, causing cracks and faded paint. Additionally, poorly constructed masonry walls and graffiti further mar the surfaces. Figure 8 highlights some of these damages, emphasizing the need for restoration and preservation efforts.

Figure 8. The deformed walls

The accumulation of soil and growth of grass and weed plants on the building's roof pose potential risks. The roots can compromise the structure and lead to water infiltration, while the added weight can strain the supporting elements. Proper maintenance, including regular cleaning and drainage systems, along with reinforcing the roof structure, can help mitigate these risks and preserve the building's structural integrity.

The presence of grass and weed plants on the building's roof, as shown in Figure 9 is a cause for concern alongside the structural damage. The accumulation of soil can lead to long-term structural issues. Over time, the roots of the plants can penetrate the roof's surface, compromising its integrity and creating pathways for water infiltration. The weight of the soil and vegetation can also strain the supporting elements, increasing the risk of collapse. To address these risks, regular maintenance and cleaning are necessary to remove the soil and vegetation, while implementing drainage systems and reinforcing the roof structure can help mitigate the effects of moisture and soil accumulation.

Figure 9. Soil accumulation and grass on the roof of the church

During fieldwork, it was observed that the church had been explored and excavated by artifact hunters, emphasizing the need for alternative methods of documentation. Unmanned aerial vehicles (UAVs) prove to be a suitable solution, as they can safely capture high-resolution imagery of inaccessible areas. The collected data allows for the creation of detailed 3D models, serving as a reference for future comparisons and aiding in the detection of structural changes or deformations.

UAVs offer a safer alternative to physical exploration in dangerous areas, minimizing the risk of damage to delicate structures or artifacts. The use of advanced imaging technologies enables researchers to document the church's interior and exterior without the need for human entry. The resulting imagery and 3D models provide valuable insights into the historical and architectural significance of the site.

The documentation obtained through UAVs contributes to the preservation and conservation of cultural heritage. By regularly capturing updated aerial imagery, researchers can monitor the church's condition over time and detect any deterioration or alterations promptly. This information aids in planning and implementing timely preservation efforts, ensuring the long-term protection of the site's cultural and historical value. UAVs play a vital role in documenting inaccessible areas, safeguarding artifacts, and fostering a deeper understanding of our rich heritage.

The final version of the 3D model of Germus Church is depicted in Figure 10.

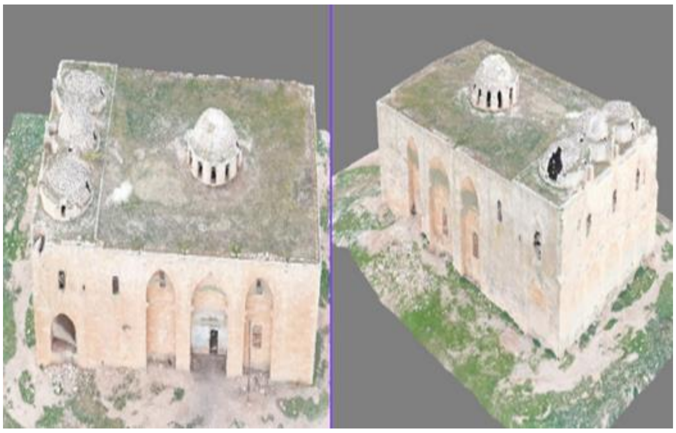

Figure 10. The 3D model of Germus Church

The 3D model generated from the site documentation serves as a valuable resource for creating architectural survey drawings. By utilizing the model, architects can accurately depict the building's main outlines and damaged sections, providing a comprehensive visual reference for analysis and preservation planning. The detailed representation of the model allows for in-depth examinations of the damage, aiding in the formulation of appropriate restoration strategies and ensuring the preservation of the building's original architectural intent.

The provided Figure 11 exemplifies the use of the 3D model for architectural survey drawings, showcasing the building's main outlines and highlighting specific damaged sections. This digital representation not only facilitates accurate documentation but also serves as an archival resource for future generations to study and appreciate the building's architectural heritage.

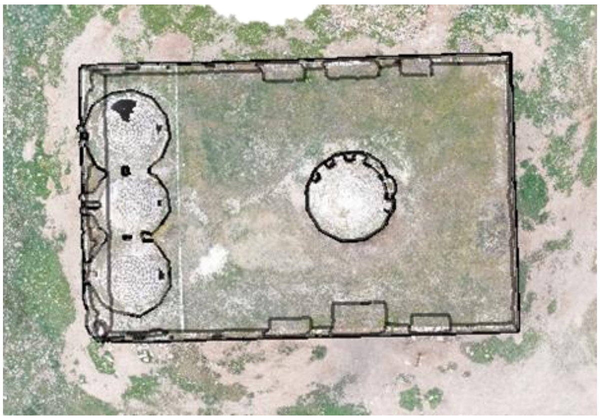

Figure 11. An example of architectural drawings over 3D model

It is possible to say that the accessibility of the 3D model enables researchers and historians to explore the structure's design elements and cultural significance, promoting a deeper understanding of its historical context.

5. Conclusion

In conclusion, this study highlights the significant contributions of unmanned aerial vehicles (UAVs) and photogrammetric techniques in the documentation and preservation of cultural heritage sites, specifically focusing on the Germus Church. The use of UAV photogrammetry has revolutionized the field of 3D modeling by offering advantages such as time efficiency, cost-effectiveness, and high-quality data collection capabilities.

The fieldwork stage involved capturing aerial photographs of the Germus Church using the DJI Mavic 2 Pro UAV system. These images were then processed using the Structure-from-Motion (SfM) approach, which automatically arranged camera parameters, positions, and object 3D geometries to create a highly accurate 3D model. The resulting model provides a comprehensive representation of the architectural intricacies and historical significance of the Germus Church.

The study area, Germus Church, located near the foothills of Germus Mountain, holds great cultural and historical value, and the generated 3D model serves as a valuable resource for researchers, historians, and the public. By documenting and preserving the current state of the church, the 3D model enables future comparisons and assessments of any deformations or changes over time.

Furthermore, the study emphasizes the suitability of UAVs and photogrammetric techniques in capturing visual data and exploring hazardous or inaccessible areas. The generated 3D model not only reveals the structural damages and deformations of the Germus Church but also aids in identifying potential preservation challenges, such as soil accumulation and vegetation growth on the roof.

This research demonstrates the immense potential of UAV photogrammetry in the field of cultural heritage documentation and preservation. The utilization of UAVs and advanced software tools offers a cost-effective and efficient means of acquiring accurate data and creating detailed 3D models. By fostering a deeper understanding and appreciation of our rich cultural heritage, these technological advancements pave the way for further applications and advancements in the field of cultural heritage preservation.

Overall, the study highlights the importance of integrating UAVs and photogrammetry in archaeological and digital documentation studies, showcasing their pivotal role in safeguarding historical artifacts and transmitting our cultural heritage to future generations.

Author contributions

Emine Beyza Dörtbudak: Field study, Data processing, Editing **Şeyma Akça:** Data processing, Methodology, Writing Original draft **Nizar Polat:** Conceptualization, Field study, Data processing.

Conflicts of interest

There is no conflict of interest between the authors.

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