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Deterioration analysis of historical village house structure in Mersin Kanlıdivane archaeological area by UAV method

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Abstract

The village house located in the Mersin Kanlıdivane archaeological site is one of the oldest settlements in the ruins, built in the second century. The house is mainly built of a yellowish beige limestone. This stone, which is the main material of the building, shows many deterioration patterns today. The aim of the study is to determine the dominant deterioration pattern of the stones in the village house structure in the Mersin Kanlıdivane archaeological site and to investigate the source of the deterioration. In order to investigate the deterioration patterns in the structure, the images obtained by UAV photogrammetry were interpreted and the types of deterioration were mapped. In the study, it is seen that even the types of material problems based on the smallest detail can be determined based on virtual visual inspection, thanks to UAV photogrammetry, without observing the structure in situ with UAV photogrammetry. The findings obtained in the study shows that the color change and surface loss deterioration on the stone surfaces has reached advanced levels as a result of the structure's exposure to the strong climate-induced sun and water effects for centuries. The results of the study show that the main damage observed on the stone surface of the structure is caused by the erosion by the effect of water. Restoration methods should be tried to stabilize the deterioration and replace the most degraded stones. It is recommended to use water-repellent surface coatings to protect the natural stone, especially against the intense water effect in the building.

1. Introduction

Natural stone is one of the oldest building materials. The majority of cultural heritage structures in the world, such as the Ancient City of Petra in Jordan, the Temples of Luxor in Egypt, the Ancient City of Nimrud in Iraq, are made of stone. Historical stone structures are important in terms of reaching values such as the living spaces, aesthetic concerns and beliefs of past societies to the present. However, these cultural heritage values are threatened by various deterioration processes due to natural or anthropogenic reasons [1].

Water-related damages are reported as the most common problems affecting stone monuments in the world. Various findings have been obtained in many studies on the corrosive effects of rainwater. A study conducted on sandstone material by [2] was reported that pitting formed in the stone material in contact with rain water. Bonazza et al. [3] reported that rainwater has a corrosive effect even at low exposures, especially on carbonated stones. Gulotta et al., [4] reported that there is intense erosion on the marble in the parts exposed to atmospheric water. Winkler [5] reported that the facade walls exposed to rain water in marble and limestones occured significant erosion, while the facade walls on the protected side were less damaged. In addition, it has been emphasized by many studies that long term effect of stone material with water causes erosion, especially in architectural structures such as fountains built of carbonate stone [6-8]. Germinario et al. [9] reported that the siltstone material can be completely disintegrated by the action of water. In addition, it has been reported that the stone has got colour of change when stones exposed to water long terms [10-13]. Gulotta et al. [14] reported that the water effect causes as spalling, fragmentations, pitting due to the structure of the minerals in the serpentinite stone.

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Other situations in the literature caused by the effect of water were reported as mass loss problems in stones exposed to cycles simulating sunlight, evaporation, condensation [15-23]. Lubera [24] reported six stone types (fine-grained conglomerate, breccia, limestone, sandstone, amphibolite, and two granites) in the study, with the effect of water about 6% in breccia samples, 0.5% in limestone and 4% in fine-grained conglomerate samples. The study reported that there was a mass loss below 0.3% in other samples. In addition, the various studies is emphasized that the acidity of water tends to increase over time due to atmospheric pollutants in stone structures, which further increases erosion in stones [25-26].

In order to ensure the sustainability of the buildings, the deterioration of the stone structures should be documented firstly. Conservation recommendations should be made by experts with reference to correct documentation. Nowadays, modern technologies should be used in documentary works which made by architects [27-29]. Different methods are used in order to be documented, protected and introduced of these monuments [30-31]. Today, technologies such as photogrammetry and laser scanning techniques are used to document the material problems of a cultural heritage property. The use of three-dimensional visualization techniques is also becoming more popular day by day. Laser scanning is an object-contact technology that digitally captures the shape of physical objects using laser light. 3D laser scanners collect "point clouds" as data from the surface of an object [32-34]. These techniques provide more realistic visualizations than graphic-based object models [35-38]. In addition, the use of Unmanned Aerial Vehicles (UAV) provides great convenience for documenting material deterioration problems. Unmanned aerial vehicle is a very useful tool for documenting the structure and material problems without touching the object [39-42].

UAVs have become more accessible to individual users due to their low cost, flexibility, ease of use and readiness for implementation [43-45]. The use of UAVs in cultural heritage studies is becoming more and more common. It enables fast, accurate and low-cost data collection, especially in areas where access to structures is difficult [46]. In the literature studies conducted to evaluate material damage by using unmanned aerial vehicles (UAV) reported that the benefits of unmanned aerial vehicles (UAVs) in identifying material deterioration in structures [47-50]. Pepi et al. [51] investigated the material deterioration of a stone bridge by UAV and photogrammetric methods. The study reported that damage can be detected quickly from the images obtained. Material deterioration such as cracks, microcracks, material loss problems can be easily documented and mapped by this method. In addition, the results of the study emphasized that the method provides significant advantages by reducing time for documantation. Duque et al. [52] conducted a study using UAV for damage assessment (crack lengths, thicknesses, and rust-stained areas) of a wooden bridge in South Dakota. In the results of the study stated that high quality images were obtained to measure bridge damage. In addition, damage level classification based on the UAV image can be created based on the damage levels wiht the details in the images obtained. Khaloo et al. [49] used UAV to observe the damage in a bridge and reported that missing bolts, damaged beam connections and defective beams could be detected from the data obtained from the results. In addition, the reported that damages can be detected in a shorter time and without the risk of injury compared to the traditional method. Kim et al. [50] reported that they were able to measure concrete cracks from images captured by a UAV, and the method gave accurate results for cracks with a thickness greater than 0.1 mm. Harrington [53] reported that sufficient high-quality images can be obtained from the images obtained by UAV in damage detection. The study reported that these data can be used for crack length, thickness and rust-stained area measurements and the UAV-image-based method reduces time, expense and safety risk.

In summary, several studies have reported that UAVs have many potential benefits in detecting material problems. The aim of the study is to determine the problems of the stone material in a historical village house in Mersin Kanlıdivane archaeological site. The village house located in the Mersin Kanlıdivane archaeological area, which is the subject of the study, was built in the second century. It is one of the oldest settlements in the ruins. The house was built from a yellowish beige limestone. This stone, which is the main material of the building, shows many deterioration patterns today. In order to investigate the deterioration patterns in the structure, the images obtained by UAV photogrammetry were interpreted and the types of deterioration were mapped. In the study confirmed that even the smallest detail-based material problems can be detected, based only on virtual visual inspection, by using UAV.

In this context, the location and history of the building were explained first. In the next stage, UAV researches for the determination of material problems are included. In the next stage, the findings are explained and in the conclusion section, conservation suggestions are presented for the detected deteriorations.

2. Material and Method

2.1. Study area

Kanytella, which remained within the borders of Rough Cilicia in Antiquity, is known by its current name as Bloody Divane. The area is one of the largest archaeological sites in Mersin [54]. The ruins of Kanlıdivane consist of a sinkhole that is widely seen and believed to be sacred around Mersin and Silifke, and religious places, houses, roads, olive oil production workshops, cisterns, tower and necropolis around it. The settlement activities, which started from the Hellenistic Period (3rd century BC), continued uninterruptedly until the Late Antiquity (7th century AD). The village house, which was examined as a case study in the study, is located in the Mersin Kanlıdivane archaeological area. The building is dated to the 2nd century AD, based on other structures in the archaeological area. Thanks to its building architecture, it is only the most magnificent house of the archaeological site. Like other structures in the area, the village house was built mainly with yellowish-beige limestone. Currently, this stone shows many deterioration features in all structures in the area, especially in this structure [55] (Figure 1). Therefore, the main purpose of our research is to determine the main weathering patterns of the limestone used in the field and to investigate the causes of its deterioration. For this purpose, UAV photogrammetric survey of the village house was conducted. The data obtained were interpreted and analyzed. The results of field and descriptive analysis studies are given in the findings.

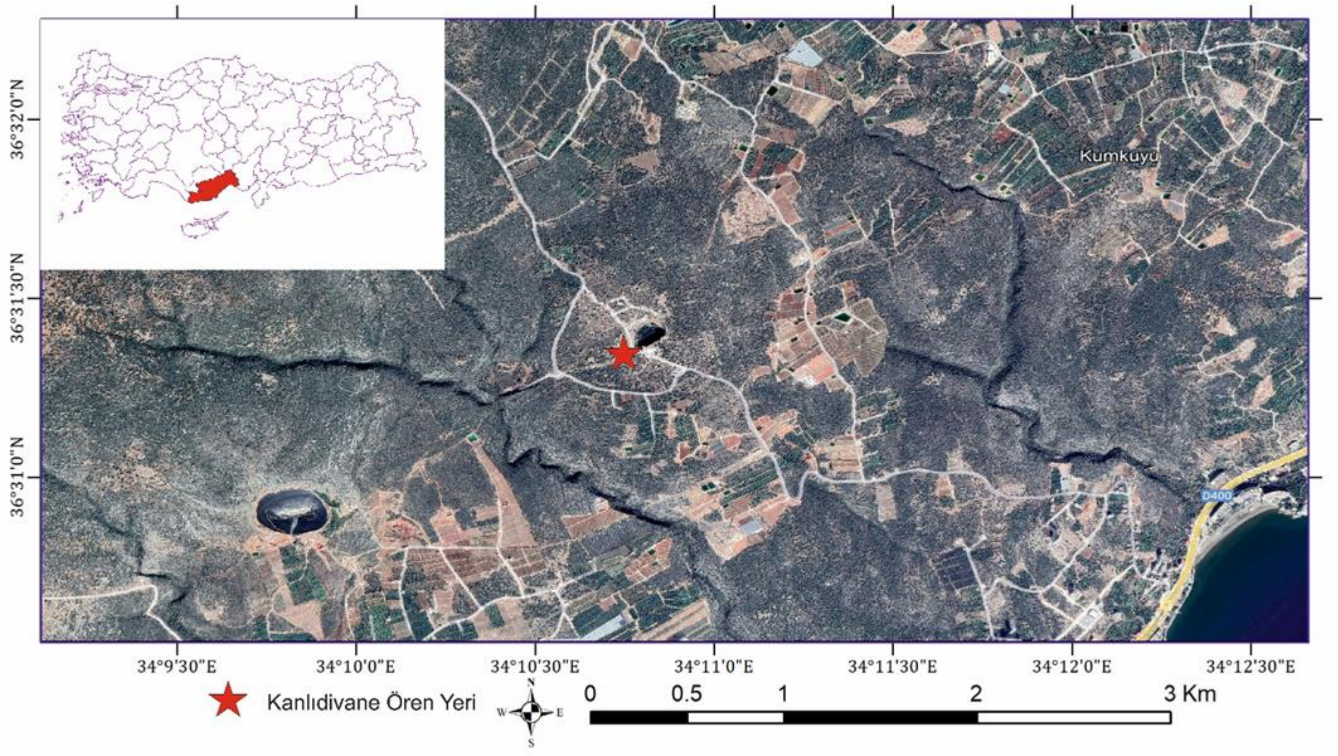

Figure 1. The location of the historical village house in the archaeological site

This study consists of two stages: field and office work. The phases of on-site examination of the study area, photographing and taking images of the mausoleum with an unmanned aerial vehicle constitute the field study phase. During the office work phase, the data taken from the unmanned aerial vehicle was transferred to the computer environment, interpreted and processed. The images collected in the field by the UAV method were transferred to the computer in the office environment. The types of material degradation from the images obtained were defined using the illustrated dictionary published by ICOMOS [56].

Identified material deteriorations were mapped by dividing them into classes on the basis of stone structural elements in masonry structures. In the literature, the structural elements seen in masonry structures are defined as vertical carriers, horizontal carriers, stairs, wall cavities and auxiliary elements [57]. Vertical carriers in the building are defined as pillars, columns and walls. There is no use of pillars or columns in the building. Horizontal carriers from the building elements are defined as floors. Flat flooring is used in the building. The auxiliary elements in the structure are; gargoyles are defined as ornaments and moldings.

2.2. UAV photogrammetry

UAV is a platform that can fly manually or autonomously without the need for a pilot. It has been frequently used in various engineering projects in recent years. landslide modeling, landslide inventory map creation [58], shoreline determination [59], pond volume determination [60], historical monument modeling [61], degradation of historical buildings [62], settlement modeling and discordance plane extraction [63] has been successfully applied in their projects. By using the UAV can obtain data without touching the object. This ensures that the original state of the object or land remains intact [64]. Through the datas can be seen the current state of the land or an object with high sensitivity and resolution [65-67].

2.3. Fieldwork

At this stage of the study, necessary permissions were obtained to fly in the Kanlıdivane region, which is the study area. Then, the flight altitudes at which the images will be taken around the grave were determined. Images were captured manually with the Parrot Anafi HDR Drone (Figure 2). Its technical specifications are shown in Table 1.

Every detail of the structure was tried to be captured by flying first at low altitude and then at high altitude. The lower the flight, the clearer the image will be [68]. A total of 101 photos were taken. The camera was calibrated beforehand and no changes were made in the parameters. A smartphone was used together with the remote control during the photo shoot. Free Flight 6 and Pix4D Capture applications have been installed in order for the smartphone and the remote to work integrated.

Figure 2. Anafi Parrot

Table 1. Technical properties of Anafi

Feature	Numeric value
Controller weight	386 g
Battery weight	126 g
Number of batteries	4
Max. horizontal speed	15.2 m/s
Max. vertical speed	4 m/s
Flight time	25 min
Max. wind resistance	13.9 m/s
Max. distance	4000 m
Operating temperature	-10...40 C°

2.4. Office-work

After the completion of the image acquisition within the scope of the field work, the office work phase was started. First of all, the data obtained from the field were transferred to the computer environment. Data processing was done in Agisoft Metashape program. The office work, which started after half a day of field work, was completed in one day. All the photos taken were used in the documentation process.

3. Results

3.1. Deterioration in vertical carriers

In the literature, vertical carriers of building elements in masonry structures are defined as feet, columns and walls. There is no use of pillars or columns in the building. The deteriorations seen in the walls in the building were determined as change of colur, surface loss and pollution of surface. Change of colour due to water effect was observed in the parts close to the ground on the south façade of the building. On the upper parts of the façade, pollution of surface, which is a gray dirt layer formed on the stone as a result of the air pollutants created by the fires in the environment, can be seen (Figure 3).

Figure 3. Change of color on the south facade (a), contamination of surface (b), contamination surface (c)

There is a gargoyle on the northern façade of the building. This gargoyle is the system that collects the rain water reaching the structure and removes it from the structure. Since the sunbathing time is shorter on this facade of the building compared to the other facades, the rain water that comes into contact with this facade remains in the inner body of the stone for a longer time without evaporation. For this reason, the color change in the structure of the stone caused by rain water on this facade is more than the other facades, and it formed as an orangish color (Figure 4).

Change of color and contamination of surface material problems were encountered on the western façade of the building (Figure 5).

Pollution of surface was detected on the eastern façade of the building (Figure 6).

(a) (b) (c)

Figure 4. Stone material problems on the north facade: a) pitting, b) change of color c) contamination of surface

Figure 5. Change of color on the west facade (a), surface contamination (b)

Figure 6. Pollution of surface

3.2. Deterioration in horizontal carriers

In the literature, horizontal carriers from building elements in masonry structures are defined as floors. Flat flooring is used in the building. There is no deterioration in the flat floor (Figure 7).

Figure 7. The flat floor seen in the building

3.3. Deterioration in auxiliary elements

In the literature, auxiliary elements of building elements in masonry structures; gutters are defined as ornaments and moldings. There is surface loss in the gutters seen on the facade of the building (Figure 8).

Figure 8. Surface loss in gutters in the structure

4. Discussion

The main purpose of the study is to determine the deterioration patterns of the stones in the historical village house in the Mersin Kanlıdivane archaeological area and to investigate the source of the deterioration. In order to investigate the deterioration patterns in the structure, the images obtained by UAV photogrammetry were interpreted and the types of deterioration were mapped. The research conducted in the historical village house with UAV photogrammetry enabled many images with high resolution to be taken, including orthophotos of the plans and façades of the building. With the UAV photogrammetry method, it was possible to detect even the types of material problems based on the smallest detail, based only on virtual visual inspection, without an on-site observation of the structure. The results shows that the damage can be detected quickly based on the visual inspection of the images obtained using UAVs. It has been determined that the deteriorations can be mapped using these images and the method used provides significant advantages in the detection of material deterioration by reducing the working time [49,51].

Another important finding is that material problems detected in the maps produced from the data obtained from the UAV method in the structure is change of color, surface loss and surface contamination. Change of color was detected in a large part of the structure. There is a gutter on the north façade of the building. The water accumulated by the rain in the structure is removed from this gutter. It is understood that the water flowing from the gutters rises from the ground and enters the interior of the body walls. For this reason, it is seen that the change of color decay patterns occurs more on the stones in contact with the ground and on the northwest sides compared to protected area from the sun. This finding supports studies stating that stones exposed to water change of color due to various external factors or the structure of the stone [9-13, 69].

On the east and west surfaces exposed to strong winds, mainly stone material occurs damage. It is seen that the change of colour problem, which is advanced on all façades, is more common on the south façade. It is predicted that this situation is due to the long sunbathing period on the south façade. The rapid evaporation of the water entering the inner surface of the wall caused color changes due to the structure of the stone. Winkler [5] supports that the exposed side of the limestones shows significant erosion, while the erosion occurs less on the protected side. For this reason, there are problems related to the corrosive effects of water, especially on the north facade. This finding supports studies that indicate erosion in stones exposed to water [3,14,70].

In addition, the water flowing from the gutters on the north façade caused pitting problems by damaging the stone material at the points of direct contact on the façade. Waragai & Hiki [70] confirms the phenomenon of pitting in stone materials in direct contact with water, which they obtained in their study results. The results confirm the findings of various studies that the stone material causes erosion, especially in fountains built of carbonate stone, as a result of constant contact with running water [6-8].

Another result is that the gray layer, which is seen in the form of surface pollution on the facades, may be caused by the fires that people set to clean the bushes. It is known that the residents of the area carried out stubble burning in order to clear the bushes around the building. This situation caused the formation of a gray layer on the walls of the building. It is remarkable that the gray layer is excessive on the façades except the south façade, where the water stays on the wall for a long time. This situation shows that the water evaporates faster from the wall of the building due to the sunshine duration on the south façade, causing a change of color. On the north façade, as the water stays in contact with the body wall more and evaporates slowly, the black layer caused by the fire smoke on the façade is less cleaned and forms a crust. This determination was made by de Azcona et al. [25] support the fact that the acidity of water tends to increase over time due to the atmospheric pollutants obtained in the results of the study, which further increases the erosion and change of colour in the stones.

Another important finding is that the gray layer seen in the form of surface pollution on the facades is thought to be caused by the fires that people lit to clear the bushes. It is known that the residents of the area carried out stubble burning in order to clear the bushes around the building. This situation caused the formation of a gray layer on the body walls of the building. It is remarkable that the gray layer is excessive on the façades except the south façade, where the water stays on the wall for a long time. Based on this situation, it is predicted that due to the sunshine duration on the south façade, the water evaporates faster from the wall of the building and causes a color change in this situation. On the north façade, the water stays in contact with the wall more. In this case, the fact that the water evaporates more slowly from this façade is less able to clean the black layer caused by the fire fumes on the façade and forms black crusts. This determination was made by de Azcona et al. [25], the fact that the acidity of water tends to increase over time due to atmospheric pollutants, which further increases the erosion and discoloration of stones.

5. Conclusion

In the study presented, UAV photogrammetry was used to investigate the stone decay patterns of the village house, which is a historical masonry building in Kanlı Divane, one of the largest archaeological sites in Mersin, and the deterioration types were mapped by interpreting the images obtained. The results shows that the main damage observed on the stone surface of the structure is due to the erosion by the effect of water. It is seen that the change of color and surface loss decay types on the stone surfaces have reached advanced levels as a result of exposure to the strong climate-induced sun and water effects for centuries. Restoration methods should be tried to stabilize the deterioration and replace the most damaged stones.

To clean surface pollution deterioration, to increase the stone's resistance to environmental pollution and to prevent subsequent exposure to weathering, treatment should be considered. Firstly, stubble burning processes in the environment, which will eliminate the main reason for this process, should be prohibited and prevented.

In addition, in this study, it is important to create a database containing the hydromechanical and thermal properties of limestone in order to protect the village house and other structures in the Kanlıdivane archaeological site area. Given ICOMOS code principles such as compatibility, reversibility and durability, these data can be used as a reference level to define requirements for the selection of restoration materials, mortars, replacement stones, surface protection and reinforcement products. Secondly, it is recommended to replace the deteriorated masonry stones to decontaminate and consolidate the affected stones. Third, a systematic approach should be taken to select suitable raw materials for the formulation of compatible and durable repair and cleaning materials. The properties of the materials (especially new materials) used in restoration works and their compatibility with existing materials should be determined exactly. This should include long-term effects to avoid unwanted side effects.

In addition, it is recommended to prepare a research plan that includes one-year monitoring of the microclimate, as well as tests and analyzes on the stone, in order to determine the damage process in the structure and to establish a solid foundation for the preservation of the structure. First of all, the stone type should be determined by macroscopic features and thin section microscopy, and the moisture distribution in the structure should be determined gravimetrically on samples taken at different heights and depths. The content and type of salt in the building stone should be determined by X-ray diffraction and ion chromatography [71].

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Author contributions

Lale Karataş: Conceptualization, Methodology, Software, Writing-Original draft preparation **Murat Dal:** Data curation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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