Mersin Photogrammetry Journal

https://dergipark.org.tr/en/pub/mephoj

e-ISSN 2687-654X

Detection and documentation of stone material deterioration in historical masonry buildings using UAV photogrammetry: A case study of Mersin Sarisih Inn

Lale Karataş*[1], Aydın Alptekin[2], Atilla Karabacak[3], Murat Yakar[4]

[1]*Mardin Artuklu University, Department of Architecture and Urban Planning, Mardin, Türkiye*
[2]*Mersin University, Department of Geological Engineering, Mersin, Türkiye*
[3]*Mersin University, Vocational School of Technical Sciences, Department of Architecture and Urban Planning, Mersin, Türkiye*
[4]*Mersin University, Geomatics Engineering Department, Mersin, Türkiye*

Keywords
Cultural heritage
UAV
Photogrammetry
Material deterioration

Research Article
DOI:10.53093/mephoj.1198605

Received: 02.11.2022
Revised: 05.12.2022
Accepted: 19.12.2022
Published: 22.12.2022

Abstract

Detection of material degradation of urban facades constitutes a preliminary activity for the preparation of any restoration response project. The traditional method for fixation relies on mechanical contact means and requires a great time effort to obtain a few preliminary points. In addition, the size of buildings and historical places make it difficult to examine the types of material deterioration, and on-site visual analyzes and current inspections by experts can also lead to human-induced errors. The development of methods based on UAV photogrammetry in order to reduce the labor force and margin of error in solving this situation brings great convenience for the detection of material deterioration in historical areas. The aim of the study carried out in this context is to document the material problems of "Sarışıh Han", a historical masonry building located in the Tarsus district of Mersin, which is of great importance for its continuity. Contributing to the documentation, detection and repair of financial problems for the preservation of the cultural heritage of the region and thus the sustainable management of the structures in the geographical region. In this context, material problems in the structure were documented using UAV photogrammetry method. In the study, the use of UAV photogrammetry to support the constraints of material deteriorations allows for more detailed results in façade analysis of material deteriorations, leading to simplification of manual and direct search procedures.

1. Introduction

Historical buildings are heritage sites that ensure the sustainability of collective memories such as the lifestyles and beliefs of past societies. Stone, which is the most used material in movable and immovable cultural heritage in these areas, which helps to reconstruct history, is under threat due to deterioration processes due to various reasons. These deteriorations in historical buildings are caused by natural environmental factors such as meteorological conditions and anthropological factors such as air pollution, as well as the properties of the materials that make up the building. For example, rain water, which is a natural factor, accelerates the dissolution processes after freezing / thawing cycles, and also increases the amount of deterioration by accelerating the mechanical events in the structure of the stone by creating changes in the chemical structure of the stone [1]. In addition, the side exposed to water shows significant erosion in the limestones [2-10]. In addition, various studies in the literature report that the effect of water on stone structures tends to increase the acidity of atmospheric pollutants over time, which further increases erosion and color change in stones [11,12]. Failure to take control and precautions in stone deterioration caused by the effects of water can turn small-scale (for example, flaking, fragmentation, cracking) deterioration into larger-scale deterioration over time, and this may lead to loss of cultural traces in historical areas [13]. For this reason, pre-detection and mapping of material deterioration in order to take the

* **Corresponding Author**

*(karataslale@gmail.com) ORCID ID 0000-0001-8582-4612
(aydinalptekin@mersin.edu.tr)) ORCID ID 0000-0002-5605-0758
(atilakarabacak@mersin.edu.tr) ORCID ID 0000 – 0002 – 1096 – 3949
(myakar@mersin.edu.tr) ORCID ID 0000-0002-2664-625

Cite this article

Karataş, L. Alptekin, A., Karabacak, A., & Yakar, M. (2022). Detection and documentation of stone material deterioration in historical masonry buildings using UAV photogrammetry: A case study of Mersin Sarisih Inn. *Mersin Photogrammetry Journal, 4(2), 53-61*

necessary measures is one of the most important stages of restoration works in the protection of heritage in historical areas.

Material degradation mapping of urban facades constitutes a preliminary activity for preparing any restoration response project. The traditional method for mapping relies on mechanical contact means and requires a great deal of time effort to obtain several front points [1]. In addition, the size of the building and historical sites makes it difficult to examine the types of material deterioration, and on-site visual analysis and up-to-date inspections by experts can also lead to human-induced errors. The development of methods based on various technologies in order to reduce the labor force and margin of error in the solution of this situation brings great convenience for the detection of material deterioration in historical areas [13]. In addition, the use of digital tools to support mapping activities allows for more detailed results on façade analysis [14] leading to simplification of manual and direct survey procedures [1].

In the literature, it is defined that the method that represents the best solution for the detection of material deterioration on facades should be tools that can obtain both spatial (XYZ) and RGB data by allowing the combination of geometric and material information. In the literature, in the detection of stone material deterioration, devices such as terrestrial laser scanning and photogrammetry are supported by computer software, and studies on surface erosion investigation and pixel-based material properties determination confirm the usability of these methods for material properties. However, although all these methods have important advantages in heritage areas, it has been determined by various studies that they have some inadequacies in the detection of material deterioration. For example, although Terrestrial Laser Scanning (TLS)-based surveys used to detect material deterioration allow us to obtain dense point clouds, obtain sufficient geometric data to be used in the modeling process for facades [15], due to the low resolution in RGB data, they are insufficient for distortion mapping [16]. The most important of these inadequacies in the terrestrial laser scanning method is the fact that the distortion groups are different from each other in shape, texture and color, and the distortion groups must have sufficient resolution for the interpretation of the data during identification. Other disadvantages are that they are expensive and data processing times are long. In some TLS devices, this is partially resolved by adding an external high-performance digital camera or by adding a digital camera. Digital close-range photogrammetry, on the other hand, is still subject to limitations in material deterioration, as it is time consuming and requires high labor force to record every area of the structures due to the location of the camera angle [17]. In addition, techniques such as terrestrial laser scanning and photogrammetry are insufficient to easily visualize the area, especially in historical urban contexts with narrow streets and tall buildings. A close-range photogrammetric survey study to analyze the material deterioration of a large historic building facade in Bologna (Italy) shows that this technique can only be used in structures that can be closely examined and detected in situ, and that the size of the areas makes it difficult to study the types of deterioration and the use of different technologies to compensate for these disadvantages. reported that it would be useful in the detection of material deterioration.

Various studies in the literature emphasize the importance of using UAVs in the detection of material deterioration as a method to overcome the disadvantages of methods such as terrestrial laser scanning and photogrammetry. Russo et al. [1] studied material deterioration detection by drone technology, and found that this technique is an efficient method to support restoration analysis because it is low cost, fast and easy to use in material deterioration mapping. It has also been confirmed by various studies that UAV technology is a good method to overcome terrain limitations and to search for hidden front areas [18-20].

Remote sensing technologies have been frequently used in engineering projects in the last decade [21-36]. In this context, it is aimed to identify and document the material problems of the "Sarışıh Han" building, which is located in the Tarsus district of Mersin, which is the subject of the study, and which is of great importance to be preserved in terms of the continuity of the cultural heritage of the region, by using UAV photogrammetry, which is emphasized to be of great convenience in detecting material problems in the literature. Thus, it will contribute to the detection and repair of material problems for the sustainable management of buildings in the geographical region. In this context, within the scope of the study, firstly, information about the historical importance and spatial situation of the "Sarışıh Han" building was given, and in the next step, how the building was documented using UAV photogrammetry was explained in the method section. In the results section, the stone material problems in the building, which were determined by using the data obtained from UAV photogrammetry, are included, and in the conclusion section, intervention suggestions for the repair of the detected material problems are presented.

2. Study Area

Tarsus has been an important administrative, commercial and military center since ancient times due to its strategic location. Connecting Central Anatolia to Çukurova and Northern Syria the caravanserai, located on the right arm of Anatolia and on the route where the Pilgrimage route passes, is on the Tarsus-Pozantı Road near Gülek Pass and 90 km from Tarsus. The caravanserai, which is within the borders of Çukurbağ Village of Tarsus district of Mersin, is located in Sarı Işık (Sarışih) Neighborhood. Caravanserai is called “Sarı Işık Han” or “Sarışıh Han” by the villagers (Figure 1).

The building was built on a land that slopes from south to north. On the eastern façade, it is seen that most of the outer cladding has been shed. Again, on this façade, there are three shapeless openings made later in the wall. The building was used for soda production for a period, and during this use, large openings were probably created on the eastern wall. The top of the building is completely covered with concrete, laterally inclined in two directions. The northeastern corner of the building, which is in a very neglected condition today, is about to be demolished. It is noteworthy that the exterior coating on the north and west façades has been renewed from place to place. This repair was made in the 1970s. There are crenellated windows in the upper part of the north and south façades. The caravanserai, which has a rectangular plan and a single closed space extending in the north-south direction, was built with coarse stones and rubble. The low-arched entrance, located on the western façade from the long sides, is arranged in the form of an iwan protruding from the façade. The entrance iwan is covered with a pointed arched vault. The side walls and vault of the entrance iwan are partially collapsed. The top of the single-room caravanserai is covered with a north-south oriented pointed arched vault parallel to the entrance façade. The vault is connected by eight support arches.

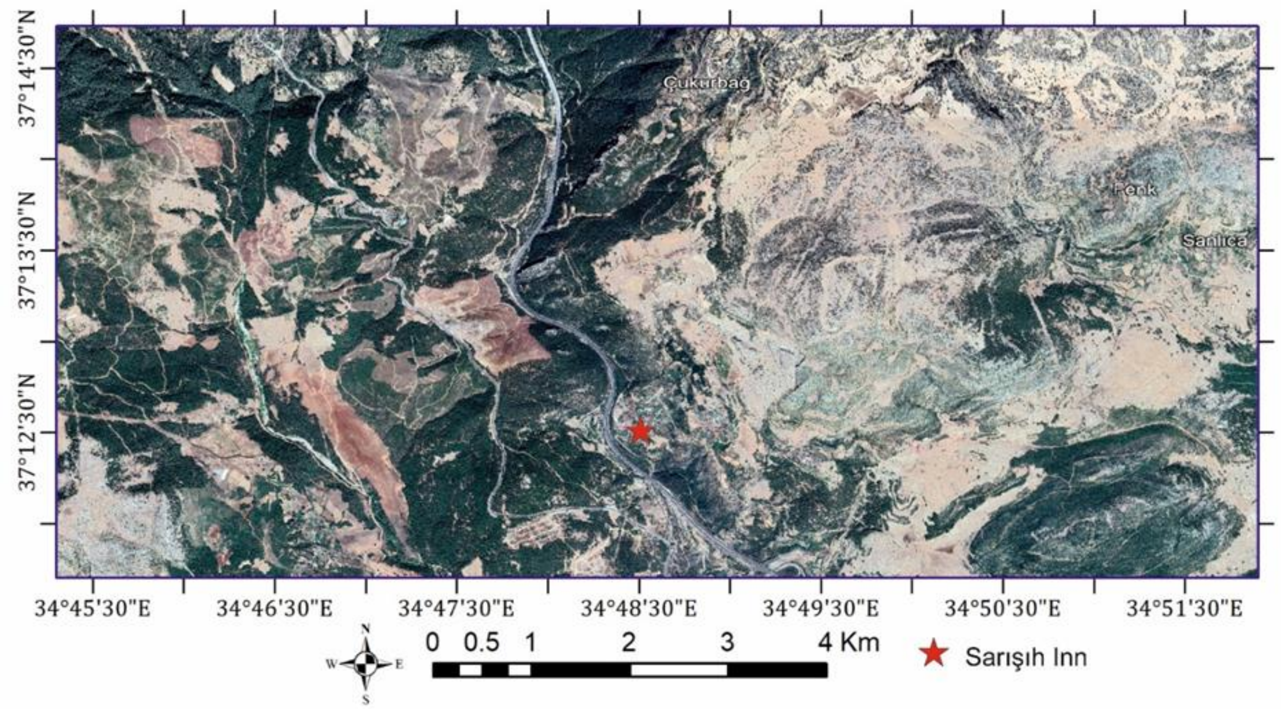


Figure 1. Location map

3. Method

This study consists of two stages: field and office work. Controlling the study area, preparing it to be photographed, and taking images of the caravanserai 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 photogrammetry method were transferred to the computer in the office environment and the classification of the types of deterioration in the building was made. The deterioration of the stone material in the building has been mapped by considering the International Stone Scientific Committee (ICOMOS-ISCS) classification prepared according to the International Council of Monuments [37,38]. Identified material deteriorations are tabulated by dividing them into classes on the basis of stone building 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 [39,40]. 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. In the literature, auxiliary elements in stone structures are defined as gargoyles, ornaments, moldings, and no auxiliary elements were used in the structure.

3.1. Field study

At this stage of the study, first of all, the necessary permissions were obtained to fly in the Tarsus District of Mersin Province, which is the study area. Images were captured manually with a Parrot Anafi HDR drone (Figure 2). The technical properties of drone 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. During the photo shoots, the camera was calibrated beforehand and 101 photos were taken without any changes 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.

3.2. 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. The pictures taken were examined in detail and material deteriorations were detected. From the images collected in the field by the UAV photogrammetry method, the pictorial dictionary published by ICOMOS and the findings regarding the material deteriorations summarized in Table 2.

Figure 2. Anafi Parrot

Table 1. Technical specifications of the UAV (Parrot 2021)

Feature	Value
Drone	
Size folded	244x67x65 mm
Size unfolded	175x240x65 mm
Weight	320 g
Max transmission range	4km with controller
Max flight time	25 min
Max horizontal speed	15 m/s
Max vertical speed	4 m/s
Max wind resistance	50 km/h
Service ceiling	4500m above sea level
Operating temperature	-10°C to 40°C
Lens	
Sensor	1/2.4" CMOS
Aperture	f/2.4
Focal length (35 mm eq.)	23-69 mm (photo)
Depth of field	1.5 m - ∞
ISO range	100-3200
Digital zoom	up to 3x (4K Cinema, 4K UHD, FHD)
Photo resolution	21MP (5344x4016) / 4:3 / 84° HFOV

Table 2. Stone material deterioration in the structural elements of the building

NATURAL STONE CONSTRUCTION ELEMENTS				PROBLEMS ENCOUNTERED ON CONSTRUCTION ELEMENTS MADE OF MASONRY MATERIAL																		Faulty Repairs		
				Loss of surface	Fragmentation	Formation of gap/ hole	Pitting	Cracks	Spalling	Foliation	Discharge of jointing	Surface contamination	Shell formation	Efflorescence	Crystallization	Formation of plant	Formation of moss	Corrosion (Rust stain)	Tear	Loss of form	Colour change	Use of cement	Fall of plaster	Other
VERTICAL BEARINGS	SINGLE BEARINGS	Leg		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VERTICAL BEARINGS	SINGLE BEARINGS	Column		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VERTICAL BEARINGS	CONTINUOUS BEARINGS	Wall		-	-	-	-	-	-	-	x	x	-	-	-	x	-	-	-	-	x	-	-	-
HORIZONTAL BEARINGS	FLOORINGS	Flat		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HORIZONTAL BEARINGS	FLOORINGS	Curvilinear		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WALL OPENINGS		Window	Lintel / jamb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WALL OPENINGS		Window	Sill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WALL OPENINGS		Door	Lintel / jamb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WALL OPENINGS		Door	Sill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WALL OPENINGS		Arch		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AUXILIARY ELEMENTS		Network		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AUXILIARY ELEMENTS		Moulding																						
AUXILIARY ELEMENTS		Gargoyle																						
AUXILIARY ELEMENTS		Chimney																						
AUXILIARY ELEMENTS		Element for passage to the cover																						

4. Results

4.1. 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 deterioration in the walls of the building was determined as plant formation and joint loss. On the south façade of the building, there are plants growing in the areas close to the ground where joint loss and joint losses occur due to the effect of water. Joint discharge and plant formation problems were detected on the south façade of the building (Figure 3).

On the eastern façade of the building, vegetation, surface pollution, discoloration and joint discharge problems were detected (Figure 4).

Partial fragmentation problems were encountered as a result of the effects of the loads on the building caused by the excess plant growth on the northern façade of the building (Figure 5).

4.2. Deterioration in horizontal carriers

In the literature, horizontal carriers from building elements in masonry structures are defined as floors. Flat flooring and vaulted roof use are seen in the entrance with iwan on the south façade. Vegetation type stone degradation is observed on the flat floor and the vaulted roof (Figure 6 and Figure 7).

4.3. Deterioration in auxiliary elements

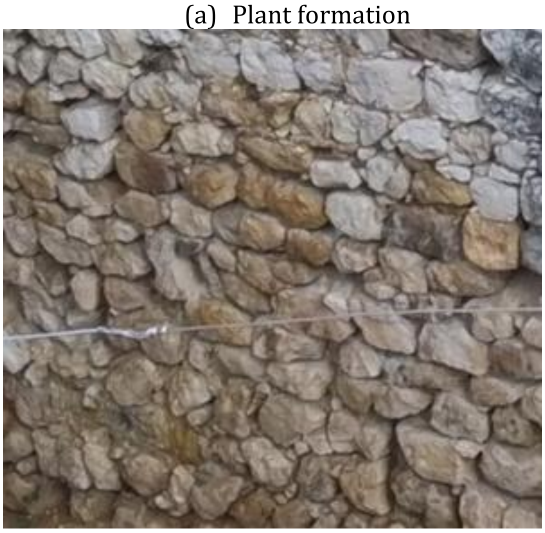
In the literature, auxiliary elements of building elements in masonry structures are defined as gargoyles, ornaments and moldings. No auxiliary elements were found in the building.

(a) Plant formation (b) Joint discharge

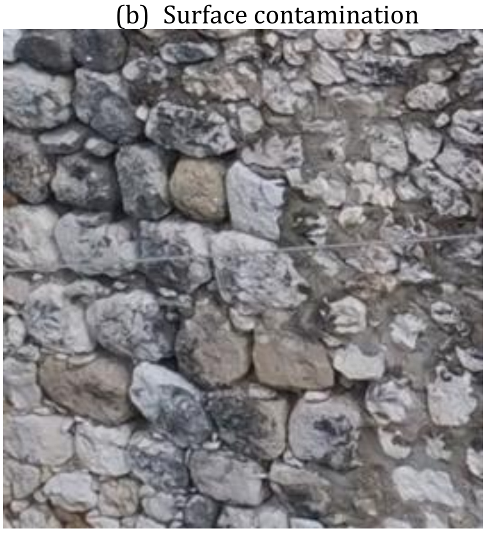
Figure 3. Stone material deteriorations detected on the south façade

(a) Plant formation

(b) Surface contamination



(c) Color change



(d) Joint discharge

Figure 4. Stone material deteriorations detected on the east façade

Figure 5. Fragment rupture

5. Discussion

The main purpose of the study is to identify and document the deterioration patterns of the stones that make up the structure of the "Sarışıh Han" located in the Tarsus district of Mersin. In order to investigate the deterioration patterns in the structure, the images obtained by UAV photogrammetry were interpreted considering the ICOMOS stone material classification and the types of deterioration were determined. In this context, the use of UAV photogrammetry to support stone material deterioration detection activities appears to lead to simplification of manual and direct detection procedures by providing more detailed results in the detection of material deterioration, façade analysis. As a result of the study, it has been seen that it is possible to detect material problem types down to the smallest detail based on visual inspection only, without an on-site observational examination, thanks to UAV photogrammetry. In addition, it is seen that UAV photogrammetry is an effective method to support restoration analysis because it saves manpower, labor and time in the detection of stone material problems, and this technique is low cost, fast and easy to detect material deterioration.

In addition, the results of the study show that this method is a useful method to compensate for the disadvantages of terrestrial laser scanning and conventional photogrammetry in detecting material deteriorations due to its low cost and low data processing time [15,16]. In the study process, material deteriorations were easily detected on the images obtained from UAV photogrammetry without the need for on-site inspection of the structure. This finding supports the results of studies that found UAV technology to be a good method to circumvent terrain limitations and search for concealed front areas [18-20].

Another important finding obtained from the study is that the material problems detected in the data obtained by the UAV method are plant formation, joint discharge, surface pollution and color change. It is seen that the problem of plant formation and joint grooves is dominant in a large part of the building. While the water entering the body wall eroded the joints, causing joint discharge, the water effect between the drained joints created the necessary environment for various living things to live in the province. This finding supports that the side exposed to water in limestones, which was also determined in the results of various studies in the literature, shows significant wear and therefore there are problems related to the abrasive effect of water on all facades exposed to water [2-10].

In addition, in the determinations made in the study, it is seen that the deterioration patterns in plant formation generally cause plant formation in the joint spaces thanks to the environment provided by rain water. This finding confirms that if control and precautions are not taken against rain water, which is a natural factor mentioned in various studies, small-scale deterioration (such as flaking, flaking, etc.), fragmentation, cracking can turn into larger-scale deteriorations such as plant formation over time [1,13].

Another important finding obtained in the study, the gray layer called surface pollution, draws attention on the facades except the south façade, where the residence time of water on the wall is longer. This situation suggests the fact that the water evaporates faster from the wall of the building due to the sunshine duration on the south façade and causes a color change in this situation, while on the north façade, the water stays in contact with the body wall more and evaporates slowly, so it can clean the black layer caused by the pollution on the façade less. This finding supports the fact that the acidity of the water tends to increase over time due to the atmospheric pollutants obtained in the results of Fort et al [11] and Castaño González et al. [12], which further increases the erosion and color change in the stones.

6. Conclusion

In the study presented in this article, UAV photogrammetry was used to investigate the deterioration patterns of the building material of the "Sarışıh Hanı" building, which is one of the most important buildings in terms of the sustainability of the cultural heritage in Mersin, and the deterioration types were determined by interpreting the images obtained. In this context, the use of UAV photogrammetry to support stone material deterioration detection activities appears to lead to simplification of manual and direct detection procedures by providing more detailed results in the detection of material deterioration, façade analysis.

The results show that the main damage observed on the stone surface of the building is the erosion by the effect of water and the problems caused by the lack of repairs in the worn areas, and plant formations occur in almost all parts of the facades and the plant formations cause large fragmentation on some facades. It is seen that the joint loss on the stone surfaces and the deterioration of plant formation have reached advanced levels as a result of the exposure of the building to the effects of sun and water caused by the strong climate for centuries. Restoration methods should be tried to stabilize the deterioration and replace the most degraded stones. To treat surface contamination degradation, consideration should be given to removing the gray layer to increase the stone's resilience to environmental pollution and to prevent subsequent exposure to weathering.

Author contributions

Lale Karataş: Conceptualization, Methodology, Software **Aydın Alptekin:** Data curation, Writing-Original draft preparation, Software, Validation. **Atilla Karabacak:** Field study, Editing **Murat Yakar:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Russo, M., Carnevali, L., Russo, V., Savastano, D., & Taddia, Y. (2019). Modeling and deterioration mapping of façades in historical urban context by close-range ultra-lightweight UAVs photogrammetry. *International journal of architectural heritage*, *13*(4), 549-568.
2. Bonazza, A., Vidorni, G., Natali, I., Ciantelli, C., Giosuè, C., & Tittarelli, F. (2017). Durability assessment to environmental impact of nano-structured consolidants on Carrara marble by field exposure tests. *Science of the Total Environment*, *575*, 23-32.
3. Gulotta, D., Bontempi, E., Bugini, R., Goidanich, S., & Toniolo, L. (2017). The deterioration of metamorphic serpentinites used in historical architecture under atmospheric conditions. *Quarterly Journal of Engineering Geology and Hydrogeology*, *50*(4), 402-411.
4. Waragai, T., & Hiki, Y. (2019). Influence of microclimate on the directional dependence of sandstone pillar weathering in Angkor Wat temple, Cambodia. *Progress in Earth and Planetary Science*, *6*(1), 1-14.
5. Bello, M. A., Martin, L., & Martin, A. (1992). Decay and treatment of macael white marble. *Studies in conservation*, *37*(3), 193-200.
6. Sarró, M. I., García, A. M., Rivalta, V. M., Moreno, D. A., & Arroyo, I. (2006). Biodeterioration of the lions fountain at the Alhambra Palace, Granada (Spain). *Building and Environment*, *41*(12), 1811-1820.
7. Sanjurjo-Sánchez, J., & Alves, C. (2012). Decay effects of pollutants on stony materials in the built environment. *Environmental Chemistry Letters*, *10*(2), 131-143.
8. Germinario, L., Siegesmund, S., Maritan, L., Simon, K., & Mazzoli, C. (2017). Trachyte weathering in the urban built environment related to air quality. *Heritage Science*, *5*(1), 1-17.
9. Germinario, L., Oguchi, C. T., Tamura, Y., Ahn, S., & Ogawa, M. (2020). Taya Caves, a Buddhist marvel hidden in underground Japan: stone properties, deterioration, and environmental setting. *Heritage Science*, *8*(1), 1-20.
10. Winkler, E. (1997). *Stone in architecture: properties, durability*. Springer Science & Business Media.
11. González, R. F., De Buergo, M. A., Martín, F. M., & De Azcona, M. L. (2004). Stone decay in 18th century monuments due to iron corrosion. The Royal Palace, Madrid (Spain). *Building and Environment*, *39*(3), 357-364.
12. Castaño González, J. G., López de Azcona, C., & Morcillo Linares, M. (2001). Deterioration of ancient metallic elements taken from Toledo cathedral. Revista De Metalurgia, *37*(4), 519–527
13. Hatır, E., Korkanç, M., Schachner, A., & İnce, İ. (2021). The deep learning method applied to the detection and mapping of stone deterioration in open-air sanctuaries of the Hittite period in Anatolia. *Journal of Cultural Heritage*, *51*, 37-49.
14. Del Pozo, S., Herrero-Pascual, J., Felipe-García, B., Hernández-López, D., Rodríguez-Gonzálvez, P., & González-Aguilera, D. (2016). Multispectral radiometric analysis of façades to detect pathologies from active and passive remote sensing. *Remote Sensing*, *8*(1), 80.
15. Guidi, G., Russo, M., & Angheleddu, D. (2014). 3D survey and virtual reconstruction of archeological sites. *Digital Applications in Archaeology and Cultural Heritage*, *1*(2), 55-69.
16. Soudarissanane, S., Lindenbergh, R., Menenti, M., & Teunissen, P. (2011). Scanning geometry: Influencing factor on the quality of terrestrial laser scanning points. *ISPRS journal of photogrammetry and remote sensing*, *66*(4), 389-399.
17. Kraus, K. (2007). *Photogrammetry: geometry from images and laser scans* (Vol. 1). Walter de Gruyter.

18. Remondino, F., Spera, M. G., Nocerino, E., Menna, F., & Nex, F. (2014). State of the art in high density image matching. *The photogrammetric record*, *29*(146), 144-166.
19. Fernández-Hernandez, J., González-Aguilera, D., Rodríguez-Gonzálvez, P., & Mancera-Taboada, J. (2015). Image-based modelling from unmanned aerial vehicle (UAV) photogrammetry: an effective, low-cost tool for archaeological applications. *Archaeometry*, *57*(1), 128-145.
20. Hatır, E., Korkanç, M., Schachner, A., & İnce, İ. (2021). The deep learning method applied to the detection and mapping of stone deterioration in open-air sanctuaries of the Hittite period in Anatolia. *Journal of Cultural Heritage*, *51*, 37-49.
21. Doğan, Y., & Yakar, M. (2018). GIS and three-dimensional modeling for cultural heritages. *International Journal of Engineering and Geosciences*, *3*(2), 50-55.
22. Yakar, M. (2009). Digital elevation model generation by robotic total station instrument. *Experimental Techniques*, *33*(2), 52-59.
23. Alptekin, A., Çelik, M. Ö., & Yakar, M. (2019). Anıtmezarın yersel lazer tarayıcı kullanarak 3B modellenmesi. *Türkiye Lidar Dergisi*, *1*(1), 1-4.
24. Yilmaz, H. M., Yakar, M., Mutluoglu, O., Kavurmaci, M. M., & Yurt, K. (2012). Monitoring of soil erosion in Cappadocia region (Selime-Aksaray-Turkey). *Environmental Earth Sciences*, *66*(1), 75-81.
25. Yakar, M., Yılmaz, H. M., & Mutluoğlu, Ö. (2010). Close range photogrammetry and robotic total station in volume calculation. International Journal of Physical Sciences, 5(2), 86-96
26. Alptekin, A., & Yakar, M. (2020). Heyelan bölgesinin İHA kullanarak modellenmesi. *Türkiye İnsansız Hava Araçları Dergisi*, *2*(1), 17-21.
27. Taşdemir, Ş., Yakar, M., Ürkmez, A., & İnal, Ş. (2008, June). Determination of body measurements of a cow by image analysis. In *Proceedings of the 9th International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing* (pp. V-8).
28. Unal, M., Yakar, M., & Yildiz, F. (2004, July). Discontinuity surface roughness measurement techniques and the evaluation of digital photogrammetric method. In *Proceedings of the 20th international congress for photogrammetry and remote sensing, ISPRS* (Vol. 1103, p. 1108).
29. Erener, A., & Yakar, M. (2012). Monitoring coastline change using remote sensing and GIS technologies. *Lecture Notes in Information Technology*, *30*, 310-314.
30. Karataş, L., Alptekin, A., & Yakar, M. (2022). Creating Architectural Surveys of Traditional Buildings with the Help of Terrestrial Laser Scanning Method (TLS) and Orthophotos: Historical Diyarbakır Sur Mansion. *Advanced LiDAR*, *2*(2), 54-63.
31. Karataş, L., Alptekin, A., & Yakar, M. (2022). Determination of Stone Material Deteriorations on the Facades with the Combination of Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Historical Burdur Station Premises. *Advanced Geomatics*, *2*(2), 65-72.
32. Karataş, L., Alptekin, A., & Yakar, M. (2022). Analytical Documentation of Stone Material Deteriorations on Facades with Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Şanlıurfa Kışla Mosque. *Advanced LiDAR*, *2*(2), 36-47.
33. Karataş, L., Alptekin, A., & Yakar, M. (2022). Material deteriorations occurring on the facades of the Mor Sergios Bakhos Church. *Advanced Engineering Days (AED)*, *4*, 48-51.
34. Karataş, L., Alptekin, A., Kanun, E., & Yakar, M. (2022). Tarihi kârgir yapılarda taş malzeme bozulmalarının İHA fotogrametrisi kullanarak tespiti ve belgelenmesi: Mersin Kanlıdivane ören yeri vaka çalışması. *İçel Dergisi*, *2*(2), 41-49.
35. Kanun, E., Alptekin, A., Karataş, L., & Yakar, M. (2022). The use of UAV photogrammetry in modeling ancient structures: A case study of “Kanytellis”. *Advanced UAV*, *2*(2), 41-50.
36. Karataş, L., Alptekin, A., & Yakar, M. (2022). Detection and documentation of stone material deterioration in historical masonry structures using UAV photogrammetry: A case study of Mersin Aba Mausoleum. *Advanced UAV*, *2*(2), 51-64.
37. Fitzner, B., Heinrichs, K., & La Bouchardiere, D. (2003). Weathering damage on Pharaonic sandstone monuments in Luxor-Egypt. *Building and Environment*, *38*(9-10), 1089-1103.
38. ICOMOS-ISCS (2008). Illustrated Glossary on Stone Deterioration Patterns, Champigny/Marne, France.
39. Karataş, L. (2016). Mardin Kentsel Sit Alanındaki İbadet Yapılarında Malzeme Kullanımı ve Sorunları Üzerine Bir Araştırma. Master’s Thesis, Uludağ University, Fen Bilimleri Enstitüsü, Bursa, 340p.
40. Karataş, L., Alptekin, A., & Yakar, M. (2022). Investigation of Molla Hari (Halil) Süleyman Paşa Mosque’s material deteriorations. *Advanced Engineering Days (AED)*, *4*, 55-57.