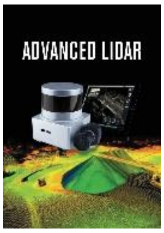
Advanced LiDAR

http://publish.mersin.edu.tr/index.php/lidar/index

e-ISSN 2791-8572



Terrestrial Laser Scanning with Potentials and Limitations for Archaeological Documentation: a Case Study of the Çatalhöyük

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Keywords
TLS
Archaeology
Documentation
Catalhoyuk

ABSTRACT

The evolution of digital technologies has impacted the documentation of cultural heritage. One of the steps that have passed considerable change is maybe the stage of data collection field. Today many different technological tools may be found at affordable prices. The suitable method for cultural heritage documentation should be chosen considering the needs of research, analysis and conservation. There is no definite way in order to determine which survey technique is the most suitable one in any situation. Digital photogrammetry, total station, GPS, texture mapping, laser scanning techniques are mostly preferable when high accuracy needed and can be supported by traditional tools like rectified photographs and stereophotogrammetry. In recent years, laser scanning shows great versatility for capturing any type of shape and speed of data acquisition. However in some cases, Terrestrial Laser Scanning (TLS) can have some limitations. In this study, Çatalhöyük archaeological area was documented with TLS and experiences were shared as potentials and limitations of TLS for archaeological documentation.

1. INTRODUCTION

In archaeology and cultural heritage, related projects there is often need for a rapid and accurate documentation of the objects. Since the process is dynamic, it requires fast and preferably non-immersive documentation techniques. Besides, the technique inevitably should be suited to cover the complete area (Sauerbier and Eisenbeiss, 2010). Even though fast, accurate, cheap modelling and visualization of archaeological areas is a demand, there are some justifications making this demand difficult. The first reason for this difficulty is directly related with the complexity and geometric and radiometric features of archaeological areas, while the second one is more related with its conceptual interpretation since it is a scientific document. These reasons make a need for new methods instead of traditional ones for archaeological documentation.

String grids and basic traditional methods may not provide accuracy standard which architects need in many situations. Simple survey of the site similarly can only provide a layout with a few accurate points connected with vectors, without any further information. These methods both need extra people working within archaeological site for a defined period of time, which increases the economic cost, as well as the possibility of accidental destruction of important findings. Additional security precautions should be taken in order to prevent any possible damage to the surveyor or archaeological remains (Ioannidis et al., 2000). Another used traditional techniques like tracing with wet paper and pencil/crayons, free-hand drawing, photography, plaster molding, latex and wax rubbing to record inscriptions or significant details on the surfaces may not reproduce the degree of detail and accuracy required by today's researchers and conservators (Diaz-Andreu et al., 2005). Besides it takes time to prepare it for drawing which could be only 2D.

In last decades, there has been an increasing demand in the digital documentation of archaeological sites and artefacts with development of new technologies. In this sense, three-dimensional photo-realistic models allow to document, manage and analyze

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Cite this article;

S A G Korumaz (2021). Terrestrial Laser Scanning with Potentials and Limitations for Archaeological Documentation: a Case Study of the Çatalhöyük. Advanced LiDAR, 1(1), 32-38

Research Article

Received: 02/09/2021; Accepted: 27/09/2021

the shape and dimension of the represented objects with a high degree of accuracy and resolution with the potential for recording.

Archaeological data is extremely complex from a geometric point of view and existing methods of 3D modelling lead to large simplifications. In addition, the data also should be easily scalable to support different levels of visualization quality. Detailed geometric information about archaeological sites can be obtained by using terrestrial laser scanning (TLS) methods as well as topographic surveying, photogrammetric techniques and Terrestrial Lidar Acquisitions (Apollonio et al., 2011; Brown et al., 2001; Lerma et al., 2010; Yilmaz et al., 2012; Yakar et al., 2010). These techniques made it possible to obtain a high level of detail and accuracy and result to be very effective, especially for small or medium-extension archaeological sites (up to tens of hectares).

According to the classification of metric survey techniques by English Heritage, direct and indirect techniques are mainly applied in cultural heritage documentation field (Heritage, 2011; Ulvi & Yakar, 2014; Yılmaz & Yakar, 2006)). Direct techniques includes hand measurement, levelling, total station and GPS while indirect techniques involves remote sensing, rectified photography, artefact scanner, close range photogrammetry, remote sensing, terrestrial laser scanning, airborne lidar and aerial photogrammetry. In most cases the combination of these technologies and related methodologies regarding their benefits may be the best solution depending on the final product since each of them has some limitations and advantages (Grussenmeyer et al., 2008; Patias, 2006; Alptekin et al., 2019).

As a direct technique, hand measurement can provide dimensions and positions of objects and scenes of a few meters, sketches in small size which is sometimes more impractical and not enough for larger objects. In this case, photogrammetry and terrestrial laser scanning could be more suitable by covering larger areas and enabling a large quantity of three-dimensional measurements to be collected. The studies have shown that photogrammetry has advantages for large amount of data, accurate data, possibility to texture in high resolution and detail, geo-reference data with stereo-viewing capability of the 3D data (Grussenmeyer et al., 2008, Patias, 2006). Similarly Terrestrial Laser Scanning technology has high performance in terms of data acquisition speed in different field of uses and has advantageous when used appropriately (Andrews et al., 2010).

In this project, archaeological area Çatalhöyük was surveyed with TLS in order see the TLS potentials for archaeological areas.

2. TLS AS ARCHAEOLOGICAL DOCUMENTATION TOOL

One of the most referred, accepted and detailed categorization of survey techniques has been made by English Heritage (Bryan et al., 2009). With this study, all metric survey techniques are divided mainly two parts called "direct" or "indirect". "Metric survey" can be defined as: the application of precise, reliable and repeatable measurement methods for heritage documentation (Andrews et al., 2009). These direct and indirect techniques are put together depending on final product, application areas, subject size and limitations in their use.

In recent years, 3D laser scanning shows great versatility for capturing any type of shape and speed of data acquisition. Definition of a laser scanner, adapted from (Böhler and Marbs, 2002) is 'any device that collects 3D co-ordinates of a given region of an object's surface automatically and in a systematic pattern at a high rate achieving the results in near real time' (Böhler and Marbs, 2002). This device a kind of "robotic total station" for the mass capture of 3-D coordinate data known as "point cloud" using with rapid-range measurements(Andrews et al., 2009; Hassani, 2015).

Laser scanners have been used in many diverse applications in cultural heritage documentation depending on the purpose such as: structural or condition monitoring, deformation analysis, making record, spatial analysis, getting a digital geometric model and 3D model (Table 1; Heritage, 2011). They can be either small objects or complex buildings. Mainly three steps are followed with laser scanner:

-Field survey and data acquisition,
-Editing and data processing and
-Production of final data (Bryan et al.,2009).

Related to the size of the object, the point density becomes more significant. It's possible to make survey from 1mm point density to 10 m (depending on the instrument capability).

Another key factor documentation with laser scanning is scale, the point density and the accuracy of measurement required by the project. A simple guide to appropriate point densities is given Table 1 (Bryan et al., 2009).

Point density/Rate of capture

Required distribution of measured points

scale	*point cloud*	*digitising**	*field survey†*
1:10	1mm	1–15mm	2–30mm (max 0.5m)
1:20	3mm	3–30mm	5–60mm (max 1m)
1:50	5mm	5–50mm	10–100mm (max 2m)
1:100	15mm	15–100mm	20–200mm (max 3m)
1:200	30mm	30–300mm	50–600mm (max 5m)
1:500	75 mm	75–750mm	0.1–1.5m (max 10m)

* From photogrammetric stereo model or point cloud: the higher value in each range represents the maximum permissible point interval.

† For example by electromagnetic distance measurement (EDM) or global positioning system (GPS). Where lines appear straight or detail is sparse the interval may be increased up to the maximum shown in brackets.

Table 1. Required distribution of measured points for photogrammetry, laser scanning, EDM or GPS techniques (Bryan et al., 2009)

3. ÇATALHÖYÜK ARCHAEOLOGICAL AREA

Çatalhöyük is one of the most ancient and prominent of the archeological sites in Turkey. It was built in the Neolithic period, and located near the town of Çumra district within the province of Konya, 52 km South east of the city (Figure 1-2).

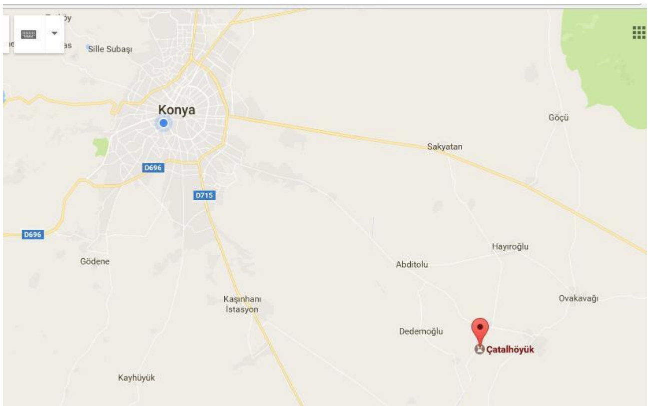

Figure 1. Çatalhöyük and Konya

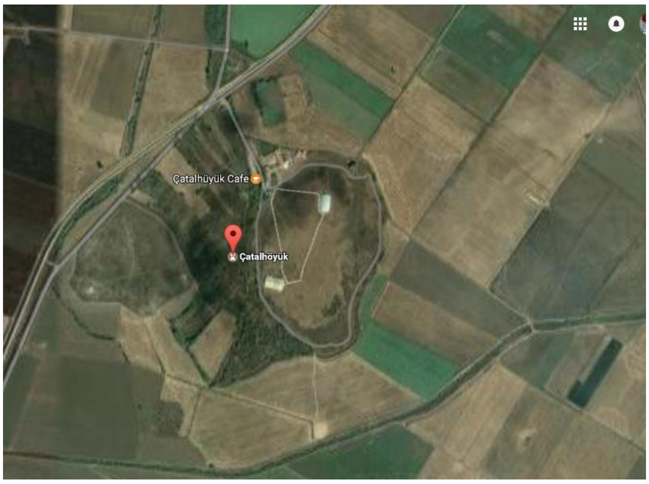

Figure 2. Çatalhöyük from the satellite (image from google earth)

Çatalhöyük consists of two hills form the 37 ha site on the Southern Anatolian Plateau. The taller eastern mound contains eighteen levels of Neolithic occupation between 7400 BC and 6200 BC, including wall paintings, reliefs, sculptures and other symbolic and artistic features. Together they testify to the evolution of social organization and cultural practices as humans adapted to a sedentary life. The western mound shows the evolution of cultural practices in the Chalcolithic period, from 6200 BC to 5200 BC (Figure 3). Çatalhöyük provides important evidence of the transition from settled villages to urban agglomeration, which was maintained in the same location for over 2,000 years. It features a unique streetless settlement of houses clustered back to back with roof access into the buildings (URL-1).

This site was first discovered in the late 1950s and excavated by James Melaart between 1961 and 1965 (Figure 4). The site rapidly became internationally famous due to the large size and dense occupation of the settlement, as well as the spectacular wall paintings and other art that was uncovered inside the houses. Since 1993, an international team of archaeologists, led by Professor Ian Hodder of Stanford University, has been carrying out new excavations and research, in order to shed more light on the people that inhabited the site. In July 2012, Çatalhöyük was listed on the UNESCO World Heritage List. The Turkish Cultural Foundation (TCF) has been a sponsor of the Çatalhöyük excavation project for multiple years. The TCF grants were allocated to build a shelter over the excavation site, and to help improve access and informational signage on the site. TCF worked with the Global Heritage Fund in California on this project. To further expand its knowledge on Çatalhöyük, TCF has been taking its Teacher Study Tours to Çatalhöyük for many years (URL-2).

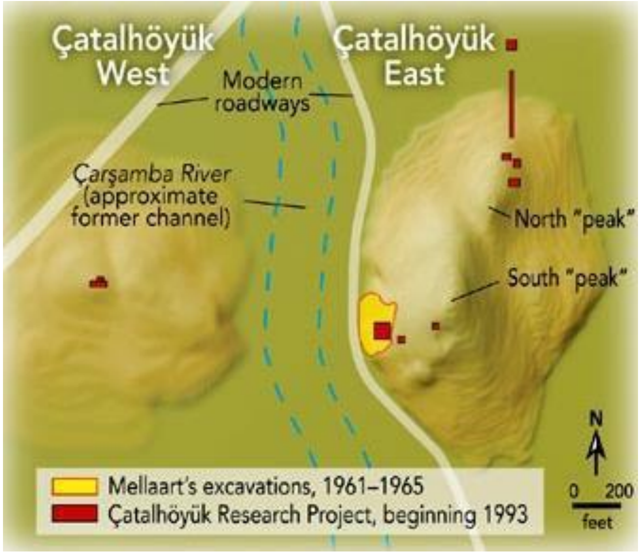

Figure 3. Site of Çatalhöyük, located in the semiarid Konya Basin of Anatolia (now central Turkey), comprises two mounds that accumulated as the settlement's inhabitants repeatedly built, tore down, and rebuilt their mud-brick houses. The eastern mound, dating from 9,400 until 8,000 years ago, has two "peaks," suggesting that the population may have been divided into two intermarrying kin groups. The western mound was occupied from about 8,000 until 7,700 years ago. Map by Joe Le Monnier (URL-3).

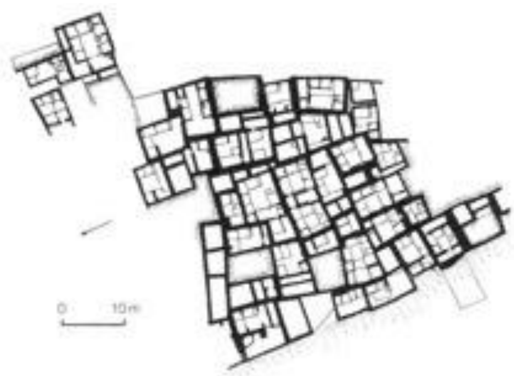

Figure 4. Plan of James Mellaart's excavations showing the dense house layout (URL-4)

3.1. Architecture in Çatalhöyük

One of Çatalhöyük's most defining attributes was its inhabitants' gradual, continuous building and rebuilding of their houses. These houses were very important to all aspects of their lives: material, social and ritual. Houses were roughly rectangular and closely built together with no streets in-between. Instead, people moved around on roofs and accessed their homes down a wooden ladder via an opening in the ceiling (URL-5).

All the houses found at Çatalhöyük are different in shape and size, yet most follow a general layout. Each central room had an oven below the stairs where people carried out domestic tasks such as cooking. Raised platforms within the rooms were used for sleeping and other domestic activities. Beneath these platforms inhabitants buried their dead. Side rooms were accessed off the central room providing essential storage areas (Figure 5).

Figure 5. A reconstruction showing the use of space and the layout of a typical house. Illustration by Kathryn Killackey (URL-5)

The case study was in Eastern Mound, North Peak where there is a big shelter on excavation area (Figure 6-7).

Figure 6. Excavation area of eastern mound, north peak

Figure 7. Excavation area of eastern mound, north peak

4. DATA CAPTURE AND PROCESSING

The scanning of the field was completed in one day and the whole area was covered with 12 scans. The scanning could be done only on the edges of the excavation area since it was forbidden to walk on the middle part of the archaeological area. Since the scanning was carried out only from the edges of the area, there were some missing parts in the data (Figure 14). Totally 515.726.448 million of points were acquired from 12 scan stations (Figure 10-11-12-13-14-15). The point spacing was 1-3 cm.

FARO Focus3D 120 was used for TLS survey. It is a phase-based laser scanner. It captures objects in range from 0.6 m to 120 m with distance accuracy up to ±2 mm. Similar to other phase-based scanners, it is characterized by a high measuring speed at a maximum of 976.000 measuring points per second. The scanner is equipped with an internal color camera. A built-in 8 mega-pixel HDR camera captures detailed imagery easily This integrarted colour camera is able to get photorealistic 3D colour scans with up to 70 megapixels resolution and parallax-free colour overlay to the scan data in exreme ligthining conditions (Figure 8). The GCPs were measured with RTK GPS (Real Time Kinematik Global Poistioning System) (Figure 9).

Figure 8. Terrestrial Laser Scanning with FARO Focus3D 120

Figure 9. GCPs GPS measurements

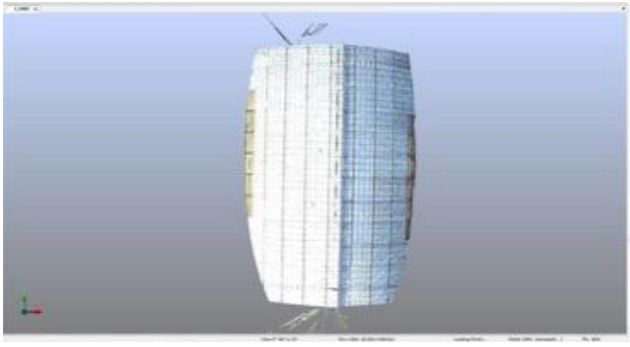

Figure 10. TLS data point cloud after the alignment in Scene software

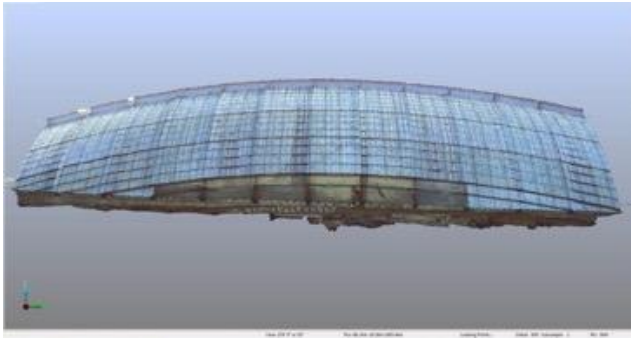

Figure 11. TLS data point cloud after the alignment in Scene software

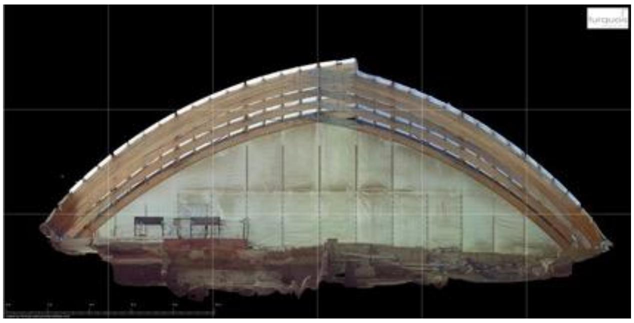

Figure 12. Cross section or archaeological area from TLS data point cloud data in Scene software

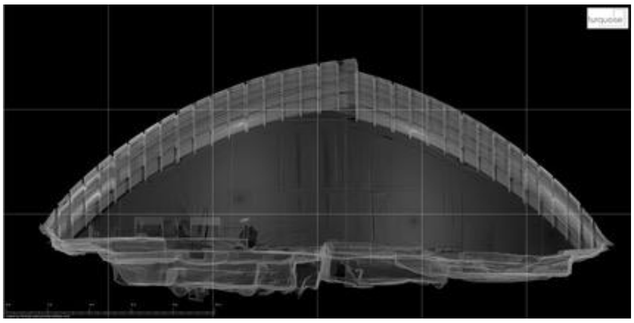

Figure 13. Cross section or archaeological area from TLS data point cloud data in Scene software

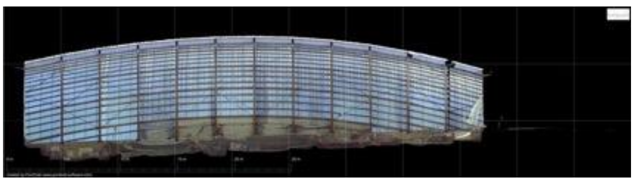

Figure 14. Longitudinal section or archaeological area from TLS data point cloud data in Scene software

Figure 15. Plan of archaeological area without shelter from TLS data point cloud data in Scene software

5. POTENTIALS AND LIMITATIONS OF TLS IN ARCHAEOLOGY

A wide range of use technologies applied in cultural heritage proved the variety of alternatives for documentation of an object. However, a single method is insufficient for the desired accuracy and each method has its own advantages and limitations. Cost, time, complexity and size of the object, accessibility, personal skills, instrument capabilities has a significant effect on choosing the most appropriate survey method. In most cases, it is needed to use a single method with the support of other techniques or a combination of different techniques in order to achieve result. If the budget allows, it is the most suitable solution and best possible method.

In order to acquire information in all survey processes require mainly on 3 issue:
-Understanding of techniques and their performance in terms of precision and accuracy
-Understanding of the subject of the documentation
-Presenting the information in accessible, clear and consistent way (Blake, 2010).

Even data capture techniques have increased there is still a lack of standards in data presentation AND 3d modelling for cultural heritage including archaeological areas. Today standards are as much about work practice as they are about listing quality constraints. The present suite of developing documentation technologies need expert guidance on their application and given the contraction of institutional support for sustaining metric skills.

Accessible technologies like laser scanner is known with its power for 3D data by heritage managers. The standards required to achieve conservation specific data from laser scanner are developing and the indications are that the "of the laser scan isn't a "magic tool" all in the sector.

However, TLS has been used for many tasks and great potentials in archaeology for:
-A detailed record of a site which helps to assist any intervention and analysis process,
-Working at different scales for archaeological features
-Structural or conditional monitoring and observing changes
-Detailed and achievable record of archaeological excavation areas or site at risk

-Supporting 3D models and animations for presentation of archaeological area through media or different technologies
-Supplying a digital geometric model for reconstruction or replica models in order to display or for virtual museums
-Helping the interpretation of archaeological features
-Spatial analysis with 3D data (Heritage, 2011).

As it was pointed out before, TLS or any method is not sufficient for a comprehensive documentation. It is always recommended to take photography, to take some measures manually, on-site drawings and other survey methods can be consulted and needed for better interpretation of the cultural heritage. Among the limitations;
-It doesn't provide unlimited geometric accuracy and completeness of the objects/areas. In many cases TLS can be unnecessarily expensive or redundant for requested output.
-Laser scanners are not always so variable or flexible as cameras for getting data. If high resolution is required for data, the time for acquiring data can take much more time than expected.
-During on-site working TLS cannot see through objects like dense vegetation. Besides they may have some problems of reflection related to object materials. In addition to all, health and safety precautions should be taken while using the equipment.
-For archaeological areas or objects, irregular edges may not be guaranteed as in precision. TLS, in general, is much more effective for recording of regular surface data. (Historic, 2018; Ruther et al., 2003). The areas with natural or unnatural obstacles, hidden or unseen points, objects with reflective materials are the reasons causing laser scanner fails to provide accurate data. Rainy weather condition and moisture affects the data as well. It still requires high cost, skilled operators and careful and relatively long data processing process (Amorim, 2011; Hassani, 2015; Heritage, 2011).

6. DISCUSSION AND CONCLUSION

This paper highlights the common use of TLS in archaeological area in order to get comprehensive and accurate data for archaeological areas. It's apparent that the use of TLS facilitates documentation process in many perspectives. However, in some special cases, like Çatalhöyük it may become insufficient for a detailed documentation.

In case study area, we were not able to get all data with TLS because of the prohibits on archaeological area. It was forbidden to walk or to put anything through the middle of the excavation area. Since the ruin is made of adobe, it is easily dispersible which it has to be very careful. So, we had to set up our scan stations close to the border or the area where, at the same time, close to the beginning of the shelter. It unfortunately caused lack of data. Also we couldn't get the certain edges of the ruins because of this limitation in data capture. We needed another technology to get aerial data. For this reason, our further research will be to use both TLS and UAV to acquire data of all area.

As another limitation, the GPS disconnected because of the shelter. While we could get GPS data outside, we were rarely, or sometimes not, able to get it. It changed also depending on our position inside.

During this case study, it became obvious that TLS cannot be a solution alone for a complete documentation. Beside its significant contributions to documentation and presentation of archaeological area, there are still some missing/need to develop parts in TLS pipeline, starting from data collection, including the type of the instrument, data processing, presentation and sharing.

Acknowledgement

This paper was organized from a part of completed PhD thesis name of "Improved Documentation of Cultural Heritage using Digital Photogrammetry with Visible and Thermal Images from Unmanned Aerial Vehicles (UAVs)" of author Dr. S. Armağan GÜLEÇ KORUMAZ which was submitted to the Department of Architecture, Civil Engineering and Environmental Sciences University of Braunschweig – Institute of Technology and the Department of Civil and Environmental Engineering University of Florence.
The author also would like to thank Erkan BAYGÜL from PAKSOY TEKNIK Tic. Ltd. 513 Şti. for their help and effort for technical support on field work.

Author contributions

Conceptualization, Methodology, Writing-Reviewing, Field Survey,

Conflicts of interest

The authors declare no conflicts of interest.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics

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