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Original article

Detection of geometric changes for an historic theatre by comparing surveying data of different chronological periods

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ABSTRACT

This paper presents results from a study where identification and documentation of geometric changes are examined from a weathered ancient theatre using map regression methods. Specifically, a comparison is made between a topographic map created in the 1960s by the German Archaeological Institute and a new map of the same area using state-of-the-art geodetic and terrestrial laser scanning (TLS) techniques. The work scale of the maps is 1:100 and can reveal changes and deformations of relevant size to the scale of the map (over 1.5 cm). The process, described in detail, entails georeferencing, planimetric and vertical comparison and assessment of the changes. The study demonstrates the importance of detecting topographic changes in cultural heritage sites and can be applicable to similar analyses over a range of time periods.

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1. Introduction

The conservation, preservation, and documentation of cultural heritage landscapes and sites have concerned conservationists, historians, and scientists for many years. The conservation of a cultural heritage site depends on the materials of which it is composed and on complex processes such as ageing and environmental effects. Therefore, detecting and quantifying even small-scaled changes in cultural heritage sites helps further understanding the deterioration process, particularly in relation to the underlying mechanisms which drive their evolution. Considering the large number of cultural heritage sites, the monitoring methods must be reliable and accurate and capable of detecting and documenting changes on various scales.

Historic changes in cultural heritage sites can be quantified with geospatial data from a number of techniques depending on the application. These techniques vary from field topographic surveys to advanced technologies of dense data collection by satellite, airborne imagery, laser detection ranging or terrestrial laser scanning (TLS). TLS is a favourable technique allowing complex sites to be rapidly surveyed at previously unattainable point densities. It also provides the resolution and accuracy for cultural heritage applications requiring detection, characterization, and analysis of changes, as well as large-scale deformations.

Often, it is possible to use data from historical maps to examine differences in heritage sites. In maps where accurate historical topographic data are available, map regression techniques can be implemented between recent and earlier maps of the same area to determine changes or to locate past features [1]. Using modern maps to transcribe or reproject earlier maps can help to locate these features with contemporary survey controls and techniques. Map regression is performed either by comparing individual features between maps, or by reprojecting an entire map so as to fit another onto which it can then be superimposed. The process can include resolving any differences in map scale, projection, datum, or format; and the interpretation of each map in its meaning and accuracy.

In map regression, the comparison is made planimetrically and vertically. The most common approach refers to the vertical component and such comparisons are performed using digital surface or elevation models (DEMs). The comparison is performed using the DEM reconstruction from the historic map with subsequent DEMs from recent maps, which produce DEMs of difference. Examples include change detection in archaeological sites using satellite imagery data or for predictive archaeological research [2–4]. The use of DEMS derived from TLS for the detection of changes has

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been reported for landscape archaeology [5], as well as comparisons with other historic data in order to extract information about archaeological resources and landscape change [6–7].

This paper aims to present a methodology used for detecting topographic changes for the archaeological site of the Kabeiroi in Thebes, Greece using map regression by comparing an early topographic map of the late 1960s created by the German Archaeological Institute [8] with a recent map created using TLS data. Emphasis is given on the ancient theatre of the sanctuary. Ancient theatres have always appealed more in the preservation and restoration of historic monuments, due to the increased interest of countries to enhance the cultural activity of a region. Often, an ancient theatre can be used for performances but the usage of an ancient theatre for such purposes needs to be approached with particular attention [9]. The work presented in the paper is linked to the restoration of the ancient theatre of the Kabireion sanctuary and involved surveying measurements for the structural documentation of the theatre to plan and optimize maintenance of the theatre. Over the years, researchers have monitored and studied changes in ancient theatres and their surrounding sites using either classical surveying techniques for small scale phenomena, or aerial photogrammetry for larger ones [10–12]. Related TLS research has expanded substantially, delivering high-resolution elevation models and significantly improving the monitoring of degradation processes in ancient theatres [13–15].

In this work high accuracy geometric documentation techniques are used (TLS and geodetic techniques) to create a 3D model and a topographic map of the ancient theatre. The comparison to identify geometric changes is performed planimetrically and vertically. The georeferencing and integration of the data is performed within a geographic information system (GIS) environment. Planimetrically, the comparison is made through polygons and vertically, through selected sections of the theatre. Finally, a statistical analysis is given to identify whether the positional differences of well-identified objects in both maps represent real differences and not considered artefacts of the old map. The remainder of the paper is structured as follows. Some historic notes of the study area are given in section 2. Section 3 provides a description of the 1960s topographic maps and the present data acquisition using TLS and geodetic techniques for the documentation of the theatre. The methodological framework is outlined in section 4, followed by the data processing and the results for the planimetric and vertical comparison between the two maps. Also, a statistical analysis is given to assess the differences within a specified uncertainty. Finally, section 5 gives a discussion regarding the obtained results along with concluding remarks.

2. Historical notes on study site

The archaeological site of Kabeirion of Thebes in Greece has been the target of a number of previous archaeological studies [16]. In 1887 the Kabeirion was discovered due to a chance find of bronze statuettes. It was exclusively excavated in 1888-9 by the German Archaeological Institute [17] and the excavation was continued by Bruns between 1956 and 1966. A supplementary excavation took place in 1971 [8].

The most important monuments of the Kabireion sanctuary are [18]:

- the temple: devoted to the gods called Kabeiroi. It is a rectangular building the oldest remains of which are dated at the 6th century B.C. onwards. The preserved foundations are from the end of the 4th century B.C. The temple was supplied with pronaos, cella and a courtyard with two rectangular sacrificial pits and was enclosed by a circuit wall;
- the theatre: built during the hellenistic period (3rd–1st centuries B.C.) on the same axis as the temple. It had no front scene, but had 10 sectors in the cavea and an altar in the middle of the orchestra. It was used for the attendance of religious ceremonies concerning the initiation of the pilgrims;
- the Stoa: built in the 1st century B.C. and is a long-narrow building of 40 m length, on the south-east of the theatre;
- circular and elliptical buildings: found everywhere in the sanctuary. They contained sacrificial pits and benches along the walls for the practices of initiation. The largest one from the end of the 5th century B.C., between the temple and the stoa, was probably a plain unroofed enclosure wall;
- the circuit wall: before 300 B.C. enclosed the temple and an open-air area in front of it. In the 2nd century B.C. it extended to the east in order to include the cavea of the theatre.

Over the years, wild vegetation and the shutdown of the ancient drainage systems have caused damage while a large part of the ancient buildings and constructions have been filled in by soil embankments. To date, following excavation of the area several visible remains can be seen with the most important being the theatre and the temple (Fig. 1a).

3. Data

In the following subsections, a presentation of the data (old topographic data and up-to-date TLS data) collected for the Kabireion theatre is given.

3.1. Topographic Maps of 1960s

The German cartographic presence in modern Greece started in the 19th century with its origin in matters of archaeological and historical interest. Its contribution to the topographic mapping of several parts of Greece is extremely important [19]. The historic material that was used in this work involves three maps:

- paper copy of a map at a scale of 1:1000, created in 1966 by von W. Zick and revised in 1969 by W. Heyder, showing the Kabeiroi sanctuary and its environs (Fig. 1b);
- paper copy of a map at a scale of 1:100, created in 1969 by W. Heyder, showing the Kabeiroi theatre prior any excavations (Fig. 1c);
- paper copy of a map at a scale of 1:65, created in 1969 by W. Heyder, providing height levels of the Kabeiroi theatre prior any excavations (Fig. 1d).

There is no firm information regarding the field surveying techniques that were employed in the creation of the above maps. Based on the surveying techniques employed at the time, it is certain that angle observations were acquired using theodolites. The accurate measurement of long distances is achieved using electronic distance measurement (EDM). However, it is certain that EDMs were not used in the specific archaeological expedition, besides tape measuring. The first EDM equipment by the early 1960s was large and cumbersome and it was not until the 1970s that EDMs came into everyday topographical use. Towards the end of the 1950s, photogrammetry was introduced for the topographical mapping of some German states but it is almost certain, from the above three maps, that photogrammetric type data were not acquired for the Kabireion sanctuary. Regarding height information, it is considered that geodetic levelling was used to estimate height differences, this being a mature technique in the 1960s.

Clearly, the challenge of using historic data from topographic maps is dependent on the quality of source materials and processing methods for their construction. For example, contour

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