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Original article

3D DOCUMENTATION AND VISUALIZATION OF GRECO-ROMAN MONUMENTS FROM JORDAN THROUGH THE APPLICATION OF DIGITAL TECHNOLOGIES

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Abstract:
Digital technologies have gained significant traction over the past decade in cultural heritage conservation and management. Modern technologies have been increasingly used in documenting, conserving, interpreting, and presenting cultural heritage sites, monuments, and objects. Particularly 3D modeling techniques have become a useful tool when it comes to reconstruction and accurate representations of monuments and architectural remains that sustained significant degrees of damage and destruction. 3D modeling can be used to reconstruct the morphology, color, and texture of damaged features making it possible to effectively communicate their values and significance to the general public. In this study, 3D models have been used for the documentation and reconstruction of several important monuments in two famous Greco-Roman Decapolis cities, namely Gadara and Gerasa. 3D laser scanning and image-based modeling techniques were used to generate 3D models of several key monuments in the two cities. 3D modeling technology proves to be an effective instrument for interpreting and presenting these monuments, particularly those poorly preserved due to the adverse effects of nature and humans.

1. Introduction

In recent years cultural heritage practice has overtaken decisive steps towards new digital technologies. Its implementation can be multifarious, ranging from digital scanning and documenting heritage objects and sites to creating elaborate 3D visualizations as a vital part of their conservation and presentation [1,2]. Computer graphics have become strategic for the development of projects aimed at the interpretation of archaeological evidence and the dissemination of scientific results to the public. Among all the solutions available, the use of 3D models is particularly relevant for the reconstruction of poorly preserved sites and monuments destroyed by natural causes or human actions. These digital replicas are, at the same time, a virtual environment that can be used as a tool for the interpretative hypotheses of archaeologists and as an effective medium for a visual description of the cultural heritage [3]. Various acquisition techniques can be used for 3D model creation. Passive sensors (e.g., digital cameras) deliver image data which are then processed with some mathematical formulations to infer 3D information from the 2D image measurements. Reality-based techniques (e.g., photogrammetry, laser scanning) employ hardware and software to survey the reality as it is, documenting the actual or as-built situation of a site and reconstructing it from real data [4]. However, a single method cannot guarantee the desired accuracy and there are always obstacles and problems, which limit the capabilities of a technique. Cost, time, complexity and size of the object itself, accessibility, the skill of the survey team, etc. play an important role in selecting a survey method [5]. In this research combinative techniques were employed to reconstruct a 3D model of several Greco-Roman monuments from many Decapolis sites in Jordan. The monuments have sustained significant deterioration and damage which adversely impact their preservation state. This makes the communication of their values and significance to visitors quite difficult and ineffective. This problem can be overcome by the utilization of 3D modeling techniques to serve as a tool for effective interpretation and visualization of the poorly preserved and damaged monuments.

2. 3D Modeling Techniques

The categorization of 3D modeling techniques is based on the metric data and acquisition of point coordinates of the targeted object with or without taking images [6]. On that basis, three main techniques are identified:

- Image-based techniques
- Non-image-based techniques
- Combinative techniques

2.1. *Image-based techniques*

In this category, the image is the base for data acquisition of the targeted object and the coordinates can be accessible after the processing phase. Photogrammetry is the most commonly used image-based 3D modeling technique. In this technique photographs from different points of view are taken using an ordinary camera and then using these photographs as a "starting point" in the process of using point-to-point measuring tools in an image-based modeling application. Delivered image data requires a mathematical formulation to transform the 2D image measurements into 3D information using specialized software applications [7].

2.2. *Non-image-based techniques*

Images are not the base of the surveying process and the coordinates of the different points can be accessible directly using range-based tools. Range sensors deliver direct distances thus 3D information in the form of unstructured point clouds. The most commonly used range-based sensor technique in cultural heritage documentation and 3D modeling is the laser scanner. Laser scanning, from the air or the ground, is one of those technical developments that enables a large quantity of three-dimensional measurements to be collected in a short space of time. Laser scanning from any platform generates a point cloud: a collection of XYZ coordinates in a common coordinate system that portrays to the viewer an understanding of the spatial distribution of a subject. Laser Scanners collect 3D coordinates of a given region of an object's surface automatically and in a systematic pattern at a high achieving the three-dimensional coordinates in near real-time [8,9].

2.3. *Combinative techniques*

As the two previous categories of 3D modeling have their weaknesses and problems, the combinative technique is a try to overcome the weaknesses and problems of the two categories. The combination takes advantage of image-based methods with a photogrammetry base, and non-image-based techniques, which survey the target by transmitting a beam to the surface [10]. Examples of effective combinative techniques are Photo-laser scanner which combines close-range photogrammetry with the point cloud produced by laser scanning; Structured Light which operates with a similar method to photogrammetry while finding and matching points from different images forms the foundation for producing a 3D model; David Laser Scanner (DAVID) which is a low-cost three-dimensional documentation method, composed of a computer, video camera, a background containing control points and a line laser source [11].

3. The Decapolis

The Decapolis was a group of ten cities on the eastern frontier of the Roman Empire in the southeastern Levant in the first centuries BC and AD. The cities formed a group because of their language, culture, location, and political status, with each functioning as an autonomous city-state dependent on Rome. Impressive monuments and archaeological features include rock-cut tombs with architectural ornaments, facades and Greek inscriptions, theatres, colonnaded streets, nymphaeum, bath complexes, churches, temples, forums, arches, and water aqueducts. The Decapolis cities are Gerasa (Jerash); Nyse-Scythopolis (Beit-Shean); Hippos-Sussita; Gadara (Umm Qays); Pella (Pahal); Philadelphia (modern Amman); Dion; Canatha; Raphana (Abila); and Damascus [12,13]. Seven of these cities are located in Jordan as shown in fig. (1).

Figure (1) Locational map of the Decapolis cities (*After: Commons Wikimedia, 2024)* [14]

4. Methodology

The field measurement of the monuments and their adjacent areas was performed with a terrestrial laser scanner (TLS), fig. (2), with which the entire monument was scanned, together with its courtyard.

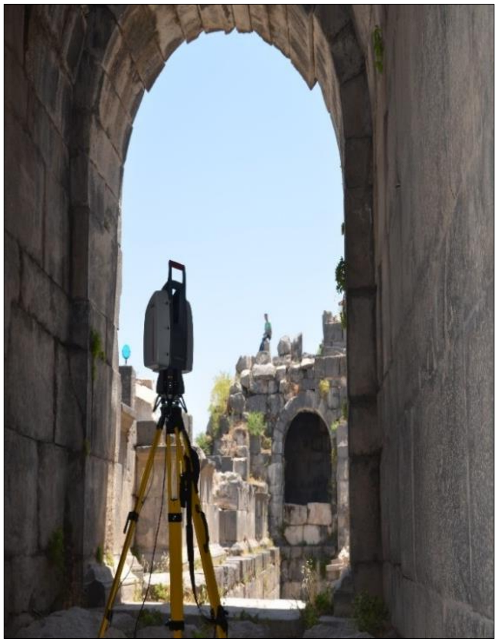


Figure (2) Laser scanner used for collecting 3D clouds of the monuments

Additionally, complete photographic documentation was prepared using close-range photogrammetry to acquire a greater amount of data on the subject of the study. The data pools obtained with the two measurement methods were integrated, thus forming one pool. Terrestrial Laser Scanning data serves as the reference material, providing information on the geometry of monuments, their shapes and dimensions. TLS Measurements were supplemented with pictures, increasing the detail level of acquired information. TLS data were integrated with pictures to enable the acquisition of real models. A point cloud generated by scanning allows the creation of a 3D model, whereas pictures allow the creation of a new thematic layer to represent the texture of the created solids.

5. Results

5.1. *3D models of selected monuments from the Decapolis*

5.1.1. Nymphaeum of Jerash (Gerasa)

On the western side of the Cardo Maximus is the elegant Nymphaeum, fig. (3-a), the main ornamental fountain of Jerash, dedicated to the water nymphs. Built about AD 191, the two-story construction was elaborately decorated, faced with marble slabs on the lower level, plastered above, and topped with a half dome. Water cascaded into a large pool at the front, with the overflow pouring out through seven carved lions' heads. The combined TLS measurements and close-range photogrammetry enabled the reconstruction of a detailed 3D model of the Nymphaeum, fig. (3-b).

Figure (3) **a.** the Nymphaeum of Gerasa, **b.** 3D reconstruction of the Nymphaeum based on archaeological evidence

5.1.2. Octagonal church of Gadara

This Byzantine Basilica church, fig. (4-a) was built in the early 6th century using Roman basalt columns. This church is unique in terms of its architectural plan. It was a square with an octagonal interior and a rectangular atrium or colonnaded courtyard. It has a fine opus sectile floor. The early sixth-century octagonal church was formed by re-used basalt col-umns and capitals, the atrium was also formed by re-used limestone columns and capitals. The church was destroyed by earthquakes in the 8th century and the ruins were discov-ered in 1806. Close-range photogrammetry with the point cloud produced by laser scanning enabled the creation of a 3D model of the church showing how it was before the destruction, fig. (4-b).

Figure (4) **a.** view of the octagonal church in its current condition, **b.** 3D reconstruction of the octagonal church to its state before destruction

5.1.3. Colonnaded street of Gadara

The Decumanus Maximus, fig. (5-a) is the main east-west axis and grand colonnaded street of Gadara. It runs through the entire northern quarters of the ancient town. Around the mid-1st century AD, a first road section was paved with basalt slabs. When the development of Gadara reached a peak in the Severian period (193-235 AD), the Decumanus Maximus w = -09876543 as greatly enhanced and prolonged into the city areas which had continued growing westwards. Estrades with numerous statues of honor, colonnades, and porticoes as well as other monuments of urban representation were built on both sides. The street and its monuments were severely damaged by an earthquake in the middle of the 8th century. 3D reconstruction of the Decamnus-Maximnus at its height was done by integrating data from laser scanning clouds and close-range photogrammetric images, fig. (5-b).

a

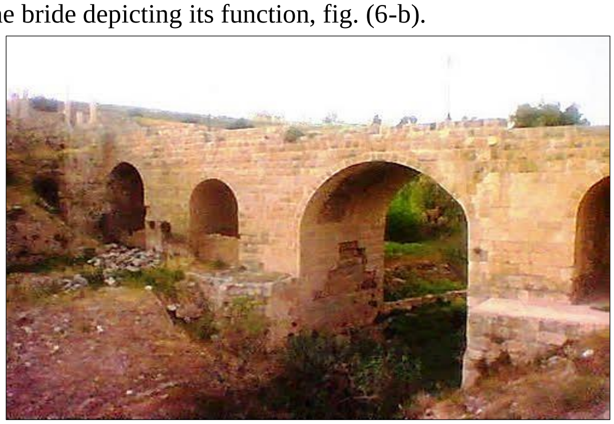
b

Figure (5) **a.** the colonnaded street of Gadara as it is today, **b.** 3D reconstruction of the colonnaded street of Gadara

5.1.4. Gerasa Roman Bridge

The bridge is a typical example of a Roman semicircular arch bridge, fig. (6-a). The bridge was built by the Romans in the second century and spans the dissecting valley of Jerash. The semicircular arch bridge was a great technological achievement in architectural design. The greatest difficulty facing the Romans when building a bridge across water was the construction of the supporting pillars rather than the arches which span across them. Jerash Bridge has a semicircular design with abutments on each end. The stability of this true arch depends on the compression between its wedge-shaped stones. (That is, the stones are forced to squeeze against each other.) This results in horizontal outward forces at the springing of the arch (where it starts curving), which must be supported by the foundation (abutments) on the stone wall on the sides of the arch. Very heavy walls on either side of the arch were constructed to provide horizontal stability. The bridge has flood openings and was constructed of limestone. The combined laser scanning clouds and detailed images captured by photogrammetry enabled the reconstruction of the bride depicting its function, fig. (6-b).

a



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b

Figure (6) **a.** the current condition of Gerasa Roman bridge, **b.** 3D reconstruction of the Roman bridge showing its function.

6. Discussion

The monuments included in this study are highly significant and represent an important part of Jordans' cultural legacy. Unfortunately, these irreplaceable cultural treasures suffer from deterioration and damage due to a combined effect of human and natural factors. This may lead to a huge loss of cultural, educational, and economic opportunities that these monuments can serve. Therefore, it is of paramount importance to keep the legacy alive by preserving our cultural heritage so that future generations can benefit from it. 3D modeling is an excellent technique for accurately and intricately recreating or digitizing historically important monuments and artifacts, enabling users to visualize them in new and unique ways. In this study, TLS data integration with pictures enables the acquisition of real models, which represent the examined monuments. A point cloud generated by scanning allows the creation of a 3D model, whereas pictures allow the creation of a new thematic layer to represent the texture of the created solids. The textured model is used for complementing the primary solid and giving it characteristics of the real object. The detailed 3D models produced in this study allow the monuments to be viewed virtually from various angles and perspectives. The generated 3D models of the monuments go beyond better and more accessible archives. It can be an instrumental tool for future restoration and monitoring of the state of conservation of the monuments. Accurate 3D models can help to determine changes or alterations in morphology and disposition of objects and structures, which provides the possibility of foreseeing and taking action on time when they are getting some kind of harm. Additionally, the created 3D models can be used for engaging interpretation and visualization of the monuments, providing an opportunity for these landmarks to integrate into the social, economic, and cultural fabric of the community.

7. Conclusion

The integration of two important three-dimensional digital survey technologies, such as TLS and photogrammetry in this work proves to be effective in producing high-quality 3D textured models of monuments of complex and irregular facade details. The TLS data were used to reconstruct the basic shape of the monument, while the photogrammetric images and data were effectively used to enhance the TLS point clouds for improving the geometry, data interpretation, and textural details of the facade. The information obtained from the digitization of these monuments will serve in addition to facilitating and enhancing the interoperation and presentation of these monuments' other important purposes. These include documentation and conservation of these monuments and preparing a 3D presentation in a

Web application for the promotion and sponsorship of tourism of the sites containing these monuments.

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