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Developing a documentation system for desert palaces in Jordan using 3D laser scanning and digital photogrammetry

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A B S T R A C T

Desert palaces in Jordan are unique pieces of art scattered in the desert as standing symbols of ancient civilizations. Due to their location, these palaces witness different environmental conditions which affect their status and sustainability. This raises the need to have a 3D documentation system reporting all spatial information for each palace, which can be used later for monitoring purposes. Digital photogrammetry is a generally accepted technique for the collection of 3D representations of the environment. For this reason, this image-based technique has been extensively used to produce high quality 3D models of heritage sites and historical buildings for documentation and presentation purposes. Additionally, terrestrial laser scanners are used, which directly measure 3D surface coordinates based on the run-time of reflected light pulses. These systems feature high data acquisition rates, good accuracy and high spatial data density. Despite the potential of each single approach, in our opinion, maximum benefit is to be expected by a combination of data from both digital cameras and terrestrial laser scanners. By these means the efficiency of data collection as well as the geometric accuracy and visual quality of the collected textured 3D models can be optimized. Within the paper, a 3D documentation system for Umayyad desert palaces in the Jordan desert will be presented using digital photogrammetry and laser scanning. The approach is demonstrated by generating high realistic 3D textured models for Amra and Kharanah palaces.

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1. Previous work and research goal

The generation of 3D models of historical buildings is an important task while aiming at a continuous monitoring of the related spatial information at different time epochs. Such photo-realistic models have to provide high geometric accuracy and detail at an effective data size. Traditionally, close range photogrammetry is used during the required data collection of heritage sites (Gruen et al., 2002; Debevec, 1996). Within the past two decades, the efficiency of this image-based technique has been increased considerably by the development of digital workflows. Furthermore, 3D data collection based on laser scanning has become an additional standard tool for the generation of high quality 3D models of cultural heritage sites and historical buildings (Alshawabkeh, 2006; Boehler and Marbs, 2002). This technique allows for the quick and reliable measurement of millions of 3D points based on the run-time of reflected light pulses, which is then used to effectively generate a dense representation of the respective surface geometry.

Despite the transformation of these approaches from research work to generally accepted techniques, there are still some limitations, which have an effect on the quality of the final 3D model (Shin et al., 2007; El-Hakim, 2007). Even though current laser scanners produce dense information along homogeneous surfaces, the resolution of this data can still be insufficient if breaklines such as cracks have to be collected and analyzed. In contrast, digital photogrammetry is more accurate if such outlines have to be measured, while on the other hand, image-based modeling alone is difficult or even impractical for surface parts, which contain irregular and unmarked geometric details. Additionally, photogrammetry requires long and tedious work, especially if a considerable number of points have to be captured manually. In addition to geometric data collection, texture mapping is particularly important for the area of cultural heritage to have complete documentation. Photo-realistic texturing can for example provide information on the object's condition, such as decay of the material, which is usually not present in the 3D model. Additionally, color image information is also indispensable for features like frescos and mosaics. Texture mapping is also considered a prerequisite for

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visualization and animation purposes. Thus, some commercial 3D laser systems additionally provide model-registered color texture using a camera, which is integrated in the system. However, these images are frequently not sufficient for high quality texturing as required for documentation. Usually, the ideal conditions for taking the images may not coincide with those for laser scanning (Alshawabkeh, 2006; El-Hakim et al., 2002). So it is therefore more useful to acquire geometry and texture by two independent processes and allow for image collection at optimal position and time for texturing. If the characteristics of spatial data as acquired from imaging and laser scanning systems are considered, the combination of both techniques by integrated data processing will be beneficial for accurate and complete description of the object space. The disadvantages of one approach can be compensated for by the advantages of the other technique.

In archaeology and especially in projects dealing with historical building survey, laser scanning and other digital technologies'' capacity of representing the entire 3D nature of archaeological objects has initially provoked – and still continues to cause – overwhelming enthusiasm (Weferling et al., 2001; Riedel et al., 2006). A large number of projects focusing on using such spatial technologies for 3D modeling of heritage sites can be seen in the literature. Among these is the work of Lambers et al. (2007) for the 3D modeling of the site ground plan and stone architecture at Pinchango Alto, Peru, based on a combination of image and range data. Their work emphasizes the importance of using such integrated technologies in 3D documentation of heritage areas. The generated 3D textured models in their work suffer from a large number of occlusions in both point clouds and images, which causes difficulties during surface reconstruction and texture mapping. Our work focuses on solving such occlusion problems efficiently. Along these lines is the project carried out to record stone 11 of the Castlerigg stone circle in Cumbria through two different non-contact techniques: laser scanning and ground-based remote sensing (Díaz-Andreu et al., 2006). Researchers in this project encourage the usage of such technologies, based on the digitization of 3D surfaces, due to their ability to produce models with high accuracy without being in direct contact with the object. 3D laser scanning also presents a future direction for researchers to enhance the quality of their 3D models. This is clear in the work of Losier et al. (2007) who are planning to use 3D laser scanning as a substitute for generating 3D models from GPS positions taken at the top and the bottom of the excavation units' boundaries. Another example of current documentation projects is the work of Henze et al. (2005). Their interdisciplinary research project for the sustainable restoration of the late Gothic St. Petri cathedral of Bautzen used combined of geodesy and photogrammetry methods, supported by several laser scans from different positions, to create a form-correct and deformation-true documentation of the facades. Due to the extensive use of laser scanning in documentation, some researchers (e.g. Barber et al., 2003) call for articulated work to define specifications for such usage. This includes defining standard deliverables relevant to cultural heritage subjects.

Our work presented in this paper introduces a methodology for the 3D high quality digital preservation of selected desert palaces in Jordan, using laser scanning and digital photogrammetry. The 3D digital documentation of such palaces is of considerable interest for heritage management professionals besides its importance for conservation, education, virtual visits and as a monitoring system. A complete description of the work carried out at these palaces is presented, including the acquisition of laser scan and image data, co-registration of point clouds, 3D modeling and texture mapping. The acquisition of the relevant image and laser scanning data besides data pre-processing, which is mainly required for a perfect alignment of laser and image data for high quality mapping as well as our approach for texture mapping, is presented in Section 3. Only the exterior facades of the buildings have been covered in the paper. This work will be expanded in the future to cover the rest of these palaces in Jordan to form a complete documentation system.

2. Desert palaces in Jordan

2.1. Umayyad palaces

Umayyad is the first Arab Muslim dynasty of caliphs (religious and secular leaders) founded by Muawiyah I in 661 and lasting until 750. The buildings erected by the Umayyad dynasty constitute the earliest Islamic monuments reflecting the dynasty's adaptation of the Hellenistic and Sassanian cultural traditions in their region (Bosworth, 1996). The most famous Umayyad architecture is a number of desert palaces, constructed of stone and/or brick that have been interpreted as princely residences, scattered in the region containing areas of Jordan, Syria, Lebanon and Palestine. The purpose such palaces served is not completely known, however existing theories indicate that they might have served a variety of defensive, recreational, agricultural and/or commercial agendas (Creswell, 1989; Finster and Schmidt, 2005; Genequand, 2005). Examples of the most famous desert palaces in the region include: in Jordan (Kharanah, Amra, Azraq, Hallabat, Qastal, Mushatta, Tuba and Muaqqar); Syria (Qasr Al-hayr East, Qasr Al-hayr West and Palmyra); Lebanon (Anjar); and in Palestine (Khirbat Al-mafjar). Fig. 1 presents a detailed GIS map (the topography layer is ©HU GIS lab and other GIS layers are created by the authors) showing the distribution of the most famous desert palaces in the region. Desert palaces in Jordan (Fig. 1) are located in the desert to the east of Amman (capital of Jordan) on the ancient trade routes. These palaces are easily accessible by following the northern route from Amman to Azraq city. The architecture of these complexes, a square floor plan of stone construction with corner bastions and semicircular towers, has the influence of construction techniques drawn from Egypt, Mesopotamia and elsewhere throughout the region (Ettinghausen and Grabar, 1987).

A number of desert castles are adjacent to an international highway that connects Jordan to Saudi Arabia and Iraq. For this reason these palaces witness different environmental conditions which affect their status. The most fatal threat to the monuments results from the vibration of heavy trucks and lorries traveling along the highway (Euromedheritage, 2008). The effect is clearly visible through the serious longitudinal cracks in the walls, as can be seen in Fig. 2. A comprehensive study is needed to assess the current threats and the conservation needs of the palaces to ensure their sustainability.

2.2. Amra and Kharanah desert palaces

This section provides a detailed description of the two most famous desert palaces documented in this paper, Amra and Kharanah, in terms of geographic location, functions, architectural style and conservation status.

Amra palace, a UNESCO World Heritage site located about 85 km to the east of Amman, was built by the Umayyad Caliph al-Walid between 712 and 715 AD probably for use as a vacation residence or rest stop (Bianchin et al., 2007). Most of the Amra buildings, originally protected by a small square fortress and a watchtower on a nearby hill, are still standing and can be visited (Meloy, 1996). Fig. 3 shows a number of pictures of the Amra exterior from different view points.

Fig. 4. shows a detailed plan of the Amra main edifice (Abela and Alliata, 2001; Arida, 2003), which is composed of three long halls with vaulted ceilings resting on transverse arches: the audience hall, the baths and the hydraulic system (Al-Asad and Bisheh, 2000; Creswell, 1989; Ettinghausen and Grabar, 1987; Hillenbrand, 2000).

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