Visualization of the Past-to-Recent Changes in Archaeological Heritage based on 3D Digitization

NAOKI MORI, TOKIHISA HIGO, HIROSHI SUITA, and YOSHIHIRO YASUMURO, Kansai University, Japan
SALMAN ALMAHARI, Bahrain Authority of Culture and Antiquities, Kingdom of Bahrain
KAORU SUEMORI, National Museum of Ethnology Japan

This paper is motivated by work at “Barbar Temple”, which is one of the significant archaeological sites in the Kingdom of Bahrain. This site dating back to the 3rd millennium BCE belongs to the ancient Dilmun civilization which has a relation with the Mesopotamian and Indus civilizations. This remarkable site has been required to be protected and listed on the Tentative List of UNESCO World Heritage. The documentation of Barbar Temple has been started since the first excavations by a Danish mission in the 1950s -1960s. There is a possibility to grasp the changes and damages of the site caused by environmental or human factors over the decades by utilizing the photographs taken in the past. As a case study to apply 3D digitalization for protecting the archaeological site, this paper proposes a methodology for collation of the ‘past photographs’ and current physical appearance. The process of this method consists of three steps; 1) estimate 3D positions and the orientation of the camera by which ‘past photographs’ were taken; 2) make corresponding pairs between ‘past photographs’ and the 3D data of the current site; 3) render a CG (Computer Graphics) model of the current site from the viewpoint of the estimated camera position and orientation; 4) overlay the CG with the ‘past photographs’ on the same view. This paper applied the method to the ‘pool’ area of Barbar Temple, which was a pivotal facility of the temple with a sacred spring used for worship of Sumerian water god Enki. It was expected that the piled-up blocks of the stone construction surrounding the spring have caused strains on itself and changed its appearance. This methodology enabled us not only to grasp the changes in the whole appearance of this area easily but also to find the slight changes in the orientations of the stones quantitatively.

Key words:
Investigation history, Structure from Motion (SfM), PnP Problem, Photographic record.

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INTRODUCTION

Bahrain is an island country consisting of 33 islands with Persian Gulf Bahrain Island as the main island. Dilmun is the first civilization on this island, dating back 3300 BCE. This civilization flourished as a trade city connecting the Mesopotamia region and the Indus region. There are many ruins built in the Dilmun period like the world heritage Karat Al Bahrain on this island now. However, due to rapid urban development in recent years part of the ruins have been destroyed or disappeared. For that reason, activities to protect these ruins are being conducted mainly by the Bahrain Agency for Cultural Affairs.

The Temple of Barbar is the oldest temple ruin in Bahrain, built around 2200 BCE. This remain is a particular ruin which conveys aspects of the early Dilmun civilization, and it is registered in the World Heritage Provisional List.

Authors addresses: Naoki Mori, Graduate School of Science and Engineering, Kansai University, 3-3-35, Yamate, Suita, Osaka, Japan; email:k069406@kansai-u.ac.jp; Salman Almahari, Archaeological Conservation Department, Bahrain Authority of Culture and Antiquities, Kingdom of Bahrain; email: @nrc.ca; Tokihisa Higo, Graduate School of Letters, Kansai University; email:th0105.mm@gmail.com; Kaoru Suemori, National Museum of Ethnology, 10-1, Senri Expo Park, Suita, Osaka, Japan; email: kaorudoco@hotmail.com; Hiroshi Suita, Faculty of Letters, Kansai University; email:horus@kansai-u.ac.jp; Yoshihiro Yasumuro, Faculty of Civil Engineering, Kansai University; email: yasumuro@kansai-u.ac.jp

Currently, the Bahrain Agency for Cultural Affairs is planning to develop for the construction of the site museum mainly.

The Temple of Barbar was discovered by Denmark Corps headed by P.V. Glob et al. in 1954 and excavation work was done until 1962 [Andersen and Hojlund 2003]. After the excavation, the ruins were developed as tourist attractions by Bahrain authorities. At that time, slopes and walking paths for pedestrians, reinforcement of vulnerable parts of the ruins were carried out. As a result, the appearance in 2017 (Fig. 1, right column) has changed significantly compared with the survey record (Fig. 1, left column) at 1959.

For future conservation, it is desirable to repair these stones and relocate them to their original positions. However, although we can qualitatively confirm changes at the time and the current situation, we cannot confirm the actual minor changes. Therefore, in this paper, we utilize spatial and geometric information and associate the past with the present situation. By doing so, we aim to visualize the systematic support of visual verification work. Also, by projecting past research records on the present site virtually we quantitatively evaluate changes in past and present conditions.

Fig. 1. Photograph records taken in 1959 (left column) and 2017 (right column) at Barbar temple site

RELATED WORK

The data recorded by three-dimensional (3D) measurement is widely used not only for preservation but also for academic, educational and tourism purpose. CyArk[1], for example, a nonprofit organization in the United States, publishes a digital archive on the website that associates 3D data acquired by a laser scanner and photogrammetry and related academic information. A walkthrough system that allows free movement and viewpoint change within the created 3D space is implemented so that the user does not need to visit the actual place and can observe the object from a place that he/she cannot actually enter. In recent years, while the performance of UAV improves and the price drops, 3D modelling over cultural property structures and wide area is spreading for site management of the site and post disaster assessment [Brutto et al. 2014; Meyer et al. 2015; Themistocleous et al. 2014; 2016; Yasumuro et al. 2016]. These systems aim at information disclosure of ruins using 3D data and do not assume the support of constant maintenance and management of cultural assets. Besides, there is 4D modeling that adds the dimension of

[1] http://www.cyark.org/

the time axis to the 3D model as a method to grasp the current state of the ruins [Glowienka et al. 2017]. Rodriguez and his colleagues [2018] used "Structure from Motion" (SfM) [Tomasi and Kanabe 1992] which is a method of restoring the 3D shape from stored aerial photographs and photographs in order to analyze past natural disasters and landscapes changed in urban development [Pablo et al. 2018]. By comparing 3D shape information at different times, analysis over time is easy, and it is useful for future conservation and risk management.

METHOD

Overview

To grasp the difference between the past and the present situation of the site, the authors attempted to restore the 3D shape at the excavation in the 1960s, using the photographs described in the excavation survey report [Andersen and Hojlund 2003] and SfM process. However, recorded pictures did not retain sufficient lap rates, so they could not be restored. Therefore, a strategy that directly connects the present situation with the past photographs is necessary. In this research, we will reproduce the photographing position of the recorded photograph in the current 3D space co-ordinate. Observing the scenery from the same viewpoint enables to confirm and examine the differences over the time. Fig.2 shows the process flow of the proposed method. First, photogrammetry (SfM) and laser scanning are used for preparing the current 3D shape data. Next, giving the correspondences between the 3D points coordinates and their 2D coordinates projected on a photograph enables estimating the photographing position of the photograph. Rendering CG of the 3D shape data from the viewpoint of the estimated photographing position shows the current scene of the site viewed from the past photography viewpoint. By superimposing and observing the past and the current situation from the same viewpoint, it is possible to grasp the differences between them precisely visually.

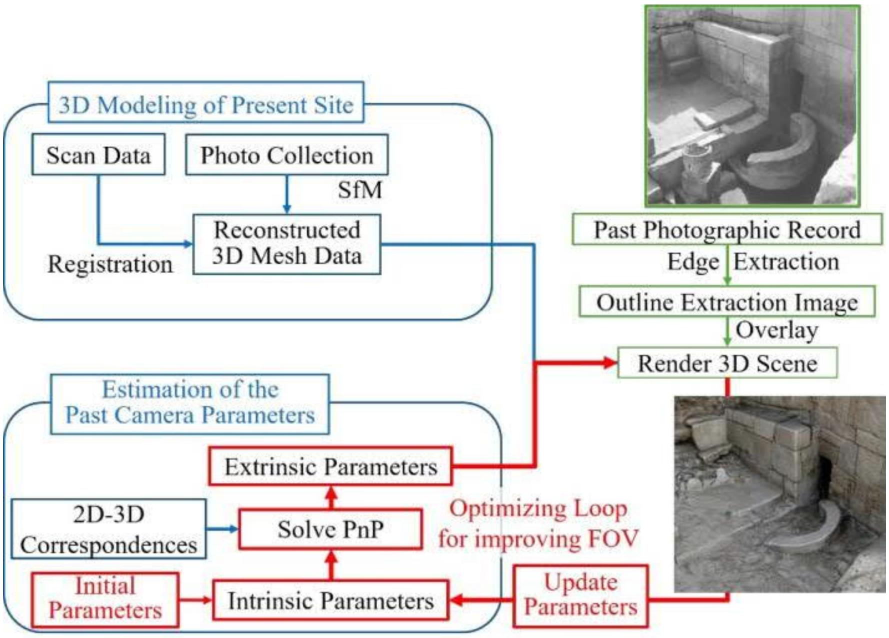

Fig. 2. Process chain of the proposed method

Preparing 3D Data

3D shape data is created using SfM. This technique is to simultaneously restore the 3D shape of the scene captured in the image from the multi-viewpoint image group and the shooting position of each image. In this research, the authors use multiple images taken with UAV. The 3D data created by SfM cannot restore the actual size of the object in principle. As a method of giving an actual size, there is a marker that can understand the scale and GCPs (ground control points) such as water marks and related survey points. By including a plurality of images reflecting these points, it is possible to give an actual size and geodetic coordinate system. Since GCP and markers were not arranged at the time of aerial photo-graphing this time, scaling and positioning are performed on the laser-scanning data which measured the same place, so that the actual size is given to the 3D shape data.

Estimation of the Camera Parameters Used in the Past Survey

In order to create a 3D model of the ruins, we attempted 3D restoration by combining a plurality of recorded pictures of the same part taken in the picture taken from 2017. However, as shown in Fig.3, matching with keypoints (ORB (Oriented and Rotation BRIEF) [Rublee 2011]) did not work correctly even in photographs taken from the same part and 3D shapes could not be reconstructed. Based on this fact, the authors decided to link the past with the present situation manually. We focused on a '"Perspective-n-Point" (PnP) problem' [Hartley and Zisserman 2004] to estimates the shooting position and orientation of a camera by associating a point (2D coordinates) in the image with a point (3D coordinates). The solution to this problem is to use the correspondence between one point in the 3D space and a specific point on the imaging plane of the camera. When a plurality of corresponding pairs is established simultaneously, the position and orientation of the camera can be uniquely determined. It is supposed to estimate the extrinsic camera parameters (shooting position and orientation) of the photograph from the correspondences between the 3D coordinates of the object and the 2D coordinates (pixel coordinates) of the image, and the internal camera parameters (camera projection characteristics). As shown in the Fig. 3 automatic correspondences between photographs cannot be found correctly, and it is difficult to use them for estimating the position of the camera automatically. Therefore, in this research, the authors manually give the correspondences between past photo and a rendered current 3D scene.

Fig. 1. Example results of automatically finding correspondences between a past photo and a rendered current 3D scene by natural feature points (ORB)

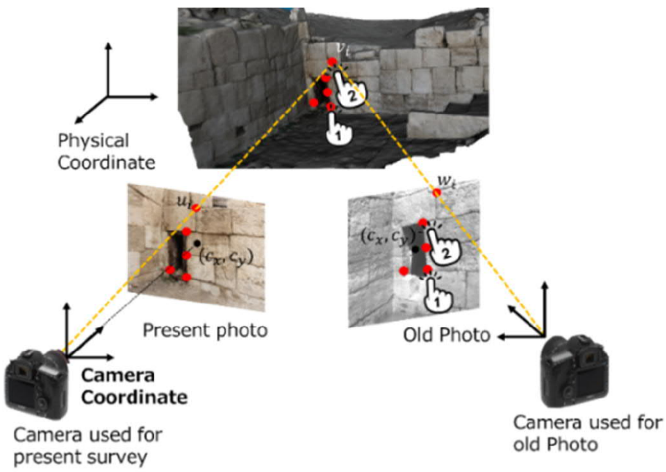

Fig. 4. A figure caption is always placed below the illustration. Short captions are centred, while long ones are justified. The macro button chooses the correct format automatically

Intrinsic Camera Parameters

In order to obtain the external parameters of the camera, parameters specific to the individual camera (internal parameters) such as the focal length of the used camera and the image centre are required. Camera calibration is to estimate internal parameters of a camera. This is generally known as a method of estimating internal parameters from the correspondence between images obtained by photographing a checkerboard as a visible reference pattern from multiple viewpoints and the reference coordinates of the checkerboard. [Zhang 2000] To estimate the external parameters of the recorded photograph, the internal parameters of the used camera at that time must be taken. However, information on the camera is unknown. Therefore, it is impossible to acquire internal parameters by calibration. So, in this research, the authors set the initial values of internal parameters and render, and then compare the results with the recorded pictures visually. Our process repeats adjusting the focal length value manually so that the current perspective matches past viewpoints, assuming that the effect of the lens distortion is small. To set the initial focal length parameters; f_x in the *x*- and f_y in the *y*-direction in units of pixels, f_x is obtained by $f_x = f * w_p / w$ (1), and f_y is obtained by $f_y = f * h_p / h$ (2), respectively. The parameter f is the focal length in mm, and w, h are the height and the width in the actual dimension of the image sensor plane. The parameters w_p, h_p are the width and the height size of the image in pixels, that is scanned image size taken from the printed photo from 1960. We assume that the camera used for the documentation in the 1960s was medium format in still photography. Referring to the format of *6 × 6* cm frame size or *6 × 8* cm frame size in *120* film, whose one side of the nominal size of the file is 56 mm, another side of the nominal size of the file is 77 mm, from which we derived the initial focal length value.

Photo Overlay

By applying the external parameters to the camera in the 3D space, the screen in which the current state is observed is rendered from the past photo-graphing viewpoint. By transparently superimposing the recorded pictures on this screen, the authors can visually grasp the difference between former and present time. When superimposing, in the original image, the 3D data behind and the color mix with each other, making it difficult to recognize the difference. Therefore, only the outline portion of the subject is extracted from the photograph, and the color tone is changed and highlighted. Alpha blending is used for blending during overlapping. In this process, a parameter representing transparency called an alpha value is required. However, in general, the image is composed of three channels of RGB, and does not have an alpha value. Therefore, a channel for storing the alpha value is newly created in the image from which the outline is extracted. Then, only the outline portion is made opaque from the color information in the pixel. As a result, only the information of the image to be displayed is rendered on three dimensions.

IMPLEMENTATION

3D Digitization

The authors performed 3D reconstruction of the entire temple using SfM processing software PhotoScan (Agisoft[2]) from about 900 images taken with UAV (DJI Inc[3]). Next, in order to give the actual size to the SfM data, positioning with the scan data obtained by measuring the same place with the laser scanner Focus 3D (manufactured by FARO) was performed. ICP (Iterative Closest Point) which is an available function in a free software CloudCompare[4] for point cloud processing is used for aligning two sets of point cloud; scan data and SfM data. Five pairs of corresponding points to be matched are selected from scan data and SfM data for determining an initial state. Then ICP finds the rotation, movement, and scale elements to minimize the residual in RMS (Root Mean Square) for fitting two sets of the point cloud. By aligning SfM data to the scan data as a reference, the current 3D shape data with actual size was created as a result. (Fig.5.)

[2] https://www.agisoft.com/
[3] https://www.dji.com/jp/phantom-4
[4] https://www.danielgm.net/cc/

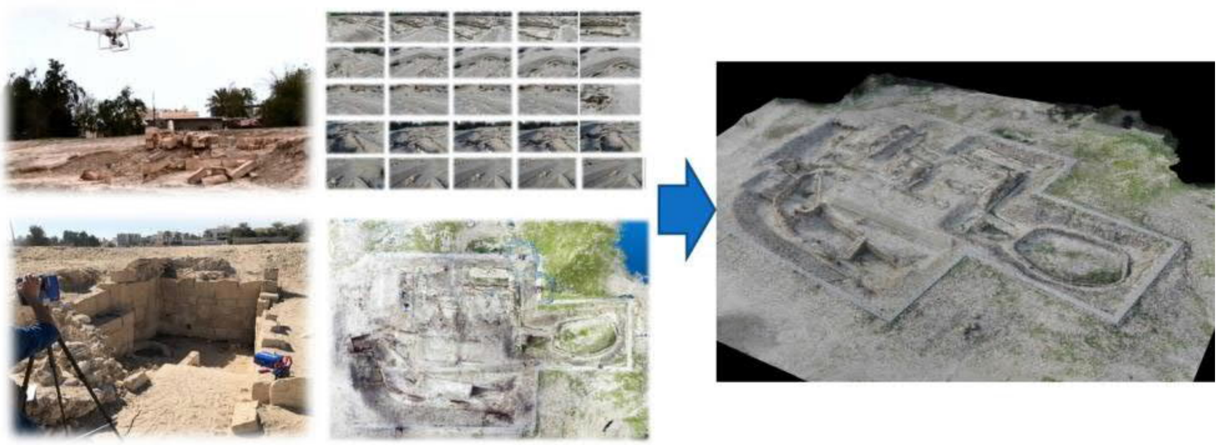

Fig. 5. 3D model generation: Reconstruction of the 3D geometry whose scale matched using ICP for photogrammetry (top) and laser survey (bottom) data by UAV

Position estimation of recorded photographs throughout the temple

In the survey so far, a plurality of parts corresponding to the photographic record at the time has been found. The authors applied the proposed method to nine recorded pictures of the remains at present. Using the formula (1) and (2), the focal length of the camera was determined as the internal parameter. As for the pairs of 2D coordinates and 3D coordinates, while checking the 3D shape, multiple corresponding pixel coordinates were selected from each recorded picture. Also, corresponding 3D coordinates were acquired by mouse picking. Past shooting position and orientation were obtained by solving a PnP problem formilated by the internal camera parameters and the set of 2D and 3D coordinates. Our implementation uses a function in OpenCV[5] for solving PnP problems with RANSAC (RANdom SAmpling Consensus) algorithm that suppresses the influence of outliers, considering that noise included in image data. [Fischler et al. 1981] Fig. 8 shows the result of plotting the photographing points of the recorded photographs at present by applying the estimated position and posture for each photograph.

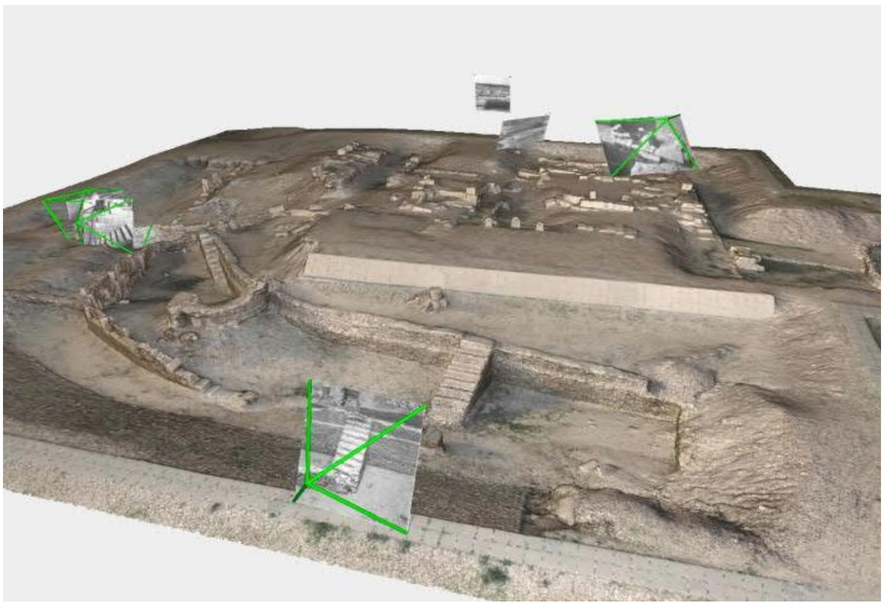

Fig. 6. Result of the past camera estimation in overall of the temple

[5] https://opencv.org/

Collation in local recorded pictures

As shown in Fig. 6, the shooting position of recorded pictures are estimated in the current 3D scenery. Then, the recorded pictures were superimposed on the 3D data, and the change between the past and the present condition was confirmed. In the following sections, this paper shows the applied results of the area of "pool" and "altar" in Barbar Temple. The pool is a symbolic structure for Dilmun culture, which shows the association with the Mesopotamian God Enki. The altar has unique stone arrangements, whose shapes are similar to the numeral 3. These areas are still left in the state close to the time of excavation even now.

Case study（Pool）

The authors targeted the south wall of the pool facility. Fig. 7 shows the process flow. Fig. 7 (a) shows the present situation of the pool represented by SfM data. Fig. 7 (b) shows the photograph of the south wall of the water storage facility taken in 1960. The width and height of this image are 700 pixels and 661 pixels, respectively. We used the frame size of 6×6 cm was adopted and the width of 56 mm and the height of 56 mm are set as nominal values for setting the internal parameters. For the correspondence between 2D coordinates and 3D coordinates, 26 points were selected for the same place in the recorded photograph and 3D data. (Fig. 7 (a) and (b)) The PnP problem was solved by using these two datasets. Fig. 7 (c) shows the result of rendering the screen observing the current situation from the past shooting viewpoint. To detect contours from recorded pictures (Fig. 7 (b)), the Canny function implemented in OpenCV was used. The Canny edge filter [Canny 1986] is a contour detector suitable for extracting continuous lines of objects' shape. Upon contour detection, the image was smoothed using a Gaussian filter to reduce noise. If the value of the kernel for the Gausiona filter is small, the noisy surface patterns of the stones are detected. So, the value of the kernel argument of the Gaussian function was manually adjusted for extracting the contours of the stones. Also, the threshold value of the Canny function appears was selected for extracting continuous contour lines, as shown in Fig. 7 (d).

To display only the colored part of the created image, a 4-channel matrix was created by adding OpenCV channel for alpha value. The first three channels copied from the color information of the image. For the last one channel, a threshold value is set for the RGB value, and if it is smaller, the transparency of the pixel is set to 0. Alpha blending is used to superimpose the contour images with transparency onto 3D data as viewed from the past shooting viewpoint. (Fig. 7 (e)) The angle of view of the camera at this time was manually adjusted so that the photograph and the three dimensions overlap precisely.

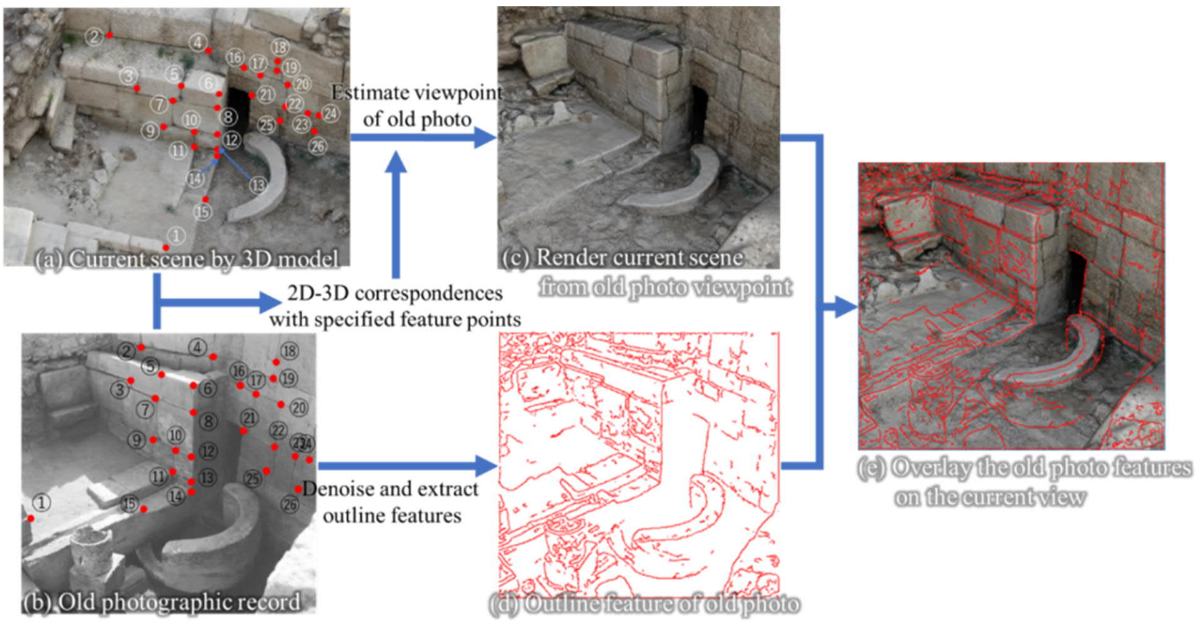

Fig. 7. Result of the proposed method

Case Study (Altar)

Fig. 8 (a) is a photograph taken from the south side of the observatory in the center of the ruins in 1955. The width and height of this image are 1083 pixels and 757 pixels, respectively. We used the frame size of 8 × 6 cm. A width of 77 mm and a height of 56 mm are set as nominal values for setting the internal parameters. The stone in the central part of this altar cannot be confirmed at present. Also, stones surrounding the altar are seen moving from the original position and missing. As in Fig. 8 (b), adjust the value of the Gaussian filter, Canny function so that the ridgeline of the stone is extracted, and extract the outline from Fig. 8 (a), (b) was generated. In addition, 17 points common to (a) are selected, and what is seen from the photographing position of the recorded photograph is Fig.8 (c). Fig. 8 (d) is the result of superimposing Fig. 8 (b) on Fig. 8 (c). As a result, we were able to visually grasp the minute difference between the excavation and the present situation, such as sediment deposition condition and stone defect.

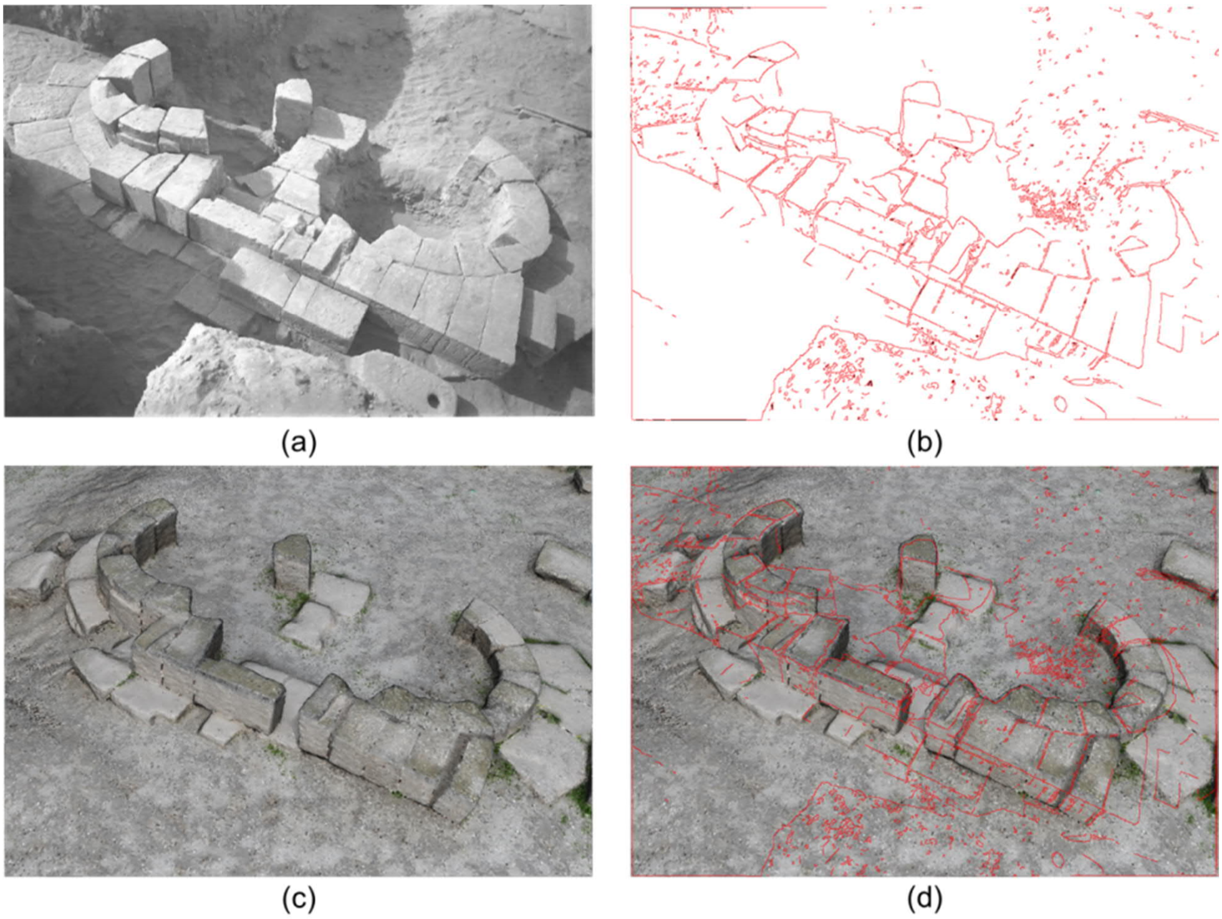

Fig. 8. Another result of the proposed method

DISCUSSION

By superimposing the photograph record on the 3D data, it became possible to confirm the differences from the past. However, it is difficult to read the amount of change only by overlaying the two views, and thus they are hardly applied to the next conservation and repair activities. Therefore, this paper showed the effectiveness of superimposing a virtual reference indicating the actual size. Putting an imaginary ruler in a place where a change was observed in the superposition result of the pool part, and the altar (Fig. 7 (e), Fig. 8 (d)) enables to assure the displacement of the stone. In Fig. 9, the virtual ruler is placed from the edge of the circular structure at the center, showing the change in the past and the present situation. As shown in Fig. 9 (right), it was found that the end of the circular structure moved 15 cm from that time. In Fig. 10, a ruler was placed on the stone which was in contact with the missing part in the recorded photograph at present. When the results were expanded, it turned out that the missing stone was 30 cm wide. Performing the quantitative evaluation can be used as a reference for the progression of degradation, whose information can prioritize the restoration work.

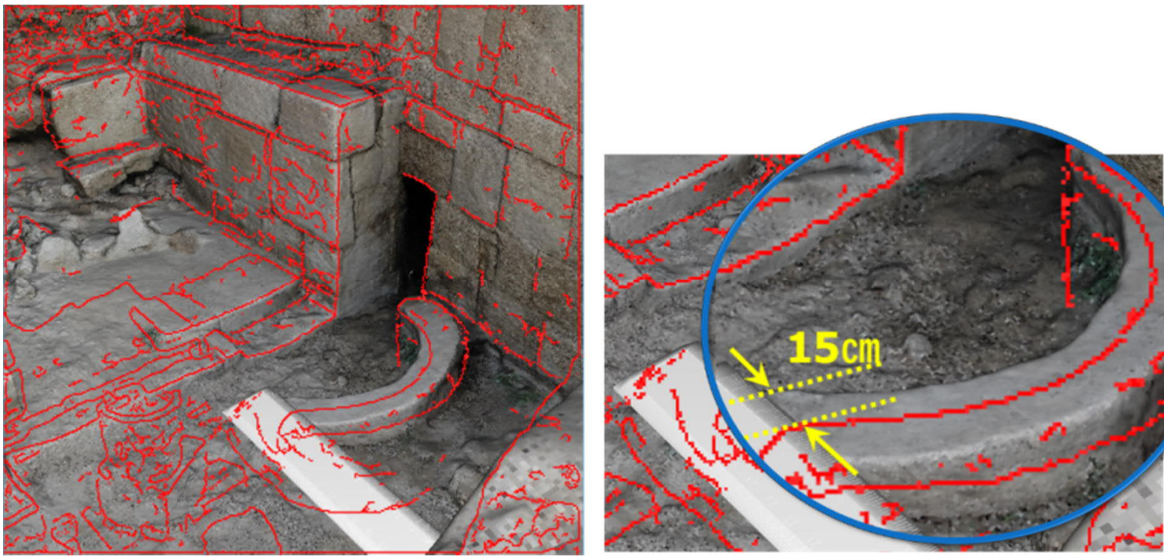

Fig. 9. Overlaid virtual ruler (pool)

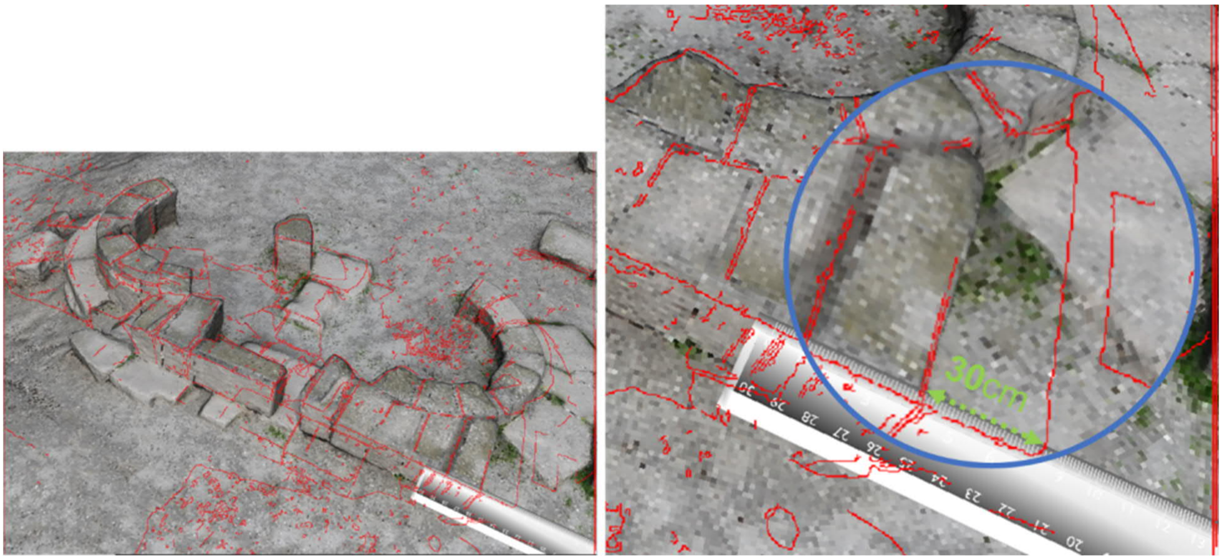

Fig. 10. Overlaid virtual ruler (altar)

CONCLUSION

In this paper, by looking over the measured 3D data from the viewpoint applying the past photographing position and the posture of the camera, it was possible to give the recorded photograph an actual size. The proposed method is capable of quantitative confirmation of temporal changes from the past that are physically impossible. Since the estimation of the camera viewpoint may contain some errors due to manual adjustment of intrinsic camera parameters, an optimization process to determine the parameters is planned for the next implementation.

Temple of Barbar is now being developed for site museum construction. However, due to improper maintenance management in the past, the present situation has changed considerably compared with that time. Therefore, using the camera position estimation, which is a primary method of computer vision, it is now possible to grasp and discover changes over time in the ruins. Future research required in this site is to construct CH-BIM for the creation of a framework capable of quantitatively measuring changes in arbitrary areas of ruins, improvement of reliability during measurement, and periodic management of ruins.

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