

## 3-Dimensional Documentation of the Hadrian's Temple in Ephesus/Turkey

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*The so-called Hadrian's Temple is one of the most prominent monuments in the Roman city of Ephesus in modern Turkey. An up-to-date architectural documentation is the basis of a new research project dedicated to the structure. This paper addresses the aims and needs from the perspective of architectural historians and the existing conditions for this undertaking. It also discusses the different systems of 3D surface scanning, which were employed for this task: fringe projection and 3D laser scanning based on phase shifting. Both methods are ideally suited to record certain areas of the temple, with respect to the desired resolution and the scale of the documentation. Certain post-processing steps lead to the final result. These are still two-dimensional ortho-projections that can be published in a monograph or book.*

*Keywords:* 3D Scanning, Architectural Documentation, Ephesus.

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### 1. Introduction: Previous Research and Goals

The so-called Hadrian's Temple (Fig. 1) is one of the most famous monuments in the ancient city of Ephesus. It occupies a prominent location in the western section of Curetes Street, one of the chief thoroughfares of the site. Its building type is essentially a variation of the tetrastyle prostyle temple layout, with an oblong pronaos or front hall and a larger main room. The



**Figure 1:** Hadrian's Temple in Ephesus.

street façade is formed by two pillars anchoring the axis of the antae and two regular columns between them.

Although it was discovered in 1956, this structure has never been systematically analyzed, studied, or published. As a result, it has remained a subject of controversy for over half a century. Until now, scholars have been unable to ascertain its chronology, function, and definitive architectural reconstruction. A new project conducted at the Austrian Archaeological Institute and funded by the Austrian Science Fund (FWF Project P20947-G02) is designed to redress all these problems.

#### 1.1. History of Research

An inscription on the architrave of Hadrian's Temple provides important information on the structure: It states that it was dedicated to the city goddess Artemis, the emperor Hadrian and the people of Ephesus. From literary sources we know that the permission to build an imperial cult temple for Hadrian in the province of Asia Minor was granted to Ephesus in the years between 130 and 132 A.D. Such an undertaking bestowed great honours on the city and many cities in Asia Minor competed for such an authorization (BURRELL, 2004). In the preliminary excavation report, Franz Miltner, the then excavation director, interpreted the building –

presumably in accordance with the building inscription – as this “official” temple for the worship of the emperor Hadrian (117–139 A.D., MILTNER, 1959a).

The text of the inscription from “Hadrian’s Temple” on Curetes Street includes also names of officials and donors that are known from other contexts. Therefore it is possible to date this building quite securely to 117/118 A.D. (WÖRRLE, 1973). This implies, that it predates the official Temple of Hadrian for approximately 15 years. As a result, this clearly contradicts Miltner’s initial identification as the imperial cult temple for the province of Asia Minor and has left the building without a valid interpretation. Answering this question is the most important challenge of the current project.

A year after the discovery, in the summer of 1957, the reconstruction work for an anastylosis began (MILTNER, 1959b). The short time between the discovery and the reconstruction of the building left little possibilities to study the building’s history and phases. Until now, only a plan and a restored elevation have been published.

### 1.2. Goals of the Hadrian’s Temple Project

Before issues such as interpretation and function could be addressed, it was of vital importance to clarify the architectural history of the structure. The first step towards this goal was to produce an up-to-date documentation of the building. For various reasons, 3D surface scanning methods were chosen:

- Time was a very important factor for the undertaking. Hand drawings as the standard form of architectural documentation take a long time and require a substantial amount of infrastructure, such as scaffolding.
- Curetes Street is the major thoroughfare for tourism in Ephesus, up to two million people a year. Work at night with fringe projection systems (Fig. 2) was especially advantageous, both for researchers, who were not disturbed, and for tourist, who could enjoy an unobstructed access to the monument during the day.
- In addition to the architectural documentation, the scanning results should provide the basis for mapping cracks and fissures during the examination of the monument by a professional conservator. Therefore it was necessary to document not only the ancient building parts, but also modern concrete additions from the 1950s anastylosis. Architectural hand drawings for the latter areas seemed by all means inefficient and too time consuming.

In archaeology, the standard form of publication is still a book or monograph. Therefore, the creation of ortho-projections was the main objective. 3D models are valuable for presentations, but not a goal in itself during this project.

## 2. Methods and Data Acquisition

As dictated by the desired resolution, different scanning techniques were applied. Fringe projection scanning was used for all the architectural blocks made out of marble. In areas where a lower resolution seemed sufficient, a laser scanning system based on phase shifting was chosen. This method was applied to areas that contain fewer details, e.g. rubble walls. For both the sake of completeness, as well as the aforementioned purpose of mapping, modern concrete additions like the front columns also had to be documented. In this case, laser scanning proved being the most efficient technology in relation to the desired resolution. The two different methods were also chosen according to the desired resolution and scale of the 2D images for the final publication (see below section 3).

The dimensions of Hadrian’s Temple posed the biggest challenge for the project. The building is approximately 10 by 10 m, with a height of about 8 m. Due to its modern reconstruction the building, and its architectural components, form a solid structure that cannot be transferred or disassembled. Especially its height presented difficulties: The entablature consists of finely carved marble blocks, which required documentation with fringe projection scanners.

### 2.1. Fringe Projection Scanning

Two different systems of fringe projection scanners from the Breuckmann GmbH were used:

- a Breuckmann smartSCAN-3D with a field of view of 600 mm
- a Breuckmann triTOS with field of view of 1.400 mm)

	Scans	Raw Data	Mesh
The Hadrian’s Temple	~ 775	~ 20 GB	~ 2 GB
4 Bases (each)	~ 75-100	~ 3 GB	~ 0.5 GB
5 Single blocks (each)	~ 25-50	~ 1.5 GB	~ 0.25 GB
Further objects	~ 300	~ 8 GB	~ 1 GB
Two Original friezes in the Museum of Selçuk (each)	~ 40	~ 1.0 GB	~ 0.15 GB

Table 1: Summary of high definition scans.

Two teams consisting of two persons each worked parallel with two scanners for ten days. As described above, the size of Hadrian’s Temple does not allow the construction of a protective roof or tent for the purpose of scanning. To avoid the interference of direct sunlight, all measurements were performed at night. For the documentation of the entablature the Breuckmann triTOS was employed. Its operating distance of about 1.30 m ideally suited the mobile elevated platform, which was used for three nights to reach the uppermost parts of the building (Fig. 2). Altogether, approximately 1800 scans were taken with the fringe projection systems from the Breuckmann GmbH (see table 1).



Figure 2: Fringe projection scanning at night.

To guarantee an overall accuracy of the fringe projection scans, they were referenced with photogrammetric measurements of about 75 index marks. This was carried out with an AICON DPA PRO system with a NIKON D3 camera. In addition, 35 of these index marks were also measured with a total station. This defines the position of the resulting 3D model within the coordinate reference frame of the site.

## 2.2. Laser Scanning based on Phase Shifting

In addition to the high-resolution fringe projection method, a laser scanning system based on time-of-flight/phase shifting was applied. During a second scanning campaign of five days, approximately 70 scans were taken with a Z+F IMAGER® 5006i. With this method, work could be carried out during the day.

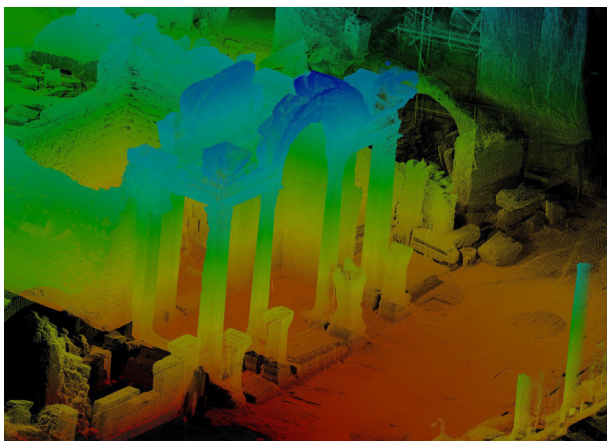


Figure 3: Point cloud from 3D laser scan.

The goal of this scanning process was the coverage of the whole temple and the structures in its immediate vicinity in order to provide insight into its architectural context (Fig. 3). Measurements were taken from different viewpoints to acquire a sufficient amount of data and to eliminate gaps in the resulting 3D model. Some areas of the temple therefore were recorded repeatedly. This leads to a certain redundancy that is unavoidable and has to be addressed during post-

processing. The resulting point density lies within a range of approximately 3 points for every 2 mm. Nevertheless, some areas could not be viewed from any of the standpoints, e.g. the top parts of the front arch. Voids in the documentation can be filled by using the fringe projection scans.

## 3. Data Processing

As has been mentioned above, the main goal of the project was the creation of a two-dimensional documentation for the publication of the building in the form of a monograph. Three different types of illustrations were planned: Plans, sections and general views, which should be rendered in a scale of 1:25. Architectural blocks with decoration (Fig. 5) yield considerably more information on the building process and the reconstruction. They have to be presented at a scale of 1:10.

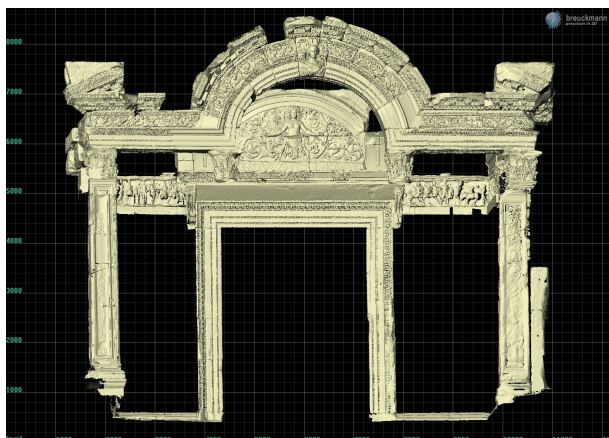
Due to this reason, during the first step of data processing, we decided to create one 3D-model for each scanning method and extract the necessary 2D-illustrations from both of them individually: For the 1:25 illustrations, the laser scans provide enough data, and the addition of the fringe projection scans would not lead to a better image quality. The fringe projection measurements, on the other hand, covered all the individual pieces that have to be depicted on a scale of 1:10. Further additions from laser scanning were not necessary in these areas.

For the presentation as a 3D model we are currently working on the combination of both models into one data structure.

### 3.1. Data from Fringe Projection Scanning

In a first pre-processing step, all scans were registered into the same coordinate system, with reference to the photogrammetric data of the index marks. The overall accuracy of this “constrained alignment” process for the 3D structure of the whole temple is in the range of 1–2 mm, the local accuracy is typically better than 500 µm. The second step was the merging of all data into combined polygon meshes. Optionally, small holes could be filled automatically. All pre-processing steps were carried out with a 64 bit version of the OPTOCAT software of the Breuckmann scanner.

The data volume of the high resolution fringe projection scans presented the main challenge during the post-processing carried out in Vienna. Compiled from individual scans, the meshed model of the structure reached a size of up to 2GB (Fig. 4). The majority of software tools still cannot cope with such an amount of data.



**Figure 4:** Overall model of Hadrian's Temple showing architectural pieces made out of marble, created from fringe projection scans.

Therefore, we mostly worked with sections of the model in high resolution as well as an overall model of the structure in lower resolution. The implementation of 64-bit systems in the near future will provide the condition to process a high resolution model of the Hadrian's Temple as a single entity.



**Figure 5:** Final result: An inscribed statue base as ortho-projection, compiled from fringe projection scans.

### 3.2. Laser Scanning Data

During pre-processing, the single laser scans have to be aligned manually with the targets identified during the scanning process. In a second step, an ICP algorithm was used to register the relevant areas for the architectural documentation. Similar to the processing of the fringe projection scans, the amount of data posed difficulties for the majority of the software.

Contrary to post-processing of the fringe projection scans, we used the point cloud obtained from the laser scans directly for documentation. After several tests we renounced the idea of creating polygon meshes from the point cloud: they would have increased time and effort for post-processing considerably, but do not lead to better quality of the images. In fact, at a scale of 1:25 for the ortho-projections created from the scans, the use of reflectivity information from the point cloud (turned into a gray-scale value, Fig. 6) improved the rendering of the final picture considerably, as opposed to the results we could have achieved from polygon meshing.



**Figure 6:** Section through Hadrian's Temple created from point cloud from 3D laser scanning.

Due to the transparency of a point cloud, objects that lie behind surfaces had to be removed manually. Therefore, the scans relevant for each ortho-projection had to be selected carefully to reduce both the amount of data and the effort of manually "cleaning" the point cloud. The last challenge during post-processing was the export of the final ortho-projections to scale, because this relatively simple feature has yet only been implemented in few programs.

### Conclusions

As the Hadrian's Temple project has shown, a combination of fringe projection and laser scanning techniques is ideally suited for architectural documentation of a complex building structure. Both for the means of recording and post processing, it is of utmost importance to choose the scanning method according to the desired resolution and accuracy. Otherwise, a needless amount of data not only leads to extended computing time during post processing, but also requires unnecessary time and effort during

recording. Architectural blocks made out of marble, on the contrary, must be documented at a larger scale and a higher level of detail (Fig. 5 and 7). Fringe projection scanning provides the ideal tool to meet these requirements.

### Acknowledgements

The authors would like to thank the director of the Austrian Archaeological Institute and head of the Ephesus excavation, S. Ladstätter, for supporting the projects. The director of the Efes Müzesi Selçuk, C. Topal, enabled the scanning of the original frieze blocks in the museum. M. Büyükkolancı made it possible the scanning of fragments that are now stored at the Basilica of St. John in Selçuk. F. Öztürk was an invaluable help for organisation, as well as the workmen Yusuf Turan and Mustafa Cobanoğlu and the foreman İbrahim Kınacı. Ch. Kurtze provided the necessary surveying data. We would also like to acknowledge TU

Vienna/Department of Spatial Development, Infrastructure and Environmental Planning for infrastructure and IT support.

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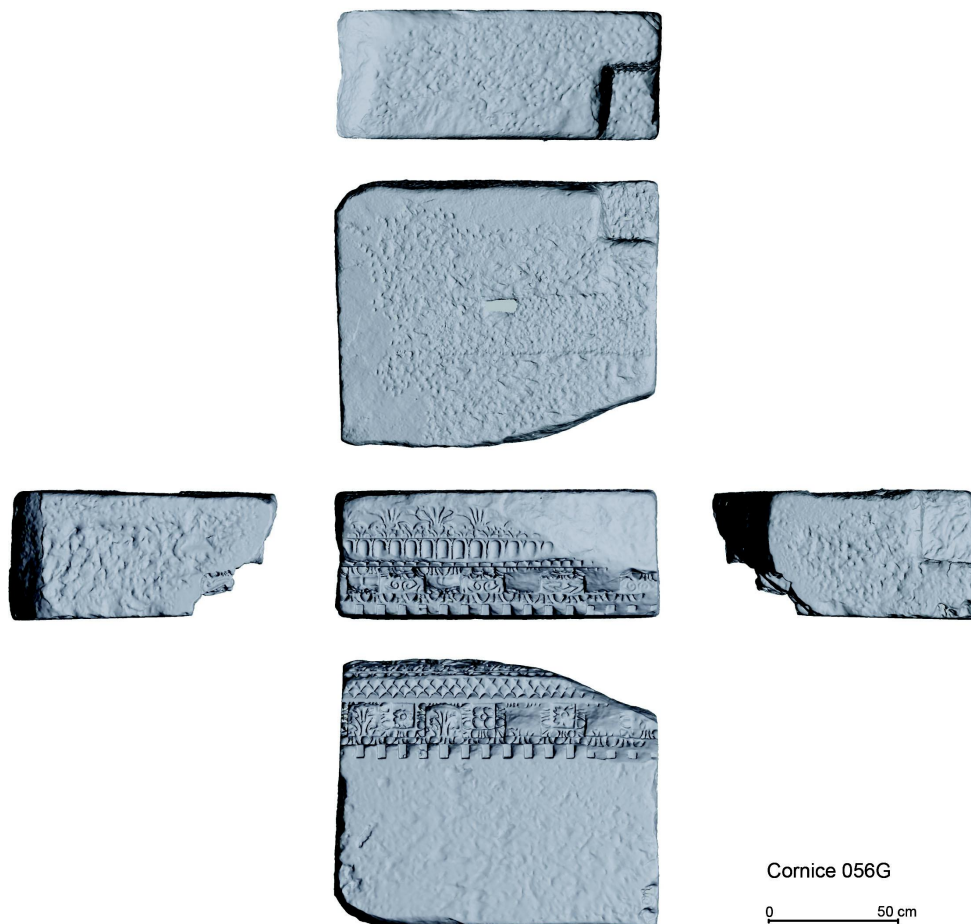


Figure 7: Cornice block from the Hadrian's Temple as ortho-projection, from all six sides.

