# 3D Scan of the Pergamon Altar

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**ABSTRACT:** The Pergamon Altar, built around 200 years BC during the reign of the Greek King Eumenes II to the north and west of the Turkish city of Bergama, is one of the most visited exhibits of the Pergamon Museum on the Museumsinsel in Berlin which in itself is a UNESCO World Heritage Site. This unique historical ensemble is currently undergoing renovation, restoration and modernization. In particular the foundations of the various museums including the Pergamon Musem are being reinforced. Due to this reason, the Pergamon Altar has been closed to public from Nov29th, 2015 until 2019 and its famous Gigantomachy frieze is now under wraps. In this paper we present our 3D scanning project of the Pergamon Altar and preliminary results before its closure.

## 1. INTRODUCTION

Shortly after its establishment, the German Empire felt a need to match the other great powers, so after Alexander Conze, former head of the sculpture collection of the Royal Berlin Museums discovered the connection between the description of the great marble Altar at Pergamon by Lucios Ampelios around 200AD and fragments of the altar Frieze sent to Berlin by the German engineer Carl Humann and several scholars beginning excavations in Pergamon around 1871, the German government arranged for a license to dig in Turkey and made an agreement with the Ottoman Empire to transfer the findings to the Collection of Antiquities in Berlin. After temporary exhibit locations, delays caused by World War I and hyperinflation in 1922, the Pergamon Museum was finally built in 1930 to host the Pergamon Altar and the Gigantomachy frieze as well as the smaller Telephus frieze. Currently the Museumsinsel in Berlin is undergoing renovation, restoration and modernization including reinforcement of the foundations of the five museums on the island, one of which is the Pergamon Museum. As part of that masterplan, the Pergamon Altar has been closed to public Nov 29th, 2014 and its friezes have been wrapped until 2019. In an effort to preserve and document the current condition of the Pergamon Altar before renovation, Fraunhofer IGD was asked to 3D scan the entire exhibit hall two weeks prior to closure with special focus on the Gigantomachy frieze.

## 2. 3D SCANNING CONCEPT

The original Pergamon Altar was an almost square structure 36,44m wide and 34,20m deep with the Gigantomachy frieze encircling it mounted on its walls below the collonade.

***Figure 1:*** *The Pergamon Altar*

The Pergamon Hall at the Pergamon museum is 45m wide, 32m deep and 12m of height. The Pergamon Altar exhibit (Fig.1) put on display shows the frontside of the Altar with its 20m broad stairway and is about 36m wide and 13m deep. On top of the stairs, visitors can enter an inner courtyard displaying the Telephus frieze. The Gigantomachy frieze is mounted on the walls of the Altar and along the walls of the Hall and has a total length of around 113m and a height of 2,30m at 2,35m above ground. To scan the Hall including the Altar and the Gigantomachy frieze within the last week open to public with one week preparation time was a huge challenge and required fast but careful planning.

The decision was made to use two technologies: 3D Laserscanning for the Hall including the Altar and a close-up photo-grammetry setup for the Gigantomachy frieze to achieve high resolution results. A Faro X330 Laserscanner including a 6m telescopic mount was chosen to to do 360 degree laserscans at 51 selected positions in the hall on ground floor and on top of the stairways promising a resolution of 1-2mm for the final 3D Laserscan model (Fig.2).

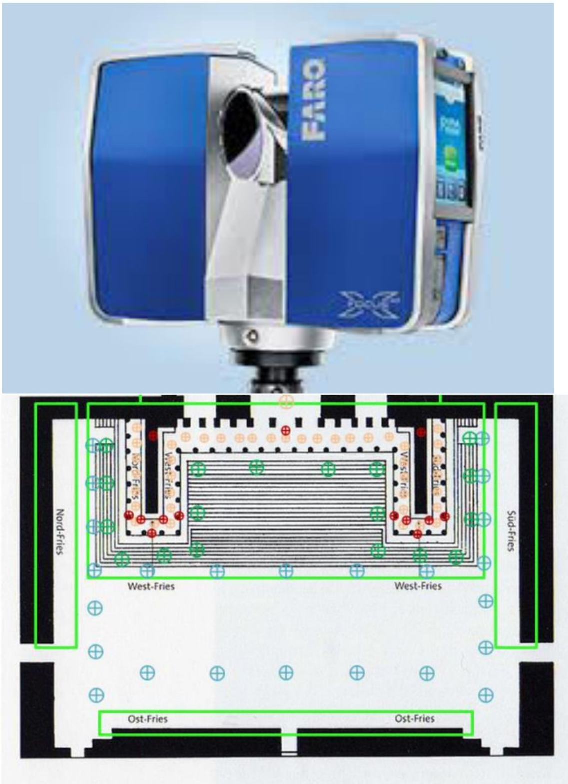


**Figure 2:** *Faro X330 and 51 Scanpositions*

The close-up scan of the Gigantomachy frieze (Fig.3) presented a series of challenges. Due to ongoing construction work, palettes, crates and smaller exhibits would obstruct access to the frieze on ground level, so any structure carrying a camera rig would have to be extremely flexible to avoid obstacles on the ground, while preserving a fixed distance to the frieze which is mounted at a height of 2,35m to 4,65m above ground.

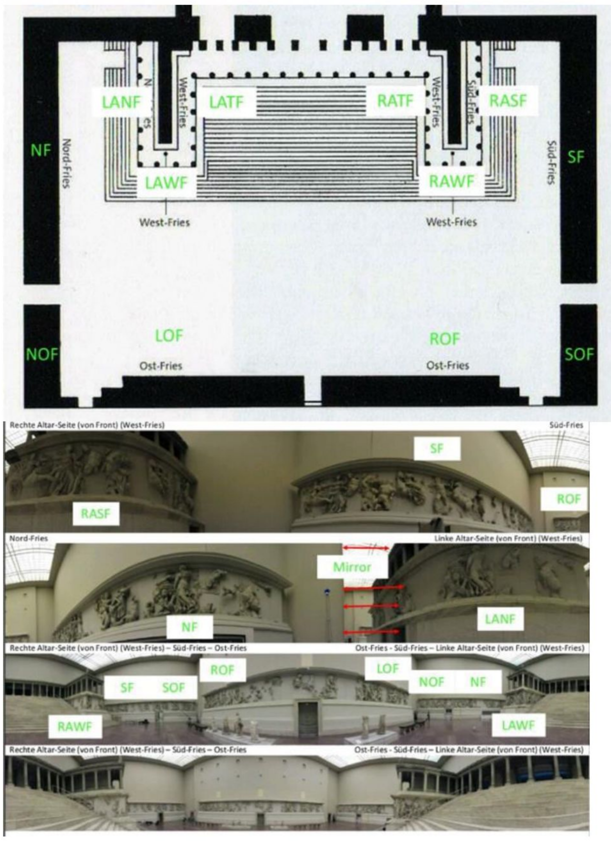


**Figure 3:** *Gigantomachy frieze 133m x 2,30m split up in 12 sections*

The final photogrammetric scanning solution consists of a mobile, 8m long telescopic camera crane with a motor-mounted Nikon D610 Camera on its end-effector, diffuse lighting and 70Kg of counterweights to keep the measurement head balanced, allowing to scan the 12 individual sections of the frieze line-by-line (Fig. 3), taking several photos at each position while maintaining a fixed distance to the exhibit at all times. To ensure safe operation and in view of the thousands of pictures to be taken, care was taken to remote-control every part of the setup, including the programmable motor-mount for the camera up to the wireless transmission of the taken shots to a processing rack featuring a 32 core Dual-Xeon computer with 256GB RAM. To avoid being bound to power outlets the whole setup runs on batteries. The main digitization principle of the photogrammetric setup is to start in the left most upper corner of a section of the frieze, take 5 shots (Center, North, West, South, East) and then shift right to the next position and repeat this until the very end of that section. Subsequently the setup returns to the left most position and scans yet another line.

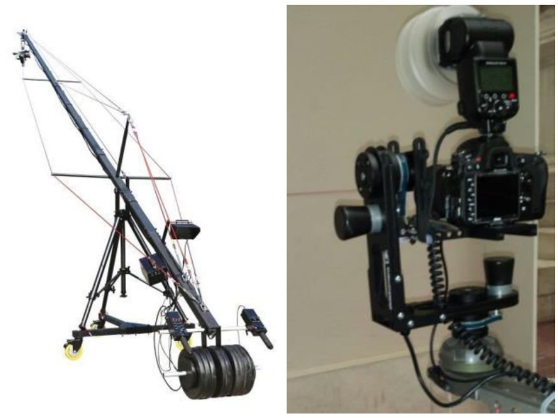

***Figure 4:** Gigantomachy frieze 133m x 2,30m split up in 12 sections*

The procedure is repeated as many times as needed to scan a whole section of the frieze (Fig.4). To make sure the targeted resolution of under 500µm was met, preliminary calculations took into account the camera resolution, the types of lenses and their field of views as well as the distance to be maintained to the exhibit at all times and the overlap of all images needed for best possible 3D reconstruction. In addition the amount of time per shot was estimated to make sure, all shots could be taken within the last remaining week before closure of the Pergamon. The process of reconstructing geometries from images has been improved by the development of powerful feature extractors invariant to a wide class of image transformations (e.g. rotations, scales, brightness or contrast, viewpoint [1], [2]). SIFT (scale-invariant feature transform) [1] was a breakthrough algorithm which has become popular for many computer vision applications. Matching large collections of images is time-consuming. To speed up the matching process, recent work has used ideas from the text-retrieval community to create much more efficient image matching algorithms [3], [4], [5], [6].

## 3. SCANNING

Scanning took place in the final week open to public, therefore 360 degree Laserscans were made during nighttime to avoid removing temporary scene elements such as visitors (Fig.5) in the final results, and photogrammetric scans were done during the day, section by section (Fig.6).


***Figure 5:** Laserscans of the Pergamon Altar*

***Figure 6:** Photogrammetric Scans of the Pergamon frieze*

Given the very short amount of time and the fact that the museum remained open to public, light conditions could not be entirely optimized to remain stable over the whole duration of the scans. Laserscans were done using a resolution of 176 Million points per measurement in 51 locations. Each scan took about 17min to be completed. To allow for later registration, 5-6 sphere markers were placed in each scanned scene. Each 360 degree scan also yielded a 70Mpixel texture. For a final resolution of under 500µm the photogrammetric capture setup has been moved along a matrix of 8065 capture positions (63cm horizontal distance and 50 cm vertical distance from each other) taking over 40000 2D colour images at 24,2 Mpixel each along the 113m of frieze.

**4. RESULTS**

The final results yield 150GB Laserscan raw data and 750GB of photogrammetric raw data.

***Figure 7:*** *Laserscan Point Cloud*

The resolution of the final Laserscan model is around 2-5mm and the final model size in highest possible resolution is around 90GB. The resolution of the final frieze models is less than 500µm. For better handling, the 12 frieze sections have been split up in panel sections of 3-4 panels each (Fig.8,9).

***Figure 8:*** *Original image taken from a frieze section for the reconstruction process*

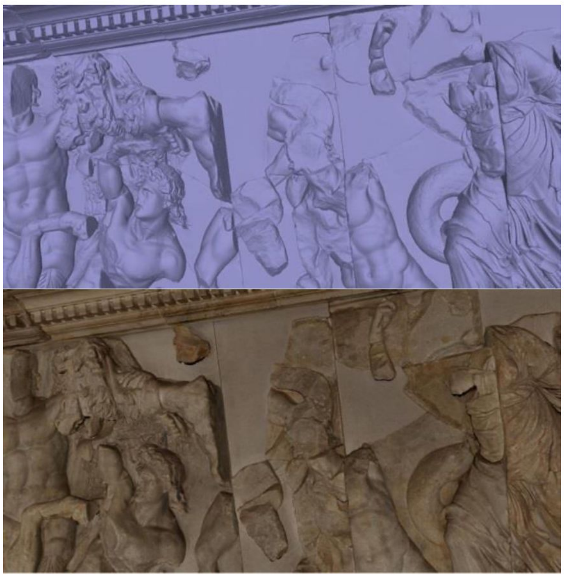

***Figure 9:*** *Photogrammetric reconstruction detail in final quality*

**3. CONCLUSION**

This paper presents the results of the 3D digitization of the Pergamon Altar in the Pergamon Museum during the final week open to public. The outcome has been a 3D model of the entire Pergamon hall exhibit and a high resolution 3D model of the 113m of the Gigantomachy frieze, both are currently being annotated with metadata to be stored for future use.

**4. ACKNOWLEDGMENTS**

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