SPATIAL RECONSTRUCTION AND MODELING OF THE SUNDAGGER SITE IN CHACO CANYON

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ABSTRACT

In Chaco Canyon, New Mexico, one of the most interesting astronomic observatories used by native Americans was discovered more than a decade ago. It is known as the Sundagger Site, and consists of three rocks which cast shadows onto a spiral carved into the wall at the back of these slabs. At the summer-solstice these shadows form a "dagger", which moves exactly through the center of the spiral. It is also assumed that this site was used as a lunar calendar, where the moon casts shadows on the same spiral.

During the past ten years, five different sets of photographic images of this site were captured by different parties. However, they were never utilized to create a comprehensive, 3-dimensional model of this observatory. In this paper, we report about the integration of two of these photo-sets and the creation of a full 3-dimensional model of the three slabs and its surroundings. We will discuss the problems encountered with the old photographs, some of which have neither a metric calibration nor sufficient control. The model of the Sundagger Site is visualized by a sophisticated surface modeling program, which allows shading and ray tracing. Computer animation techniques are then applied to simulate and study the casting of the shadows on the spiral and their changes over time.

Keywords: Archeological, Close-range, Non-metric, Visualization

1. INTRODUCTION

Chaco Canyon is located in the northwestern corner of New Mexico, which is an area rich in archaeological sites dating back to 1000 AD. In this part of the USA there are a large number of pueblos of the Anasazi Indians who established a far reaching trade-network and built many ceremonial buildings. To date nobody knows for sure why this civilization vanished. As there are no written records archaeologists have to rely on artifacts and ruins to solve the mystery of the Anasazi.

Photogrammetric and geodetic techniques are of great importance for creating data bases that can be used to analyze the findings and establish connections between related sites. The Anasazi pueblos have been studied for a long time. Some were also surveyed and integrated in a geographic data-base (GIS). One of the most interesting results of these investigations was that all major buildings of Chaco Canyon are aligned to either the cardinal directions or to various positions of the solar or lunar cycles. Although it is difficult to prove, archaeologists assume that the Anasazi were experienced astronomers, who did not only know about the precise motion of sun and moon over the year but also utilized this knowledge for creating calendars and observatories.

Probably the most interesting observatory is the Sundagger Site. It consists of three slabs which are aligned in front of a rock-wall on Fajada Butte in such a way that they cast shadows onto a spiral carved into the wall (figure 1). At the summer-solstice these shadows form a sun-dagger, which moves exactly through the center of the spiral. It can also be shown that it serves as a lunar calendar, where the moon casts shadows onto the same spiral at its major and minor standstills.

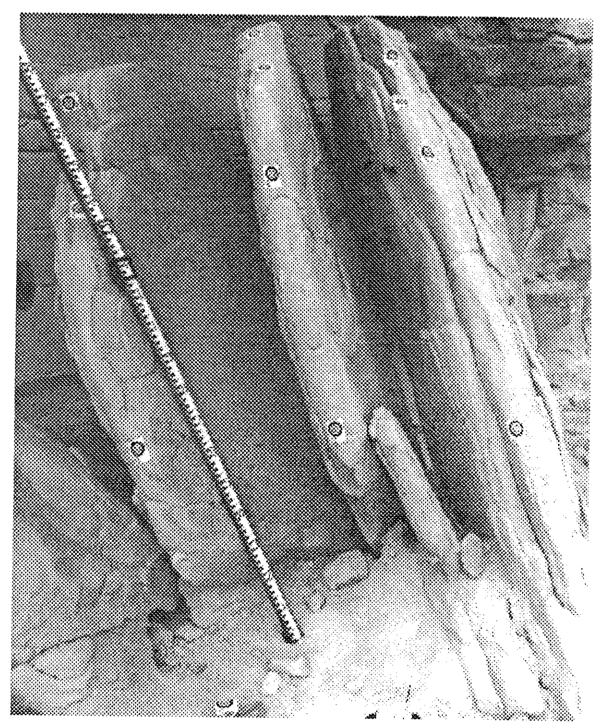

Figure 1: The Sundagger Site consists of three rocks that cast shadows onto a spiral.

Although these phenomena were directly observed at the site, and could be empirically verified, archaeologists want to be able to simulate these findings on a computer, for the purposes of demonstration, education and archiving.

Although this site was discovered almost a decade ago most efforts to create a spatial model of it failed. Five different sets of photogrammetric images have been taken over the years, but until recently they either missed control information, camera parameters or did not provide sufficient coverage. When the Department of Geodetic Science and Surveying and the Center for Mapping of The Ohio State University got involved in 1991, the National Park Service had closed the Sundagger Site completely, so that nobody is permitted access to the slabs. This was necessary as the popularity of the site brought many visitors to Chaco Canyon and resulted in severe erosion and vandalism around the slabs that threatened to permanently destroy the site. Therefore, we did not have any means of acquiring new imagery or establishing control. We had to fully rely on existing data.

In this paper we discuss the procedures that were applied to combine various sets of photographs of the Sundagger Site. We explain how we created a spatial surface model, and simulated shadow-casting by computer animation. In the next chapter we give the reader some more detailed information about the Sundagger Site.

2. SOME FACTS ON THE SUNDAGGER SITE

The Sundagger Site is located close to the top of Fajada Butte in Chaco Canyon, New Mexico (Longitude: W 107^{o} 54' 33", Latitude: 36^{o} 01' 08") (figure 2). Although the existence of the site had been known for a long time, it did not become the focus of scientific investigation until 1979 when its interesting shadow-casting phenomena were described by Anna Sofaer, president of the Solstice Project (Sofaer et al., 1979). It consists of three flat slabs, each about 2.5 m high, which are leaning against a rock-wall. Through the narrow gaps between the slabs sunlight can penetrate at certain times of the day. On the wall in the back of the slabs there are two spirals. The larger one consists of ten rings which are about equally spaced. At the summer solstice the shadows cast by the slabs form a dagger, which moves from the top to the bottom of the spiral. This dagger changes its location every day until it arrives at the edges of the spirals at the winter solstice. At this time two Sundaggers appear at the left and right edges of the spiral. Additionally, one edge of the right-most slab casts shadows onto the spiral at the major and minor lunar standstills. This finding promoted the assumption that the site was used both as a solar and a lunar calendar by the Anasazi Indians, which is unique in North America. Figure 3 shows the solar and lunar markings observed at the spiral.

3. PHOTOGRAMMETRIC RECONSTRUCTION

Five sets of photogrammetric images were taken between 1979 and 1987, each with different, mostly non or semi-metric cameras. Each photo-set had individual control-points, however, for some the coordinates were missing. An astronomic azimuth was measured for at least one of the image sets. Table 1 shows a comparison of photography taken at various epochs. Due to the quality of the images and the availability of control points we selected the 1983 photographs and added a few images from 1979 to cover a larger area of the rock formation.

The photos were taken with a metric stereo-camera (40 cm base). The focal lengths of the two cameras and all control points were made available to us. We found out that these images were used by Aero-Metric, Inc. of Sheboygan, Wisconsin, to create maps of the slabs. About 9000 points representing slabs and spiral were already available in a local, 3-dimensional coordinate system. These points were never displayed in a proper spatial model and thus deemed useless for archaeologists. To check the potential accuracy of these image-pairs we ran a bundle triangulation using the control points and tie-points available. It turned out that the points on the Sundagger Site can be located to about 3 mm. In addition to the points collected by Aero-Metric, we captured a number of breaklines, as well as the whole back wall from the stereo-pairs. We also added two photos of the 1979 data-set, in order to cover the rock to the left of the slabs. This is the back wall. It is important for the simulation of the creation of the Sundagger Site.

4. GENERATION OF A SPATIAL SURFACE MODEL

The large number of 3-dimensional points collected in the stereo-plotter cannot be visualized on a 2-dimensional map. The high point density makes it virtually impossible to distinguish any of the features of the rock surfaces. Therefore, all points belonging to a slab or to the back-wall were connected by triangles to create a surface model. Unlike TIN structures used for digital elevation models (DEMs), which are based on elevations plotted on top of a plane and therefore, create a unique network of triangles, our network must represent multiple surfaces for any point of the X,Y-plane. This means that our surface model has to cover both top and bottom of any object.

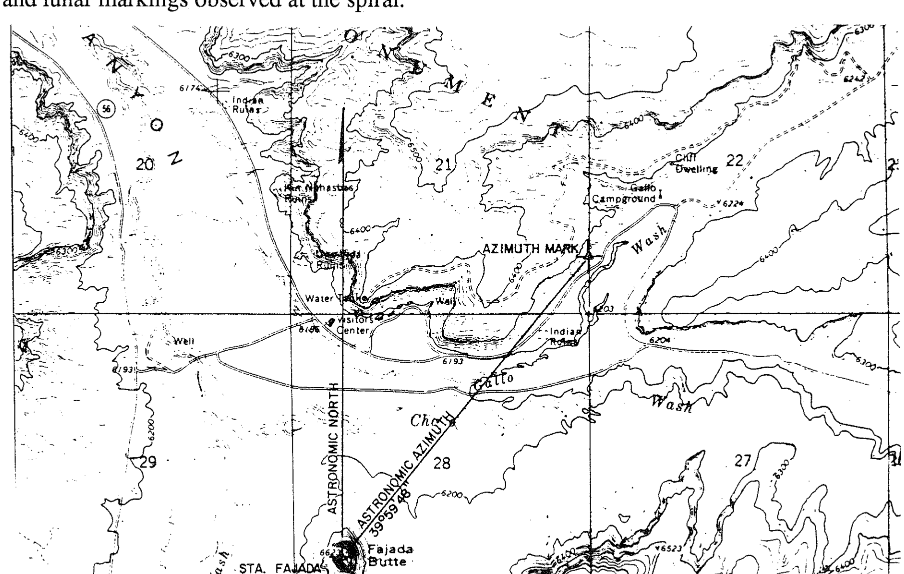

Figure 2: Map of Chaco Canyon, New Mexico, showing Fajada Butte which holds the Sun-dagger Site.

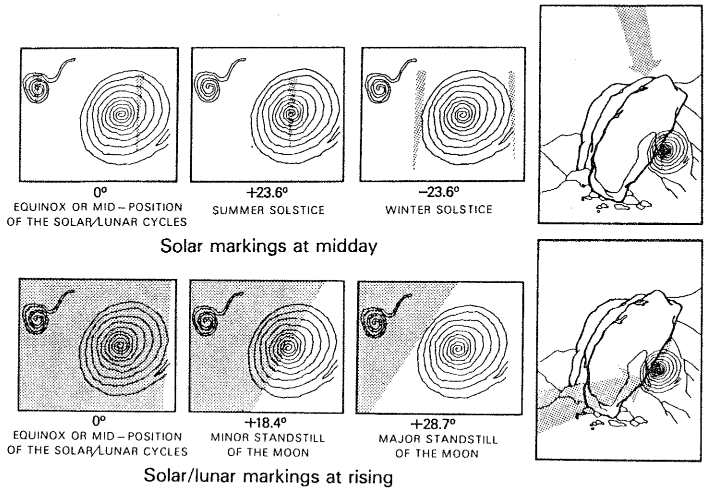

Figure 3: The solar and lunar markings at the spiral of the Sundagger-Site.

Right: Formation of solar and lunar shadow/light patterns by the three slabs near meridian passage (upper) and at rising (lower). Left: Schematic of the resulting patterns on the spirals at the indicated declinations and seasons (see Sofaer et al. 1979,). Illustration by Pat Kenny, cc: The Solstice Project (Sofaer et al., 1986).

Date	1979	1983	1986	1986	1987
Camera	Kelsh K-470	Wild P-32	Hasselblad	Rollei	Rollei
Calibration	No	Yes	Bad	No	Yes
Targets	Yes	Yes	Yes	Yes	Yes
Control	No	Yes	No	No	No
Coverage	General & Lunar Edge	Everything	Everything	Interior	General
Image Quality	Good	Excellent	Good	Good	Good

Table 1: Comparison of the photographs of the Sundagger-Site captured by different parties (courtesy of VEXCEL, Boulder, CO).

The strict analytical derivation of a triangular network of that kind through given reference points is an ambiguous problem. It would have required a lot of programming and developmental effort. Furthermore, we wanted to take advantage of existing software and avoid the implementation of new functions. This was especially important as we wanted to visualize the surfaces in perspective views.

We selected Intergraph's InRoads program to create the triangular network, and ModelView to display the shaded model. As InRoads is limited to single surfaces above the datum plane the points representing the slabs had to be separated into various subsets, each based on an individual reference plane.

Once the triangulation of each subset was completed in a local reference system, the points were transformed back into the original system. The connections between points, which actually define the triangular surface, were maintained. Figure 4 shows a shaded view of the Sundagger Site as it was created by MicroStation.

To visualize all details of the site a video-animation was created, which moves the viewer all around the slabs and even in between the gaps so that the spiral can be seen. Furthermore, we experimented with moving each slab separately. This was used to demonstrate the possible creation of the Sundagger Site. The formation of the three slabs was originally attached to the overhanging rock to the left of the existing site. Archaeologists assume that the slabs fell straight down and were somehow moved to the current upright position. Again, we created a video-animation to demonstrate the theorized motion of the rocks in the computer.

5. SHADOW CASTING

In order to better visualize and verify the functioning of the Sundagger Site, the casting of the shadows that create the dagger on the spiral was simulated. This can be done by the ModelView software using the 3-dimensional surface model generated previously. Due to some limitations of this package, such as the requirement to define illumination angles to the nearest degree, and the very time-consuming ray-tracing which is performed to cast shadows, we looked for an alternative.

A few years ago, when the first attempts were made to reconstruct the Sundagger Site, a shadow-casting program was written by Erich Brechner, a computer-engineer now employed by Boeing. It runs on Silicon Graphics workstations and casts the shadows of the rock onto a user defined plane. The direction of the illumination source can be defined either as a date and time for the sun, or as the lunar declination. The surface of the rocks is not needed for this program, which finds the outline of the projected shadows simply from the group of points that defines a slab. The combination of these shadows results in the sundagger projected onto the spiral which is lying in the projection plane. Although this is a simplification of the real situation, as the spiral is not completely flat, but rather spherical, the results proved satisfactory.

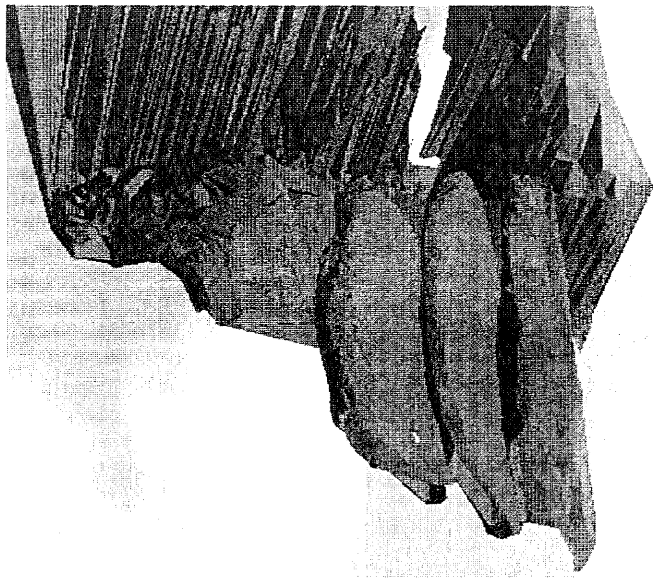

Figure 4: Shaded view of the Sundagger-Site model in MicroStation.

Erich Brechner made the source code of his original program available to use, so that the newly collected data could be implemented. In addition to the three slabs we also included part of the back-wall which supports the tops of the slabs. This part of the wall cuts off the sundagger and, therefore, is an important component of the site. Figure 5 shows the shadows of the slabs which were generated by the named program using the 3-dimensional points we compiled photogrammetrically.

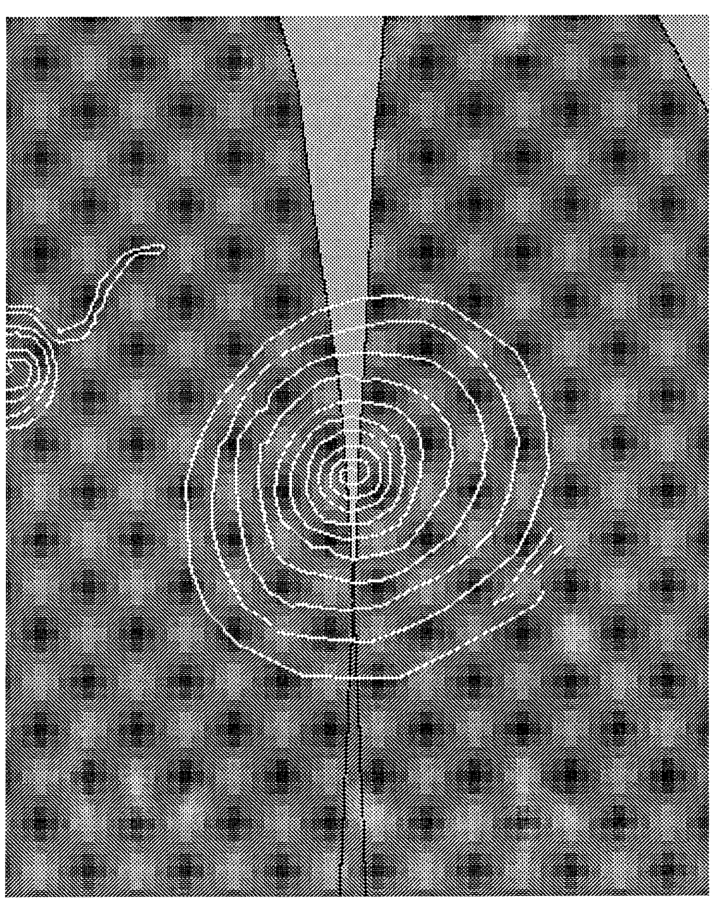

Figure 5: The Sundagger projected onto the back wall in a computer simulation.

The coordinates of all surface points are available in a local coordinate system, which was oriented to north, east and vertical by geodetic measurements (astronomic azimuth). During our investigations we tried to simulate the light and shadow patterns created by the Sundagger Site:

- the dagger moves through the center of the spiral at the summer solstice,
- there are two daggers at the edges of the spiral at the spring and autumn equinoxes,
- there is one dagger cutting through the small spiral at the winter solstice,
- the moon casts a shadow at its major standstill exactly through the center of the spiral.

6. CONCLUSIONS

Archeo-astronomers assume that the Sundagger Site of Chaco Canyon, New Mexico served both as a solar and a lunar calendar for the Anasazi Indians. Its origin and use remain a mystery and a controversy in the archeological community. In this paper we described the successful creation of a 3-dimensional computer model of the site which can be used as a visualization tool both for education and experimentation. It might be useful for solving some of the mysteries of the Sundagger Site in the future.

The surface model of the site was created by combining data from different, existing sets of metric photographs. It is represented as a 3-dimensional TIN in the computer. Visualization of the model is accomplished by applying surface modeling techniques, such as shading and ray-tracing. Computer animation was used to accurately recreate the shadows and light-patterns which are cast onto the spiral on the back-wall at various stages of the solar and lunar cycles. Additionally, the ability to perform transformations of the rock-slabs in the model permit to study how movements of the slabs may affect the light patterns.

We are currently integrating the Sundagger Site model in a GIS of the whole Chaco Canyon area. This data-base will contain various pueblos located in and around the canyon. They are being scanned from existing drawings prepared by archaeologists. Their correct geographic locations are determined by GPS. This GIS will allow researchers to study the culture of the Anasazi Indians in a more comprehensive way; it will also permit to easily comprehend the spatial relationships between the buildings and their astronomic orientations.

7. REFERENCES

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8. ACKNOWLEDGMENT

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