Drawing Accurate Ground Plans from Laser Scan Data

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Abstract. In addition to the kinds of standard documentation that a 3D archive can provide for a site of cultural heritage, laser scan data can also be used as the basis for accurate ground plans and other orthographic views. The resulting plans can be used to draw comparisons with existing documents and are also readily usable by architects and engineers for physical work at the site. The latter is the case for the Mosque of Farag ibn Barquq, a monument currently receiving restoration by ARCE Egyptian Antiquities Project in Cairo.

1. Introduction

This brief paper introduces a project to create accurate ground plans for a Fatimid-era monument in Cairo. The Egyptian Antiquities Project of the American Research Center in Egypt (EAP, ARCE) has undertaken conservation of the Zawiya and Sabil of Sultan Farag Ibn Barquq (Al-Dehisha); this monument is listed as Supreme Council of Antiquities Islamic and Coptic Antiquities Monument No. 203.

Well-researched documentation already exists for this mosque, including full architectural drawings of the monument[1]. Several ground plans and photos are available, including documentation dating from before the mosque was moved in 1922-23. The goal of our laser scanning work was not to duplicate the published material on the monument, but to describe the building as it stands today. Dr. Chip Vincent, Director of the EAP, requested accurate architectural drawings that could be used by the team working on a physical reconstruction effort at the monument. In particular, accurate plans and section views of the Iwan (Prayer Hall) and Fountain (Sabil) were requested.

At Dr. Vincent's suggestion, exterior data was also taken to correlate with future studies of the building. Here, our team team recorded important features of the mosque at particularly high resolution. By comparing this 3D data to future documentation, changes to the building through erosion, pollution, and restoration can be quantified, as suggested in Section 4. As with the plan data, it is hoped that this laser scanning archive will prove a useful addition to ARCE's ongoing research and documentation of Farag Ibn Barquq.

Many thanks are due Dr. Chip Vincent, Director of the Egyptian Antiquities Project at the American Research Center in Egypt (ARCE), for allowing the INSIGHT team to scan on site and for their ongoing review of the resulting data. Dr. Nairy Hampikian, Director of the ARCE Bab Zuwayla Conservation Project in Egypt, provided invaluable insight to our team during the scanning in Cairo and deserves a special mention for her exceptional graciousness.

2. Scanning at Farag ibn Barquq

Laser scanning can be used to create an image of an object in space, but the construction of this image comes by a very different method than is used in conventional photography. When a photo is taken, the image is captured through a lens. The specifications of the lens determine the observed perspective in the final image; also, the lens introduces distortions that make it difficult to extract accurate drawings or measurements. The orthographic drawings commonly used by architects and engineers are drawn without perspective so that relationships between any given points on the drawing can be measured at a constant scale.

In our methodology, laser scanning measures the distance from the scanner to a number of points in space. After making these measurements, the relationship between the gathered points can be expressed in the constructed 3D space of the computer. By taking thousands or millions of measurements, a "cloud of points" emerges, which accurately describes the subject being scanned. Finally, when rendered from the point of view of a synthetic, orthographic camera in the 3D world space of the computer, accurate views are generated.

The scanning and registration process at Barquq involved multiple viewpoints, which were later correlated. The main interior viewpoints (1-12) and exterior viewpoints (A-G) are shown in plan view as Fig. 1.

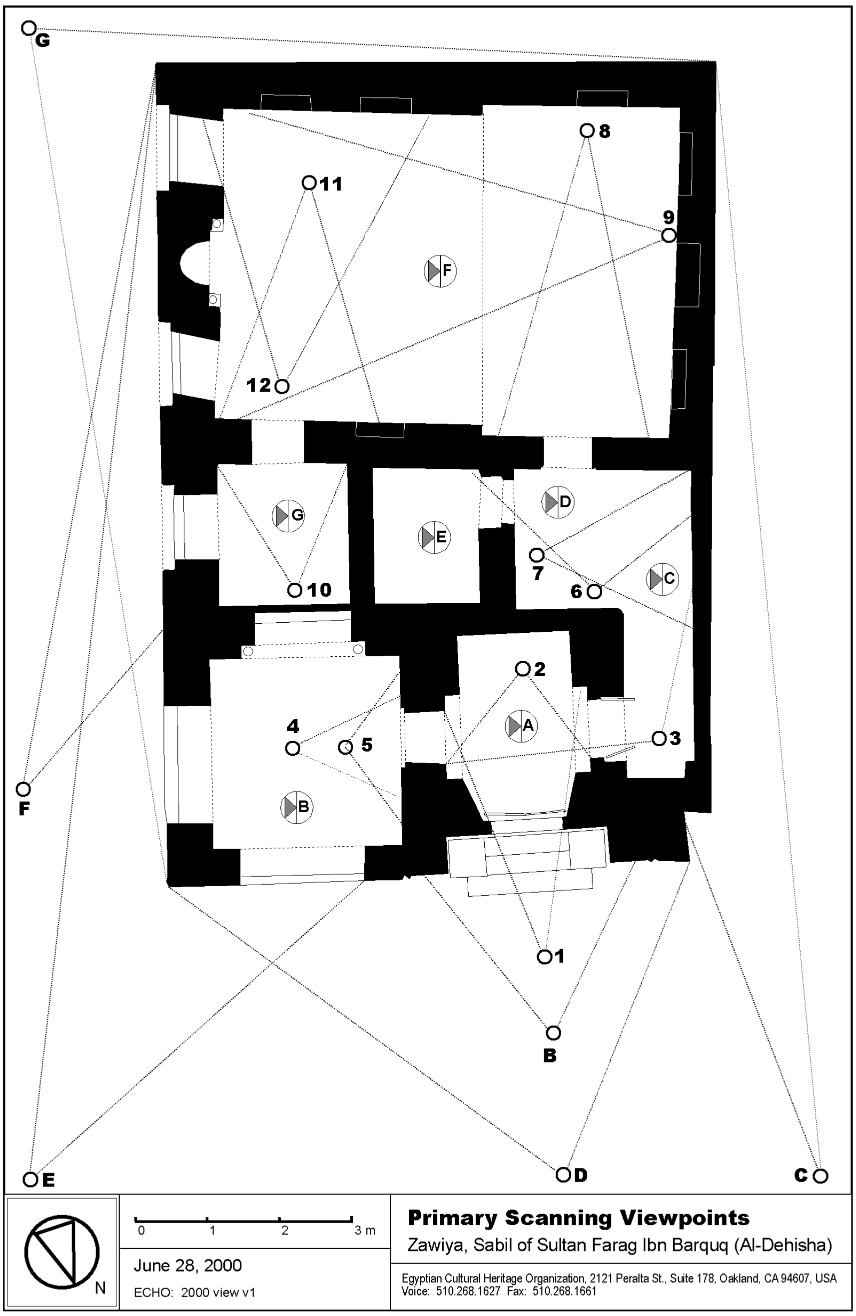

Fig. 1 (left)—Primary scan viewpoints for the interior and exterior

In selecting viewpoints, the goal is to describe the scan subject completely, while maintaining common objects between views to register the resulting data. Each viewpoint contains only a fraction of the total information for the subject. Just as a light projects a region of shadow on an object, here each view contains areas where data is "shadowed." In order to register the data from multiple viewpoints, spheres of known diameter were included in the scanned scene. As the spheres appear the same from any view and are uniform in diameter, they can be quickly isolated by the computer, named, and treated as distinct objects.

The goal of creating an integrated interior and exterior model presented unique problems because of the number of common reference objects required to survey the entire monument. For the methodology we used, at least three distinct entities (spheres or otherwise) are needed to accurately reconcile two viewpoints; care was used to place reference spheres where they could be included in as many viewpoints as possible. In the case of scan #3, for example, the spheres in Area A were placed to be visible through the narrow passage to Area C. The scanner itself had to be positioned so that it could see the spheres in Area A and C, which further limited the placement of spheres. Finally, it was crucial that all spheres be left in place during scans, and that all spheres be named in the computer for registration purposes. In Fig. 2, it is possible to see one red reference sphere on a tripod, and two spheres placed on the floor. Viewpoints and their corresponding reference objects were planned on paper before scanning.

Fig. 2 – The laser scan sensor on site (positioned vertically); a red reference sphere is visible on its tripod.

Since the final output for the project calls for orthographic drawings of the monument (plans, centerline sections, front elevations, and details), different methods were used for the interior and exterior scans. For scans #1-12, the goal was to capture an accurate cross-section of the interior walls; these scans were used to construct the plan view. Viewpoints A-G, the exterior scans, required scanning over larger distances. Important areas, both interior and exterior, were scanned in greater detail as a reference for future changes to the building. The specific rationale for these decisions is addressed in Section 4.

3. Provisional Interior Data

As shown in Fig. 1, 12 viewpoints were taken of the interior walls and floor regions for the purpose of generating an accurate ground plan. The resulting 3D data from these 12 views, is shown orthographically in Fig. 3.

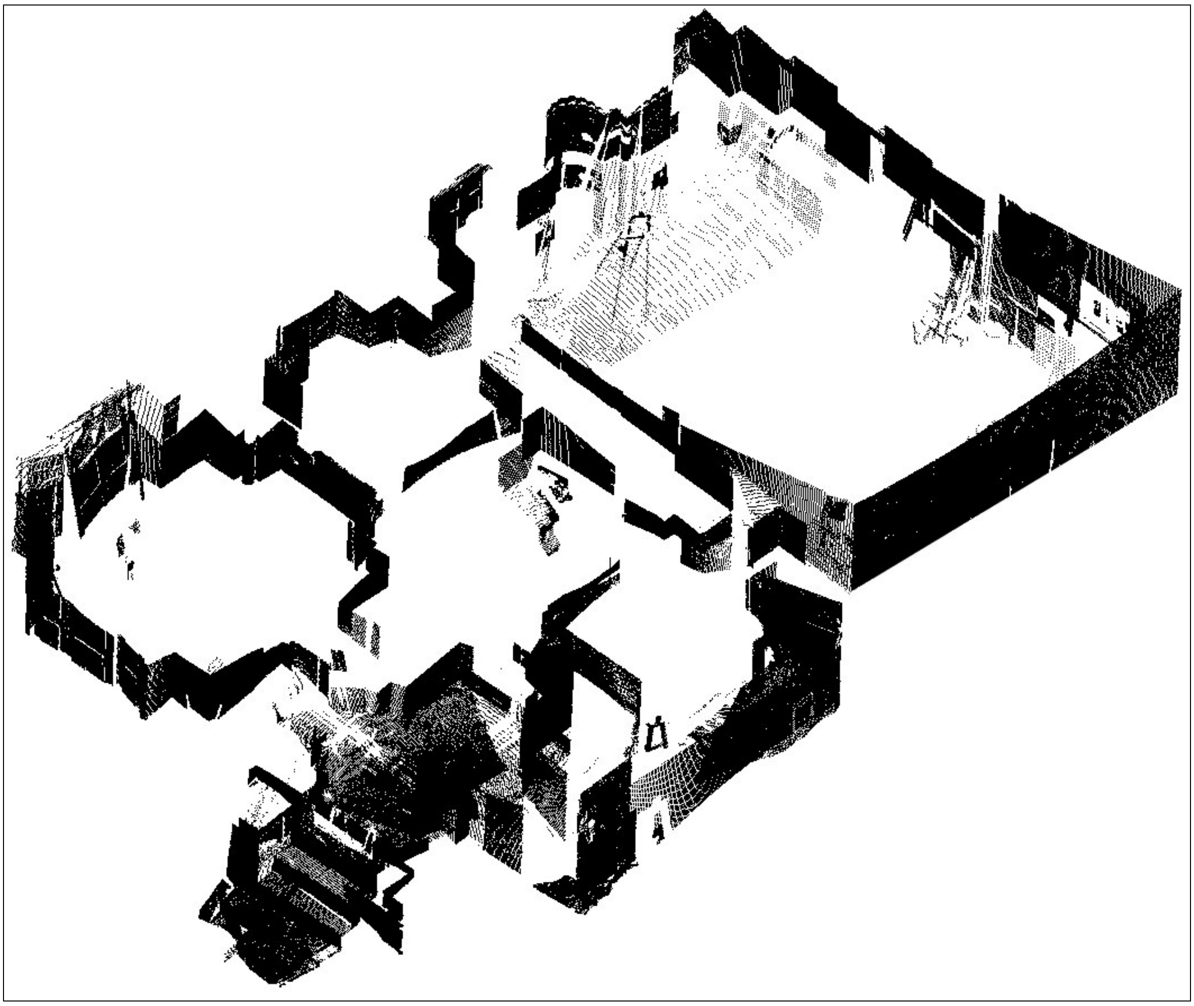

Fig. 3—An orthographic view of the interior walls, seen from above

Once the 12 viewpoints were registered using 20 distinct entities (including registration spheres as shown in Section III), a 3D model for the whole interior plan was generated. Fig. 4-5 show two orthographic views of this point cloud model: a ¾ view of the interior from above, and a traditional plan view of the point clouds.

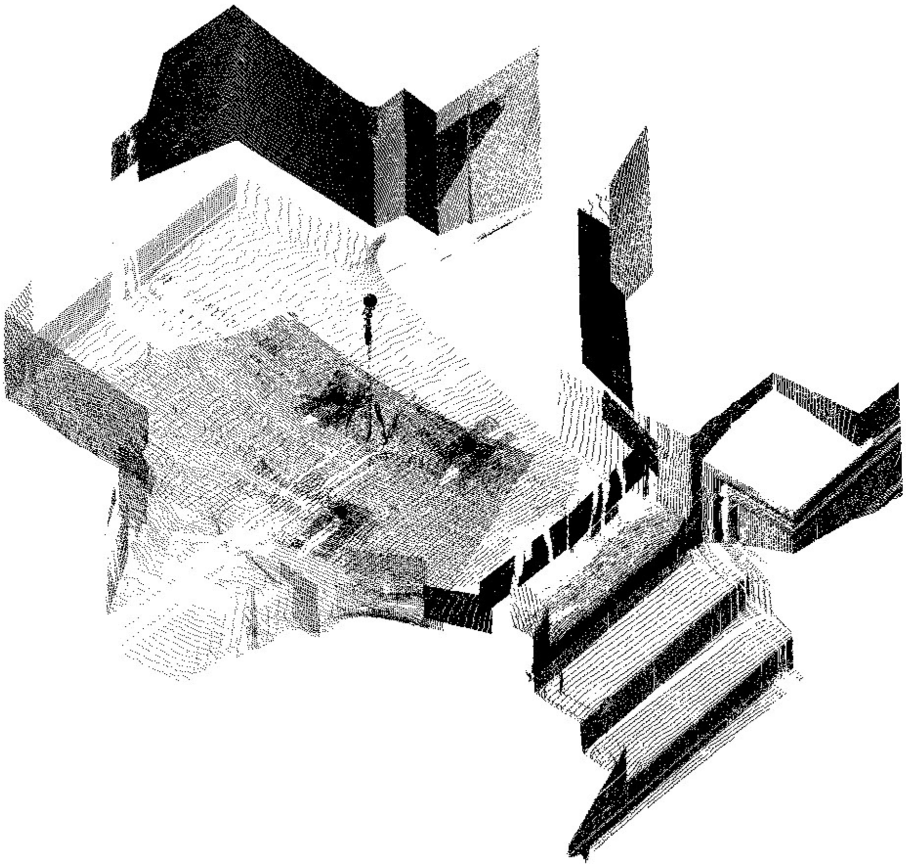

Fig. 4—Detail of Area A Entry

Note the vertical depth of the accumulated point cloud, representing an approximate 1 meter cross section of the whole building. While it would be possible to derive a ground plan with fewer points along the Y-axis, sampling a significant section of every wall reveals their implicit vertical angles.

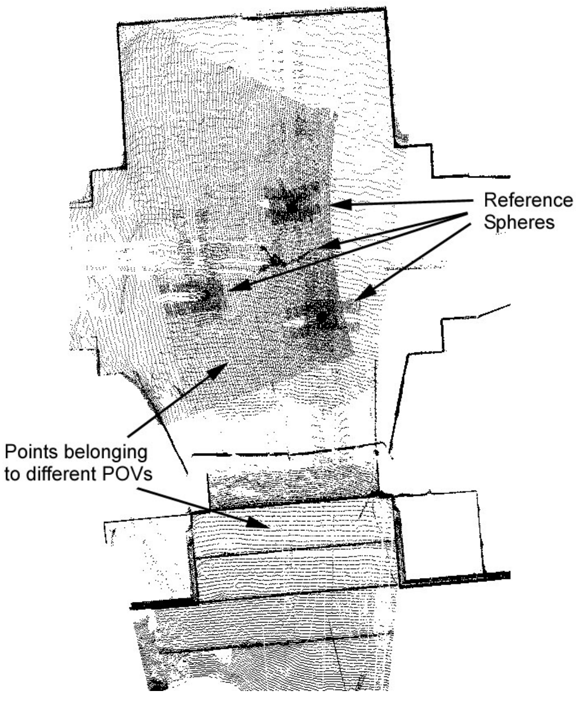

Fig. 5—Orthographic ¾ view of Area A

As described previously, the 12 interior scan viewpoints were merged into an integrated model by using reference spheres common to two or more views. The proper correlation of these separate views is crucial, since the registration process can introduce errors. The integrity of the data taken from each viewpoint is initially secure, resulting in a high level of confidence in the measurements made from the data. When two viewpoints are registered, however, the accuracy of the union is limited by the three or more common reference entities designated. To improve the accuracy of these unions, entities were created to supplement the reference spheres. For the plan shown at left, the average possible error was computed as 0 - 0.6mm.

By imaging an orthographic top view from the 3D dataset shown in Fig. 3, we see a ground plan expressed as a cloud of points (Fig. 6). This collection of 3D viewpoints also incorporates the exterior scans.

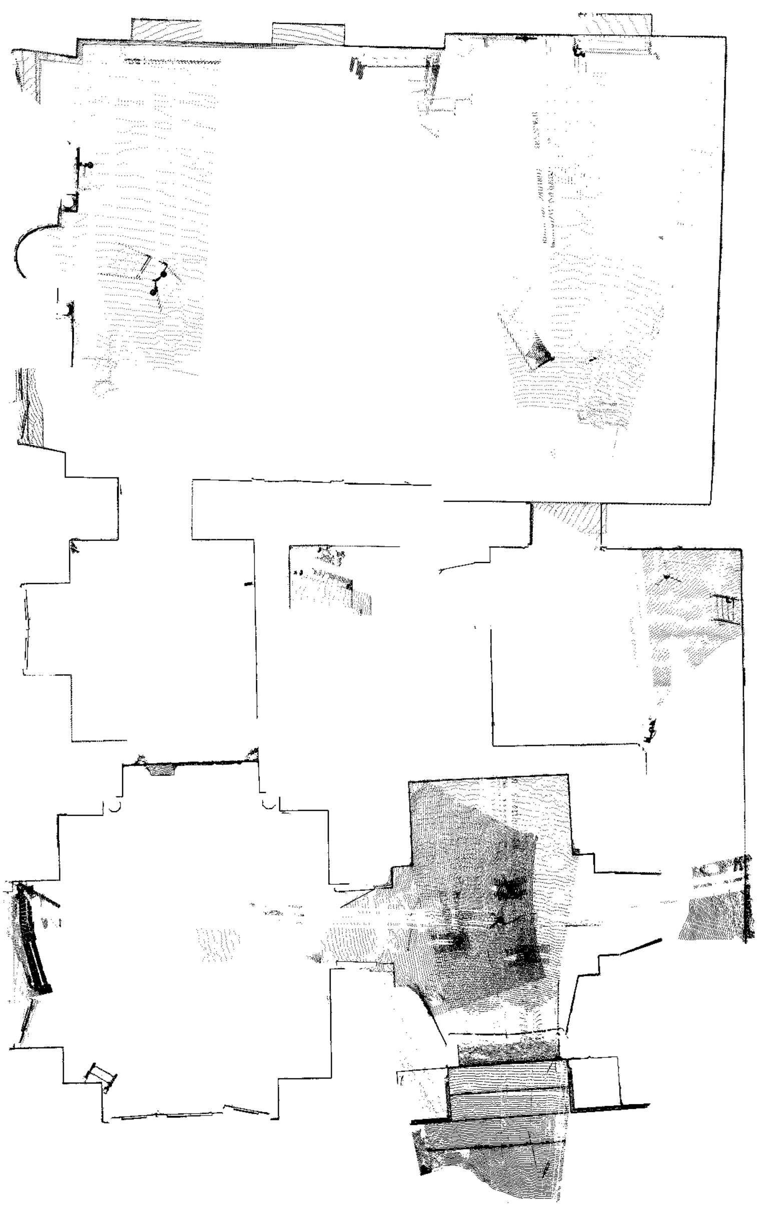

Fig. 6—An orthographic plan view of interior point clouds.

Finally, by expressing the 3D cloud of points as a 2D line drawing, a conventional ground plan can be extracted from the dataset (Fig. 7).

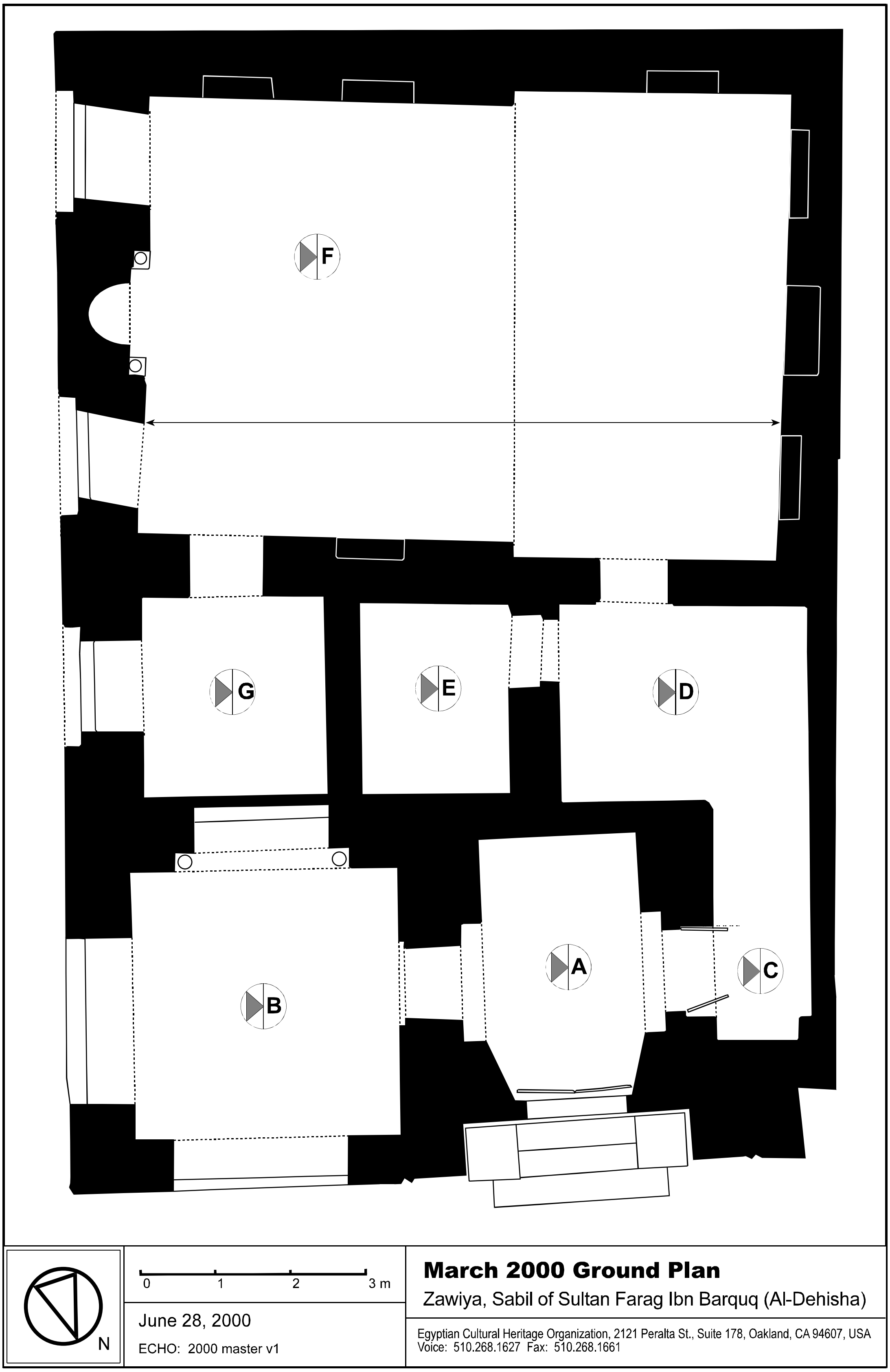

Fig. 7—Ground plan using March 2000 interior and exterior scan data

In order to verify the accuracy of the new ground plan, room dimensions were manually taken for all areas. Where practical, tape measures were used and simply read to the nearest cm. For longer measures, an acoustic device accurate to within 1 cm was used.

The measurements shown in the new plan and elevation drawings were checked against the manual dimensions and are seen to agree within +/- 1 cm tolerance. A representative sampling of manual room dimensions is shown in Fig. 18, below. These manual on-site measurements are here shown overlaid on the draft laser scanned plan shown in Fig. 17.

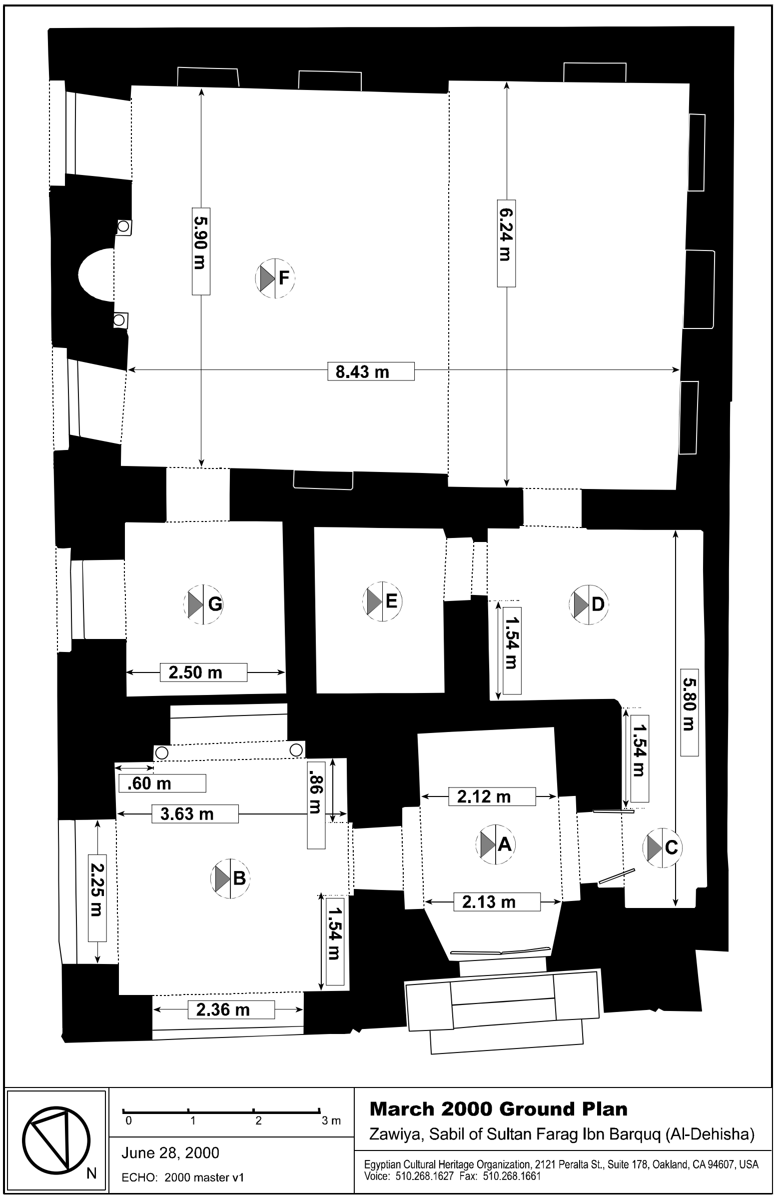

Fig. 8—Manually taken measurements, here superimposed on Fig. 7.

In some cases, the irregular limestone surfaces in the mosque influenced the accuracy of the acoustic readings. This is particularly true when sharp, reflective surfaces were measured since the measuring device depends on a strong, coherent acoustic echo to take an accurate measurement. In these cases, multiple readings were taken of each measurement to test accuracy.

4. Exterior Documentation

As requested by Dr. Vincent, director of the ARCE EAP, sections of the mosque exterior were scanned at high resolutions as a baseline for future study of environmental effects on the structure. Easily quantifiable landmarks were designated on the exterior of the mosque; these regions were then scanned and archived as 3D clouds of points. Areas recorded in the way include the upper Muqarnas rows along the eastern façade and the main entry portal area on the north façade. By comparing the data recorded in March 2000 with future 3D scans (of any kind) it will be possible to study changes to the structure.

Fig. 9—Photographic reference for the scanned area

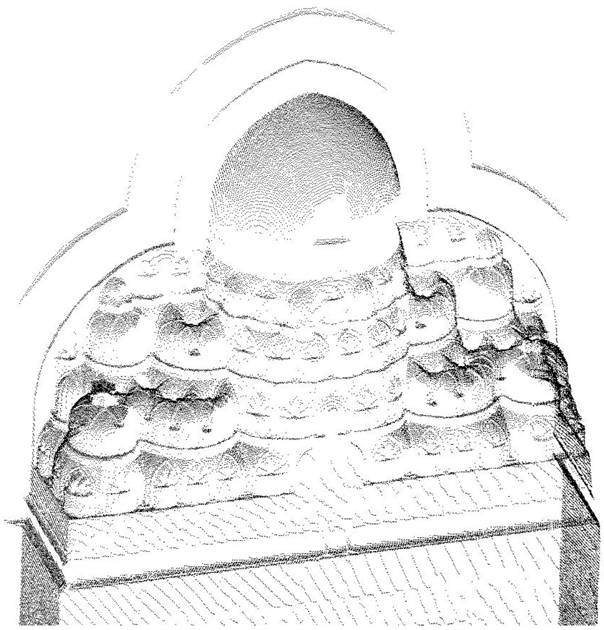

Fig. 10—Point cloud view of the north façade entry portal

5. Conclusions

One way to judge the success or failure of our work at Barquq is to compare our methods against traditional techniques for creating ground plans. Specifically, it is useful to compare 1. cost, 2. accuracy, and 3. speed. Considering the scans of Farag Ibn Barquq as a study case, the following generalizations can be abstracted:

Laser scanning can be an accurate technique for full 3D documentation

While it is still a challenge to deal with the large amount of data generated from 3D scans, the scanning process remains the best digital method to quickly gain comprehensive 3D documentation of a site. This is especially crucial for imperiled sites, where details risk being lost before they can be documented. In such "crisis" cases, 3D scan data could potentially be the only resource available to future researchers.

An integrated approach is ideal, balancing laser scanning with traditional techniques

While 3D scanning can be accurate and rapid when compared to traditional techniques, it is important to test the data provided via traditional techniques, where possible. There are also clear advantages to traditional techniques in terms of cost and time, depending of the project. Below, a small chart of relative merits is discussed:

Technique	Advantages	Limitations
Photography	Low cost, Fast	Limited accuracy
Traditional Illustration	Relatively low cost	Slow, Limited accuracy
QTVR / digital panoramas	Allows user to navigate a 3D scene	Fixed viewpoints
Traditional surveying	Accurate, Established technology	Limited number of 3D points
3D Laser scanning	Accurate, High number of 3D points	High cost, Technically demanding

Figure 11-- Comparison of 2D / 3D documentation types

Advantages of 3D Scanning for Cultural Heritage Projects

3D scanning enables a site to be accurately measured in a relatively short amount of time. 3D scanning remains the only viable way of documenting the precise measurements of a complex subject such as Barquq's deteriorated stalactite ceiling.

Importantly, scan models can be transferred to popular formats (i.e., AutoCAD) for use by architects and engineers. These same files can be used as the basis for reconstructions, physical models, or object movies. Provided that the files are continually migrated, 3D scanning is a permanent, durable record of the site.

Limitations of 3D Scanning for Cultural Heritage Projects

During fieldwork, our team has found that 3D scanning hardware is inevitably delicate. While scanners differ in the robustness of their performance, all require special handling and careful operation. Also, the costs required to complete large-scale scans and the computational heaviness of the resulting data files is currently a significant problem.

While laser scanning can approach sub-millimeter accuracy, it is very difficult to accurately capture epigraphy with 3D laser scanning. Large-scale scanners are not designed to record detailed inscriptions while small-scale scanners are not equipped to deal with the scale of a building. Since epigraphy must be scanned at high resolution to capture vital detail, heavy files are again an issue.

References

[1] Saleh Lamei Mostafa, Mosque of Farag ibn Barquq in Cairo. J. J. Augstin, Gl□ckstadt, 1972.