HISTORICAL PRESERVATION AND RESOURCE DOCUMENTATION IN THE SALINAS PUEBLO MISSIONS NATIONAL MONUMENT, NEW MEXICO WITH HIGH-DENSITY LIDAR AND THREE-DIMENSIONAL GIS

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ABSTRACT

HDR | e²M was contracted by the U.S. National Park Service (NPS) to generate highly detailed three-dimensional (3D) models in the Salinas Pueblo Missions National Monument using stationary terrestrial LiDAR for historic preservation efforts. The scanned features included the Abo Mission Complex and the Abo Painted Rocks. The objective was to record and catalog the integrity of both sites. Ultra-high density point clouds were created using LiDAR scans recording both intensity and RGB values. The datasets were analyzed using Applied Imagery's Quick Terrain Modeler. Quality control processes included removing data anomalies, extracting inadvertent features, conducting an independent accuracy report, and qualitative assessments. The Abo Painted Rocks dataset was further processed to facilitate GIS integration by altering default coordinate system orientation to compensate for rock shelter wall overhang. Digital elevation models (DEMs) were created using the LiDAR point clouds. The DEMs provided the means to generate Triangulated Irregular Networks (TINs) that were integrated, shared, displayed, and analyzed in ESRI ArcScene. RGB values recorded from the scans were applied to the TIN to create a realistic visualization of the project sites. An aerial photograph was draped onto an USGS DEM to further enhance the existing 3D environment. Deliverables included refined point clouds, DEMs, TINs, aerial photography, and associated project files. A freeware visualization and basic analysis tool was supplied to NPS for further investigations. Most importantly, the LiDAR scans and derived geospatial products will serve as baselines for future change analysis studies.

Key words: stationary terrestrial LiDAR, historical preservation, three-dimensional (3D) GIS, CnU technique

INTRODUCTION

Light Detection and Ranging (LiDAR) is an active laser ranging sensor system that records highly accurate geo-referenced three-dimensional (3D) points. LiDAR can record millions of 3D points by emitting timed pulses of light and recording their return times (Campbell, 2002). It is an efficient, highly accurate, and versatile technology that records a wealth of spatially referenced information. LiDAR technology is currently being used in applications for archaeology, geology, historical preservation, measuring landscape change, forestry, shoreline mapping, bathymetric mapping, human anatomy, military reconnaissance, law enforcement, and NASA Mars missions.

Stationary terrestrial LiDAR is based on the same principles as airborne LiDAR, but data is recorded from a single location instead of a mobile or airborne platform. High-density LiDAR scans are an effective method for documenting exiting conditions and measuring change over time for historical preservation efforts (Shan and Toth, 2009). LiDAR scanners only record data in their field of vision, so multiple scan locations and angles are required to adequately cover all areas of a project site. However, a much higher density of recorded 3D points can be achieved using stationary terrestrial LiDAR versus mobile or airborne platforms because of the close proximity to the features of interest and longer occupation times at discrete locations (Maune, 2007).

The production of highly detailed 3D models in the Salinas Pueblo Missions National Monument (SAPU) was intended to aid the National Park Service (NPS) in the development of preservation strategies based on scientific analysis and documentation that are focused on areas and sources of structural deterioration. LiDAR was the best option for this preservation effort because of the non-intrusive nature of the technology and "hands-off" technique for data collection. In addition, using stationary LiDAR for the establishment of a historical record allows for accurate and precise depictions of current conditions for project sites. In short, historical sites are not protected in the same way artifacts are in museums because these sites are subject to natural processes and human disturbances. Scanning these sites with LiDAR proved less costly and time-consuming than conventional preservation efforts while creating a higher standard with respect to accuracy, visualization, and analytical capabilities.

STUDY AREA

The Abo unit of Salinas Pueblo Missions National Monument is located approximately 9 miles west of the town of Mountainair along New Mexico State Highway 60 (Figure 1). The Abo unit, measuring 279 acres, encompasses the remains of several Native American pueblos dating from the 13th through the 17th centuries, a 17th century Spanish mission, and various other prehistoric and historic structures and out-buildings. The study area is comprised of two distinct locations including the Abo Mission Complex and the Abo Painted Rocks.

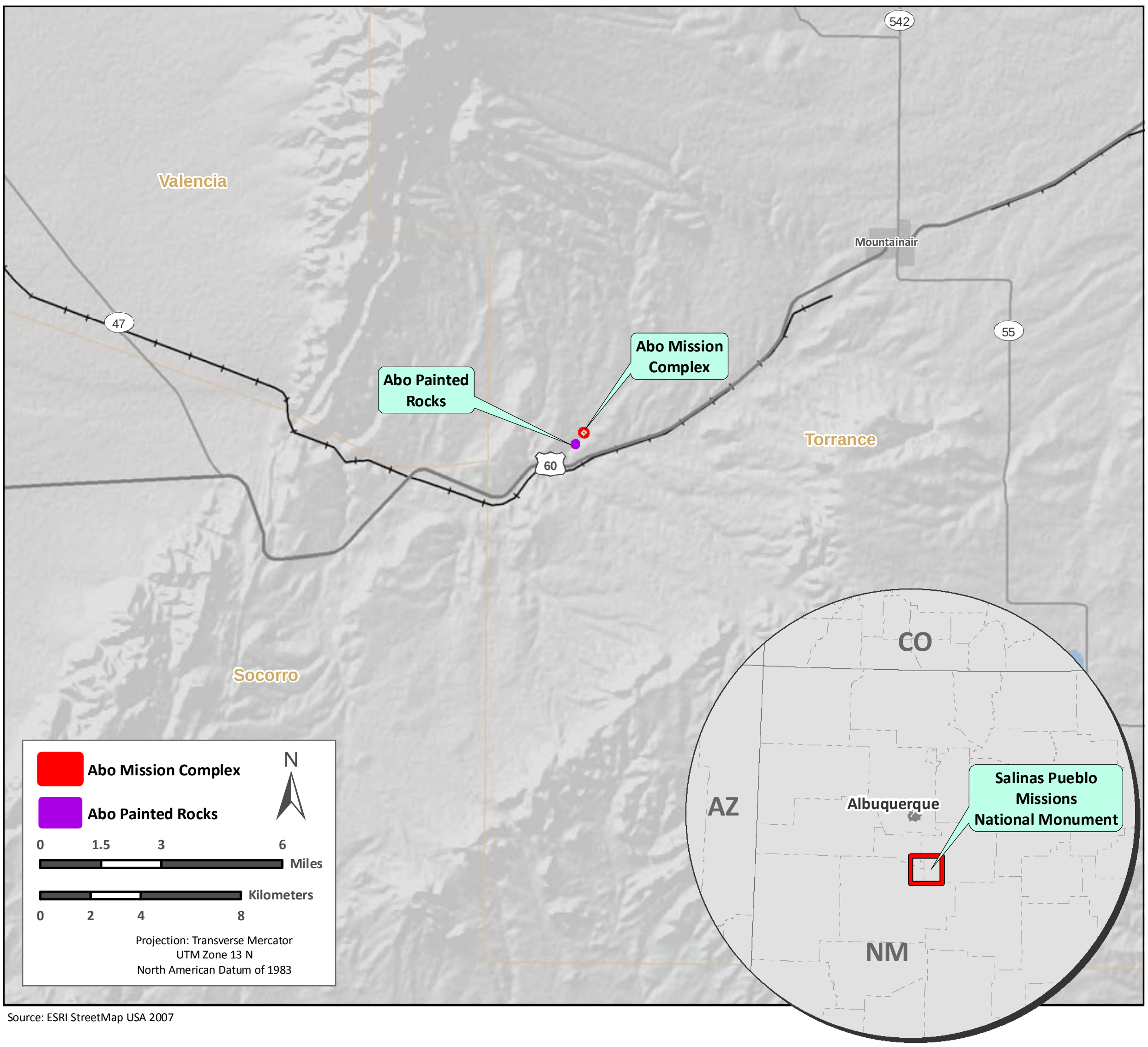

Figure 1. Vicinity Map of Salinas Pueblo Missions National Monument.

Abo Mission Complex

According to Derek Toms, SAPU archeologist, “the San Gregorio de Abo Mission Complex is a significant park resource, representing one of only five pre-pueblo revolt Spanish Missions remaining in New Mexico that have been excavated and are open to the public. The mission, in direct association with the adjacent Native American Pueblo Mounds, is the primary resource of the Abo unit. The Abo Pueblo and Mission was designated a National Historic Landmark in 1962 and was listed on the National Register of Historic places in 1976. In 1980 the site was designated as a unit of the National Park Service with the creation of Salinas Pueblo Missions National Monument. Stabilization of San Gregorio de Abo Mission Complex has been ongoing since 1938, and the structure was listed as 100% stabilized in 2004 for the first time in its history as a monument.”

Abo Painted Rocks

According to Derek Toms, SAPU archeologist, “the Abo Painted Rocks is a significant, well-known, park resource consisting of numerous Native American pictographs. The pictographs which give the site its name are housed within a shallow rock shelter that is located along a northeast-southwest trending, Abo sandstone cliff. The monochrome and polychrome rock art at the Abo Painted Rocks is extensive and covers a horizontal distance of 115 meters. The resource is in a severe and rapid state of deterioration: the site is located less than 50m from a major roadway (HWY 60), exposing the site to extreme vibration and pollution. The close proximity of the highway also makes the site accessible to trespassers, which results site disturbance and graffiti. The Burlington Northern & Santa Fe Railroad’s Abo-Pass Line is a major freight route with constant rail traffic and is less than 200m from the site, dramatically increasing the vibration. Carbon monoxide (exhaust) pollution from the trains and road traffic is also a major issue. Rock swallows use the shelter for nesting, resulting in numerous mud nests adhered to the Abo Painted Rocks, compromising paint integrity. These impacts are historic, as well as current, some of which date back as much as 150 years. As time has progressed, the impacts have intensified and compounded. Total measurable impacts to the resource, as indicated by historic documentation, indicates increasingly rapid deterioration. The site is also a backcountry site vulnerable to wildland fires that could seriously and irreparably damage the paintings.”

METHODS AND DATASETS

The project goals included using 3D terrestrial laser scanning to obtain high resolution survey data for the purposes of conservation, restoration, and site planning. The intended outcome was to generate point clouds and digital photographs of the Abo Mission Complex and Abo Painted Rocks. The NPS required that all methods, procedures, and techniques would be totally non-intrusive and resulting in no physical impacts upon the historic fabrics and cultural deposits. The point clouds that resulted from these efforts allowed the team to create accurate and reliable 3D models without degrading the sites.

Scanning Methodology

A Leica Scan Station 2 was used to collect the datasets for the Abo Mission Complex and Abo Painted Rocks. The sites were scanned at a high resolution and selected areas (particularly the Abo Painted Rocks) were scanned at an ultra-high resolution (Table 1). Ultra-high resolutions were selected for areas of high interest and planning of a later project. The Abo Painted Rocks site was scanned in extremely high definition formats to better capture the intricate detail of the rock faces and the painted images. The scanned data and digital photographs were tied to park coordinates. All data capture and ‘notes’ are within the selection of the scan setups and internal to the Leica scanner.

The scanning methodology captured the interior and exterior of the Abo Mission Complex with 13 scan positions in two days of fieldwork. Over 24 million individual geo-referenced points were recorded. In the Abo Mission Complex’s interior sector, higher-density scan positions were needed to record its precise location. In coordination with the laser scanner measurements, the team determined the positions of the control points for the laser and image data were equally distributed over the site. For identification purposes, the control points were equipped with retro-reflecting targets mounted on survey rods with bipods. Finally, the control points were surveyed with RTK-GPS. Each setup position was leveled with the scanner’s “dual axis compensator.” There were 36 target based constraints and 14 cloud mesh based constraints. The registration mean absolute error was 6 mm.

Table 1. LiDAR Scanning Datasets

ABO MISSION COMPLEX		
Item	Number of Points	Point Spacing
RGB Full Mission Point Cloud	21,451,324	5 cm
RGB Full Mission Terrain	9,720,400	5 cm
RGB Mission Walls Terrain	1,323,019	5 cm
RGB Mission Walls with Interior Terrain	3,393,316	5 cm
Intensity Full Point Cloud	21,451,324	5 cm
Intensity Full Terrain	9,720,400	5 cm
ABO PAINTED ROCKS		
Item	Number of Points	Point Spacing
RGB Full Rock Art Site Point Cloud	7,022,169	2 cm
Intensity Full Rock Art Site Point Cloud	7,022,169	2 cm
RGB Rock Art Site Terrain	71,857	5 cm
Intensity Rock Art Site Terrain	71,857	5 cm

Point Cloud Datasets

The Abo Mission Complex data collection involved capturing the San Gregorio de Abo Mission Church and surrounding vicinity (Figure 2) for the production of architectural sheets to aid in feature assessment, recording stabilization histories, site monitoring, exhibits, and animations. The scan data was registered and geo-referenced to the local park coordinate system to allow integration with existing GIS data. This project focused on scanning the walls and floor of the main church building.

Figure 2. Point Cloud Renderings of Abo Mission Complex (left: RGB image, right: elevation profile).

The Abo Painted Rocks data collection was an effort to document the rock shelter at SAPU (Figure 3). The scanning was geo-referenced so that metric data tied into the park coordinate system for seamless integration with existing GIS data. A 3D model of the rock shelter was later created from the data collected during the laser scanning process. The TIN model of the shelter was prepared to create a highly detailed photo-realistic visualization for analysis and animation purposes. In addition, the data was also used to prepare planimetric maps and generate additional geospatial data sets such as topography, profiles, drip-line, etc.

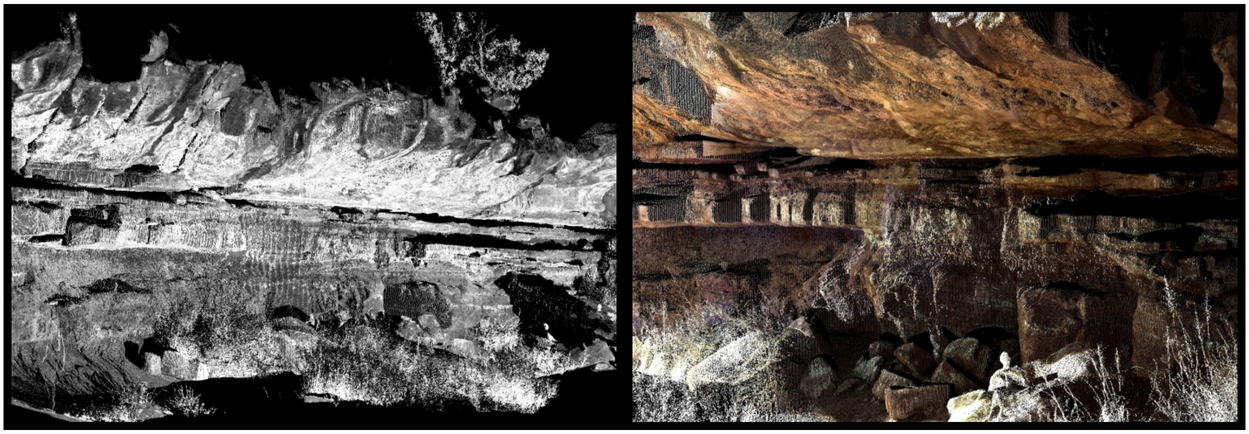

Figure 3. Point Cloud Renderings of Abo Painted Rocks (left: intensity image, right: RGB image).

QUALITY CONTROL AND RESULTS

Quality Control

The Abo Mission Complex quality control (QC) process was a significant effort due to the size of the site, the number of scans, and the volume of data. The scans were reviewed to verify accuracy and density to ensure the recorded data met the requirements of NPS. The alignment of the multiple scans was then evaluated to determine quality of registration. The dataset was cropped to the area of interest and followed by another density check. Any anomalies were then removed such as bird strikes, people, inanimate objects, or scan errors.

The Abo Painted Rocks QC included removing shrubs and brush from the foreground after verifying the accuracy and density of the point cloud. The next stage of the QC process involved cropping the polished point cloud to the area of interest. Removal of peripheral objects from the point cloud was primarily for aesthetic purposes, but also had the benefit of lowering file size. As with the Abo Mission Complex, a final visual inspection was performed by a team member to ensure all major QC tasks had been executed properly.

Results

A number of geospatial datasets were derived from the final point clouds including DEMs, TINs, and ArcScene project files (Table 2). The TINs were transformed into terrains with Applied Imagery's QT Modeler. The terrains were exported into ArcGIS as highly detailed raster DEMs. The DEMs were then processed into TIN models with the ArcGIS 3D Analyst extension. Raster images were also processed and exported from the terrain models in QT Modeler. RGB and Intensity image overlays were generated as an enhancement to the visualizations in ArcScene. All geospatial products were delivered in the New Mexico Central NAD83 State Plane coordinate system.

DISCUSSION

Processing of Abo Painted Rocks

The project team during the course of the project developed a methodology it termed the "CnU technique" for processing a true 3D model into a 2.5D TIN. The CnU technique was developed due to the inherent nature of the Abo Painted Rocks and the difficulty of importing this structure into a GIS environment. Specifically, the site is a rock shelter with an overhang. The overhang is significant because of the top-down nature of conventional projected coordinate systems. The problem with creating a conventional ArcGIS TIN for this type of structure is that TINs can only have one elevation (Z value) for every horizontal coordinate (XY). However in this case, the Abo Painted Rocks has multiple Z values for many XY coordinates (later described as 'C').

In short, the CnU technique manipulates the original XYZ orientation of the cliff overhang (C) and renders the model rotated downward (n) to be inverted for use (U) in a GIS. The letters are simply an expression to describe how the rock shelter is being rotated in coordinate space. The development of the CnU technique was a noteworthy technical achievement. The ability to render complex 3D objects in ArcGIS for interaction, viewing, and analysis was paramount because of software costs, distributability, and the capability to convert to other file formats.

Table 2. Geospatial Datasets (DEM and TIN geospatial products)

ABO MISSION COMPLEX				
Item	Number of Vertices	Edges	Triangles	Cell Size
Full Mission TIN	134,051	662,577	220,859	n/a
Mission Walls TIN	1,305,834	7,735,494	2,578,498	n/a
Mission Walls with interior TIN	3,406,193	20,398,299	6,799,433	n/a
Mission Intensity Image Overlay	n/a	n/a	n/a	1ft
Mission RGB Overlay	n/a	n/a	n/a	1ft
ABO PAINTED ROCKS				
Item	Number of Vertices	Edges	Triangles	Cell Size
Rock Art Site TIN	84,992	498,153	166,051	n/a
Rock Art Site RGB Image Overlay	n/a	n/a	n/a	5 cm
Rock Art Site Intensity Image Overlay	n/a	n/a	n/a	5 cm

The CnU Technique is outlined in the stages below:

C: 'C' represents the original 3D rock shelter model in its conventional top-down or native XYZ orientation (Figure 4). An ArcGIS TIN created from this orientation outputs a hill not a rock shelter because the TIN creation process is similar to draping a blanket over a feature. In other words, a true representation of complex 3D objects is not possible with the ArcGIS TIN process in the Abo Painted Rocks because it masks the interior detail of the rock shelter. This particular phenomenon is also why ArcGIS 3D data is often referred to as 2.5D (only having one Z value per XY).

n: 'n' represents the manipulated XYZ orientation in QT Modeler. The restrictions described in the 'C' stage made it necessary to develop an alternative methodology for TIN creation. The furthest points recorded on the rock surface were located at the back of the rock shelter. After reimporting the data, the model was rotated facing downward ('n') to ensure that only the back rock shelter wall was reflected in the final TIN (Figure 4). Now when creating the ArcGIS TIN, or draping the blanket over the model, a user can be certain that it reflects the rock shelter's surface with no interference.

U: 'U' represents the final model that was incorporated into an ArcScene environment (Figure 4). Using the 'n' terrain model, the team exported an ASCII XYZ into ArcGIS. The ASCII XYZ was then imported in ArcScene as a raster surface in the 'n' position. The raster was inverted and mirrored to accurately represent the rock shelter model. The new 'U' shaped rock shelter model was converted to a TIN and overlaid with an RGB representation of the rock shelter. The 'U' TIN with the RGB overlay viewed in ArcScene represented the final stage in the process.

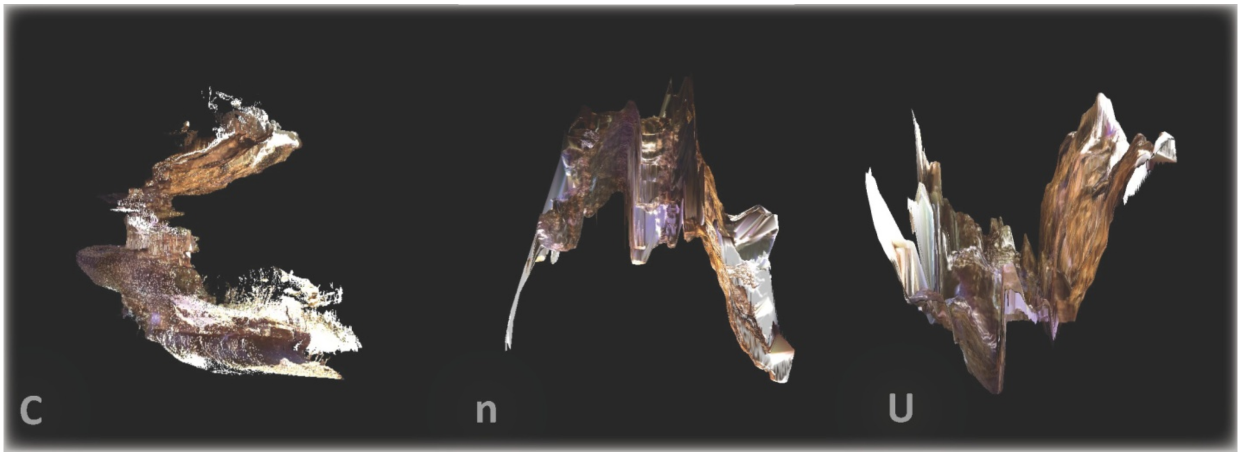

Figure 4. The CnU Technique.

Integration into ArcScene

LiDAR data file sizes are typically large and bulky, and as a result, the datasets can be difficult for an average computer system to quickly process and render. Secondly, the GIS software that was accessible to NPS staff was ArcGIS 9.2 and ArcScene. These file size and software variables reduced deliverable options to a collection of points, a raster, and/or a TIN model. The performance of ArcGIS while handing large amounts of LiDAR points was marginal. ESRI's technical suggestions to manipulate LiDAR datasets for ease of processing and analysis inside of their software were insufficient (e.g. single-point to multi-point, using file geodatabases, and utilizing LiDAR extensions).

The project team developed a solution for software compatibility and data exchange to facilitate data interoperability between software applications. As such, the ASCII XYZ file is a primary export format in QT Modeler and is readily compatible with ArcGIS. ArcGIS recognizes an ASCII-based raster. The raster file sizes exported from QT Modeler were acceptable to ArcScene. However, ArcScene degrades the raster format for display and loads this type of elevation dataset slowly during navigation. As a result, the preferred option became the TIN. Taking the ASCII raster and converting to a TIN generated a product without a loss in quality or accuracy, and furthermore, provided an accurate model that loaded and navigated smoothly in ArcScene (Figure 5). The primary drawback to the TIN format is a significantly larger file size. However, it was determined processing ability was more important than smaller file size especially when trying to render a realistic scene.

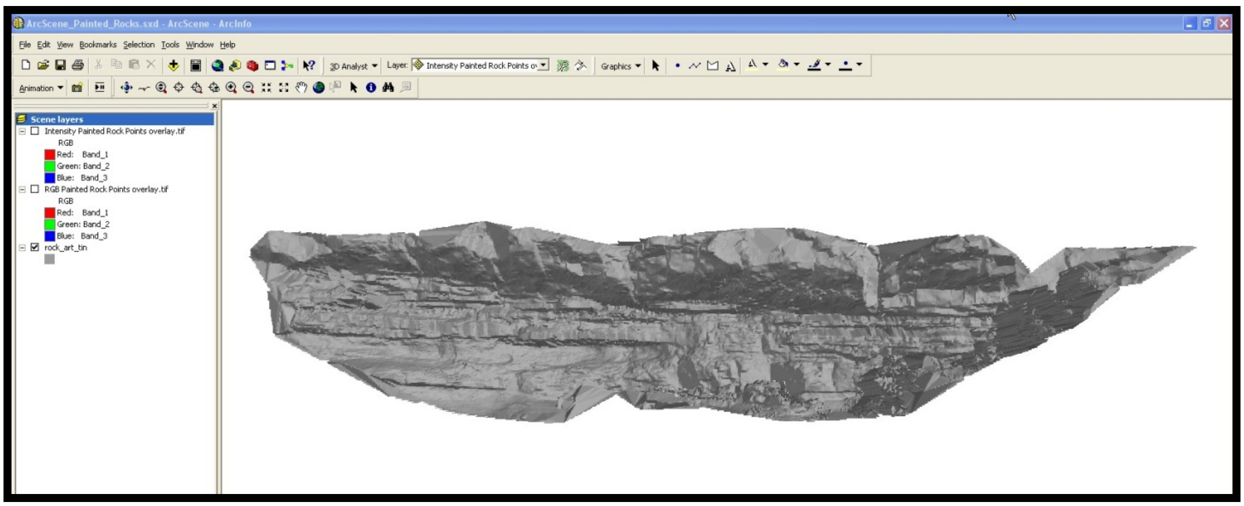

Figure 5. ArcScene Rendering of Abo Painted Rocks.

At the conclusion of the study, the project team provided NPS a freeware LiDAR visualization and basic analysis tool (Applied Imagery's Quick Terrain Reader Version 6-1.1). QT Reader allows NPS to view every pertinent recorded point in a visually interactive 3D environment. Using QT Reader, users can also measure geometry and create markers to save locations of interest. In addition, the project team discussed a unique approach for data dissemination and accessibility of the Abo Mission Complex with Google Earth. A Google Earth interface would allow a user to easily open and zoom to the Abo Mission Complex where they would have the ability to interact with the data sets. Specifically, users could click on the model to initiate an information window. The information window could display photos of the site, descriptions, and perhaps most importantly, links to an FTP site where documents, QT Reader, and the recorded point clouds could be downloaded with the appropriate security credentials.

CONCLUSIONS

HDR | e²M achieved the historic preservation goals of the U.S. National Park Service in the Salinas Pueblo Missions National Monument by generating highly detailed models of the Abo Mission Complex and the Abo Painted Rocks. The team utilized high-density stationary terrestrial LiDAR and three-dimensional GIS to accomplish the project's objectives. The Abo Mission Complex and Abo Painted Rocks TINs were migrated into ESRI ArcGIS for use by the

NPS. The Abo Painted Rocks dataset was further processed using the CnU technique to accurately and properly represent rock shelter wall overhang in ArcScene. Additional project deliverables including refined point clouds, DEMs, TINs, aerial photography, and associated project files. The LiDAR scanning and 3D modeling of these historical sites proved not only detailed and accurate, but also timely, affordable, and non-intrusive. Most importantly, the LiDAR scans and the derived geospatial products will serve as the baselines for future change analysis studies.

ACKNOWLEDGEMENTS

The authors wish to thank Derek Toms, Mark LeFrancois, and the National Park Service at Salinas Pueblo Missions National Monument for their support during the preparation of this publication. In addition, we appreciate the contributions to the manuscript provided by Dietrich Evans of 3D Laser Imaging.

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