Fort Matanzas National Monument Digital Documentation Project: Utilizing Terrestrial Lidar For The Understanding Of Structural Integrity Concerns For Coastal Forts And Coquina Structures (Cesu, National Park Service)

Lori D. Collins  
*University of South Florida, lcollins@usf.edu*

Travis F. Doering  
*University of South Florida, tdoering@usf.edu*

Jorge Gonzalez  
*University of South Florida, jorgegonzale@usf.edu*

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FORT MATANZAS NATIONAL MONUMENT DIGITAL DOCUMENTATION PROJECT:
UTILIZING TERRESTRIAL LIDAR FOR THE UNDERSTANDING OF STRUCTURAL INTEGRITY CONCERNS FOR
COASTAL FORTS AND COQUINA STRUCTURES (CESU, NATIONAL PARK SERVICE)

LORI COLLINS, PH.D. AND TRAVIS DOERING, PH.D., 8/2013

CONTRIBUTIONS BY: JORGE GONZALEZ, STEVEN FERNANDEZ, JAMES MCLEOD, AND JOSEPH EVANS
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Introduction
Fort Matanzas, described as the “guardian to St. Augustine’s backdoor” (Arana 1978), is a National Park Service site locale that is facing issues of damage and decay due to its age and continual exposure to natural environmental and anthropogenic factors. The construction has persistently deteriorated and its structure and materials require constant maintenance and restoration. The weight of the coquina stone and erosion of foundational support have led to significant, uneven settling or sinking of the foundation into the sandy soil. This condition is exacerbated by the wetness of the soil caused by annual rains and the Fort’s placement within meters of the river’s edge. The most substantial weight of the structure is concentrated below its vertical exterior walls causing the perimeter of the building to sink deeper into the soil than the center. This circumstance, along with the weakening and deterioration of the subsurface foundation, has caused the walls of the structure to bow and ultimately crack at its weakest points.

In addition to the foundational breakdown and wall fractures, other structural problems are also of concern. The coquina stone used in the fort’s construction is a partially consolidated sedimentary rock composed of compressed seashell or coral and, because of continual exposure to natural elements, some of the stone is dissolving. The joints bonding the coquina blocks together were originally made with lime-based mortar that, over time, has deteriorated and decomposed from weathering and moisture intrusion. Previous restoration efforts to repair these joints often utilized materials such as Portland cement, a material that is now known to cause cracking of the stone and fissuring of the joints.

In September 2012, the University of South Florida (USF) Alliance for Integrated Spatial Technologies (AIST), undertook a survey utilizing terrestrial laser scanning (TLS), survey-grade global positioning systems (GPS), GPS imagery, and photogrammetric and other forms of standard and advanced photo imagery. Using these non-contact, non-destructive techniques, the entirety of the fort and its surrounding terrain features were captured in high resolution details (structural aspects at +/- 2mm), to provide a holistic landscape context documentation for planners and managers. These data were processed and brought together with existing digital legacy data detailing environmental and cultural historical aspects and remotely sensed aerial data such as aerial imagery and LiDAR. These data sets were then combined using a geographic information systems (GIS) approach with outputs consisting of a geodatabase structure, as well as user-friendly and interpretive deliverables including virtual globe (Google Earth) modeling, and 3D fly-through videos and models. All 3D work performed is supportive of computer automated drawing (CAD) output, and data are archival in formats to allow for use in long-term monitoring and management assessment at the site.

Background
Historical Overview
The Fort Matanzas National Monument is located in St. Johns County, Florida, approximately 15 miles south of St. Augustine and its sister fort, the Castillo de San Marcos. Approximately 225 acres including the fort and surrounding areas are owned and managed by the National Park Service. This land includes approximately 100 acres of salt marsh and barrier islands along the
Matanzas River. Fort Matanzas was constructed at this site to guard the Matanzas Inlet, an important alternate route to the city of St. Augustine (Figure 1). Along with the Castillo de San Marcos, Fort Matanzas served to protect this Spanish city (National Park Service 1976). The site is strategically located on Rattlesnake Island, next to a small inlet opposite the south end of Anastasia Island, on Florida’s Atlantic Coast. The human history of the land that comprises the National Monument begins with the Paleo-Indians, prehistoric hunter-gatherers who inhabited the region 12,000 years ago. More recently (c. AD 1100 to 1600) the area was occupied by Timucua Indians, a large, socially complex society of Native American people who lived in Northeast and North Central Florida and southeast Georgia (Milanich 1994; Smith 1985).

The Florida Master Site File (FMSF) lists four cultural resources associated with Fort Matanzas National Park. Resource Group 8SJ44 includes both the fort (8SJ44a) and the related archaeological site, 8SJ44b. Historic structure 8SJ5404, the Fort Matanzas National Monument Headquarters and Visitor Center, was constructed in 1936, and was listed on the NRHP on December 31, 2008. The visitor’s center is located across the river, to the east of Fort Matanzas. A prehistoric midden is also located on the Fort Matanzas National Monument parcel. Site 8J28 (Fort Matanzas Midden) is a shell midden with a surface scatter of shell and historic artifacts (Deagan 1976).

With the arrival of European explorers in the 16th Century, coastal Florida became a battleground for Spanish, French, and British forces fighting for control of the New World. In 1565, on orders from King Philip II of Spain, Admiral Pedro Menéndez de Avilés, founded St. Augustine to protect Spain’s claim to La Florida. This colony was established on or near the Timucuan Indian village of Seloy, and was to become a bastion of Spanish dominance. The successful defense of St. Augustine was critical to Spanish plans to hold and expand their empire. Matanzas, meaning slaughter, was such named following the massacre of Jean Ribault’s French forces at the site (Deagan 1976). In 1569, a fortification consisting of a watchtower and sentry house was built on the site to guard the southern approach to St. Augustine from French and British forces. Several of these non-permanent (wood) defensive structures were constructed through time around the same location as Fort Matanzas structure (Paige 1978; Deagan 1976).

The stone fortification was erected between 1740 and 1742, built of coquina masonry and set on a foundation of pine timbers and oyster shells. The fort was comprised of an observation deck, an elevated gun deck, officer’s quarters, soldiers’ quarters, a water cistern, and a powder magazine (Service 2012). Although equipped to have six cannons, the fort only had only five at one time (National Park Service 1976).

The fort was abandoned in 1819, when Florida was ceded to the United States by Spain. By 1821, the fort was already in disrepair, with numerous cracks in the walls and foundations, and became the subject of curiosity with visitation by interested tourists evident from postcards, etchings and drawings of the time (Figure 2).
Fort Matanzas was largely forgotten after its military abandonment, certainly from a financial commitment perspective. According to the NRHP nomination form for 8SJ44, Fort Matanzas had split into three sections sometime during the 19th century (Figure 3). Almost a century later,
between 1916 and 1924, the War Department stabilized these fragmented sections. Also in 1924, the fort was accorded National Monument status, and additional restoration included the reconstruction of the sentry box, rebuilding of the gun deck parapet, and rebuilding of the lower walls (Arana 1986). The land on Rattlesnake Island surrounding the fort was also preserved as a bird sanctuary at this time. In 1933, Fort Matanzas was transferred to the National Park Service from the War Department, and in 1934, the Historic Americans Building Survey (HABS) conducted work at the site to acquire measured drawings (Figure 4). Between 1935 and 1940 the Works Progress Administration (WPA) completed restoration work on the fort and constructed the building now used as the visitor’s center (8SJ5404)(Figure 5). On October 15, 1966, the fort and its related archaeological site were listed on the National Register of Historic Places (NRHP) (National Park Service 1976).

Figure 1. Photograph taken in the early 1900s (above) and one taken in 1913, of Fort Matanzas showing significant cracking and poor condition (below). Images courtesy of the Florida Memory website (http://www.floridamemory.com).
Figure 4. HABS measured drawing from 1934, showing the west elevation of Fort Matanzas.
Understanding the Historic Appearance
Fort Matanzas has gone through several historic metamorphoses in architectural structure and restoration through time. Several wooden watchtower features were erected on Rattlesnake Island near the present-day fort, and the coquina stone fort we see today has been through a series of on-going maintenance, repairs, reconstructions, and restorations. It is important to understand the basic structural nomenclature for the components of the Matanzas construction in order to track the changes through time. These components are referenced in the historical literature and are used descriptively in drawings and depictions (Figure 6). Our analysis and comparison of the present condition at Fort Matanzas utilizes these component understandings for comparative history analysis for the structure.

Figure 5. Photograph of Fort Matanzas after restorations, taken in 1964. Image courtesy of the Florida Memory website (http://www.floridamemory.com).
In 1843, Lieutenant Henry W. Benham, United States Army Engineer, submitted a drawing of Fort Matanzas showing major deterioration of the structure. The tower had been split vertically by two large cracks and the southeastern angle of the platform had been under-mined by tides splitting it from the parapet to the foundations at the frontal and lateral walls. Further, a segment of wall, was projecting forward, and the body of the sentry box at the southwestern angle had disappeared, although the base remained. Benham drawings depict the building as it existed in the first Spanish period (Figure 7) (Arana 1986). While there were no funds available for repairs at the time of Benham’s drawings, minimal funds were allocated in the early 1900s to allow repairs to the réduit or tower and to provide oyster shell stabilization of the walls by 1924. In 1926, an attempt to reconstruct the sentry box was made, but the architectural element was not compatible with the look of the structure and it was taken down, rebuilt, and reinstalled in 1929 (Arana 1986:89). These areas represent the first major structural repairs at the site and the Benham drawings, early modeling, and historic photos of the site, provide legacy data that assists in the comparison with the as-built data collected by our present TLS survey work at the site.
Figure 7. 1843 elevations and plan view drawings of Fort Matanzas by Lt. H.W. Benham (National Park Service 1980:198).
In 1951, park historian Albert Manucy presented a model of the fortification that he based on research of the site. This model provided an historical representation of the fortification and offered an understanding for probable placements of architectural features (Figure 8). Historical photos and maps are another source of legacy data and can be used to understand changes in the structure and to the surrounding environmental landscape through time, including both natural and cultural transformative events such as reconstructions and repairs and shoreline erosion (Figures 8-15).

Figure 8. Manucy model of 1951 (National Park Service 1980:199).
Figure 9. Stereograph collection images from Bloomfield’s Guides, showing Fort Matanzas. Photos were taken between 1873 and 1890, prior to the 1929 reconstruction of the sentry box, and the 1934 HABS work (National Park Service 1980:203) (http://www.floridamemory.com).

Figure 10. Photo from post 1929 reconstruction showing the newly erected sentry box that was torn down again because it was not in fitting with the structure (http://www.floridamemory.com).
Figure 11. Reconstruction of the sentry box area noted in the HABS photo documentation. Historic American Buildings Survey Herbert Kahler, photographer, March 26, 1934. (http://memory.loc.gov/).
Figure 12. Shoreline erosion and stabilization efforts shown above (Historic American Buildings Survey, Herbert Kahler, photographer, March 26, 1934) (http://memory.loc.gov/), and below (AIST 2012).
Figure 13. Legacy data in the form of a topographical survey map from 1867, georeferenced and digitized into the GIS geodatabase for Fort Matanzas and used in the assessment of shoreline change.
Figure 14. Larger consideration for the historic landscape derived from legacy data from coastal topographic surveys and georeferenced and digitized as part of the current project GIS approach.
Figure 15. Coastal dynamics and shoreline changes through time in the vicinity of Fort Matanzas.
Methods
Techniques for documentation in the field that were selected for this project included terrestrial laser scanning (TLS) survey, Global Positioning System (GPS) survey, photogrammetric imaging of exterior of structure, standard photography, spherical imagery acquired with the TLS survey, pre-field reconnaissance review of aerial LiDAR and imagery, GPS photographs from target points and for feature attribute tagging, and gigapixel high resolution imagery. From these data, effective and communicative visualizations were achieved including 3D models and other graphic presentations that clearly document the results of our analyses. These visualizations are presented in the results section of this report and through available associated datasets and web platforms (videos, online demos, interpretive application examples, management application examples).

Several park and NPS cooperators assisted the fieldwork and planning/implementation on this project, including Dr. Margo Schwadron, Archeologist with the Southeast Archeological Center, NPS; Fort Matanzas Site Supervisor Andy Rich; NPS Park Ranger Jon Burpee, Chief of Interpretation and Education for Fort Matanzas and the Castillo de San Marcos; and Gordon Wilson, Superintendent of Fort Matanzas and the Castillo de San Marcos.

TLS Survey
Field survey was performed using a phase shift scanner (FARO Focus 3D). A total of five referenced targets were established along the south elevation of the building. Higher resolution settings (+20 meter, 4x and 5x resolution) were utilized to compensate for the bright sunlight present during the outside scans at the site. Additional considerations for the survey included non-interference with park visitation. This was accommodated by wait time between scan set ups and acquisition, timing scans between visitor arrival via boat to the site. A total of 26 scan locations, or set ups, were performed, covering the interior and exterior of the structure (Figure 16). Two elevated scans were taken to provide maximum coverage using an industrial mast system with the phase shift scanner (Figure 17).

Spherical imagery and photos were acquired with each of the scan positions utilizing the onboard camera system. These images were then utilized in the scan data processing to colorize and overlay the scan data collected. Additionally, external and higher resolution images were also acquired to be used for documentation and in the texture mapping of the scan data models produced from the TLS survey data.

TLS survey was completed in approximately eight hours, over two days (9/21/2012 and 9/22/2012) on site. The AIST crew was comprised of three members (Doering, Fernandez, and McLeod) who performed the TLS, GPS and photographic survey aspects concurrently.
Figure 16. Scan set up locations (n=26) with viewshed projection tool showing areas captured in scan view for the registered project. The viewer in the figure is part of the online platform called Webshare®.

Figure 17. A mast tripod system allowed for elevated scan data capture at the site. Shown is the Blue Sky Mast with FARO Focus3D and established reference targeting at Fort Matanzas.
Photography
Documentary photo record of all levels, elevations, and portions of the interior and exterior of the fort were taken over the course of the two field days. Photographs were both tripod and non-tripod based, with some taken using photogrammetric practices for software matching (targeting). Spherical images were acquired simultaneous with the TLS survey, using the onboard camera with the scanner instrumentation (Figure 18).

GPS images were acquired using a Ricoh G700SE camera equipped with a GPS receiver. GPS photos were taken of Fort Matanzas from multiple positions and angles and at select photo points on the exterior and interior of the structure (Figure 19), as well as to document attribute data such as interpretive signage, viewsheds/points of viewing, and select features (e.g. cannons, stairs, and points of entrance)(Figure 20).

Gigapixel or high resolution imaging was performed at locations to provide site level detail and panoramic overview. Additionally, standard videography was undertaken with park story interpretation and description, and to provide a sense of virtual walk-through for the site.

Figure 18. Spherical images acquired during the TLS survey can be used in web platforms to show the fort in full panoramic detail, with selections made by view area and with imbedded associated documents, such as videos, images, maps and historic legacy data linked to spatial locations.
Figure 19. Example of surface detail showing Masonic symbols carved on rear wall elevation at Fort Matanzas. Photo shows GPS location information and associated metadata.
Figure 20. Example of GPS camera used for viewshed capture at Fort Matanzas.
**GPS Survey**

GPS data was collected with mapping grade and carrier phase (sub-meter and sub-decimeter and centimeter level) equipment. Points, areas, and linear data reflect areas surveyed, used for control or to establish reference points for monitoring, and areas of interest such as features, architecture, signage, and other aspects relating to the site and project scope. All data were post-processed and corrected, and are included in the site geodatabase materials provided as part of this effort. GPS data collected was utilized in concert with the spatial information obtained from the TLS survey to create GIS site plan view maps (Figures 21 and 22).

**Results**

All datasets were brought together to create a 3D and digital terrain model for the Fort Matanzas structure and surrounding environs. Understanding of the terrain is an important aspect to the project, as storm surge remains a threat to the erosion of the site. Aerial LiDAR and terrestrial LiDAR were integrated to provide managers with detailed topographic elevation information.

TLS data were utilized to create 3D visualizations and models of the fort structure (see: [http://youtu.be/N3PEdCJ-0tE](http://youtu.be/N3PEdCJ-0tE)). These models are in the form of a project point cloud (a dense set of data points within a defined coordinate system), surface models and polygonal meshes, and final fully-rendered models with high resolution image texture mapping and modeling (Figures 23-24). Figure 25 illustrates a major feature of three-dimensional data. In this example, a vertical slice of the data has allowed the rear wall of the structure to be removed to visualize a cross-section of the fort. From this view, precise measurements can be made and the actual morphology of the walls can be observed and analyzed. Traditional methods of recording cannot produce this information at this level of accuracy. Feature extractions were also performed with the scan data, so that areas of interest such as the fireplace feature could be analyzed in detail (Figure 26). The TLS data also provided highly accurate metrology information to create CAD and tomographic slice-through views of the structure (Figures 27 and 28).

Important features for management and monitoring purposes are that surface elevation and reflectivity data are acquired during the laser scanning process. Surface elevation data can be processed to allow for the detection of changes in surface morphology and examination of areas of deterioration. Differences or changes in reflected values can be analyzed to identify potential areas of concern and their causes. For example, reflective differences can show variation of mortar textures such as lime-based mortar as opposed to Portland cement, and can be used for monitoring conservation treatments and planning restoration activities (Figure 29).

The methods selected and developed for the presentation and visualization of the data permit their use and implementation by a greater number and variety of users for broader and more democratic applications. The geospatial data (e.g., TLS, Aerial LiDAR, georeferenced legacy maps
Figure 21. Site Plan of Fort Matanzas derived from the current terrestrial laser scan and GPS survey.
Figure 22. Planview CAD rendering of Fort Matanzas derived from the TLS and GPS survey.
Figure 23. TLS data from the survey was used in creating 3D surface models (left, shown in blue) and colorized point cloud representations (right).
Figure 24. Initial TLS models were further processed and combined with high resolution images to create finalized renderings.
Figure 25. Interior renderings were made using the TLS data and images to create virtual models (note that back wall is virtually ‘sliced’ open to reveal the interior.)
Figure 26. Feature detail of the fireplace collected during the TLS survey. A photo of the feature with interpretive materials present (top, left) and TLS colorized data with materials extracted to allow for detailed interior modeling from data (top, right). The two middle images show details of scan data without photo texturing. The model image below illustrates the ability to measure and slice data to reveal interiors, and to photo texture and model final visualizations of these data.
Figure 27. Example of CAD rendering derived from the TLS survey data in the current survey.

Figure 28. Tomographic (sectional) slice taken through the center of the fort TLS data, showing wall and floor line features.
Figure 29. Area along west elevation of tower with different mortar reflection signatures evident (above left), suggesting a difference in mortar type from surrounding features (above right). The same area is extracted from the scan data (below) and compared to present-day photo of the wall. The area corresponds to courses of face stones that cover tie rods and plates. This area is being dislodged due to face stone and plate exfoliation (NPS 1980:222). Examination of reflectivity and surface elevation can be a tool used by managers and conservation specialists to inspect integrity of fabric and rock surficial areas and to readily identify areas of different mortar characteristics and to assess degrees of exfoliation and change.
and aerials, archival narrative and images, GPS data, previously recorded cultural site location data, GPS camera locations, and relevant shapefile data and layers) were brought together in both a GIS geodatabase platform and in a virtual globe environment (Google Earth) platform. The Google Earth database for Fort Matanzas contains a digital elevation model derived from aerial LiDAR, links to photographs and GPS location images, videos of 3D models, and Webshare® links to the archived laser scan project presentation (Figure 30).

**Future Research and Considerations**

Many of the same problems elucidated in the 1980 NPS Historic Structure Report (National Park Service 1980), remain vital concerns at the site today. Issues, such as the natural dynamics of the site, storm-induced wave action, coquina fabric and surface deterioration, inappropriate repairs, and impacts from visitation, are all still of relevance and impact to site preservation and management.

Geospatial documentation techniques such as terrestrial laser scanning and GPS survey, advanced photographic and 3D modeling techniques, and remote sensing techniques, such as aerial LiDAR and imagery analysis using Geographic Information Systems processing are powerful tools for site assessment and consideration. These new techniques demonstrated at Fort Matanzas National Monument allow for a clearer presentation and understanding of the conditional aspects and spatial features. Documentation at this level of standard allows for a variety of analytic and conservation strategies to emerge from the project, with the added value that the data is also highly useful for interpretive and tourism site development aspects.

In addition to this report, deliverables as part of this project entail a GIS geodatabase for these locations, visualization models using the 3D data, and a hosted demonstration website developed as a prototype to show usefulness for the 3D data capture for on-going management and preservation projects. The web server allows for the 3D data to be shared and viewed without the need for specialized software, and provides capabilities such as document linkages with spatial locations, and on-the-fly measurement and dimensional understanding. Google Earth and 3D animation videos were also rendered to provide a range of end product examples to assist managers in understanding the kinds and types of derivative data that can emerge from TLS survey work in our National Parks.
Figure 30. The Google Earth customized KMZ database file for the Fort Matanzas project, showing digital terrain applications (above) and associated file types and locations (below).
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