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3D SCANNING FOR STRUCTURAL MONITORING OF HISTORIC CALIFORNIA ADOBE STRUCTURES

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Abstract

At the University of San Francisco Architecture & Community Design Program, the Architectural Engineering curriculum utilizes a Leica ScanStation C10 3D Laser Scanner to document historic structures and monitor their structural behavior. Some of the oldest structures in the State of California are the historic adobe missions built by Native Americans and Spanish Catholic missionaries between 1769 and 1833. California is a region of very high seismic activity, and the adobe structures have withstood significant earthquakes over their lifetime. However, they are sensitive structures in need of active preservation and very few original adobe buildings remain. Working together with local structural engineers who specialize in seismic restoration of historic adobe structures, USF students have scanned Mission Santa Cruz and Mission San Miguel Arcángel, creating extensive 3D point cloud records, and developing architectural drawings which establish the current state of these structures.

Completed in 1821, Mission San Miguel Arcángel suffered significant damage in the nearby 2003 San Simeon earthquake. The original adobe structure has undergone partial repairs such as banding at the top of the walls of the Sacristy. Using the 3D laser scanner, thorough scans are stitched together to create full interior and exterior 3D point cloud files, which are processed in Leica Cyclone and then imported into AutoCAD to create detailed line drawings of plans, elevations and sections of significant areas. Wall lean and other indicators of crack progress and deterioration are areas of special focus. With these records, a structural monitoring program has begun to document the condition of the buildings in wet seasons and dry seasons, and to determine the long-term effect of seismic restorations which have been implemented. This paper presents a detailed account of the process, pedagogical value and structural and architectural lessons learned over the course of the 3D scanning of these valuable heritage landmarks.

Keywords: 3D laser scanning; adobe; seismic; engineering education; California missions

1. Introduction

Twenty-one missions and religious outposts line the modern California coast, established between 1769 and 1833 by Catholic Franciscan priests in order to spread Christianity among Indigenous Peoples [1].

Fig. 1 – Map of California Missions numbered in order of founding [1].

The missions were largely built in Spanish style, designed and directed by the Franciscans and primarily built and maintained by local Native American communities using materials locally available to each site, usually resulting in adobe block structures adapted to local limitations, with varying construction techniques and climate protection.

Fig. 2 and 3– Destruction of Mission Santa Clara by fire in 1926, current mission is sixth iteration [1]

Unreinforced adobe construction is now well understood to perform poorly in earthquakes due to its heavy, non-ductile nature. Over time and especially in the 20th century, many mission structures have undergone retrofits and restorations to counteract damage due to seismic and other dynamic forces as well as erosion, catastrophic fires and changes of use. Still others have remained in states of slow decay with increasing need for restoration.

This paper details the process and early results of the use of 3D laser scanning to accurately document the structural condition of a number of California historic missions – in particular Mission San Miguel Arcángel, located in the Central Coast region (#16 on the map of Fig.1). Because of the complex and delicate conditions of these aging hand-made buildings, the laser scanner is the most appropriate non-destructive means of documenting these special structures. Undergraduate students in the Architectural Engineering program at the University of San Francisco are fortunate to have access to a state-of-the-art Leica ScanStation C10 3D laser scanner, and have participated in the collection and processing of data toward structural monitoring efforts. The data also has architectural and cultural-historic value for local populations of the Chumash and Salinan tribal people, leading to a rich community engagement opportunity.

2. Mission San Miguel Arcángel

2.1 Background

Fig. 4 – Historically depicted painting of Mission San Miguel by Edwin Deakin, c.1898 [2]

Mission San Miguel Arcángel was founded on July 25, 1797 by Father Fermín Francisco de Lasuén, partially to serve as a way-point between the already established missions of San Antonio to the north and San Luis Obispo to the south, which were otherwise more than a day’s travel apart. After a fire in 1806 consumed a temporary church building, a second period of construction ensued in which Spanish soldiers and then local indigenous Salinan people are recorded as participating in construction [3]. By 1810 there was a significant increase in employment of the Native Americans for the production of building materials, such as adobe block and roof tiles, while their original work of textile-making became obsolete. Ultimately, the Natives became the main driving force in overall construction due to the need for new living quarters and sectors with only a small numbers of priests and soldiers available to keep up with the construction work. A massive stone foundation was laid in 1816, and adobe blocks had already been prepared by Natives by this time. Obtaining large redwood logs for the roof beams was difficult as they needed to be felled and transported from the Santa Lucia Mountains at least 40 miles (65 km) away. Once roofing began, a common practice of using cowhide leather straps to secure the rafters to the beams was utilized (Fig. 5), due to the scarcity of metal hardware. The adobe church was finally completed in 1818 with a lime plaster exterior finish, and the intricate interior paintings still visible today (Fig. 6) are the only original such paintings remaining among the California missions, hand-painted by Salinan community members in 1820-21 with the direction of the artist, rancher and Spanish diplomat Estéban Carlos Munras of Monterey [4].


Fig. 5 (left) – Leather lashing of beams with reed sheathing under eave, photo by author
Fig. 6 (right) – Interior painting, photo by author

"Indian housing" originally built to house neophytes appears in this 1859 survey drawing (Fig. 7) but has since been separated from the overall site due to the construction of North-South train tracks, leaving essentially the main quadrangle of church and monastery wings forming a courtyard, with the cemetery on the north side. The Sacristy in the northwest corner of the church was part of the original construction, but is vulnerable to seismic forces due to its discontinuity from the main church structure. Its thinner walls and abrupt configuration are visible in the floor plans (Fig. 8 and 9).

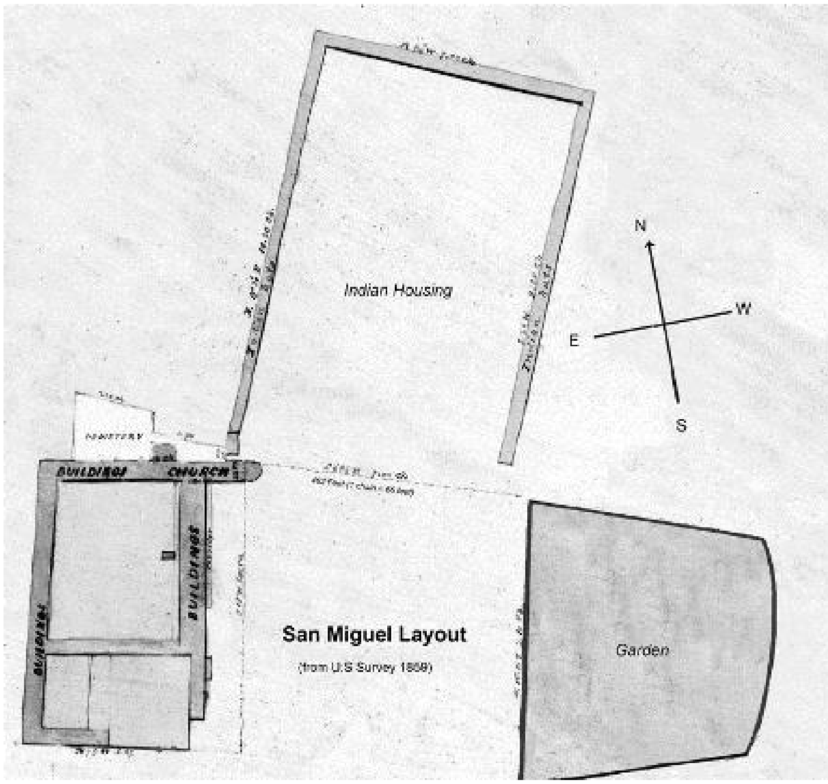
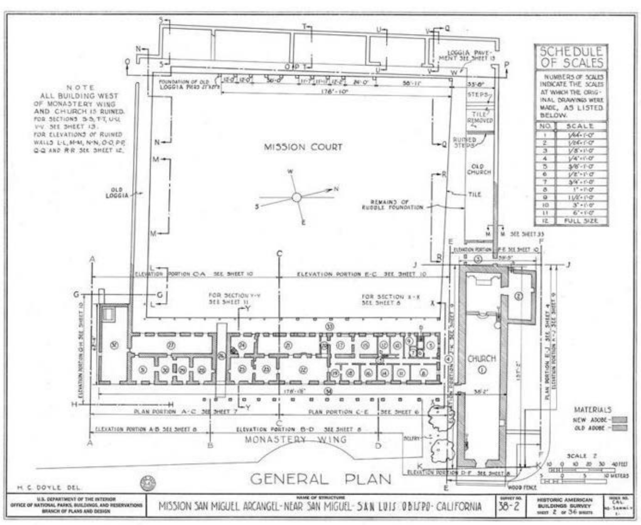


Fig. 7 – Site plan of Mission San Miguel complex as of 1859 United States survey [1]



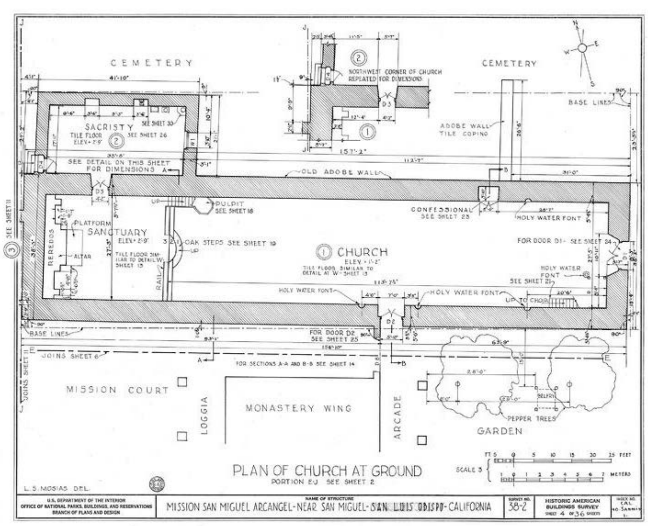


Fig. 8 (left) - Overall building plan of mission, Historic American Buildings Survey, 1937.
Note that North is to the right in this drawing.

Fig. 9 (right) – Main floor plan of Church with Sacristy in northwest corner,
Historic American Buildings Survey, 1937.

In its current form, still represented fairly accurately by Figures 8 and 9 above, the Mission is a very community-oriented, active church, hosting many events and celebrations per week in addition to multiple masses conducted in both Spanish and English. The strong motivation for any monitoring or retrofit activity associated with this church is to keep it open and safe for its congregation.

2.2 San Simeon Earthquake of 2003

A magnitude 6.5 seismic event was recorded on 22 December 2003 with an epicenter located 36 miles (59 km) west of Mission San Miguel, in the Santa Lucia Mountains most likely on the Oceanic Fault Zone. In addition to extensive damage and building collapse reported throughout the region, the effect on the various buildings in the Mission San Miguel complex was quite severe, with large cracks developing in the church façade as well as other walls. Damage included structural cracking in the unreinforced adobe walls, spalling of large areas of wall and ceiling plaster from substrates and rotation of adobe walls out of plane. Shoring at the north wall of the sacristy, at the windows and doors of the church, and at the east arcade was installed as a temporary measure [5]. Diagonal cracking is clearly visible here, characteristic of unreinforced masonry failure due to significant lateral loads.

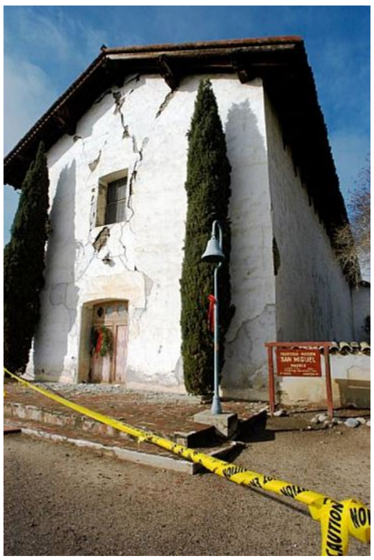



Fig. 9 (left) – Cracks in façade immediately following 2003 San Simeon earthquake [1]
Fig. 10 (right) – View of main church during restoration, cracks repaired and plaster reapplied [1]

This damage resulted in the closure of the entire complex which was incrementally restored until fundraising and repairs made possible a rededication ceremony on the Feast Day of St. Michael the Archangel, 29 September 2009.

2.3 Restoration and Seismic Retrofit

Shortly after the earthquake and closure of the mission complex, structural engineers Dr. Frederick Webster and Nels Roselund were called upon to conduct an assessment of the mission buildings, especially the north wall of the Sacristy which had rotated out-of-plane due to the ground motion, perhaps already begun due to settlement before the earthquake. They noted cracks (Fig. 11) which were forming in the east wall as well, which seemed to accompany the outward leaning of the north wall. Dated horizontal and vertical lines drawn across cracks make visible any displacements in either direction over time. With these observations, they designed and implemented a bond beam retrofit to prevent further rotation of the north wall.


Fig. 11 (left) – Displacement markings on east Sacristy wall, photo by author
Fig. 12 (right) – Overall view of retrofitted Sacristy looking west, photo by author

According to Mr. Roselund [6], the bond beams at the tops of each of the three walls consists of two interventions: A) For shear diaphragm to the wall: two layers of 3/4" (1.9 cm) x 8-ft (2.4 m) plywood panels lap-spliced in ½" (1.27 cm) half panel lengths, and B) For flexure: a bond beam chord on each side of the wall - on the exterior, a continuous stainless steel strap, with bolted continuity joints, including around corners, and a continuous wood ledger on the interior. The bond beam is connected to the top of the wall with epoxied shear bolts plus periodic anchors that extend deeply into the wall to develop shear friction between the upper adobe courses. This work has been beautifully finished with new plaster and stucco, rendering it invisible from either inside or outside the Sacristy.

When Dr. Webster learned that I was looking for practical and educational opportunities to use our new laser scanner, he suggested that a monitoring program for Mission San Miguel would be ideal. Since the installation of this retrofit, there have been a number of relatively dry, drought years and crack propagation has been somewhat minimal. However, it has been qualitatively observed that significant rainfall can cause the walls to absorb water and expand, exacerbating the wall lean and cracking [6]. It was decided to start this program in order to determine the efficacy of the recent retrofit efforts, and identify future areas of work. Our first scanning trip was conducted in October of 2015, just before a particularly rainy "El Niño" season began.

3. 3D Laser Scanning and Structural Monitoring

Lidar (light+radar) is a technology in which laser light is directed on to a target surface, and the exact distance to that surface is calculated knowing the speed of light and measuring the time it takes for that light to be reflected and return to the laser. That reflection point is recorded as a point in space, and as the laser light sweeps through a radial pattern in all directions, a three-dimensional point cloud is created. Conducting scans from multiple locations around a site allows the operator to collect enough information about the surfaces to create complete 3D models or drawings. This tool has been used with very favorable results to document an increasing number of complex or historic structures such as dams and notable buildings, especially in conjunction with Ground-Penetrating Radar as well [7]. USF's Leica ScanStation C10 laser scanner (Fig. 13) is a robust instrument with the capacity to record points up to a 2mm resolution at a distance of 200m. While this may not be fine enough to capture the thinnest crack lines, because of the scale and complexity of the mission sites as well as the very irregular and delicate nature of the building surfaces, laser scanning is significantly more preferable and appropriate for this task compared to documenting such structures by hand with tape measures and photography.

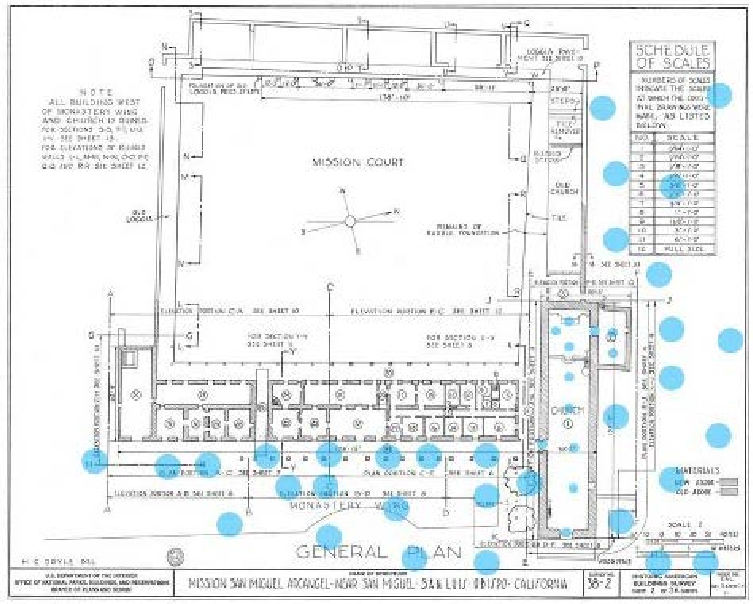


Fig. 13 (left) – USF's Leica ScanStation C10 laser scanner, photo by author
Fig. 14 (right) – "Scan plan" record of scanning locations throughout site.

For a typical scanning assignment, the team prepares in advance by using drawings, photos and other prior knowledge of the site in order to create a "scan plan" (Fig. 14). This can include marking up a site or floor plan with desired scanning stations approximately located, or obtaining access into spaces such as nearby building rooftops in order to conduct scans from a variety of vantage points. Once on site, we have learned two distinct procedures to follow – one which utilizes visual targets placed around the site for the purpose of registering (combining) individual scans later in the computer lab, and one which utilizes geo-located control points set beforehand by a survey engineer throughout the site, so that every scan can be "told" where it is in relation to the other scans, minimizing the time to register scans to each other later. For the Mission San Miguel project, we were met at the site by a volunteer team from O'Dell Engineering of Modesto, CA, surveyors who would set control points on our behalf in order to follow the second procedure described above.

The control points method is significantly slower in the field than the target registration method due to the necessity of exactly locating and leveling the scanner on each pre-determined point, but we were able to conduct nearly 50 scans over one weekend, focused on the main church building with Sacristy, colonnade and exterior of the Monastery Wing. Back in the lab these scans are opened up using Leica proprietary software Cyclone in order to register scans together, and prepare for import into Autodesk drawing software such as Revit and AutoCAD. The point clouds are then oriented to desired views in order to be traced in AutoCAD – plans, elevations, and building sections.

In the example of the north wall of the Sacristy of Mission San Miguel, Fig. 15 and 16 below illustrate the point cloud and ensuing detail drawing of a specific area of interest. Since it is a 3D model, all future records can be compared to this model in order to study propagation of major cracking or any increase in wall rotation. Even swelling in wall thickness due to moisture absorption can be observed in the combination of interior and exterior scans into a cohesive 3D model.

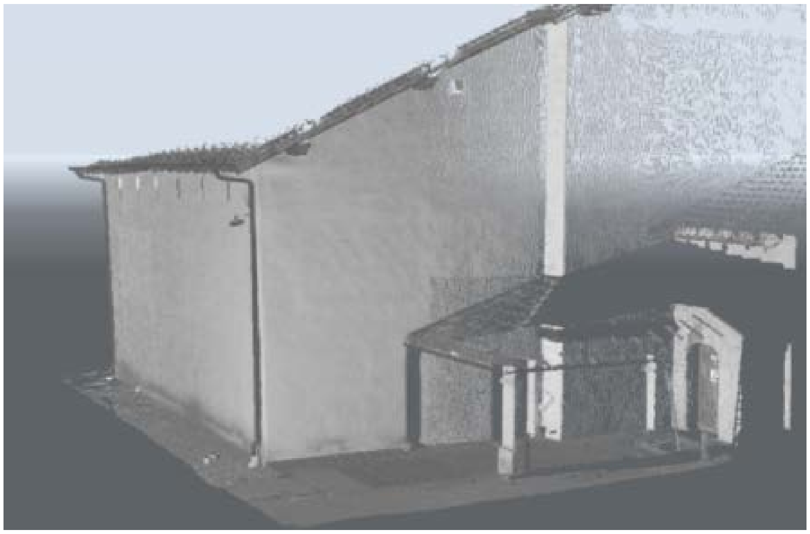


Fig. 15 – Point cloud of Sacristy exterior east and north walls, as viewed in Autodesk Recap.

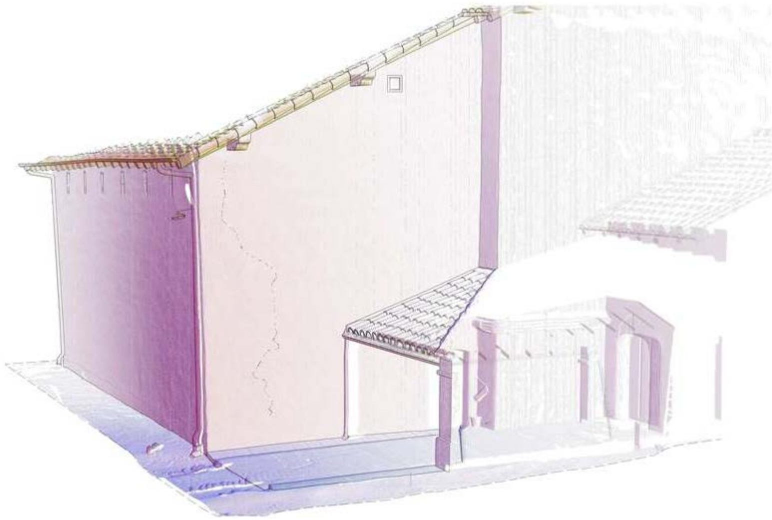


Fig. 16 – 2D line drawing overlaid on point cloud in AutoCAD.

Fig. 17 – Photograph of same area.

4. Conclusions and Plans

It is clear that the use of the 3D laser scanner is a powerful and efficient way to exactly monitor the changing condition of delicate structures such as the California missions. The October 2015 scanning exercise was the beginning of our monitoring project, thereby establishing baseline data to which future scans can be compared. The next planned trip will be in late spring of 2016, at the end of a particularly wet rainy season. We hope to continue every fall and spring to establish the building's behavior over time and in reaction to moisture levels, and work with structural engineers who may develop future retrofit projects. We are identifying a great number of possible beneficiaries for this scanner data and end-products – the most obvious may be the mission itself, to them we offer a detailed record of the current condition of the buildings for the sake of historic preservation, likely in the form of line drawings. Organizations such as CyArk in Oakland CA are devoted to collecting and storing point cloud data for heritage sites all around the world, and our partial data has already been delivered to them. We will continue to add to this collection with each return visit. Additional possible beneficiaries are the local Chumash and Salinan tribal communities, for whom this mission represents a significant part of their own history. We have begun communications with members of the tribal organizations in order to determine what records or products would be most useful to them, toward end-products such as interactive or representational models of the mission for education about their history.

The undergraduate architecture students who have worked on this and other laser scanning projects have had a truly unique opportunity in several ways. First of all, they have gained a perspective on analyzing their built environment which is not commonly presented in architecture education – much of graphic communication associated with architecture focuses on views of the site and structure which are never physically possible – completely flat views of one whole façade, for example. Use of the scanner enables students to avoid this artificial step and instead record the structure more intuitively, in the way it is more directly experienced by occupants, viewer-centered from location to location.

Second, the study of historic buildings provides the opportunity to consider how stories are embedded in construction details – one can see the mark of the hands that plastered, the legs over which tiles were formed, inventiveness in adjustments made because of resource limitations, indigenous building techniques incorporated that were learned by the Franciscans from the local population, and so on. A more conservative or biased historian can make such observations and then decide to omit or subdue them, but documenting by use of a laser scanner mandates that all details are reported without bias. A more complete picture can be told.

Finally, while the scanner itself is a relatively simple tool which merely calculates distances very quickly, its power makes complex projects much more accessible to students. Undergraduate students having had experience with 3D laser scanning are still very rare in our field. Most of the local firms our recent graduates and current interns have interacted with are surprised to hear they have had this kind of exposure, and it makes them unique among their peers. Becoming at ease with this high-tech equipment boosts their confidence and prepares them to be resourceful, thoughtful practitioners who can look quickly beyond technical logistics to the bigger picture.

5. Acknowledgements

Heartfelt thanks to structural engineer Fred Webster, Ph.D. for his decades of mentorship and proposing the Mission San Miguel monitoring project as an educational exercise; Thomas Lucas, S.J. for obtaining the laser scanner on behalf of the USF Dept. of Art + Architecture; structural engineer Nels Roselund for his assistance to understand the structural retrofits after Dr. Webster's passing; surveyors Landon Blake, Blake DeLuca, Adam Sandoval and Julian Padilla of O'Dell Engineering; Resident Father Max Hottle and Reverend Pedro Umaña for their gracious hospitality during our scanning visits; students Jeffrey Wang and Drew Wilson for assistance with scanning, and Makenna Murray of the CyArk organization for coordinating access and logistics.

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