Informing Historical Preservation with the Use of Non-destructive Diagnostic Techniques: A Case Study at Ecab, Quintana Roo, Mexico

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Abstract. This paper presents work performed at the northeastern tip of the Yucatan peninsula aiming to assist in the preservation planning for the 16th century church at Ecab. The main goal of the presented work was to accurately document the existing site using non-destructive methodologies in order to perform visual and structural diagnostics off-site. The non-destructive methods used in the two day documentation of the church were 3D laser scanning, stereo panoramas, high-resolution imagery, aerial photography and thermal imaging. Documenting the current state of health is extremely important, and the data acquired can also inform plans for protection and preservation of cultural patrimony. The scope of this project was aimed towards the structural diagnosis and preservation of a historical monument, but the implications of combining all of these diagnostic methodologies reach much farther into the realm of historical, archaeological and anthropological analyses.

Keywords: cultural heritage, preservation, non-destructive evaluation, e-documentation.

1 Introduction

The main goal of the presented case study was to accurately document the early colonial church at Ecab using non-destructive methodologies in order to perform visual and structural diagnostics off-site, therefore eliminating the need for the long journey to the site. This work was done in collaboration with Mexico's National Institute of Anthropology and History (INAH) which was working to develop a conservation plan for the site.

The church is situated on a costal rise, where it has long been vulnerable to hurricanes and powerful seasonal winds. It is amazing that the site has fared as well as it has over hundreds of years. Along with the church on this coastal rise is the curate's house referred to as Casa Cural, where the caretaker of the church stayed. The church is adorned with merlons and a bell screen, or espadaña, and is composed of four

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components: the presbytery where the altar is located, sacristy, baptistery, and the long nave that extends from the main structure of the church, which used to be covered by a thatched roof, but has since decayed. Casa Cural is situated northwest of the church and is a small building that consists of six rooms [1]. Casa Cural has not withstood time as well as the church and is need of reinforcement to prevent the structure's collapse.

The critical issues observed upon initial walks around the structures were the encroachment of vegetation into the masonry structures and damage due to long-term effects of rain water. There were trees growing from the roof of the structures which produced roots that wove through and penetrated walls and barrel vaults. Accurate documentation and assessment of these issues is required in order to develop a comprehensive preservation plan.

The methods used in the two day documentation of the church were 3D laser scanning, spherical stereo panoramas, high resolution imagery, aerial photography and thermal imaging. Incorporating all of the presented non-destructive field methodologies to document an entire site with limited time and resources is a challenging and noteworthy accomplishment that contributes towards a better understanding of the historic structures.

1.1 History

The churches and chapels first established by Spanish friars on the Yucatan Peninsula bore witness to the earliest of interactions between European and Maya cultures. Needless to say, this deliberate intrusion into Maya society had profound and lasting effects, and these places of worship still stand as physical and symbolic reminders of this period of remarkable struggle and transformation. Indeed, the unique form of syncretism that characterizes Maya religious practice today has its roots in colonial institutions and ideology. Centers of early Spanish authority across the Yucatan offer the archaeologist an opportunity to explore the material evidence of Maya adaptation and resistance in the colonial context.

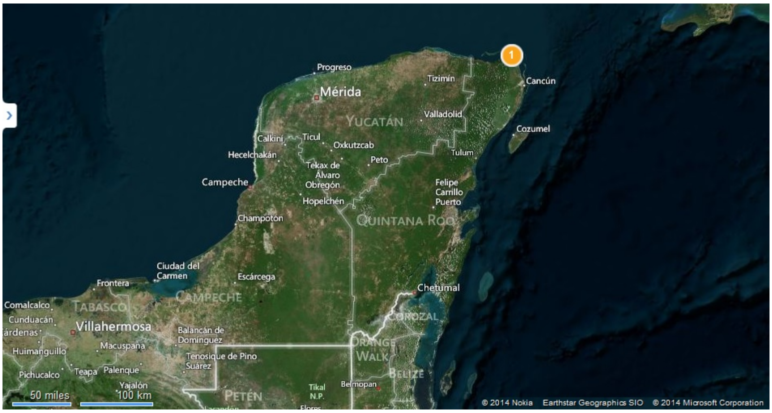

Fig. 1. Map depicting location of the church at Ecab [2]

In 1517, conquistador Francisco Hernández de Córdoba came ashore on the Yucatan Peninsula and gazed upon the first Maya community to be encountered by the Spanish. He called it “Gran Cairo.” This is the ancient site of Ecab, which was later partially razed to build what is thought to be the first church in Mexico. The site is also known as Boca Iglesias, and is located south of Cabo Catoche in northeastern-most Quintana Roo as shown in Figure 1.

Ecab became of one of the more remote encomiendas (or centers of tributary labor) in colonial Mexico and was the site of a number of interesting historical events in the region, including the attack by the French pirate Pierre Sanfroy in 1571. Abandoned in 1644, the church and the curate's house, Casa Cural, lie half-ruined today in a remote and completely empty corner of the Yucatan Peninsula and can only be reached by boat. The ruins have managed to survive centuries of hurricanes, but are fast approaching a more precarious state of decay. (For detailed descriptions of the site and discussions of it storied past, see [1], [3]).

2 Field Methodologies

The team who participated in this field expedition are affiliated with the Center of Interdisciplinary Science for Art, Architecture and Archaeology (CISA3) and brought a range of non-destructive technologies with the goal of applying these techniques to gain a better understanding of the church's state of health. Since 2007, CISA3 has been using cutting edge technology and research efforts in order to develop cultural heritage diagnostic techniques that can be applied to a broad range of historical structures and artifacts. The data acquired with the diagnostic tools combined with CISA3's immersive visualization environments create a unique opportunity for collaborative analysis of the layers of data. The field methodologies used in the two day field expedition at Ecab were 3D laser scanning along with aerial, ground based, stereo, and thermal imaging techniques. Deploying these methodologies in the field is rarely done because it requires trained personnel and involves risk of damaging expensive equipment when confronting humidity, water, dust, tripods on uneven terrain and all of the other scenarios that are inherent when working in uncontrolled environments. Due to the remote location of the site and the limited time available, all of these techniques were utilized simultaneously which required a significant amount of coordination between all of the equipment operators. If operators cross each other’s paths it can lead to adulterated data. The operators of the different equipment did not solely specialize in their own equipment, but also understood the requirements for all of the other field methodologies which allowed for the acquisition of clean and useful data of an entire site in just two short days.

2.1 Terrestrial Laser Scanning

The most important tool in preservation of buildings is an accurate model of the existing structure, and 3D laser scanning serves as an extremely accurate technique that can be used on site and processed elsewhere. Laser scanning is a line-of-sight technology that reflects a distance laser off of a rotating mirror to capture distance measurements at a specified resolution that can be on the order of one millimeter between measurement points. Line-of-sight scanners are limited because they can only acquire data from surfaces that are visible from the scanner's position. Terrestrial laser scanning has been used for digital documentation of similar cultural heritage sites in Mexico and at other sites all over the world [4], [5], [6], [7]. As well as providing an accurate three-dimensional model of the space, the laser scanning point cloud serves as the geometric scaffold for the other types of data that are acquired. High-resolution and even thermal images can be layered onto this scaffold in order to provide additional information to the professionals that are to analyze the data. The data acquired from these methodologies should not simply serve as visual aids, but should be used to their fullest extent for collaborative analysis among a multidisciplinary team. For sites that at risk, laser scanning records can facilitate accurate reconstruction if the structures were to collapse.

On this two day expedition a FARO Focus 3D scanner was used because of its small size and portability. The size and complexity of the church and its surrounding features required twenty-two scan positions in order to obtain data from enough angles to yield a complete model of the space. Spherical markers were placed throughout the site to serve as targets to be used in the co-registration of the many scans in the post-processing stages. Two days of scanning yielded twenty-two scans of the church and seven scans of Casa Cural totaling 800 million points.

The lower third of the exterior walls of the church and Casa Cural have suffered a significant loss of mortar between stones due most likely to erosion and vegetation intrusion. The site has endured many hurricanes since its establishment which have accelerated the effects of water on the masonry structure. It is concerning to observe loss of structural material in the lower portions of the wall that serve as support for the rest of the structure above, so one of the conservation actions would likely be the structural reinforcement of the lower walls and foundation. Other than environmental damages, the church has unfortunately also experienced acts of looting and vandalism. It can be observed that some sort of altar piece that was fixed to the wall has been ripped out and now loose stones are all that remain.

Using the data acquired with the laser scanner, the damaged areas can be measured in order to obtain quantitative measures of the damage as well as the qualitative determinations that can be performed using imagery. These quantities can be utilized to aid in estimates for repair material costs and to serve as building records that can be analyzed over time to see if damage is progressing. An example of the data utilization, shown in Figure 2, displays the vandalized area of the altar. A scaled grid is shown to demonstrate how the damaged area can be measured to quantify the amount of masonry was damaged and what size stones would be required to repair the area.

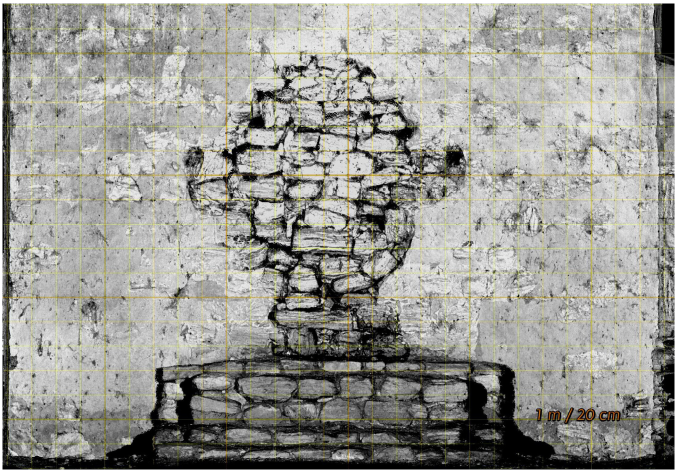

Fig. 2. Orthogonal image from the grayscale laser scanning point cloud outlining the vandalism of the church's altar

2.2 Remote Airborne Imaging

One of the fastest emerging technologies right now is remote imaging platforms including aerial drones. Our team brought its own fleet of remote control, multi-rotor drones that have been designed for airborne imaging applications. A pilot stands on the ground controlling the drone and monitors the battery levels, altitude, orientation, etc. while simultaneously capturing images of a target below. As mentioned earlier, lightweight imaging drones are not often deployed to the field because the level of expertise required and the treacherous flying environment, such as dense vegetation and water. Aerial imagery obtained from satellites can be low quality and not helpful for detailed applications while renting aircrafts that can capture the desired image quality is very expensive, so small remote imaging drones are an extremely attractive option. Images taken from the sky provide context of the site and generate viewpoints that would not otherwise be available.

For this application, a high-resolution, Sony QX100, camera was attached to a small quadcopter and flown over the site to capture images. As shown in Figure 3, the images give an amazing perspective of the structures and their surroundings with a high level of detail. During the post-processing workflow, these aerial images can be processed using structure from motion (SFM) techniques to generate a 3D model [8]. SFM is a process used to triangulate features in three-dimensional space from two-dimensional images. With enough images, these triangulated features become a point cloud of the target. The aerial SFM model can be scaled appropriately using correspondence with the terrestrial laser scanning data. Combining the scaled SFM point cloud with the point cloud generated from the laser scans produces a model that represents the historical structure at millimeter resolution as well as the surrounding site which provides three-dimensional context of the structure in relation to the site as a whole.

Fig. 3. Image Captured from airborne imaging drone showing the Church at Ecab (Right) and Casa Cural (Left)

2.3 High-Resolution Imaging

A stereo photography rig referred to as the CAVEcam was also employed at Boca Iglesia to capture spherical panoramas specifically calibrated for immersive virtual reality systems (referred to as CAVEs). The CAVEcam rig is composed of a two Panasonic LUMIX GF-1 cameras mounted on a GigaPan EPIC Pro Robotic Controller which automates photo capture and panorama configuration. The compact size of the LUMIX cameras permits side-by-side mounting with an interocular distance of 70mm that mimics binocular vision and minimizes distortion caused by camera offset, or the distance between the zero parallax points of the cameras to the center of rotation. The custom Ainsworth CC-2 Dual-Camera controller serves as the interface between the GigaPan and cameras, using the GigaPan signal output to trigger synchronous image capture in the cameras. The CAVEcam typically captures six rows of twelve images per panorama, producing seventy-two images per eye with a 360x180 degree field of view and a stereo panorama of approximately 1.8 gigapixels [9]. The CAVEcam panoramas are shot entirely in manual mode with a single, panorama-wide exposure due to stitching requirements. In environments with even and adequate exposure, CAVEcam acquisition can be finished in less than 5 minutes, with approximately ten minutes of system set-up. In areas with more complex lighting, the use of light panels or panorama bracketing for HDR have proven to be successful but may extend set-up and/or capture time.

Eighteen CAVEcam panoramas were captured at Ecab during the two days onsite. CAVEcams were taken in the rooms of the church and Casa Cural as well as around the perimeter of the buildings to archive the state of preservation and record architectural and artistic details that may not be adequately captured through other multispectral techniques. Panoramas were also taken from the roof and bell tower of the church as well as the roof of the Casa Cural in order to contextualize the structures within the landscape and record the lines of sight from these locations. Point clouds generated by laser scanning and SFM oftentimes do not render the same color depth or texture as high resolution photography. The CAVEcam supplements these tools by producing more realistic detailed texture information that is ideal for analysis, immersive visualization, and phenomenological reconstruction (at a resolution higher than 20/20 vision). Projecting stereo panoramas in immersive virtual reality environments enables collaborative analytics of artwork, architecture, and structural integrity without time or travel constraints and permits digital tourism by making sites available and accessible to individuals who otherwise may never physically visit the location. The exploration of space and context is best conducted within immersive VR systems, but the CAVEcam also produces panoramas suitable for a wide range of applications. Future research aims to bring 3D CAVEcams to a broader range of accessible platforms beyond CAVE virtual reality systems. Currently, CAVEcams can be rendered in mono and easily shared via web platforms and mobile or desktop viewers in order to explore a space, similar to an ultra-high-resolution version of Google StreetView. High resolution rectilinear projections can also be rendered for use on tiled display walls, projection systems, desktop computers, or for photographic prints with a field of view and resolution that can surpass the results of single camera systems.

Ground based photography was also used to acquire thousands of images that can then be layered onto the geometric scaffold of the laser scans in order to render a photorealistic model of the site. The high-resolution images can be combined with the aerial images generate three-dimensional models through the use of SFM. With enough computing power, this model can be very accurate up to scale, as seen in Figure 3. To give some perspective of the amount of post-processing required, a computer with 128 gigabytes of RAM ran for two weeks processing 5000 images in SFM software [10] in order to generate a point cloud of the church which totaled 130 million points.

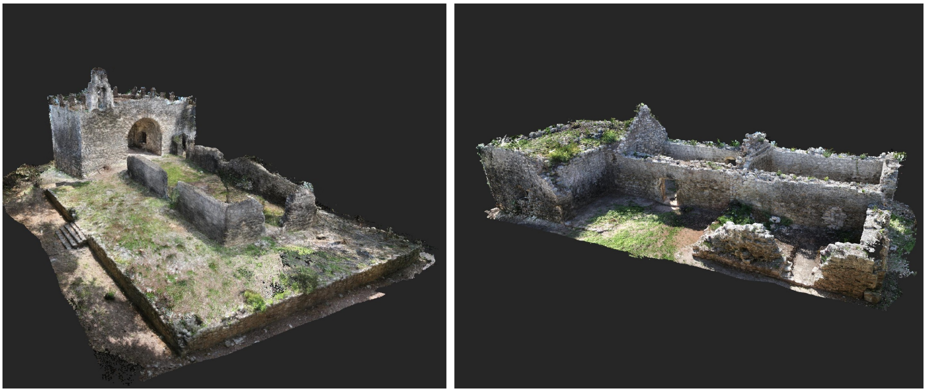

Fig. 4. SFM point clouds of the Church (Left) and Casa Cural (Right)

There are certain procedures to follow when generating photos for SFM models. Experience with the process gives way to learning the things to do and not to do. Generating a photorealistic model of an outdoor structure can be difficult because of unpredictable changes in lighting and the size of the target structure, which requires many camera angles, some of which cannot be obtained from the ground. Through studying the process as well as results obtained from many trials, we have developed a better understanding of how to generate high quality photos for SFM applications.

2.4 Thermal Imaging

A custom camera platform designed to acquire high-resolution thermal image mosaics was also implemented at the site of Boca Iglesias. Infrared thermography is an imaging technique that measures the radiation in the infrared range of the electromagnetic spectrum that is emitted by a surface. Thermal images can reveal surface and subsurface information that may not be visible to the naked eye and this information can be analyzed along with the rest of the toolkit presented here to make informed decisions about the state of health of the structure.

Grinzato et al [11] explain how thermal image mosaics can be acquired and used towards determining what types of modifications have occurred over the history of the structure as well as documenting cracks and areas of moisture. Thermal imaging is extremely important in these situations because it is a non-intrusive technique that provides information about features that are not visible without opening damaging the existing structure in any way. As a part of the documentation of the church, two thermal image mosaics of the altar area were captured, one of which is shown in Figure 5. The mosaic shown here is composed of 70 thermal images and was acquired using a FLIR A615 thermal camera which was mounted to the custom, automated camera platform. The native resolution of the FLIR camera is only 640x480 pixels, so being able to get a holistic view of the altar with maintaining a suitable level of detail is extremely important for accurate diagnostic analysis.

Fig. 5. High-resolution thermal image mosaic

3 Conclusion

The documentation and conservation of the world's cultural heritage is a monumental task, but it is an extremely important matter that should receive a considerable amount of attention from the government officials responsible. The International Council on Monuments and Sites (ICOMOS) outlines the importance of site documentation highlighting the acquisition, dissemination and analysis of the data necessary for informed preservation and management of the site [12]. INAH is currently in the initial stages of developing a plan for preservation of this colonial heritage site.

It is difficult to prescribe a standard set of guidelines for the documentation and analysis of cultural heritage sites because of the varying typologies, cultural significance, and advances in diagnostic technologies, but there are some suggested criteria that have been published and widely accepted [12], [14], [15]. In a document adopted by ICOMOS in 2003, general guidelines are issued for the analysis and conservation of historical structures. The first item listed under general criteria states, ``Conservation, reinforcement and restoration of architectural heritage requires a multi-disciplinary approach" [13]. United Nations Educational Scientific and Cultural Organization (UNESCO) also recognize the need for multidisciplinary collaboration between the responsible officials and specialists in the related fields of study. The mission of CISA3 is to provide this multidisciplinary team that can collaborate with government officials to address the needs of cultural heritage sites around the world. After only two short days of work, a significant amount of data was captured in the documentation of the church and nearby Casa Cural. INAH and CISA3 will now work in collaboration to use the acquired data to aid in the developing plan for preservation.

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