Reflectance Transformation Imaging for the Recording of Incised Graffiti

A Case Study from the Maya Site of Holtun, Guatemala

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ABSTRACT

Precolumbian Maya graffiti is challenging to document because it is complex, multilayered, and difficult to see with the naked eye. In the Maya Lowlands, precolumbian graffiti occurs as etched palimpsests on parts of substructures such as stucco walls of residences, palaces, and temples that are frequently only accessible through dark and narrow tunnel excavations. Experienced iconographers or epigraphers with advanced drawing skills are the most qualified researchers to accurately record, analyze, and interpret precolumbian Maya graffiti. Because these scholars have a vast knowledge of conventions and styles from multiple time periods and sites, they are less likely to document the complex and seemingly chaotic incisions incorrectly. But as with many specialists in Maya archaeology, iconographers and epigraphers are not always available to collaborate in the field. This raises the question, how might an archaeologist without advanced training in iconography accurately record graffiti in subterranean excavations? Advances in digital applications of archaeological field recording have opened new avenues for documenting graffiti. One of these is Reflectance Transformation Imaging (RTI), a method that uses a moving light source and photography in order to visualize, interact with, and analyze a three-dimensional object in a two-dimensional image. With practice, RTI images can easily be produced in the field and later shared with specialists for the purposes of analysis and interpretation. Performed on a series of 20 unique graffiti from the Maya archaeological site of Holtun (two examples are presented here), RTI shows promise as a viable technique for documenting and preserving graffiti as cultural heritage.

Keywords: Maya archaeology, graffiti, Reflectance Transformation Imaging (RTI)

Los grafitis Mayas precolombinos son difíciles de documentar debido a que son complejos, de múltiples capas y difíciles de observar a simple vista. En las Tierras Bajas Mayas, los grafitis precolombinos ocurren como palimpsestos grabados en partes de subestructuras, como en las paredes estucadas de residencias, palacios y templos; frecuentemente, solo son accesibles a través de oscuros y angostos túneles excavados. Experimentados iconógrafos y epigrafistas con avanzadas habilidades para dibujar son los investigadores mejor calificados para documentar con precisión, analizar e interpretar los grafitis precolombinos. Debido a que estos investigadores tienen un amplio conocimiento de las convenciones y estilos de múltiples períodos temporales y sitios, es menos probable que registren incorrectamente las complejas y aparentemente caóticas incisiones. Pero, al igual que muchos especialistas en arqueología Maya, los iconógrafos y epigrafistas no están disponibles todo el tiempo para colaborar durante el trabajo de campo. Esto lleva a la pregunta, ¿cómo puede un arqueólogo sin formación avanzada en iconografía documentar con precisión los grafitis dentro de excavaciones subterráneas? Avances en las aplicaciones digitales para documentación en el campo arqueológico han abierto nuevas oportunidades para registrar los grafitis. Una de estas es, Imágenes de Transformación de Reflectancia (RTI, en inglés), un método que utiliza una fuente de luz en movimiento y fotografía para así visualizar, interactuar con y analizar un objeto tridimensional en una imagen de bidimensional. Con la práctica, las imágenes de RTI pueden ser fácilmente reproducidas en el campo y ser compartidas después con especialistas para su análisis e interpretación. Realizado en una serie de 20 grafitis únicos del sitio arqueológico Maya de Holtun (dos ejemplos son presentados aquí), el RTI parece prometedor como una técnica viable para la documentación y preservación de grafitis como patrimonio cultural.

Palabras clave: arqueología maya, grafitis, Imágenes de Transformación de Reflectancia (RTI#en inglés)

"Graffiti" (plural form of the singular "graffito") is an Italian term that translates to "a scribbling" (Harper 2023). In the archaeological sense, this term was first used in the eighteenth century to describe incised markings on the walls of structures at Pompeii, becoming a descriptor of an informal artistic style and rendering (Źrałka 2014:25). It is important to note here that although, in the

Advances in Archaeological Practice, 2024, pp. 1–11

DOI:10.1017/aap.2023.34

colloquial sense, the term "graffiti" can often be used to describe acts of protest or vandalism, this is not always the case for ancient graffiti. Peden (2001) argues that some of the oldest examples of textual graffiti in Egypt were likely produced by state authorities, and they recorded the names and titles of pharaohs or other high-ranking officials. In Roman Pompeii, many noble houses contained textual graffiti in open spaces where people would gather, and they were likely carved by the house's inhabitants (Benefiel 2010). Finally, scholars argue that graffiti found in many elite Late Classic residences or occupational structures were also carved by their inhabitants and not considered acts of vandalism or subversion; notable examples include Tikal (Webster 1963), Xultun (Rossi et al. 2015), Nakum, and Yaxha (Źrałka and Hermes 2009), among others.

Precolumbian Maya graffiti are scratched or incised onto much harder surfaces, including limestone architecture, stucco surfaces, cave walls, and in certain cases, ceramic vessels or sherds (Źrałka 2014:37). Over 90% of documented images are thin, incised lines within rooms of structures, which can be found in secluded contexts but not necessarily hidden from view (Lovata and Olton 2015:139). The most important aspect of precolumbian Maya graffiti is the fact that they were not part of the original design of the structure. This does not mean that graffiti are of lower quality or less clarity; many examples of graffiti at Maya sites are detailed and intricate (Callaghan et al. 2017; Hutson 2011; Lovata and Olton 2015; McCurdy et al. 2018; Navarro-Castillo et al. 2018; Vidal Lorenzo and Muñoz Cosme 2009; Źrałka 2014). Usually, there is a distinct lack of spatial arrangement to the images. Unlike painting and sculpture, graffiti tend to be scattered and chaotically distributed on walls, floors, or other architectural elements, with little to no stylistic cohesion (Brittenham 2023; Lovata and Olton 2015; Źrałka 2014:40).

Because of the frequent location of Maya graffiti on fragile surfaces in buried architecture (the Ancestral Maya used sequential building techniques encasing earlier structures), they must be recorded as accurately as possible with little to no contact by archaeologists. To avoid further erosion and collapse, tunnels used to reach earlier structures must be filled and may never be opened again. Finally, as Helmke and Źrałka (2021:99) note, although specialists who are trained in the canons of Maya art are the most appropriate scholars to record graffiti, they are usually not the ones who do it, which can lead to errors in recording. We argue that Reflectance Transformation Imaging (RTI) addresses these challenges and has proven to be a viable technique to record and analyze ancient and historical graffiti in other areas of the world, including Italy (Cosentino et al. 2015; Sammons 2018), the Sudan (Davis et al. 2018), Cyprus (Demesticha et al. 2017), Egypt (Frood and Howley 2014), the UK (Dhoop et al. 2016), and Ireland (McAtackney and Devlin 2014; see also Valente and Barazzetti [2020:3] for synthesis of approaches). We argue that RTI is also suitable for the Maya area and other North American regions, especially in instances when neither an experienced iconographer (to record contexts) nor scanning equipment is immediately available. The primary advantage of RTI is the ability to fully record shallow incising that allows post-recording manipulation in a lab environment where an iconographic specialist can review the material and not having to rely on a nonspecialist rendering that may have missed features in the field. RTI accomplishes this because it not only has a movable light source to highlight finely incised lines but also is relatively low cost (see below) and uses easily accessible or available equipment.

Precolumbian graffiti found at the Maya site of Holtun, Guatemala, particularly benefit from this type of documentation for several reasons. First, the graffiti are extremely fine and incised into fragile stucco on walls of a substructure in a heavily looted building that is difficult to tunnel. Second, multiple dating methods (radiocarbon and ceramic seriation) suggest that these graffiti were incised into an E-Group structure during the Maya Terminal Preclassic period (0–AD 250) at Holtun (Callaghan et al. 2017). E-Groups are important early ritual structures in the Maya Lowlands, and archaeological contexts dating to the Terminal Preclassic period are rare and may not be anticipated as a possibility in excavation. Consequently, project directors may not be prepared to immediately record what has been found. Third, many of the images appear layered and complex, requiring more time to record and analyze than a field season can afford. Finally, these unique graffiti face active threats from both the harsh tropical environment and looters, which often adds to the need for urgency in recording and the use of available technology to accomplish it as quickly as possible.

There are a number of digital documentation methods available for recording these fragile graffiti, all with varying degrees of applicability and cost. At the time of the excavation season and subsequent research, we selected RTI as the documentation method because of its relative low cost and its ability to display low light and low relief as the graffiti required. We could have considered other techniques that were equally valid and at a similar cost, such as photogrammetry, but the low relief of the graffiti likely would not have been as easy to see and manipulate digitally. Other methods, including 3D scanners, were more expensive at the time but would provide a similar dataset. The costs associated with these at the time of the research were prohibitive, and there was very little room within the budget to accommodate these more expensive methods. It was also difficult to procure equipment for these methods during the field season in a remote location with an unexpected find of graffiti. Recently, the cost of these technologies has declined, and lidar is even available on newer model iPhones (iPhone 12 Pro, iPhone 13 Pro, and iPad Pro). We still argue that RTI is a viable choice and comparatively inexpensive and accessible, given that many projects already have much of the necessary equipment on hand (see below). In contrast, procuring a 3D scanner, lidar scanner, or even a newer iPhone, if one is not already owned, can be cost prohibitive given that most projects already have a DSLR camera. If surprise finds appear and have to be documented before backfilling at the end of the season, RTI can be easily and cost effectively used to document graffiti and shallow relief incisions. Valente and Barazzetti (2020) note that although 3D digital recording techniques can mimic the usefulness of RTI in that light sources can be moved by changing the light settings and orientation directly in the digital model, worldwide documentation of graffiti RTI is still the most published method used for recording. In fact, RTI was recently used in Maya archaeology to document graffiti outside of this study (Nowakowski 2023).
No studies of laser or 3D mapping of graffiti have been carried out on Maya graffiti (although they have been used in other world contexts), and the efficacy of recording graffiti using iPhone lidar has not yet been tested in any situation and compared to other methods.

METHOD: ARCHAEOLOGICAL FIELD APPLICATION OF RTI

RTI relies on the movement of light to visualize and analyze an object from a variety of angles. This method was initially developed in 2001 in the Hewlett-Packard research laboratories and, at the time, was called Polynomial Texture Mapping, or PTM (Earl et al. 2010). PTMs are often used to increase photorealism in a photographed object when lighting varies and can help enhance existing colors within the pixels (Malzbender et al. 2001). Once it was clear that this method could be applied outside of enhancing photorealism, and that computer programs were not just capable of mapping textures through the polynomials but could also digitize and enhance information on reflectance, the name was changed, and PTM became a subset of RTI (Newman 2015).

In this technique, both the camera and object being photographed remain stationary, which eliminates the need for complex geometry and other more complicated texture models (Malzbender et al. 2001). The only movement is from a single light source, but this light source must remain at the same distance from the object even when the angle of the light source changes (Figure 1). Keeping these variables consistent is required by the software program, which eventually renders these images into a single RTI file where all the images can be viewed at one time. If the locations of the camera or object change, or if the distance of the light source changes, the output file will be at best blurry and unclear, or at worst, completely corrupt and entirely indecipherable. Per object, 24 to 60 photos are recommended, and the goal is to create a dome of light around the object. In order for the software to detect what angle the light is coming from, two reflective black spheres are also placed in the frame of the photo (although one sphere can be used for smaller objects, and the sphere can be red in color). These spheres may be cropped out of the final RTI files, but they serve to tell the software where the light is located within the image (Mytum and Peterson 2018:494).

The RTI builder software (created by various researchers funded through grants by Cultural Heritage Imaging, see below) has several algorithmic fitters that may be accessed and used with the same base set of photos. Polynomial Texture Mapping and Highlight-Based Detection fitters both function in similar ways and allow for the software to formulate how light will reflect off an object and then to construct this in an interactive digital atmosphere. Highlight detection differs from PTM in that the information created can undergo "specular enhancement," where the surface shape can be more easily distinguished. In order to complete the composite file, the software uses the sphere(s) captured on the images to find the reflection of light on each image (Earl et al. 2010).

To photograph an image, users employ an "RTI kit" that includes the black reflective spheres mentioned above, along with various tools to prop up and place the spheres. For this study, we used the RTI Highlight Capture Starter Kit sold by Cultural Heritage Imaging (CHI) (https://culturalheritageimaging.org/What_We_Offer/Downloads/rti_kits.html). A list of other suggested tools (tripod, DSLR camera, remote trigger, etc.) and specific methods (flash vs. static light source, distance measurement, etc.) can be found within the RTI image capture and processing guidebooks

Figure 1. Photo of Rachel Gill Taylor measuring distance to graffito from the camera with a string, and RTI Highlight Capture Starter Kit sold by Cultural Heritage Imaging (photo by Michael Callaghan).

provided by Cultural Heritage Imaging. These also outline the best practices for RTI image capture. After all these suggested tools are acquired, the main setup is consistent for all types of subjects; reworking of the setup is not needed. The camera can be secured to the tripod, and the remote trigger can be linked to the camera. This ensures that the camera does not move or vibrate, which negatively affects the final RTI file.

In order to process the images, the RTI Builder software was installed on the computer. RTI Builder software is now out of date, but Relight open-source software can be downloaded from the CHI website (https://culturalheritageimaging.org/What_We_Offer/Downloads/). The first step was to transfer the original RAW files from the memory card of the camera to the workstation computer. After reviewing each of the photos and deleting unusable images, those RAW files were converted into both JPEG and DNG files. The DNG files are used as a backup for the primary capture data, whereas the JEPGs are used within the RTI Builder applications. At this point, the black spheres that are placed in the photo *should not* be cropped out. They are needed for the analysis in the program.

After upload into the software, a fitting algorithm is chosen, and the light positions are calibrated in a two-step process: identifying the spheres and then detecting the highlights, both of which are interactive processes. The first step is to identify the area around

https://doi.org/10.1017/aap.2023.34 Published online by Cambridge University Press

the black reflective sphere so that the software can detect the highlights and then use them to compute the light positions for each image. After identifying the spheres, the highlight detection can begin. This process—done entirely by the software—was lengthy using RTI Builder, but it resulted in a final composite image of all the detected highlights on the black sphere. This is a useful resource during analysis. It can show where there are more light points, and where light was lacking, making limitations clear for future analysis. Once the final product is cropped, the final RTI file can be saved and later analyzed. Relight software functions in similar ways and is improved in others; for example, RTI Builder could only analyze one sphere for highlight, whereas Relight can use two, which allows for rapid highlight generation and is much less time intensive than RTI Builder (one hour vs. 10 minutes; see Nowakowski 2023:34).

RTI FEASIBILITY

In comparison to other digital and technological methods such as laser scanning or handheld lidar (see Beltrán 2018; Garrison et al. 2016; Tokovinine and Estrada-Belli 2017), RTI is often still more accessible because most projects have a DSLR Camera and light source on hand. In addition to a DSLR camera (the current average cost for a 24-megapixel Canon Rebel with two lenses and case is approximately $600) and a light source (which can be anything from a flashlight to a remotely triggered flash), two reflective spheres—or an RTI Starter Kit from CHI ($370, see below)—are needed, but ball bearings can be used (Nowakowski 2023:149). Since this research study was conducted, many other RTI hardware units, such as the ScopeD50 or Dome LEDs, have been constructed, which further reduce potential for human error (broncolor.swiss 2023). However, unlike the basic applications and uses, these units are expensive and more suitable for lab studies documenting portable artifacts that can be brought to the machine than larger, nonportable features in the field that will not fit within the smaller machines.

At Holtun, the combination of complex graffiti on fragile subterranean stucco, short field seasons, and lack of an experienced iconographer on site at all times made it challenging to document graffiti accurately. By utilizing RTI, which records many images over the course of a capture session, iconographers and archaeologists could accurately record the multilayered graffiti for later analysis and interpretation. This would eliminate the need to return to the site itself and the risk of continual exposure of these fragile contexts.

APPLICATION OF RTI TO E-GROUP GRAFFITI AT HOLTUN

Holtun is located in the Department of Petén, Guatemala, just 35 km from the Classic period site of Tikal, and almost as close to other notable large Classic period sites such as Yaxha, Nakum, and Naranjo (Figure 2). This region of Guatemala is located in the Maya Lowlands, which consists of parts of eastern Mexico, Belize, and northern Honduras. The area was continuously occupied by the Maya for over 5,000 years (Lohse 2020; Sharer and Traxler 2006:42). Holtun is a large civic-ceremonial center with monumental architecture and outlying residential groups. Occupation at Holtun dates from the Middle Preclassic (800 BC) to the Terminal Classic (AD 900) periods (Callaghan et al. 2017:26).

Located at one of the highest points of Holtun, the structure containing the graffiti used in this analysis (Structure F2-Sub. 1) lies in Group F, positioned in the southeastern portion of the site (Figure 3). This is also the location of the site's "E-Group." Named for the group at Uaxactun where this specific architectural compound was first identified (Ricketson and Ricketson 1937), the Holtun E-Group contains a large pyramidal structure to the west and a range structure to the east. Although first believed to be used specifically for celestial observation, E-Groups are now known to have functioned in many ways that involved the gathering of large groups of people (e.g., agricultural and other rituals, possible markets, and royal ascension ceremonies; see Aveni 1981; Doyle 2012; Freidel et al. 2017; cf. Šprajc 2021). It is also thought that although they were initially part of a community cooperative event, these structures may have planted the seeds for later social inequality (Doyle 2012; Inomata et al. 2015; McAnany 2010). Regardless of function, E-Groups have proven to be among the first monumental ritual structures in the Middle Preclassic Maya Lowlands (Inomata et al. 2015).

The E-Group complex at Holtun experienced four major construction episodes beginning in the Middle Preclassic period, followed by significant additions in the Late Preclassic and Terminal Preclassic periods, and a final renovation in the early Late Classic period. As concerns this study, radiocarbon dates place initial construction of the E-Group during the Middle Preclassic period at 2577 ± 25, with two possible calibrated ranges: 799–776 cal BC ($p = 0.05$) and 809–597 cal BC ($p = 0.95$; calibrated with OxCal 4.3, IntCal13 atmospheric). Late Preclassic construction begins 2254 ± 25, with two possible calibrated ranges: 385–235 cal BC ($p = 0.05$) and 394–209 cal BC ($p = 0.95$; calibrated with OxCal 4.3, IntCal13 atmospheric). The graffiti discussed in this study were located on pillars of a sanctuary (structure F2-Sub 1), which was constructed on a platform that was added to the west (plaza-side) of the eastern E-Group platform in the Terminal Preclassic period. Charcoal found in fill of the platform of the Terminal Preclassic structure that contains the graffiti on its walls returned dates of 1916 ± 29, with two possible calibrated ranges: 61–125 cal AD ($p = 0.05$) and 7–207 cal AD ($p = 0.95$; calibrated with OxCal 4.3, IntCal13 atmospheric). Finally, charcoal found in the fill inside the rooms with graffiti returned dates of 1828 ± 24, with two possible calibrated ranges: 139–221 cal AD ($p = 0.05$) and 126–247 cal AD ($p = 0.95$; calibrated with OxCal 4.3, IntCal13 atmospheric). Together, calibrated radiocarbon dates and pottery analyzed by the Callaghan (2018) conclusively date the construction of the sanctuary, the creation of the graffiti, and the sealing of the sanctuary entirely to the Terminal Preclassic period (see Figure 4 for a reconstruction of structure F2, the eastern platform of the E-Group at Holtun).

F2-Sub1 itself consists of six limestone pillars coated in a layer of limestone stucco as well as a plaster limestone floor, characteristic of the Preclassic periods (Figure 4). Red pigmented paint is present on the stucco walls, and a series of postholes above the pillars suggests a roof made of a perishable material—possibly round wood beams. The function of the structure is unclear, but its location in front of the highly ceremonial range structure of the site's E-Group outside of residential compounds suggests a ritual function. There is a history of ritual practice found in E-Group

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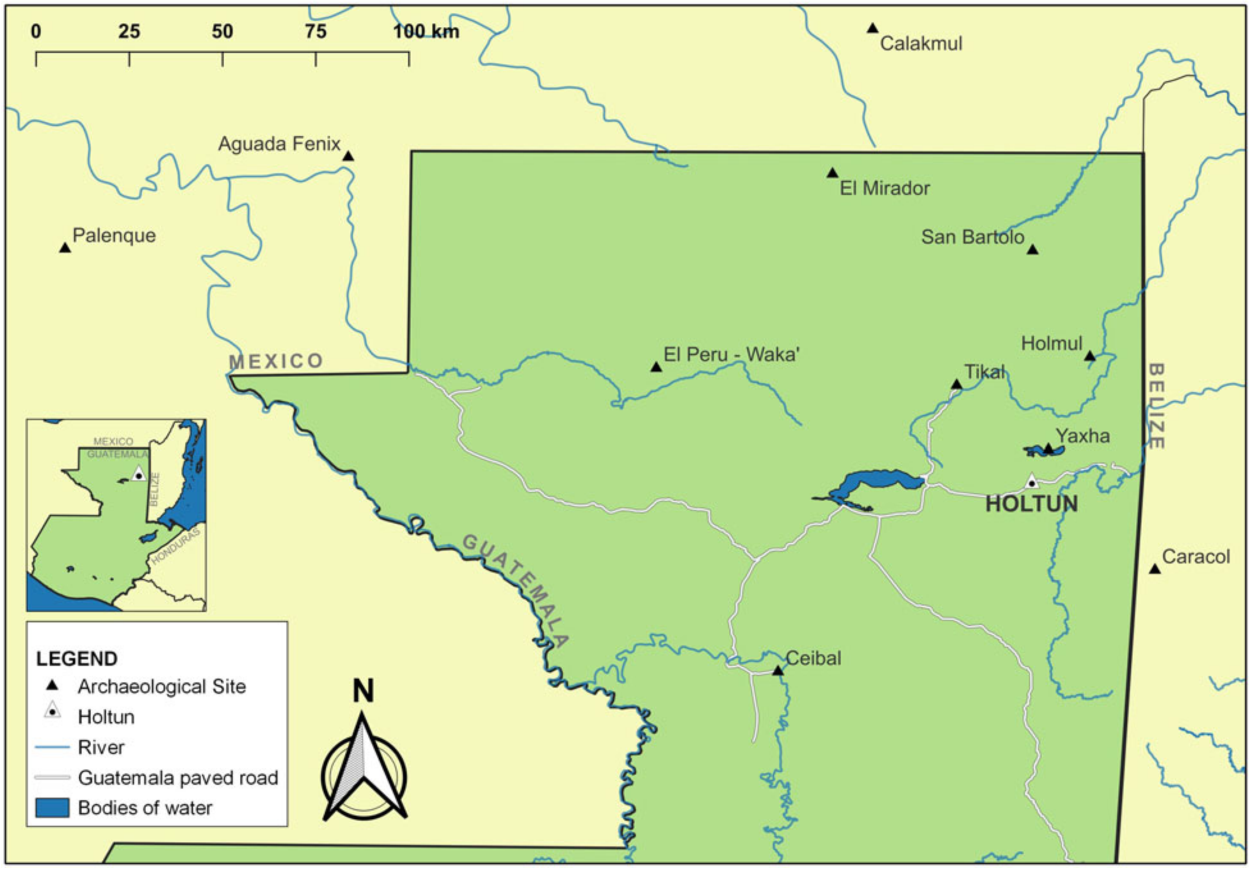

Figure 2. Map of Maya area showing the location of Holtun (map by Melvin Rodrigo Guzman Piedrasanta).

structures in the Maya Lowlands, which involved creating cruciform cuts containing offerings located in the bedrock of the plaza in front of the eastern structure (Estrada-Belli 2006). This practice indicates a form of ritual memory because ceremonial structures are then placed directly on top of these offerings (Aoyama et al. 2017; Estrada-Belli 2006). In the case of Holtun, the graffiti structure sits directly on top of a bedrock cut, further suggesting the sacredness and ritualization of the building (Callaghan et al. 2017; see Bauer [2005] and Inomata et al. [2017] for other sites). This makes the graffiti inside the structure a rare and valuable cultural phenomenon.

The Holtun E-Group was excavated in June and July of both 2016 and 2017. The sanctuary structure with graffiti was partially exposed in 2016. Coauthor and iconographer Mary Clarke was present during the 2016 season and produced to-scale drawings of the primary compositions in the graffiti discovered that year. In 2017, excavations were reopened in order to stabilize and conserve the finds before permanently sealing the tunnels at the close of the season. Unfortunately, Clarke was not present during this phase, leading the project to explore alternative methods for documenting so that Clarke and others could analyze and interpret the graffiti in the lab. RTI seemed the most appropriate because we owned most of the necessary equipment, and the implementation was relatively easy, although with certain limitations, described below.

The Holtun graffiti were accessed by tunneling through the eastern range structure of the E-Group. At its widest, the tunnel was approximately 0.80 m, but it narrowed to approximately 0.25 m wide in some areas. The height of the tunnel ranged between 1.30 m and 1.60 m. Even at its highest point, archaeologists could not stand while excavating or documenting the graffiti. Because of these tight quarters, it was difficult for a person to move inside of the tunnels even *before* all the RTI equipment was in place. After the necessary equipment was put in place, it was nearly impossible to move from one side of a wall to another. Some types of user error (movement of camera / reflective spheres) were mitigated by limiting activity in the tunnels to only the photographer.

The size of the tunnels and the location of the graffiti at particular points on the walls also led to certain limitations in the method. Because the camera and the light source must be two to three times the diagonal distance of the image away from the actual object, these distances limited the potential size of the actual image. For this reason, whole walls could not be captured in a single image, and only primary compositions of graffiti identified with the naked eye were included in this study. Additionally, the close proximity of the walls and the roof of the tunnel limited where the light could actually be placed. Therefore, there are some angles of light that could not be used. Despite this, the data produced are still useful and can provide additional information about the subtle and sometimes overlapping lines of the graffiti.

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Figure 3. Map of Holtun showing the location of the E-Group (in red) (Group F) (map by Melvin Rodrigo Guzman Piedrasanta).

An advantage of using this type of method inside an underground tunnel is specifically related to camera settings. For RTI, in order for the camera to pick up only the specific light source that will move around over the course of the process, the ISO and aperture settings must be set so that when the light used for the photograph is not shining on the object, the image appears completely black (i.e., so no ambient light is picked up in the image). Typically, a low ISO and medium aperture will achieve this in a place with ambient lighting. While we were working underground, the only ambient light came from the entrance to the tunnel into the structure, so these settings did not have to be adjusted at all between the documentation of each graffito. This provided consistency throughout the entire process and allowed each graffito to be documented using the same camera settings.

In many of the images, the shadows of the reflective spheres could not be eliminated entirely, so the focus was on making sure that those shadows did not overlap with the specific graffito. The reason these shadows could not be eliminated entirely is due, once again, to the confining space of the tunnel. In order to make sure that the spheres were close enough to be visible in the image but far enough from the graffito that they could later be cropped, the shadows could not be eliminated entirely. There was also an attempt to use smaller spheres, which would, in theory, take up less space and, in turn, cast smaller shadows. However, they were not large enough to register in the RTI Builder software. Although there are shadows present in several photos, the images of the graffiti themselves were not affected.

Once the images were captured in the field, they were transferred from the camera directly onto the computer with the RTI Builder software and processed immediately. This allowed for faulty capture sessions to be caught immediately and redone on the same day. Furthermore, with a long battery life, multiple image capture sessions could be processed on-site. Because the processing software does not require internet access, this could be done in remote locations such as the site of Holtun.

RESULTS AND DISCUSSION

With a few notable exceptions, most precolumbian Maya graffiti dates to the Late Classic period, much later in Maya history than the collection at Holtun appears to be (Źrałka 2014:190). This could be due to both cultural practice and natural formation

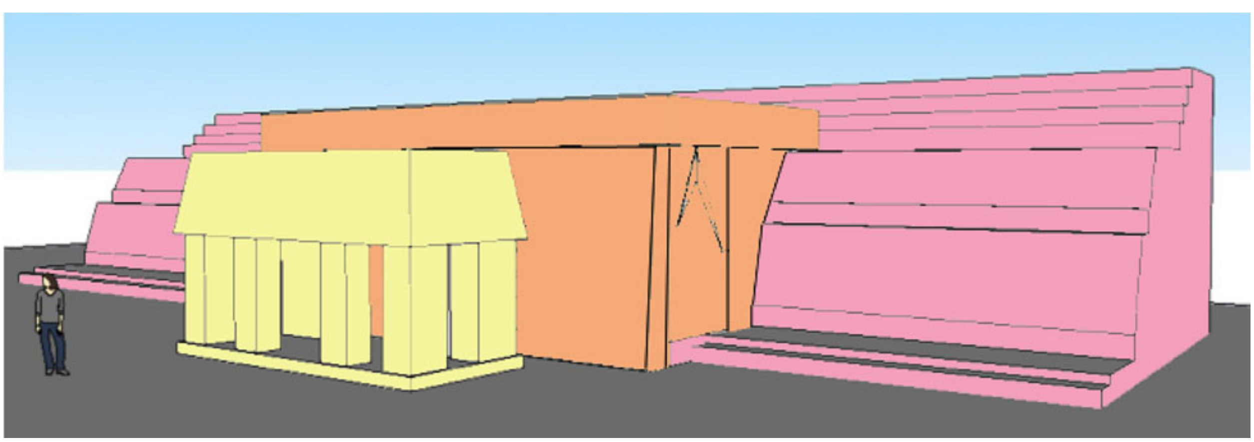

Figure 4. Reconstruction of Holtun E-Group eastern platform showing Terminal Preclassic period sanctuary with graffiti in yellow; Late Preclassic period platform with intrusive Classic period vaulted room in orange; and Middle Preclassic period series of platforms in red (image by Mary Clarke, modified by Michael Callaghan).

https://doi.org/10.1017/aap.2023.34 Published online by Cambridge University Press

processes. Many of the sites in the southern lowlands have very large Classic period population sizes, which led to a sharp increase in monumental construction. The precolumbian Maya built ceremonial structures like Russian nesting dolls, filling each previous occupation of a structure to build a larger, more impressive structure on top (McKillop 2006:239–241; Sharer and Traxler 2006:215). This means that earlier, Preclassic art and architecture can be discovered intact, buried beneath later construction. Archaeologists face more than the usual challenges in documentation of these early constructions, and tunneling must often be used to reach them. The benefits and limitations of RTI for this specific situation and others will be presented in this case study at Holtun (see also Gill 2018). Here, we focus on two specific instances of graffiti: D4-A and E3-B (see Figure 5 for location within structure). These two sets of images are described below (for further interpretation of the graffiti itself, see Callaghan et al. 2024).

Graffito D4-A consists of two zoomorphic figures (Figure 6). One appears to be a deer or rabbit figure, and the other may be a fox or some kind of serpent. Located near the top of the wall, this is one of the largest graffiti discovered and some of the only zoomorphic figures found within the structure. In comparing the initial line drawing with the RTI images, it is clear the original artist (Gill, who was not an experienced iconographer at the time) missed a significant portion of the body of some of the figures within this particular graffito. The body of the larger zoomorphic figure greatly adjusts the potential interpretation of the images' iconographic significance. Armed only with the line drawing, a future iconographer may interpret the images much differently (a deer versus a rabbit, which have a very different cultural significance). With the RTI images, a crescent shape also becomes clearer near the body of the first animal figure.

Graffito E3-B is the most unique of all the graffiti in the tunnels because it appears to be a large continuous scene (Figure 7). If one reads it from left to right, there are first two anthropomorphic figures that are tall, with large legs and cranial modifications that resemble a nude figure from Graffito B1-A (see Figure 5 for location) with exposed genitalia (not depicted here), although these figures do not have genitalia exposed. These two figures are standing in front of what appears to be a head inside a bowl or other vessel that are both seated on top of what looks like scaffolding (Taube 1988). RTI, in this case, revealed a third figure behind the scaffolding, along with several details that appeared to be botanical in nature both surrounding and inside the scaffolding that were missed in the original line drawing.

Because this graffito appears to be a composed scene, it stands apart from the scattered figures present throughout most of the structure and most graffiti in general. As previously stated, graffiti are typically marked by a *lack* of artistic composition and are often scattered without any clear connection. This graffito, although it does not have any clear connection with the graffiti throughout the structure apart from stylistic similarities, has at least three figures that appear compositionally connected with each other. The RTI of this complete scene may offer more detailed information that could shed light on what this scene ultimately represents.

These two examples were drawn by hand using simple measuring tapes, raking light, and sight by primary author Gill during the

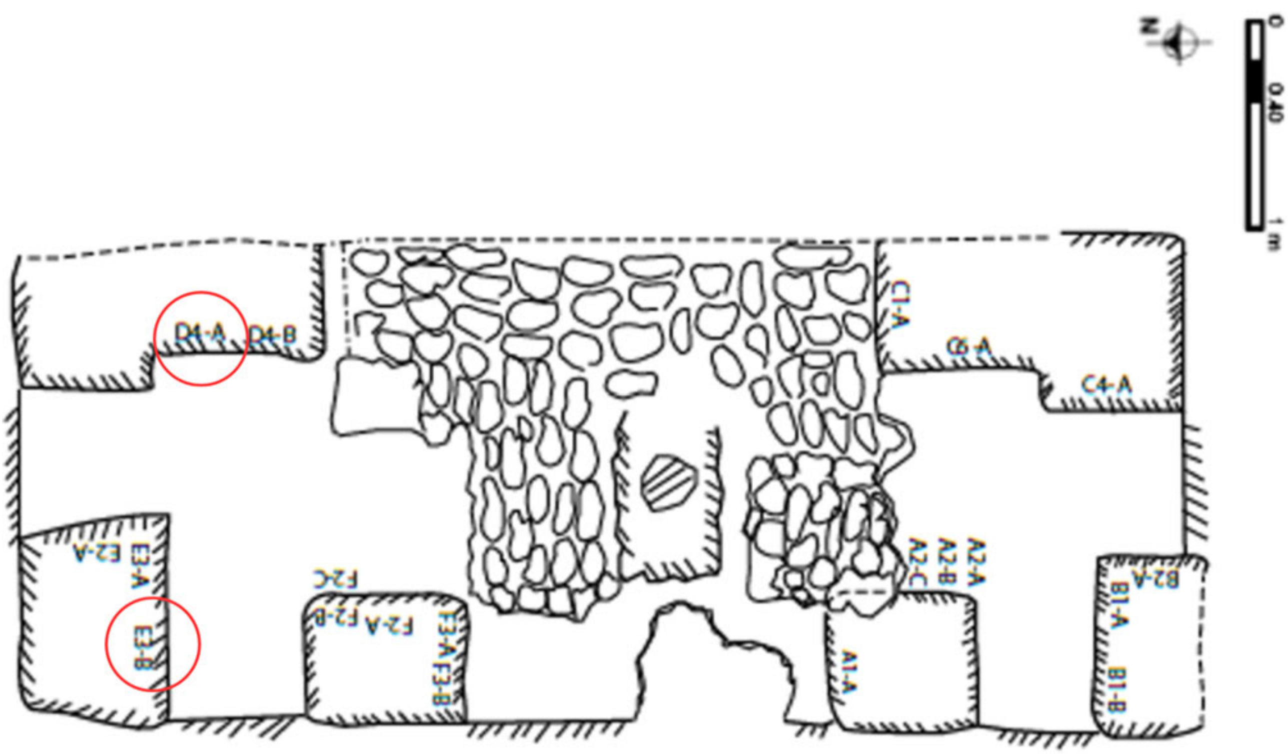

Figure 5. Plan drawing of Structure F2-Sub1 showing locations of graffiti (drawing by Rachel Gill Taylor).

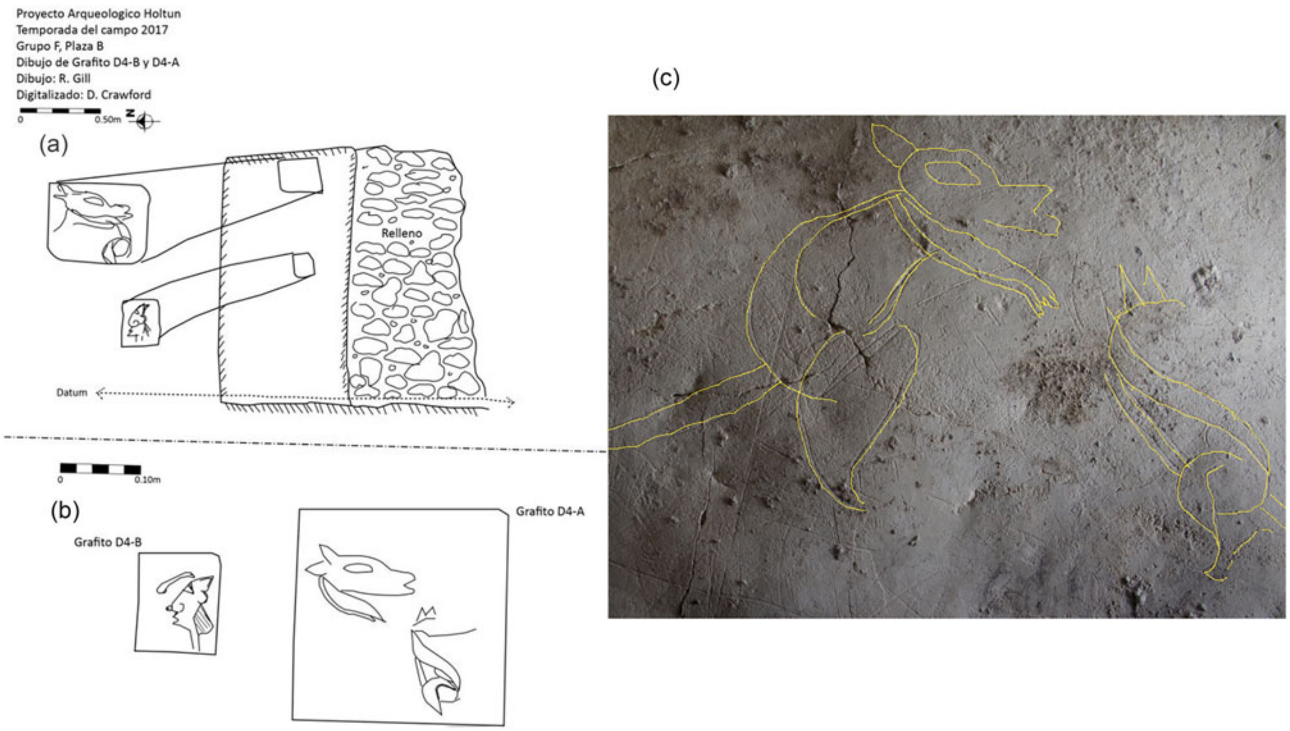

Figure 6. (a) Graffito D4-A line drawing, (b) RTI image, and (c) RTI image with drawing overlay (drawings and RTI image by Rachel Gill). Note: the still image does not illustrate incisions as well as the RTI software, where users can dynamically manipulate direction of the light source.

initial documentation of the walls, and each RTI composite image displays the difficulty in seeing all elements of a drawing in a low-light and cramped environment with the naked eye (see Figures 6 and 7). These omissions alter potential interpretations to the iconographic meaning of each of the images and eventually could alter the interpretation of the graffiti, the structure, and the site in general. RTI provides an additional method to revisit a series of complex images without the need for additional travel, excavation, or exposure of these fragile incisions. RTI allows researchers to revisit images from multiple lighting perspectives in a lab environment to uncover perspectives and details possibly missed in the field.

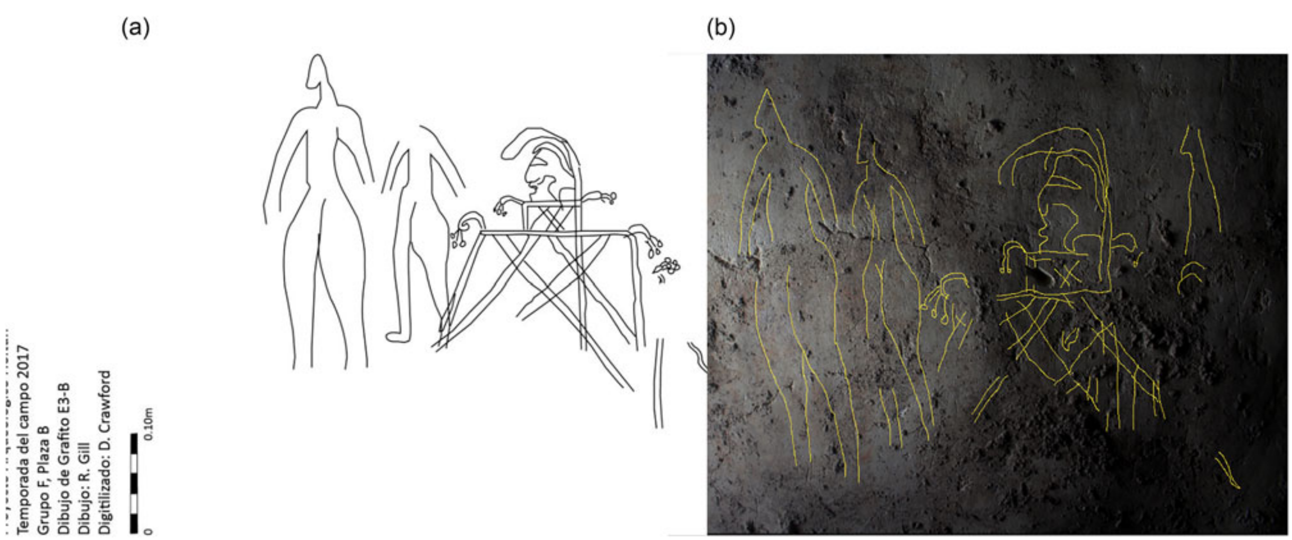

Figure 7. (a) Graffito E3-B line drawing and (b) RTI image with drawing overlay (drawings and RTI image by Rachel Gill). Note: the still image does not illustrate incisions as well as the RTI software, where users can dynamically manipulate direction of the light source.

https://doi.org/10.1017/aap.2023.34 Published online by Cambridge University Press

LIMITATIONS, CONCLUSIONS, AND FUTURE DIRECTIONS

RTI was a solution to our need for preservation and documentation of a fragile context in a tunneled excavation context. The time constraints and need to consolidate and preserve the fragile stucco walls mean that the photographic documentation work described here was completed in just under two weeks. Any corruption in the data cannot be corrected (i.e., new photographs cannot be taken in the time allowed). Therefore, the current dataset is, as of now, the only dataset. Additionally, photographs were taken before conservators cleaned and preserved the stucco on the walls, so some of the photographs may be unclear because of surface imperfections.

The camera used—a Canon Rebel XT—was released in 2003, and the model ceased being produced in 2005. At the time, this camera was considered the ultimate in capturing a high-quality image. Now, the images appear fuzzy when zoomed in or cropped to be smaller. In future studies at Holtun, a camera from at least the last five years should be used to keep up with the standard of photo quality in the current decade.

The modifications to the process that were made in the field may also prove to be a limitation, because the challenging environment and limited space inside the excavated tunnels prevented us from capturing the ideal number of photos and light angles advised by the RTI Capture Guide. Although the guide indicates that usable data can still be gathered from the capture session, the missing data cannot be recovered. One graffiti locus could not be documented using this method because it was located on a wall that could not be completely exposed during excavation for safety reasons. This example shows that, as versatile as RTI photography can be in remote and hard-to-reach spaces, there remain specific requirements of camera position and space that must be met.

Finally, it is worth noting that technology is progressing quickly, and this research was done and completed in 2017. Since then, scanning and 3D technology have become more readily available with simple lidar applications that exist for the iPhone. The Cultural Heritage Imaging software used in this study is slightly out of date; however, there are downloadable alternatives to CHI's processor to create RTI or PTM files, which function in a similar way and, in some cases, are improvements on the original RTI Builder.

Other techniques, including Virtual Polynomial Texture Mapping Virtual PTM (VPTM; see, for example, Kościuk et al. 2020), could be used to overcome some of the limitations of the close proximity of the tunnel in that the light source is applied after a 3D photogrammetric model is created. However, a drawback would be that the 3D model would need to be created and checked in the field to make sure that all details were recorded sufficiently, and very faint incisions, as is often the case in graffiti, may not always be recorded.

Outside of the Guatemalan lowlands, RTI can be applied anywhere in the world, in even the most remote of field sites, for a relatively inexpensive price tag, with basic equipment that most archaeological projects have on hand (e.g., a DSLR, flash, and two ball bearings), and it is relatively easy to learn and implement (see also Nowakowski 2023:149). It could provide a wealth of information not only on incised graffiti but potentially on a wide variety of immovable archaeological features that lend themselves to being difficult to photograph or document with any sense of realism. Used in combination with other digital and archaeological record-keeping techniques, a more complete picture of the past can be constructed. Analysis can be done by scholars years into the future and miles away from the actual feature itself. For delicate materials prone to speedy degradation after excavation, this method of documentation and analysis would limit graffiti and stucco exposure to harmful environments but still allow analysis of the materials to continue.

Precolumbian Maya graffiti themselves are an understudied area of archaeology—one that is critical to uncovering how other portions of the population interact with iconography, myth, and legend. Identifying graffiti as its own specific art form unlocks its potential for understanding other aspects of those familiar myths and legends and how they were interpreted. By preserving otherwise invisible features of the incised graffiti, archaeologists are allowed to pursue additional avenues of investigation into past social and artistic behavior that were once elusive.

Acknowledgments

This work was completed in 2016 and 2017 under permits from the Instituto de Antropología e Historia of Guatemala (DAJ-220-2015) and our inspectors—Adriana Segura, Mónica Pellecer, Byron Hernández, and Silvia Alvarado—as well as the people of the community of La Máquina, Guatemala, who provided labor and support for the project.

Funding Statement

This work was supported by the National Science Foundation, Grant Number BCS-1430954, Brigitte Kovacevich and Michael Callaghan PIs.

Data Availability Statement

The data presented here are available in the STARS digital repository as part of the master's thesis of Rachel Gill Taylor, available to the public through the University of Central Florida Library: https://stars.library.ucf.edu/etd/5762/.

Competing Interests

The authors declare none.

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https://doi.org/10.1017/aap.2023.34 Published online by Cambridge University Press