Carved in stone: Field trials of Virtual Reflectance Transformation Imaging (V-RTI) in Classical Telmessos (Fethiye), SW Turkey

Abstract

Virtual Reflectance Transformation Imaging (V-RTI) is a hybrid method that combines 3D, Virtual Reality (VR) and 2D+ technologies into a rapid, lightweight, and user-friendly method of recording archeological monuments in the field. The resultant image file can be interactively lit from various positions to highlight surface texture and detail not generally visible to the naked eye. In this article we describe the V-RTI method and critically compare it the current standard Highlight (H-RTI) method. We present results of a field trial of V-RTI in a challenging urban environment that yielded a new inscription, new readings, and epigraphic palimpsests that significantly change our understanding of the ancient Lycian city of Telmessos. We conclude that V-RTI is a valuable new tool for recording at-risk heritage worldwide and should be considered a default recording tool for field survey and conservation for many different classes of field monument.

Keywords: Middle East, epigraphy, archeology, conservation, digital heritage, Structure from Motion, Virtual Reality

Introduction

The purpose of this article is to introduce field archeologists to a new lightweight and rapid method for recording rock-cut inscriptions that allows for the analysis of fine surface details using Reflectance Transformation Imaging (RTI). RTI is especially useful for visualizing details of eroded or damaged texts, designs, or images, and has a wide range of applications including conservation, heritage education, underwater archeology, and forensics. This article will focus on its use for archeological research in the field, particularly in the Near and Middle East where the need to record and preserve heritage at risk is recognized as a global priority by both local stakeholders and western governments. Across this region vandalism and theft of immovable field monuments, such as rock-cut inscriptions and reliefs, is happening on an industrial scale (FIGURE 1) and there is a need within the heritage community for lightweight, easy-to-use, versatile techniques to record monuments that are often in isolated and inaccessible locations and which cannot be removed to museums for safe-keeping.

To work, RTI requires a series of digital photographs of an artefact taken from a fixed position but lit from different angles. These images are then processed by the RTI software into a single interactive digital file that the user can illuminate from any angle within a full hemisphere to highlight fine surface details using raking light. However, RTI does not provide metric data and image capture is complex and adversely affected by practical challenges in the field, especially high levels of ambient light. 3D Laser (3DL) scanning and Structure from Motion (SfM) photogrammetry, which is a range imaging technique for constructing three-dimensional structures from two-dimensional images, do record accurate metric data but do not necessarily help with reading and interpretation of monuments. 3DL in particular is difficult to use and can be prohibitively expensive and both RTI and 3DL require

cumbersome equipment that hinders recording in remote or inaccessible places (Greaves et al. forthcoming).

In this article, we describe in a new hybrid technique that combines SfM with RTI and Virtual Reality (VR) that is lightweight, versatile and easy-to-use in the field and provides both accurate metric data and user-friendly visualizations of fine surface detail. This innovative approach represents a completely new image capture workflow for RTI that uses 3D models generated by SfM which are then illuminated and photographed in a VR environment before being processed in RTI Builder to create interactive visualizations of artefact surfaces. We call this technique Virtual Reflectance Transformation Imaging (V-RTI).

We have previously conducted a field trial to compare different methods of RTI image capture on a rock-cut relief in a remote rural location that demonstrated that V-RTI is a robust image capture method and the resulting RTI files are of comparable quality to those achieved by other digital recording methods, including 3DL and Highlight RTI (H-RTI) but without the need for costly and cumbersome 3DL scanning equipment or the photographic tripods needed for H-RTI, which is currently the standard method for field recording (Greaves et al. forthcoming).

In this project, we aimed to test V-RTI in an urban environment by using it as the primary recording technique for a new epigraphic survey of the ancient city of Telmessos (modern Fethiye), SW Turkey (Greaves 2019). Dense urban environments are challenging to archeology and require rapid recording of materials in a variety of states of preservation and difficult locations. The rock-cut tombs of Fethiye's back streets experience natural erosion, seismic movement, vandalism, and looting, although the biggest risk to their integrity is encroachment by new buildings (FIGURE 2). The friable character of the Fethiye bedrock

means that the inscriptions are often heavily eroded, making them difficult to read. The pronounced eaves of Lycian tombs also cast of deep shadows over their inscribed lintels causing self-occlusion when using H-RTI. Some of the inscriptions and reliefs were too large or too inaccessible for H-RTI image capture, demonstrating some of V-RTI's advantages.

The inscriptions of ancient Telmessos were first published a century ago (Kalinka 1920) and our survey is the first modern archeological survey of the city (Greaves 2019). We present all the accompnying digital data, including seven V-RTIs, five H-RTIs, and a complete catalogue of tombs and epigraphic analysis as Supplementary Data online (DOI: XXX). To compare the result from H-RTI and V-RTI we present a series of 'contact sheets' that directly contrast screenshots from both workflows in the catalogue of tombs in the Supplementary Data. Using V-RTI, we were able to identify one new inscription (TAM II 50c), produce new readings of five previously published inscriptions, identify a later addition to an inscribed relief panel, and identify a series of epigraphic palimpsests that demonstrate the repeated re-inscription of a single tomb on four separate occasions over a period of over a thousand years. These new readings provide valuable information on which a new understanding of the city's history can begin to be built.

As an emergent technology, V-RTI has the advantage over previous RTI image capture methods in that it is also extremely quick for new users to acquire and overcomes a recognized 'bottleneck' in user acquisition that has posed a challenge to RTI's wider adoption by the heritage community since it was first developed (Mudge et al. 2006: 196). V-RTI imaging is a non-contact method of recording that can be acquired and used rapidly and safely by local stakeholders (e.g. museums, security services, and community groups) with minimum training and using standard digital cameras or even mobile phones (greaves et al. forthcoming). V-RTI also does not experience the same limitations as standard H-RTI relating to ambient light levels, camera movement, or limitations imposed by the size,

position or shape of the heritage resource being recorded. Its limitations relative to H-RTI are that post-processing is more time-consuming and requires skill sets, high-powered computers and proprietary software licenses that, for now at least, may put it beyond the reach of some stakeholder communities.

We conclude that, although not without its drawbacks, this innovative hybrid application of RTI is a valuable new tool for rapid recording of reliefs and inscriptions in difficult-to-reach locations or areas of high risk, especially where time, equipment, and trained specialists are limited. The V-RTI method outlined here is replicable anywhere in the world and has considerable potential in becoming a more commonly used technique in field archeology, not just in the Near and Middle East but worldwide.

Method and Context

The development of RTI

RTI is an umbrella term that refers to various recording methods, processing techniques, and file formats. It is a computational digital photography approach in which information about the surface shape and colour of a subject, captured in a set of digital photographs, is compiled into one specialized file that can be interactively viewed and illuminated, often revealing fine detail not visible upon physical inspection. The specialized RTI file is generated from a series of digital images in which the camera remains in a fixed point and a light source is moved to a series of different raking light positions around the surface of the subject in each photograph. Photo sets can be captured using one of two workflows: either using a prefabricated frame, or 'dome', placed over the artifact (D-RTI), or using an artificial light source to create highlights (H-RTI).

The technology was first developed at Hewlett-Packard Labs by Tom Malzbender and Dan Gelb who invented the Polynomial Texture Mapping (PTM) processing method (Malzbender et al. 2001; Malzbender et al. 2000). Since then, alternative processing and capture approaches have been developed (e.g. Selmo et al. 2017; Mudge et al. 2008; Corsini et al. 2006; Mudge et al. 2006). D-RTI was originally developed to be applied to small, portable museum artefacts (Mudge et al. 2005; Malzbener et al. 2001). The H-RTI recording workflow was subsequently developed to address field-based challenges such as uneven terrain, sunlight, portability and subjects of varying size (CHI 2013b; Duffy et al. 2013; Mudge et al. 2006).

Optimal H-RTI photography conditions require control of the recording environment, such as eliminating ambient light, a stable flooring, and positioning objects so they can be illuminated in the round. Museums or depots where target objects can be photographed from all angles in a hemispherical arrangement radiating in toward the central target are therefore ideal. Controlling ambient light is one of the biggest challenges to H-RTI in the field but using photographic reflectors to shade the object or neutral density filters over the lens can make image contrast clearer. The most effective way to compensate for intense daylight is to increase the reflectance information generated by the light source above that of the ambient background light by using a portable, high-intensity flash gun remotely synced to the camera. However, this requires multiple operators and adds an extra layer of complexity to the photographic skill set required to use RTI outdoors.

During post-processing, specialized software (RTI Builder) is used to locate the position of the reflectance point on the target in each photograph and produce a light position file. The software then draws upon the image set and lighting file, synthesizing color and shape information per pixel to generate an RTI file. There are multiple processing algorithms that can be used to process, or ‘fit’, an image set; Polynomial Texture Mapping (PTM) and

Hemispherical Harmonics (HSH) are the two applicable to this work (Mudge et al. 2008; Malzbender et al. 2001; Malzbender et al. 2000). HSH, the most recently developed fitting method, is considered superior in terms of accuracy, reproducibility, and color representation (MacDonald 2015; Manfredi et al. 2014; Frood and Howley 2014; Duffy et al. 2013). However, PTM fitting offers more Algorithmic Rendering (AR) options which often provide enhanced views of subtle surface relief (Schroer et al. 2014; CHI 2013a).

Using the dedicated viewing software (RTI Viewer), the user can then digitally interrogate surface features of the subject by interactively moving a virtual light source, zooming into areas of interest as well as enhancing the color information captured during imaging using various rendering modes available in the viewer. Although it is based on a set of 2D images, the resulting output provides visual information about 3D surfaces aided by the highlight and shadow data in the photographs and allows a user to visualize 3D geometry (Zányi et al. 2007; Mudge et al. 2006). RTI is therefore sometimes described as 2.5D or 2D+ and often reveals faint surface features not visible to the naked eye (e.g. Hameeuw 2017; García-Fernández 2015; Mathys et al. 2013; Duffy et al. 2013).

In D-RTI an object is placed within a prefabricated frame and photographed with a stationary camera as a selection of lights fire from established locations around the dome (Earl et al. 2011; Malzbender et al. 2001) or arc (Earl et al. 2010; Porter et al. 2016). D-RTI is useful for rapid, systematic acquisition of image sets but has limitations – namely cost, portability, construction of a frame, and the size of objects recorded (lights should be distanced at four times the diameter of the subject, so the size of objects recorded is limited by the frame). Field-based recording with D-RTI is difficult because frames are costly to construct, cumbersome to transport and inflexible.

The H-RTI method was developed to address the limitations of D-RTI and uses a relatively inexpensive, lightweight tool kit (Mudge et al. 2006). It is particularly useful in addressing outdoor, field-based challenges because it is cheap, portable, and scalable to subjects up to c. 1.5 m in diameter (CHI 2013b; Duffy 2013; Zanyi et al. 2007; Mudge et al. 2006). The technique, which is sometimes referred to as the 'Egyptian Method' (Mudge et al. 2006) requires a camera be mounted in a stationary position over, or in front of, a subject, and a light source (either continuous or flash) is manually moved around the subject as each photograph is acquired. The light is separated from the surface of the subject at a consistent distance using a premeasured piece of string at least four times the diameter of the object. The illumination angle is captured using a reflective, spherical target (such as a billiard ball) which records the reflectance position of the light in each photograph.

To compensate for ambient sunlight when using H-RTI, image capture can be done at night or with a high power flash gun (CHI 2013b; Duffy et al. 2013; Mudge et al. 2006). Whereas lighting positions are pre-determined with the D-RTI dome system, in H-RTI the lighting angle in each photograph is calculated during post-processing using the reflective target in each image frame. However, sometimes obstructions such as trees can prevent a full hemispherical arrangement of images being captured and this results in shadowing from certain angles in the finished RTI file, obscuring some of the fine surface details in affected areas. Where this is caused by part of the target object itself (e.g. the projecting eaves of Lycian tombs), we refer to this as 'self-occlusion' (FIGURE 3). The H-RTI process is very unforgiving of even the slightest movement in the camera or spherical target during image capture and will result in a blurred final output. Set-up and photography are time-consuming and complex, requiring a small team of people working closely together to hold flash guns, string, and operate the camera.

RTI is now an established technology within the heritage sector and has wide applicability (Earl et al. 2010). Examples of artefact-based studies include cuneiform tablets (Malzbender et al. 2000), numismatics (Mudge et al. 2005), glass tesserae (Zanyi et al. 2007), lithics (Earl et al. 2010), ceramics (Bridgman and Earl 2012), and paintings (Padfield et al. 2005; Payne 2013; Manifredi et al. 2014). Used as a research tool, RTI has been applied in the analysis of palimpsests such as pentimenti on paintings (Padfield et al. 2005), the *chaîne opératoire* of worked bone artefacts (Newman 2015), tooling and modification marks on timber (Selmo et al. 2017), sequencing of text production (Zuckermann 2004), erasure and reworking of carved stone artefacts (Jones et al. 2015), overlaid graffiti (Duffy 2013; Frood and Howley 2014), and fingerprints on clay objects (Bennison-Chapman and Hager 2018). Field-based H-RTI has been applied successfully to the study of monuments and engraved stone reliefs situated outdoors (e.g. Mudge et al. 2006; Díaz-Guardamino et al. 2015; Frood and Howley 2014; Duffy 2013) but is not yet a standard recording technique on archeological surveys, despite its potential (Akçay 2016; Mytum and Peterson 2018).

Development of the V-RTI workflow

In addition to the existing D-RTI and H-RTI methods, the development of the V-RTI workflow now represents a new, third method of image acquisition for RTI analysis. It has a number of specific advantages over the other two methods with regards to its easy acquisition by stakeholders and its use in the field, particularly in the Near and Middle East where there are high levels of ambient sunlight, remote and inaccessible locations, and a need for speedy recording.

Having previously used H-RTI to record rock-cut reliefs in Turkey (Greaves et al. forthcoming), our aim in the *Carved in Stone* project was to train members of the heritage community in Turkey in the H-RTI capture method for recording rock-cut inscriptions and reliefs. During the project over 300 people attended RTI awareness training and 50 heritage professionals from universities, museums and freelance commercial heritage consultancies across Turkey undertook intensive practical training (see Supplementary Data). However, many of those who undertook the training reported difficulty in applying it in the field due to the complexity of the image capture process. There is, therefore, a significant barrier to the wider adoption of RTI as a method of field recording.

Mudge et al. (2006: 196) had previously noted that despite its many advantages (e.g. safe acquisition of data, fostering on-line collaboration and 3D representations of surfaces), the complexity of the then current dome-based (D-RTI) acquisition technique created a 'bottleneck' that slowed RTI's adoption. Others suggested that the slow uptake of RTI may be because it requires more skill than traditional digital photography, that it is not taught alongside other common field recording techniques, and that methodological guidance should be written in a non-specialist, user-friendly language (Kotoula and Kyranoudi 2013: 85; Beale and Beale 2015). Even though a newer image capture approach (i.e. H-RTI) had been specifically developed to eliminate some of the complexities and limitations inherent in D-RTI and is successful as a tool for cultural heritage recording and community engagement (e.g. Rabinowitz et al. 2010; Duffy 2008; Beale and Beale 2015), our experience suggests that a 'bottleneck' still exists when it comes to the application of RTI in the field. In developing the V-RTI workflow set out in this article, our priority has therefore been to establish a reliable and flexible approach that is straightforward for new users to learn, and requires a relatively inexpensive and lightweight field kit (i.e. a digital camera or mobile phone).

Our V-RTI workflow, summarized in Figure 4, builds on work previously done with datasets generated by LiDAR, 3DL and Structure from Motion (SfM) photogrammetry, (https://www.wessexarch.co.uk/news/interactive-landscape-relighting; Earl et al 2010b; García-Fernández 2015, respectively). In our workflow, SfM is used to produce a 3D data set of the resource to be studied and this forms the basis for the RTI (FIGURE 5). SfM has the advantage of also being a non-contact recording method that uses a relatively inexpensive tool kit - namely a digital camera (or even a mobile phone: Jalandoni and Kottermair 2017). Unlike RTI, SfM has the potential to generate metric data and is gaining popularity within the archeological community (e.g. Karauğuz et al. 2012; De Rue et al. 2013; McCarthy 2014; Wilhelmson and Dell'Unto 2015; Evin et al. 2016; Hixon et al. 2018). Being a rapid capture approach, V-RTI is well placed to record cultural heritage at risk in the field (e.g. Ashton et al. 2014; Fangi et al. 2013).

Firstly, a set of images are captured for SfM – i.e. a series of digital photographs of the subject which have at least 60% overlap. Where necessary, training in the SfM recording method can be delivered remotely allowing image acquisition in the field to be completed by local stakeholders. Where reliefs are located at height, the camera can be mounted onto a mast or monopod and operated remotely (FIGURE 6), or a selfie-stick if using a mobile phone. The image set is then processed using specialized software (Agisoft's Photoscan) to generate 3D geometry from the overlapping photographs by detecting and tracking movement of points of interest through the set (Agisoft 2018). Outputs from the processing technique include point clouds, orthographic images and 3D models (FIGURE 7).

Next, the resulting 3D model produced by the SfM is positioned within a VR environment using an advanced 3D graphics suite (in this case, Cinema4D). To replicate standard H-RTI image capture, a target with the same properties as an RTI target (i.e. reflective, black and spherical – a virtual billiard ball) is included in the capture scene. The surface of the model

and target is then virtually illuminated and rendered within the VR environment, with the target capturing the position of the light source in each image as it does in the standard H-RTI workflow. Finally, following the same approach used to create standard RTI files (see above), the image set is processed using RTI Builder and an interactive lighting file, referred to as an RTI or PTM depending on the fitting method, is generated and can be examined interactively using RTI Viewer (FIGURE 8).

Ancient and Modern Fethiye

Fethiye in southwest Turkey is the site of the Lycian city of Telmessos, or Telebehi in the ancient Lycian language (Zahle 1980; Bryce 1986; Keen 1998; Behrwald 2000; Domingo Gygax 2001; Schweyer 2002; Çevik 2012; Borchhardt and Bleibreu 2013: 40–42; İşkan and Dündar 2016). The precise geographical limits of Lycia are ill-defined until the Roman period but, during the Classical period, Telmessos is thought to mark its western border (Keen and Hansen 2004, citing Pseudo-Skylax 100 and Arrian *An.*1.24.4. See also Pliny *Nat.* 5.101). Lycia's distinctive material culture is typified by its mountainous limestone landscape, use of Lycian script, and many prominent tombs (Kuban 2016). There may have been settlements here from as early as the second millennium B.C. (Tietz 2003, 2016) but, as yet, no securely stratified Bronze Age finds are known. The Archaic and early Classical period city was located two kilometers to the east of Fethiye on a hilltop at Hızırlık (Buschmann 1993; Tietz 2003: 81–85) but later moved to its current location, closer to the superb natural harbour of the Bay of Fethiye, in the 5th century B.C. Although under Persian control from 547 B.C. onwards, Persian influence on Lycian architecture and culture is hard to identify (Kuban 2016; Özer 2014. Together with Xanthos, Pınara and Tlos, Telmessos was one of the big four settlements in western Lycia and it has its own mint, was mentioned in

Herodotus (Hdt.1.78, 1.84), and was a member of the Delian League and listed in the Athenian Tribute Lists (Zahle 1980; Keen 1993; Tietz 2003: 33–61). The largest settlement on the Gulf of Fethiye, it is nevertheless not considered to have been a *polis* in the sense that the concept has come to be understood for the Archaic and Classical Greek world (Keen and Hansen 2004; *contra*. Tiertz 2003: 297). Hellenistic period Telmessos became part of the Ptolemaic world after the death of Alexander the Great and, together with its membership of the Delian League, this marked a shift in its cultural orientation towards the west and away from Anatolia (Wörrle 1980). The Tomb of Amnytas (FIGURE 9) is the most outstanding example of the temple tomb style in Lycia and, together with other sites in western Lycia, shows that Telmessos was part of a distinct cultural grouping on the Lycio-Carian border region that came under strong Greek influence in the post-Alexander period (Keen 1998: 184–5).

Telmessos' cemetery was extensive and visitors approaching the city by land from the east would pass an impressive array of tombs. The necropolis' northern and southern limits are defined by the shore to the north and precipitous cliffs to the south, each marked by one of the city's most prominent ancient monuments – the so-called Great Lycian Sarcophagus on the shore and the rock-cut tomb of Amyntas (FIGURE 9). The ancient city's western and eastern limits are harder to determine due to Fethiye's urban sprawl but there are 36 known rock-cut house-tombs (Zahle 1980), extending from the *kale* (fortress) in the east and sporadically west along the cliffs towards Deliktaş, a kilometer to the east, as far as Hızırlık (FIGURE 10).

Despite their historical value, often very little is known about the earlier history of intensively occupied urban centers (Mayne and Murray 2001: 2). Fethiye is no exception and Werner Tietz has noted that the lack of systematic archeological research in Fethiye itself limits our understanding of regional dynamics (2003: 85). There had been no systematic archeological

research of ancient Telmessos until our own survey in November 2017 (the primary epigraphic study is Kalinka 1920; for brief historical syntheses see Marksteiner 2010: 39–43; Çevik 2012: 81–83; Tietz 2016: 340–5). In 1956 an earthquake leveled much of Fethiye and the resultant rubble was dumped in the harbor to create the foundations for the new city and, in doing so, altered the adjacent coastline (Bean 1978: 38; Çevik 2012: 81). Many rock-cut tombs and large sarcophagi survived both the earthquake and subsequent clearance but during the rapid rebuilding that followed some surviving remains were built over, or incorporated into, new buildings (FIGURE 2). In recent years booming tourism and rapid urban expansion have compounded pressure on Fethiye's remaining archeological assets, making this project timely for informing future urban development.

Research questions

In order to prove that rapid V-RTI recording can provide high-quality archeological data, even in complex and challenging environments, we conducted a survey that sampled a range of Fethiye's inscribed tombs to see if V-RTI could add to our understanding of the least well understood of Lycia's major cities. We applied for, and were granted, the permit to conduct an epigraphic survey of 78th Street (78 Sokak in Turkish). This is a densely packed area of convoluted backstreets that are too narrow for vehicular traffic and is positioned in what was once the center of Telmessos' necropolis between the Kale, the tomb of Amyntas, and the Great Sarcophagus (see FIGURE 10).

Stone-carved tombs are the most remarkable and enduring feature of Lycian material culture and they dominate every archeological site in the region (Zahle 1983; Bryce 1986: 116–29; Keen 1998: 182–192; Hülden 2006; Özer 2014; İşkan and Dündar 2016: 367–436). Jan Zahle's (1983) original typology of Lycian tomb styles included Heroön-type tombs (i.e. built

monumental tombs), pillar tombs, 'Gothic' sarcophagi, and rock-cut house-tombs. Oliver Hülden subsequently produced a more refined typology that categorizes vertically cut rock-tombs (including simple rock-cut 'pigeonhole' tombs and more complex façaded structures), sarcophagi, *chamosorion* (i.e. horizontally-cut rock-graves), tumuli, chambered tombs, podium- and terrace-tombs, and others. In 78th Street we documented three sarcophagi, one of which was inscribed, and six vertically-cut façaded rock-tombs, including five that were inscribed. Only a minority of Lycian tombs carry inscriptions and only seven inscribed sarcophagi are known (Zahle 1983; Keen 1998: 185). The nine tombs in 78th Street, therefore, represent almost a quarter of the known house-tombs in Fethiye (Zahle 1980 identified 36 in the city, although this excludes small pigeon-hole tombs), 1% of all known Lycian tombs (estimated at c.1051 by Keen 1998: 182), and one of only c. 400 known Lycian inscriptions (Bryce 1986: 42–98).

The 78th Street tombs have the potential to contribute to a number of key research themes in Lycian archeology. These themes include: (1) clarifying readings of previously known inscriptions and the discovery of new ones, (2) Lycian funerary practices, (3) the position of the élite within Lycian society, and (4) the changing cultural identity of Telmessos and its orientation towards Greek culture in particular.

On the first question, different scholars have proposed varying readings of the few Lycian inscriptions that do exist (see Tekoğlu 2016 comparing the readings of Kalinka 1901, Friedrich 1932, and Melchert 2001; see Supplementary Data). There are only five known Lycian inscriptions in Fethiye (Melchert 2001: Telmessos 1–5), one of which falls in our case study area, making it not only the most westerly known example of the Lycian script (Tietz 2016) but also the first ever to be analyzed using RTI.

Heads of households evidently commissioned tombs for their families while they were still alive, specified who could (and could not!) be buried in them, and even stated in which part of the tomb they wanted to be laid. They also named punishments for those who were buried without permission and made financial provisions for the *miñti* (cemetery commission), which oversaw the correct conduct of funerals and perhaps also maintenance of the cemetery itself (Bryce 1986: 121–5). In the Lycian epichoric period, from the 6th to 4th centuries B.C., the Lycian language and script had been most common but Greek came to predominate from the 4th century B.C. onwards (although see Hülden 2011 on 'epichoric' Lycian culture). The settlement of Telmessos/Telebehi is thought to have moved from Hızırlık to Fethiye sometime around the 5th century B.C. and most inscriptions in the city are in the post-epichoric language of Greek. This marks not just a change in language but also in funerary traditions. Greek inscribed tombs commonly include names added at a later date and this has been taken as evidence for the decline of the miñti as an institution with authority to ensure that correct burial protocols were being followed (Bryce 1986: 121–5). Again, V-RTI is an ideal technology by which to identify such epigraphic additions and modifications and for this reason it is our second research theme.

Our third theme is the changing position of the élite within Lycian society. Beginning in the 6th century B.C., purpose-built monumental tombs and pillar tombs are generally thought to have been the preserve of ruling dynasts (Kuban 2016). Vertically-cut rock-tombs with intricate carved façades that imitate wooden architecture became more widespread in the 4th century B.C., approximately 100–150 years after the first monumental tombs (Draycott 2015) and are thought to have been used by lower classes. Scholarly opinion differs about the significance of the increasing use of sarcophagi. It has been suggested by some that their increasing popularity signifies "a more egalitarian atmosphere removing social barriers to

such burials" (Keen 1998: 183) or some other phenomenon, such as increasing Carian cultural influence (Zahle 1983: 182).

Finally, and perhaps one of the broadest and most enduring research themes in Lycian archeology, is the question of Lycian identity itself. Lycian cultural identity has many unique features and each city or region also had its own tomb-carving tradition for executing façades with a common "modular system" element that reflected a shared understanding (Kuban 2016: 414). At different times during its history the region was also in contact with the Persian, Carian, and Phrygian cultures as well as different Greek regional influences, including Attic, Rhodian and Ionian. The extent to which Lycian culture became Hellenized by its exposure to Greece through, for example, its membership the Athenian-controlled Delian League or the commissioning of Greek artists by Lycian dynasts is much discussed (e.g. Bryce 1986: 11–41, 203–215; Keen 1993; 1998: 66–70; Tietz 2003: 33–61; Draycott 2015), as is Lycia's relationship to the classical world and classical archeology as a discipline in general (İşik 2016 and Hodos 2015, respectively). However, until now, there had been no systematic study of the funerary architectural traditions of Fethiye as a regional phenomenon in their own right and the city is often overlooked in regional studies (e.g. Telmessos is not included in Özer's 2014 catalog of Lycian sarcophagi). Understanding the evolution of Telmessos' identity as a Hellenized Lycian society is therefore our fourth and final research theme.

Results

Firstly, with the help of V-RTI we are able to publish here new readings of six previously-known inscriptions, one completely new inscription, and a new reading of the relief panel on Tomb Six (see Supplementary Data). Only on Tomb Eight, where the inscription was

exceptionally well preserved, were no new observations made. Given that the natural bedrock in Fethiye is prone to erosion, this shows the utility of V-RTI in this particular city and its capacity to add to Lycia's epigraphic corpus.

In relation to our second research question, Trevor Bryce (1986: 121–5) observed that the institution of the miñti disappeared from Lycian tomb inscriptions with the arrival of the Greek language and argued that without it to ensure correct funeral observances, names were added to Greek inscriptions in ways they had not been in Lycian. Bryce goes on to say that this reflects burials becoming more inclusive, rather than exclusive. However, our V-RTI analysis of the epigraphic palimpsests on Tomb Two shows that there was already a practice of over-writing in the Lycian epichoric period, although this appears to have been by total erasure of the earlier inscription rather than by the simple addition of new names and inscriptions. Given that the settlement is thought to have moved to Fethiye from Hızırlık in the later 5th century B.C., this would suggest that this practice, and possibly the decline of the miñti as an institution, was already underway at this time and certainly cannot be attributed to just cultural influences associated with the introduction of the Greek language. The naming of at least two different families on Tomb Six, or possibly three if the newly-discovered inscription on it were more intelligible, shows that, as Bryce had suggested, the attribution of tombs to different owners and even altering their decorative relief panels was certainly underway by the 2nd to 1st centuries B.C.

Thirdly, another debate in Lycian archeology has been whether the increased use of sarcophagi reflects a new spirit of social egalitarianism in Lycian history or just an increase in Carian influence (Zahle 1983: 182 and Keen 1998: 183–4, respectively). The pillar tombs that are associated with early Lycian élite burials are only known at the earlier settlement of Hızırlık (Buschmann 1993) and our survey identified no new ones. This may be read to mean that ancient Telmessos/Telebehi had become more egalitarian or had lost its status as a

dynastic seat during this period, but as so much of the later city was leveled and built over after the earthquake of 1956 we should be cautious not to read too much into an argument made on the absence of evidence. However, there is nothing 'modest' about the prominent positioning of Tombs Four and Six, and certainly not the shameless ostentation of the Tomb of Amnytas. Indeed, the prominent positioning of Tombs One to Four, with Tomb Six in front of them, along a natural ridge below the Kale that was the core of the Classical period city (Tietz 2003, 2006) is reminiscent of the "monumentalized skyline" of Xanthos (Draycott 2015: 97). However, this skyline is now obscured by the construction of so many houses around and in front of this important tomb group (FIGURE 11).

Finally, let us consider what our new evidence tells us about the identity of the Telmessian community itself. The 78th Street survey allows us, for the first time, to begin to think about the archeological remains that pepper Fethiye's backstreets as a coherent "tombscape" (Small 2015: 78, quoting Cook 2011: 5). Until now, Fethiye's archeology had been, literally and figuratively, dominated by the iconic temple-tomb of Amnytas and its strong Greek aesthetic (FIGURE 9) but without systematic study of the city's remaining tombs to put it into context, we have not previously been able to understand how typical this iconic tomb was of the community's identity as a whole – be it Hellenized or otherwise. Attempts to categorize Lycian tomb architecture as a whole fail because each community or region exhibited its own variant practices (Zuban 2016). Telmessian funerary culture is not well understood, but it is known that tombs in Fethiye often feature applied rock façades (Kuban 2016: 417). The 78th Street tombs fit general patterns observed elsewhere in Lycia – such as the use of the 'modular system' on carved tomb façades – but also make use of full (e.g. Tomb Five) or partial (e.g. Tomb Seven) use of applied rock façades. However, as Laurence Cavalier (2017) observed at Xanthos, the use of applied façades is most probably a product of the quality of the natural bedrock, rather than a defining cultural characteristic. In 78th Street, the rock on

the east side of the road is generally of poorer quality than that on the west. There is more use of applied façades here and the lid of Tomb Six, which has four lifting lugs, featured a defect with one of the lugs being off-center. This side of the lid was then turned away from the decorated panel side, showing an awareness of 'frontality' in the way the tomb was intended to be viewed from the west. Although not unique to Telmessian funerary culture (see Draycott 2015 and Cavalier 2017 on Xanthos), this reflects an awareness of how positioning of the decorative elements that carried symbolic meanings affected how those elements were viewed by others, in this case those approaching the city from the west by road.

Discussion

The V-RTI Workflow

The results presented above and in the Supplementary Data show that the V-RTI visualization method is a viable alternative to H-RTI and has a number of key advantages. Given the range of imaging contexts and resources recorded for this project, V-RTI has proven to be a beneficial analytical tool that facilitates a synergy between 2D+ and 3D technologies (i.e. RTI and SfM) creating new opportunities for visualization, research, and collaboration.

Other digital recording methods common in urban archeology, such as LiDAR, laser scanning, and terrestrial and aerial photography, can be used for 3D processing but face challenges from adverse weather, prohibitive costs, and transporting equipment to site (Bitelli et al. 2018; Remondino 2011). Complex built environments also pose logistical challenges from manmade features that can lead to holes in the data and limit time for data acquisition due to commercial or political considerations (Bitelli et al 2018; Davies and Parker 2016;

Remondino 2011). To overcome these logistical challenges, authors highlight the importance of an integrated recording approach (Mayne and Murray 2001; Remondino 2011; Davies and Parker 2016). Bitelli et al (2018) specifically consider the use of SfM in urban settings, highlighting the importance of speed, reduced tool kit, imaging team (i.e. single operator), and elimination of external power sources. They also point out that SfM provides opportunities to capture data in situations to which access would otherwise be unsafe (Bitelli et al 2018) and this is one of the key advantages of V-RTI over standard H-RTI in the field.

Although the high-resolution information about surface texture provided by standard RTI is attractive, the V-RTI capture approach using SfM featured here affords users the opportunity to record resources of a larger size (e.g. over 1.5 m), that are located at height, or have more complex geometry (i.e. self-occluding features can be cropped). Moreover, metric data can be captured in instances where a scale bar is incorporated into the image scene. While both RTI and SfM provide an opportunity to produce a digital surrogate with empirical provenance (Mudge et al. 2008), the V-RTI visualization approach provides enhanced objectivity over H-RTI because it is not necessary to pick just one view of a subject whilst in the field. The surface can be re-interrogated and illuminated from different positions after image capture, allowing a reflexive approach to analysis and future re-investigation of the digital surrogate, perhaps in light of new research questions, even if the original monument has been subsequently destroyed or damaged – which is a key consideration in the Near and Middle East.

Whereas using SfM image capture can be undertaken with a smaller recording team in the field (one person is usually sufficient), our training experience suggests that a minimum team size of three is optimal for H-RTI (see Supplementary Data). Ambient light levels are a major problem when using RTI in Mediterranean and Near Eastern climates but this too proves to

be less of an issue with V-RTI. Finally, the key advantage of our V-RTI image capture approach is the opportunity to record heritage at risk in challenging outdoor conditions using a rapid, non-contact image acquisition method with a highly portable and easily sourced tool kit, allowing monuments that are in imminent danger to be recorded swiftly. Once recorded, they can then be rapidly re-recorded at a later date to allow for periodic conservation monitoring of on-going degradation caused by human or natural causes, or after conservation interventions. Because the model can be manipulated digitally before the RTI is captured, it is also possible to align RTIs from different years or record incidents to more clearly illustrate any changes.

However, V-RTI is not without its disadvantages. The primary challenge of using V-RTI is the required processing skill set, higher specification hardware, and licenced software. The licenced software packages used in our V-RTI workflow are relatively costly compared to RTI software and although open source options with the desired functionality may exist, they were not explored during this project due to time limitations. Furthermore, the quality of the finished V-RTI is largely based on the quality of the model produced. Tomb Seven was recorded using V-RTI by mobile phone and standard H-RTI. Comparison of the two appears show that H-RTI by a D-SLR camera provides more accuracy in terms of very fine surface topography (see Supplementary Data) due to the lens quality of the mobile phone used but also the resolution at which the SfM is processed (see below). The results are, nevertheless, exciting as they suggest that good quality V-RTIs can be produced using equipment to which almost everyone has access (Greaves et al. forthcoming). Furthermore, even in ideal conditions there is still a risk of camera shake interfering with the H-RTI photographic capture; therefore V-RTI's flexibility in challenging field-based situations is a major advantage over H-RTI.

As discussed above, there is a direct correlation between the settings used to process the SfM model and the resolution of the finished RTI – i.e. the higher quality the 3D model, the better the final V-RTI. Generally, higher quality models depend on the capture of larger and higher resolution datasets, as well as processing those images on the highest resolution settings possible. However, although processing on 'Ultra High' may result in a near-equivalent result to standard H-RTI, it requires much higher specification processing power (i.e. RAM and graphics card) and processing time. In this sense V-RTI is unlike standard RTI processing, which can be undertaken on most personal computers and laptops.

The specularity characteristics (i.e. the reflective properties) of the surface are not captured when using V-RTI and there is also the potential of some loss of very fine detail depending on the quality of the image sets and processing specifications and these are disadvantages when studying fine surface texture details, such as very fine tooling. However, for our stated aim of developing a method of rapid in-field recording these are not a major hindrance.

Finally, it is not advised to consider any form of imaging absolutely objective since each one is the product of certain choices and interpretative pathways determined by the people who captured and then processed them (Daston and Galison 2007, esp. 125–173). Based on this, and the fact that technology is always advancing, we should not consider the potential of datasets to be exhausted once the output has been generated and it would be advisable to archive the RTI files together with their originating photoset, ideally in .RAW or .DNG format, for future research, condition monitoring or for use with other digital applications (e.g. D-Stretch, see FIGURE 12).

The archeology of Telmessos (Fethiye)

Our survey of 78th Street allows us, for the first time, to begin to understand Telmessian funerary culture as a dynamic phenomenon and how the 'tombscape' that greeted visitors to the city was negotiated over time. V-RTI made this possible not just because it is well-suited to use in urban environments but also because it allowed us to record very inaccessible or very large inscriptions (i.e. Tomb Six and Tomb Seven, respectively). In the VR environment we were able to crop out the distinctive projecting eaves of Lycian vertically-cut house tombs that would otherwise have caused self-occlusion of the RTI image, permitting more detailed examination of the fine surface detail than is available by any other workflow. The resulting RTI files helped us to produce new readings, a new inscription, and series of palimpsests that, combined with other digital recording methods, field observations and antiquarian sources, significantly change our understanding of the history and identity of Telmessos.

The elements of the necropolis that could be said to be most typically Lycian are the tomb forms themselves, the monumentalized skyline that they form, and their clear engagement with general Lycian epigraphic and funerary culture. Following the typology proposed by Hülden (2011), the 78th Street tombs include six vertically-cut house tombs (Tombs One, Two, Three, Five, Seven and Eight), three sarcophagi (Tombs Four, Six and Nine) and possibly one horizontally-cut *chamosorion* adjacent to Tomb Six. Together, they formed a monumentalized skyline (Allan 1843; Texier 1882; see Supplementary Data), reminiscent of western Lycia's most important power center, Xanthos (Draycott 2015, Cavalier 2017). This skyline would have been particularly impressive to those approaching the city by land from the west, where a major route connected it to Xanthos and the other major Lycian cities in the Xanthos Valley, via Hızırlık (Buschmann 1993). The phenomenological impact on its viewers of such a skyline as an expression of power, specifically Lycian power, should not be underestimated (c.f. Greaves 2010: 180–193 on sacred ways in Ionia). The inscription on Tomb Two is typically Lycian in character, a funerary inscription in the Lycian script making

provision for the miñti, but with the help of V-RTI we can see that there had been an earlier inscription, presumably also in Lycian, that had been completely erased. This shows that re-using tombs, which has been assumed to be introduced at the end of the Lycian epichoric period and the decline of the miñti as an institution under Greek influence (Bryce 1986: 121–5), was already an established Lycian practice, that dedications to the miñti endured despite this, and that this was perhaps not so much a cultural shift associated with Greek influence as a change in epigraphic practice (i.e. moving from total erasure of the names of previous owners, to the simple addition of new names and texts, c.f. TL2 on Tomb Two with TAM II 50b on Tomb Six). Further V-RTI analysis of other Lycian funerary inscriptions will, hopefully, be able to confirm such a hypothesis.

The extent to which Greek culture came to predominate in Lycia is especially relevant to any discussion of Telmessos' identity as it was the westernmost of the major Lycian cities and therefore geographically and, it is often assumed, culturally the closest to Greece. Identifying truly Telmessian elements of the city's funerary culture is difficult but the default assumption that the city's Classical period identity was Hellenized by its proximity to Greece is geographically determinist and culturally problematic.

Graffiti, which is often overlooked or dismissed as mindless vandalism by academics, plays a vital role in helping us to understand the changing character of Telmessos. Our V-RTI analysis of the Lycian inscription on Tomb Two shows that the tomb's Lycian identity was consciously subverted and its Lycian characters were overwritten to modify them into Greek letters. This was an active decision made by a later generation of Telmessians not to erase or vandalize this prominent Lycian monument in their midst, but rather to actively Hellenize it. The fact that the same tomb was, presumably at a later date, 'baptized' by the addition of two crucifixes shows that this quintessentially Lycian feature of the tombscape was being actively negotiated into the city's new identity as a Christian community over a period of at least one

millennium. Indeed, by virtue of its enduring prominence, Tomb Two remains a "privileged site" (Taş and Taş 2014: 327) within Fethiye's urban public space and it attracts the attention of graffiti artists to this day (FIGURE 12).

Antiquarian interest in Telmessos also generated a graffiti tradition of its own, beginning when the famous French antiquarian Charles Texier inscribed his name prominently above the door of the Tomb of Amyntas in 1882 (FIGURE 9, inset). Travellers, like the British antiquarian John H. Allan (1843), were attracted to Fethiye (then known as Makri) by contemporary Western culture's fixation on Classical Greek culture, such as the Great Sarcophagus which Charles Fellows had earlier described as "a valuable monument … of more simple beauty than is found in any age but that of the purest Greek art" (1852: 303). Following Texier's egregious example, British, French and German sailors then proceeded to incise their names and those of their ships into the façade of the Tomb of Amyntas which can be clearly seen by ships approaching the city by sea. Indeed, there are now so many historic graffiti on the tomb's façade that it has become a veritable historical document of Fethiye's cosmopolitan history as a trading port worthy of study in its own right. This shift in attention away from the monumental skyline of 78th Street towards the Tomb of Amyntas also marks a shift in the city's orientation away from the Anatolian interior, when it would be approached by road, towards a more a maritime outlook, where it was primarily approached by sea. However, in doing so the city still continued to greet its visitors with a monumentalised skyline in a manner that is now identified as being characteristic of Lycia and an expression of Lycian cultural agency and identity at a time when Greek culture predominated.

This antiquarian legacy continues to inform how we discuss the city's history, and the cultural parallels we draw between Lycia and Greece. For example, there is an assumption that the interior structure of Lycian tombs took their architectural inspiration from the Greek *andrōn*, or dining room (Aktaş 2016). However, we know virtually nothing about Lycian

domestic architecture and therefore cannot say how it relates to contemporary funerary traditions. Also, although they were multi-functional family spaces, the most common understanding of Greek *andrōnes* was as a male space (Hobden 2014), yet we know from Lycian sepulchral inscriptions that these tombs were for families. The arrangement of space within the Greek *andrōn* also suggests it was an egalitarian space for male peers, but some Lycian inscriptions designate specified *klinē* for the head of household, which is somewhat at odds with any putative egalitarian ethos (on the Anatolian origins of the funerary *klinē* tradition see Baughan 2013).

The very presumption of a movement towards increased social egalitarianism is itself a projection of a master narrative from classical Greek archeology onto Lycia – in this case that the course of Greek history led inexorably towards the emergence of an Athenian-style democracy and that this social progression can be traced in sumptuary practices in Greek burial archeology (Small 2015). The argument goes that élites were forced to restrain their luxurious funerary displays in deference to the democratic zeitgeist of classical Athens. However, David Small (2015) has argued that sumptuary laws, far from constraining élite displays of wealth may, in fact, have served only to consolidate the standing of élite families within society and suppress aspirant middle classes. Small also notes that it is not just the construction of tombs that reflects a family or individual's élite status but also expenditure for the on-going maintenance of that tomb. One could ask for no better evidence of such elaborate maintenance practices than endowing the miñti with payments to oversee correct funeral standards and, as it is commonly presumed, to see that graves were properly maintained. Interestingly, even though the amounts paid to the miñti appear to have been relatively small, they were deemed worthy of being included in funerary inscriptions on tombs as a demonstration of deceased's commitment to the maintenance of their family's tomb after death. In Lycia, sacrifices were made to the dead, which is a practice that has a

long history in Anatolia (İşkan 2004) but is thought to be almost unique within Classical Asia Minor (Bryce 1986: 127; Hülden 2006: 294–315). The recent discovery of an undisturbed tomb at Tlos also shows that there were multiple post-funerary acts of votive dedication (İşkan Işık 2009). In 78th Street, the addition of three senatorial figures to the relief panel on Tomb Six, together with its physical prominence, might appear to counteract any claims to egalitarianism in Telmessian funerary culture.

Conclusions

The development and application of V-RTI presented in this article means that there are now three ways by which image sets can be captured and then processed into interactive digital RTI files. Each method has its own advantages and disadvantages and should be selected according to the specific nature of artefact being recorded. During our rapid urban survey, V-RTI allowed us conduct analysis of the surface details of the inscribed monuments in their proper context and led to important new discoveries, such as palimpsests and even the discovery of a new and previously unsuspected inscription (TAM II 50c).

The features of the V-RTI workflow that made this possible were the ability to use it at height (FIGURE 6), the ability to crop out the projecting tomb lintels that cause self-occlusion (FIGURE 3), the ability to use it in open areas where there are high levels of ambient sunlight, the flexibility to process targets larger than 1.5 m in length (FIGURE 2), the lack of cumbersome equipment, and the speed with which it could be used in the field.

However, the biggest advantage of V-RTI is undoubtedly that it overcomes the ‘bottleneck’ in the acquisition of the photographic image capture process by new users. The required precision of the process has been a recognized obstacle to the wider adoption of RTI almost

since its first inception and has severely limited its uptake by communities within the heritage sector that could potentially benefit from it most. Our experience on the Carved in Stone project has been that, although trainees were enthusiastic about RTI's potential, they generally had more confidence in processing the photos on computers rather than capturing the original image sets themselves. We therefore developed a workflow making this initial step, where time, good weather conditions, and resources may be limited, more straightforward. Other advantages of V-RTI to make it attractive to heritage users are the size of the minimum field team needed to operate it and the relatively low cost of the outlay for photographic equipment.

Processing V-RTI images does still require considerable technical expertise, high specification computer hardware, potentially expensive software, and a lot of time. It is, therefore, not necessarily cheaper or more straightforward to process than standard D-RTI and H-RTI workflows. However, neither is it necessarily inferior in terms of the quality of the outputs, if the inputted data used is of a sufficiently high quality and processed to a high resolution. 3D data can also be manipulated in the post-processing stage to manage issues such as self-occlusion, which has always been a limitation of D-RTI and H-RTI, and allows the image capture viewpoint to be re-positioned and re-run virtually, without needing to re-visit the field.

While advocating the adoption of V-RTI as a default recording technique for rock reliefs at risk due to its speed and flexibility, we emphasize the value of an integrated, reflexive approach that recognizes the value of many different digital recording systems. Our extensive experience of teaching and demonstrating RTI to potential users has shown us that RTI's interactivity and the fact that it enhances the legibility of inscribed surfaces makes it appealing to researchers and the public alike. It is these advantages that will contribute to the technique's wider adoption as a research and conservation tool. Furthermore, the successful

generation of V-RTI outputs using mobile phone data enhances its potential as a method for rapid community-based activist archeology and recording by trained non-archeologists, such as security services or members of the public, in areas where archeology is at high risk.

Geolocation Information

Fethiye, Muğla Province, Turkey: 36.6592° N, 29.1263° E

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LIST OF FIGURES WITH CAPTIONS

Figure 1: A rock-relief of a disk and stele at Seki-Eceler Höyük, Muğla Province (Turkey) that has been bisected using quarrying machines. The human figure in the center provides scale. Since this image was taken in 2014, other reliefs at the same site have since been attacked with dynamite. Photo Credit: Alan M. Greaves.

Figure 2: Tomb Seven. Note how the foundations of a building incorporate the tomb structure and how cracks in the rock have become colonised by fig trees. Photo credit: Alan M. Greaves.

Figure 3: Lycian Inscription over the entrance to Tomb Two in (a) H-RTI and (b) V-RTI.

Image credits: Sarah Duffy, Alan M. Greaves, JR Peterson.

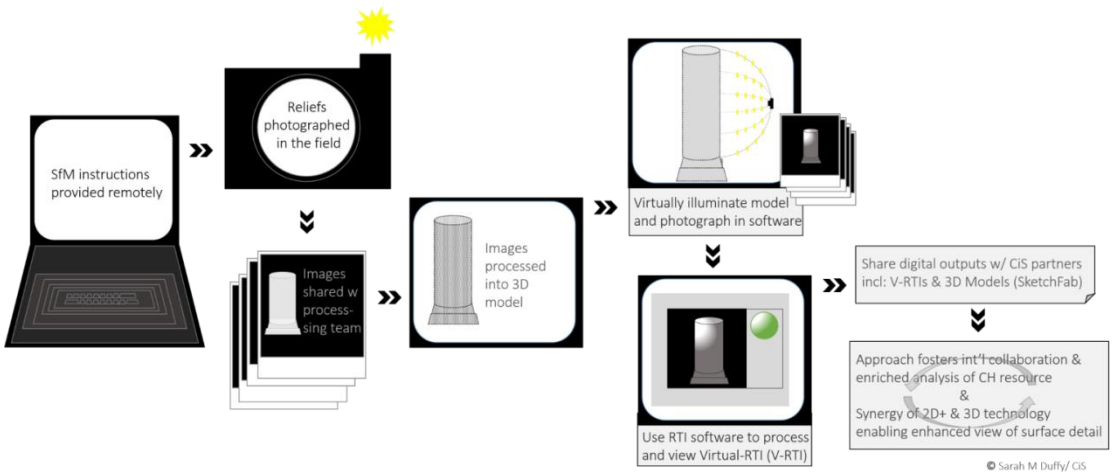

Figure 4: The V-RTI workflow. Image Credit: Sarah Duffy.

[In-line 3D interactive model will be included here in the publication]

Figure 5: 3D model of Lycian Inscription over the entrance to Tomb Two. Image Credit: JR Peterson and Alan M. Greaves.

Figure 6: V-RTI recording of Tomb Six in 78. Sokak using a remote controlled digital SLR camera on an extensible monopod, viewed from ground level. Image credit: Alan M. Greaves.

[In-line 3D interactive model will be included here in the publication]

Figure 7: 3D model of inscription and relief panel on Tomb Six. Image Credit: JR Peterson and Alan M. Greaves.

Figure 8: Screenshot of V-RTI recording of the inscription and relief on Tomb Six. Image credit: Sarah Duffy, Alan M. Greaves, JR Peterson

Figure 9: The Tomb of Amnytas, Fethiye. (Inset: Charles Texier's graffito above the door of the tomb). Image Credits: Alan M. Greaves.

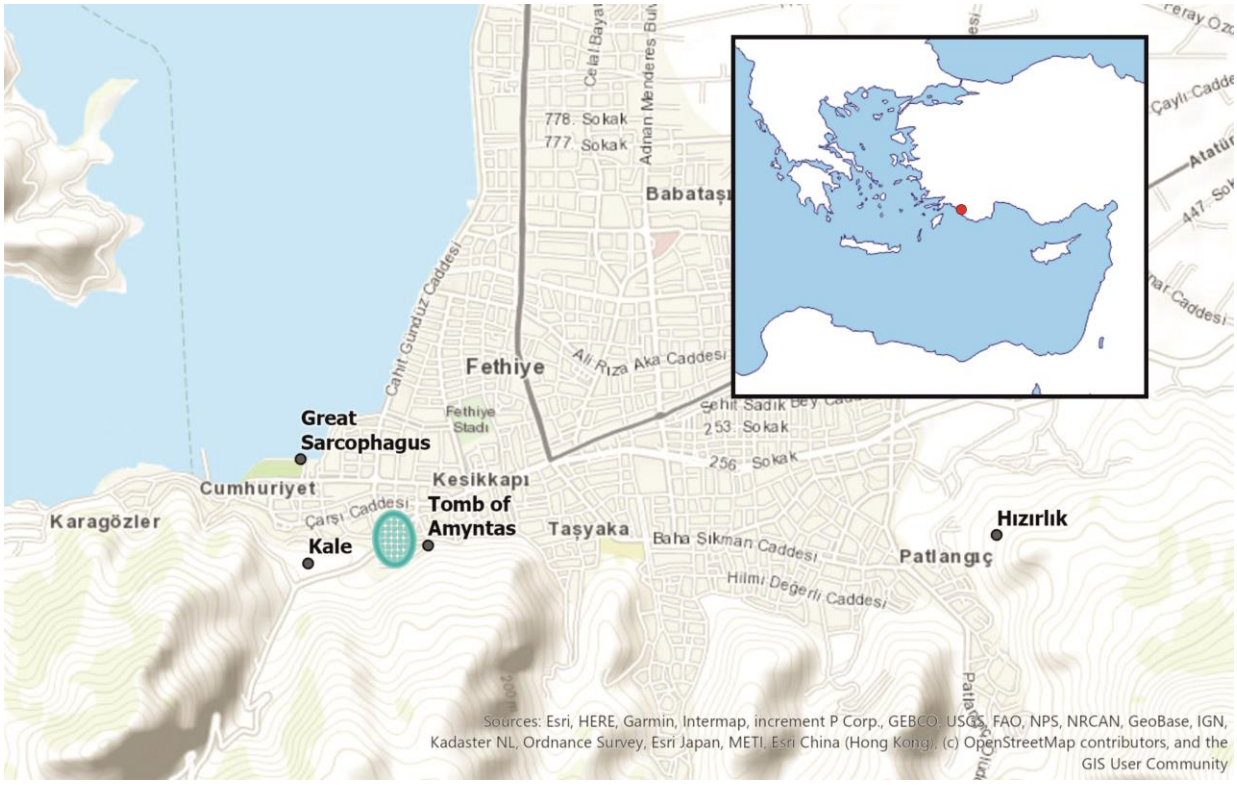

Figure 10: Map of Fethiye showing major monument. Shading indicates the survey area.

Image credit: Dan Socaciu.

Figure 11: Rock-cut tombs on the west side of 78. Sokak, Fethiye. (From left to right: Tombs One, Two, Three, and Four). Image Credit: JR Peterson.

Figure 12: Lycian Inscription over the entrance to Tomb Two in DStretch. Image credits:

Sarah Duffy, Alan M. Greaves, JR Peterson.