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A combined use of image and range-based data acquisition for the three-dimensional information mapping archaeological heritage

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ABSTRACT

Acquisition of accurate archaeological heritage data is fundamental for the prospective steps of architectural conservation process. As of today, digital data capturing technologies such as image-based and range-based systems are rapidly becoming prevalent and generating digital surface representations of the object(s) in the form of three-dimensional point clouds. Point clouds assist heritage experts to carry out heritage analysis in digital forms, in particular to conduct condition assessment based on orthophotos of archaeological assets. In this paper, we introduce an integrated strategy by using Terrestrial Laser Scanning (TLS) and photogrammetry for the scope of obtaining orthophotos as basis for analyzing geometric, texture and color information of archaeological remains. Such a combination allows overcoming insufficiencies especially in terms of color due to the high natural light exposure. To remedy such visual obstacles, this paper demonstrates results to generate maximum visual data coverage of an archaeological heritage asset for the conservation process.

1. INTRODUCTION

Archaeological heritage fosters heterogeneous data types and information (Cipriani & Fantini, 2017). The scale of these data differentiates from microbiologic formation on a stone element to remains of an ancient mega structure. The surveying of these data to a maximum level plays a significant role for the sustainability of heritage information, hence the conservation process.

Immersive data acquisition technologies such as Terrestrial Laser Scanning (TLS) and photogrammetry provides accurate three-dimensional (3D) visualizations of the heritage assets` *as-is* state. Guidelines and strategies from suggestive studies have shown benefits of implementing TLS and photogrammetry in terms of high accuracy in the 3D recording of the archaeological heritage (English Heritage, 2011; Historic England, 2017). Surveying outputs, like point clouds and orthophotos, are essential to convert heritage data in architecturally elaborated datasets. With the help of these visual outputs, acquired data and information mapping about the asset could directly be represented and identified for heritage analysis (Chiabrando, Sammartano, & Spanò, 2016; Letellier, 2007). These visualizations could be presented either as 2D drawings and 3D models, and provide a basis for information mapping purposefully carried out (Santana-Quintero & Addison, 2007).

Heritage analysis illustrates, the material aspects, physical condition assessment of the remains and historical background of the assets` lifecycle (Arnold & Geser, 2008). The information assessment regarding building materials such as material types, decay patterns, deteriorations and failures is not only encouraged, but also strongly recommended for supporting the conservation process (ICOMOS, 1964, 1990, 1999). Digitally generated outputs have strong affordances as such actions. For instance, orthophoto based analysis of material types and deterioration patterns is a well-established approach in terms of conservation process (Cheng & Han, 2016; Chiabrando, Lo Turco, & Rinaudo, 2017; Dionísio, Martinho, Grangeia, & Almeida, 2013; Dore et al., 2015; Stanga et al., 2017). Orthophotos are particularly helpful for information mapping as the required surface, such as

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color and shape, data could be mirrored digitally. Such orthophotos should accommodate high-resolution properties and accurate colors to assess the visual aspects and support heritage analysis. To achieve that, data acquisition techniques and selection of surveying method play a critical role, defining the qualities of the surveyed data such as point clouds.

3D data capturing technologies provides accurate and precise dimensional digital visualizations of the heritage asset, with that acquisition methods heritage analysis is quite achievable. Yet, depending on the physical conditions sometimes this data could not be as salvageable in terms of analytic studies.

Furthermore, it is quite common to face data loss due to natural light exposure during TLS, which in turn creates a monochromic dataset, point cloud and orthophotos. Such a result is not viable when it comes to the 1:1 scale requirement when conducting archaeological heritage analysis.

This paper addresses maximizing the visual qualities of the orthophotos and illustrates the orthophoto rendering process and 3D model and proposes a strategy to combine TLS and photogrammetry to support heritage analysis, and in turn benefit conservation process. We focus on archaeological remains, in particular, work on the *Heroon* remains located at the *Erythrae* archaeological site, on the west coast of the Karaburun peninsula in Izmir, Turkey.

2. LITERATURE REVIEW

Digital data acquisition methods have been used in the field for over twenty years and are well recognized for surveying archaeological heritage subjects (Del Pozo et al., 2020; Fiorillo, Jiménez Fernández-Palacios, Remondino, & Barba, 2015; Şasi & Yakar, 2018, Yakar et al., 2010). These digital data acquisition techniques allow gathering 3D geometric point clouds, which are basically surface visualization of the object formed by 3D points with color data.

TLS method is among the most widely used technique for the reality-based documentation (Holden, Silcock, Arrowsmith, & Al Hassani, 2015), geometric and 3D textured visualizations purposes in the field (Fiorillo et al., 2015). Visualization of material deformation, structural monitoring and digital management are extended forms of TLS utilization for archaological heritage (Del Pozo et al., 2016; Fregonese et al., 2013).

Photogrammetric data acquisiton is widely acknowledged as an efficient documentation methods in the field, as well (Yilmaz, Yakar, Gulec, & Dulgerler, 2007). Moreover, photogrammetry has extensive usage from virtual reconstruction, material analysis, and to a small object modelling in the archaeological heritage (Pierdicca, Frontoni, Malinverni, Colosi, & Orazi, 2016; Porter, Roussel, & Soressi, 2019; Trizio, Savini, Giannangeli, Boccabella, & Petrucci, 2019).

These methods have advantages, but they are not free from limitations. Surveying archaeological heritage asset with TLS stands out as time consuming as well as costly since it requires tedious on-field setup, device maintenance, and highly priced equipment (Zeybek & Kaya, 2020). On the other hand, photogrammetric surveying is considered as cost-effective, accurate and easily accessible (Georgopoulos & Ioannidis, 2004; Zeybek, Şanlıoğlu, & karauğuz, 2013).

Nevertheless, only a few studies extend these innovative applications to professionally applicable use complementary to conservation process. For instance, Corso, Roca, & Buill (2017) suggests a methodology to illustrate material loss on a 13th century Cathedral using TLS point cloud and generated orthophotos. Another research shows weathering on a 12th century church facade, from orthophotos rendered by TLS point cloud which are supported with radiographical sensory device (Del Pozo et al., 2016). Gaiani and others (2017) propose a methodology to automatically provide color equalization of an 16th century heritage building by photogrammetry. In that research, authors use color checkers and have more realistic chromatic representation of the building's façade surface with corrected texture map. Even though, Gaiani et al. (2017) achieves a color fidelity, the results are limited to 3D facade visualizations.

Although, these studies successfully represent geometric accuracy and façade pathologies by using point clouds, texture maps and orthophotos, cannot fully foster a semantic 3D dimensionality in the scale of archaeological heritage, especially in the archaeological remains which are Greek or older. In such cases, there is a lack of dominant verticality (such as facades), and the research methods offered for successful condition assessment of building facades for architectural conservation, fail to respond the needs of efficiently documenting archaeological remains elaborately for analysis.

3. METHOD

In this paper, we offer 3D textured visualizations as surface modellings and methodology benchmarking by the integrated use of TLS and photogrammetry to provide effective and accurate visual outputs for heritage analysis. We focus on the combination of two surveying methods potential for heritage analysis, particularly for archaeological heritage dating before the *Common Era*. Our research differs from the previous research on two counts: 3D data acquisition and developing semantic surface image renderings. We chose TLS as for the primary surveying but resulting data was not salvageable enough for an archaeological heritage asset. That prompted us to re-surveying, we implemented ground-based photogrammetry to compensate the gap in the data. In addition to surveying decision, we rendered ample amounts of orthophotos as parallel to every surface both horizontally and vertically to have information mappings on the assets` modelled survey, not to have textured 3D representation of the survey data. More importantly, our case, dating back to 4th century BC, requires a different approach of representation due to its historical and physical characteristics of *in-situ* remains. Besides, calling the case *Heroon*, we think a Greek temple like building, which is architecturally distinctive with respect to its scale, construction system and material aspects.

Architecturally, this kind of typology requires a close look at the element scale in the conservation process. For example, Heroon had walls, but *in-situ* remains should be evaluated stone by stone. As a result of these particularities, the surveyed data management is dissimilar to the studies mentioned in Section 2.

4. *IN-SITU* REMAINS OF THE *HEROON*

The *Heroon* remain is situated at the northern part of the archaeological site of *Erythrae* (Figure 1, Figure 2)). The remains occupy a rectangular area of 10 by 18 meters at sides.

A scripted graph, points the main construction dates to 4th BC (Engelmann & Merkelbach, 1972). The meaning of the *Heroon* originates from the word 'heroin', and signifies sacred places in the forms of temple-like tombs of important people of the time (Andronikos, 1980). Nevertheless, there is no further information regarding its historical background. In fact, the scarcity of the information is not limited to that, there is also no architectural documentation of the remains since its discovery in 1965.

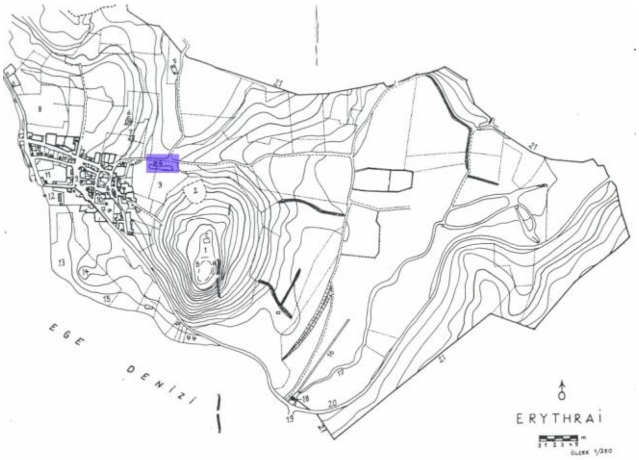

Figure 1. Location of the Heroon in Erythrae, based on the map by Akurgal (1979)

Figure 2. A drone image of the Heroon from above in 2019 (taken by the excavation team)

5. SURVEYING CAMPAIGN – KEY ASPECTS

In this paper, we focus on the data acquisition, from raw data like geometric values (i.e., height and depth) to metadata such as point cloud and orthophotos, of the in-situ remains. We carried out data acquisition at the location in two campaigns first by TLS in August 2019, and second by photogrammetry in November 2019. Our paper does not extend to any coupling with an excavation campaign since the remains are on private property.

We planned the survey for the requirement of 1:1 drawing scale. We used *TLS FARO Focus S 350* for TLS which provides under 2mm measurement accuracy (URL-1). Additionally, for the second surveying, we worked with ground-based photogrammetry (with *Canon EOS 200D*) method to benefit from 4-10 mm at 100m geometric accuracy that it could afford (Vanneschi, Eyre, M., & Coggan, 2017). The workflow of this approach is as follows; I) data acquisition, ii) point cloud generation, iii) point cloud alignment, iv) orthophoto rendering and v) model concept.

5.1. Data Acquisition

5.1.1. Terrestrial Laser Scanning

We scanned the *Heroon* by renting *Faro Focus S350* terrestrial laser scanner in August 2019. Scanning took place with 24 colored scan positions (Figure 3). Target spheres and target papers was placed in the scanned area for registration purposes. Each scan lasted between 8 to 9 minutes and resolution parameters set to ½ (high) (Table 1).

Table 1. TLS Parameters

Faro Focus S 350	
Resolution	1/2 (High)
Quality	2x
Scan Time	8-9 mins
Angular Area (Vertical)	90^0 to -60^0
Angular Area (Horizontal)	0^0 to 360^0
Target Type	Sphere and Paper
Coordinate System	Local (GPS)

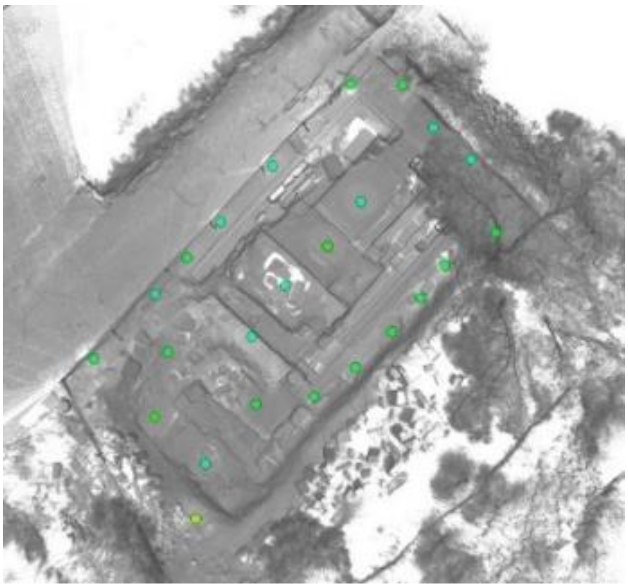

Figure 3. The scan positions (green dots), and gray scaled point cloud of the Heroon remains.

After that, we imported the raw scans through the scanner`s processing software, *Scene*, and processed and performed registration. Following scan registration, point cloud data rendered reaching 680 million points. Although, surface geometry generated to test the point cloud was favorably accurate and factual, the point cloud itself was not be sufficiently colored due to the high intensity of the natural light exposure during the scanning process. That showed insufficient results in testing as almost monochromic orthophotos, which creates an obstacle for the next steps of the research. To mitigate the data gap, we revisited and performed with photogrammetry in November 2019.

5.1.2. Ground-based Photogrammetry

For the ground-based photogrammetry, we used Canon EOS 200D DSLR camera with 35mm fixed lens (Table 2). We gathered 2709 photographs in JPG format, of each overlapping at least two-third of the previous one for the maximum convenience of the photogrammetric survey as well as the *Agisoft Metashape Professional* (Version 1.5.2) photogrammetry software (Agapiou & Georgopoulos, 2006). *Agisoft Metashape* allows automatic generation of a sparse cloud based on the structure from the motion (SfM) algorithm (URL-3).

The white balance of the images has been decided in accordance with the built-in auto ambient priority of the camera considering the climatic condition of the site which was dry and unpolluted in consequence of previous rainfalls.

Table 2. Canon EOS 200D Specifications (URL-2)

EOS 200D 24.2MP DSLR Camera	
Effective Pixels	24.2 P
Sensor Type	CMOS
Sensor Size	22.3 x 14.9mm
Focal Length	f/2.8
ISO Rating	ISO 100 - 25600
Image Processor	DIGIC 7

Following the fieldwork, we imported raw images into the *Agisoft Metashape* photogrammetry software for the alignment. We aligned photos in one chunk, also rendered sparse point cloud with medium accuracy setting selected (Figure 4). This process took 14 hours with 16 GB RAM configurated computer. At the time of photogrammetric data capturing, we could not measure control points with a total station since the equipment was not available. Instead, we re-used the coordinates of 11 targets from TLS scans by importing them before the dense cloud calculation. Next, with medium accuracy and aggressive filtering mode, we built dense point cloud (almost 78 million points) in a process taking 24 hours. In addition, we cleaned and decluttered off the noise to generate the final point cloud of the *Heroon* remains.

5.2. Point Cloud Alignment

We could achieve accurate scale and dimension thus the real orientation of the surveyed object by implementing control points. Some studies suggest using a geodetic device to record geoinformation of the control points and in the photogrammetry process in order to scale and orient the point cloud (Yakar & Yılmaz, 2008; Yıldız et al., 2011). However, in this research, due to the equipment limitations, we realized georeferencing manually. In order to achieve maximum level of accuracy, we used the data from TLS point cloud as a base by first exporting 11 distinct points in the TLS point cloud, and then converting them into .csv format. Subsequently, we imported the same control points into *Agisoft Metashape* over the course of dense cloud building phase (Figure 5, Figure 6) and used them as 'markers' in *Agisoft Metashape* before dense cloud rendered. That procedure provided setting of the photogrammetric point cloud georeferencing based on the in-house TLS point cloud; therefore, alignment is concluded (Figure 7).

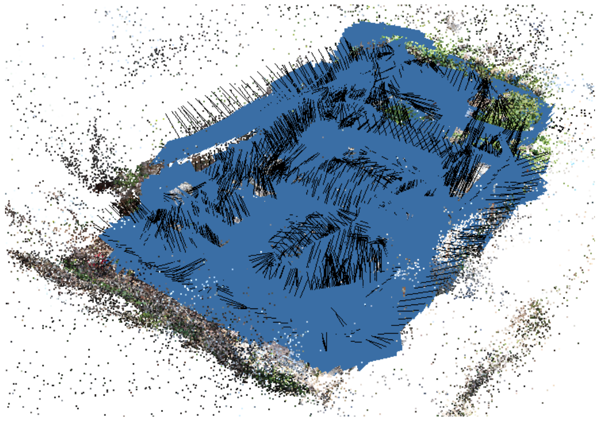

Figure 4. Photogrammetric survey workflow; a) Camera positions, and b) sparse point cloud

Control point implementation helped georeferencing the point cloud. Yet, we calculated cloud-to-cloud distance to check on this alignment for the data accuracy. We used *CloudCompare* (Version 2.11.3) to perform *cloud-to-cloud* distance calculation in accordance with the set workflow (URL-5). We converted both TLS and photogrammetric point cloud into. E57 file format as it fosters both RGB and three-dimensional location data.

Imported point clouds subjected to cloud-to-cloud distance tool (URL-5). This tool calculates two or more clouds according to the user-based area of interest from the point cloud data. First, base point cloud decided, in this case TLS point cloud. Octree level, built-in subdivision parameter of the point cloud, is set to be auto. Following, cloud-to-cloud distance tool activated and performed (Figure 8).

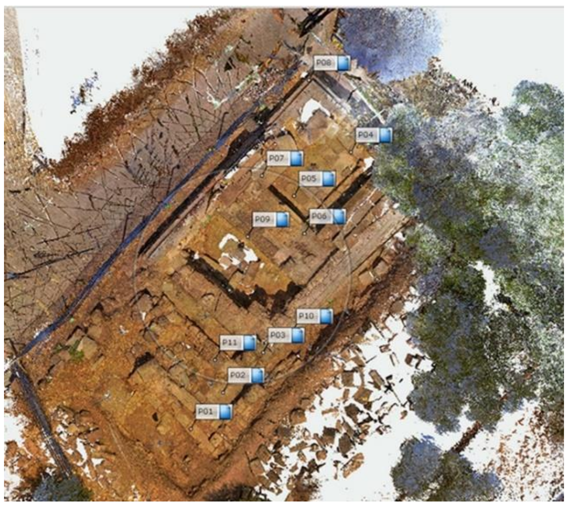

Figure 5. Alignment workflow of the point clouds; data from TLS.

(a)

Markers	X (m)	Y (m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
P01x	16.772970	28.029010	440.661430	0.005000	0.053869	10	0.318
P02x	30.324180	43.458310	439.713440	0.005000	0.043362	16	0.256
P03x	46.991510	60.623030	448.030320	0.005000	0.020725	19	0.718
P04x	84.156400	145.142730	437.517280	0.005000	0.030165	35	0.901
P05x	60.140450	126.657340	436.014560	0.005000	0.035965	15	0.641
P06x	64.543310	110.425040	442.590980	0.005000	0.052833	5	0.650
P07x	46.620030	134.594570	447.987060	0.005000	0.039142	10	0.887
P08x	66.067060	174.605430	446.128080	0.005000	0.049923	11	0.251
P09x	40.689130	109.270050	442.829130	0.005000	0.066763	4	0.282
P10x	58.871630	68.642900	445.590130	0.005000	0.023498	34	0.225
P11x	26.974190	57.337360	440.616610	0.005000	0.033754	13	0.385
Total Error							
Control points					0.043043		0.596

(b)

Figure 6. Alignment workflow of the point clouds; a) imported .csv into Agisoft Metashape, b) x, y, z values of the implemented control points.

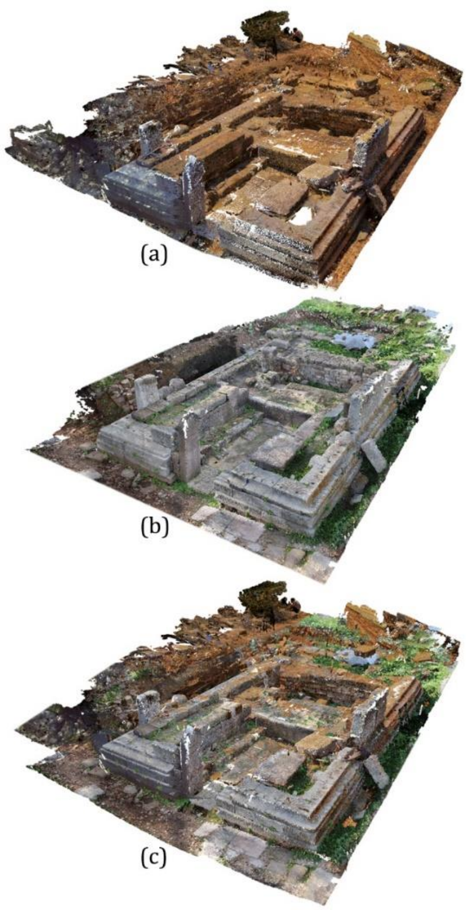

Figure 7. Generated and aligned point clouds, (a) TLS, (b)Photogrammetry, (c) TLS& Photogrammetry.

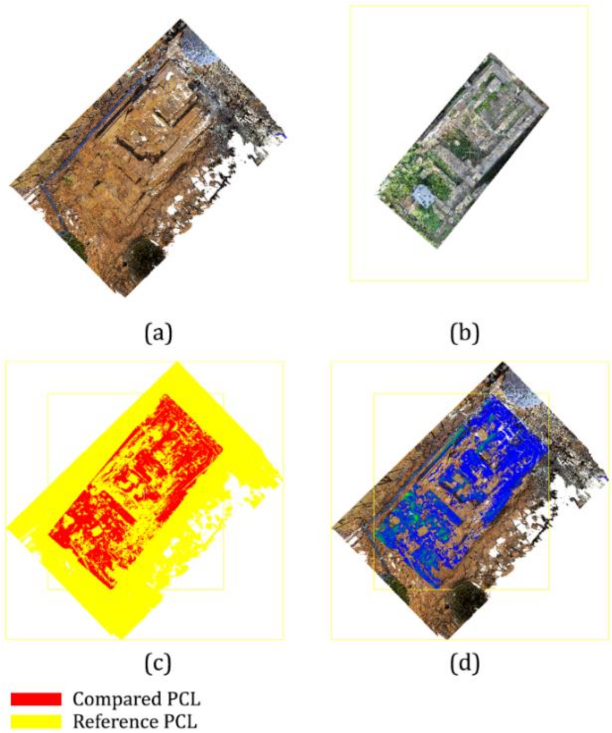

Figure 8. Cloud-to-cloud distance computing process, (a) TLS point cloud, (b) photogrammetry point cloud, (c) comparison decisions, (d) TLS and photogrammetry point cloud overlap.

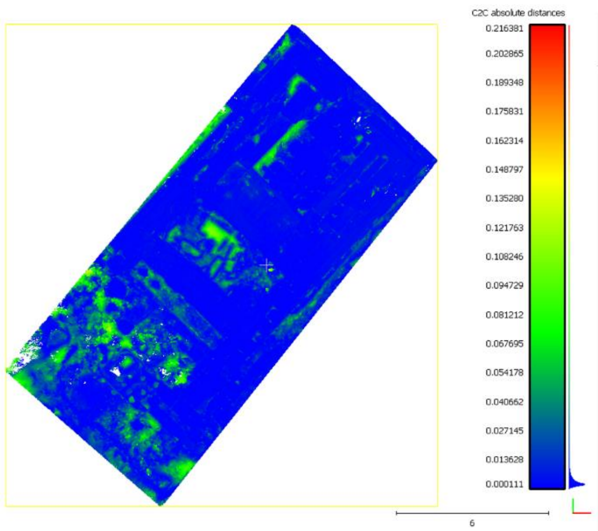

Figure 9. Computed result with scalar field`s color scale, meters.

According to the final calculation graphic, blue represents maximum overlapping points and red *vice versa*, green, areas are the vegetation due to rainfall on the in-situ remains (Figure 9). The maximum distance (non-visible red areas on green vegetation) is under 22 cm, minimum distance is under 1mm.

5.2.1. Orthophoto Rendering

Following the georeferencing of point clouds, their alignment and calculation, we decided resulting photogrammetric point cloud is comprehensive enough to render orthophotos of the remains.

We used *PointCab* (Version 3.9), point cloud processing software, to generate the orthophotos. TLS point cloud and photogrammetric point cloud processed in the *PointCab* separately. Since the purpose of the photogrammetric survey was to compensate the TLS`s data gap, we set orthophoto rendering parameters constant for both operations (TLS and photogrammetry).

PointCab renders orthophotos with axis-based projection settings. User could decide position of the axis and then sets the parameters as required. The *Heroon*`s building line is $47^0$ to $43^0$ according to the TLS survey. As a result of that, we set the axis` angles as -133^0, -43^0, 137^0, and 47^0, for the orthophoto operations to create parallelly projected rectified images (Figure 10-11-12).

To create mutually complementary orthophotos, we set the same parameters for each of the section and layout axis. Position of the axis of the section and layout is critically vital to create constant point projections; therefore, we first decided on TLS then carried the same x, y, z, angle, and orientation data on photogrammetric point cloud. Furthermore, we set the image resolution to 2mm, zero reflectivity and 100% color for processing each orthophoto. Also, for the CAD parameters, we decided on white background, PNG format, metric unit system and 3D projection. All in all, we generated more than 400 orthophotos between the separately obtained point clouds. In this way, formed orthophotos became compliable and interchangeable, which is critical to remedy data loss from the original TLS survey.

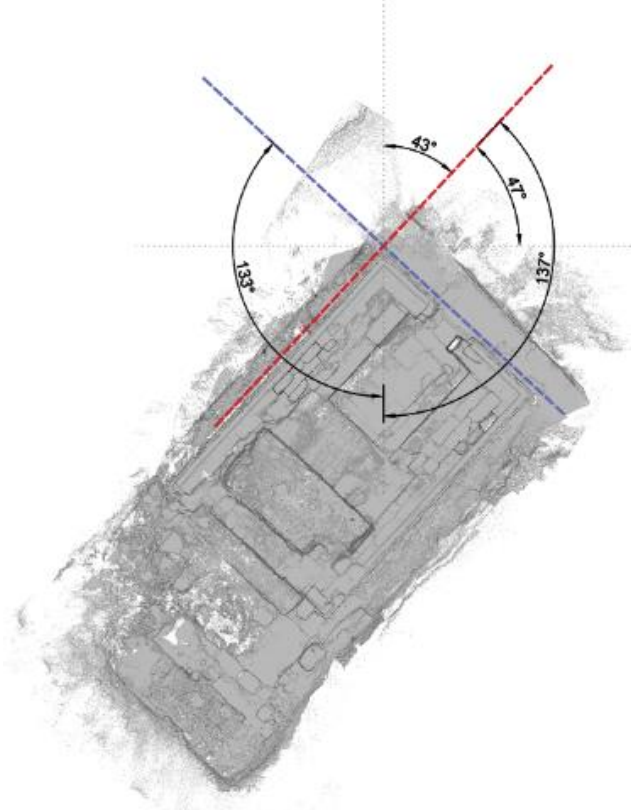

Figure 10. Projection angle for orthophoto rendering process, on photogrammetric point cloud.

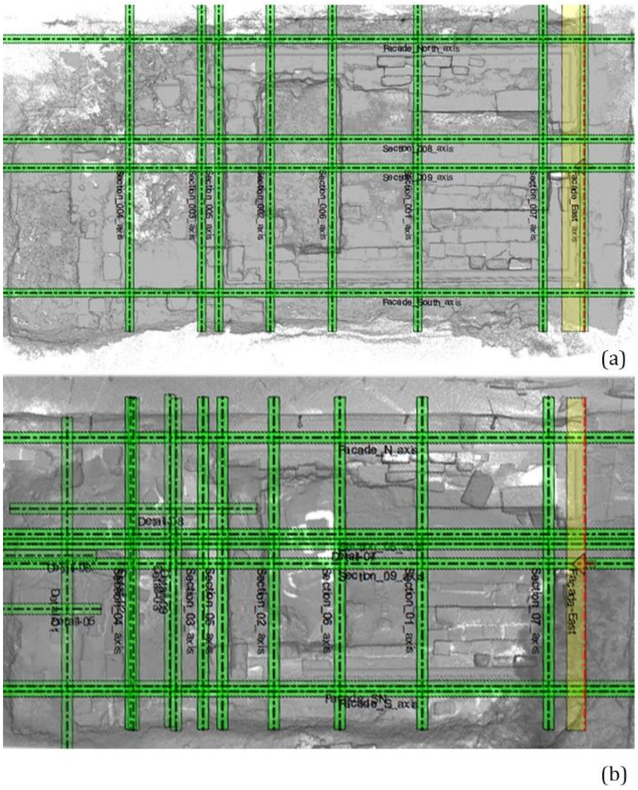

Figure 11. Orthophoto rendering process (47^0 flipped for visual purposes), section axis are green lines, (a) photogrammetry point cloud, (b) TLS point cloud.

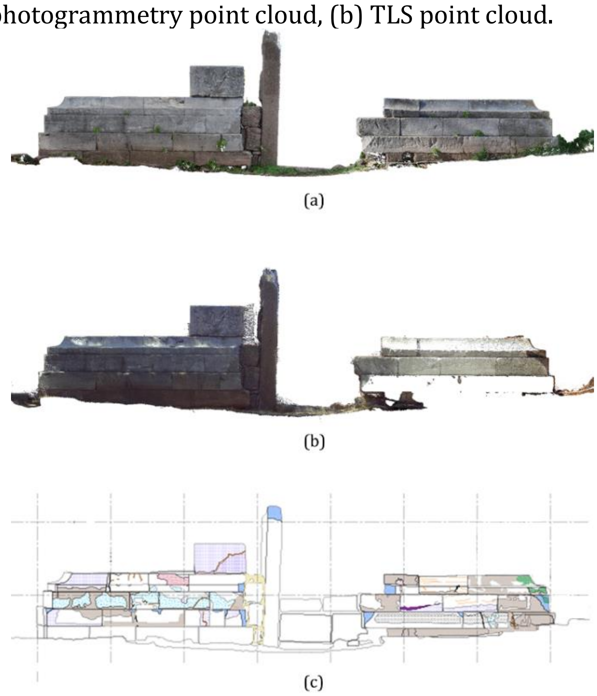

Figure 12. East elevation orthophotos of the in-situ remains, generated from (a) photogrammetry and (b) TLS, and (c) information mapping of material deteriorations.

6. RESULTS

Surveying an existing geometry is easily practicable with the implementation of digital data capturing procedures. Eminently, both image-based and range-based methods have been implemented on the same object in this research. That resulted in two different datasets which are aligned and scaled and prepared to be utilized for the next steps in the holistic conservation process (Table 3). Most importantly, we managed to cover the data gap such as in the color or texture from the first survey, TLS, with implementing second one, photogrammetry.

Table 3. Data Acquisition Processing

Methods	TLS	Photogrammetry
Area (WxLxD)m	33x23x5	9.7x19.3x2.7
Data acquisition time	24 hrs.	40hrs.
Acquisition Locations	24 Scans	2709 Images
Resulted Datasets	PCL(680mm)	PCL(72mm)
White Balance	Not Appl.	AAP*

*Auto Ambient Priority

Terrestrial laser scanning covered larger environmental data. Also, the scanned surface representation was quite dense. However, due to natural light exposure, some shading and monochromic color recording has occurred. TLS being a rapid and robust surveying method provided the field work to finish less than 8 hours. Yet, also resulted with ample of redundant data recording such as tree leaves and even flying birds. Thus, the data had too much noise and we had to devote an extensive time in data cleaning while registering the scans. Although, we tried to implement auto white balance to the scans, in *Scene*, that was not impeccable to continue due to shadings became more obvious in the scans and created data liability. It is also worth mentioning that rapid scanning cost partially data loss of the Heroon remains, too.

The photogrammetric survey was particularly effective for graphically strong orthophoto generation. However due to not having access to a geodesic device, point cloud generation took time in terms of georeferencing. In this paper, we particularly tried to solve this issue manually yet meaningfully. To do so, we specified control points from registered TLS point cloud and converted and imported them into Agisoft Metashape during photogrammetric point cloud generation. That immensely help to reduce scale and positional errors for photogrammetric survey. In addition to manual control point implementation, we performed cloud-to-cloud distance with CloudCompare, which proved the validity of the aligned photogrammetric point cloud (Figure 13).

Orthophoto generation of the *Heroon* ensured extensive metadata for the conservation process, analysis, of the heritage asset. Aligned point clouds with relevant accurate orthophotos played a significant role for information mapping of the remains` material and condition assessment.

7. CONCLUSIONS

In this paper, we illustrated three-dimensional data acquisition methods for an archaeological heritage. Particularly, we attempted to combine the TLS and photogrammetric data acquisition, offering an alignment in the workflows to reach accurate and reliable 3D representation of heritage and accurate representation in orthophotos. Information mapping of the Heroon remains, material culture and condition, is digitally visualized by point clouds, and off rendered orthophotos.

Our technique shows a clear advantage over terrestrial laser scanning in terms of texture detail of the orthophoto dataset. The evidence from this study suggests, even after geometrically accurate but off textured survey data acquisition, image-based cost-effective surveying could remedy this issue. We have managed to do information mapping and 3D modelling of the Heroon holistically with highly detailed and precise survey datasets.

It is crucial to note the data acquisition actions, as well as the methods, could be distinctive depending on the specifications of the heritage itself and the opportunities to research on, but in the end, the generation of accurate heritage data to use as a basis for conservation actions remain fundamental.

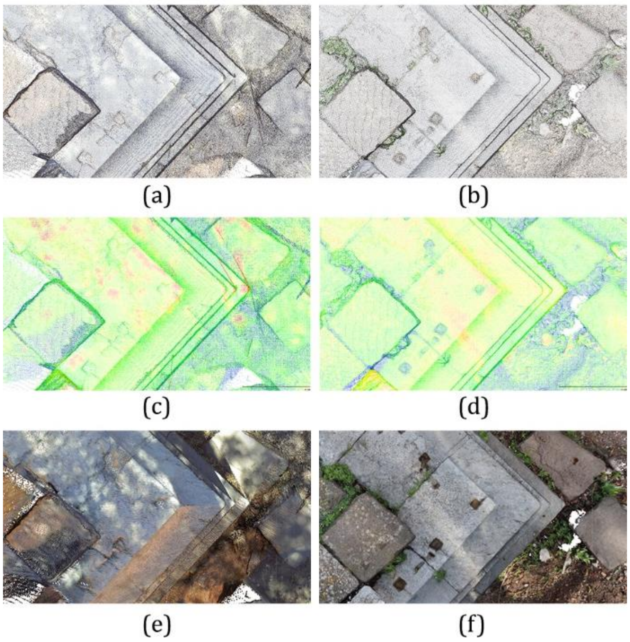

Figure 13. Core data of rendered orthophotos (a) TLS point cloud, (b) photogrammetric point cloud, (c) TLS scalar field, RGB, (d) Photogrammetry scalar field, RGB, (e)TLS orthophoto, (f) photogrammetric orthophoto.

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Author contributions

Tuğba Sarıcaoğlu: Collected the data, Performed the analysis and synthesis, Wrote the paper, designed the methodology; **Nezihat Köşklük Kaya:** Supervised the progress, Contributed the data representation

Conflicts of interest:

The authors declare no conflicts of interest.

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