DIGITIZING ARCHAEOLOGICAL EXCAVATIONS IN 3D, AN IMAGE BASED MODELING APPROACH AT KOMANA PONTIKA

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ABSTRACT

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In spite of the fact that they are not widespread in Turkey, 3D applications have been implemented in increasing numbers of archaeological activity around the world. These methods were introduced in archaeology due to mere intentions of three dimensional visualization and reconstruction in the beginning however they have recently started to become an important part of the scientific research with the development of technological and theoretical infrastructure of the field. It is now possible to digitally document excavation process and findings, to digitally handle the obtained information and to easily share the data with others.

In this thesis, Image Based Modeling is discussed in detail due to the facts that it has unique characteristics making it applicable to almost any archaeological research and it can significantly contribute the scientific work in the processes of data recovering, interpretation and dissemination. It is critical that this approach should be, as soon as possible, adopted by Archaeology that needs to evolve into more collaborative, openly accessible, audience oriented state and multi-layered, multi-dimensional and questionable content in order to keep up with the change and improvement in the information exchange brought by new media.

Keywords: Virtual-digital archaeology, Image based modeling, Archaeological and cultural heritage, 3D digitization, Dissemination of Data

ÖZ

ARKEOLOJİK KAZILARIN 3D SAYISALLAŞTIRILMASI,
KOMANA PONTİKA' DA FOTOĞRAF BAZLI MODELLEME YAKLAŞIMI

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Her ne kadar Türkiye' de yaygınlaşmamış olsa da, son yıllarda 3D uygulamalar arkeolojik çalışmaların bir çoğunda kullanılır hale gelmişlerdir. İlk zamanlarında sadece üç boyutlu görselleşirme ve rekonstrüksiyon amacıyla arkeolojinin ilgi alanına giren bu yöntemler geçen süreçte teorik ve teknolojik altyapının da gelişmesiyle bilimsel araştırmaların önemli bir parçası haline gelmeye başlamıştır. Artık bu yöntemler kullanılarak kazı süreçleri ve buluntuları dijital olarak belgelenebilmekte, elde edilen bilgi yine dijital ortamlarda işlenip değerlendirilebilmekte ve yine aynı şekilde kolayca paylaşılabilmektedir.

Bu tez içeriğinde Fotoğraf Bazlı Modelleme yaklaşımının, barındırdığı özellikler bakımından hemen hemen tüm araştırmalara uygulanabilirliği ve bu çalışmalarda ulaşılan bilginin belgelenmesi, yorumlanması ve yaygınlaştırılması süreçlerine olan ek katkısı tartışılmaktadır. Gelişimi için yakın gelecekte, yeni medyanın da etkisiyle daha işbirlikçi, dışa açık, kitle odaklı bir yapıya ve çok katmanlı, çok boyutlu, sorgulanabilir içeriklere doğru evrilmesi gereken arkeoloji biliminin bu yöntemi şimdiden sahiplenmeye başlaması önem taşımaktadır.

Anahtar Kelimeler: Sanal-dijital arkeoloji, Fotoğraf bazlı modelleme, Arkeolojik ve kültürel miras, 3D Dijitalleştirme, Bilginin yaygınlaştırılması

To My Grandfather

“once in a lifetime”

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LIST OF ABBREVIATIONS

IBM	Image Based Modeling
CRP	Close Range Photogrammetry
SFM	Structure From Motion
VR	Virtual Reality
DEM	Digital Elevation Model
DSM	Digital Surface Model
EXIF	Exchangeable Image File Format
WWW	World Wide Web
JPEG	Joint Photographic Expert Group
UAV	Unmanned Aerial Vehicle
RMSE	Root Mean Square Error
GIS	Geographic Information System
PDF	Portable Document Format
IT	Information Technologies
SAVE	Serving and Archiving Virtual Environments
DAACH	Digital Applications in Archaeology and Cultural Heritage

CHAPTER 1

INTRODUCTION

3D applications in cultural heritage started to become a promising method to visualize the location and appearance of subjects as virtual scenes, and also lately as a tool to document, discover and recover data from archaeological remains. Over the past two decades advances in computer graphics have enabled researchers to render archaeological structures, artifacts and landscapes in increasingly realistic ways and in addition, target materials can now be placed into virtual space that allow users to navigate through the structure and explore its details in real time with the inclusion of the third dimension. Besides, increasing development of virtual/augmented reality, game and interaction technologies also help institutions, museums and cultural centers to embrace advanced virtual technologies and support their transition from the research laboratory to the public realm where audience are not mere viewers of the given scenery, but can actively participate in the program through their actions. Virtual heritage environments thus, provide researchers and the general public a tool for exploring archaeological data in detail in a dynamic and interactive fashion and preserve the cultural heritage in digital formats for further generations. Moreover; when 3D digitization methods are used to record the progress of a new excavation, they have *"the potential to mitigate the irreversible and destructive nature of archaeological excavation"* (Frischer, 2008: v). Widespread adoption of 3D technologies to record and reconstruct archaeological sites allows the archaeologist to virtually preserve the site and the artifacts through 3D data capture that provides digital interpretative environments as well as the integration of other researchers directly to the process.

This thesis specifically focuses on the conduction of 3D documentation methods in archaeological excavations due to the fact that data recovering and preservation is the first and most important variable for the latter actions in the subject area. Besides explaining and discussing various tools and applications, the project also consists a case study in which one of the digitization methods; “image based modeling” is used to document archaeological artifacts and edifices through the use of Agisoft’s Photoscan software. The author aims to test applicability, accuracy and efficiency of this approach in four different steps of the excavation process that are registration of archaeological layers and sections in a trench, visualizing artifacts and generating drawings out of them, digitizing a burial scene and lastly documenting architecture and generating drawings out of it. Apart from the case studies, the overall potential as well as the prospect of virtual applications in documentation, representation and dissemination processes of archaeology is evaluated.

1.1 Problem Statement

Data capture is the key factor behind the idea of an archaeological research. Archaeologists dig the ground with the intention of gathering physical and spatial information in order to analyze and interpret. Even though these are the right intentions, the traditional approach captures the excavation only in 2D space along with what is observed, recorded and remembered by the excavator. Unfortunately, it is impossible to pass the data and experience gathered during the process thoroughly to another person or researcher which means loss of information in the end. However, virtual reality applications stand as a solution to this problem. Among those, image based modeling seems to be a promising, low-cost and user friendly method for capturing 3D data during the excavation process and creating reversible virtual experiences that allow further research and reflexive contents. The potential of this medium becomes more apparent when it is considered in parallel with the evolution of new media that altered the way of exchanging information in the last years.

1.2 Research Objectives

- To test the applicability of image based modeling in different cases of archaeological excavations.
- To analyze the empirical accuracy of 3D models generated by image based modeling.
- To examine in which steps of archaeological activity close range photogrammetry offers solutions.
- To reveal in what ways close range photogrammetry improves the data capturing process compared to conventional methods.
- To discuss the future of data recovery, processing and dissemination in archaeology with respect to image based modeling.

1.3 Thesis Structure

This thesis' structure is based on virtual reality applications that can be used in archaeology and it mainly concentrates on how one of these methods; image based modeling could serve as a tool to improve the collection, visualization and transmission of archaeological data by testing several cases from Komana Pontika excavations. Chapter 2 of this research reviews the role and aims of virtual applications in archaeology. Chapter 3 explains and compares image based modeling with other 3D digitization techniques and also looks at various cases in which computer vision was successfully implemented. In chapter 4 the study area and the methodis defined, the documentation workflow for the cases is explained as well. The results are analyzed in chapter 5 whereas chapter 6 discusses the prospect of archaeology in terms of digital documentation, interpretation and dissemination. Lastly, chapter 7 concludes the research.

CHAPTER 2

ROLE OF VIRTUAL APPLICATIONS IN ARCHAEOLOGY

The aims of using 3D methods in cultural heritage vary significantly. Considering different scales of archaeological activity, virtual techniques can help researchers to understand archaeological features and physical context better as a whole at landscape scale. At the monuments/sites scale, 3D can give accurate measurements and objective documentation as well as a new view under a different point of view. At the artifact scale, 3D modeling allows to reproduce digital/physical replica of any artifact that can be studied, measured, shared, exhibited etc. as well as visuals for general public use, virtual restoration and conservation (Remondino et al., 2007: 36). Remondino et al. summarizes the key benefits of virtual archaeology as follows: (Remondino et al., 2007: 42)

- *Interaction: a 3D model involves a high degree of interaction.*
- *Difference: the representation in 3D produces more difference in cybernetic sense; interacting with 3D data we develop a major exchange of information.*
- *Spatial relationships: 3D spatial features visualize, model and develop relations generally not identifiable in 2D space*
- *Multi-modality: 3D interaction stimulates our cognitive system to adapt and follow the spatial coordinates of reference, in scale and size.*
- *Light: 3D interaction and movement involves changes of the light and shadow conditions of the reconstructed model so that a better perception and also interpretation is achieved.*

- *Geometry: the more complex is the geometry of an object the more we have a capacity of analysis.*
- *Transparency: the reconstructive processing of information can be validated and shown by a sequence of 3D spatial maps in overlay or different representations.*
- *Multi-modality: 3D information allows a multimodal and multi-sensorial interaction with the 3D model.*
- *Connectivity: each 3D spatial information multiplies in a conceptual network of links its communication model.*
- *Preservation: 3D digital data are useful for site/object documentation and storage in case of lost of destruction.*
- *Fruition: a 3D model can be exchanged between users or used in virtual museum for people who cannot visit the real site.*

Whatever the scale and/or the expected benefit is, aims of using 3D applications can be grouped among three main steps of the archaeological activity. These are documentation, analysis and dissemination processes. Addison describes these as 3D documentation being any of formerly mentioned methods applied to site investigation and information acquisition, 3D representation being the visualization process and 3D dissemination being the set of actions to share the generated content. (Addison, 2000: 22)

In the following part of the thesis, these steps will be discussed separately.

2.1 3D Documentation

A classic claim for archaeology: Excavation is a destructive process (Carmichael et al., 2003: 31). This is often quoted in order to draw attention to the vitality of proper and detailed documentation of archaeological work area that will be physically lost forever afterwards. Traditional documentation methods with forms, drawings and photography provides limited data acquisition and preservation. The archaeologist in charge records what s/he observes and some of pre-existing information can never be experienced again. Even though the findings are recorded and preserved in collections as a data source, it is mostly not possible to keep contextual information alive. De Reu describes this situation as two dimensional interpretation of a 3D structural datasets that future researchers will have to cope with (De Reu et al., 2012: 3). However, adoption of 3D technologies to record archaeological subjects may turn the tide due to the fact that these methods allow the researchers to virtually recover and preserve the site as well as the artifacts.

The virtual registration and documentation is achieved by capturing 3D information as much as possible during and also after the excavation process. Commonly, an excavation starts with the clearance of surface soil inside the square or rectangle trench. Afterwards, the excavation goes deeper layer by layer. According to the traditional approach, the archaeologist records coordinate points with total station, takes photographs of these cultural layers, makes notes and sketches. This mainstream process implies that huge amount of cultural information is not documented and the quality of the documentation is highly correlated with the ability of the archaeologist, therefore; subjective. On the contrary, if a 3D digitizing method is applied, it is possible to record shape, topology and texture information of each layer and section accurately. Using 3D information afterwards, one can even generate orthophotos and line drawings way more fast and accurate than manual on-site drawings. The huge difference between traditional and 3D documentation approaches is more understandable when directly compared to a total station example. While using the total station to record layers, archaeologists read corner points and maybe a middle point making five pointsin total. However, when 3D scanning or photogrammetry used, millions of these points are recorded together with texture information. Thus, this kind of approach allows the stratigraphy of the trench to be reconstructed in a three dimensional space with high resolution and it becomes possible for the archaeologists as well as other experts to analyze the outcome.

To summarize, the scanning will provide an accurate 3D surface model with sections, geo-referenced coordinates and even photorealistic textures. Besides, the unearthed artifacts can be placed in 3D space along with their position and orientation values. Thus, if the excavation is properly and continuously documented in 3D, it is possible virtually, to merge the whole process into a three dimensional rectangular prism consisting all the layers, sections and artifacts as it was before the excavation. The key point here is continuous recording. As the shape, color and texture information in a trench is dynamic and always changing, so the capturing process needs to be. In this way: (Lu et al., 2011: 37- 39).

> "[...]*the whole archaeological excavation process can be turned from a non-reversible process into a book, which can be browsed arbitrarily with the assistance of dynamic information from the excavation. This will greatly support future archaeological research and potential utilization."*

In traditional excavations, more or less similar walkthrough is applied also to the finds. The archaeologists unearth a vast variety of artifacts such as man-made objects, bones, plant remains etc, but they are only recorded by their position along with photographs and/or manual drawings. As this type of workflow captures 2D information, it commonly makes the archaeologist ignore the possible correlations of artifacts, whether they were placed together or separately, whether they were piled up or juxtaposed and whether there are related relics around (Lu et al., 2011: 38). Placing the artifacts in 3D space with respect to their positions and orientations, the researchers become able to conduct spatial analysis in a healthier way.

Putting excavation activity aside, the cultural heritage is also in the scope of 3D documentation. The heritage sites all over the world are affected by wars, disasters, weather conditions and human negligence (Remondino et al., 2009: 1). Agricultural activity, state politics and mass construction actions are a few of other threats to be listed. In a similar way museum objects or objects in the storerooms are subjected to continuous corrosion and deterioration. For any of these cases 3D documentation stands as a powerful tool to create a virtual, unchanging replica of the subjects that can be used for further and future actions such as monitoring, conserving, reconstructing, reinterpreting, reanalyzing etc. (Remondino et al., 2007: 36).

2.2 3D Representation

3D representation of archaeological material and cultural heritage is characterized by the visualization and analysis processes of these subjects. Once an object or an edifice is documented in 3D, the outcome can be used with various forms and intentions of representation. Frischer et al. describes this as translation of empirical phenomena into geometric language (Frischer et al., 2002: 11). A similar point was also made by Niccolucci (Niccolucci, 2003: 2):

> "[…]*since interpretation, explanation and communication involve reasoning, Virtual Archaeology can provide virtual creations to organize and synthesize known facts, showing them with greater clarity to others or to one's 'inner eye', or virtual substitutes of physical objects.*"

Here it is important to note that comprehension of any information being directly correlated to visualisation is a cognitive psychological fact. In other terms, the better the visualisation tool, the better and easier the understanding of the content becomes (Sermon, 2008: 36). If so, how could 3D visualization contribute to post-excavation research?

Regarding the on-going excavation digitization, the obtained models can be viewed for to achieve a better understanding of the site or can be used to interpret, test and suggest new hypotheses based on the spatial information. If continuously and properly recorded, it is possible to digitally integrate and reproduce all the phases of an excavation layer by layer in three dimensional space and simulate the whole excavation in a way that any other person than the trench supervizor could interpret even without being on the site. Besides, the opportunity to view a digital, contextualized stratigraphy of the work area allows researchers to evaluate the past use of the space as a whole (Forte, 2012: 353). Apart from the contextual data, 3D digitization of findings also provide further opportunities. For instance, the created documentation allows scientists to preserve the items and conduct the study on the virtual models. This especially becomes vital with objects like frescoes, wall paintings, organic materials etc. that may easily deteriorate after being unearthed. In this way invasive traditional methods are left aside and the analysis as well as restoration and reconstruction activities are conducted on the digital model. In some projects, mass 3D documentation is also used to create material databases containing pottery, objects or animal bones to help archaeologists to identify, compare and interpret their findings.

In addition one must consider that enormous amount of artifacts are unearthed in excavations, parallel amount of time and effort is devoted to make drawings and sketches in conventional approach. No matter how carefully drawn, they are subject to errors and simplifications due to time/budget limits and artists' individual skill/choices (Hörr et al., 2009: 3). Even though there are globally or locally standardized ways to illustrate artifacts, they fail to provide adequate information and detail about the shape, decoration and the material of the findings. If time and effort spent for manual drawing is transferred to object digitization, the artifacts can be visualized both in 3D and 2D with various options such as section drawings, sketches, orthophotos and unrolling textures in very short time even with different lighting/shading opportunities. This makes creation of 3D artifacts preferable in contrast to conventional recording methods. Besides, the digitization also increases the accuracy of illustrations. Hörr et al. compared the traditional pottery drawings with digitally created ones and claimed that significant errors occur in areas with high perspective distortion when the object is hand drawn (Hörr et al., 2009: 11). Similar cases that showed 3D modeling adding new dimensions to the analysis and presentation of ceramics were experimented also by Karasik (Karasik, 2008).

To sum up, accurately 3D digitized space or object could be used as a digital representation that provides opportunity for elaborate analysis and interpretation due to its massive content of information as well as an efficient medium of visualization because of its modifiable nature that could make the model turn into various formats.

Virtual applications are not used only for documentation and scientific illustration but in fact they also allow archaeologists to create simulations and reconstructions of their ideas based on the actual data on hand. In this way the researchers can experiment with their case to test various alternative scenarios in digital worlds. A good example for this is the work of Johanson and Frischer on the Sanctuary of Sun in Bolivia (Johanson and Frischer, 2008). Two towers belonging to the sanctuary that were formerly thought to be tombs, were interpreted as *"markers of the position of the sun at sunset on the winter solstice, enabling large-scale audience participation in solstitial ritual."* (Johanson and Frischer, 2008: 98). To test this hypothesis, the topography of the island was modeled through digitized contour maps along with the reconstruction of partially existing towers and by using a scientifically correct ephemeris software; Horizon from NASA's Jet Propulsion Laboratory, the scene of sunset on the winter solstice in 1500 CE was digitally created. As a result, their virtual-empirical test did not only validate the hypothesis, but also showed the potential of 3D modeling as a heuristic and communicative tool.

2.3 3D Dissemination

Outcomes of archaeological activity is targeted to reach two different communities: the academic environment and the general public. Conventional methods for the dissemination of knowledge among academicians are the publications and the conference presentations that are formerly mentioned as inadequate mediums of information exchange. To reach the public on the other hand museums, archaeological parks and sites and multimedia are several common options. Considering both target groups, use of 3D applications in archaeological activity definitely provides the opportunity to enhance the communication in between and they have proven to be the most efficient tools for education and communication of cultural heritage (Hermon, 2008, 36).

The last two decades revealed a significant breakthrough in the mediums of content dissemination with the development of computer based publications and World Wide Web. In this way, it became possible to include digital information such as fieldwork data, unlimited numbers of colored photos, drawings, graphs, sound and video and lately 3D models in the electronic publications reducing the gap between the archived knowledge and shared content (Meyer et al., 2007: 400). Moreover, it eliminates the slow process, page limits and high costs of publishing, transporting and keeping traditional books and journals. Digitization and e-publication of archaeological or cultural subjects therefore, allows the researchers to share more of the content with other people in digital formats such as spreadsheets, databases, GIS data, virtual models etc. and even to include them in the identification or interpretation processes by providing access to research outcomes. Considering the 3D models generated during the archaeological research, it has recently become much easier to share them as digital files through web and e-publications. Adobe’s 3D PDF technology for example, allows viewers who have the latest version of Adobe Reader to examine the 3D artifacts directly in their browser window or PDF reader. This option provides the opportunity to include 3D models containing 200,000 polygons at maximum however it also offers rotation, zoom and measurement capabilities as well as cross sectioning that are advantages not currently available in any other dissemination method (Payne et al., 2009: 293). Additionally, other common 3D formats such as OBJ and VRML can be used to retain high number of polygons or in other words, high detail available for downloading and they can be examined in desired 3D applications. Therefore, it could be said that portable digital formats open new perspectives for 3D data sharing and collaboration and offers an intermediate solution in between data capturing and final interpretation (Çatalhöyük Archive Report, 2012: 233). Besides, in the very near future web based applications will be able to render millions of polygons in real time (Scopigno et al., 2011: 48) stimulating the access to virtual contents.

CHAPTER 3

THE IMAGE BASED MODELING APPROACH

Until recent years, digitization of archaeological data had been limited to digital photography and electronic databases that consist fieldwork reports. However, more and more excavations all over the world, started using various 3D digitizing approaches due to better documentation and visualization purposes. Setting aside the common goals of these methods, they differ in various aspects such as accuracy, working scale, cost, time consumption, etc.

3D modeling can be conducted in two main ways, either using real subjects as a source or creating content with computers. Photogrammetric applications, surveying and range image modeling are listed in the first group, hand and procedural modeling through softwares are in the second (Remondino et al., 2009: 2). This chapter will review these techniques in the beginning, with the intention of presenting the foreknowledge needed for the comparison between computer vision and the other methods.

To start with, 3D digitization of an archaeological artifact, structure or space can be done by hand modeling which is explained as a manual reconstruction procedure using CAD softwares. Besides their widespread use in architecture among many other industries, they are commonly applied to digitize especially archaeological plan and section drawings as well as creating 2D-3D visual representations.

The CAD softwares allow the user to create polygons from points and lines inside a 3D coordinate system. Therefore, reference information such as drawings, dimensions, blueprints and images can be used to model all parts of the target subject step by step. As a result a visual appearance of the subject is reconstructed (Haegler et al., 2009: 3). However; the vector nature of these CAD applications provides the modeled objects with perfectly straight lines making the outcome less realistic, in other words; scientifically less correct. Attempts to achieve better results by increasing the number points, lines and polygons in the model, thus having more detail, may become a painful, time consuming task. Even if the time cost is embraced, the accuracy of this method may compete neither with 3D scanning nor image based modeling. Besides, extra work must be conducted to correctly texture the final mesh.

Considering these characteristics, hand modeling is commonly used in archaeology to create visualizations of artifacts and architecture for representative reconstructions and scholar/public display. The Wesleyan-Brown Monastic Archaeology project (known as MonArch) is one of the researches that goes above and beyond the shortcomings of this approach. In their study at Saint-Jean-des-Vignes, the researchers used hand modeling for representing the evolution of the monastery in several phases with alternative scenarios. By introducing time and uncertainity variables, Monarch project was able to create a new way of publication that allows reconsidering and rewriting (Bonde et al., 2009: 275).

Another method for 3D digitization is procedural modeling. This is a term in computer graphics that refers to the automated creation of 3D models and textures according to sets of rules and parameters assigned. In other words, the algorithms of the software generate procedural variations of 3D objects using the information given (Müller et al., 2006: 614). The method therefore, fills a big gap in heritage studies due to the fact that archaeological information is always only available in fragments and procedural modeling uses the recovered data in combination with researchers' ideas and interpretations to reconstruct the architectural output (Müller et al., 2006: 7). Being more oriented to spatial and semantic relationships between objects rather than absolute geometry and coordinates (Haegler et al., 2009: 4), it is possible to visualize large ancient cityscapes with low cost and effort to observe and test periodical and spatial hypotheses. One of the most intriguing implementation of the approach was made in Rome Reborn project in which 6750 residential buildings were procedurally produced along with 250 hand modeled monumental buildings with the intention of illustrating the urban development of ancient Rome from late Bronze Age to the early Middle Ages (Dylla, 2008: 62) (Fig. 2). Procedural modeling was specifically used in this project to create buildings that the researchers have no precise information about.

What is being generated with this method can also be done by hand modeling but it will take way more time and resource to reach similar outcome. This is the reason behind the introduction of procedural modeling in archaeology as well as other work areas. Nevertheless, one needs to note that procedural modeling can only be used to visualize or represent the ideas because of the uncertainties involved in the source and the outcome. Therefore, it can not be used for documentation purposes.

Probably the most popular digitization principle in heritage and archaeological studies is the range imaging technique that is commonly known as 3D Scanning. The roots of this technology date back to 1960's, however; its first use in cultural heritage recording was conducted in the late 1980's (Lu et al., 2011: 12). In the following two decades this technology improved substantially and became one of the most efficient methods of accurate 3D data capture.

Basically, a common 3D scanner uses laser beams or sometimes pattern projection to geometrically analyze the position of different points of the target with reference to its own position and creates a coordinate system placing all analyzed points in that 3D space. This cloud of points afterwards, are connected to form meshes or in other words; surfaces. Given that the number of calculated points can reach even millions, it becomes possible to form a substantially detailed 3D model of a target object.

Laser scanners are categorized as active sensors and they are classified according to their measurement and sweep systems. Different measuring systems include time of flight, phase shift and triangulation methods. Sweep systems on the other hand, can be divided into camera, panoramic and hybrid types (Farjas et al., 2012: 154). Time of Flight and Triangulation scanners are the most common types of 3D scanners. The first of which sends laser beams to a point and receive it back. Time delay between the beam's emission and return is used to calculate the distance that the laser beam traveled with a simple mathematical operation: speed multiplied by time equals distance traveled (Fig. 3). This action is repeated in the whole study area and as a result; a digital map with depth information can be obtained. Considering the extraordinarily fast speed of light, this method lacks sensitivity when applied to short distances. Therefore; it is commonly used for long-range cases such as terrestrial mapping and monument digitization with an accuracy within one centimeter. Triangulation scanners on the other hand, additionally use a camera along with the laser emitter. The camera receives the emitted light, after it is reflected from the target object, creating a triangle for each point on the object (Fig. 3). Using the known angle and distance between the camera and laser emitter, the position of each point can be calculated with simple trigonometric equations. This method proved to be highly accurate, within less than one millimeter, and it is used in short–range cases and high precision purposes such as artifact modeling. The accuracy of measurements depends on the triangle base relative to its height. "*For practical reasons, the triangle base is rather short, triangulation-based systems have a limited range of less than 10 meters"*(Boehler et al., 2002: 432).

In the last decade 3D laser scanners have been used more and more in the 3D reconstruction and documentation processes, because precise 3D data can be measured in rather short time spans (Alshawabkeh, 2006: 14). Moreover; different types of scanners can effectively be used in various scales: to digitize a landscape or a trench or even tiny artifacts. However, it also has several issues to be dealt with. Most important shortcoming of 3D scanners is generating the texture of the target object. As the scanners obtain only (x, y, z) data and luminance values, it is not possible to texture the digital model. Therefore, additional work must be conducted. To overcome this problem, producer companies started implementing digital cameras to newer versions of their scanners. However, most researchers opt to use separate digital cameras with higher resolutions to achieve accurate texturing due to the fact that ideal conditions for scanning and imaging are diverse (Remondino et al., 2006: 271).

Either an area or an object, it is impossible to scan an object from single point of view. The device and sometimes the object must be moved and/or rotated to let scanner analyze the different sides of the subject due to the fact that neither scanners nor photogrammetric softwares can retrieve information from the points that they did not analyze. Therefore, the scanning process has to be repeated from several angles to increase the amount of data captured and consequently the time spent for documentation increases. Some high tech scanners, especially artifact oriented types, are capable of registering data automatically while the scan is continuing but in most cases the user has to help the software manually to merge those by linking the common points of each scan. In addition, the cost of this technology is still high to be used in every case. Depending on the need and the level of accuracy, the price of the hardware and software may exceed tens of thousands Euros. Besides, the use of both the hardware and the software requires a degree of specialization that means the method is not user-friendly enough, yet.

3.1 Image Based Modeling as an Alternative 3D Digitization Method

The principle behind image based modeling is an old one. Nearly as old as the invention of photography itself. Stereo photography that has been used for almost a century, helps us to see ordinary images with some 3D depth information. As also used in archaeological practices, it is efficient when observing air photos of landscapes. More common application of the principle is 3D televisions and movies. By exposing visuals of slightly rotated point of view of an object to each eye, human brain can be deceived to see 3D dimensional scenes. The idea to use this method to build digital 3D models on the other hand, is a very recent development of the last decades. In a similar but advanced way, computer vision uses at least two photographs of an object taken from different angles to create a 3D model. The IBM algorithm analyzes the images with respect to each other and by identifying common points among them, it deduces the depth information using the principles of collinearity. As a result it provides a point cloud representing the 3D structure of the object.

Computer vision is an inexpensive and portable technique compared to laser scanning. All one needs is a digital camera, a computer and software in order to create a 3D model of a subject regardless of its size. However, for many years this photogrammetric approach has been a difficult task. Precise camera calibration, matching and orientation procedures needed to be conducted to form detailed, accurate and photorealistic models. Fortunately, the passing years have helped the softwares to evolve from highly manual state to semi-automated or automated workflow. In addition, the interface of these softwares have been very confusing until recently but in the last few years different companies presented user-friendly versions that make image based modeling a straightforward task.

As mentioned earlier, hand modeling and procedural modeling are not the proper mediums for scientific 3D digitization leaving range imaging and image based modeling as the mere solutions in the field. Currently, what is being done with a laser scanner can also be done by close range photogrammety up to a certain extent. Moreover, the method is more preferable than scanning due to several features. Firstly, the software and hardware needed for this approach is very cheap compared to scanning. There exist even open source softwares for modeling and managing 3D data. Secondly, necessary hardware; a digital camera and computers are notably mobile making it easy to carry anywhere for fast digitization procedures. Last but not least, the technique is applicable to both small scale and terrestrial scale subjects making it superior to range imaging in terms of flexibility due to the fact that one needs two different types of scanners for different scales.

However, it should be mentioned that computer vision technology is not able to yield results as accurate as 3D scanners which can reach submillimeter precision. In general, image based modeling will introduce more noise and less detail on the surface of obtained mesh that should be kept in mind before making a decision for digitization.

The subjects to be digitized in archaeology and cultural heritage are significantly diverse in terms of scale, shape, detail, lighting, coating etc. as well as the aims for digitization. Therefore, it is not possible to offer a single perfect 3D technique among formerly mentioned methods that provides a low-cost, portable, automatic and efficient workflow with high scientific accuracy, photorealistic and flexible results (Remondino et al., 2006: 272). Choosing the approach according to the aim and requirements of the project is vital and this implies that combination of several techniques could also be implemented to reach the desired outcome. One should note that this view is a best case scenario. Considering the high number of archaeological and heritage studies and relatively low budgets/scarce time provided for these, it may not always be possible to apply expensive laser scanning techniques among others in every case. However, this can not be an excuse for incomplete documentation and data representation. With its low cost and user friendly nature, image based modeling offers a solution to digitize archaeological and heritage subjects in a fast and efficient way. As a matter of fact, this technique has been applied to various other projects around the world in many of which revealed significantly successful results.

3.2 Digitization Pipeline in IBM Approach

The process of 3D digitization in IBM is carried through the following steps respectively:

- Data Capture
- Data Processing and Point Cloud Generation
- Geometric Modeling
- Texture Mapping

The data capture is the first step in the 3D digitizing pipeline where a set of images of the subject is captured from various angles. This is the most important step in image based modeling due to the fact that the quality of the results in all consequent steps depends strictly on the images used as input. One of the very recent but promising companies in this industry, Agisoft reveals the to do's and don'ts for successful data capture in their user manual of Photoscan software (Agisoft LLC, 2013: 4). According to the manual, the images should be at least 5 Mpix and the user should avoid photographing not textured, flat, shiny and transparent objects. If not, the software can not create a model as the algorithm matches the photos using only the light and texture information. Similarly, either moving or stable objects in the foreground other than the intended subject should not be included in the photographs in order to obtain accurate results. There is no upper limit of number of images mentioned, the users should take as many photographs as their systems can handle. The manual also exemplifies how to capture photos in different cases (Fig. 4).

Besides the quality, quantity of images and photographing angles, ambient light and texture conditions also affect the precision of the obtained model. Monotonous and smooth textures does not provide significant track points for the algorithm to detect and match therefore, the 3D modeling process may fail. The problem can also stem from improper lighting conditions and exposure settings that results in washed out parts or almost black shadows in the images. These kind of situations make it impossible for the software to retrieve enough 3D information. In these cases the created models could be used for visualization purposes but they will not be accurate representations for further scientific work.

The camera settings also have an effect on the process. Picture profiles must be adjusted, if possible, in order to achieve the best outcome because standard picture profiles of DSLR cameras compress the images with high contrast. This means bright areas in the image become brighter and dark areas become darker which may result in parts where there is no or little textural information is left. Therefore, it is logical to decrease the contrast level and shoot with a flatter picture profile. Aperture is also an important variable for quality data capture. Larger apertures decrease the depth of field in the images thus making the area in focus more shallow. In order to have sharp and clear photographs, the aperture must be closed as much as possible. Smaller shutter values should also be used in order to get rid of the motion blur caused by camera movements.

The second step in the image based digitization is data processing and point cloud generation. In this step, all the captured images are aligned and structure from motion (SFM) algorithms of the software create a cluster of individually calculated points that are dispersed in 3D space. As photogrammetric application is a passive action which means it uses formerly taken photographs, the input is analyzed at once and the outcome will be a single point cloud. However, it is also possible to merge several clouds obtained from different set of images. Along with obtaining a point cloud, the erroneous points, noise and unwanted parts should also be removed either manually or by the help of built-in filters of the operating software in this step.

Next, the points should be connected to each other by lines to form a surface or mesh which is known as geometric modeling. In this step, Dense stereo-reconstruction algorithms of the software are used to create polygons out of the point cloud. This creation of polygons can be achieved by several mathematical methods such as marching cubes, voronoi triangulation etc. but the important part for the archaeologist is; the action in this step creates a three dimensional surface topography of the scanned object with a scientifically acceptable accuracy.

The last step of the 3D digitizing workflow is texture mapping in which the images of the objects are mapped onto the model. This action adds each vertex of the mesh a texture coordinate along with the 3D position values provided in the registration part and create a projection of overall texture in the following order: (Li et al., 2010: 383)

- *Capture high resolution photos from multiple views under proper light conditions.*
- *Segment the mesh into several parts.*
- *Recover the projection relationship between each part of the 3D model and the photos to obtain the correspondence between the vertex on the 3D models and the pixels in the images.*
- *Blend the color between the corresponding points on different photos.*
- *Generate the texture images for different parts of the model.*

In image based modeling, these photographs are already being used to form the mesh therefore, the software can create the texture of the model by one click. Once the texture is mapped onto the object, the researcher observes a photorealistic replica of the subject (Alshawabkeh, 2006: 13). However, the term photorealistic does not imply scientific correctness. The quality of the obtained data in image based methods depends strictly on the quality of both the stereo algorithms and the taken photographs (Alshawabkeh, 2006: 13). Remondino et al. listed the variables that affect the accuracy of the outcome as follows: (Remondino et al., 2006: 275)

- *the accuracy of a network increases with the increase of the base to depth (B:D) ratio and using convergent images rather than images with parallel optical axes;*
- *the accuracy improves significantly with the number of images in which a point appears. But measuring the point in more than four images gives less significant improvement;*

- *the accuracy increases with the number of measured points per image. However, the increase is not significant if the geometric configuration is strong and the measured points are well defined (like targets) and well distributed in the image;*
- *the image resolution (number of pixels) influences the accuracy of the computed object coordinates: on natural features, the accuracy improves significantly with image resolution, while the improvement is less significant on well-defined, large, resolved targets.*

To summarize, current photogrammetric applications can create accurate 3D models in four main acts given that the image capturing step is done right. However, the pipeline is not restricted only by these steps. The softwares also give the researchers the opportunity of geo-referencing and digital scaling as well as exporting the results in different representations. Various formats such as point clouds, camera position and calibration data, 3D meshes, orthophotos and digital elevation models allow further processing and editing activity through various 3D based programs like CAD softwares, game engines and GIS.

3.3 Literature Review on Image Based Modeling Applications

In the last decade, 3D digitization processes started to be used commonly in various steps of the archaeological activity and proved to be significantly useful. Laser scanners have been the first choice up to now but nowadays growing number of researchers are moving to computer vision to digitize cultural heritage. When applied, the technique yields scientifically correct 3D models that can be used to document, visualize, preserve and reconstruct cultural heritage. Several applications up to date were conducted to record monuments and edifices and also artifacts. This digitization process provided researchers with accurate models, textural information, orthophotos and drawings to be used for further studies. Koutsoudis et al. compared the quality of digitization between photogrammetry and laser scanning while recording an Ottoman monument in Xanthi, Greece(Koutsoudis et al., 2013) whereas Nuttens et al. digitized the remains of Asclepius Temple in Titani, Greece due to restitution and conservation purposes (Nuttens et al., 2012). In both monumental scale applications the method proved to be fast and highly accurate.

The technique also revealed its usefulness at endangered or demolished subjects. Plets et al. presented the efficiency of computer vision techniques through their studies on the rock art of the Russian Altai (Plets et al., 2012: 139) (Fig. 5). These petroglyphs were deteriorating because of environmental conditions, human pressure and most importantly traditional intrusive documentation techniques. In contrast, the photogrammetric approach they used, accurately documented rock art petroglyphs in 3D without any physical contact that could possibly cause additional damage otherwise. Moreover, by changing the illumination settings and stripping off the textures the team was able to notice new details on the reliefs that are normally invisible to the naked eye due to corrosion and erosion effects (Plets et al., 2012: 147). Plets et al. had the same result during the survey of Dzhazhator Valley when the team scanned Turkic antropomorphic stones that are covered by lichen eroded due to weather conditions. (Plets et al., 2012: 890) (Fig. 6). These examples clearly indicate that 3D documentation of an object reveals more detail than a camera or an eye can see. Moreover, in the studies of Sanz et al., the accuracy of the method on petroglyphs that are rather flat surfaces, was calculated below 1mm even though two or a few images are used (Sanz et al., 2010: 3168). On the other hand, Grün et al. used image based modeling in a spectacular way to virtually recreate the colossal Buddha statues of Bamiyan Valley (Afghanistan) that were demolished by Taliban government (Grün et al., 2004: 177). Due to the fact that there are no physical remains to be digitized, the researchers used several images acquired from internet, tourist photographs and images left from a former research (Grün et al., 2004: 183) and they were able to bring the monuments back to life at least in digital terms.

Besides its use in cultural heritage, image based modeling was applied directly to archaeological fieldwork. Olson et al.'s total archaeology approach at Tel Akko contained close range photogrammetry to digitize the mound, the trenchesand even small artifacts such as sealsand figurines (Olsen et al., 2012) (Fig. 7). In 2010, Çatalhöyük team also started a massive virtual archaeology project called “3D Digging at Çatalhöyük” with the aim of visualizing all steps of the ongoing excavation. The team mainly uses 3D laser scanning to model the trenches, processes the 3D data on site and uploads the results to a virtual database called Vrui that shows layers, stratigraphy and models along with data and metadata (Forte et al., 2012: 351-352). Additionally, image based modeling was implemented to make a comparison between scanning and photogrammetry and their results showed that image based modeling can be a low cost, time saving substitute for laser scanning in their excavation recording workflow (Forte et al., 2012: 357). Similar results were also obtained by others who tested computer vision to record the evolution of their excavations (Dellepiane et al., 2011) (Doneus et al., 2011).

Remote sensing applications play an important role in archaeological activity. Among all remote sensing techniques, aerial reconnaissance has been used for site discovery and interpretationfor years. Up to date, images and stereo images has helped archaeologists to distinguish shadow, soil, crop and snow-frost marks on the landscape and to identify them in 2D or 2.5D (Verhoeven, 2012: 2060). Lately, the third dimension was introduced to aerial archaeology with airborne laser scanning and LIDAR in which expensive time of flight sensors are used to obtain digital surface models. In comparison, recent works that tested image based modeling on aerial photography both from high altitudes and low altitudes showed that it is possible to obtain high quality digital surface models at terrestrial scale even with very low number of images (Martinez-del–Pozoet al., 2012: 243) (Verhoeven, 2011: 71-72) (Fig. 8). Even though the photogrammetric techniques yield noisier results than the laser scanning, they provide a cheap, fast and accurate way of geo-referencing and DSM generation (Stal et al., 2012) (Bruttoet al., 2012). Using automated image based procedures on different scaled cultural heritage, Pierrot-Deseilligny et al. showed the easiness and success of orthophoto generation (Pierrot-Deseilligny et al., 2011: 2). In addition, Chandler et al. and Heng et al. also used close range photogrammetry to extract digital elevation models from landscapes in order to monitor river channel changes and soil erosions (Chandler et al., 2012) (Heng et al., 2010). Another use of computer vision was discussed by Butnariu et al. In their project, close range photogrammetry was applied to create 3d meshes of statues that can be used for virtual restoration purposes (Butnariu et al., 2013: 16). Similarly, Aries et al. modeled a Roman bridge by photogrammetric surveying to define its geometry and damage state in order to conduct structural analysis (Arias et al., 2007). The method' s capacity was even challenged by tests of 3D modeling small scale archaeological artifacts such as a low featured Cycladic figurine (Koutsoudis et al., 2013), ceramics (Chow et al., 2009) and bones (Brickley et al., 1999).

Considering formerly mentioned examples, IBM stands as a powerful tool to improve the quality and quantity of documentation and visualization in archaeological projects, especially the ones with rather limited time and budget. Forte's thought on the method is also notably explanatory: (Çatalhöyük Archive Report, 2012: 227)

> *"Computer vision (shape from modeling) is undoubtedly the most effective, user friendly and robust technique in intra site contexts. The fact that involves the use of standard digital cameras (from 8 to 18 Mpixels) and very low cost and open source software (Photoscan and Meshlab), makes all the pipeline very portable and usable from different teams; de facto using the same technologies. At Catalhoyuk computer vision is typically used at intrasite level for data recording of buildings, layers, units, features and burials."*

CHAPTER 4

3D DOCUMENTATION OF KOMANA EXCAVATIONS

4.1 The Site and the Excavations

The site of Komana Pontika in central Black Sea region of Turkey, ancient Pontus was a major cult center for the Kingdom of the Mithradatids during the Hellenistic Period and continued its independence through most of the Roman era after it was conquered by Pompey Magnus. In this time span Komana served as a sanctuary for the Anatolian goddess Ma, a trade center for the surrounding regions, and possibly a bank for the kingdom (Sökmen, 2005: 23). The site was described as a temple-state by Strabo (12.3.34) that functioned autonomously in economical and even sometimes in political terms dominating the surrounding lands. Its festivals, busy market, sacred prostitutes and fertile lands attracted people from all around Anatolia. This political and economical activity must have continued until the rise of Christianity in the region that eventually led the loss of function and significance of the sanctuary (Erciyas, 2014).

The site was first identified by 19th century travelers and is accepted to be situated 9 km northeast of Tokat, on a 250 x 250 m sized hill, now called as Hamamtepe (Sökmen, 2005: 23) (Fig. 9). This identification is largely based on the Roman architraves found near this hill and the architectural blocks with greek inscriptions used in a nearby roman bridge (Erciyas et al., 2010: 283). Besides these, there are no more Hellenistic or Roman architectural remains that could stand as a clue for the location of the cult center. In the Middle Ages the area was controlled by the Byzantines however, starting with the eleventh century the region witnessed a continuous struggle between them and the Turks. Eventually, the Danişmendids took control of the city and the islamization of the region had started.

Komana Archaeological Research Project began in 2004 with the objective of identifying the location and urban fabric of the site. Between 2004-2008, extensive and intensive surveys were carried out in order to determine the boundaries of the settlement and identification of its sectors (Erciyas et al., 2010: 120). The excavations on the other hand, started in 2009 at Hamamtepe mainly revealing remains of Late Byzantine and Danishmendid occupation at the site. A thick fortification around the hill, series of workshops–kitchens inside the fortification, Byzantine burials and a church can be listed as the most significant outcomes of the excavation. Later additional dig was started at a hexagonal water basin a few kilometers away from the mound situated at the northwest of Omala valley on a man-made trapezoidal terrace (Fig. 10). Several trenches were dug around the basin and a network of water pipes leading to and from the structure was identified along with former construction traces. After 2011, the excavation of the basin was finished and the field team continued to excavate only at Hamamtepe.

In Komana Archaeological Research Project, the archaeological activity is documented by using conventional mediums. The trench supervisors are expected to register the excavation process and the findings through the use of total station, fill-in forms, photography, notes and sketches. The whole generated documentation afterwards, is uploaded to a web based database. This concrete data is also accompanied by supervisor diaries in which their daily observations are written. The excavation team also consists an architect who makes the architectural drawings of trenches and edifices along with three students that illustrate the ceramic findings by hand drawing.

4.2 The Method and 3D Documentation Workflow

As mentioned earlier, the visualization of archaeological work in Komana excavations is currently restricted to photography, trench and section sketches, architectural drawings, pottery and cross section illustrations. In this study, the author aims to find out how image based modeling can be used to improve visual documentation in terms of accuracy, detail, spent time and costs therefore, four different features of archaeological activity, (i) whole excavation in a trench, (ii) an artifact, (iii) a skeleton and (iv) an architectural edifice are chosen to be documented in 3D. In each case, the workflow proceeds with data collection and data processing steps respectively.

To acquire 3D information for each of the four cases the subjects are photographed by using Canon 60D DSLR camera with Sigma 17-50mm f2.8 lens. This lens is considered to be a wide angle lens that may distort the images and negatively affect the 3D modeling outcome, however, due to the crop factor of the camera' s sensor, the field of view corresponds to 27,2 mm which is an acceptable amount. To get rid of problems like over exposing and under exposing that may be caused by direct sunlight and therefore dark shadows, a rather flat picture profile with low contrast levels is used. In this project both RAW and JPEG images were captured but to test the capability of this medium, only JPEGs were processed. Besides, faster shutter values and small aperture levels were used in order to increase the depth of field thus providing clear and sharp images. In the cases that were captured by the author, a set of images was taken from all possible angles and heights. In order to place the generated 3d models into real world coordinates (geo-referencing), several ground control points that are also visible in the images, are recorded using total station. In other cases without ground control points, a pre-measured object was placed in the scene to digitally scale the 3D model.

Agisoft's PhotoScan software is used for the data processing. The reason for the choice is due to the claim that this software is a low cost and user friendly option and capable of automatically extracting accurate 3D information from images taken with uncalibrated digital cameras by using surface from motion and dense stereo matching algorithms (AgiSoft LLC, 2013).This software specifically uses the EXIF data of the images to automatically calibrate the camera itself. Therefore, the user should not crop, rotate or warp any photographs. It is also possible to calibrate the camera by series of actions if there is no EXIF data available for the used camera.

The workflow through Photoscan starts with aligning the image set. In this process the software calculates the 3D sparse point cloud, the camera positions and camera parameters by using SFM algorithm. The quality of the final output is significantly based on this step therefore, the user needs to check the scene to see whether all the images are correctly aligned or not. Another variable to check is the computed projection error (De Reu et al., 2012: 9). With the last update of the software form version 0.9 to version 1.0 a new step was introduced after the image alignment procedure. In this new step, the program calculates depth information for each camera to be combined into a single dense point cloud based on the previously estimated camera positions. The dense point cloud resembles all features of the modeled subject and currently it is the most time consuming part of the digitization process. Following step is building geometry from the point cloud. In this part the software uses dense multi-view stereo-matching algorithms to create polygons from points which as a result shape the 3D mesh. The software tends to produce 3D models with millions of polygons therefore, sometimes mesh decimation is needed for the ease of mesh management. Depending on the number of points in the cloud or in other words number of qualified images, the desired level of detail in the outcome and lastly the power of the used computer, this whole procedure may last for several hours.

Agisoft presents the recommended system requirements for Photoscan as follows: (Agisoft LLC, 2013: 1)

- *Windows XP or later (64 bit), MacOSX Snow Leopard or later, Debian/Ubuntu (64 bit)*
- *Intel Core i7 processor*
- *12GB of RAM*

The reason for the necessity of a powerful computer is that maximum number of images to be processed by Photoscan depends on the available RAM and reconstruction parameters used. Besides the software can be accelerated by the use of OpenCL technology that exists in current high end graphics cards. In this study a PC with Intel Core i7-2700K processor, 16 GB DDR3 1666MHz Memory, 1,5GB DDR5 Nvdia GTX 570 graphics card and 64-bit Windows 7 operating system was used to process the captured data. This set up allows the processing of more than 200 18 megapixel images in a scene.

The relatively long lasting dense point cloud procedure also assigns color information to each point in the cloud. Thus, when the mesh is obtained user can see a representation of a simple surface texture mapped on the object. However, in the next step the software allows the user to apply accurate texture mapping using the input images. By doing so it becomes possible to have an almost perfect digital replica of the scanned subject which stands as the aim of this research.

To sum up, these four steps digitize the archaeological work but the resulting model is placed somewhere in the local coordinate system of the software with a default scale. To transform local coordinates to absolute world coordinates and achieve the correct scale, at least three ground control point coordinates need to be recorded in fieldwork for each case and they must be matched using the program. Another option is to place a scale bar nearby the photographed subject or measure a specific length on it in order to set as a scale in virtual 3D space. Once the model is geo-referenced and/or scaled, it becomes possible to compare the real life distances with virtual ones to observe the accuracy of the obtained mesh.

CHAPTER 5

THE ANALYSIS AND DISCUSSION

5.1 Documenting the Trench

The archaeological activity at Hamamtepe is conducted on three separate sectors. One of these sectors; HTP 01, situated in the center of the hill, is the most intensive excavation area in terms of stratification and findings. Trench 272/613 in this sector was selected as a case study in which the whole excavation process from the first layer to the last one would be captured and modeled. The aim was to re-create the trench stratification along with the findings distributed in virtual 3D space. However, the excavation team decided to stop the work on this trench a few days after its start. Therefore, the experiment of trench strata digitization had to be canceled. Instead, the neighboring 10 m x 10 m 277/613 trench in which the team uncovered foundations of a Byzantine church was intensely photographed and digitized as a single surface layer.

In contrast to the other cases, a 12.3 megapixel Nikon D90 camera was used to capture over 200 images of this trench. In order to shoot from higher angles, a 2.5 meters long pole was also used throughout the photo shoot. In total, 192 of these images were used for digitization. The alignment of these photos produced 1,244,708 points in the sparse cloud and the process took 17,209 seconds (Fig. 11). Next, the dense point cloud containing over 40 million poins was calculated in 21,937 seconds. After the unnecessary points were cleaned the cloud had 36,540,635 points. This point cloud was used to generate the 3D mesh limited to 20 million polygons (Fig 12). 2115 seconds was needed for this step. Lastly a texture of 16,384 x 16,384 pixel resolution was produced in 1,132 seconds.

In order to geo-reference the obtained model, four ground control points were noted using total station. After registering the GCPs by inserting the recorded coordinates, the software provides the root mean square errors in the model. RMSE values were as follows:

Label	X error (m)	Y error (m)	Z error (m)	Error (m)	Projections	Error (pix)
point 5	-0.000232	-0.018036	0.011591	0.021440	97	0.000053
point 4	0.000308	-0.014584	-0.002043	0.014730	107	0.000062
point 2	0.049097	0.032746	-0.016540	0.061289	100	0.000076
point 3	-0.049175	-0.000126	0.006991	0.049670	67	0.000063
Total	**0.034745**	**0.020064**	**0.010735**	**0.041533**	**371**	**0.000064**

This average error of 4 cm is relatively small however the accuracy could have been improved if the images were taken parallel to the ground surface and if more ground control points were recorded. Even though the test trench was quite complex in shape and detail, the outcome seems satisfactory. As a result a digital surface model from the excavation area is generated. It was not possible to record more layers from the trench to integrate on to each other in virtual space however the test shows that in theory, the method is applicable to trench recording given that continuous data capture is conducted.

The resulting model can now be viewed and analyzed in 3D, the researchers can make measurements of any features of the mesh, calculate volume and also use it to generate digital representations in an easier way. It becomes possible to generate texture, orthophotos (Fig. 13) and height maps (Fig. 14) once the model is geo-referenced. Combination and derivatives of these will provide more exploratory and explanatory visuals both for the archaeologists and the 3rd persons (Fig. 15). Moreover, users can create excavation plans (Fig.16) out of the geometric information as well use it as a DSM for GIS and vectorize the data through related software for further applications.

Inside the trenches, horizontal formation is not the only part accommodating historical information. Vertical structure also plays an important role in the understanding of the use of space. IBM can be used to capture those data in detail by section recording. Commonly trench sections are documented by hand drawings accompanied with digital photographs. In a similar way, it is possible to shoot several photos parallel to section walls and record several ground control points to rectify the image in 3D space. This idea was experimented on a section from HTP 01 227/688 trench by using 49 images and four ground control points (Fig.17). However, much less number of images such as 10-12 is even enough for this purpose as the subject scene is rather planar and does not have much depth. The process resulted in a high resolution section model that can consequently be used to generate orthophotos and stratification sketches (Fig. 18). The high detail in the texture separates this approach from the traditional section drawings.

5.2 Documenting the Artifact

Pottery is one of the most common artifacts in archaeology and has an important role in archaeological research. Ongoing work on pottery for years, have made it a vital source of information for archaeological interpretation. It is now possible to derive deductions about chronology, use of space, social status as well as inter and intra-site economic/political/cultural relationships by studying unearthed ceramics. In the last decades, improvements in archaeometric techniques even provided further opportunities for solving manufacturing parameters and also patterns of trade. Such new technologies are constantly being implemented to pottery research however visualization of these items have not changed for years. Manual black and white drawings are the standard means of illustrating these finds as it is also the case in Komana excavations. This traditional approach in fact, is bound to artist's individual skill and prone to subjectivity and simplifications in shape, manufacturing process, surface treatment, ornamentation and state of preservation of the ceramics, thus means loss of information in the visualization process (Hörr et al., 2009: 2). Besides, the simplification does not only affect the presentation of ceramics but also the analysis and interpretation of these artifacts. Karasik explains this situation as follows: (Karasik, 2008: 104)

> *"The justification for using a 2D abstraction of 3D pots and potsherds is that most ceramic vessels are axially symmetric, especially wheel-thrown ones. Where a vessel is axially symmetric around its centre (henceforth 'axis of rotation'), a single profile is thought to reveal all morphological information. However, this is only true in a perfect world. Deformation can occur throughout the production process, e.g. when a vessel is removed from the wheel to dry elsewhere, when several (wheel-thrown or handmade) parts are assembled to make a composite pot, during the finishing and/or decoration process (necessitating remounting on the wheel or not), or during firing. Therefore, 3D modeling can improve our understanding of pottery production and add a new dimension in the representation and publication of pottery."*

Based on this view, one of the rather well preserved ceramics of the last season was selected for 3D digitization. The artifact was placed on a turntable and photographed with camera standing still on a tripod. 145 images in total were captured from three different heights, slightly rotating the turntabe in each shot. 39 of these images was seen to be sufficient for the modeling process. Those that are selected were processed in Photoshop and their backgrounds were masked out as the background stood still in each image. The top part of the turntable was not deleted from the pictures due to the fact that a 5 cm long scale bar was drawn on it in order to scale the 3D model and make accuracy tests. The images were saved as PNG files with alpha channels and imported to Photoscan in this format. These 39 images were aligned in 466 seconds and the process calculated 130,901 points. Afterwards, dense point cloud algorithm was initialized and a point cloud of over 13 million points was obtained in 6,441 seconds (Fig. 19). Then visible erroneous points were deleted and remaining 12,245,141 points were used to create the 3D mesh of

2,449,027 polygons (Fig. 20). The process took 529 seconds. Lastly 8,192 x 8,192 pixel texture map was generated in 192 seconds.

The accuracy test was conducted by using the formerly mentioned 5 cm scale bar. After the scale bar optimization in Photoscan, two markers were placed on the both edges of the broken part of rim and other two markers to measure the height of the ceramic. The distance between the broken edges of the rim was measured as 69 millimeters on the physical model. The digital distance was calculated 71.2 millimeters revealing the difference of 2.2 millimeters. Similarly, the height of the pot was measured as 81 millimeters formerly and the digital calculation gave the result of 82.7 millimeters (Fig. 21).

The resulting model stands as an almost perfect replica of the ceramic and it provides the opportunity of in detail analysis of surface structure and decoration reducing the need for physical contact with the actual object. One should note the observable depth information in the shaded model (Fig. 20) and painting traces in the textured model (Fig. 21). Besides this conservational contribution, the software allows rendering of orthographic images from several angles (Fig. 22) that can be used instead of or along with conventional illustrations and cross-section drawings. In any case, it is obvious that computer vision model contributes the visualization of these artifacts by adding depth and texture information as well as versatility through various formats of representation.

Apart from the ceramic, IBM was also applied to an inscribed stele uncovered in 2013 season that is not clearly readable by naked eye, to see the effect of texture and different lighting conditions on the visibility of inscriptions. In this case, 80 images were aligned in total and the step generated 387,692 points in 3,187 seconds. Dense point cloud that contained 15,676,373 points was created in 8,440 seconds (Fig. 23). The digitization procedure generated too many points so that in the geometric modeling process the maximum number of polygons was limited to 10 million (Fig. 24). After the mesh was created, it was exported as an OBJ file and then imported to Cinema 4D software. In this 3D modeling software an infinite light source was created and several images of the model were rendered under different light conditions. The renders clearly show that the text is more readable in the shaded model compared to textured model (also to the naked eye) and beyond that the visibility of the inscription significantly improves by changing the direction of lighting (Fig. 25).

5.3 Documenting the Human Skeleton

The excavations up to date showed that Hamamtepe was used as a graveyard in the late Byzantine period which means numerous burials are unearthed at each season. Since the beginning of the excavations these graves have been documented using data sheets, photography and manual drawings that are shared with a specialist in order to be analyzed and interpreted. Due to the reason that the specialist is not a member of the field team, the information he gets is limited and two dimensional. Therefore, one of the last season's burials was chosen to be modeled to test the possibility of a more efficient way of data transfer between excavation team and the specialist.

Grave 61 was documented by 31 photographs at 320 ISO with an exposure of f/14 and shutter speed of 1/50. In order to test the limits of software's accuracy, the images were captured randomly from oblique angles in contrast to what is suggested in software manual. Using Photoscan, the photographs were processed and a sparse cloud of 240,149 points was obtained. The software finished calculating this step in 528 seconds. Second step generated a dense point cloud containing 13,676,817 points in 7,461 seconds (Fig. 26). Afterwards, this cloud was used to create the 3D geometry limited to 10,000,000 polygons that took 727 seconds to process (Fig. 27). In the last step, 8,192 x 8,192 sized texture map was generated in 243 seconds.

Due to the reason that there were no ground control points recorded, a piece from scale set, visible in all images, was used to relatively scale and test the accuracy of the model (Fig. 28). During the fieldwork, the length of the piece was measured as 3.53 cm and it was registered with the same size in the generated mesh. Setting the relative scale, the digital length of the humerus was compared with its actual length resulting in the difference of 0.0335 cm (Digital length: 22.5335 cm, Actual length: 22.5 cm). One must note that this level of accuracy is impossible to achieve using any manual documentation method. The total time spent for capturing the photographs was around 5 minutes and the digitization procedure took almost two and a half hours. This total time may seem like CRP is a slower workflow than hand drawing nonetheless, the model generation process can be conducted any time after the fieldwork, saving from the critically scarce time of researchers to work in the field especially because it is possible to derive the skeleton drawing from an ortho image (Fig. 29).

The resulting 3D model of Grave 61 is a significantly accurate data that can be exported to various digital formats allowing virtual analysis similar to the formerly mentioned cases. In addition, the obtained mesh can be transferred as a 3D textured object via World Wide Web. In this way, the model can easily be viewed and analyzed by other people using any 3D modeling software or even PDFs. The possibility for the researchers to observe the burials in three dimensions as well as in situ will certainly flourish the information perceived by the specialist who is not always available at the excavation site.

Grave 49 of this season was also modeled through image based modeling. In this case, one of the trench supervisors was asked to take a set of photographs of the burial scene from different heights and angles. In the modeling process, 22 images captured only by her were used (Fig. 30). Although some parts of the mesh were absent, the resulting model was a sufficient digital representation of the burial scene consisting 7,738,510 points in the dense point cloud. This experiment revelaed that people who are not experienced in both photographing and IBM can still capture data qualified enough for the 3D digitization (Fig. 31, 32). Besides, the quality of the image capturing process can be increased with a slight guidance. In this way it becomes possible to recover more content at the same time in case the trench supervisors are assigned with this task.

5.4 Documenting the Architecture

Drawing plans is one of the most essential but at the same elaborate and time consuming tasks in an archaeological work. Even though carefully measured and drawn by talented architects, it is usually not possible to note every small detail in these drawings. Therefore, the outcomes become somehow simplified and subjective as it is the case in pottery illustration. Apart from these, the publication of drawings in papers and books have the disadvantage of being two dimensional that it does not accommodate the information for the scientists to make spatial analysis. In other terms it is difficult to make metric examination such as calculation of areas, angles, distances and volumes while reviewing the text (Breuckmann et al., 2009: 42). As image based modeling presents the opportunity of creating digital replicas and processing these replicas in various modes, they can also be used to improve the manual plan drawing workflow with a faster, more objective and more detailed procedure. In order to test this claim, the hexagonal basin situated at the surroundings of Komana was selected as one of the case studies. The plan of this edifice was drawn by Ahmet Çinici back in 2009 using traditional mediums. His work on the basin took almost around 100 hours to measure-draw and 20 hours to digitize it.

The hexagonal basin and surrounding trenches were photographed with the purpose of archiving in 2012 season by using Canon 5D Mark II camera attached to a hot air balloon. In this test 40 of those images were selected and used as the input for terrestrial modeling. During the modeling process the photo alignment step generated 272,033 points in 970 seconds. Dense point cloud calculation took 4,192 seconds and resulted in 11,416,697 points after the region of interest was resized (Fig. 33). In the geometric modeling step, the maximum number of polygons in the resulting 3D mesh was restricted to 10 million faces in order to ease the management of the model (Fig. 34). This process took 407 seconds to complete. Lastly, 8,192 x 8,192 pixel texture map was generated in 267 seconds (Fig. 35).

Due to the reason that the images were not captured with the intensions of 3D modeling there were no ground control points recorded. However, a 150 cm long scale bar was placed inside the pool which can be used to scale the mesh (Fig. 36). According to the former plan drawing the side walls of the structure was measured as 521 cm , 527 cm, 519 cm, 529 cm, 526 cm and 529 cm in length respectively beginning with the north side wall and continuing in clockwise direction (Erciyas et al., 2010: 285). The digital scaling and measurement on the other hand produced the results of 522.7 cm, 525.6 cm, 520.4 cm, 528.5 cm, 526.9 cm and 526.5 cm for the same order. The comparison of the height of the side walls on the other hand revealed an average difference of 5-6 cm between the actual and digital measurements. This means that Photoscan was not able to calculate the scene depth as accurate as the (x, y) planes due to the fact that the number and quality of used images were less than the software needed. However, the case shows that even though the images were not captured with the aim of 3D digitization and by a 3D specialist, the program is able to produce models with acceptable accuracy. Consequently the method is also applicable to archived footage (Fig. 37).

This test was also applied to the HTP 01 excavation area using air photography from the 2012 season. The model of the sector was created by using 34 images from the archives (Fig. 38). The whole process took around 1,5 hours to generate a mesh with 15 million polygons (Fig. 39). There were no ground control points or scale bars to geo-reference or scale the scene however the aim of this application was to see how the digitization of larger contents is solved by the software. Due to low number of images and the relatively long distance between camera and the subject, the detail in the resulting mesh and the texture is not as high as the former cases.

Nonetheless, the obtained model seemed to represent the planar and depth information quite well. Therefore, it can be used to generate digital plan drawings with the additional data of texture (Fig. 40). It is also possible to view the model in a 3D software, to separate and colorize the mesh representing the different phases of use and to observe those phases individually.

5.5 Evaluation of IBM Applications at Komana

The cases tested at Komana varied significantly in terms of scale. To illustrate, the HTP 01 region is a 35 m x 20 m area and the pottery that was modeled has a diameter of 18 cm. In each case the procedure was straightforward and the resulting visuals were tempting. Besides, the created models were notably accurate. The approach revealed amazing results when it was especially applied to small and mid-sized objects. The software failed to digitize only shiny or transparent objects made of metal and glass or covered with glaze due to the fact that the texture on the reflections changes when either the camera or object moves. Here, it should also be noted that there can be several other cases in which Photoscan can not produce intented modeling outcomes even though it was not observed in this study. Flat textured objects that does not allow point matching as well as extremely deep and tight scenes that does not allow the capture of overlapping images would result in poor representations (Agisoft LLC, 2013: 4-5). In any other situation the method proves its reliability.

The photo shoot for artifacts, trench section and burial was quite fast. None of those took more than 5 minutes to capture. Nonetheless, the same can not be said for terrestrial scale applications. When the size of the subject got bigger, the time spent for photography also increased. In trench recording case the photo shoot took around 20-30 minutes to document a 125 square meters area. The problem in cases like this is that it gets harder to reach necessary heights for correct angles. Even though a 2.5 meters long pole is used, it is not usually possible to shoot photographs parallel to the subject surface. Combination of two poles on the other hand, is hard to operate. As a result, the accuracy and detail of the generated models decreases. An efficient solution to this problem could be using UAVs, specifically multicopters to capture images. In this way, series of photographs can be taken parallel to subject surface in short time intervals even from different height levels.

There are a few other issues about this method. One of them is about the photo recording format. Today's digital cameras provides two image format options that are RAW and JPEG. RAW image files are minimally processed data coming from the sensor of the camera and they let the user to alter many image features after they are shot. JPEGs on the other hand, are lossy compressed images that are processed by the camera. The issue with JPEGs is that these images are not suitable for luma and chroma correction. Whatever the setting the user chooses while shooting, the resulting photographs have to be used as they are. Apart from the user mistakes, in countries like Turkey most archaeological work is conducted under strong sunlight casting contrasty shadows. When the exposure setting is adjusted according to the sunny parts of the scene the shadows reveal little detail. Therefore, when these images are used in 3D digitization the areas with shadows can not be calculated efficiently causing loss of information. In this study, the burial scene and the artifacts were photographed in shade therefore the point clouds were distributed homogeneously. However, this issue was clearly observed in the point clouds of other cases. In fact, the software manual recommends using lossless TIFF files derived from RAW images due to the fact that JPEG compression decreases the resolution and creates unwanted noise (Agisoft LLC, 2013: 4). What is not mentioned in the manual is that RAW files also allow the user to play with exposure settings after they are shot so the user can process these images by decreasing the exposure in highlights and raise the exposure in shadows. Consequently the dynamic range of the images can be increased to solve the problem. However, this creates another issue. Raw image files take up almost four times more space than the JPEG files. To illustrate, the 80 18 megapixel JPEGs captured to digitize the inscribed stele occupies 450 MB in disk space whereas the same images in RAW takes up 1.8 GB. This means when image based modeling is continuously applied to an excavation, it will generate an enormous amount of data to be processed and archived. It is obvious that data storage and preservation is a serious obstacle however the contribution of the 3D digitization is certainly beyond these limitations and software/hardware developments could be a solution in the near future.

In several cases of the study CRP showed its efficiency in creating digital illustrations and drawings. In most cases the approach was significantly faster than conventional methods and if not it generated more scientific, highly detailed and multi dimensional information out of the subject. However, this does not mean that computer vision must replace traditional drawing. In a case where an experienced architect or illustrator draws a trench plan or an object, the drawing action becomes a part of the interpretative process thus, their interaction with the subject may create a subjective contribution to archaeological research. The 3D digitization on the other hand, is rather more objective and it provides straightforward data to be processed afterwards. In other terms, whoever makes a drawing or illustration over a rectified 3D model the result would seem more or less similar. For archaeological researches that do not have permanent talented architects and illustrators, IBM could be a powerful solution for pacing and standardizing archaeological drawings as well as providing visuals with additional color and texture information.

Despite a few issues to be dealt with, the case studies showed that image based modeling is a solid method for digitizing and improving the documentation of archaeological fieldwork. It only relies on the existence of a decent camera along with a few other tools and little preparation for specific situations. In these terms, it is surprisingly mobile and cheap. Additionally, there is no recognizable difference in the quality of the results of the first and latter tests conducted by the author. This shows that a little bit of pre-research will be enough for anarchaeologist to start applying close range photogrammetry in his/her studies. Considering these advantages and also the formerly mentioned features of this method, it is not hard to predict that growing number of archaeological projects will implement IBM in their workflow in the following years.

CHAPTER 6

DISCUSSION

In its first two decades, virtual archaeology followed the purpose of simple illustration, in other words non-complex 3D reconstructions, far from theoretical background, created to visualize the study area, especially the edifices. In the last decade, however, the scientific value of 3D digitization was discussed and its role in archaeological research started to be questioned. In this period, several initiatives such as Ename Charter (http://www.enamecharter.org/), London Charter (http://www.londoncharter.org/) and Principles of Seville (http://cipa.icomos.org/fileadmin/template/doc/PRAGUE/096.pdf) were taken with the aims of scientifically validating and standardizing virtual archaeology. Ename Charter focused on interpretations of cultural heritage sites and tried to set a theoretical base for visual reconstructions in this process by stressing the necessity of strong background evidence such as "*detailed and systematic analysis of environmental, archaeological, architectural, and historical data, including analysis of written, oral and iconographic sources, and photography*" (http://www.enamecharter.org/principles_0.html, Article 2.4) for 3D modeling of the structures. London Charter on the other hand was specifically designed to "*ensure methodological rigour of computer-based visualization as a means of researching and communicating cultural heritage*" (Denard, 2012: 57). Placing the "transparency" in the core of the initiative, in 6 principles that are implementation, aims and methods, research sources, documentation, sustainability and access, the charter set guidelines to be considered by those who plan to apply virtual applications in any field of cultural heritageresearch. Based on this charter in the following years, Principles of Seville was declared for the reason that the mass application of computer-based visualizations revealed both the huge potential and weaknesses of these approaches as well as the need to improve the applicability of principles of London Charter specifically in the field of archaeological heritage (Lopez-Menchero et al., 2011). By introducing new propositions such as the absolute need for collaborative and interdisciplinary approach to virtual projects, the view of computer-based visualizations being not a replacement for a traditional approach but in fact just a complementary tool and the vitality of the discrimination of what is real and what is reconstructed, in other words the authenticity of the models the Principles of Seville organized an advanced base for the use of virtual techniques in archaeological research. Afterall these initiatives, new questions are being asked now. How can virtual archaeology improve archaeological research? How can 3D applications be used as an analytical tool for archaeology rather than being a way of simple visualization? How can 3D data flourish the interpretation and collaboration of captured information? How can these methods create new research opportunities? There are some certainly obvious contributions of 3D digitization to be mentioned however, the field is so new that neither the full potential of these mediums are understood nor the necessary conditions, appropriate technical and intellectual infrastructure developed yet.

To start with, it is important to remember that Archaeology is a field dealing with at least 4 dimensions: (x, y, z) and time. For this very reason, conventional 2D tools and applications used for recording and interpreting archaeological data provides limited data preservation as well as scarce information resource to the perceiver. However, adoption of new technologies to record, visualize and reconstruct archaeological sites allows the archaeologist to virtually preserve the site and the artifacts through 3D data capture that can be used to create 3D digital environments potentially allowing further analysis along with the integration of other researchers and also the public directly to the process or the outcome. This becomes especially important when the irreversible and destructive nature of archaeological work is taken into consideration. The method allows the archaeologist to recover as much information as possible from the excavation before it is lost forever. Therefore, the initial contribution of 3D digitization starts from the very first steps of archaeological research.

The issue mentioned above insists that archaeology needs multi-layered, multi-dimensional and high resolution documentation techniques in order to recover and preserve maximal data out of excavations. Remondino explains the required properties of a desirable documentation method as follows: (Remondino, 2011: 1115)

- *accuracy: precision and reliability are two important factors of the surveying work, unless the work is done for simple and quick visualization;*
- *portability: a technique, in particular for terrestrial acquisitions, should be portable due to issues of accessibility for many heritage sites, absence of electricity, location constraints, etc.;*
- *low cost: most archaeological and documentation missions have limited budgets and cannot afford expensive surveying instruments;*
- *fast acquisition: most sites and excavation areas have limited time for documentation so as not to disturb works or visitors;*
- *flexibility: due to the great variety and dimensions of sites and objects, the surveying technique should allow for different scales and it should be applicable in any possible condition.*

Although it is not perfect, close range photogrammetry started becoming such an option in the last few years. The softwares like Photoscan are not expensive and there are even free programs such as Autodesk's 123Dcatch, Photosynth and Bundler. The only prerequisite of this method is the use of a digital camera that any excavation already has in its tool box. In contrast with laser scanning, the computer vision softwares are becoming more and more user friendly, making the digitization process a straightforward task that any person with a slight guidance can proceed. Except being low-cost and easy to use, the method has proven to be significantly accurate in generating models in various cases from artifact scale to terrestrial scale as mentioned in previous chapters. In addition, it was seen that it provides much more detailed, optional and faster results compared to traditional drawing and illustration work. Last but not least, the models created through this medium can be disseminated in digital formats that provide the opportunity of secondary analysis, questioning and interpretation. So to summarize, virtual methods and specifically image based modeling in this case notably improves the quality and quantity of data recorded through excavation in order to be used for the following processes.

Considering Turkey, most of the archaeological projects still use traditional documenting methods. However, there is an exponentially increasing number of virtual applications all over the world. In fact, last decade has experienced a drastic explosion of 3D content in archaeology. Many projects have used 3D scanning, close range photogrammetry, procedural and hand modeling to document and visualize their researches. Besides, in several cases these applications have become the key element of archaeological interpretation and hypothesis testing. The number as well as the workframe of 3D applications will continue to grow exponentially in the following years. Nonetheless, there should not be formed a common view that virtual applications turn the data capturing process into a perfectly objective state and solve all the problems of documenting and visualizing archaeological subjects. At the very end, these are only tools to be used according to certain purposes. Therefore, the introduction of 3D applications in archaeology is just a positive evolution. The revolution on the other hand, is the recent change on how the information can be handled, improved and disseminated through digital mediums.

In the last two decades, introduction of World Wide Web and advancements in computing-programming technology reformed the world. It became possible to use highly complex algorithms to process or create a content and to reach, share and alter it from almost anywhere in the world. This opportunity therefore, created the new media. This new media in fact, has shifted the medium of information exchange creating the possibility of on-demand access to data and user generated, reflexive contents rather than the dictated knowledge. It is important to note that the most successful initiatives of recent years are energized by this stream. Take Facebook, Youtube, App Store, Wikipedia and so on, all of their content is created, developed and shared by its users that makes them unique and keeps them growing. The world is changing. The information is becoming more transparent and more accessible in various formats. And the demand for the information is getting more complex. This recent digital transition, however, has not much diffused into archaeology and with a few exceptions on hand, most of the archaeological works remain proprietary and unknown until a publication is done in widely spaced intervals. Thus, the main and up to date platform for information exchange at present become the conferences but only a few of these publish their proceedings. Digital contents form, evolve and travel notably faster than the conventional data so print publication can not compete with this pace (Bentkowska-Kafel, 2007: 52). Moreover, today's archaeological publication and presentation is dominated by text and static images thatare not adequate to fully represent archaeological subjects' dynamics, detail and complexity and do not solve the inherent problems of traditional data mining as well as the efficient transmission of data.

The potential of 3D techniques is huge, it is obvious. This is the most probable reason behind the boom of virtual archaeology. Nonetheless, it should be mentioned that there is a notable gap between our capability to capture 3D data and to manage those. It is currently possible to create millions of polygons in meshes, gigabytes of files documenting the excavations layer by layer, artifact by artifact, edifice by edifice but "*the indiscriminate accumulation and growth of content present serious problems of information management and of knowledge which concern the relationships between data and perceptions*" (Forte, 2008: 23). Therefore, archaeology needs new mediums to manage the digital data in 3D space that provide solutions for accessibility, interoperability and scientific authentication challenges. Besides, there is a growing need for archiving the digital artifacts to ensure their long term survival (Koller et al., 2009: 7:1).

In order to integrate the captured models and information, most virtual archaeologists are obliged the use 3D modeling softwares such as Meshlab, Blender, 3ds Max etc and/or GIS applications that are not optimized for this kind of use. Even though it is possible to handle 3D data through these programs and create layer by layer, object by object geo-referenced scenes, there has to be a specialized application that turns archaeological work into a collaborative and interactive visual database. For this very reason 3D virtual archaeology team at Çatalhöyük created a tele-immersive system based on Vrui VR Toolkit designed by Unversity of California, through which they can improve the accessibility and transmission of virtual data: (Forte et al., 2012: 10)

> *"The Vrui VR Tookit aim to support fully scalable and portable applications that run on a wide range of virtual reality systems using different display technologies and various input devices for interaction. The applications built with Vrui can thus run on various clients, from laptops to desktop servers, and support different display technologies, such as 2D displays, stereo displays or fully immersive 3D displays (e.g. CAVE). The collaborative extension of Vrui allows linking two or more spatially distributed virtual environments. Thus users from different geographical locations, represented by 3D avatars, can work together in the same cyberspace, interacting in real time with models of artifacts, monuments and sites.*
>
> *In a tele immersive session it is possible to browse and measure all the layers, querying data by code and category, turn on and off digital items and finally reconstruct the entire excavation process. Playing with digital levels of transparency allows the recognition of spatial relationships of layers, units and artifacts otherwise not understandable."*(Fig. 41)

This system is still at development stage and it has a great potential for intra-site applications especially if it becomes usable by a wide group of archaeologists. However, looking at the bigger picture, it does not answer the needs of our whole community. A central repository for virtual archaeology is needed to collect, review, preserve, distribute and publish the generated 3D data due to the reasons that: (Koller et al., 2009: 7:3)

- *there are no specific tools designed for querying the digitized cultural heritage*
- *there is no peer review mediumto evaluate the quality of the digitized work for publication*
- *there is no resource providing access to a wide range of high- quality scientific 3D models*
- *there are no long term plans by content creators for preserving the digital data they generated.*

As formerly mentioned, hundreds or even thousands of scientific 3d models of cultural heritage is being created these years. Unfortunately a notable portion of these models shares the destiny of conventional archaeological data that are not being disseminated to academic world or sometimes lost due to lack of long term archival plans. This is the idea behind SAVE (Serving and Archiving Virtual Environments) project designed by Virginia University's Virtual World Heritage Laboratory (http://vwhl.clas.virginia.edu/save.html). The project intended to preserve 3D digital Cultural Heritage models and to provide access to them for the scholarly public. Several years after its declaration, it has not been able to create a universally usable virtual system for researchers however a new peer-reviewed online journal called "Digital Applications to Archaeology and Cultural Heritage (DAACH)" (http://www.journals.elsevier.com/digital-applications-in-archaeology-and-cultural-heritage/) was initiated through this project. In this e-journal, the researchers have the opportunity to publish their papers along with interactive 3D models, images and videos. The peer-review does not only deal with the text but also the multimedia attached to the paper. Considering and validating the accompanied data and metadata about the professional qualifications of the author as well as the documentation on the design of digitization project, hypothesis and uncertainties of the 3D data (Koller et al., 2009: 7:3) the project claims to become a scientifically authenticated central database for digital cultural heritage models and the academic communication on those subjects.

Even though DAACH stands on firm grounds for being a scientific repository, the project fails to provide an advanced web based 3D content viewer or analyzer. Without the existence of this kind of system, it will never be able to serve fully to the intended purpose. In fact, only Smithsonian Institute's Digitization Program Office seems to solve this problem. Through Smithsonian X 3D project supported by leading 3D modeling software developer Autodesk, the office was able to present a web based browser for their high resolution 3D content generated by the digitization of the museum's assets (http://3d.si.edu/browser). Although it was started very recently, the project proves to be promising for the following years with its interactive tools that allow the users to conduct measurements, observe cross-sections, change materials and lighting conditions over high resolution objects (Fig. 42). As a more recent development, albeit not as sophisticated as Smithsonian's tool, Sketchfab (https://sketchfab.com/browse/view) also offerred an online service that allows uploading and sharing of 3D meshes up to 200,000 polygons and 4,096 x 4,096 pixel texture size. Using WebGL technology, the initiative lets users to interact with the 3D models and even to embed the content in other websites just like Youtube videos. It is certain that neither the upper limit of detail nor the sole visualization theme without measurement tools in this service is enough for scientific dissemination but still, Sketchfab represents a strong indication to what will be possible in the near future.

In spite of the fact that theoretical base for digital archaeology has been consolidated over the passing years, the practical approach on the subject has not been adopted by the majority of archaeologists especially in the interpretation and dissemination processes. It is obvious that archaeology should evolve to a state where the researches are not seen as a personal belonging but as a pile of interpreted data to be shared and collectively discussed/questioned. This can be achieved by the use of collaborative virtual environments that allows users to publish multi-dimensional contents and interact with the preloaded data. With the increasing number of users and therefore the amount of content, Archaeology could posses a huge global database. Even though there is not an existing system to accommodate this kind of information exchange yet, the recent improvements in IT present the clue that it could be possible in the very near future. Therefore, the current responsibility of the archaeologist should be designing his/her research keeping in mind that the audience demands multi-dimensional, multi-layered, questionable and reformable digital data which can be achieved through 3D digitization methods. Considering the image based modeling applications experimented in Komana excavations as well as the reviewed projects, it is clear that this medium proves itself in providing highly accurate, manageable and portable documents as well as versatile representations. Its applicability to any archaeological research due to being low cost and straightforward make computer vision an efficient way of recovering information from the excavation, preserving and disseminating it in digital formats.

CHAPTER 7

CONCLUSION

In this thesis, virtual practices that are being used in archaeology were evaluated in general. Various 3D digitization methods were discussed with respect to their working principles, application area and purpose of use however, the research concentrated mainly on one of these applications, that is Image Based Modeling through the use of Agisoft's Photoscan software, due to its unique features such as being mobile, fast, low-cost, highly accurate and applicable to a range of scales. The previous reviews of this approach all over the world as well as the case studies conducted by the author at KomanaPontika excavations revealed that this medium stands as a powerful tool for digitizing archaeological information in more objective and detailed way than the conventional methods. It was observed that with the use of computer vision, it is possible to generate 3D models of objects and areas consisting millions of polygons with photorealistic texture information that have an accuracy of a few centimeters or sometimes even millimeters and to handle/integrate these data in digital spaces. Consequently, this situation provides the archaeologist with several opportunities such as to archive information digitally and derive diverse types of representations out of it, to make interpretations by viewing 3D spatial data any time and collaborate with other specialists on the decision processes, to convert the content into various digital formats for the dissemination of the research to academic audience with multi-layered, multi-dimensional, questionable formationand to the public with visually appealing, more understandable design.

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APPENDIX A

FIGURES

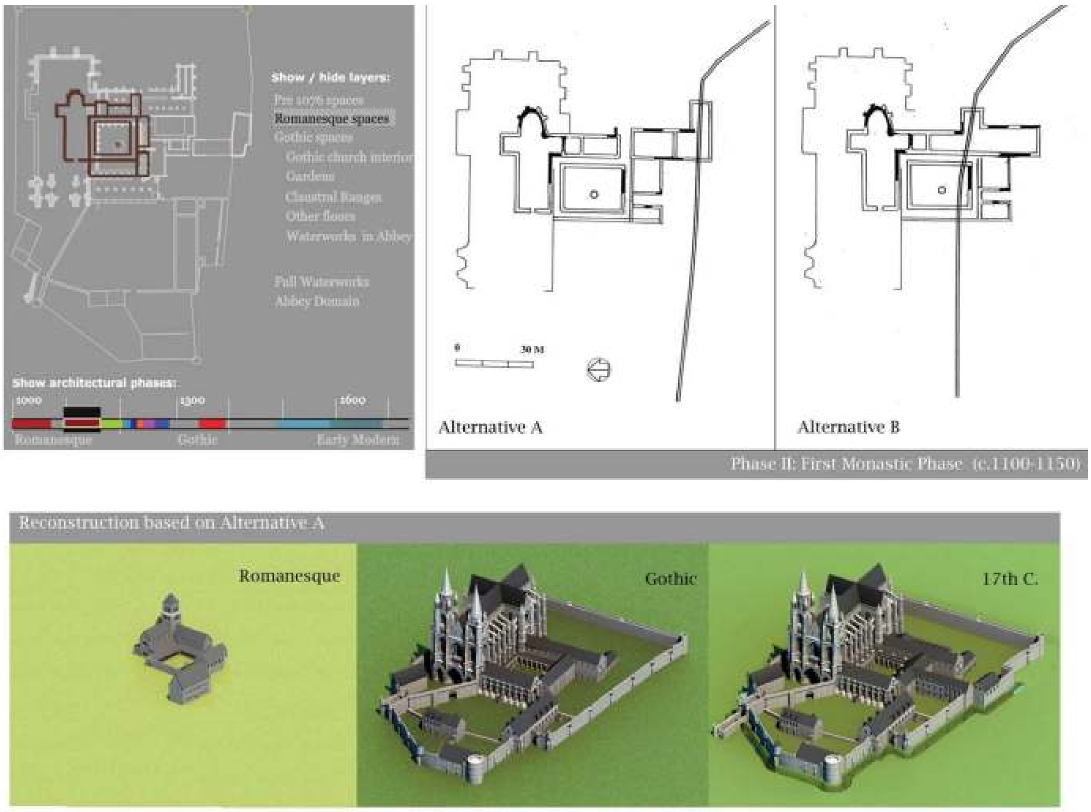

Figure 1: An image of interactive site plan from the Wesleyan-Brown Monastic Archaeology project (known as MonArch) showing alternative cases for the evolution of the monastery by a time slider and hand modeled 3D phases (Bonde et al., 2009: 367).

Figure 2: Images from Rome Reborn project showing the buildings generated by procedural modeling. Rome Reborn. Retrieved February 10, 2014, from: http://romereborn.frischerconsulting.com/gallery-current.php

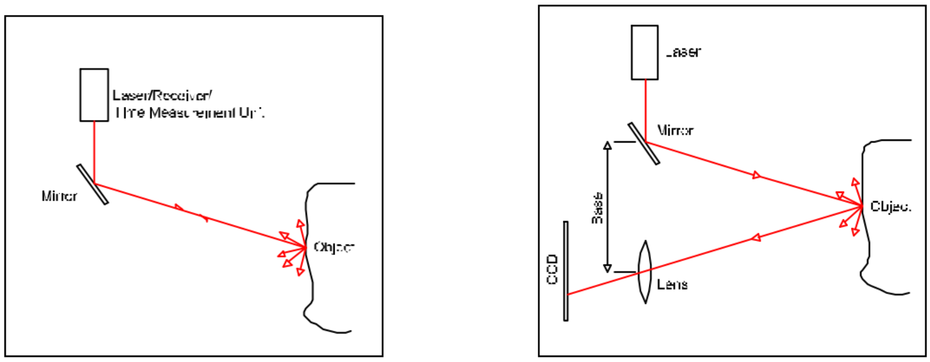

Figure 3: Working principles for two different types of scanners: (Left) Time of Flight Scanner, (Right) Triangulation Scanners (Boehler et al., 2002: 431).

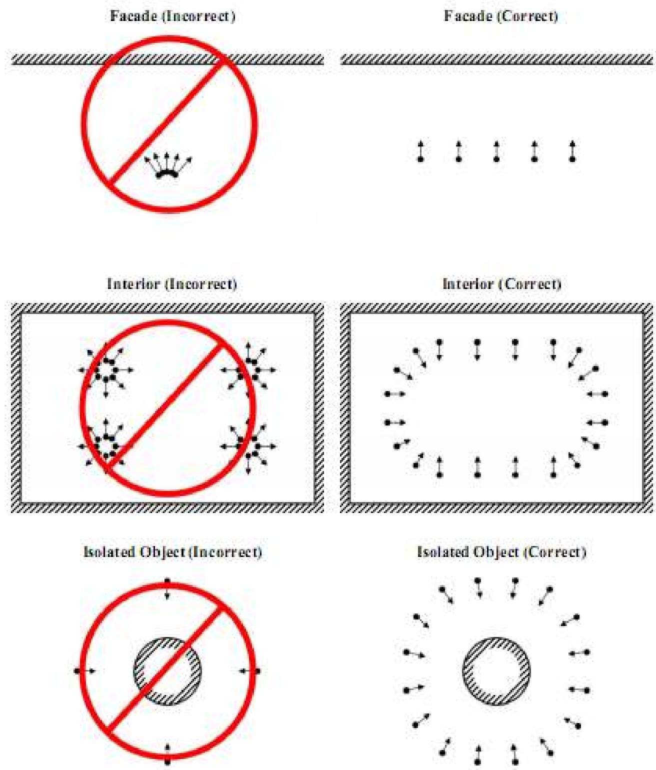

Figure 4: Agisoft Photoscan Photographing Manual (AgiSoft LLC, 2013: 5).

Figure 5: 3D textured model of a piece from Altai Rock Art generated by IBM (Plets et al., 2012: 142).

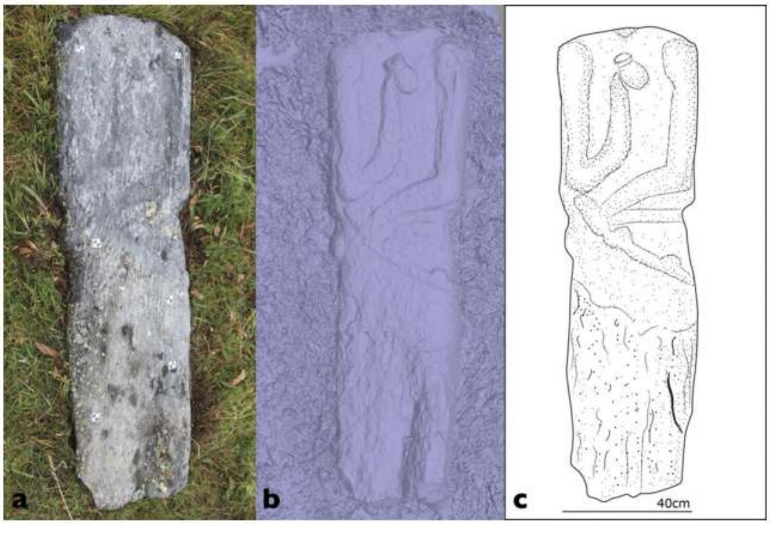

Figure 6: Impact of 3D modeling on the visibility of antropomorphic stones from Altai mountains. (a) Actual photo, (b) shaded 3D model, (c) drawing generated from the model (Plets et al., 2012: 891).

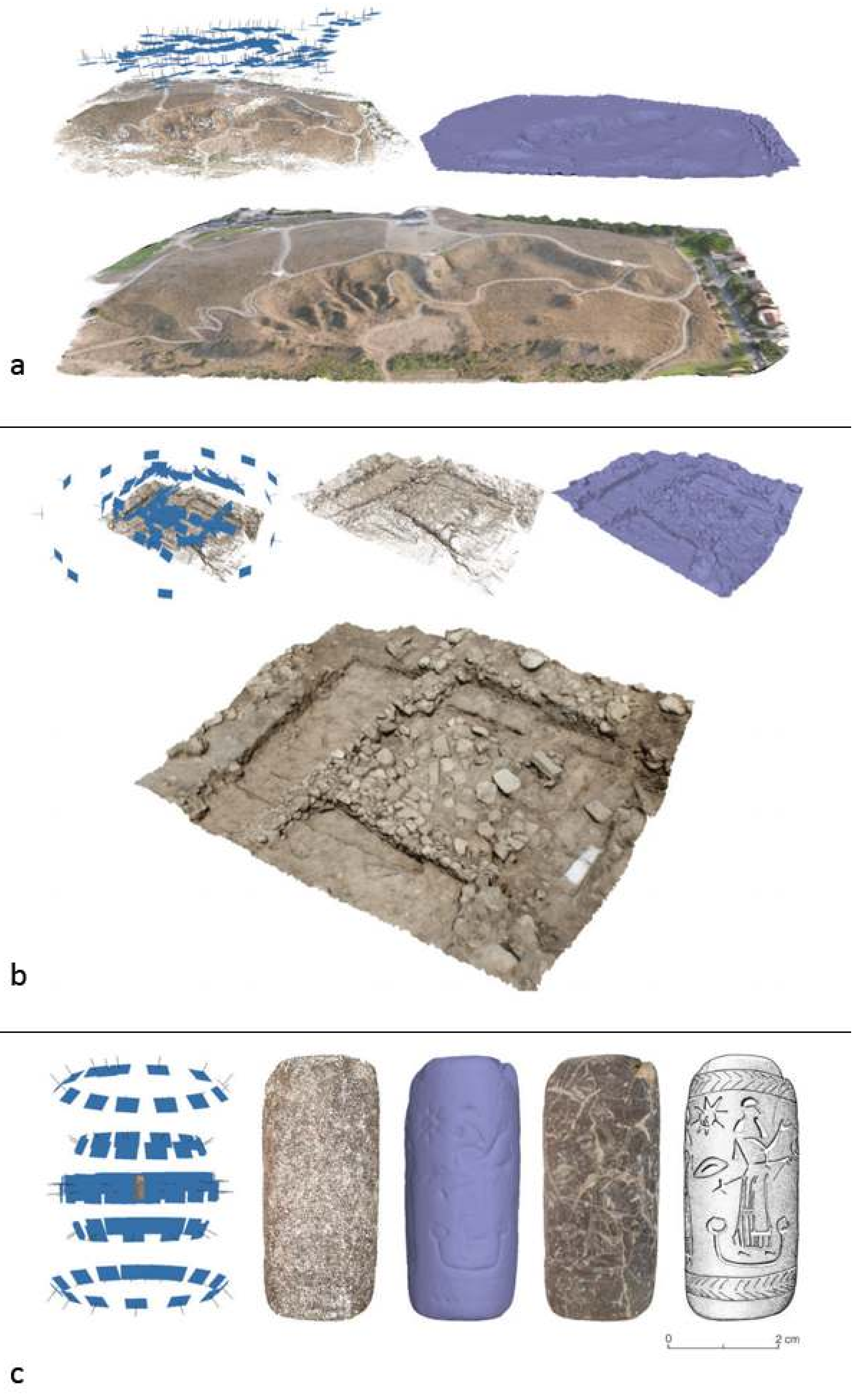

Figure 7: Various applications of CRP in archaeological fieldwork at Tel Akko to digitize (a) 3D model of the mound, (b) an excavation unit, (c) a cylindrical seal (Olson et al., 2013: 251,253, 255).

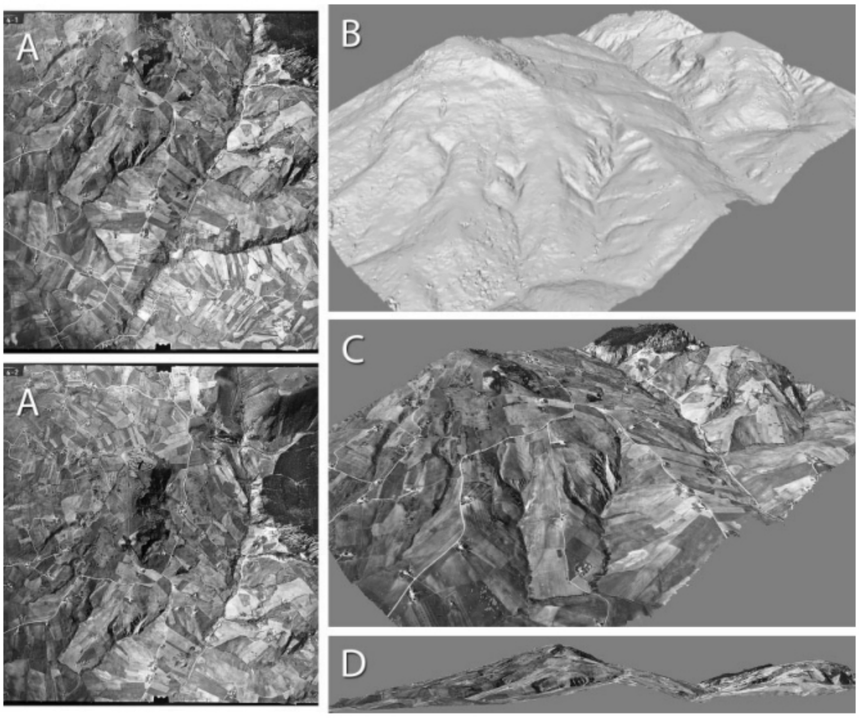

Figure 8: Generation of (B) 3D surface model and (C, D) textured DSM out of only (A) two images (Verhoeven, 2011: 72).

Figure 9: Hamamtepe and HTP 01 excavation sector.

Figure 10: The hexagonal basin and excavated trenches.

Figure 11: Sparse point cloud and camera positions of trench 277/613.

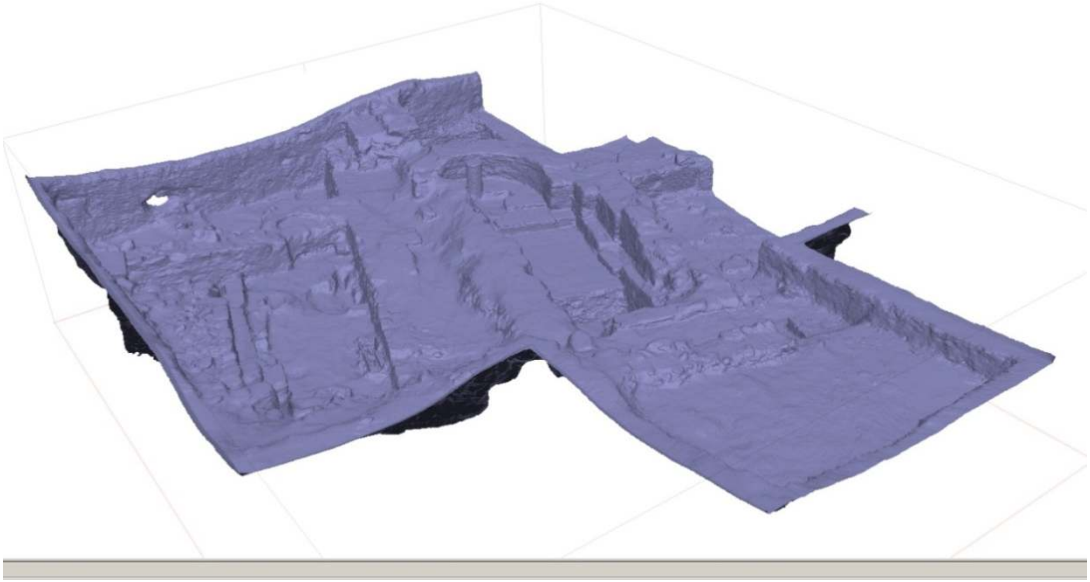

Figure 12: Shaded model of trench 277/613.

Figure 13: Textured ortho image of trench 277/613 with recordedground control points.

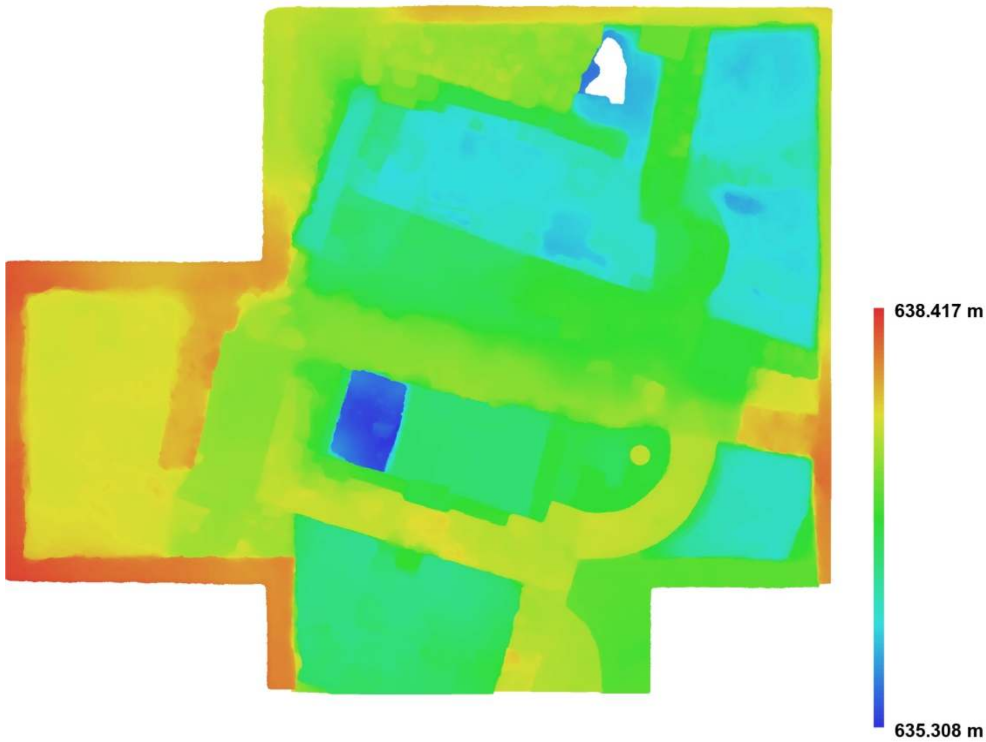

Figure 14: Height map of trench 277/613.

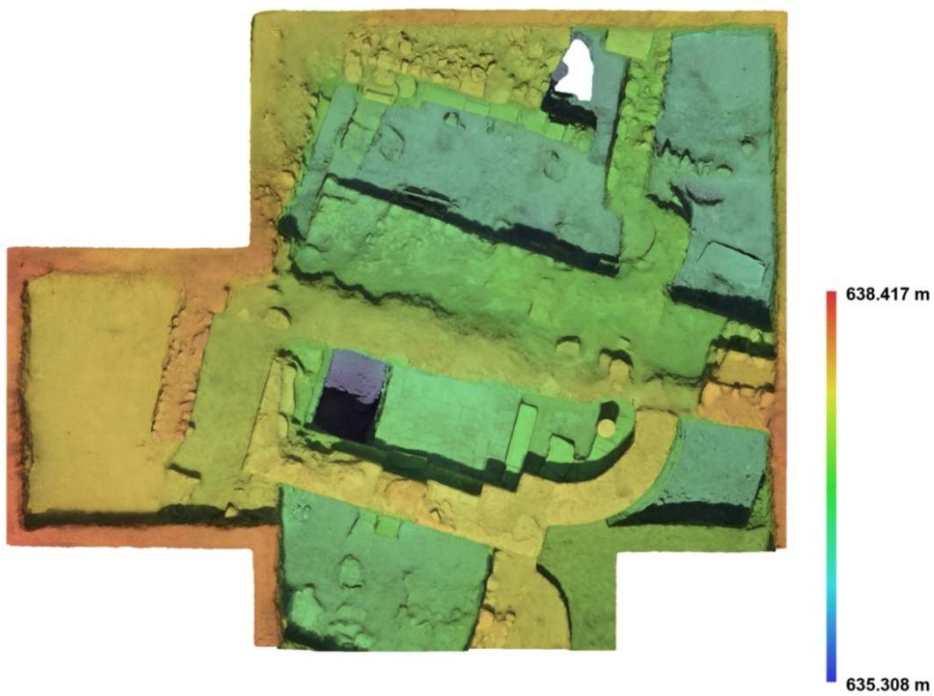

Figure 15: Height map of trench 277/613 blended with texture.

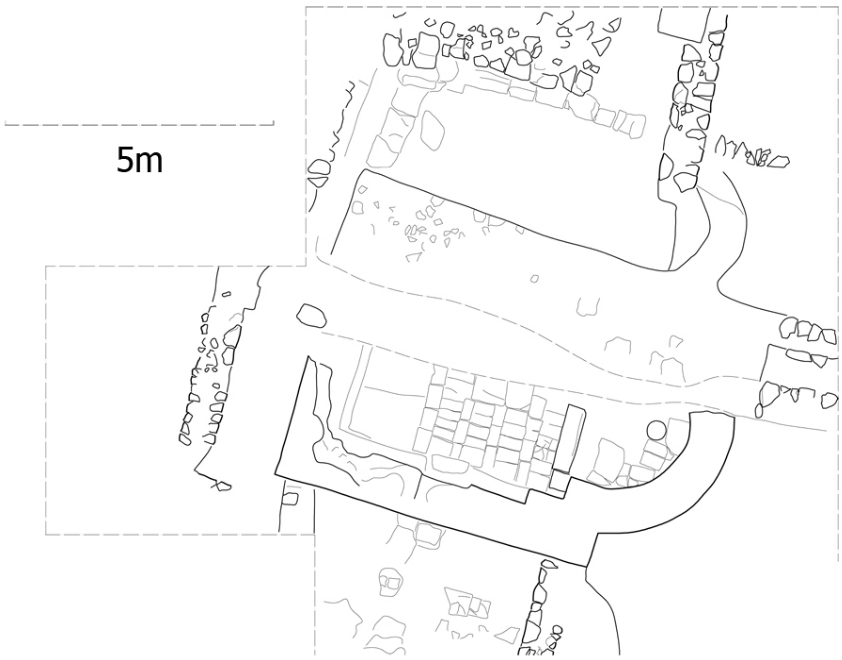

Figure 16: Quick plan drawing of trench 277/613 using ortho image.

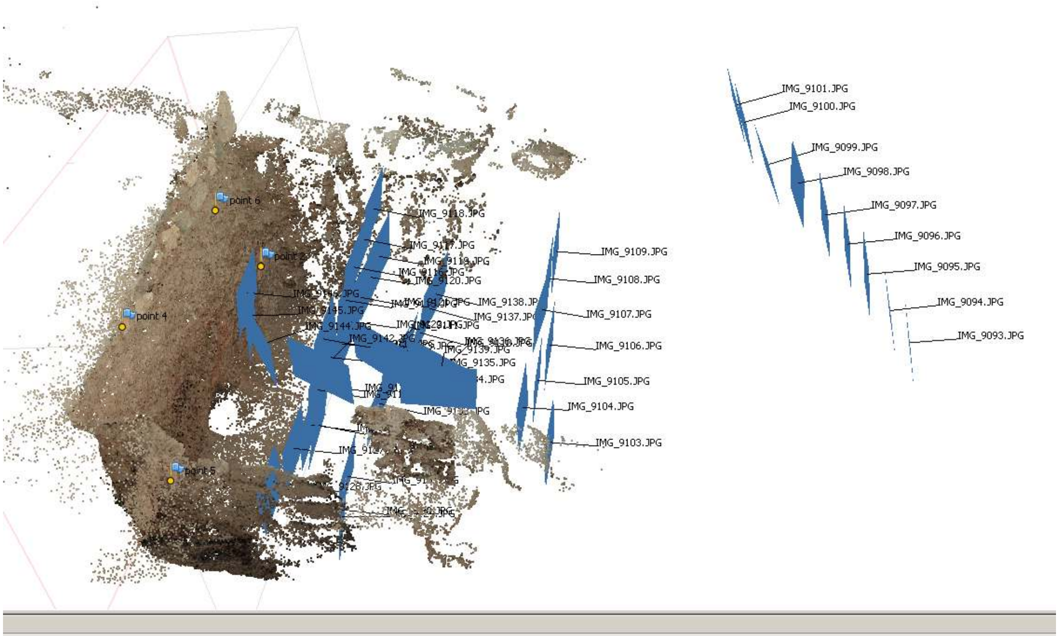

Figure 17: Point cloud and camera positions for the east section of trench 227/688.

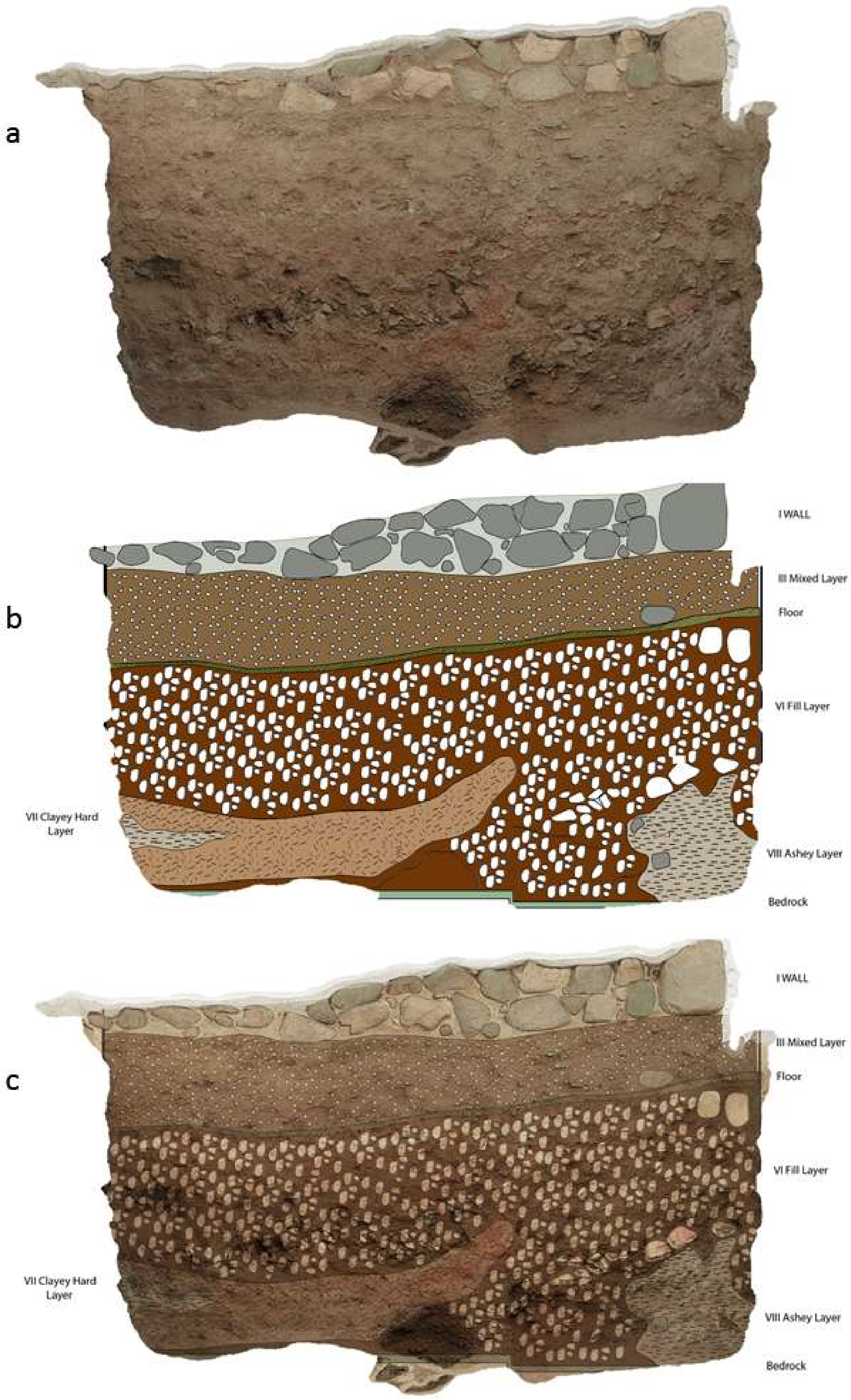

Figure 18: The east section of trench 227/688 represented as (a) ortho image, (b) stratigraphical sketch, (c) sketch overlayed on ortho image.

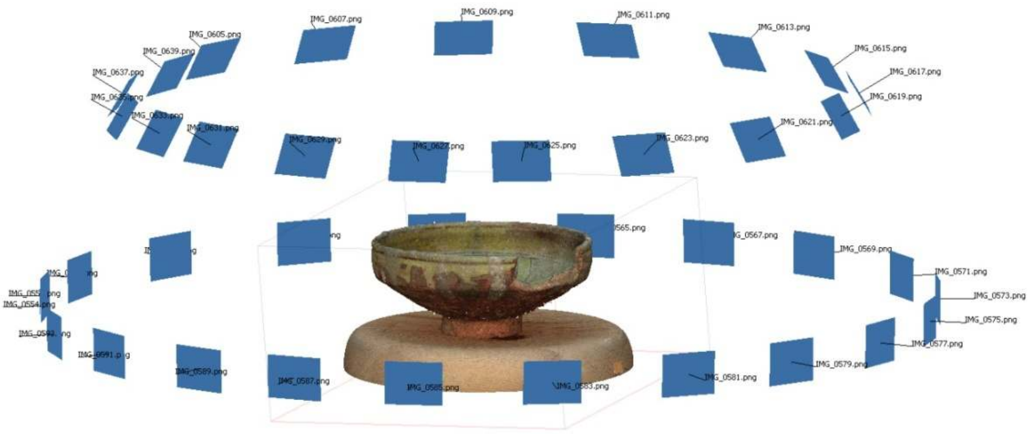

Figure 19 : Dense point cloud and camera positions for the selected ceramic.

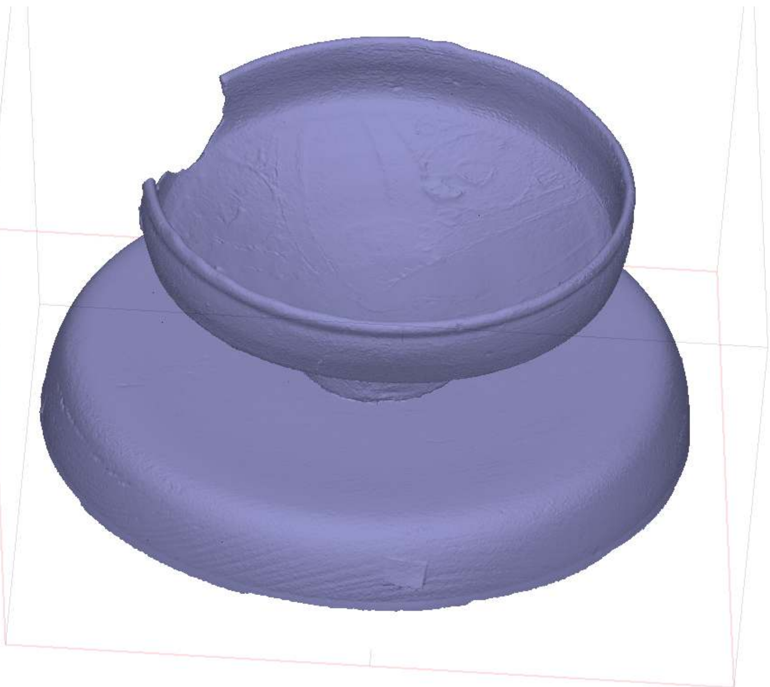

Figure 20: Shaded model of the selected ceramic.

Figure 21: Textured 3D model of the selected ceramic along with digital scale bar and reference measurements.

Figure 22: Ortho images of the ceramic with texture: (Left) top view, (Right) side view.

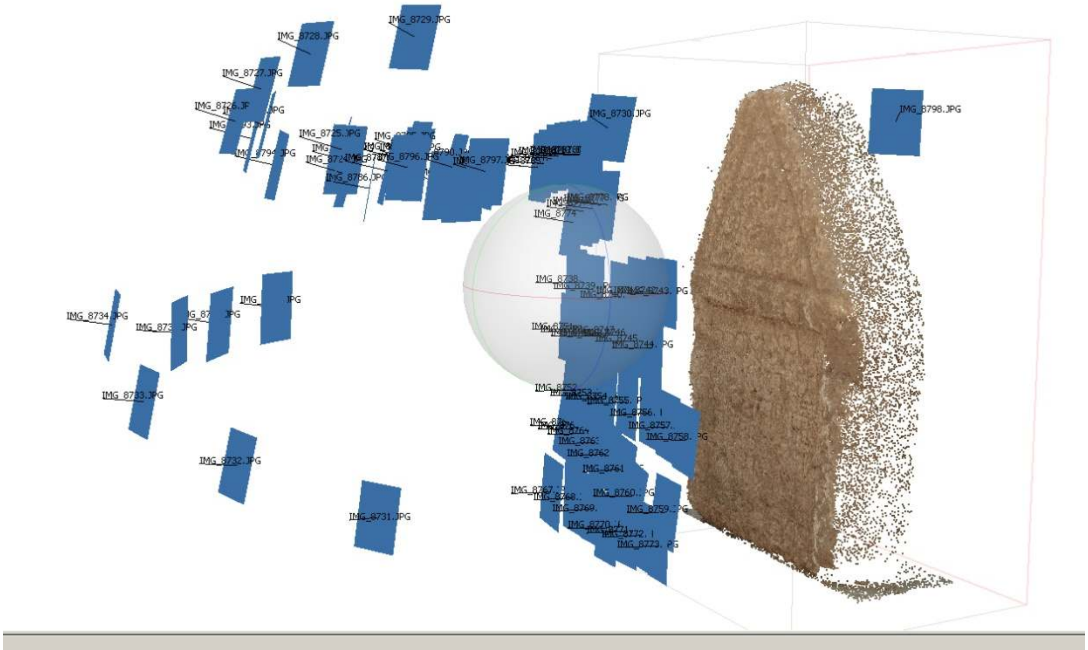

Figure 23: Dense point cloud and camera positions of the inscribed stele.

Figure 24: Textured 3D model of the inscribed stele.

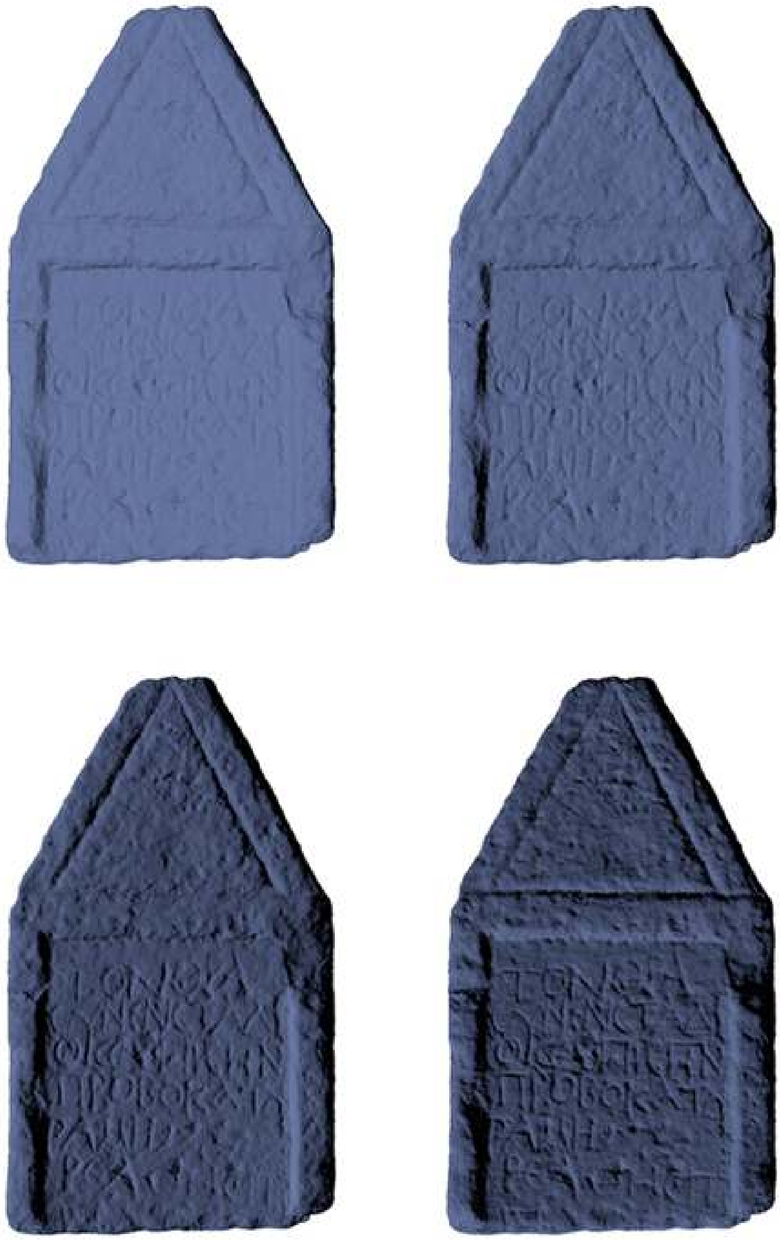

Figure 25: Surface details of the inscribed stele under different lighting conditions.

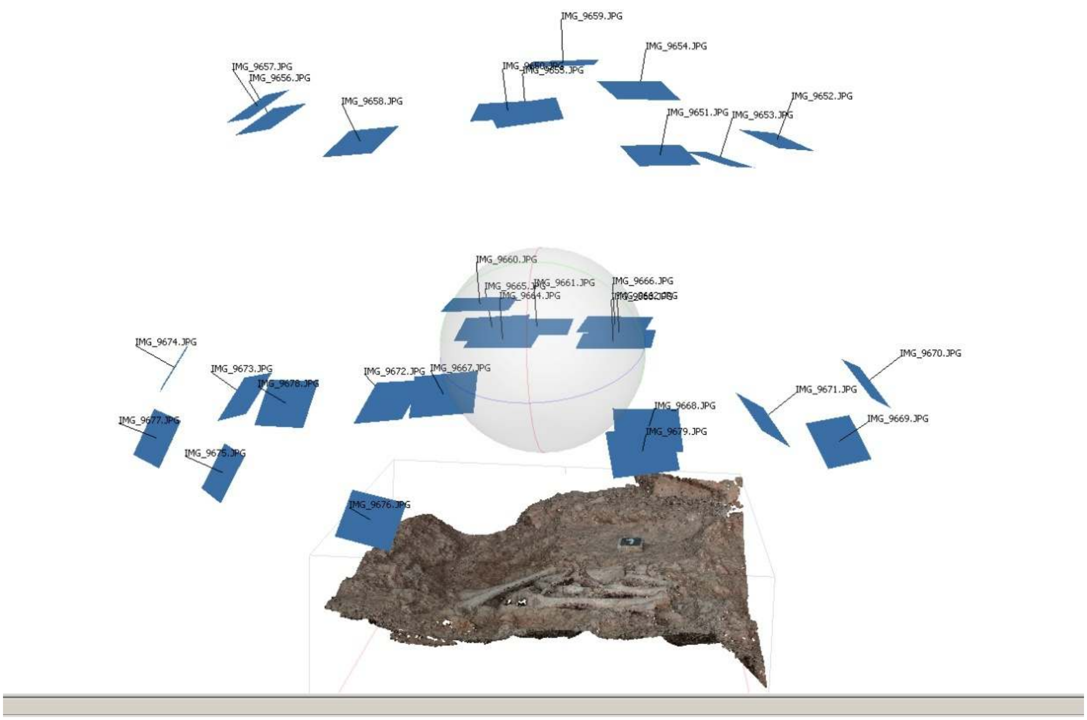

Figure 26: Dense point cloud and camera positions of grave 61.

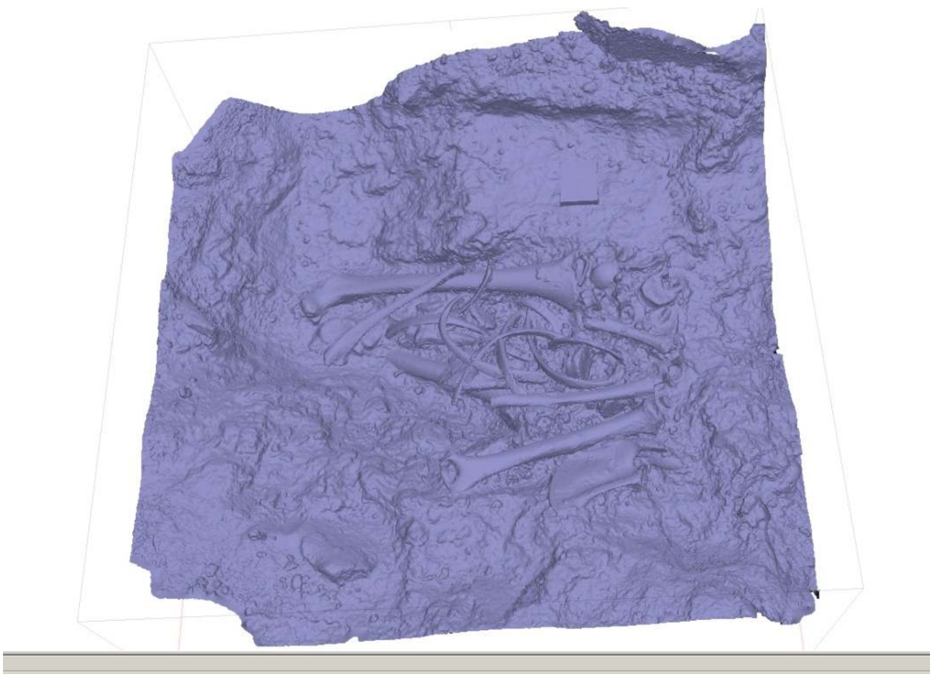

Figure 27: Shaded model of grave 61.

Figure 28: Textured 3D model of grave 61 along with digital scale bar and reference measurement.

Figure 29: Ortho image of Grave 61.

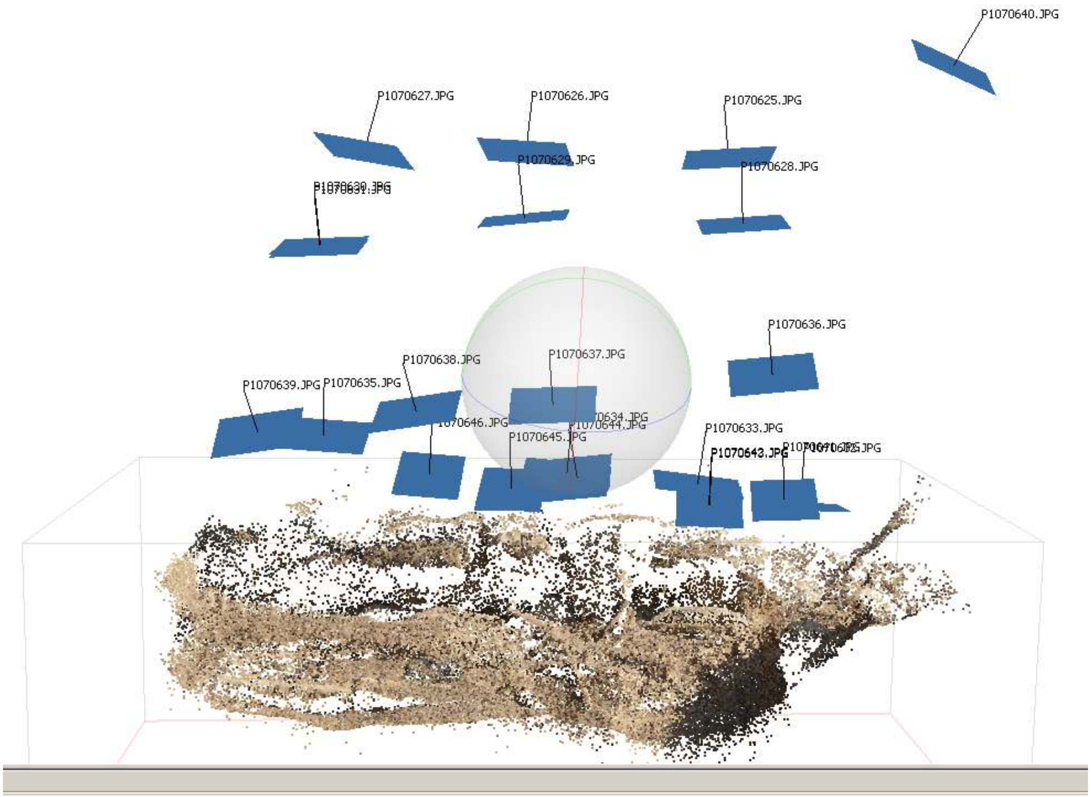

Figure 30: Sparse point cloud and camera positions of Grave 49.

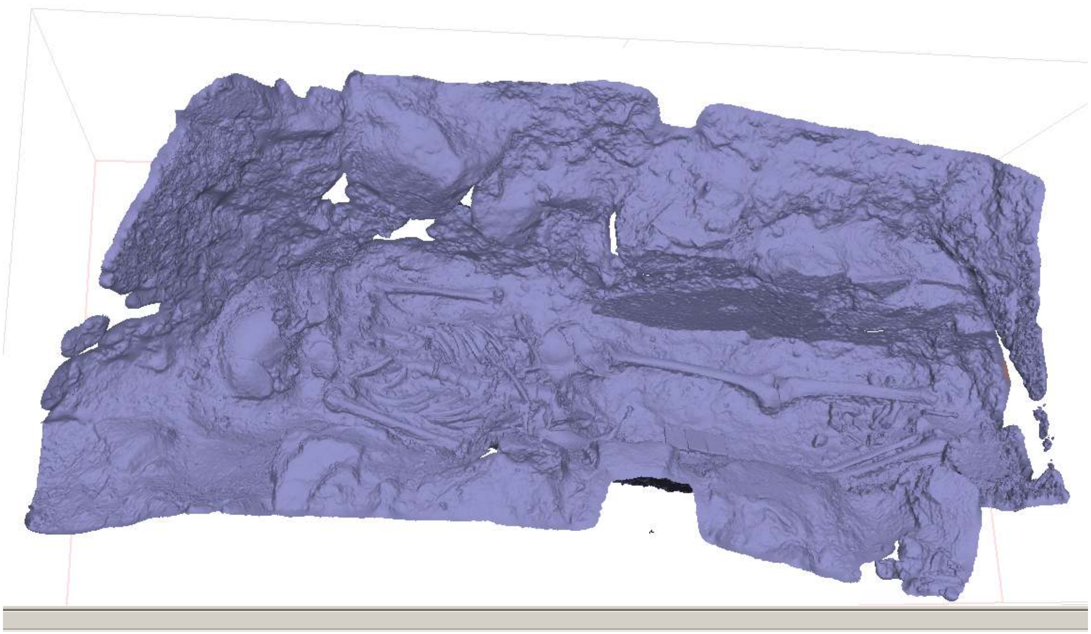

Figure 31: Shaded model of Grave 49.

Figure 32: Ortho image of Grave 49.

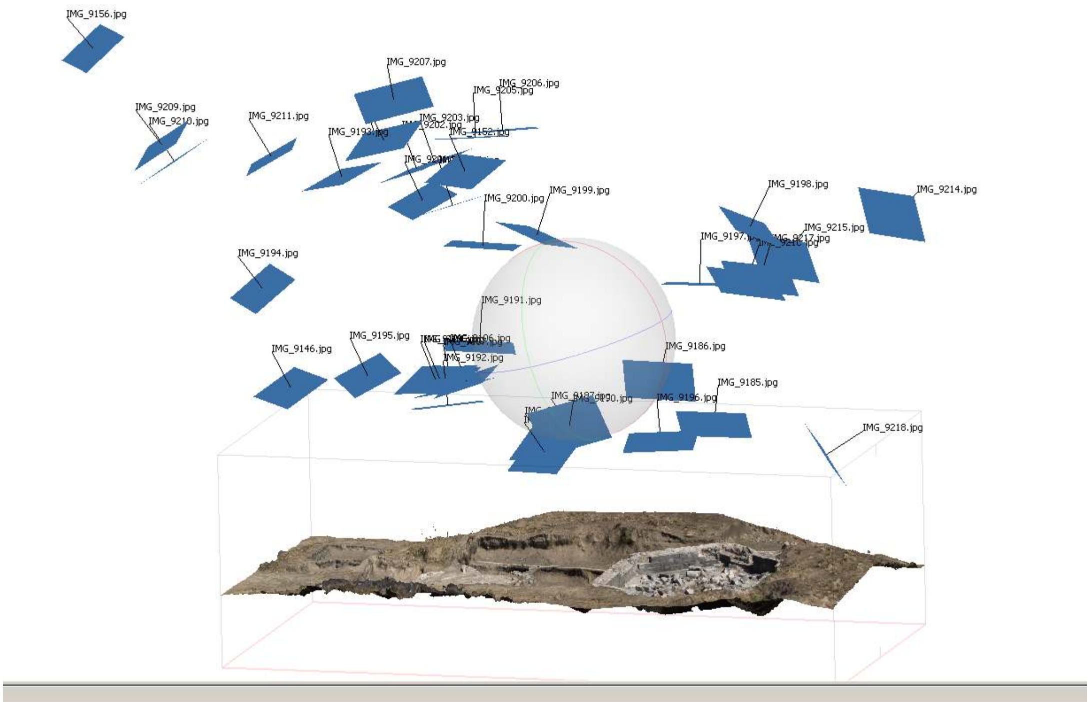

Figure 33: Dense point cloud and camera positions of the hexagonal basin and surrounding trenches.

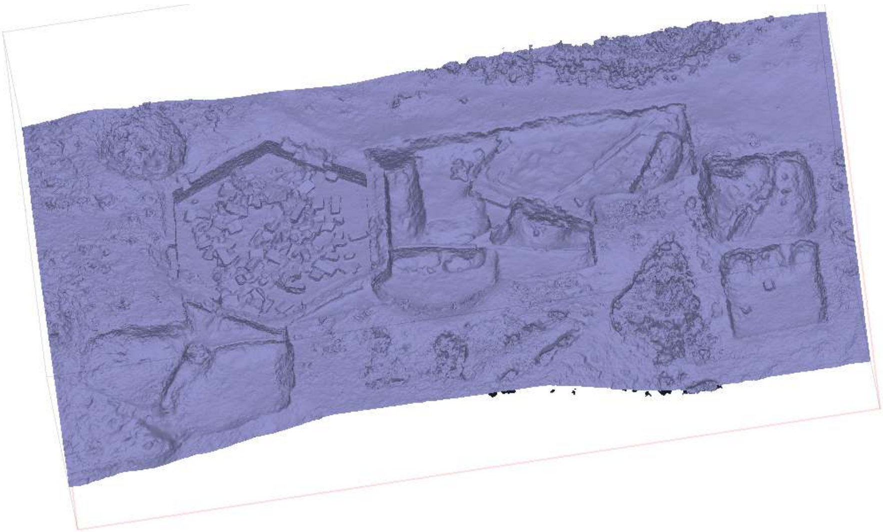

Figure 34: Shaded model of the hexagonal basin and surrounding trenches.

Figure 35: Textured 3D model of the hexagonal basin and surrounding trenches.

Figure 36: Scale bars generated in Photoscan for digital measurements.

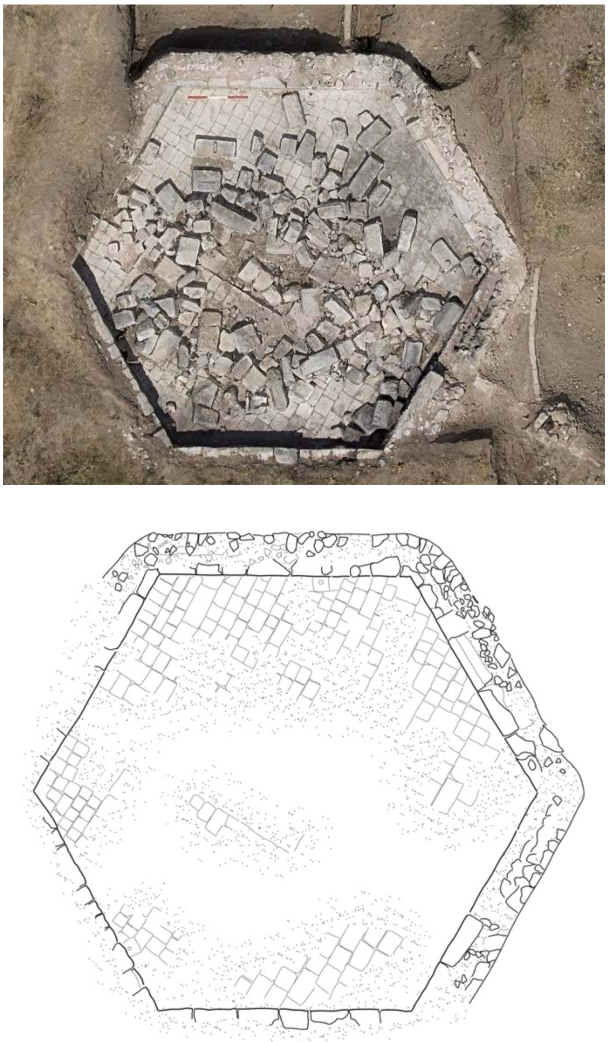

Figure 37: (Up)Ortho image of the hexagonal basin and (Down) plan drawing generated out of it.

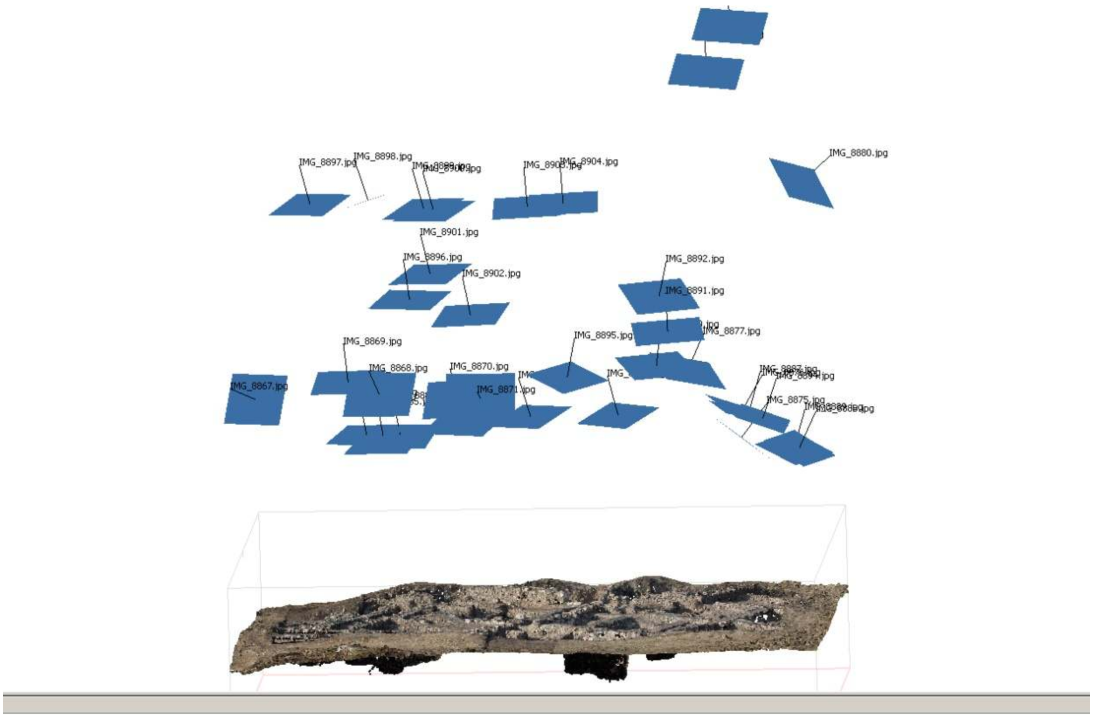

Figure 38: Dense point cloud and camera positions of HTP01 excavation sector.

Figure 39: Textured model of HTP01 excavation area.

Figure 40: Textured ortho image of HTP01 excavation sector.

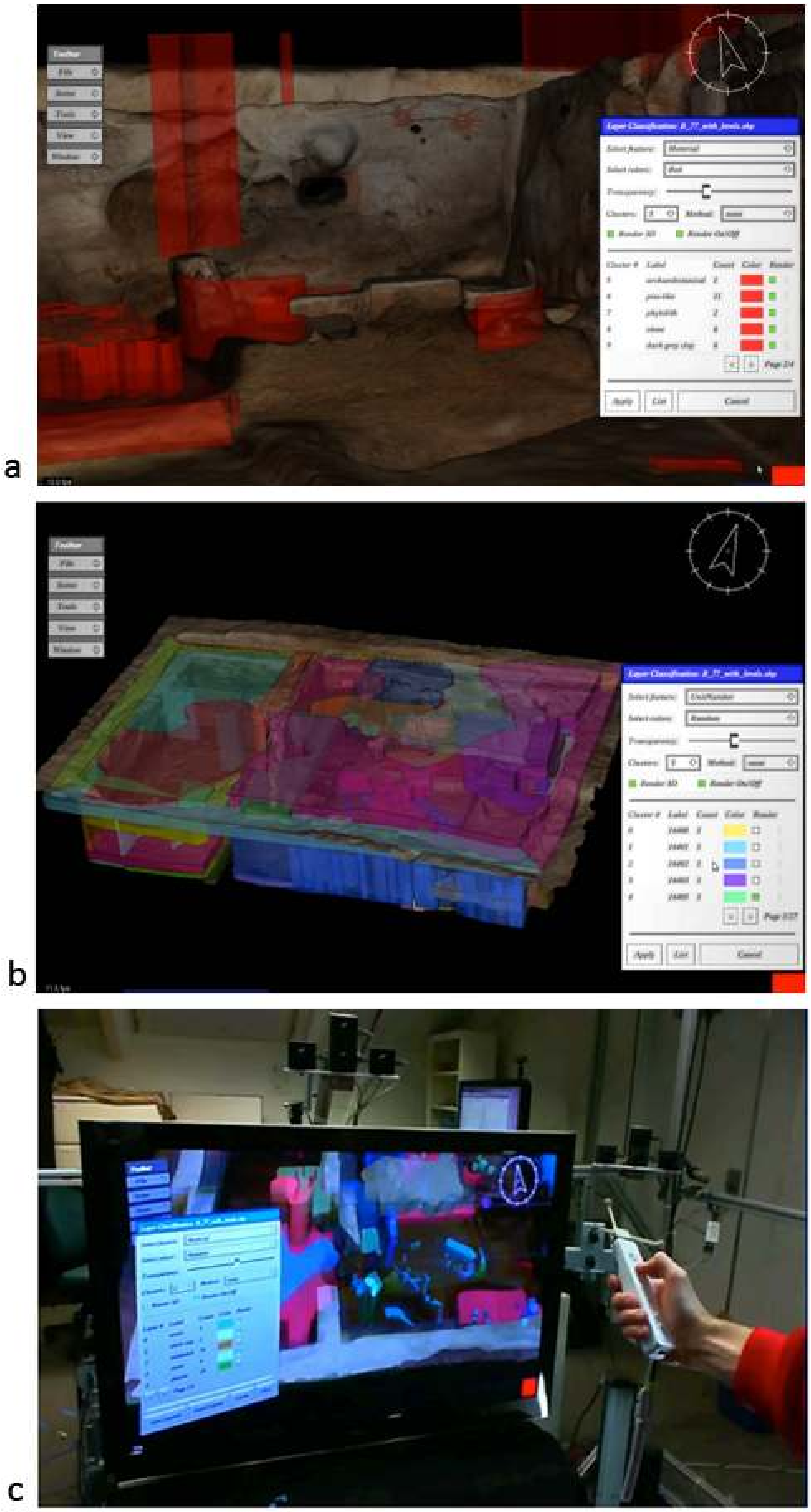

Figure 41: Vrui software. (a, b) Screenshots from the software showing a querry of layers in a trench, (c) tele-immersive session interacting with layers and artifacts through the use of Wii (Forte, 2012: 351, 378).

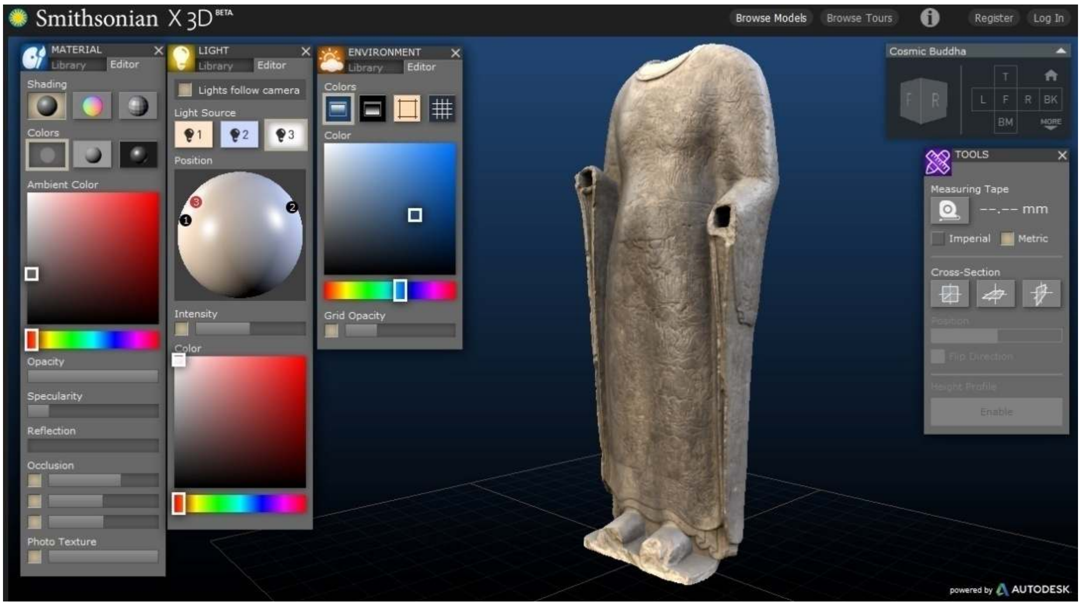

Figure 42: Screenshot from Smithsonian X 3D browser showing 3D model of Cosmic Buddha statue along with interactive tools. Source: Smithsonian X 3D. Retrieved February 10, 2014, from: http://3d.si.edu/explorer?modelid=44.

APPENDIX B

TURKISH SUMMARY

Her ne kadar Türkiye' de yaygınlaşmamış olsa da, son yıllarda 3D uygulamalar arkeolojik çalışmaların bir çoğunda kullanılır hale gelmişlerdir. İlk zamanlarında sadece üç boyutlu görselleşirme ve rekonstrüksiyon amacıyla arkeolojinin ilgi alanına giren bu yöntemler geçen süreçte teorik ve teknolojik altyapının da gelişmesiyle bilimsel araştırmaların önemli bir parçası haline gelmeye başlamıştır. Artık bu yöntemler kullanılarak kazı süreçleri ve buluntuları dijital olarak belgelenebilmekte, elde edilen bilgi yine dijital ortamlarda işlenip değerlendirilebilmekte ve yine aynı şekilde kolayca paylaşılabilmektedir.

Bu tez içeriğinde 3D sayısallaştırma uygulamalarının günümüz arkeolojisindeki yeri ve gelecekteki rolü tartışılmıştır. Bunun yanında fotoğraf bazlı modelleme yaklaşımının, barındırdığı özellikler bakımından hemen hemen tüm araştırmalara uygulanabilirliği ve bu çalışmalarda ulaşılan bilginin belgelenmesi, yorumlanması ve yaygınlaştırılması süreçlerine olan ek katkısı vaka çalışmaları ile ele alnımıştır. Gelişimi için yakın gelecekte, yeni medyanın da etkisiyle daha işbirlikçi, dışa açık, kitle odaklı bir yapıya ve çok katmanlı, çok boyutlu, sorgulanabilir içeriklere doğru evrilmesi gereken arkeoloji biliminin bu yöntemi şimdiden sahiplenmeye başlaması önem taşımaktadır. İlerleyen paragraflarda bu içerik daha detaylı bir şekilde özetlenmiştir.

Arkeolojide 3D uygulamalar farklı ölçeklerde çok çeşitli amaçlara hizmet edebilir. Fakat bu amaçları üç ana başlık altında toplamak mümkündür. Bunlar 3D belgeleme, 3D temsil ve 3D yaygınlaştıma başlıklarıdır.

Bilindiği üzere arkeolojinin tahrip edici bir tarafı da vardır. Kazı sürecinde farkedilmeyen ve kaydedilmeyen tüm bilgiler, tekrar tanık olunamayacağı için yok olmaktadır. Belgeleme için kullanıdığımız geleneksel yöntemler ise dört boyutlu bir ortamı yalnızca iki boyutta kayıt altına alabildiğinden arkeolojik bilgiyi tüm kapsamıyla temsil edememekte ve de özellikle konteks bazındaki verilerde kayıp yaşanmaktadır. 3D belgeleme uygulamaları ise alan ve objeleri çok boyutlu ve detaylı bir şekilde sanal ortama aktarabildiği için bu sorunu çözme ihtimaline sahiptir.

Günümüzde dijital yöntemler ile bir kazı sürecinin tamamını üç boyutlu olarak belgelenebilmektedir. Kazı alanında sürekli olarak 3D taramaların yapılması ile açmadaki tüm katmanları sanal ortamda üst üste yerleştirerek, açmanın kazılmadan önceki yapısını dijital olarak terkradan yaratmak mümkün olmaktadır. Buluntuların da aynı şekilde sayısallaştırılarak yerlerine yerleştirilmesiyle analiz ve çıkarım süreçlerindeki verim artırılabilmektedir. Sonuç olarak 3D belgeleme, araştırmacıya geleneksel yöntemlerin sunamadığı, derinlik, doku ve mekansal bakış açısı opsiyonlarını sunmaktadır.

Yalnızca arkeolojik kazılar değil aynı zamanda kültürel miras da 3D belgelemeye ihtiyaç duymaktadır. Sit alanları ve anıtsal yapılar, dünya çapında savaş, devlet politikaları, doğa olayları ve ilgisizlik gibi birçok nedenle zarar görmekte ve yok olmaktadır. Bunun yanında müzelerin depolarında saklanan birçok belge ve tarihi eser de zamana karşı koyamamaktadır. Fakat 3D belgeleme ile bu objelerin dijital kopyaları yapılabilir ve bu şekilde birçok tarihi yapı ve obje gelecek nesillere aktarılabilir. Bunun dışında dijital kopyalar, koruma altına alınmış objeler üzerinde herhangi bir temasa gerek kalmadan çalışılabilmeyi sağladığından kültürel mirasın ömrünün artırılmasında önemli bir rol oynayabilir.

Sanal arkeoloji yöntemlerinin arkelojideki diğer bir rolü olan 3D temsil da yukarıda bahsedilen durumlarda toplanan verilerin sanal olarak görselleştirilmesini kapsamaktadır. Herhangi bir obje, yapı veya alan sayısallaştırıldığında veri, farklı uygulama ve amaçlara uygun olarak iki veya üç boyutlu çok çeşitli görsel formatlara dönüştürülebilmektedir. Bu da arkeolojik bilginin çok boyutlu ortamlarda analiz edilmesinin, bilginin anlaşılmasında ve yeni çıkarımlar yapılmasında belirgin ilerlemeler kaydedilebileceğini ortaya koymaktadır.

Dijital arkeolojinin en önemli amaçlarından biri de 3D paylaşımdır. Sayısallaştırılıp, sanal ortamda analiz edilen arkeolojik verinin yine dijital ortamda yaygınlaştırılmasının önemi büyüktür. Geleneksel bilgi paylaşım yöntemi olan basılı yayınların yavaşlığı, yüksek maliyetleri, dağıtım ve koruma ihtiyaçları gibi sorunların tamamı elektronik yayınlarla çözülebilmekte ve bunun yanında basılı kaynakların tersine ihtiyaç duyulan miktarda görsel, video, 3D model ve GIS verileri bu yayınlara eklenebilmektedir. Kısacası arkeolojik araştırmalarda arşivlenen ve paylaşılan bilgi arasındaki uçurum bu yöntemle azaltılabilmektedir.

Arkeolojik bilginin sayısallaştırılmasında kullanılan yöntemlere gelecek olursak, bu konuda kullanılabilecek yöntemler şu şekilde sıralanabilir: El ile modelleme, prosedürel modelleme, lazer tarama ve fotoğraf bazlı modelleme. El ile modelleme çeşitli görsel, çizim ve ölçümlerin referans alınarak arkeolojik obje veya yapının CAD programları kullanılarak üç boyutlu modellenmesi olarak tanımlanabilir. Prosedürel modellemede ise yazılımlar, onlara verilen bir kurallar ve parametreler dizisi üzerinden otomatik olarak çeşitlendirme yaparak modelleri oluştururlar. Söz konusu iki metot da objelerin dijital temsillerinde bilimsel gerçekliği ve doğruluğu sağlayamadıklarından bir belgeleme yöntemi olarak değil daha çok görselleştirme ile zamansal ve mekansal hipotezleri test etmek için kullanılırlar. Diğer iki yöntem ise arkeolojik obje ve alanların 3D olarak belgelenmesinde kullanılan yegane uygulamalardır. Bunlardan lazer tarama yöntemi, arkeolojide 2000' li yıllardan itibaren artan bir yoğunlukla uygulanmaya başlamıştır. Lazer tarayıcılar temel olarak bir lazer ışınının tarayıcıdan çıkıp hedef objeye çarptıktan sonra tarayıcıya geliş zamanı veya geliş açısı üzerinden (x, y, z) bilgisinin hesaplanması prensibiyle çalışırlar ve bu yapıları nedeniyle oldukça yüksek hassasiyete sahiptirler. Obje bazında milimetrenin altında, karasal ölçekte ise santimetrenin altındaki hata payları lazer tarayıcıları en poüler dijital belgeleme yöntemi haline getirmiştir. Fakat bu yöntemin uygulamasında değerlendirilmesi gereken önemli konular bulunmaktadır.

İlk olarak, lazer tarayıcılar modelledikleri objelerin dokularını sayısallaştıramamaktadır. Dokuların kaydedilmesi ve 3D model üzerine doğru bir şekilde kaplanabilmesi için ikincil uygulamalar gerçekleştirilmek zorundadır. Bunun yanında hiç bir obje veya yapı tek yönden taranamamakta ve bu nedenle tarama işlemi farklı açılardan tekrarlanmaktadır. Modelleme işlemine başlanmadan önce bu taramalardan çıkan ayrı sonuçların bir araya getirilmesi için ekstra çaba harcanması diğer bir zorunluluktur. Ve bu işlemlerin yapıldığı yazılımlar henüz kullanıcı dostu bir hale gelmediği için söz konusu uygulama ancak uzmanların gerçekleştirebileceği bir yapıdadır. Son olarak da lazer tarayıcılar hala çok pahalı aygıtlar olduklarından, duruma göre gerek duyulan teknolojinin maliyeti onbinlerce lirayı bulabilmektedir.

Fotoğraf bazlı modelleme yöntemi ise lazer tarayıcılara nazaran çok daha ucuz, hızlı, taşınabilir ve esnek olması nedeniyle ön plana çıkmaktadır. Özellikle bu metodu kullanan yazılımların son birkaç yılda hızla gelişip, kolay ve kullanıcı dostu bir hale gelmesiyle fotoğraf bazlı modelleme uygulamalarında çarpıcı bir hareketlilik yaşanmaya başlamıştır.

Bu fotogrametrik yöntem, temel olarak iki fotoğraf arasındaki ortak noktaların saptanıp, bu noktaların fotoğraflar arasındaki yer değiştirme miktarına göre derinlik bilgisinin çıkarımı prensibine dayanır. Sonuç olarak, bu şeklide hesaplanıp üç boyutlu düzleme aktarılan milyonlarca nokta objenin 3D modelini oluşturur. Yöntemin iş akışını daha detaylı bir şekilde açılamak gerekirse, öncelikle modellenmesi istenen obje veya yapının farklı açılardan birçok fotoğrafı çekilir ve bu fotoğraflar yazılıma aktarılır. Yazılım ilk adımda bu fotoğrafları tarayıp ortak noktaları ve fotoğrafların çekim anındaki kameranın bulunduğu uzaklık ve pozisyonu hesaplar, sonrasında da bu bilgiyi kullanarak üç boyutlu düzlemde bir noktalar kümesi oluşturur. İkinci adımda ise yazılımın barındırdığı algoritmalar hesaplanan noktalar arasında bağlar kurarak noktaları poligonlara dönüştürür ve üç boyutlu bir model ortaya çıkar. Son adımda ise fotoğraflarda bulunan doku, oluşturulan modelin üzerine kaplanır ve sonuç olarak modellenen obje veya yapının foto-gerçekçi, dijital bir kopyası çıkartılmış olur.

Fotoğraf bazlı modelleme yönteminde sonucun hassasiyeti ve doğruluğu, fotoğraf çekiminin kalitesine ve kullanılan algoritmaların kapasitesine doğrudan bağlıdır. Son dönemde ortaya çıkan fotogrametrik programlar ile oluşturulan 3D modellerde yüksek hassasiyet yakalanabilmektedir. Her ne kadar bu metot ile lazer tarayıcılar kadar hassas sonuçlar almak henüz mümkün olmasa da, sonuçların birçok çalışma için yeterli doğruluğa sahip olduğu görülmektedir. Bununla beraber, yöntemin kullanımında sadece bir kamera ve bir bilgisayara ihtiyacın olması ile yazılımların oldukça ucuz ve kullanıcı dostu olması nedeniyle tüm araştırma ve araştırmacılar tarafından uygulanabilir olduğu göz önünde bulundurulmalıdır.

Arkeolojik ve kültürel miras, boyut, şekil, detay ve kaplama gibi özelliklerde çok çeşitlilik göstermektedir. Mirasın sayısallaştırılma amaçları da aynı oranda çeşitliliğe sahiptir. Bu nedenle tüm arkeolojik ve kültürel miras için tek bir mükemmel yöntem sunmak mümkün değildir. Çoğunlukla en iyi uygulama bu yöntemlerin bir arada kullanılmasını gerektirir. Tabi bunun en iyi şartlar altında gerçekleşecek bir durum olduğu unutulmamalıdır. Çoğu proje böyle bir çalışmayı finanse edebilecek bir kaynağa sahip değildir. Fakat fotoğraf bazlı modelleme yukarıda bahsedilen özellikleri nedeniyle, teorik olarak tüm arkeolojik çalışmalarda kullanılabilir. Böylece kazı sürecindeki bilgi ve belgeleme hem kalite hem de miktar olarak artırılabilir, dijital ortamda farklı uzmanlarla işbirliği içinde çıkarımlar geliştirilebilir ve çeşitli formatlarda çıktılar alınarak, araştırma sonuçları dijital olarak akademik dünyaya ve halka sunulabilir.

Söz konusu yöntemin arkeolojik kazılarda uygulanabilirliğinin ve çıkarttığı sonuçların değerlendirilmesi amacıyla Komana Arkeolololojik Araştırma Projesi kapsamında bir vaka çalışması tasarlanmıştır. Buna göre proje kapsamında yapılan Komana Pontika kazılarında dört ayrı başlıkta fotoğraf bazlı modelleme uygulamaları yapılmış ve sonuçları analiz edilmiştir.

Komana Pontika, bugün Tokat-Niksar karayolunun dokuzunucu kilometresinde bulunan ve Hamamtepe olarak adlandırılan höyük merkezli bir yerleşimdir. Komana, Hellenistik dönemde Mitridat hanedanına bağlı, siyasi ve ekonomik yönden oldukça güçlü bir tapınak şehir olarak gelişmiş ve bölgedeki Roma hakimiyeti döneminde de bu gücünü korumuştur. Daha sonraları tapınak, hristiyanlığın yayılmasına paralel olarak etkisini yitirmiş ve Bizans döneminde oldukça küçük bir yerleşim haline gelmiştir. Türklerin anadoluya yerleşme sürecinde bölgede siyasi ve askeri çatışmalar yaşanmış ve şehir zamanla Danişmentlilerin kontrolüne geçerken bölge de islami kültürün etkisi altına girmiştir.

Komana arkeolojik araştırma projesi ise 2004 yılında bölgede gerçekleştirilen yüzey araştırmasıyla başlamış ve daha sonra 2009' da Hamamtepe' de kazı sürecine geçilmiştir. Söz konusu kazıda, ülkedeki diğer birçok kazı gibi geleneksel belgeleme yöntemleri kullanılmaktadır. Buna göre açma ve buluntular total station kullanılarak koordinatlandırılmakta, fotoğraflama, form doldurma ve çizim uygulamalarıyla da kayıt altına alınmaktadır. Komana araştırmaları bu yapısıyla fotoğraf bazlı modelleme için etkili bir uygulama alanı oluşturmaktadır.

Kazı dahilinde bir açma, bir buluntu, bir mezar ve bir mimari yapı olmak üzere dört ana başlıkta fotoğraf bazlı modelleme uygulaması yapılması ve bu uygulamaların sonuçlarının değerlendirilmesi planlanmıştır. Söz konusu uygulamalarda fotoğraf bazlı modelleme yazılımı olarak Agisoft şirketi tarafından üretilen Photoscan programı kullanılmıştır. Yöntem ile ilgili daha önce bahsedilen tüm özellikleri taşıyan bu program, buna ek olarak girdi fotoğrafların EXIF bilgisini kullanarak otomatik kamera-lens kalibrasyonu yapabilmesi nedeniyle tercih edilmiştir. Fotoğraflama işlemi için ise 18 megapiksellik sensöre sahip Canon 60d kamera, Sigma 17-50 mm f2.8 lens ile birlikte kullanılmıştır. Yazılımın yüklendiği bilgisayarın temel bileşenleri ise Intel Core i7-2700K işlemci, 16 GB DDR3 1666MHz hafıza, 1.5GB DDR5 Nvdia GTX

570 ekran kartı ve 64-bit Windows 7 işletim sisteminden oluşmaktadır. Bu yapıyla yazılım, tek bir modelleme için 200' den fazla fotoğrafı işleyebilecek kapasiteye sahip olmuştur.

İlk uygulama Hamamtepe üzerindeki HTP 01 alanındaki 10 m x 10 m boyutlarındaki 277/613 açmasının bir yüzey katmanın fotoğraflanmasıyla gerçekleştirlmiştir. Açma etrafından çekilen toplam 192 fotoğraf kullanılarak 20 milyon poligona sahip bir 3D yüzey modeli oluşturulabilmiştir (Fig. 12) ve bu sayısallaştırma süreci 12 saat sürmüştür. Arazide koordinatları alınan dört nokta kullanılarak jeo-referans işlemi yapılan modelin ortalama 4 santimetrelik bir hata payına sahip olduğu görülmüştür.

Bu haliyle oluşturulan model artık üç boyutlu ortamda analiz edilebilir, üzerinde uzunluk, alan ve hacim ölçümleri yapılabilir, doku, ortofoto (Fig. 13) ve yükseklik haritaları (Fig. 14) gibi birçok görsel formata türevlenebilir bir hale gelmiştir. Aynı zamanda ortofotolar kullanılarak açmanın plan çizimi (Fig. 16) yapılması ve hatta verilerin, GIS gibi yazılımlara aktarılacak şekilde düzenlenmesi mümkündür. En önemlisi de bu sayısallaştırma her katmana uygulanarak açmadaki tüm kazı sürecinin dijital bir kopyası arşivlenip, yorumlama sürecinde çok boyutlu bir bakış açısı kazanılabilir.

Buna paralel olarak, fotoğraf bazlı modelleme uygulaması 227/688 açmasındaki güney kesitin sayısallaştırılması için de kullanılmıştır. 49 fotoğraf kullanılarak oluşturulan kesit modeli yine dört koordinat ile jeo-refereanslanmış ve sonrasında da kesitin ortofotosu çıkartılarak kesit çizimi bu veri üzerinden oluşturulmuştur (Fig. 18). Böylece geleneksel kesit çizimine nazaran doku bilgisini tamamıyla muhafaza eden ve bilimsel doğruluğu daha yüksek bir belgeleme yapmak mümkün olmuştur.

Diğer bir sayısallaştırma işlemi de kazı buluntularına uygulanmıştır. Birinci örnekte, seçilen bir seramik 39 fotoğraf kullanılarak 2.5 milyon poligona sahip bir 3D modele dönüştürülmüştür (Fig. 20). 5 cm' lik bir ölçek kullanılarak göreceli olarak boyutlandırılan seramik üzerinde yapılan iki karşılaştırmalı ölçüm ile modelin hassasiyetinin ortalama 2 mm olduğu ortaya çıkmıştır. Toplamda 2 saat süren bu işlem ile seramiğin dijital bir kopyası elde edilebilmiştir. Bu haliyle seramiğin normal şartlarda el ile yapılan kesit ve doku çizimlerinin yerine kullanılabilecek veya onları destekleyecek görseller doğrudan bu dijital model üzerinden çok hızlı bir şekilde çıkartılabilir (Fig. 22). Dijital bir kopya elde edilmesinin bir diğer önemli tarafı ise, obje üzerindeki tüm detaylar korunduğundan, seramik müzeye veya depoya kaldırılsa bile istenilen yer ve zamanda obje üzerinde çalışma yapılması mümkün olmaktadır. Seramik için çok geçerli olmasa da, temasa çok duyarlı olan organik buluntular veya fresk gibi hassas objeler bu şekilde sayısallaştırıldığında konservasyon uygulamalarının etkinliğinin büyük ölçüde artacağı unutulmamalıdır.

Buluntu bazında diğer bir modelleme de bu sezon kazılarında ortaya çıkan bir stel üzerinde denenmiştir. Üzerinde çıplak gözle okunması çok mümkün olmayan bir yazı bulunan stel, 80 fotoğraf kullanılarak sayısallaştırılmış ve 10 milyon poligonluk bir model elde edilmiştir (Fig. 24). Elde edilen model Cinema 4D yazılımına aktarılmış ve burada bir ışık kaynağı oluşturularak, ışığın farklı yönlerden gelmesi durumunda yazıların görünürlüğündeki değişim gözlenmiştir. Sonuç olarak ışık yönüyle oynanarak yazıların daha görünür bir hale getirilmesinin mümkün olduğu ortaya çıkmıştır.

Fotoğraf bazlı modelleme aynı zamanda iskeletlerin modellenmesinde de kullanılmıştır. Birinci uygulamada, 31 fotoğraf kullanılarak oluşturulan Mezar 61 modelinde (Fig. 27) yapılan hassasiyet testleri milimetrenin altında bir doğruluk olduğunu ortaya koymuştur. 5 dakikalık bir süreçte fotoğraflanıp yaklaşık 2.5 saatte modellenen bu deneme sonucunda yine ortofoto ve ortofoto üzerinden çizim yapmak mümkün hale gelmiştir. Fakat bunun dışında yöntemin en önemli özelliği, oluşturulan modelin web ortamında paylaşılabilir formata kolayca dönüşebiliyor olmasıdır. Komana kazılarında ortaya çıkan iskeletleri inceleyen uzman kazı ekibinin sürekli bir elemanı olmadığı için, normal şartlarda mezarlar fotoğraflanıp el çizimleriyle birlikte uzmana gönderilmektedir. Fakat uzman sadece iki boyutlu belgeler kullanarak çıkarım yapmak zorunda kaldığından çıkarımların gücü zayıflamaktadır. Fotoğraf bazlı modelleme yönteminde ise iskeletlerin dijital kopyaları uzmana gönderilebilmekte ve uzman üç boyutlu ortamda in-situ obje üzerinde inceleme yapabilmektedir.

Vaka çalışması dahilinde ikinci bir iskelet daha modellenmiştir. Mezar 49' un modellendiği bu uygulamada, fotoğraf çekim görevi fotoğraf bazlı modelleme ve hatta fotoğraf çekimi konusunda uzmanlığı bulunmayan bir arkeoloğa verilmiştir. Onun çektiği fotoğraflarla gerçekleştirilen sayısallaştırma sonucunda ise her ne kadar Mezar 61' in modeli kadar yüksek sayıda poligona sahip olmasa da, aynı işlevi görecek kalitede bir modelin oluşturulabildiği görülmüştür. Bu da arkeologlara kısa bir eğitim ve görevlendirme verilerek arkeolojik kazıların hızlı ve efektif bir biçimde sayısallaştırılmasının mümkün olduğunu ortaya koymuştur.

Komana kazılarında fotoğraf bazlı modelleme son olarak da mimari bir yapı olan kesme taştan yapılmış bir altıgen havuz üzerinde uygulanmıştır. Fakat diğer uygulamalardan farklı olarak bu yapını fotoğrafları çekilmemiş, bir önceki sene arşiv amacıyla sıcak hava balonu ile havadan çekilen fotoğraflar arasından uygun olanları seçilerek sayısallaştırma işlemi gerçekleştirilmiştir. Seçilen 40 fotoğraf işlenerek 10 milyon poligona sahip bir model 1.5 saatlik bir süreçte oluşturulmuştur. Fotoğraflarda bulunan 1.5 metrelik bir ölçek kullanılarak boyutlandırılan model, 2009 yılında geleneksel yöntemle çizilen plan çizimiyle karşılaştırılmıştır. Model ve plan arasında (x, y) düzlemlerinde ortalama 2 santimetrelik bir fark çıkarken, (z) değerlerinde bu farkın 5-6 santimetreyi bulduğu görülmüştür. Yeterli sayı ve kalitede fotoğraf kullanılmaması nedeniyle oluşan bu farka rağmen fotoğraf bazlı modelleme amacıyla çekilmemiş fotoğrafların kullanılarak da yüksek kalitede modeller oluşturulabileceğinin görülmesi önemlidir. Hal böyleyken, yıllar öncesinden kalma arşivlerdeki görseller kullanılarak, yok olmuş veya tahrip edilmiş obje ve yapıların modellenmesinin de mümkün olduğu öne sürülebilir. Bunun yanında, havuzun plan çiziminin 120 saat civarında bir zaman aldığı düşünüldüğünde, bu metodun geleneksel yönteme göre hızlı ve öncül bir uygulama olabileceği ortaya çıkar.

Komana' da gerçekleştirilen fotoğraf bazlı modelleme çalışmasını özetlemek gerekirse, yöntemin küçük, orta ve büyük ölçekli tüm uygulamalarında başarılı sonuçlar ortaya koyduğu söylenebilir. Özellikle küçük ve orta ölçeklerde çıkan sonuçlardaki detay üst düzeyde olmuştur. Yöntem, sadece metal ve cam gibi yansıma oluşturan objeleri modelleyememiştir. Modelleme için gerekli olan fotoğraflama süreleri obje ve mezarlar için 5 dakika civarında olmuştur. Fakat modellenmesi gereken alan büyüdüğünde fotoğraf çekimi için gerekli süre de aynı oranda artmıştır. Örneğin, açmanın modellendiği uygulamada fotoğraflama süresi 30 dakikayı bulmuştur. Bu gibi durumlardaki en önemli sorun, alanın doğru modellenmesi için gerekli yüksekliklerdeki açılara ulaşmadaki zorluktur. Bu çalışmada 2.5 metrelik sırıklar kullanılmış olsa da insansız hava araçları bu sorunun en uygun çözümü olarak göze çarpmaktadır. Uygulamalarda farkedilen diğer bir sorun da fotoğraf formatları ile ilgilidir. JPEG sıkıştırımış bir format olduğundan kalitesi düşüktür ve üzerinde çok belirgin oynamalar yapılamaz. Özellikle güneşin çok güçlü olduğu durumlarda çekilen fotoğraflardaki yüksek kontrast nedeniyle gölgeler siyahlaştığından sayısallaştırma yapılırken bu bölgelerdeki verinin diğer kısımlara göre çok daha az olduğu gözlenmiştir. Bunu çözmek için JPEG yerine RAW formatındaki görsellerin kullanılması önerilmektedir. RAW formattaki görsellerde yoğun bir ışık ve renk düzeltmesi yapmak mümkün olduğundan sıkıştırmaya veya kullanıcı hatalarına bağlı sorunların bir çoğu çözülebilir. Fakat bu durum başka bir problemi ortaya çıkarmaktadır. RAW dosyalar, JPEG görsellere göre 4 kat daha fazla disk alanı kaplamaktadır. Özellikle fotoğraf bazlı modellemenin yoğun olarak kullanıldığı araştırmalarda veri arşivlemesi konusunda sıkıntılar yaşanabileceği öngörülmelidir. Fakat yöntemin alana katkısı o kadar önemlidir ki, bu sorun yöntemin kullanılırlığını etkilememelidir.

Kısacası, Komana Pontika kazılarında gerçekleştirilen uygulamalarda, bu metodun arkeolojik belgeleme ve görselleştimenin geliştirilmesi konusunda etkili bir yöntem olduğu ortaya çıkmıştır. Uygulamaların kolaylığı nedeniyle de tüm arkeolojik araştırmalarda kullanımı oldukça mümkün görülmektedir.

Sanal gerçeklik uygulamalarının arkeolojide kullanımı aslında sadece görselleştirme amacıyla başlamıştı. İlk örnekler, teorik bir altyapıdan uzak, tarihi yapıların basit üç boyutlu modellerinden oluşmaktaydı. Fakat son on yılda, 3D sayısallaştırmanın bilimsel değeri sorgulanıp tartışılmaya başlamıştır. Bu süreçte ortaya konan Ename (http://www.enamecharter.org/), Londra (http://www.londoncharter.org/) ve Sevilla (http://cipa.icomos.org/fileadmin/template/doc/PRAGUE/096.pdf) bildirgeleri ile sanal arkeoloji uygulamlarının teorik bir temel üzerine oturtulması yönünde çalışmalar yapılmış ve günümüzde artık yöntemin arkeolojik araştırmaları nasıl geliştirebileceği tartışılır olmuştur. Vaka çalışmalarında görüldüğü üzere fotoğraf bazlı modelleme, arkeolojik bilginin detaylı olarak belgelenmesi ve görselleştirilmesinde çok önemli katkılar yapmaktadır. Fakat sayısallaştırmanın katkısı bununla sınırlı değildir, arkeolojik bilginin paylaşımı konusunda büyük bir potansiyele de sahiptir.

20. yüzyılın sonunda internetin ortaya çıkması ve o günden bugüne enformasyon teknolojilerindeki gelişim sonucunda yeni medya ismi verilen yeni bir bilgi paylaşım akımı ortaya çıkmıştır. Geleneksel durumun tersine artık bilgi talep edildiğinde hazır, genellikle ağın kullanıcıları tarafından geliştirimiş, ineraktif bir yapıya dönüşmüştür. Son yılların en başarılı girişimleri olan Facebook, Youtube, App Store, Wikipedia gibi birçok yapı da gücünü bu yeni akımdan almaktadır. Kendi kullanıcıları tarafından geliştirilmiş içeriklere yine o kullanıcılar tarafından istenilen yer ve zamanda tüm detaylarıyla ulaşılabilmesi bu yeni düzenin en büyük gücüdür. Bu şekilde bilgi katlanarak büyümekte ve dünyanın her köşesine hızla ulaşabilmektedir. Konuya dönersek, bilgi paylaşımındaki bu interaktifliğin arkeolojiye de nüfuz ettiğini söylemek zordur. Arkeolojik araştırma sonuçları araştırmacılar tarafından hala kişisel eşya olarak görülmekte ve çıktıların uzun yıl aralıklarıyla sadece küçük parçaları toplulukla paylaşılmaktadır. Bu paylaşımda kullanılan basılı yayın alışkanlığı da sadece yazı ve resim içeriğine izin verdiğinden arkeolojik bilginin dinamikliğini, karmaşıklığını ve detayını verimli bir şekilde paylaşma imkanı sunamamaktadır. Arkeolojide sayısallaştırma yaklaşımın en büyük etkilerinden biri de burada ortaya

çıkmaktadır. Sayısal bir biçimde bilgi paylaşımı yapıldığında geleneksel yönteme göre çok daha fazla miktar ve formatta bilgi, çok daha kısa sürede toplulukla paylaşılabilir ve herkesin tartışıp yorumlayabileceği bir yapı oluşturulabilir.

Bu haliyle yöntemin potansiyel olarak arkeolojiye önemli katkılar yapabileceği görülmektedir. Fakat belirtilmesi gerekir ki, günümüzde bir verinin 3D sayısallaştırılması ile bu bilginin sanal ortamda yönetilmesi teknolojileri arasında ciddi bir fark vardır. Yani istenilen bir objeyi tüm detaylarıyla modellemek mümkünken, oluşturulan model üzerinde çalışmalar yapmak ve bu modelleri herkesin inceleyebileceği şekilde paylaşabilmek konularında hala eksiklikler vardır. Çoğu sayısal arkeolog, çıktılar üzerinde çalışma yapmak için 3D modelleme yazılımlarını kullanmaktadır. Bu şekilde her ne kadar, detaylı bir inceleme ortamı oluşturulabilse de arkeolojik amaçlara özel yazılımların gelişerek bu süreci kolaylaştırmasına ihtiyaç duyulmaktadır. Çatalhöyük kazılarında uygulanan 3D sayısallaştırma sonuçlarının yönetildiği Vrui yazılımı (Forte et al., 2012: 10) veya onun türevleri yakın gelecekte araştırma ekibi içindeki veri paylaşım ve analiz ihtiyaçlarını çözebilir. Fakat dünya çapında oluşturulan 3D arkeolojik modellerin hepsine ulaşım sağlayacak, onların bilimsel doğruluk ve geçerliliklerini sorgulayacak, arşivleyecek ve üzerinde analiz yapılabilmesini sağlayacak merkezi bir havuzun oluşturulması, sayısal bilginin paylaşılabilmesi ve arkeolojinin gelişimi için çok büyük önem taşımaktadır. Virginia Üniversitesi' nin Dünya Mirası Laboratuvarı tarafından oluşturulan SAVE projesi (http://vwhl.clas.virginia.edu/save.html) bu amaçla ortaya çıkmıştır. Henüz üç boyutlu modellerin incelenebileceği ortak bir yapı üretememiş olsa da, DAACH (http://www.journals.elsevier.com/digital-applications-in-archaeology-and-cultural-heritage/) isimli e-makale girişimi ile araştırmacıların sunduğu makalelerin sadece metnini değil aynı zamanda yanına eklenebilen multimedya içeriğin de bilimsel doğruluğunu gözden geçirdiğinden söz konusu havuzu oluşturmada ilk adımları atabilmiştir. 3D sayısallaştırma ile oluşturulan modellerin ortak bir altyapı üzerindenn paylaşımı konusunu ise Smithsonian Müzesi çözmüş görünmektedir. Autodesk şirketinin desteğiyle geliştirdikleri Smithsonian X

3D (http://3d.si.edu/browser) web uygulaması ile yüksek çözünürlüklü modeller, üzerlerinde çeşitli analizler yapılabilecek şekilde web üzerinden görüntülenebilmektedir. Her ne kadar Smithsonian örneği kadar gelişmiş olmasa da Sketchfab (https://sketchfab.com/browse/view) da benzer şekilde modellerin bir Youtube videosu gibi herkes tarafından görülebileceği ve paylaşılabileceği bir altyapı oluşturmayı başarmıştır.

Çok yakın bir gelecekte arkeolojinin tüm adımlarında, belgeleme, inceleme ve paylaşım süreçlerinde 3D sayısallaştırma uygulamaları verimli bir şekilde kullanılabilir hale gelecektir. Çok sayıda arkeolojik araştırmanın bu yöntemleri uygulayarak yaratacağı birikim birleştiğinde çok kapsamlı küresel ve çok boyutlu bir bilgi ağının ortaya çıkacağı aşikardır. Hal böyleken, arkeologların sorumluluğu hem akademik topluluğun hemde halkın artık gelenseksel, dikte edilen bilgiye değil çok katmanlı, çok boyutlu, sorgulanabilir ve üzerinde yeni araştırmalar yapılabilir bilgiye ihtiyaç duyduğuna dair farkındalığa sahip olmak ve araştırmalarını bu duyarlılığı göz önünde bulundurarak tasarlamaktır. Bu tez dahilinde incelenen fotoğraf bazlı modelleme yaklaşımı da bu yapının oluşturulma sürecinde herkesin kolaylıkla kullanıp, bilimsel düzeyde sonuçlar almasını sağlayan etkili bir yöntem olarak kendisini göstermektedir.

APPENDIX C

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü	
Sosyal Bilimler Enstitüsü	X
Uygulamalı Matematik Enstitüsü	
Enformatik Enstitüsü	
Deniz Bilimleri Enstitüsü	

YAZARIN

Soyadı : Orman
Adı : Yenal
Bölümü : Yerleşim Arkeolojisi

TEZİN ADI: Digitizing Archaeological Excavations in 3D, an Image Based Modeling Approach at Komana Pontika

TEZİN TÜRÜ : Yüksek Lisans [X] Doktora [ ]

1. Tezimin tamamından kaynak gösterilmek şartıyla fotokopi alınabilir. [X]
2. Tezimin içindekiler sayfası, özet, indeks sayfalarından ve/veya bir bölümünden kaynak gösterilmek şartıyla fotokopi alınabilir. [ ]
3. Tezimden bir bir (1) yıl süreyle fotokopi alınamaz. [ ]

TEZİN KÜTÜPHANEYE TESLİM TARİHİ: