ABSTRACT

Title of Thesis:	MODELING THE PAST: EMPLOYING CLOSE-RANGE PHOTOGRAMMETRY AND 3D MODELING METHODOLOGIES FOR DIGITAL HERITAGE PRESERVATION AT THE BRONZE AGE SITE OF BÉKÉS-VÁRDOMB IN TARHOS, HUNGARY
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This paper aims to test and illustrate the effectiveness of close-range photogrammetry/3D modeling for documenting archaeological fieldwork and recovered artifacts during the Körös Consortium's “Understanding the Emergence of Cities” project at the Bronze Age site of Békés-Várdomb in Tarhos, Hungary. This thesis will detail the specific methods utilized to produce 3D models during the field project, document variables, and gauge the quality of models produced, to assess this method of documentation for public outreach, future archaeological research, and as a form of digital heritage preservation. The main research questions for this thesis include: “Why is photogrammetry not used more often within the field of archaeology”, “Do the photogrammetric methods conducted for this project efficiently create accurate and accessible 3D models?”, and “How does the use and popularization of photogrammetry for digital recordation change the field of archaeology, and can these changes be utilized in American

cultural resource management (CRM)?". Previous academic work has been done to assess the usefulness and limitations of 3D modeling in archaeology, including archaeological site modeling and individual object modeling. This thesis will build on previously published photogrammetry works, while also documenting specific methods used for the creation of 3D models to produce a photogrammetry "toolkit" for archaeologists to employ on projects. Additionally, this paper will detail the benefits and challenges associated with carrying out photogrammetry for ongoing archaeological investigations.

This project took place at the Bronze Age Site of Békés-Várdomb in Tarhos, Hungary, which was identified as a significant archaeological site from archaeological investigations carried out as early as 1950. This region of the Great Hungarian Plain has experienced frequent large-scale migration movements of different cultural groups, which intensified during the Bronze Age, resulting in deeply stratified cultural deposits at the site of Békés-Várdomb. Images to be used for the generation of photogrammetry models were taken primarily by a Canon EOS 70D, with some imaging sessions utilizing an iPhone 13, which would be imported into Agisoft Metashape Professional Edition for the model generation process. Select georeferenced models were then imported into ArcGIS to be included within the site-wide GIS map. Models were georeferenced by including 1-6 numbered temporary fiducial markers, with the location information of these markers being recorded by a total station. A range of photographs was taken of each finished cultural layer under different environmental conditions (lighting, soil moisture, soil color, etc.) to introduce variables to determine the best possible conditions and methods to produce accurate models for ongoing field projects.

The quantity of models produced, their overall quality, and the relatively low time commitment in the field point towards photogrammetry being an effective tool for accurately capturing cultural resources within the field. While photogrammetry remains a relatively niche field in archaeology, the popularization of this method would benefit both archaeologists and stakeholders by better documenting the spatial layout of excavated deposits that may be challenging with 2D photographs and site maps alone. Archaeologists, and in turn the public, would greatly benefit from the popularization of photogrammetry in cultural resource management, as this method provides a way to capture the 3D nature of a site, or artifacts, in a specific moment of time, acting as a form of digital heritage preservation while also allowing for these resources to be more accessible to the interested public.

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by

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Chapter I: Introduction

Since its inception, the science of photogrammetry has rapidly evolved alongside major technological advancements made in the fields of imaging and computing. Although the methodologies utilized for photogrammetry have varied drastically since the introduction of the technology in the late 19th century, the creation of a highly accurate 3D depiction of a subject from a collection of 2D images has remained the same throughout the decades. While imaging from theodolite and stereoscopic camera rigs were the main instruments for conducting photogrammetry in the past, these methods have long given way to the use of digital imaging in the modern era of photogrammetry (Albertz & Wiedemann 1998). These technological advancements have allowed for the practice of photogrammetry to be increasingly available and feasible for non-specialists. The reduction in the price of the necessary photogrammetric equipment and the sheer increase in the popularity of the field in recent years have removed some of the most substantial roadblocks to photogrammetry faced in the past.

One of the primary research questions posed within this thesis is "How does the use and popularization of photogrammetry for digital recordation change the field of archaeology, and can these changes be utilized in American CRM?". The research conducted for this project aims to answer the previous questions concerning the effectiveness of photogrammetry in the field of archaeology, specifically regarding the accessibility of the method to non-specialists, the level of capture accuracy achievable within the field, and the expenditure of resources necessary to employ this methodology. Additionally, the benefits of photogrammetry as a tool for digital heritage preservation and public outreach will be discussed, as this method can act as a bridge between the field of professional archaeology and the public, by displaying archaeological data in a more digestible and interactive manner for stakeholders. The practices conducted for this project will be utilized to create a generalized workflow for photogrammetric projects that can be utilized by heritage professionals for future projects, while also discussing potential complications that may arise during the process of conducting photogrammetry.

Significance

While photogrammetry cannot be viewed as a complete solution to the inevitable destruction or disturbance of cultural resources that is associated with archaeological excavations, photogrammetry can act as a unique mitigation measure, as it can provide a timely and accurate recordation of unit features and measurements that are essential in the documentation of the site before it's affected by destructive processes (Fussell 1982:166-167). Additionally, the creation and publication of close-range photogrammetric models of artifacts, features, and phases of the excavation process can be utilized by interested researchers who may not be able to feasibly view the collections firsthand (Fussell 1983:167). This is especially relevant for the current investigation, as the Békés-Várdomb site and the project repository (the Mihály Munkácsy Museum) are located in rural Eastern Hungary, which limits the general accessibility of the collection. Past research has solidified the significance of Várdomb as a well-preserved example of an organized Bronze Age fortified tell settlement, which hosts a unique settlement layout and has yielded deeply stratified cultural layers that allow for an in-depth habitation timeline to be constructed. Due to the site's significance within the context of the Bronze Age Great Hungarian Plain, the international archaeological community could greatly benefit from the democratization of high-quality digital models derived from the site, which could be used as supplementary documentation for any future research conducted remotely.

The methods and results generated from this project illustrate the relative ease of employing photogrammetric methods within archaeological investigations, ultimately allowing for the production of high-quality georeferenced models of archaeological features that aid in the contextualization of the site in a more interactive and informative manner. The use of photogrammetry within archaeological projects can enhance the standard process of data collection and presentation carried out by archaeologists by providing a more visually comprehensive way of displaying information, which can be more easily interpreted by stakeholder groups.

Thesis Overview

Chapter II touches upon the theoretical framework of applying photogrammetric methods for archaeological investigations, including the effectiveness that 3D models have in conveying information between archaeological professionals and stakeholders. This chapter draws from sources to further explain the value of photogrammetry as an information and communication technology (ICT) and as a method to carry out digital storytelling for public outreach (Arnold and Kaminski 2014:78). The limitations of conducting photogrammetry are also mentioned within this chapter, including accessibility of required equipment and levels of accuracy within generated models. Additionally, the topic of digital curation of 3D models will be addressed within this section. Several case studies that involved the use of photogrammetry within the Great Hungarian Plain by the Bronze Age Körös Off-Tell Archaeology (BAKOTA) project were drawn upon to analyze the photogrammetric-related methods employed to inform the workflow for the 2024 BVC project. A brief historical background of the Bronze-Age Hungarian Körös Basin is included within this chapter, identifying the relevant cultural groups that inhabited the area surrounding the site of Békés-Várdomb, while also mentioning their innovations and social factors that impacted the archaeological record of the site. Previous archaeological investigations conducted at Békés-Várdomb were also documented within this chapter, with the project research focus and the extent of fieldwork for each respective project noted.

Chapter III outlines the methods utilized for this project to develop photogrammetric models, beginning with the collection of subject images within the field, the curation of data for safekeeping, the development of the photogrammetric model within the associated software, and the exportation and distribution of the models to project personnel and the public. Close-range unit photogrammetry and individual object photogrammetry methods received separate sections within the chapter, as each involved the use of different imaging techniques and processing steps. The process of georeferencing these models within the field and during the post-processing phase is also outlined within this chapter, with the capability of georeferencing 3D models within site-wide GIS maps being a key advantage of photogrammetry when compared to standard 2D site images.

Chapter IV details the results of the project by documenting the progress of fieldwork during the 2024 BVC field season, in addition to the total number of photogrammetric models developed during the project timeline. A generalized workflow that was used for the development of 3D models within Agisoft Metashape is detailed within this chapter. Data involving time spent on photogrammetry and the number of images taken for each unit layer are presented within figures, which will be further analyzed within Chapter V.

Chapter V presents an analysis of the raw data generated from this project, explaining the dedication of time and resources for each excavation block during the fieldwork and post-processing phases. The effectiveness of the models generated for this project is discussed within this chapter, with specific examples being cited concerning complications experienced and project successes. These factors aided in the streamlining of imaging and post-processing phases for this project, with the key takeaways from this project being noted. From the experiences encountered within this project, the best methods were developed and included within this chapter to provide a more streamlined process for archaeologists to replicate in their respective projects.

Lastly, Chapter VI concludes the thesis by restating the overall purpose of the project, while also highlighting the results of the investigation. A section is included within this chapter that addresses the potential for future photogrammetric research at the site of Békés-Várdomb and for the collections generated from the site over the previous field seasons. The research avenues suggested would build upon the close-range site photogrammetry conducted within this thesis by implementing aerial and additional object photogrammetry, which would create a more complete 3D record of Békés-Várdomb and the associated archaeological collections.

Chapter II: Background

Theoretical Background

From the inception of digital photogrammetry in the early 1980s, the science has quickly evolved by utilizing advancements in technology to gradually increase the quality of source images and lessen processing time, ultimately streamlining the process of model generation and maximizing model quality (Albertz & Wiedemann 1998). Some of the more recent advancements in photogrammetry that influenced the methodology of photogrammetry utilized at Békés-Várdomb are documented in the section below. Sources were chosen for a range of reasons, including their relevance to Bronze Age archaeology in the Great Hungarian Plain, in addition to specific methods for carrying out 3D modeling on individual artifacts and features.

Purpose & Value of Photogrammetry

David Arnold and Jaime Kaminski's "*3D Scanning and Presentation of Ethnographic Collections-Potentials and Challenges"* discusses the use of photogrammetry as an "information and communication technology" (ICT) for use in the curation of ethnographic items within museums as well as the benefits that ICT has in the context of public outreach (Arnold and Kaminski 2014:78). The authors state that ethnographic objects, similar to archaeological objects, are 3D in nature and that traditional 2D documentation of these artifacts with individual pictures, measurements, and written description only creates a partial record of the object (Arnold and Kaminski 2014:78-79). 3D models produce a much more comprehensive and accurate representation of the object when created properly, producing a record of the artifact in time and acting as a safeguard against material degradation, destruction from natural disasters, and looting (Arnold and Kaminski 2014:79). The 3D scanning of artifacts also increases the accessibility of artifacts, which are often kept from public view due to lack of space in exhibits or fragility issues, as it allows for museum visitors to view objects interactively through digital media, either online or at the museum itself. Methods of 3D scanning, like close-range LiDAR, are becoming increasingly accessible to the general public, as new Apple smartphone models are being produced with 3D scanning capabilities. LiDAR technology was initially included within these devices to allow for better depth capturing in photos and to facilitate the use of augmented reality (AR), but it can also be utilized to produce extremely accurate 3D models in the context of archaeology while still having an entry-level budget. An effort to digitize large collections of artifacts within museums would allow for the creation of a “virtual museum”, which could be accessible for remote viewing by the public and researchers abroad, and in some cases may aid in repatriation efforts as the object would still be viewable at the museum through digital 3D media (Arnold and Kaminski 2014:79).

The authors also introduce the concept of 3D scanned objects, items of tangible heritage, being paired with literature on intangible heritage for “digital storytelling”, which may depict the reciprocal relationship the two concepts have with one another to represent cultural heritage (Arnold and Kaminski 2014:81). The largest issues concerning the use of 3D modeling of artifacts mentioned within this paper involves the motivation of museums and curators to commission the 3D modeling of large collections, since the process would involve large amounts of time and money, and must be done deliberately with the future benefits in mind in order to justify the process (Arnold and Kaminski 2014:81). Technical issues of photogrammetry are also listed within this article and conform largely to some of the research questions posed within this thesis regarding the effectiveness of photogrammetry in accurately capturing Hungarian Bronze Age lithics and metals, which provide some level of difficulty when imaging due to the reflectiveness they produce under lighting. Arnold and Kaminski also mention the use of Polynomial Texture Mapping (PTM), which is a method that generates a partial 3D model by using a single camera position, with different lighting conditions, to produce a highly detailed model of the artifact surface, which far exceeds the quality of traditional photographs (Arnold and Kaminski 2014:87-88).

When creating and publishing photogrammetric 3D models, the curation of the associated data must be considered. Depending on the nature and needs of the archaeological project, the methods for digitally curating the finalized 3D model files will differ. Project setting, budget, and team size may all be influencing factors on the method used for the digital curation of photogrammetric files. For multinational academic projects, a cloud-based data storage method would allow for all approved project personnel to access source images and generated models created during the project season. Alternatively, smaller-scale CRM projects, which aim to use photogrammetry as a deliverable for a client or regulatory agency, may determine that saving the files on a local company storage device would be adequate. When utilized as a tool for public outreach, photogrammetric models can be shared in a multitude of ways. 3D models can be uploaded to free-to-use websites like Sketchfab, which house and display uploaded models to be viewed by the public, but this method offers a less permanent solution to digital curation. These models can also be embedded and showcased within the project website, allowing the user to articulate the model themselves, resulting in a more immersive viewing experience.

3D Modeling Case Studies

Kalyan Chakraborty's "*A Virtual Documentation of Excavation Through 3D Modeling: Is it Worth the Effort?"* covers Chakraborty's efforts to conduct photogrammetry at the site of Békés 103, located ~50 km from Várdomb, while also explaining the benefits the models provide when conducting spatial analysis within a site (Chakraborty 2016). Control points were established outside of features, with the distance between points measured by the total station to produce georeferenced models. At this particular site, Bronze Age burials were encountered, and the photogrammetry of excavation unit levels allowed the researchers to superimpose artifacts and remains recovered from each level into one image, creating a realistic profile view of the site (Chakraborty 2016). This particular project and the methods discussed will be useful in determining the necessary methodology for conducting photogrammetry of the nearby Bronze Age site of Várdomb.

The last source of literature to be reviewed is Giles Spence-Morrow et al. "*Virtually There: Offsite georectified photogrammetric processing as onsite strategic excavation resource"*, which covers the methods utilized by the Bronze Age Körös Off-Tell Archaeology (BAKOTA) team for the 3D modeling of the Middle Bronze Age cemetery site of Békés-Jégvermi-kert (Spence-Morrow et al. 2013). When the team encountered a funerary urn, the feature was pedestalled, and the unit was cleaned up in preparation for photos. Sixteen numbered nails were placed within the unit, with the location of each of these nails being plotted with the total station to use in georeferencing, ultimately acting as photogrammetry markers (Spence-Morrow et al. 2013:3). Photos of the urn were taken in 2-3 concentric sequences with different elevation angles, with the photos having a minimum of 80% overlap between them (Spence-Morrow et al. 2013:4). The even lighting created from overcast skies or shaded units on sunny days provided for the best conditions for photographs, as harsh shadows on the object and within the unit result in harsh contrast and loss of data (Spence-Morrow et al. 2013:4). For this particular project, the team utilized an offsite photogrammetry specialist in Toronto, who received the photos and total station points over Dropbox, and then utilized their high-processing power computer to test the alignment of photos to ensure model accuracy. When the photo set was deemed sufficient, they began the modeling session of the features (Spence-Morrow et al. 2013:4). Once the photos were aligned, the technician built the geometry of the feature, added the texture, georeferenced the model using the total station points taken of nearby nail markers, and exported the model for the BAKOTA team to add into their GIS model of the site (Spence-Morrow et al. 2013:4). This article provides extensive information on the methodologies employed at the site of Békés-Jégvermi-kert, which is geographically close to Várdomb and shares the same occupation period and cultural affiliations and establishes a baseline for conducting photogrammetry in the area, while also preparing technicians for associated challenges.

The following section will provide a historical background of Bronze Age archaeology in the Körös Basin of the Great Hungarian Plain, with a specific focus on the previous archaeological investigations at the site of Békés-Várdomb.

Historical Background

The Middle Bronze Age Period (1700-1350 BC) within the Hungarian Körös Basin is characterized by frequent “migration and invasion” events, which prompted the widespread construction of fortified tell settlements, which provided the inhabitants with strategically defensible positions (Duffy 2010:104, Kiss et al. 2019:175). Due to the ever-frequent migration and invasion events, an extensive list of cultures is noted to have settled within the Great Hungarian Plain, specifically the Körös Basin, during the Bronze Age. During the Middle Bronze Age, the Hatvan and the Füzesabony cultures warred against each other, with the Füzesabony ultimately destroying a large quantity of Hatvan settlements and absorbing their territory within the Körös Basin (Duffy 2010:107). Near the end of the Middle Bronze Age, the Gyulavarsánd culture developed from the Ottomány Culture and largely took control of the Körös Basin (Duffy 2010:108). The Gyulavarsánd adopted the fortified tell innovations used by previous cultures in the area, but also constructed large flat plaza areas surrounding the central tell site, which held additional housing and specialized buildings (Gyucha et al. 2013:162). While these settlements were often situated around water sources with food subsistence in mind, social factors such as site defensibility and the proximity to other settlements in the Körös Basin largely dictated site habitation. While many cultural groups existed within the Great Hungarian Plain, the site of Békés-Várdomb experienced periods of settlement by the

Hatvan, Füzesabony, Ottomány, and Gyulavarsánd Cultures over the Bronze Age period of occupation at the site (Duffy 2010:118).

The site that is the subject of this investigation, Békés-Várdomb, is a multicomponent tell site located in the village of Tarhos, in Békés County, Hungary. The Békés-Várdomb tell was first investigated in 1950 by Hungarian archaeologist János Banner, a prominent figure in the field of protohistory, which analyzes the period immediately before a culture's discovery and adoption of the written language. Banner directed a large-scale excavation of the central tell, and the two adjacent hills (Hungarian Castle Archives Foundation 2016; Gyucha et al. 2023:4). Between the years of 1950-1955 and 1959-1960, Banner and his colleague István Bóna excavated a total of 18 trenches for their investigation (see Figure 1), conducted within the area of the central tell and in the surrounding areas to identify the location of the settlement's cemetery (Gyucha et al. 2023:4). These investigations revealed that the tell site, rising 3m above the surrounding flatlands, was constructed next to a meander of Fás Creek, which separated the main fortified area from the two adjacent settlement areas, which can be observed as dotted-line polygons to the immediate North and South of szelvény 1 (segment 1)(Gyucha et al. 2023:4; Duffy 2020:115). During the first phases of occupation of the site, the central tell was created by the inhabitants of the site who excavated ditches in a North-South orientation to intersect with the adjacent meander of Fás Creek, ultimately creating an island and increasingly fortifying the settlement (Duffy 2020:194). Banner's excavation efforts were focused on the central tell, where he excavated seven trenches, while Bóna was responsible for excavating three trenches to the North of the central tell.

Figure 1: Site map of Békés Várdomb

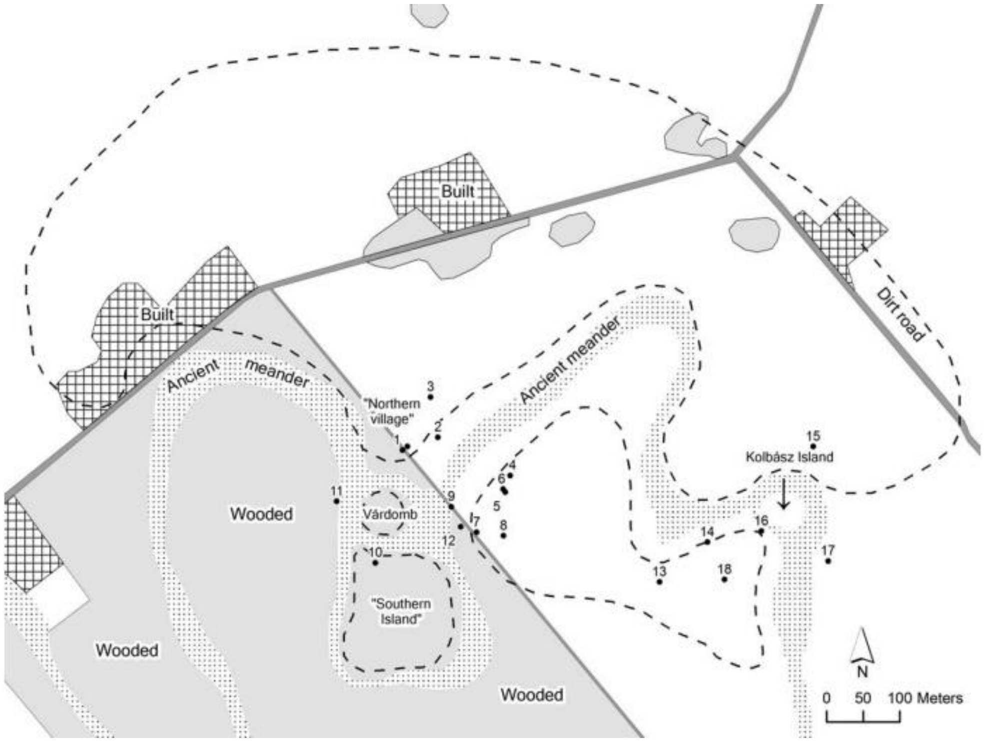

Figure 1: Site map of Banner & Bóna's 1950-1960 investigation and the location of excavation trenches #1-18 (Duffy 2020:195)(© 2020 Paul R. Duffy).

While Banner and Bóna both agreed that the Hatvan culture first occupied the site, dating the initial site settlement to ~2,000-1,800 BCE, their findings on the latest period of settlement at Várdomb differed (Duffy 2020:116). Banner struggled with determining the latest period of occupation and the cultural affiliation of the recovered materials at the central tell, ultimately deciding that the last period of occupation at Várdomb was by the Vărşand-Füzesabony Culture in 1,400 BCE (Duffy 2020:116). Based on the off-tell investigations conducted by Bóna, he determined that the Ottomány-Gyulavarsánd Culture was the last settlement group to occupy the site before its abandonment following the end of the Middle Bronze Age.

The research conducted by Banner and Bóna at Várdomb revealed that the fortified central tell, which encompassed 23 wattle and daub houses, was not the only area of habitation for its Bronze Age residents, but that additional households were constructed on the opposite sides of the fortification ditch surrounding the tell (Duffy 2020:132-133, 190).

The construction of the Várdomb households differed from those seen in surrounding Middle Bronze Age Ottomány-Gyulavarsánd tells, as the houses constructed on the central tell had wooden plank flooring and were smaller when compared to the off-tell households present at Várdomb and other Bronze Age tell settlements within the Körös region of Hungary (Duffy 2020:204-205). Bóna, who first observed these differences, concluded that the presence of wooden floors within households on the central tell suggested that the higher-status inhabitants of the site lived within the central fortified tell, while the low and middle-status inhabitants lived in daub-floored houses off the tell in the lesser fortified Northern village cluster. This theory is probable when considered within the cultural-historic theoretical framework that Bóna utilized, but it fails to consider the role of the environment during the period of site construction at the central tell. When taking into consideration the humid, unstable, and boggy environmental conditions that would have been experienced on the central tell of Várdomb (as the result of terraforming), the use of wooden floors likely allowed for greater structural stability, which may not have been necessary within the off-tell households (Duffy 2020:204-205).

Further investigations of Várdomb and other archaeological sites within Békés County were conducted throughout the late 1960s under the Magyarország Régészeti

Topográfiája (Archaeological Topography of Hungary) project, also known as the MRT survey, which was a pedestrian survey of 3,799 square kilometers of Békés County, which ultimately resulted in the identification and documentation of 6,173 archaeological sites (Duffy 2020:226-227). The flat topography and extensive plowed farmland of Békés County allowed the MRT survey teams to quickly identify concentrations of archaeological artifacts or features that were revealed as a result of agricultural activity. The accuracy of site boundaries produced by the MRT is low, as the teams relied primarily on the concentration of surface scatter artifacts and regional site size models, established by previous archaeological investigations within the Körös Basin, to inform the creation of the site boundary (Duffy 2020:226-227). Although this survey was useful in initially documenting site locations and their relative cultural associations, further ground truthing is necessary to accurately define the site boundaries, determine site function, and identify the phases of occupation and cultural affiliation of each site.

Várdomb was revisited in 2006 by Archaeologist Dr. Paul Duffy, who aimed to delineate the boundaries of sites identified by the MRT survey by using intensive surface collection and shovel testing within the areas surrounding Békés-Várdomb and Sarkad-Peckesi-domb (~6 km apart). Survey lines for the pedestrian survey were staggered 15-20 meters apart, with diagnostic ceramics, lithics, bone, and slag collected and bagged, while non-diagnostic body sherds were counted and discarded (Duffy 2020:237). Areas of high artifact density were marked with flags to be later intensively surveyed. Due to the low surface visibility at Várdomb from extensive vegetation and leaf scatter, shovel test pits were dug in 100-meter intervals, which identified the site to be roughly 22.07 hectares in area (Duffy 2020:278-279).

In 2016 and 2019-2020, the Körös Regional Archaeological Project and the Körös Consortium carried out a series of investigations at the site of Várdomb, conducting magnetometry and a surface survey within the area of the "Northern Village" (Tarhos 2) (See Figure 1). The 2-hectare magnetometry survey identified the presence of 30 anomalies believed to building foundations, aligned NW to SE, in the area of the Northern Village, which corresponds to the areas tested by Bóna decades earlier (Gyucha et al. 2023:4). In 2021 a magnetometry survey was conducted by the Körös Consortium in the area of the Southern Island (see Figure 1), which revealed 12-15 house foundation shaped anomalies and several other anomalous features within the area, believed to date to the Middle Bronze Age (Gyucha et al. 2023:4). The same year, a drone LiDAR flyover was commissioned by project directors, and covered a 78 square kilometer area in the area of the Várdomb tell, which aided in the identification of several of Banner's 1955-1960 test trenches, which are intended to be revisited during the 2024 BVC field season to obtain C14 samples (Figure 2). In 2023 the Körös Consortium excavated three two meter by two meter excavation units within the site boundary of Várdomb, with unit 1 being conducted on a magnetometry anomaly within the Northern Village, unit 2 placed on the Southern Island, and unit 3 being placed East of the tell in the nearby tilled field (Gyucha et al. 2023:6-7). These excavations revealed the foundations of three Bronze Age wattle and daub-constructed houses with plastered floors and hearths, and a 9th-10th century burial.

The findings from the various surveys and excavations at Békés-Várdomb helped to identify the primary areas of interest for further investigation in the 2024 field season at Várdomb, which will be detailed in the following section.

Figure 2: 2024 Békés Várdomb LiDAR Site Map

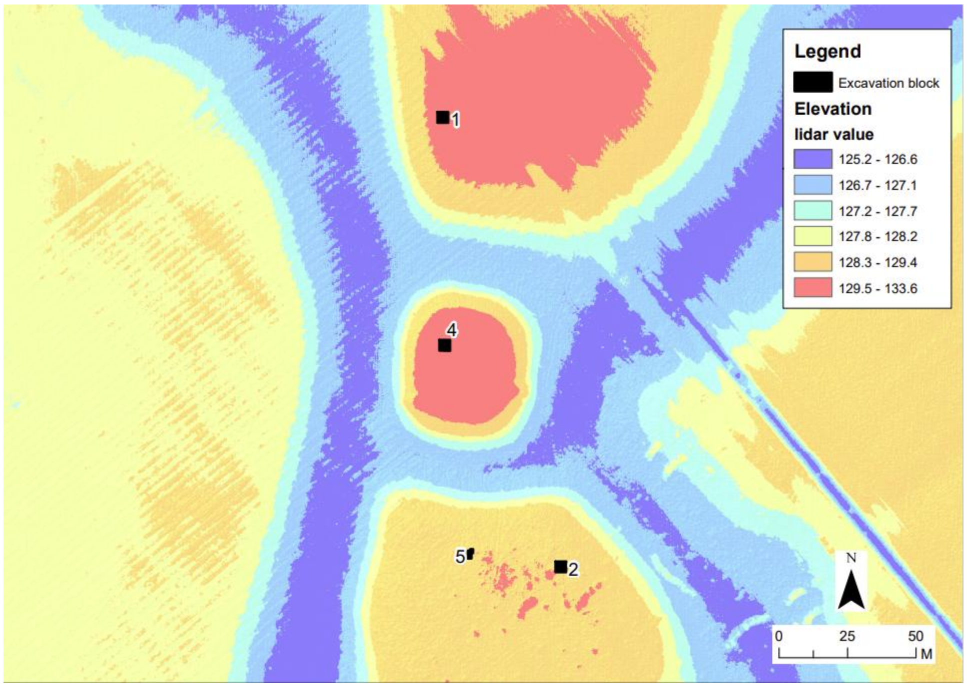

Figure 2. This map shows the elevation of the Békés Várdomb site area with the locations of the 2024 project season excavation Blocks 1,2,4, & 5 (Figure courtesy of Paul R. Duffy).

Chapter III: Methods & Data Collection

Before any photogrammetric activities are undertaken within the field, it is essential for the technician to identify which 3D modeling platform and software best fit their research subject, budget, project timeline, and the operator's technical ability. As photogrammetry has evolved exponentially within the past decade, a wide range of modeling applications have emerged for professionals and hobbyists alike, making it easier than ever for individuals to learn the software and produce models. For this project, models were primarily developed within Agisoft Metashape Professional (64-bit), while several models were also generated within the IOS application Polycam. Before the field season began, it was necessary to develop a generalized workflow within the main modeling software, Agisoft Metashape, and obtain appropriate storage for the large quantities of data generated in the field, while also ensuring that the data was properly labeled and grouped within organizational folders.

Close-Range Unit Photogrammetry

Going into the 2024 Békés-Várdomb field project, the goal of the photogrammetric investigation was to document the successive cultural layers of each excavation unit at the site (Blocks #1,2,4,5), which could later be used as an additional contextual reference by project personnel as well as stakeholders interested in viewing the findings from the 2024 BVC field season (model of Block 1 featured in Figure 3). Aside from picturing the model of BVC Block 1, Figure 3 (below) also features a QR code that will allow readers to view the source model on Sketchfab, where the model can be manipulated to view the unit in its entirety. Images captured for the development of photogrammetric models were taken independently from the standard unit closing photos, as each method required the inclusion of different contextual tools (photo board, scale bars, GCPs, etc.), and the process of capturing photos for the photogrammetric models required frequent repositioning within the unit, inevitably disturbing the floor surface. Temporary marker GCPs were placed in each block following the conclusion of the standard closing photos, in preparation for the photogrammetric photo session to facilitate the later georeferencing of the model within the larger Békés-Várdomb GIS site map.

Figure 3: BVC BL1 Model

Figure 3. This figure depicts images of the 3D model generated for excavation Block 1 during the 2024 BVC field season. Several images are taken of the excavation block from alternate points of view. The QR code provided in this figure provides a link to the model within Sketchfab, where a 3D version of this model is available (Original work by the author).

The photos for photogrammetry were taken in each block following the unit layer closing photos, as the units would already be cleaned and prepared. At the conclusion of each field day, the photos would be uploaded to an external hard drive

(HDD) and to the project's shared cloud storage to lessen the potential for data loss, while also providing project supervisors with large quantities of high-quality photos for reference. The preservation of the source data (photos) for this project was essential, as these images documented the excavation units at a specific point in time and therefore could not be replicated at a later date. With redundant backups being made for each photo session, the safety of this source data is better ensured, allowing for the generation of additional 3D models if necessary.

Numbered coded markers were utilized as ground control points (GCPs) and were temporarily placed within excavation blocks during each photo session, with each of the marker locations being recorded by the total station (see Figure 4).

Figure 4: Coded Marker Example

Figure 4. An example of the type of coded marker utilized as a GCP on the Western wall of Block 4 (photograph by the author).

The inclusion of these coded markers allows for a more precise georeferencing of the model within the project GIS map, while also aiding in the process of photo alignment during the early stages of model generation. The total number of GCPs present within each block varied, as more homogenous soil layers required more GCPs to maximize the success of the photo alignment phase, while layers with a higher contrast of soil colors and cultural deposits would not be as reliant on GCPs for alignment. For the majority of the block models, one GCP marker was placed within each 2x2 meter quadrant of the unit floor, as the relatively shallow depth of Blocks #1,2, and 5 did not warrant the use of GCPs on the unit walls.

Block 4, which was positioned within the center of the tell at Békés-Várdomb, was excavated to relocate the backfilled excavation trench dug by Hungarian archaeologists János Banner & István Bóna during their 1950-1960 investigations of Békés-Várdomb (Block 4 model featured in Figure 5). The excavation of this unit aimed to rediscover and observe the stratigraphy of the original trench wall dug by Banner & Bóna during their investigations, which reached a depth of over 2.5 meters in depth. Due to the depth and irregular shape of this excavation block, the majority of the GCP markers were placed upon the unit walls.

Following the completion of unit closing photos, the photo board and North arrow would be removed, and GCP markers would be strategically pinned in place within each 2x2 meter quadrant on an area of homogenous soil. The locations of the GCP markers would be recorded within the total station with a mirrored stadia rod or by reflector-less shooting, with the UTM coordinates of these points being used later in the process for georeferencing the unit. After the location of the GCPs were recorded, the unit would be sprayed with water by a pump sprayer to increase contrast, and the block would be shaded (on days of clear weather) with a translucent poly tarp to soften the lighting for photos. Establishing shots would be taken from the exterior of the unit facing inwards from each block wall to capture the entirety of the block, limited portions of the unit exterior, and act as a reference for ensuring that the photo and marker alignment remained accurate.

Figure 5: BVC Excavation Block 4 Model

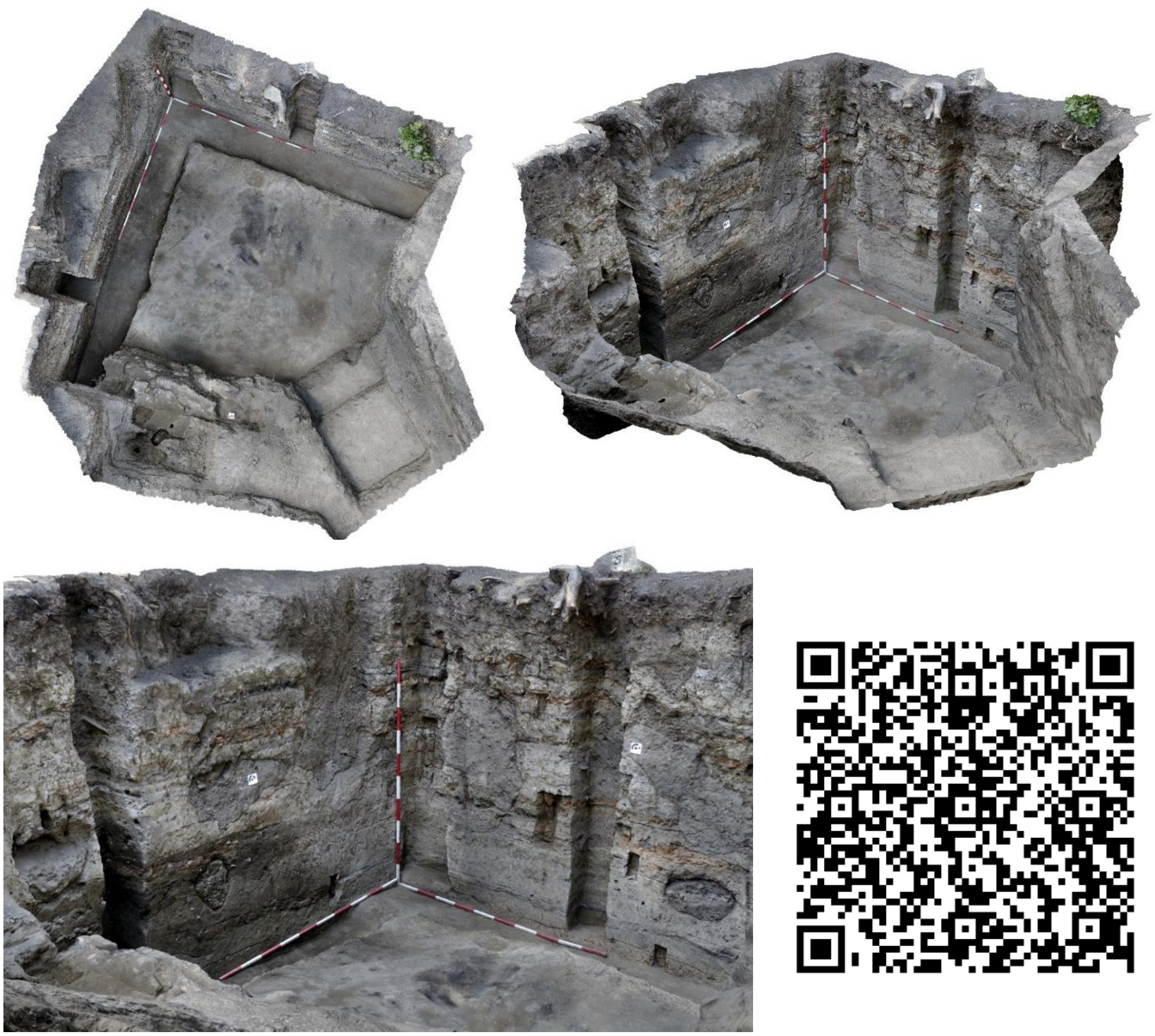

Figure 5. This figure showcases images of the 3D model generated for excavation Block 4 during the 2024 BVC field season. Several images are taken of the unit from alternate points of view. The QR code provided in this figure provides a link to the model within Sketchfab, where a 3D version of this model is available (Original work by the author).

At this point, images would be taken radially, with each image having a minimum of around 60-75% overlap with the position of the previous image, which was essential in generating unique points (referred to as tie points) in the images that the software could identify and use to stitch the images together (see Figure 6).

Figure 6: Tie point model and textured model of BVC Block 4

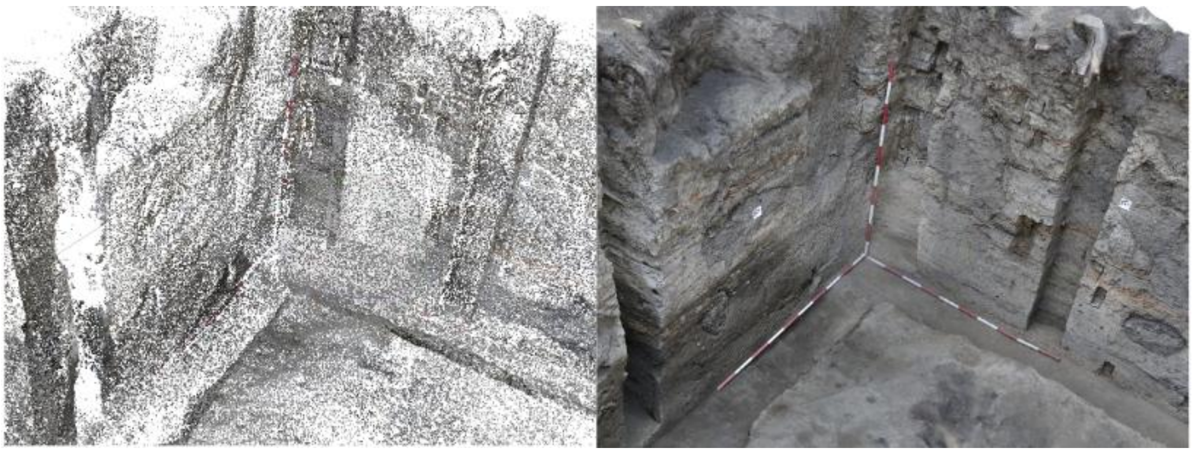

Figure 6. This figure depicts the tie points present (left) within the final 3D textured model (right) of Block 4, which are unique points used to determine the position of a photo within space and stitch overlapping images together. (Figure by the author)

Areas of uneven elevation and protruding artifacts present within the unit would also be imaged radially to ensure proper image coverage and overall model quality. The total number of photos taken for each session would vary, since the presence of large amounts of cultural materials would warrant vastly more pictures than a more homogenous plow zone layer. For the 4x4 meter Blocks 1 and 2, roughly 100-215 individual pictures were taken for each cultural layer, while the larger and more irregularly shaped Block 4 received ~90-370 photos per session.

After the field day, the images taken for each layer photography session would be downloaded from the SD card onto two external hard drives (HDDs) and uploaded to Dropbox for cloud storage. Photos taken of the block layer would be uploaded into a new project within Agisoft Metashape Professional Edition, where the model would be developed following the standardized workflow established within this paper. After the completion of the model, it would be saved in low (< 100 mbs), medium (100- 500 mbs), and high-quality resolutions (500+ mbs) for distribution to project personnel and online publication. The non-georeferenced models generated for this project were uploaded to the online program Sketchfab to make the work conducted for the 2024 BVC field project more accessible to the public.

Photogrammetric models were also made in the field utilizing the mobile application Polycam on an iPhone 13. Following the completion of the DSLR photo sessions for block layers (which would be used in Metashape), pictures would be taken on the mobile phone within Polycam and would be generated within the lab. These methods of creating photogrammetric models will be compared in the following chapter, with the accuracy and practicality of these methods for use in an archaeological investigation being assessed.

Individual Object Photogrammetry

While the close-range photogrammetry of the excavations at Békés-Várdomb remains the focus of this paper, several models of individual objects were also created (see Figure 7). While the setting and subject of the individual object models differed from the site photogrammetry, the overall workflow remained the same. The object was cleaned and placed on a turntable within a lightbox, which allowed for the lighting on the subject to be manipulated to minimize glare and make small details more visible, while the turntable made it possible to capture all angles of the object without unnecessarily moving the object off its axis. The top half of the object would be captured from three camera heights before the object would be flipped, where the process would be repeated (see Figure 8).

Figure 7: BVC BL2 Vessel Model

Figure 7. This figure depicts images of the 3D model generated for a partial vessel recovered from excavation Block 2 during the 2024 BVC field season. Several images are taken of the vessel from alternate points of view. The QR code provided in this figure provides a link to the model within Sketchfab, where a 3D version of this model is available (Original work by the author).

Figure 8: Photogrammetric Model of BVC Ceramic Vessel

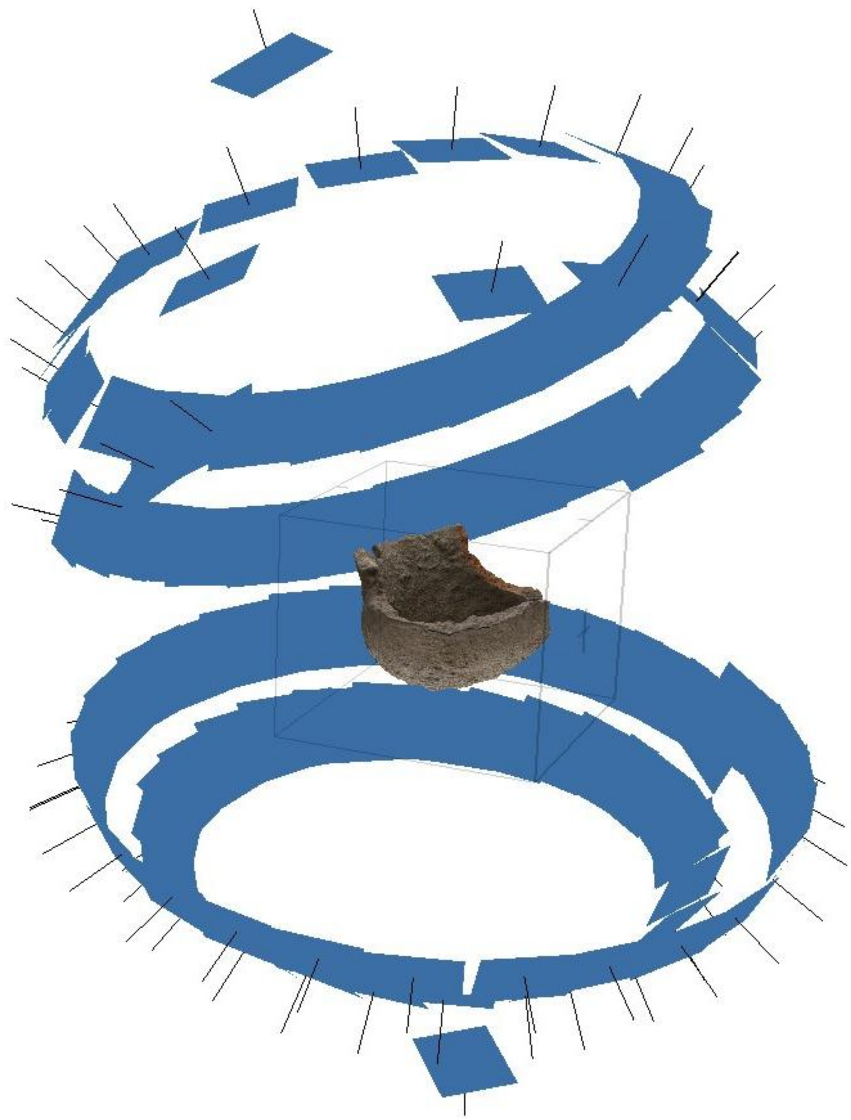

Figure 8. Depiction of aligned cameras (photos) within a 3D model of a Bronze Age ceramic vessel obtained from Block 2. (Figure by the author)

Conclusion

While this chapter mainly addresses the methods utilized for capturing images of the excavation units within the field for the creation of 3D models on both Agisoft Metashape and Polycam, additional information regarding the processing workflow within these programs will be outlined in the following results chapter. As the workflow for the image capturing process in the field was streamlined, the 3D modeling process was also adapted and streamlined to fit the project constraints and needs. The successes and complications experienced while conducting photogrammetry for the 2024 BVC project were essential in forming the finalized workflow outlined within the following section.

Chapter IV: Results

During the 2024 Békés-Várdomb Cluster Project (BVC), a total of four blocks (1,2,4, and 5) were excavated. Of these excavation units, Blocks #1 and #2 measured 2x2 meters in plan, while Blocks #4 and #5 were excavated to delineate the extent of identified features. Block #4 was dug on the central tell of Békés-Várdomb to discover and delineate Banner and Bóna's excavation trench dug between 1950 and 1960 at Várdomb, to further document the stratigraphy of the Northern and Western walls of the tell trench, while also obtaining datable samples from the strata. The excavation of Block #5 began later in the project and aimed to investigate a subsurface anomaly identified from the magnetometry survey, which, once excavated, yielded human burials. Work efforts within Block #5 focused on excavating the immediate area of the burials and removing the individuals, as the unanticipated discovery of burials within Block #5 occurred near the conclusion of the project timeline.

From these excavation blocks, a total of 12 unique, close-range photogrammetric models were created, with most of the models being made for Blocks #1 and #4, while one unique photogrammetric model was created of a partially intact Bronze Age vessel recovered from Block 2 (pictured in Figures 7 & 8). These 12 unique models were generated in low, medium, and high-quality, with georeferenced and non-georeferenced versions created for each model, resulting in a total of 67 models generated for this project. A general workflow was created and followed to streamline the process of model creation within Agisoft Metashape, which can be observed below (Figure 9).

Figure 9: Agisoft Metashape Project Workflow

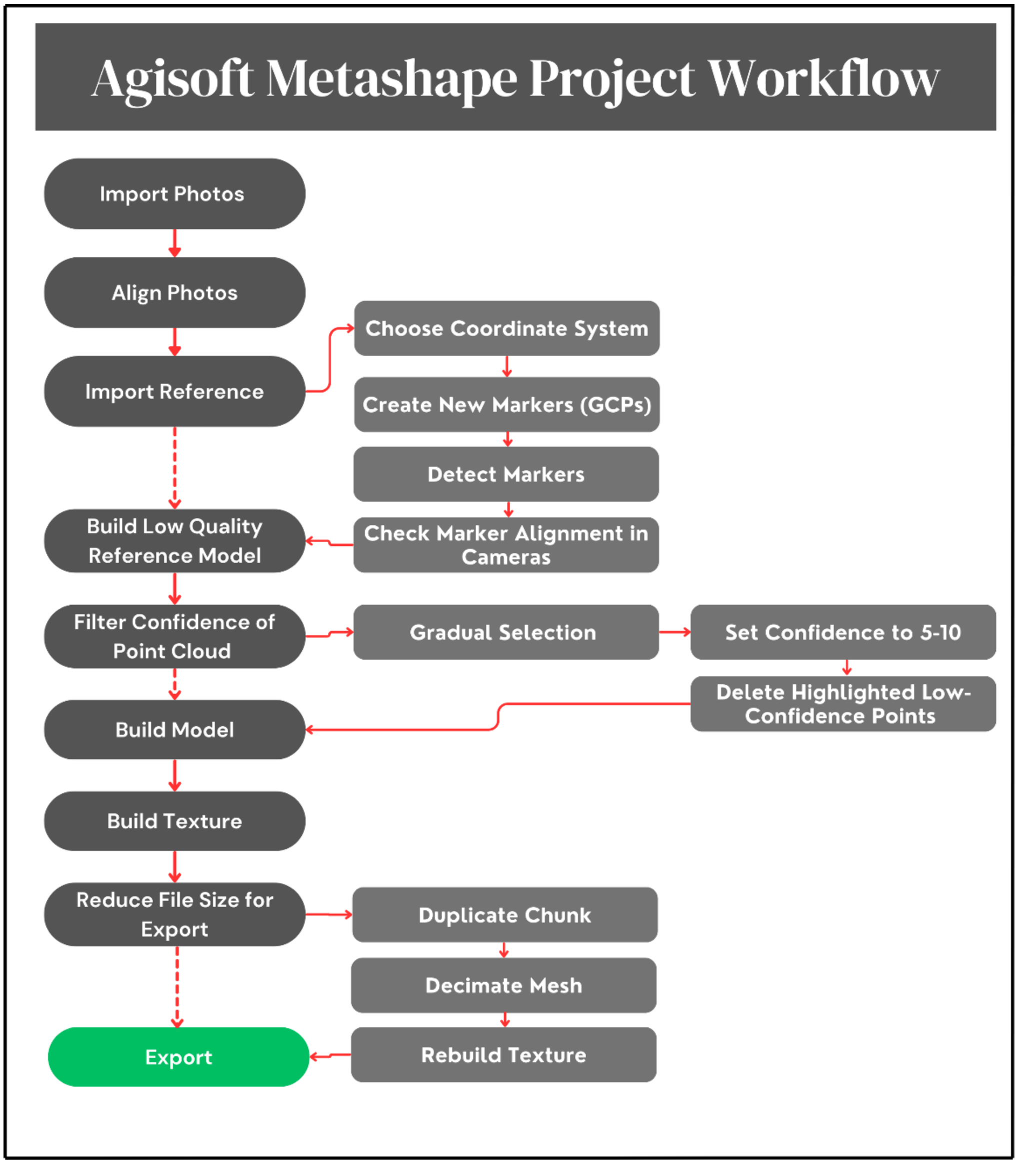

Figure 9. This Flowchart depicts the generalized workflow followed within Agisoft Metashape Professional for creating photogrammetric models for this data. (Figure by the author)

Low-quality models were generated for each set of session images to ensure that the photo alignment and marker georeferencing processes were sufficiently accurate, after which higher quality models (containing significantly more faces & vertices) were developed to achieve greater resolutions to maximize viewer experience. The georeferenced models, which contained the location information of the model, were submitted to the project directors to be included within the BVC GIS site map.

Non-georeferenced models were generated in medium to high quality and were uploaded to the online 3D modeling community database Sketchfab for online distribution, where the models were accessed by a total of 177 individuals on the platform. While the users accessing the models on Sketchfab remain anonymous, their interest in Hungarian archaeology or photogrammetry as an information and communication technology can be inferred. Mesh decimation, a process used to reduce the number of faces (and thus reduce file size) within a model, was utilized for both the georeferenced and non-georeferenced models to drastically reduce the file size of the models before exportation.

While much of my own time spent in the field was focused on the excavation of Blocks #1 and #4, several short photogrammetry shooting sessions occurred each week, typically lasting between 15-20 minutes, while never exceeding 30 minutes. This estimate includes the time spent placing temporary GCP markers, recording total station points for each of the GCPs, capturing images for the unit level, and recording notes concerning the weather conditions of the day, which may have influenced the appearance of the unit within images. This process would occur directly after the closing photos of the unit layer were taken, to avoid any additional disruptions to fieldwork. Of the roughly 23 hours spent on photogrammetry for this project, 14% of the time was spent taking images of the excavation units within the field, while 86% of the time was spent off-site, where the photogrammetric models were processed within Agisoft Metashape (visualized in Figure 10 below). The model processing stage was conducted asynchronously from fieldwork, as the model source images were already obtained, allowing for the most time-consuming step of the process to be completed without the use of additional project resources.

Figure 10: Time Spent on Photogrammetry for BVC 2024

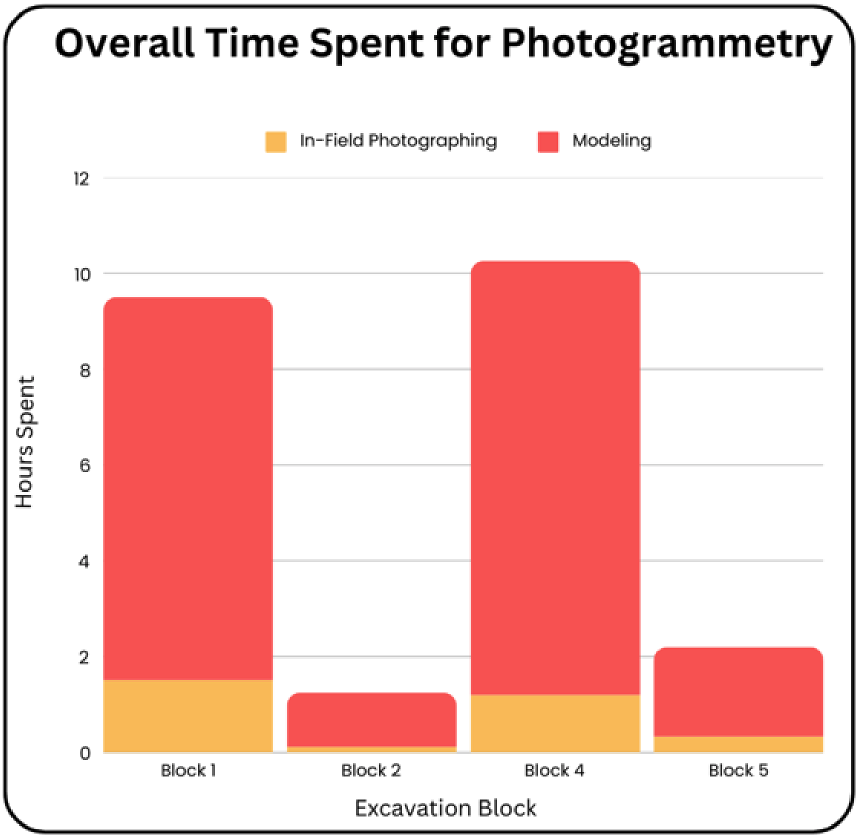

Figure 10. This stacked bar chart depicts the total time spent conducting photogrammetric activities for each excavation block, with the orange value representing the time spent capturing images in the field, while the red value depicts the time spent processing and exporting the model within Agisoft Metashape (Figure by the author).

Although an overwhelming portion of the time spent conducting photogrammetry for the BVC project involved model processing, this did factor in the production of the model in low, medium, and high-quality renderings, which would not be entirely necessary to replicate for other projects (see Table 1 below). This was essential for this study to determine an optimal balance between the time spent capturing images in the field and the quality of the photogrammetric model produced.

Table 1: BVC 2024 Photogrammetry Data List

BVC 2024 Photogrammetry Data list

EXCAVATION BLOCK	EXCAVATION UNIT	SESSION DATE	GCP MARKERS (#)	PHOTOS (#)	PHOTOGRAPHY SESSION DURATION (MINUTE APPROXIMATION)	TIE POINTS	MODELING SESSION DURATION (MINUTES): LOW QUALITY	MODELING SESSION DURATION (MINUTES): MEDIUM QUALITY	MODELING SESSION DURATION (MINUTES): HIGH QUALITY
Block 1	13-15	5/14/2024	4	220	15	135,591	24	31	73
	17	5/18/2024	2	156	20	55,125	7	9	39
	18-20	5/27/2024	4	97	17	123,744	10	16	46
	20-22	6/3/2024	4	213	21	263,470	16	31	80
	Final Closing	6/6/2024	4	127	18	158,020	14	23	61
Block 2	19-21	5/21/2024	4	102	7	103,566	8	21	39
Block 4	Checkpoint 5/20	5/20/2024	3	140	20	105,285	16	21	79
	Checkpoint 5/21	5/21/2024	3	86	10	54,598	8	15	32
	Checkpoint 5/30	5/30/2024	3	198	15	213,437	23	40	95
	Final Closing 6/6	6/6/2024	4	368	27	389,801	38	57	120
Block 5	3-4	5/30/2024	3	133	20	120,610	15	26	71

Table 1. This chart documents all close-range site models created during the duration of the project, along with the components of the models, such as the number of GCP markers, total photos, and duration of time spent on photography and model generation. (Table by the author)

The next section of this thesis will further analyze the effectiveness of the photogrammetry carried out for this project by looking at the associated model data, while also touching upon photogrammetry-related complications experienced during the project lifecycle.

Chapter V: Analysis

Looking at the Data

As previously mentioned within this paper, a total of 67 photogrammetric 3D models were produced of Blocks #1, 2, 4, and 5, which were excavated during the three-week duration of the 2024 BVC field project. The number of unique models, as well as the total number of models for each excavation block, can be noted within the figure below (Figure 11). While every unique model processed for this project prompted the development of roughly six varying models, each containing different resolution qualities and location information (or lack thereof), this process would most likely not be replicated as a part of the workflow for future field projects. This project warranted the development of these additional models to compare the differences in model quality and processing time, with the ultimate goal of determining the best workflow for employing photogrammetry in a fast-paced project environment.

Figure 11: Total Number of 3D Models Created for BVC 2024 Season

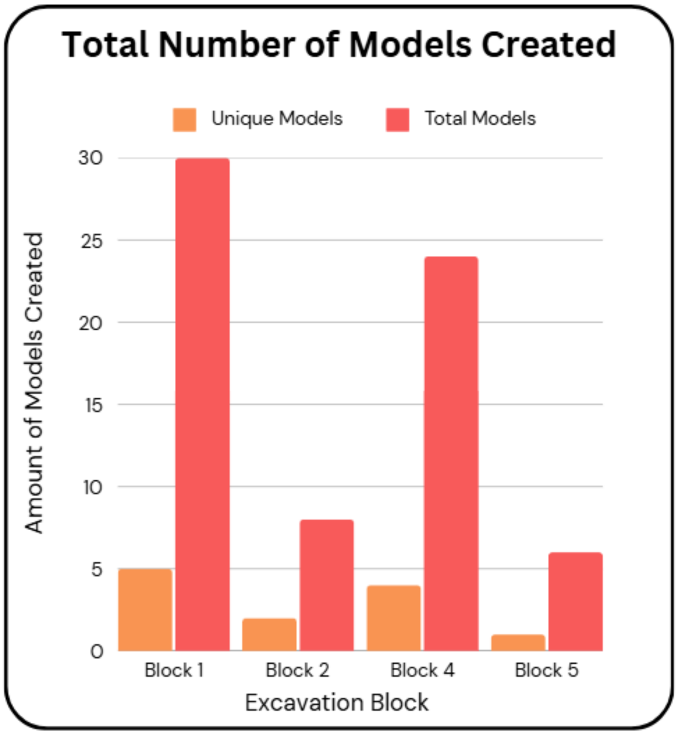

Figure 11. This graph depicts the number of unique models and the total number of models created for each excavation block during the 2024 BVC field season. The unique models captured are individual cultural layers, while the total number of models includes all the low, medium, and high-quality models produced for each layer, in addition to the georeferenced and non-georeferenced models (Figure by the author).

The majority of my time was spent conducting fieldwork occurred at both Blocks #1 and #4, which resulted in a greater number of models being produced for these two blocks, with fewer models produced for Block #2. As detailed previously, Block #5 was opened and excavated near the latter half of the field season, with the shallow burials being discovered shortly after excavation began. This meant that only one photogrammetric model was produced to document the burial context for excavation Block #5 before the exhumation process began and the unit was backfilled. One of the greatest factors that influences the clarity and accuracy of a photogrammetric model is the quantity of images taken of the subject, which are then used to generate the model. Proper photograph coverage of a subject from all angles is essential in the development of an accurate model, as gaps between photos can result in voids of data in the final model. Generally, a photo overlap of 50% between pictures resulted in a more complete coverage of the subject, and thus a higher point confidence for the model when processing it in Agisoft Metashape.

While photo overlap is necessary for creating tie points and producing accurate 3D models, the total number of photos taken per session will largely vary depending on the complexity of the excavation unit layer and the amount of available time. Unit layers that host areas of densely scattered cultural materials with differing soil colors will require far more images to be represented accurately when compared to a more homogenous and flatter plow zone layer. The successful execution of this process can be noted within Figure 12 (below), where a hearth feature was captured by taking images in a uniform overlapping way to ensure proper photo alignment and point confidence.

For this project, a range of 86-368 (20.2 megapixel) photos were taken for the development of each photogrammetric model. For Blocks #1 & #2, an average of 158 photos were taken for each model, while the Block 5 and Block 1 burial features were captured with an average of 129 photos.

Figure 12: Block 1 Closing Hearth Feature Textured Model & Confidence Map Overlay

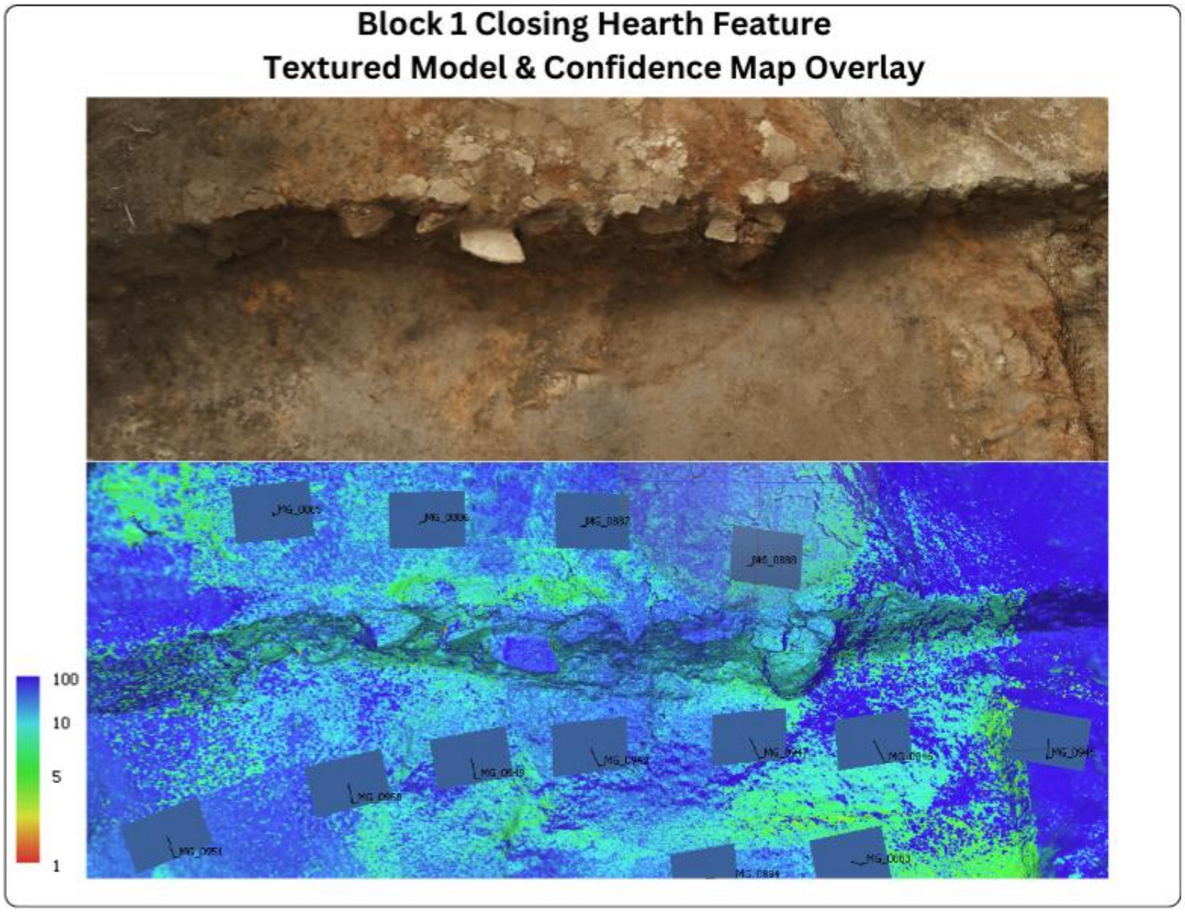

Figure 12. This figure depicts a hearth feature present within a small subsection of the block #1 closing model, with the top image showing the hearth within a textured model, while the bottom image has a point confidence map and image positions layered onto the model. Each solid blue rectangular polygon represents a singular image in the position it was taken. The color-coded scale bar highlights the varying levels of point confidence within the model, with 100 being high confidence and 1 being extremely low confidence of point location accuracy within the model (Figure by the author).

The greater depth of excavation Block 4, situated on the central tell of Békés-Várdomb, warranted a more in-depth focus on the stratigraphy present on the Northern and Western walls of the unit. To facilitate this, GCP markers were placed upon the Northern and Western unit profiles in areas of homogenous soil, as the majority of the pictures would capture the vertical extent of the unit, resulting in an average of 198 photos being taken per session at Block 4.

Low, medium, and high-quality models were generated for each set of layer photos to compare the resolution of the models (quantity of faces and vertices), while also recording the processing time associated with each model quality level. These three basic levels can be observed in the figure below (Figure 13), which depicts the textured model of each level alongside the solid model overlay. This process would not be part of a typical workflow and was conducted specifically to determine the optimal settings for creating photogrammetric models during an ongoing field project.

Figure 13: Block 2 Model Resolution Comparison

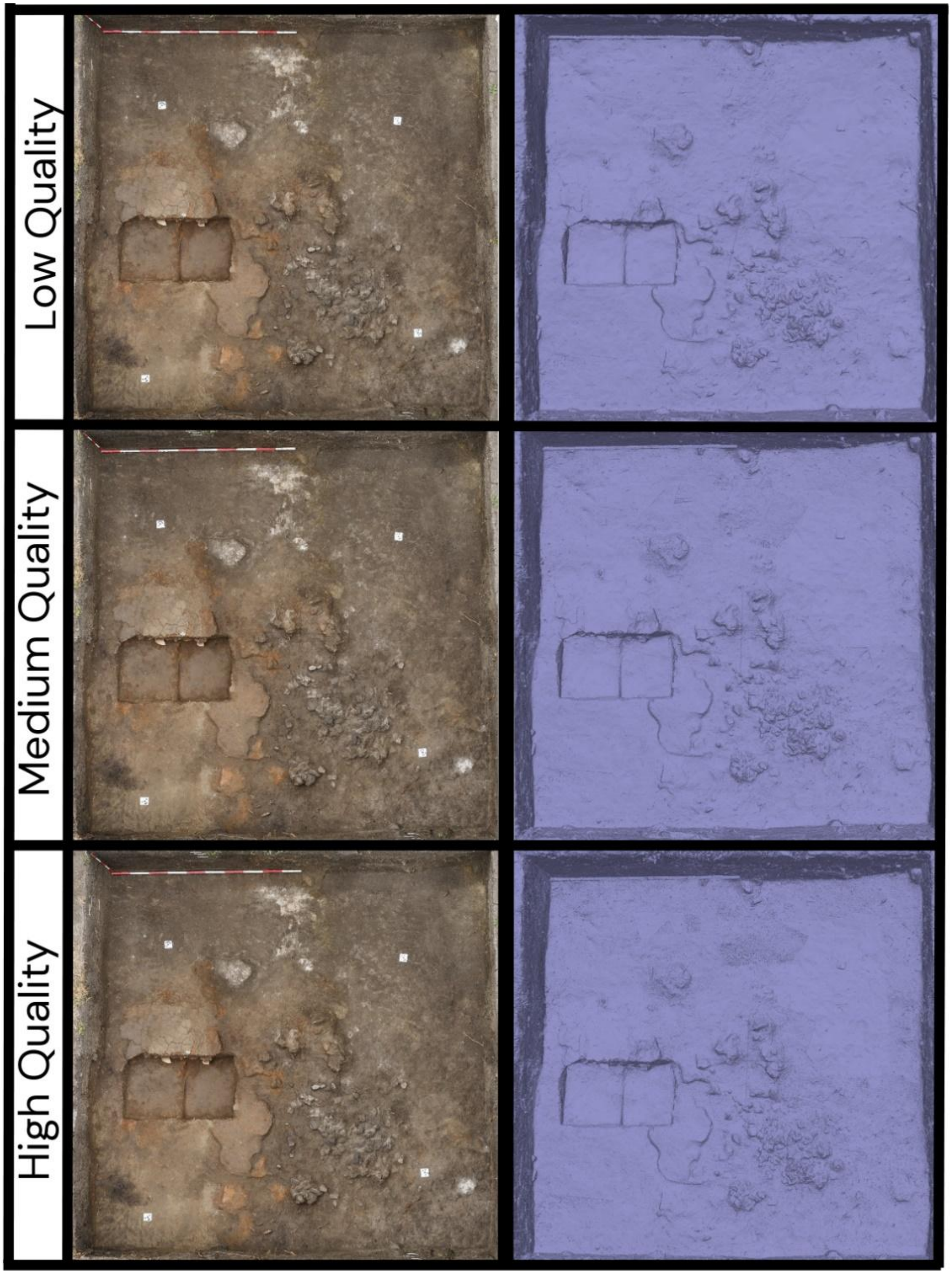

Figure 13. This figure depicts the 2x2 meter Block 1 rendered in low, medium, and high-quality models. The left column of images depicts the textured model layer, while the right column shows the solid model, where the faces (polygons) that compose the model can be noted (Figure by the author).

Complications and Potential Barriers

When conducting photogrammetry in an uncontrolled and variable environment, like an archaeological field site, a wide range of complications can occur. These complications can take the form of (but are not limited to) inconsistent weather patterns, operator inefficiency, and data loss. While these issues can be overcome or avoided in one way or another, they can challenge the process of carrying out photogrammetry and can be daunting challenges to amateur photogrammetrists. Complications that were experienced (or avoided) during this project, and the resolutions to these problems will be outlined in this subsection.

One of the most common issues, and the one most easily resolved, when capturing images of an excavation unit, involves varying weather conditions. While the optimal conditions for unit photography involve overcast skies with no chance of precipitation, this is often not the case, and during the BVC 2024 field season, weather conditions changed regularly. Most often, the weather conditions for fieldwork days involved clear skies and high temperatures, meaning the optimal time for taking photos would be in the early morning when the sun cast a soft light with no harsh shadows present within the excavation block. If the block layer closing occurred later in the day, which it most often did, the unit would be sprayed down with water to increase soil contrast, and the unit would be shaded. While a variety of shading methods were tested during this project, a large section of thick clear poly sheeting produced the best results, as it softened the direct sunlight just enough without overly darkening the unit.

A uniform photographing method is also essential for producing the best possible 3D model, as it streamlines the process of photogrammetry and increases the overall efficiency of the image capturing process, which can act as a potential bottleneck for archaeological projects. Additionally, a set plan also reduces (but does not altogether prevent) the chances of having insufficient photo coverage of the subject when the model processing phase occurs. Within a model, areas of insufficient photo coverage will result in losses of data as well as decreased resolution and accuracy. Ensuring proper photo coverage remains one of the most significant potential challenges when carrying out photogrammetry in the field, as the available time for capturing the subject is minimal, and fieldwork will likely resume immediately before the completion of the unit photography. If and when it is discovered that the excavation block layer has insufficient coverage, it is often too late to return for more photos.

Best Methods: Camera Settings

The optimal camera settings for photogrammetry will vary depending on the subject, whether it be an individual object that will be photographed within a lightbox or a large excavation trench photographed within the field (Fussel 1982; Whittlesey 1966; Arnold and Kaminski 2014).

The best method for capturing individual objects involves the subject being placed upon a turntable within a photography lightbox, with the camera fixed upon an adjustable tripod. It may be helpful to label the circular turntable with small markers indicating degrees (totaling 360) to standardize the number of degrees the object is turned for each photo to capture its entirety, although electronic turntables are available to automate this process. When one side of the object is captured completely, it should be flipped over to capture the opposite side, where the same process will be completed. The short focal length camera lens should remain at a fixed zoom during the entire duration of the subject shooting, as adjustments can result in distortions during the model generation process. Depending on the scale of the object, the lens aperture size will vary, but will most likely not exceed a f-stop of 11. The level of lighting within the lightbox can be adjusted alongside the camera's shutter speed to ensure a proper exposure of the object is obtained, but generally the shutter speed should fall somewhere between 1/60-1/500 if the camera is mounted upon a tripod.

When taking photographs of an excavation block, which exists in a more variable environment, the camera settings will need to be adjusted for each session to account for the lighting present to avoid underexposure or overexposure, although images can be edited before processing if this is encountered. To accurately capture the entirety of the excavation block, a larger f-stop (smaller aperture) should be used and will likely fall between F8-F22 depending on the lighting present and the overall size of the unit. Since these photos will be taken while moving around the unit, and the use of a tripod would be impractical, a quicker shutter speed is advised to reduce the likelihood of image blurring and should be no lower than 1/125.

While a DSLR camera was used primarily for photographing on this project, modern smartphones, in addition to point-and-shoot cameras, can also be utilized to conduct close-range site and individual object photogrammetry. The goals and limitations of the project should dictate which equipment is utilized for photogrammetry, as some projects may favor the ease of use of a smartphone over a manual DSLR camera. Many modern smartphones have the capability to capture images with manual settings, which should be used following the information outlined within this section. Additionally, the increasing prevalence of LiDAR technology in new smartphone models greatly aids in the accuracy of models generated via mobile phones. Mobile applications like Polycam almost entirely automate the process of model generation, making this method favorable to those new to the field of photogrammetry, although georectifying these models within the application is not possible at the time of writing.

Best Methods: Processing Workflow

While the general workflow previously established within this paper can be replicated for future projects, it can also be slightly changed to better fit the needs and limitations of the project. If time on the project is extremely limited and project staff do not have high-spec computers capable of processing models within the field, low quality models with minimal faces can be produced as a reference for project staff, general documentation, and can be imported into the project GIS, where the location information of special finds and features can be appended within the model.

If the priority of the project is to produce quality viewable models for referencing during and after the project, either for project staff or for public distribution, the photogrammetrist may opt to produce a medium quality model with a medium level face count, which can be generated quite rapidly depending on the number of images and computer processing capabilities.

Although all levels of model quality were produced for each unique model layer for this project, my priorities and those of the project meant that the importation of models into the site-wide GIS map and the distribution of models to the general public were the emphasis for this project. Due to this, most of the models developed for inclusion within the GIS site map were created in the low-quality model setting with a low-level face, or polygon count (50,000-500,000 faces). Models that were to be used for visual referencing by the project staff and for public outreach were developed under a medium to high quality setting with a medium face count setting, with the face count for the models falling within 800,000 to 3,000,000 faces per model, which would ultimately be limited to <1,000,000 faces during the mesh decimation process before exportation (see Figure 10 for representation of face count).

Conclusion

The variance in processing settings during the model generation process was carried out for this project to conduct a cost-benefit analysis of each setting when conducted for an ongoing field investigation. Depending on the nature and needs associated with each field project employing photogrammetry, different workflows will be followed to achieve a favorable balance between the quality of the photogrammetry deliverables and the resources expended.

Variances in the project workflow may be amplified when photogrammetry is employed for CRM projects, when compared to academic projects, due to significant differences in project purpose, timeline, and budgets within each field. CRM projects may utilize photogrammetry to provide their client, or associated regulatory agency, with a singular, highly detailed georeferenced 3D model that documents the scope of archaeological work conducted for a resource as a submitted deliverable. Academic projects, which often have extended project seasons over the span of several years, may choose to employ photogrammetry as a public outreach tool, documenting the successive excavation of units within their research site, with the intention of publishing models online to increase public interaction with the project over time. Photogrammetry field and processing methods should be altered with the purpose and limitations of each archaeological project in mind.

The next section of this paper will draw upon the previous analysis to detail how this project, and the photogrammetric methods employed, can benefit the field of academic and CRM archaeology for public outreach and digital heritage preservation.

Chapter VI: Conclusion

The research outlined within the previous sections of this paper addresses the practicality and effectiveness of employing 3D modeling methodologies during the duration of the 2024 BVC field season at the site of Békés-Várdomb. While the primary goal of this project was to produce several photogrammetric models that documented the excavation processes (and associated features) throughout the three-week field season at Békés-Várdomb, identifying a standardized method for conducting close-range site photogrammetry for duplication in future projects also remained forefront. The production of photogrammetric models for this project acts as a form of digital heritage preservation, capturing the stages of excavation at the site before the site strata are further altered by excavation or backfilling. These models served a dual purpose, as the georeferenced 3D models were imported into the Békés-Várdomb site-wide GIS map by project archaeologists to be used as a reference, while non-georeferenced models were uploaded online to be viewed by the public to pique additional intrigue in the site.

Future Recommendations

Future avenues of research regarding the use of photogrammetry within future investigations could focus on answering research questions like "Do the photogrammetric methods used for this project successfully create accurate georeferenced 3D models that will be valuable for post-field analysis by project researchers?" and "Is photogrammetry an effective tool for better engaging the local/global community in the field of archaeology?".

While this project focused mainly on conducting close-range photogrammetry for the excavation blocks of the 2024 BVC field project, there remains a significant amount of photogrammetric work that can be conducted at the site of Békés-Várdomb. For this project, individual georeferenced layer models of excavation Blocks 1, 2, 4, and 5 were imported into the site-wide GIS map to be used as an additional reference for the plotted location information of special finds. This provides a great deal of additional contextual information on a local unit scale, but additional contextual information may be developed on a site-wide scale by carrying out aerial photogrammetry.

This process could be carried out by utilizing unmanned aerial vehicles (UAVs), or drones, which could conduct flyovers at the site along transects to achieve complete coverage of Békés-Várdomb (Matthews 2008). This larger photogrammetric model of the site could be included as a layer within the site-wide GIS map and would enhance the already existing LiDAR map of the site by illustrating the current ground coverage of the site by vegetation and depicting the locations of 3D-modeled excavation units. It is still recommended that close-range site photogrammetry be conducted for individual excavation block layers, as this method could be conducted with more efficiency and accuracy for a 2x2 meter excavation unit when compared to that achieved with a drone. The various stages of excavation of a unit, which would be captured via close-range photogrammetry, would be paired with the larger site-wide UAV model to provide complete coverage of Békés-Várdomb, while still documenting the areas of interest in greater detail.

There remains the opportunity for individual artifact photogrammetry to be conducted for the Békés-Várdomb collections, as past work has largely focused on site photogrammetry. Furthermore, the issue of the long-term digital curation of photogrammetry source data and completed models should be assessed. 3D media could be more closely integrated alongside descriptive text on the project or repository website, allowing for the viewer to gain a better understanding of the process of archaeological fieldwork being done at the site of Békés-Várdomb, while also providing them with a better spatial understanding of the site. The collections generated from the previous Körös Consortium field projects (2006, 2016, 2019-2020, and 2023-2024) at Békés-Várdomb, which are housed within the Mihály Munkácsy Museum in Békéscsaba, offer an opportunity for further photogrammetric projects to be conducted on individual artifacts from the site. The digitization of a sample of diagnostic Bronze Age artifacts from these collections would aid in future public outreach initiatives and/or remote research by showcasing items of material culture in an interactive 3D format that exemplifies Bronze Age traditions at Békés-Várdomb and the greater Körös Basin. These 3D models could be digitally attached to both digital (websites, social media, flyers, etc.) and physical resources (site and museum informational placards) via QR code, which is becoming an increasingly more common practice amongst major museum institutions (Smithsonian Institution n.d., The Cleveland Museum of Art n.d.).

Conclusion

Advancements made in imaging and computing technologies in the past decade have made the practice of photogrammetry more accessible than ever for individuals. While the field of photogrammetry may have been viewed as a niche in the past by archaeologists due to barriers of inaccessibility like equipment costs and lack of publicly available information, these barriers have been largely overcome with recent developments. The exponential increase in camera imaging quality and the reduction in price of consumer-grade cameras, paired with the development of new photogrammetry software that can be operated successfully by individuals new to photogrammetry, means there are relatively few barriers for heritage professionals to employ photogrammetry for future projects. The necessary equipment for conducting photogrammetry in the field almost completely overlaps with standard photography equipment used for site photography, as the work done for this project utilizes both DSLR and mobile phone cameras successfully.

This paper aims to illustrate the relative ease of employing photogrammetric methodologies in archaeological investigations, citing the benefits of finished models for digital site preservation and public engagement, while also documenting the resources dedicated (primarily time) to generating the final models. While this paper primarily deals with conducting photogrammetry at the Bronze Age site of Békés-Várdomb, the methodology and workflow detailed in previous sections were developed with the intent of these processes being utilized as a toolkit for future terrestrial archaeological investigations and world heritage preservation projects taking place globally. This toolkit can be used as a baseline reference by heritage professionals for conducting photogrammetry at their respective project location, where minor changes can, and should, be made to the in-field and processing workflows to account for changes in the project environment, equipment, and overall project needs. The 3D models developed for this project act as a supplementary documentation method when coupled with traditional archaeological recording methods, providing researchers and the public with a more comprehensive spatial understanding of the Békés-Várdomb site and the fieldwork carried out during the 2024 BVC field season.

Chapter VII: Bibliography

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