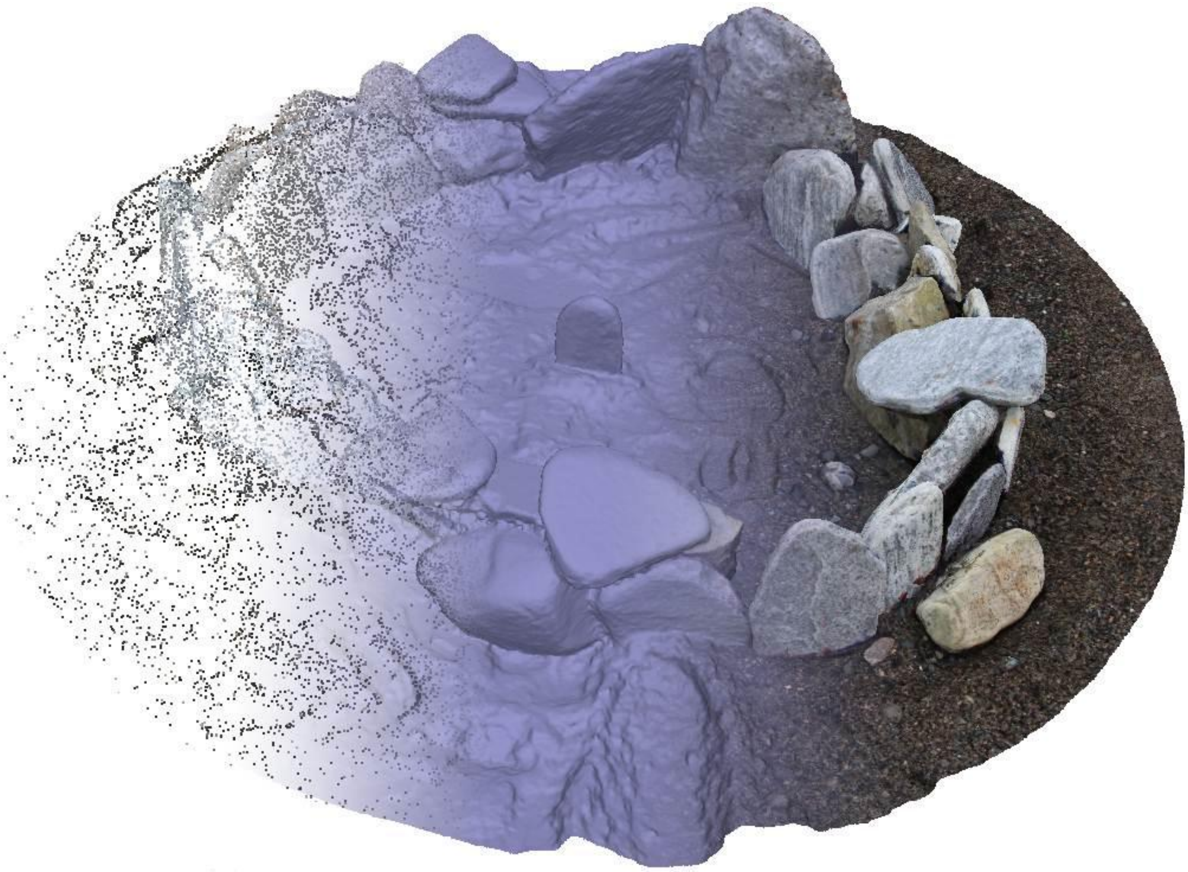
From 2D to 3D
-
A photogrammetric revolution in archaeology?



ARK 3900

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Front page: Illustration of the three main processing steps in AgiSoft PhotoScan: point cloud, mesh and texture. The structure was made by the author on a beach in Hammerfest, Finnmark, for my first photogrammetric test in 2010. This was where my interest for photogrammetry, and this thesis, began.

Abstract

This thesis investigates the possibilities of modern digital photogrammetry as a methodology for topographical field documentation in archaeology. The methodology is compared to what has become the main tool for topographical documentation in Norwegian rescue archaeology, the total station. Using self-developed methods for evaluating the data I have been able to determine the quality of each methodology in terms of resolution and time spent recording. This evaluation shows that digital photogrammetry is by far the better choice for recording topographical data at an archaeological excavation. I have also shown some possible applications for this kind of data in both visualizing and analyzing the data.

Acknowledgement

The road towards the finished product has been long and arduous. Dealing with the relatively uncharted domain of digital photogrammetry in archaeology has been challenging to say the least. It would not have been possible to do this without the support and help from a number of persons. First I would like to thank my supervisor Hans Petter Blankholm for vital guidance and feedback during the writing process of this thesis. I would also like to thank Jan Magne Gjerde and Johan Terje Hole on behalf of Tromsø Museum for allowing me to use the data from the 2011 Tønsnes excavation.

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If it had not been for the internet forum users at www.pgrammetry.com and www.agisoft.ru/forum/, this thesis would never have been finished. Their knowledge and support regarding software and hardware has been invaluable, so a big thanks to them is in order. I would also like to thank my brother Jon Øyvind Kjellman for his assistance with the mathematical part of this thesis.

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Glossary

CPU: Central Processing Unit – The part of the computer that carries out the mathematical operations as ordered by computer programs.

DEM: Digital Elevation Model - Digital elevation models are raster files that contain the elevation of the terrain on a specified area, usually at a fixed grid interval. The intervals between each of the grid points will always be referenced to xyz coordinate system.

GIS: Geographical Information System – A combined cartography, statistics analysis and database system for manipulating and analyzing geographical data.

GPU: Graphics Processing Unit – A processing unit most often found in graphics cards. With high capabilities in parallel processing it is a more effective tool for processing algorithms containing large blocks of data then CPU's.

Mesh: A collection of vertices edges and faces defining an objects polyhedral shape in 3D computer graphics.

PDF: Portable Document Format – as of July 1, 2008, an open standard document format for storing and presenting text and images in a fixed layout format.

Photogrammetry: The practice of determining geometric properties from images.

Point cloud: Surface representation in the form of a set of three-dimensional vertices in an x, y, z-coordinate system.

Raster: A graphical dot matrix representation of rectangular pixels with color information.

SFM: Structure From Motion – Using only a sequence of two-dimensional images captured by a camera moving around a scene, SFM allows the reconstruction of the three-dimensional scene geometry and the exact position of these cameras during image acquisition.

TIN: Triangulated Irregular Network – Vector based representation of a physical surface used in GIS.

Contents

List of figures

List of tables

1 Introduction

During the 2010 field season I became increasingly aware of the enormous amount of effort that went into recording topographical data from excavation and thought to myself that this was not the most efficient way of doing it. My awareness of the issue stemmed from me discovering digital photogrammetry, which quickly became somewhat of an obsession of mine. Digital photogrammetry is, simply put, a method of applying photogrammetric principles of geometry retrieval using powerful software and hardware. I envisioned this as a revolutionary way to record archaeological data. The following thesis is a result of this vision.

My intentions with this thesis are to investigate the possibilities of digital photogrammetry as a field methodology for archaeologists, particularly in a cultural heritage management setting. I want to find out if it is possible to increase the efficiency and quality of spatial data recorded at an archaeological site using digital photogrammetry rather than a total station. I will also investigate whether this technology will make it possible to apply highly detailed analysis of microtopography in a way that has not been possible with total station data.

The questions I want to address in this thesis are mainly aimed at the applications of digital photogrammetry as a topographical recording tool in archaeological excavations. The main issue is how this methodology can improve both qualitatively and quantitatively the topographical data that archaeologists record in the field. I also want to investigate how these data can be presented and analyzed, as they contain much more information than what is currently the norm. This also poses the question of the usefulness of the data in an analytical sense, which I will briefly consider. I will not, however, discuss the possible implications of such analyses in terms of cultural history. The main purpose is to find out if this methodology can and should be applied by archaeologists in their fieldwork.

In Chapter 2 I will give a brief presentation of the development of field documentation. This is to show how documentation standards have developed alongside the technological progress. I will also show how digital photogrammetry and other digital methods of documentation have spurred from this development and how it has evolved into the sophisticated states that it currently is today.

In Chapter 3 I will explain how I plan to record and evaluate the data. In order to examine the effectiveness of a photogrammetric methodology versus a total station methodology, data must be recorded with both total station and a camera. Two factors are crucial to determining the effectiveness of each methodology: time and quality. I have chosen to develop my own method for evaluating the two methodologies against one another. The quality of the data is estimated by calculating the pixel density in the digital elevation model (DEM) version of the data sets, which in turn is measured against time needed for processing the data. This will show how efficient each methodology is at recording spatial data.

In Chapter 4 I will present the localities and the process in which the data was recorded in the field. The data for this thesis have been recorded at Inner Elgsnes, outside of Harstad, and at Tønsnes, outside of Tromsø, both in Northern-Norway. At Inner Elgsnes there is a burial cairn believed to be from the Bronze Age which I have chosen for the first test. The data from Tønsnes is more varied, as it was a large scale excavation with multiple localities in an area of a few square kilometers. The localities were shoreline dated to Early and Late Stone Age.

In Chapter 5 I will present how the data was transformed from images to topographical data using photogrammetry and how I compare it with total station data. I will also present some possible methods of displaying and analyzing this data. This is to show how the different types of data visualizations can be utilized by archaeologists. The most important part of Chapter 6 is the evaluation of the two methodologies against one another.

In the last part of this thesis, Chapter 6, I will discuss the various benefits and disadvantages of each methodology. By doing so I will determine if it is possible to say whether or not digital photogrammetry is a more effective tool for recording topographical data than traditional total station approach. I will also discuss what the data can be used for and if and how this can benefit archaeology in general. In addition I will discuss some of the pitfalls and uncertainties that come with digital data in general and how we can address them.

2 Research history

2.0 Introduction

Ever since the first archaeologist figured out that it would be a good idea to record for posterity data of what was being excavated, a never ending evolution of methods to do so has run its course. From the time of the simple quill pen to the age of hyper advanced laser scanners, with names like TPS1200+ or HDS6000 bringing with them associations with sci-fi holocaust movies like The Terminator, what archaeologists document is still the same: the material remains of human culture. If we document the same traces of history as we did 150 years ago, what we actually end up documenting is a quite different matter.

In this chapter I will show how archaeologists have documented excavations in the past and how they do so today. Both our theoretical understanding of what we should document and how to do it, as well as technological evolution, have changed over the course of time. There is a gap in the creation of knowledge, where the one side is created by studying and debating theories and methods in a scholarly environment, while on the other side knowledge is created in the practical application of archaeological methods in the field.

This chapter will consist of two sections. The first section will describe the development of spatial documentation in archaeology. This is to show how the methods used today have evolved from an analogue to a digital state as well as demonstrating why the methods used were chosen. The second part will show the current state of spatial documentation techniques, with a focus on digital photogrammetry. As there are few archaeologists who have applied these techniques to an excavation, my examples will be drawn mainly from cultural heritage management.

The examples of photogrammetry in this chapter are mainly drawn from international research. In the last few years, however, an increasing interest in digital documentation techniques has emerged in Norway, as well as in the rest of the world. Archaeological institutions such as NIKU (The Norwegian Institute for Cultural Heritage Research) have had a leading position with respect to field trials of new methods of surveying and non-intrusive documentation methods. I will show how such methods have been received by the Norwegian archaeological community and how this can affect the future of archaeological documentation standards.

2.1 Archaeological documentation – the analogue past

Much can be said about archaeologists and their attitude towards documentation and how it has been undertaken throughout the last century. Only in the last 10-20 years have documenting excavations become a “science” in itself. Today we have the ability to utilize digital equipment in nearly every aspect of the documentation process, whether it be with a digital camera, a laptop or a total station. In the end, the documentation from excavations ends up as a pieces of an excavation report or a research paper, all digitalized in some shape, way or form. Archaeologists also benefit from the advantages that computers and digital storage devices give us. We can store entire documentation portfolios from excavations on portable hard drives no larger than a deck of cards. In the early years of archaeology documentation was mostly done by hand, but cumbersome equipment, like the large and unwieldy full-format cameras of the early 1900’s, were also utilized. If spatial data was to be recorded one would need to utilize expensive and fragile equipment, such as theodolites and other optical measuring systems that required trained personnel. So how did the methods and technology evolve up until the digital era, and what were the driving forces behind such changes?

In the early history of field archaeology, Lieutenant-General Pitt Rivers (1827-1900) is seen as one of the pioneers that created systematic methods for excavation and documentation. His view of archaeology differed from that of his peers and predecessors, who in hindsight have been deemed to be nothing more than mere treasure hunters, in that he was seeking the “truth” about the past through scientific methods and means. He stated that it was of utmost importance to preserve knowledge for posterity so that future archaeologists and scientist would be able to go back and re-examine the evidence in lieu of new knowledge (Lucas, 2001:21-22).

The importance of documenting topographical information from an excavation has been clear to archaeologists since the beginning of the last century, as we can see from Sir Flinders Petrie’s notes about the main objectives of an excavation: “…to obtain plans and topographical information, and …portable antiquities” (Flinders Petrie, 1904:33). Even late nineteenth-century archaeologist General Pitt-Rivers was a profound believer in topographical documentation. His keen sense of documentation made it possible to recreate sections from plan drawings after the excavation had finished instead of drawing sections from real soil profiles. In fact, Pitt-Rivers' meticulous documentation went to such lengths as to document artifacts in three dimensions, albeit without a reference to what stratigraphic layer the finds originated from. Unfortunately, the trend of precisely documenting objects in three dimensions did not last, and by the 1970's plotting objects by only their layer had become the norm, at least in medieval archaeology (Harris, 1989:22-23).

The documentation standards applied by Petrie and his scholarly peers were far beyond those of collectors or dealers of antiquities. Collectors did not care for context, nor did they document any. Dealers would at least make the effort to reproduce images of objects for sale and put them in a context of other finds. Petrie, on the other hand, sought to document for posterity and had a clear view of how to accomplish this. His keen insight made him aware of the fact that documenting every detail of an excavation would not only be foolishly complicated, time consuming and expensive, but also of no discernible scientific use. He therefore concluded that for anything to be worthy of documentation it must be as objective as possible. To obtain objectivity the recorder must fully comprehend what he is documenting (Flinders Petrie, 1904:48-50). Petrie’s understanding of the need for proper documentation led him to create a grid system for keeping track of large sites, which was still in use at such later excavations as Starr Carr in the late 1940’s (Clarke, 1954, Flinders Petrie, 1904:53, Lucas, 2001:26). Such basic rules as measuring from one point and have all numbers increasing instead of measuring the length between two points (Flinders Petrie, 1904:53-54) would make for a more user-friendly and reusable dataset. But despite his firm belief in the importance of documenting the planar data from sites, documenting sections, and thereby stratigraphy, was not of his concern.

The way layers are documented is crucial for the interpretation of data. In the early days of archaeology, standards for excavation and documentation were almost non-existent. But the way each excavator chose to document layers varied a great deal during the last century, as it continues to do so today. The reasons for choosing a particular methodology were not always bound by scientific preferences, but also by cost-efficiency, or even more so, tradition. Some would hurry through and only focus on documenting major structures while others were more meticulous and tried to record every aspect of each layer. People such as Pitt-Rivers and Flinders Petrie were trying to establish routines and standards, making archaeology a firm science. But theoretical approaches to field methodology are one thing; learning and applying said knowledge is a completely different story. As all archaeologists with a gram of fieldwork experience will attest to, fieldwork is learning by doing.

One of the best known methods for stratigraphic excavation and documentation is the system that Edward Harris developed in the 1970's: the Harris matrix system. His system is based on the idea of creating a matrix for reading the interrelational context between excavated units. There are three different possibilities of reading context between units – they are either separate from one another, in superposition or in correlation through a disturbance. The system was developed with complex stratigraphy in mind, such as that which one would encounter in a medieval urban area excavation. This system can be seen as a response to earlier attempts of documentation, in which stratigraphy – both horizontal and vertical – had been seemingly neglected. It differs in that it does not attempt to give a true representation of the stratigraphy, as one ideally seeks to in a section drawing, but rather provides an idealized representation of changes through time.

One of the most important things to notice about the general history of spatial documentation in field archaeology is the apparent lack of justification as to why one should bother with precise height measurements, even though everyone does so. The practice has seemingly been black-boxed from the early beginning, and finding any written argument for why this should be done is nearly impossible. Of the few who does try to give some reasoning to this practice are Audouze and Enloe (1997) who argue that keeping an exact record of the stratigraphy and exact placement of finds can help in interpretations of sites. But these kinds of arguments bear little value for single occupation sites.

I have presented a brief sketch of the development of documentation standards in archaeological fieldwork. But what about documentation of cultural heritage sites that are preserved rather than excavated? Documenting the state of buildings and sites of a certain value in the eyes of cultural heritage management has become increasingly important over the last few decades. As I will show later, the big changes in this area were rooted in the digitalization process of the 1980's. The need to explain the early development of documentation standards is not essential, as it will be shown later that a change in methodology was more welcomed and sought after than can be said about archaeological excavation in general. But it is important to note that even though documentation methodology has evolved, from mere tape measures to total stations, our main tools are still the simplest and inexpensive ones.

2.2 The development of digital surveying

As early as 1970 it was proposed that computers should be able to render archaeological artifacts on a CRT screen. Even though bringing computers into the field was seen as a soon-to-come reality it was viewed too complex for practical use (Burton, et al. 1970, 222). An “on-line” computer terminal in the field was used at an excavation in Doncaster, UK, connecting it via telephone lines to a computer in North Staffordshire, around 70 miles away, as early as 1973 (Moffett, 1991:17). As the computer and its associated technologies developed, archaeologists became more aware of their potential, both as an analytical tool and as a tool for visualization of archaeological data. As a analytical tool the computer had been in use since the mid 60's, but as an aid for visualization it was not until the mid-80's that one saw the full potential of computer-aided visualization.

In 1980 and 1981 a rescue excavation led by Reidar Bertelsen was undertaken on a farm mound at Soløy in Northern-Norway. This can be seen as a pioneer excavation in terms of the technology used, but also regarding the documentationof stratigraphic layers and context. Due to budgetary constraints in the first season they had to limit the excavation to about 10 1x1m test pits that, in turn, would enable them to choose a larger area for further investigations. This meant that they needed to improve the standard of documentation so that the scientific value would not suffer (Bertelsen and Urbańczyk, 1985:13). The way this was accomplished was by recording detailed topographic measurements of every stratigraphic layer so that they eventually would get a complete overview of the micro-topographic features at the site. By doing so they were hoping to gain a better understanding of the complex relations between different layers. This was achieved by plotting the dimensional data with a computer, through which they got a visualization of relative thickness of the layers (Bertelsen and Urbańczyk, 1985:79-80). The goal of this was not to achieve a true topographical recreation of the mound’s layers, but to be able to investigate the volumes of mass that each stratigraphical layer was composed of (Reidar Bertelsen, Pers. comm. 20.04.11). Although the visualization and computer-aided plotting method has become obsolete and the representations of data very cumbersome to reuse, the technological and methodological foresight shown by Bertelsen and

Urbańcyk should not be underestimated with respect to its role in the further development of digital documentation methods.

In the late 1990's digital surveying technology was rapidly becoming more and more popular amongst people in cultural heritage management and amongst archaeological researchers. Terrestrial laser scanners and prismless total stations both appeared in the last couple of years of the previous millennia, making recording of large or unwieldy structures and objects easy and highly accurate. The equipment, however, was exceedingly expensive. In 1999 a total station could cost anything between 20,000-40,000 USD and terrestrial laser scanners in the range of 100,000-200,000 USD[1] (Warden, 2009:6-7). The price levels have not changed much since then. A Leica TPS 1200 series had a price tag of approximately 42,000 USD and a Trimble VX laser scanner cost 110,000 USD in 2009[2] (Johan Arntzen, Pers. comm. 27.04.12). It is not difficult to imagine that the prohibitively high costs of this type of equipment automatically disqualified a large portion of archaeologists from partaking in this technological revolution. But at the same time as archaeologists were left behind because of high costs, the same factors became a push for the development of digital photogrammetry.

The latest in land surveying equipment that is specially designed with archaeologists in mind is the Nikon iSpace for Archaeology. This method uses radio waves instead of lasers to determine the position of the point that is being measured. With a rod that has multiple receptors and four radio emitters, the system is able to pinpoint the position of the rod's tip with a millimeter precision. Tests have shown a reduction in time spent recording structures of between 50-90% compared to traditional drawings (Nikon brochure, 2012). Since this method first was demonstrated at the CAA (Computer Applications and Quantitative Methods in Archaeology) conference in Bejing in 2011, very little testing has been done.

2.3 The development of digital photogrammetry in archaeology

Well into the 90's three-dimensional data was still being recorded using analogue photogrammetry, but with ever increasing technical and mechanical additions, such as with the Edicule tomb in Jerusalem. Because of physical restraints, the only practical way of recording accurate three-dimensional data of the tomb was to generate these through

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[1] 1999 currency. 1 USD in 1999 = 1.38 USD 2012. URL: http://www.usinflationcalculator.com/

[2] The prices are converted from NOK to USD with 27.04.2012 exchange rates. Prices in NOK are 240,000 and 640,000 respectively.

photogrammetric recording. But unlike the normal use of photogrammetric data, such as map making, the generated three-dimensional data were used to create three-dimensional string models representing the Edicule (Cooper and Robson, 1994). This was the start of a still to come digital photogrammetric revolution in the field of archaeology.

The earliest example of digital photogrammetry in archaeology in Norway comes not from the field of archaeology itself but rather from the field of land survey. In 1996 Knut Jetlund finished his dissertation at the Norwegian University of Life Sciences in Ås, Norway. Jetlund set out to investigate the possibilities of digital photogrammetry in an archaeological context. His main focus was on the technological and mathematical aspects of photogrammetric surveying, not archaeology. He did some limited field testing of the method on the ruins of a church in Trondheim, but the results were limited due to constraints in hardware capabilities and the fact that he only had one day to record the data needed. The manual approach meant that every tie-point in the model had to be carefully adjusted and aligned, which meant that recording many three-dimensional points would mean a huge time expenditure (Jetlund, 1996). In this sense, one can in hindsight say that it was a tedious task and that the output did not justify the labor costs.

Jetlund’s experiments did show, however, that it is indeed possible to apply digital photogrammetry techniques for documenting and monitoring structures. The analogue/digital hybrid-technique he used varies a great deal from the fully digital method that is the focus of this thesis. The methods he applied have now become obsolete, as the analogue aspect of photogrammetry has disappeared from modern practice. Nevertheless, Jetlund represents a pioneer phase in the use and development of digital photogrammetry in Norway. His method showed the potential for digitalization of manual processes, which later would turn towards SFM (Structure From Motion) and digital photogrammetry as we know it today.

2.4 Current trends in digital documentation

Some of the earliest testing of total station microtopographical surveys in Northern-Norway took place at the 2002 Melkøya excavation near Hammerfest and the preliminary investigations in Skjærvika in 2005 (Niemi 2003, Hesjedal et al. 2009, Gil et al. 2005). These did not have the advantage of robotic total stations, making it a very time consuming process.

The data from these investigations are not very detailed, which reduces their value. But the pioneering work that was done there should not be underestimated.

One of the most recent sizeable excavations in Northern-Norway, the Kveøya excavation in 2008-09, was surveyed and otherwise spatially documented solely using a robotic Leica TPS1200+ total station. All the spatial data were plotted in accordance with the national grid. Structures were documented by "drawing" the circumference of the feature with the prism rod to generate the shape. The robotic total station was also used to document the topography of the entire site as well as the microtopography of layers when structures were excavated in either mechanical or stratigraphic layers. The total station was also used to document events that occurred horizontally when time or other constraints prevented other methods (photo mosaic, plans) from being used (Arntzen, 2010:32-33).

In the same period as the Kveøya excavations took place, an excavation at Tønsnes, near Tromsø, also used a robotic Leica TPS1200+ for extensive plotting of microtopography. In the field, interpretation of structures could be difficult at times due to soil conditions, but by applying this methodology they could evaluate the validity of their interpretations by looking at the microtopgraphy without being confused by the soil conditions (Skandfer et al. 2010:39-40). This shows that even with a lack of national standards for documentation, project managers are trying their best to maintain and develop a high standard of documentation. It is, however, appropriate to underline the fact that these two excavations were fairly well funded, and that these excavations must be seen as an anomaly relative to what was considered the norm in Norwegian archaeology at that time.

One very recent example of how digital documentation has been implemented in Norwegian archaeology is the excavation and documentation of a medieval boat in Tønsberg, Norway. Late in 2009, the remains of a boat from around 1260 AD were uncovered during construction work under a sidewalk in the city center. The excavation revealed the boat to have been approximately 10 meters long, although parts of it were destroyed before the excavation took place. It was decided that the boat was to be preserved in situ rather than excavated. The boat was only partially uncovered, as the rest of it lay underneath the roadway and other modern structures (Molaug, 2010:4-9). The method chosen for documentation was phase-based laser-scanning, which was achieved using the Leica HDS6000, in addition to a traditional total station for georeferencing. Because of the site's location and surroundings, the task of scanning the boat was difficult. Cables and pipes hanging over the wreckage gave reflections and caused errors in the point cloud, which had to be edited in a time consuming post-processing step. The resulting three-dimensional data were used to draw profiles of the boat, as well as plan drawings. The report concluded that despite the problems they encountered in the field, the method showed remarkable cost-efficiency (Gustavsen, 2010:5-12). Even though this method brings with it high costs in terms of equipment and skilled professionals, the reduction in time needed to produce the data could be a winning factor.

At the world famous site Çatalhöyük, a group of researchers and students from University of California-Merced and Stanford University set out to record stratigraphic data and structural features using 3D laser scanners and digital photogrammetry as part of the 3D Digging Project. The goal of the project was to educate students in the application of 3D measuring techniques and representations as well as finding ways to interpret stratigraphic layers, structures and artifacts using 3D visualization techniques. The idea is that if one can recreate the entire site in a virtual environment it will become much easier to gain an overview of the inter-connectedness between different sites and structures. To achieve this they implemented the use of phase scanners as well as stereo cameras. The novel way these data were represented stimulated debates about interpretations of structures, stratigraphy and objects (Forte, 2010:128-132). This goes to show that this kind of new technology can indeed help archaeologists improve on the way we study archaeological sites and objects.

2.5 Current state of digital photogrammetry

In recent years the development of digital photogrammetry has simply sky-rocketed. Since the late 1990's and early 2000's there have been several large archaeological undertakings employing the method for documentary purposes (Ioannidis et al. 2000, Guidi et al. 2009, Hullo et al. 2009). There have also been several independent research projects which have tried to develop new software and refining existing algorithms, as well as doing quality controls of measurements (Wulf et al. 2009, Pollefeys et al. 2001). The main deployment of the method has been in cultural heritage management where the preservation of endangered sites or objects has been of the utmost importance (Gruen et al. 2004).

Today there are several online photogrammetric service providers and software packages available, both commercial and free, catering to a range of different fields, such as geology, computer FX, architecture, forensics, cultural heritage management and archaeology, to mention a few. My focus will be on the two latter applications and only on three select solutions, one in each of the categories: free online service, free software/open-source and commercial software. To show some of the potential of all available providers I will present a brief review of what is available on the market as of today.

2.5.1 Online providers

There are several service providers today, but a division between commercial and non-commercial must be made. Those services that are free to use often come with restrictions as to what the results may or may not be used for, i.e. research or profit. As most, if not all, of these services have been established during the last couple of years, there has been little to no research effort put into evaluating these services in terms of quality.

One service that has been put to the test in several publications is the Belgian web-service ARC 3D. It is a service developed and run by the Katholieke Universiteit Leuven. It was established in 2005 and receives its funding from the EU sponsored project EPOCH. The service was thought of as a way to reduce the cost and increase flexibility of reality-based 3D-modelling, with the cultural heritage community as its main target. The project set out to develop a series of tools enabling the user to upload his or her images onto the ARC 3D servers, where they are processed into 3D-point files that in turn can be downloaded from their web-page. A more overview of the pipeline of the service can be found in Maarten Vergauwen and Luc Van Gools (2006) review of the service. Briefly told, their review showed great potential for reality-based 3D-modelling, but improvements of the service would be needed, although many of the issues were sure to stem from the fact that the review was done while the service was still in Beta-mode.

As of mid-2011, at least four other online web services (http://my3dscanner.com/, http://ptak.felk.cvut.cz/sfmservice/, http://www.hypr3d.com/ and http://www.areoscan.com/) are available for the general public, but because of their relatively recent arrival on the scene, no scientific publications have been made regarding their application to archaeology or any other scientific application.

As a general remark about these web services, it needs to be stated that archaeological fieldwork is not only done in urban areas where internet access is readily available. Often one finds oneself at a remote location a long way from wireless communication or even electricity. Even in a high tech society such as ours, mobile internet access such as 3G is not a thing to take for granted on the middle of the Finnmark plateau. Cost is also an issue, where transferring of large amounts of data can be both expensive as well as time consuming. Even with such technology as 3G, transfer rates are so slow that uploading large image sets would not be practical. This makes any web service difficult to apply in non-urban field archaeology, which reduces its competitive edge compared to traditional surveying equipment. But as a tool for urban archaeology it might show some potential.

2.5.2 Free/open-source software

Open-source software is becoming more and more popular in the photogrammetry scene. But as far as archaeology goes, publication efforts have been limited, if not altogether absent. What has been done has mainly focused on developing the software and its algorithms rather than field testing it, at least in an archaeological environment.

The problem with this kind of software is that it is mainly a niche product and demands a lot of the user in the way of expertise and computer skills. Making this kind of software more accessible and easy to use would mean that more archaeologists would be able to better document data. Making a graphical user interface (GUI) and adding more automation to the processes could help in this process, but this also means that the community that has made this software is both willing and capable of doing so, which is not necessarily the case. But there have been attempts to lead archaeologists into the realm of open-source software, which can be exemplified by the efforts made by the creators of ArcheOS, the first fully integrated archaeological operating system. The OS includes GIS software as well a complete photogrammetry package with GUI, all open-source and free to use.

2.5.3 Commercial software

There are several commercially available software solutions, all of them with a broad spectrum of applications. There is a clear divide in types of commercially available software, between manual/semi-automated and automatic software. Amongst those most frequently used by archaeologist we find Photomodeler, which is a semi-automated software. Photomodeler is a product series with several photogrammetry packages from Eos Systems Incorporated. The company was established in 1990 and has been in the forefront of 3D modeling development. It has been one of the most applied software solutions in the field of archaeological photogrammetric documentation. The Pompeii Forum survey (Guidi et al. 2009) and the documentation project in the Bamiyan valley in Afghanistan (Gruen et al. 2004) are some of the projects that have utilized Photomodeler in their 3D-modelling efforts. Others have investigated the value of this software in terms of precision, such as Hanke et al. (1997).

One project that has utilized Photomodeler as a tool for photogrammetric reconstructions is the aforementioned Pompeii Forum surveying project, which is a part of a larger cultural heritage project. The goal of the project is to create a three-dimensional record of the complex and fragile structures of the Roman Forum in Pompeii, Italy, as well as establishing routines and techniques for registering and rendering of three-dimensional data in a system wide format. Moreover, the reasons for choosing a three-dimensional approach stemmed from the desire to create a tool that would be more easily available and comprehensible, both for conservation purposes and public interest. The Forum itself was the main venue for commerce, politics and religious activities in Pompeii, and is therefore considered to be of great culture-historical value to the people. The area covered is approximately 150 x 80 m. There are more than 350 finds spread over the entire area, as well as structural remains of buildings (Guidi et al. 2009:1-2).

The project had several obstacles to tackle in order to obtain maximum efficiency of the data and at the same time keep within the budget. Among the obstacles were avoiding tourists, planning of proper sensory equipment at different locations, making time estimates for scanning and photography, as well as setting quality parameters for the data acquired. They solved these problems by combining several different surveying techniques. The different techniques required different input data, such as aerial photography for a general mapping of the area, oblique aerials for texturing purposes, range-data from laser scanners, and terrestrial photography for details and gap-filling. The photogrammetric work was mainly focused on the detailed surfaces, such as ornaments and relief, because of the method’s high precision and correct color representation. Processing of the data was accomplished using a variety of software-packages, such as SAT-PP, Cyclone, Polyworks, Photomodeler and CLORAMA. The processing took about 6 months to finish, resulting in a 100 M point cloud, containing all essential data for the complete model.

As this project was intended both as a tool for conservation and as a source for public information, measures were taken to make sure that the model(s) would be easily accessible and manageable. This was partly achieved by merging low-resolution aerial photos and data from laser-scanning with detailed photogrammetric data and texture of more “visually important” objects like reliefs or ornaments. The model was further decimated[3] so that it could easily be rendered real-time on a desktop PC, which in turn makes it more accessible to the public in general via museums and online displays.

As an additional feature, and perhaps most interesting for the archaeologist, is a plan to implement existing archaeological databases into the workflow. This will create a powerful tool for archaeologists to view meta-data in its true context, which in turn can help both build and test hypotheses about the Forum and its former inhabitants.

One of the few, fully automatic softwares on the market today is PhotoScan from the Russian company AgiSoft LLC. It is a fairly new piece of software, first released May 10th 2010, and is only recently starting to make an impression within archaeology. Several articles have been published on the application of PhotoScan in an archaeological setting (Verhoeven, 2011, Verhoeven, Doneus, Briese and Vermeulen, 2011, Verhoeven, Taelman and Vermeulen, 2011, Plets et al. 2012). Geert Verhoeven (2011) describes the properties of the software in a detailed fashion, as well as demonstrating its possibilities as an archaeological tool by processing both intentionally and unintentionally shot aerial photos to generate 3D models. In his concluding remarks he states that “...creating three-dimensional visualizations for virtual displays or realistic models for site monitoring or publications has never been so easy.” (Verhoeven, 2011:73). This statement shows that photogrammetric software development is going in the right direction, and that it has great potential for archaeologists in general, as I will demonstrate later on in this paper.

2.6 Norway – current standards for archaeological documentation

As of today there are no national standards for documenting an archaeological excavation in Norway. However, the Directorate for Cultural Heritage in Norway (Riksantikvaren, RA) is currently running a pilot project in which executive authority is delegated to county level officials to decide whether excavation can be done on a number of different heritage objects.

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[3] Decimation of a model means to reduce the amount of polygons without losing too much geometry.

In this project, the RA has developed standards as to what must be documented and how (Prøveprosjekt RA, 2011). An example of this is the standard form for documenting a charcoal pit (kullgrop). Things that need to be documented are: an area plan with the pit drawn on a 1:50 scale, photos and a detailed plan of the pit in a scale of 1:20, machine-aided or manual sectioning of the pit, a drawn profile of the section in a scale of 1:20, measurements of the top of the pit rim, the bottom of the unexcavated pit, the inner and outer limits of rim, extent of bottom of the pit, the location of 14C samples (Dokumentasjonsstandard RA, 2011:5).

At The Norwegian University of Science and Technology (NTNU) in Trondheim, they have developed an archaeological field manual. In this manual they describe how excavations should be documented and otherwise executed. The approach used here is different from the documentation standards RA has developed. Instead of making detailed plans for every cultural heritage feature (e.g. charcoal pit, house structure, etc.) they have listed a range of procedural efforts that will result in data documentation. An example of this is the routine for digital surveying on excavations. Not all excavations lead by NTNU will have the necessary equipment or personnel with required expertise to implement digital documentation techniques, so some excavators must therefore utilize traditional analogue methods. Other than this, only general remarks are made about digital surveying, such as sources of error and so forth. The section concerning drawings and plans is somewhat more detailed, but even this lacks a proper description of what to document and why. It should be noted that this manual is not meant to dictate how one should execute an excavation, but is rather a guide as to how one may proceed (Feltpermen NTNU 2010).

2.7 Summary

In this chapter I have given a brief historical review of how archaeologists have documented archaeological phenomena spatially. It is clear that we have come a long way, technologically speaking, in developing new methods to assist us in the understanding of the past. It is also clear that there is a considerable delay from the methodological developments to their full scale application in field archaeology. Even though total stations have been available for almost 30 years now, people still use analogue equipment to do their spatial documentation. The reason for this might be the high cost associated with this technology. Will low-cost photogrammetric solutions be able to change this? In the following chapters I will argue that they should.

3 Method. From field to finished product

3.0 Introduction

Leading up to this chapter I have given a brief introduction of the history of spatial documentation in an archaeological context as well as a brief introduction to the use of digital photogrammetry in archaeology. Now I will focus on the method itself, showing how to apply it to archaeology, from recording in the field to the finished product. The method I have chosen is more precisely referred to as “structure from motion” (SFM) rather than photogrammetry, but I will use the term photogrammetry because it is a more commonly known term amongst archaeologists.

I will explain how the image data can be transformed into quantifiable data through automatic photogrammetry computer software called PhotoScan, by AgiSoft LLC. The main function of PhotoScan is to create quantifiable data in the form of x, y and z point data from which the software can generate a mesh and finally a fully textured 3D-model. I will show how different outputs from PhotoScan can be used for different purposes, thereby demonstrating the importance of knowledge of the entire process from start to finish.

I will also show how the data can be used for comparison with other types of spatial data. In most cases, a transformation of the data is needed before a comparison can be made. The only data output than can be directly compared is a DEM (digital elevation model), which I will demonstrate. I will also show how the data can be utilized to acquire accurate spatial information at the end-users leisure by adding a scale reference to the model, as well as showing how to make a purely visual representation of the model.

3.1 Application in the field

In order to create good spatial data using digital photogrammetry a thorough understanding of how it works is essential. To start with, it is important to understand the process of gathering raw data. With sub-par raw data it can be a very disappointing experience trying to generate something useful (see Chapter 4.). To avoid this, planning well is necessary before venturing into the field.

3.1.1 Preparations

To make a model three things are essential: a computer, photogrammetry software and a camera. There are no restrictions as to what type of camera (DSLR, compact etc.) or what kind of lens (wide angle, zoom etc.) one can use with PhotoScan. However, it is recommended to use a quality camera with a good quality lens. This is mostly for cosmetic reasons, as better equipment produces higher quality textures. Image resolution can also have a slight effect on the quality of the model, especially if the object being modeled has few distinguishable features or if it has a very uniform texture. Other photogrammetry solutions might require more specialized equipment, but mid-range DSLRs are usually more than capable of recording data for digital photogrammetric work (Callieri et al. 2011:4).

Another important tool to have close by is a laptop or stationary computer. Because of the inherent limitations of most cameras, some disturbances in photographs are likely to occur at some stage of the shooting process. This could be poor focus or unwanted objects in the frame that are hard to spot on the built-in display of the camera. That is why a computer can be a very useful companion in the field. By loading the images into the computer one can visually inspect all elements to make sure they are satisfactory, as well as doing trial runs to see if they work in PhotoScan, or any other photogrammetry software.

Another tool to bring into the field would be a measuring device. This could be anything from a simple tape measure to a handheld GPS, or even as sophisticated as a total station. The reason for bringing this equipment is to be able to reference the model. By knowing a distance between two distinguishable points, PhotoScan can transform the spatial data of the model to real-world dimensions. With a GPS one can even create a georeferenced model.

If the main purpose is to create large orthographic photographs of an area, and one wishes to obtain the best possible texture, it would be ideal to bring a photo pole. This enables you to take near vertical photographs of a large area. Vertical photographs are much more suited for creating orthographic photographs as they do not need to be stretched to fit over the model, thus minimizing blurred or misshapen texture.

3.1.2 Execution

There are several factors that must be taken into account before one can start photographing. Knowledge of what equipment to bring is one, how to use it another. The latter is probably more important than the former due to the possible problems that can occur when recording is wrongly executed. If the field procedures are not done correctly then one might experience problems during processing of data. Examples of such issues will be given in later chapters.

As photogrammetry inevitably relies upon photographs, good procedures for photographing must be upheld to achieve quality photographs for processing. I will not go into detail about how to take pictures, but will instead point to some aspects that are necessary to achieve good results in a photogrammetric setting. Having good focus in the entire subject area is important. This will increase the amount of points that can be detected and therefore increase the quality of the model. It also helps reduce the chance of failed reconstruction. The same goes for reducing shaking. Lighting is not so much a problem for reconstruction, but more of a problem when texturing. Consequently one should avoid photographing when the sun is low, or in bright blue sky conditions, as this will produce distinct shadows. It is not recommended to use a flash, as this will produce long shadows and the bright light produced by the flash is easily reflected. In general, it can be said that it is preferable to use all manual settings on the camera, adjusting in accordance to the current conditions.

In principle, the most important rule of photogrammetric recording is ensuring overlap between photographs (Callieri et al. 2011:4). Making sure that you have enough overlap between photographs is the first and foremost thing to remember when in the field. There is no exact percentage for how much overlap is needed, but a good rule of thumb is to have at least 60% of the frame matching the previous photograph. The higher the percentage of matched area, the more points the software will be able to match, thus creating a higher quality model. Figure 3.1 is a good example of good and bad overlap in two image pairs.

Figure 3.1 *Example of good (upper pair) and bad (lower pair) overlap between images.*

The second most important thing when photographing is how one positions oneself according to the object being recorded. Figure 3.2 illustrates the main idea of positioning, which is getting as much of the object as possible in every frame. There are some slight differences between the scenes, but the two key principles remain the same: achieving good overlap between shots and keeping relatively perpendicular to the surface. Asymmetrical objects can be difficult, but what is important is keeping the desired object centered.

It is also important to be aware of the surroundings when photographing. This applies especially to objects where photographs are taken in a horizontal direction. To avoid major editing before processing the images, selecting less "noisy" backgrounds could help reduce this to a minimum. Keeping moving objects, such as car, planes, boats, people etc., out of the frame would help greatly. This is of course not always possible, but should still be something to strive for.

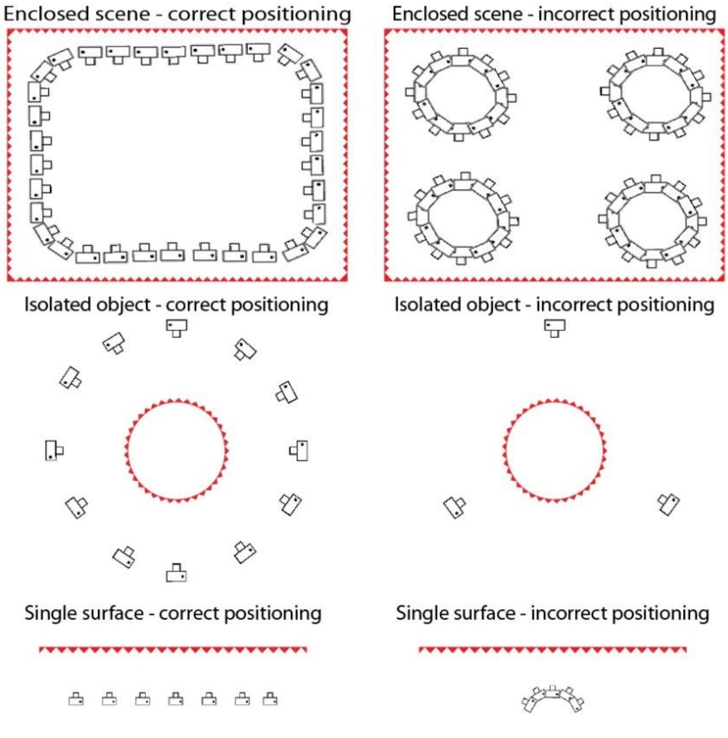


Figure 3.2 *Correct (left) and incorrect (right) camera positions for different recording scenarios.*

Another problem to be aware of is shiny, reflective surfaces, such as windows, still water, mirrors, metallic paint etc. Reflective surfaces will reflect artifacts and light that are not a part of the object, thus making recognition of points on the surface difficult or impossible at different angles. Areas that have a high reflectivity should be avoided if possible. This is because the reflected light from the surface does not represent the object itself, but rather its surroundings (Liu et al. 2011:137). In an excavation situation this is not something that affects recording too much, but ponds that form after rainfall might be a source of reflection that might cause problems. To avoid this it is best to simply dry them out or empty them as best possible. If recording of surfaces with high reflectivity is unavoidable, photogrammetric stereo technique could be used instead. For an explanation of this concept, see Vogiatzis and Hernández (2010).

For recording objects at ground level it is almost always possible to do this with only a camera. Using a tripod is usually only necessary if shooting in poor lighting conditions, such as indoors or at night. A tripod could also be useful if recording a smaller area where better control of parameters (e.g. f-stop, shutter, etc.) is needed. If larger areas are to be recorded then a photo-pole is recommended. This will reduce the number of photographs, thus reducing both time spent in the field as well as time spent processing the data.

3.2 Processing the data

It is important to emphasize the need for quality control in any situation where photogrammetry is being used as either a prime or the exclusive documentation method, especially when used at excavations. If the images that were taken for some reason do not generate the desired result then it is important to know this before you leave the field or excavate further. Even in cases where re-photographing is possible, doing so would impose added expenses. This could be avoided if proper quality control protocols are followed.

3.2.1 Software

Today there are several different digital photogrammetry solutions on the market. In this thesis I have chosen to focus exclusively on the aforementioned PhotoScan. The reason for this was mainly due to time constraints, but also because of economic as well as practical reasons. I was convinced early on that PhotoScan would be a very suitable candidate because of its ease of use and multitude of various outputs available. From a personal experience point of view, I would say that PhotoScan outperforms any of the open-source solutions available at the moment. A thorough performance analysis of the software compared to open-source solutions could help in validating my claim, but as of now, no scientific papers have been published with such comparisons.

The software is available in two editions; standard and professional. The standard edition (179 USD) is far less expensive than the professional edition (3,499 USD) but is very limited in function. There is also the choice of educational licenses intended for researchers and students at educational facilities for 59 USD and 549 USD respectively. Among the limitations in the standard edition is a lack of georeferencing, DEM export, orthophoto production and more. The professional edition was therefore the only real choice for my thesis.

For post-processing I needed to use additional software to maximize the potential of the data, as well as make the photogrammetric data comparable to data from the total station. I have chosen to use a GIS (Geographic Information System) solution from Esri, ArcGIS v10, as my main tool for handling and comparing data from the total station and from PhotoScan. As I will show later, a problem with the output from PhotoScan led me to seek out a second GIS tool, Quantum GIS (QGIS) v1.7.3. with the Geospatial Data Abstraction Library (GDAL) plugin. This software is free of charge and is based on open source code and is published under the GNU public license.

3.2.2 Hardware

In the AgiSoft PhotoScan Professional Edition Manual, Version 0.8.4 (http://downloads.agisoft.ru/pdf/photoscan-pro_0_8_4_en.pdf) the minimum system requirements are listed as follows:

> Minimum Configuration
> - Windows (XP or later) or Mac OS X (Snow Leopard or later), 32 or 64 bit
> - Intel Core 2 Duo processor or equivalent
> - 2GB of RAM
>
> Recommended configuration
> - Windows (XP or later) or Mac OS X (Snow Leopard or later), 64 bit
> - Intel Core i7 processor
> - 12GB of RAM

PhotoScan supports OpenCL (Open Computing Language) assisted acceleration, meaning it can utilize the graphics card GPU (Graphics Processing Unit) for an accelerated geometry reconstruction process. This only applies to devices with OpenCL abilities, such as NVidias GeForce 8000-series and later as well as ATIs Radeon HD 5000-series and later. NVidias Quadro series is not listed as supported. The way this support works is by moving some of the workload from the CPU to the GPU, leading to a decrease in processing time during the geometry reconstruction phase. It is only during this part of the process that the OpenCL support is utilized.

For my tests I had a HP Z400 Workstation at my disposal. It has an Intel Xeon W3503 CPU running @ 2,4GHz, 12 GB RAM and an NVidia Quadro FX 1800 graphics card. The Quadro card is, as mentioned above, not listed as supported. However, it does show as an OpenCL device in PhotoScan, making it possible to disable a core on the CPU in favor of the GPU. But a basic speed test revealed that it was in fact slower to enable the GPU than leaving it off on this particular setup. I therefore chose to leave this option turned off.

It is also worth mentioning that during the field tests at Tønsnes I did some trials on another machine at the Tønsnes project. This was a HP EliteBook 8730w from 2008, with 3GB RAM, 1,6 GHz dual core processor and an Ati FireGL Mobility V5725 graphics card. The trials were only meant as a way to double check that the data would actually work, but they also showed that even outdated hardware was able to apply this software with reasonable results. The data from these trials will not be used here, as they were only meant as in-field test data.

It is important to keep in mind what the intended use of the photogrammetric solution is before investing in hardware. Small-scale, low-detail work will demand less of the hardware to perform optimally, while highly detailed large-scale work will demand more.

3.2.3 Processes

There are three main steps in PhotoScan regarding the photogrammetric process, and additional processes for aesthetics and other non-essential features. The main steps are alignment, meshing and texturing (Figure 3.3). The latter is not necessary to create a purely spatial model, but is essential for the production of high resolution texture, making it essential for orthophoto production. I will now give a short explanation of the essentials. For a detailed step-by-step guide of the software see PhotoScan manual.

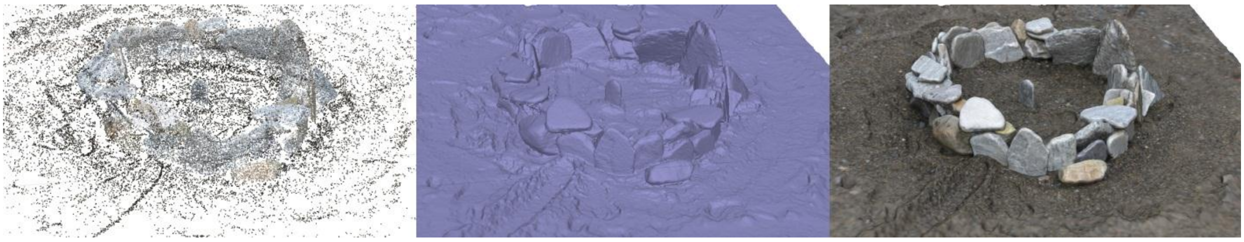


Figure 3.3 *The three main steps of the PhotoScan process: point cloud, mesh and textured mesh.*

The program works by first applying a content aware algorithm to detect key features in the images that are chosen by the user. These key features are then matched, or aligned, across different images (Figure 3.4), making it possible for the software to calculate spatial positions for both points and cameras. After camera positions have been calculated, the mesh, or surface, of the model can be generated. The last photogrammetric step is to apply texture (PhotoScan manual, 2012). This is not necessary if the only requirement is spatial data, but can be done if orthophotographic representation of the model is wanted.

An optional feature is the georeferencing tool. This enables the software to transform the coordinates from an arbitrary system into a real world one. To do this it is necessary to have x-, y- and z-coordinates of at least three known real world points visible in the photographs. Georeferencing can also be achieved by using a GPS-enabled camera that tags the images with spatial information. However, this is not as precise as using a total station or similar technology. There is also the option of setting a reference distance between two points in the model, which will provide the advantage of doing measurement inside the model as well as exporting a DEM but limiting the usage in regard to GIS applications.

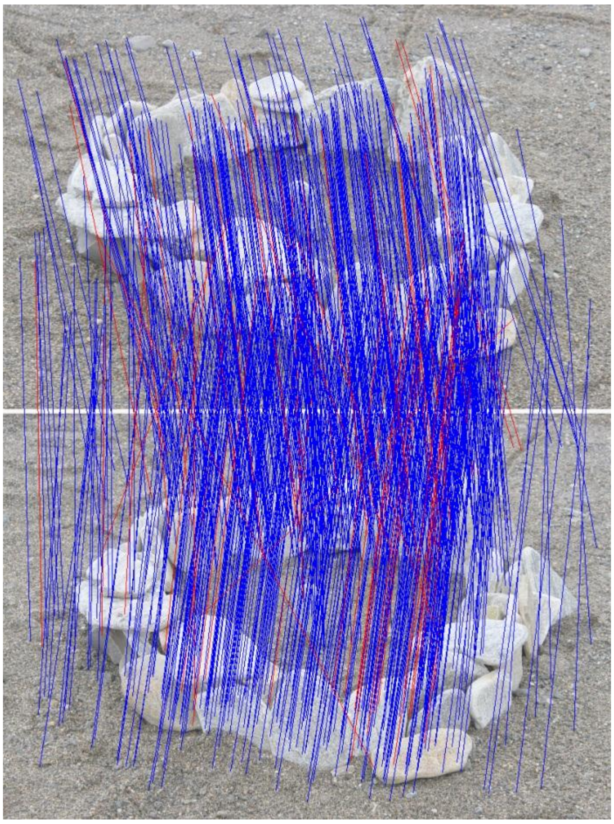


Figure 3.4 *Matched points in two images. Blue are valid matches, red are invalid.*

The finished product after all steps are completed is a meshed and textured model with corresponding camera positions. After this is finished the data are ready for post-processing, such as quantitatively or qualitatively comparing the PhotoScan data to other data sets. I will now show some of the methods for comparing the data to other data sets, as well as showing some of the possibilities that a referenced 3d model can provide.

3.3 Post-processing

After the photogrammetric process has finished and the models have been exported from PhotoScan, some work remains to be done before a comparison between the total station data and the photogrammetric data can be accomplished. Depending on what the spatial data are intended for, different methods of viewing the data are required. If the model is only intended as a show-piece, then a direct viewing in PhotoScan is optimal, or an exported PDF could do the same. Adobe Reader has a good 3D-model viewing capability and even comes with tools to measure inside the model, provided that it is referenced.

If the intended purpose is to make a comparison between two or more data-sets, then a GIS compatible output is better suited. This can be achieved in several different ways; exporting a text file with x, y and z data, exporting a DEM, or an orthographic photo. By exporting x, y and z values, the data can easily be converted into useable TIN (triangulated irregular network) data, but at the cost of details. TINs are more suitable for larger models because they need fewer points to give an accurate representation of the terrain than a DEM, thus making loading and handling of the files faster. It is also possible to generate a TIN from the DEM, but either way would produce similar results, so it is not necessary to demonstrate this further. It is important to mention that for the data to be exported to any GIS tool, georeferencing of the data is necessary.

If a more detailed version of the data is required, a DEM will be the best choice of output. The good thing about DEMs exported from PhotoScan is that they can be exported fully georeferenced. That means that if the model has geo-spatial information, the DEM will have this information embedded in itself, removing the need to do this manually in ArcGIS. The possibilities for editing and analyzing the data stored in the DEM are plentiful in ArcGIS, so I will only briefly explain how to make a comparison between two sets of DEMs.

One way to analyze the data is to do a visual-qualitative analysis of the different datasets. This only requires adjustment of the data so that they are comparable, i.e. giving the data equal visual properties. For this to be possible, the raw data from the total station have to be converted into one of the following three formats: contour, TIN or DEM. The raw data consist of x, y and z information that can be imported into ArcGIS and then converted to contour, TIN or DEM. When the files are converted it is necessary to adjust the parameters. Choosing parameters is purely subjective; only through trial and error can the best parameters be set for any given dataset.

3.3.1 Raster math

One of the methods for comparison that I will use is raster math. With a set of two DEMs one can do either a raster divide or a raster minus operation in ArcGIS, both yielding a similar output. With minus you get a resulting DEM that shows the numeric difference between the two DEMs. When divide is used, the pixel value will represent the relation between the two DEMs at the given pixels location. Which math one should choose depends on what the intended purpose is. For a reading of exact numeric difference it would be better to choose minus, while divide would give a better overall representation of the differences. Of course, both modes will give a similar visual representation of the data, so for a visual analysis it would make little difference choosing either one.

Raster math is not only suitable when comparing the quality of different types of data. For an archaeologist it could be very useful to compare two DEMs of the same area at different stages of excavation to analyze local topographical changes. The same would apply when comparing data on sites that are in danger of erosion. By applying raster math to DEMs from the same area from different dates one could easily uncover if erosion is occurring and at what speed.

3.3.2 Quality measurement

Evaluating the level of detail produced with each respective methodology requires that a quality assessment be made. Measuring the quality of models is not as straight forward as calculating time consumption. For this purpose I found it necessary to develop a function that could help evaluate the quality of the different DEMs. Actual pixel size was measured in ArcGIS. Given that a ratio of 1:1=100% it is possible to calculate a quality value Q from the resolution R given in percent using a function

$$Q = \left(\frac{100}{R}\right)^2$$

A Q value of 1 equals a 1:1 ratio in resolution, i.e. 1 pixel equals 1 square centimeter. This allows for an evaluation of the total amount of pixels per square centimeter. Such an evaluation does not say anything about the visual quality or accuracy of the data *per se*, but it can give an indication of how detailed the data are. It can also help evaluate the cost efficiency of the method when measured against time.

3.3.3 Contours

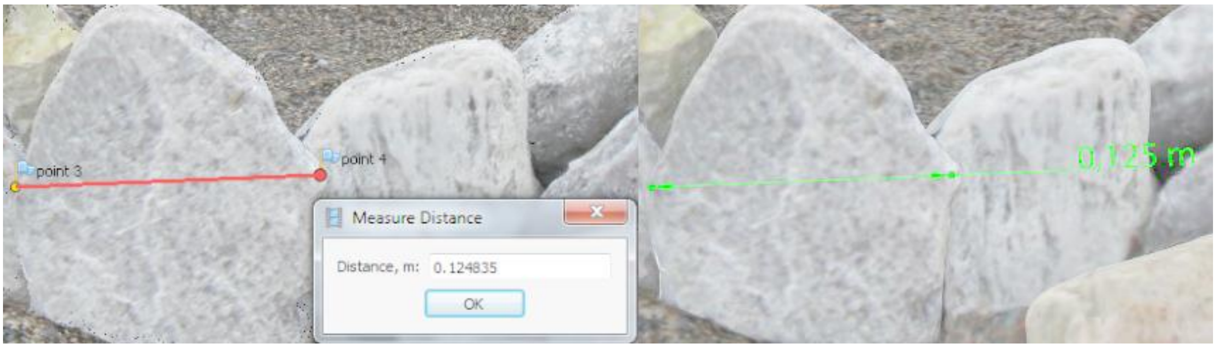
Extracting contour lines from DEMs is a fairly straight forward process in ArcGIS. But because the output from PhotoScan contains unwanted no-data, it is not as straight forward a task to do this as it would be without the no-data. One way to bypass this is to edit the DEMs in ArcGIS using an exclusion tool, or one can use QGIS and the GDAL library in order to extract the contour lines from the PhotoScan data, which is a quicker process, at least when dealing with high resolution data or otherwise large files. The results will be close to equal, but if time is important then some time could be saved using QGIS for this specific task.

Visually, contour lines have an immediate advantage over DEMs. Because the DEM gives a graded representation rather than the leveled presentation that contour lines give, it is harder to verify visually exact levels in a model looking at a DEM then what is the case with contour lines. But what DEMs lack in visually identifiability, compared to contour lines, they make up for in level of detail. Contour lines can be drawn at as low as 1cm intervals in z-value using QGIS, creating a very “detailed” presentation of the data. The problem is that by doing so one makes the data less readable compared to a presentation using 5- or 10 cm intervals. Choosing what presentation to use depends on what one wishes to study. If the purpose is to study volumetric changes, then DEMs and raster math could be a better solution than converting the data to contour lines. On the other hand, if the purpose is to provide a good presentation of how the object is placed in the terrain compared to other objects, then it could be more useful to present the data as contour lines.

I have chosen to use only a visual approach when assessing the possibilities that come with using contour lines. If quantitative measurements are the desired output from an analysis of the data, DEMs or other methods of data presentation should be opted for.

3.3.4 *Visual presentation and metric measuring*

With a model that has been set to scale using the set reference tool in PhotoScan, making accurate measurements can be easily done without exporting any data at all by using the measurement tools embedded in the software. But this option is limited to those in possession of PhotoScan software. One way to take advantage of the metric data stored in the model is by exporting it in PDF format. It is then possible to open it with Adobe Acrobat and make metric measurements of the model, as seen in Figure 3.5. This enables researchers to share much more data on artifacts and sites without having to travel to the site or have the artifact shipped by mail, minimizing the potential for irreparable damage. The potential for this is, in my opinion, huge. Examples of the interactivity of 3d pdf models can be seen in Appetecchia et al. (2012:22-29)[4].



Distance, m: 0.124835

Figure 3.5 *Measuring in PhotoScan (left) and in Adobe Acrobat (right).*

Another way to measure the model is by exporting it to PLY format, which can be opened by the open source 3D editing software Meshlab. This also has measurement tools, as well as a full range of other tools for viewing the model in different light conditions and enhancement filters. The disadvantage of Meshlab contra Adobe Reader is that it is a specialized software solution that does require some learning before it can be useful. Also, it is not as common compared to the almost universal Adobe Reader. But tests have shown that Meshlab has a great potential as a tool for analysis of archaeological sites (Callieri et al. 2011:7-8).

A purely visual option is to export the model as a snapshot from any desirable angle, or if the model has been georeferenced it can be set to an orthographic perspective that is relative to the ocean level. Such presentations can be used for depicting the site or structure in a

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[4] URL:http://www.arkeologiuv.se/cms/showdocument/documents/extern_webbplats/arkeologiuv/publikationer_uv/rapporter/uv_rapport/2012/uvr2012_001.pdf

publication from angles that are not possible to achieve using traditional photos, or it could be used as assistance when interpreting sites and/or structures.

3.4 Summary

In this chapter I have discussed what the method I am using demands of both people and computers. I have given a brief presentation of how digital photogrammetry and the photographer's actions affect the end result. By reading this chapter the reader should be able to comprehend the basic concept of digital photogrammetry to such an extent that they could go out and start experimenting for themselves.

I have also shown some possibilities in visualization as well as analysis. I have deliberately chosen not to delve too deeply into the possibilities for visualization and analytical purposes that come with photogrammetric 3d models because it is an area archaeologists have barely begun exploring. It is also because I will do my own tests in the following chapters, which will form a basis for my evaluation of the method.

4 Field tests

4.0 Introduction

In this chapter I will show how the data for this thesis were recorded in order to get a better understanding of how the process of data production works, from field to finished product. I believe that without knowledge of the entire process from start to finish one cannot assume to know what method is best for any given task, which in this case is the recording of spatial data in archaeological excavations.

I will give a short presentation of the excavation project and the localities and structures that were selected for this test. These data were gathered during a two-day excursion to Inner Elgsnes in May 2011 and at the Tønsnes harbor excavation during the summer of the same year.

To understand how the two methods - total station recording and digital photogrammetry - compare against each other, testing the detail of the finished data against time expenditure is necessary. I have also chosen to emphasize the advantages of the different solutions in a qualitative way by comparing their usefulness in their different applications as they are intended, but also in respect to how well the data are reusable for future applications. Therefore I have recorded my data with both total station and photogrammetry.

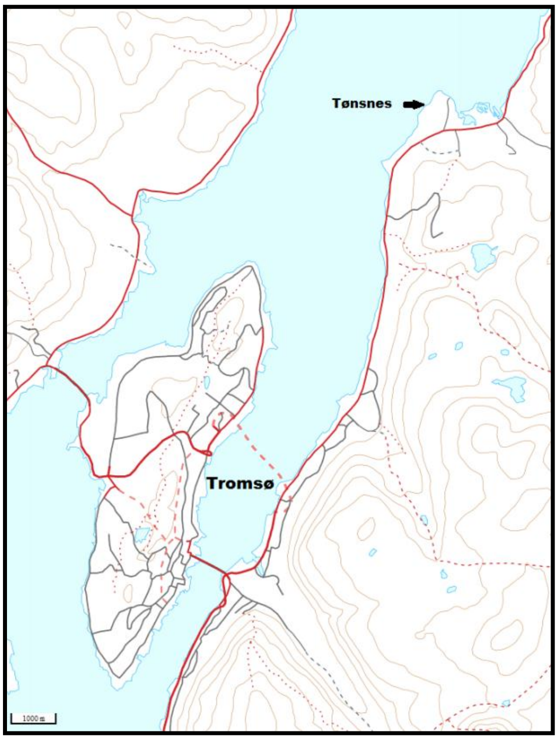

Figure 4.1 *Map of Tønses in reference to Tromsø.*

4.1 Tønsnes background

Tønsnes is located about 15 kilometers north of Tromsø on the mainland (Figure 4.1). Not much is known about settlements in the area during the Late Stone Age (5000-1800 BC). Most of the knowledge about Late Stone Age in the Tromsø region stems from a large amount of stray finds that emerged during and after World War II in connection with farming. The stray finds are mostly slate tools. Due to similarities with tools from Finnmark, the tools from Troms were seen as indicators of a similar way of life as in Finnmark (Simonsen, 1991:408). Before excavations started at Tønsnes, few house structures were known in the region from the transitional phase between the Early (Mesolithic) and Late Stone Age (Neolithic).

4.2 Excavations at Tønsnes

The excavation at Tønsnes was initiated and funded by the Port of Tromsø, a fully owned company of Tromsø municipality. The project was realized as part of a plan to build a deep water quay and industrial park at the now abandoned Grøtsund naval fort at Tønsnes outside of Tromsø. Extensive heritage registration was done in the area in 2006 by means of shovel-pit testing and machine stripping, which led to the registration of 20 localities (see Figure 4.2). These localities were to be excavated over several years, with the 2008-2009 project concentrating on the south-western part of the point (Skandfer et al. 2010) while the 2011 project focused on the northeastern parts. It is from the 2011 project that the data for this project has been collected.

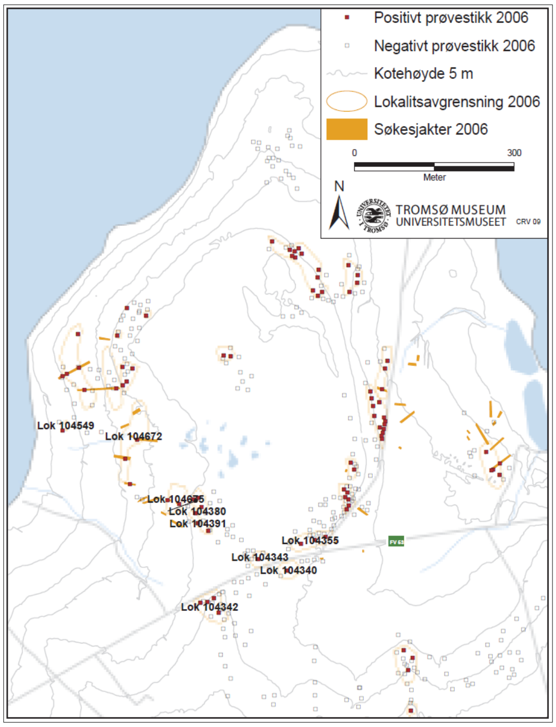

Figure 4.2 *Map of results from the 2006 registration work. (Skandfer et al. 2010:15)*

The 2011 excavation was led by Jan Magne Gjerde for the Tromsø Museum. He had a team of 25 field workers, including 4 field supervisors. Originally the project was budgeted to last from June to mid-September but was extended by three weeks (with a limited crew) due to the overwhelming number of structures that turned up during the course of the excavation. Almost all of the structures were undetectable on the surface before the excavation had begun, which had led to the excavation being severely underfunded, which in turn meant that the project had to be extended in time.

The method that was used for discovering structures was machine stripping of the top soil before manually cleaning the remaining turf from the underlying sandy ground. Already during this stage of the process one could spot archaeological structures as well as artifacts in the sand. As there was very little top soil and turf in most areas, removing it with a mechanical excavator meant that some of the archaeological material would inevitably lose its context in the process. This was taken into account before choosing the method, but was seen as preferable to manual de-turfing. The choices were to either lose some of the archaeological material or lose a large number of archaeological structures by only clearing a small percentage manually compared to what could be done by machine.

Choosing what method to use at Tønsnes was also a question of maximizing efficiency and quality. Before I started working for the project I had planned on asking permission to test the photogrammetric method at Tønsnes in my spare time. But after showing the potential of PhotoScan to both Johan Terje Hole (digital supervisor) and Jan Magne Gjerde, it was quickly decided that we should test the method more thoroughly as a potential documentation tool for the entire project. Previous to this, the plan had been to use Adobe Photoshop and ArcGIS to manually stitch together photo mosaics of structures and sites, with the help of ground control points taken with a total station. The photogrammetry method quickly convinced the project management that this was the way to go, making it the first project in Norway utilizing digital photogrammetry as its main tool for documentation of structures and sites.

For a better understanding of how the method was applied and which obstacles had to be taken into account during recording at different areas of the excavation I will now give a brief description of the locations selected and how they were documented.

4.2.1 Locality 8b

This locality is part of the northwestern group of localities. Locality 8b (Figure 4.3) is the smallest area uncovered, covering approximately 800 square meters of beach terraces on a fairly steep slope down from the small hill. The height difference is 4 meters from top to bottom. There are several clearly visible steps running parallel to the length of the hill. Due to its topography and the results from the 2006 registrations, the area was chosen for stripping, under the assumptions that it would possibly uncover activity areas or maybe even some housing structures (Jan Magne Gjerde, Pers. comm. 09.02.12). The latter were not found at 8b, but several house structures were found at 8a.

Figure 4.3 *SW view of locality 8b.Photo: Tromsø Museum*

At 8b there was only what could best be described as "knapping"-areas; areas where either very few or perhaps single knapping events had taken place. There were also several large boulders (30-50 cm diameter) in an oval structure, which I chose as a subject for one of my tests. The structure was chosen because it was initially thought that structure could have been a grave, which would have made the find quite unique. The structure was 27 meters above sea-level (masl), which gives it an approximate shoreline date of 9100 uncal. BP with isobase 16 (Møller and Holmeslet, 1997). This dating is based on preliminary results from the Tønsnes harbor excavation of 2011.

Before the area had been properly cleaned the stone structure appeared quite distinct on the embankment. Cleaning it revealed a distinctive difference in both color and texture from the surrounding area, as well as a slight elevation of the stone structure. There was also a noticeable amount of knapping debris in and around the structure. This was documented before excavation started. By placing numbered markers on the ground and plotting them with a total station, georeference points were made for use with PhotoScan. The structure was also topographically plotted with the total station for a comparison to the model produced with PhotoScan. The images were shot using a Nikon D300 that was held above my head, giving a bird's eye view. Images were taken towards the center of the structure at an angle of approximately 30 degrees to the surface. Walking around the structure gave a 360 degrees view of the structure, enabling views from all angles greater than 30 degrees.

It was decided to excavate the structure in stages, two sections at a time. The structure was divided into four segments along a north-south and west-east axis, making it possible to cross-section the middle of the structure as to make profile drawings. After two of the baulks had been excavated, leaving only the large boulders in place, the entire structure was documented. This was repeated after the other baulks had been excavated and again after the boulders had been removed. Images were shot as before excavating. No total station recording was done, except from ground control points. In addition to the 360 degree recording, some of the series were shot holding the camera perpendicular to the surface at chest height. These images were recorded in a snaking pattern across the surface, achieving very good overlap in all directions. This was done as a supplement to the images taken around the structure to create a higher resolution orthographic photo.

4.2.2 Locality 10

Photographs from both localities 10 and 11a were taken with the explicit intention of creating orthophotographic records as part of the documentation for the project. The project only intended to use manual rectification of the images, which meant that there was no need for numbered georeference markers. Instead un-numbered markers were recorded with the total station, which was used in ArcGIS to rectify the images manually. The reason this was done was that at the time of recording the georeference tool in PhotoScan had not been thoroughly tested by me and therefore could not be implemented in a way that the project was ensured not to lose any data.

Figure 4.4 *NE view of locality 10. Photo: Tromsø Museum*

Locality 10 (Figure 4.4) was originally considered as a place of little interest. It was thought that this would be a quick job with little finds and no structures. It turned out that it would be the most interesting locality, with the most clearly defined house structure in the entire excavation. This structure was found on the southernmost part of the locality, only a few meters from the road and several other modern disturbances. The main structure was a cleared out pit in the sand with clearly visible walls to the east. The structure was 4.5 meters wide and 10 meters long and 1 meter deep from the top of highest point on the wall. It is almost perfectly oriented along current day east-west axis of the earth's magnetic field. In the eastern part of the structure there was a very large open hearth with several clearly distinguishable layers going deep into the underlying sand. There were few to none rocks or boulders inside the structure, which clearly differs from what was found outside of the structure and in the general area around the structure.

The structure lies at 25 masl, making a possible shoreline dating of the structure to around 8500 uncal. BP with isobase 16 (Møller and Holmeslet, 1997). The date is unlikely to be more than a thousand years accurate, but it can give an estimate of what period the structure belongs to. Adjusting for local variations, the structure could well be in the transitional phase between the Early and Late Stone Age, at around 6000-5000 BC. One artifact, a polished red slate spear-head, found a few meters outside of the structure could indicate a correlation between the structure and a Late Stone Age date. Another view is that it could simply be a stray find or an indication of Late Stone Age reuse of an earlier settlement (Bryan Hood, Pers. comm. 07.05.12).

As with locality 8b, both photogrammetric recording and topographic recording using the robotic total station were chosen for locality 10. It was believed that this structure would be so unique compared to the rest of Tønsnes that high-detailed topographical recording of the structure would be justifiable budget-wise. The topographical documentation was done at intervals of between 10 and 25 cm, depending on the surface. Areas where depressions in the ground were clear were documented with less distance between points than in the flatter areas. Rocks were documented at all corners where the rock intersected the ground and on top of the rock so as to create a more correct three-dimensional record of the rock. Only the structure itself was recorded, with a partially arbitrary limit of ~1 meter to the wall of the structure. The entire structure was plotted in about two days (14 hours of work time) by three different persons.

Figure 4.5 *N-NW view of locality 11a. Photo: Tromsø Museum*

Before the proper field test using PhotoScan started, I had been conducting some experiments in my spare time to see which methods would yield the best results. I had come to the conclusion that although using only a handheld camera was very practical and needed minimal preparation, the best method to use on locality 10 would be the photo-pole. The pole could extend to seven meters above ground, providing a wide angle and a large section in every image. This meant that it would be easy to achieve redundant overlap between the images as well as acquiring good textures.

4.2.3 Locality 11a

The largest locality of the excavation was locality 11a (Figure 4.5, which was defined by an old beach terrace facing east. During construction of a road connecting to the old naval fort the beach terrace was significantly damaged, making a complete picture of the settlements on the terrace difficult to see. But what is clear when one looks at the locality is that the structures are aligned parallel to the beach in at least two or maybe three rows.

Before stripping the locality, no structures were visible on the surface. The decision to strip this area, as well as all other areas at Tønsnes, was based entirely on the find quantities described in the registration report from 2006. Based on the amount of finds, an estimated five structures (at best) were expected at Tønsnes. However, while stripping the localities it became clear that it would be necessary to expand the stripped areas, because of the amount of structures found at locality 11a and elsewhere. In total, more than 20 possible structures were uncovered at locality 11a alone (Jan Magne Gjerde, Pers. comm. 12.12.11).

Locality 11a covers approximately 1 400 square meters. A total of 27 possible dwelling structures were found at locality 11a, being found along nearly the full length of the field (100 m), with fewer visible ones to the north. In addition to dwelling structures, several other features were found, such as middens, activity areas and clearing cairns (Mikael Cerbing, Pers. comm. 24.01.12). All of the structures were found between ca. 17 masl and 20 masl. No structures were found above 20 masl at locality 11a. The precise number is still unclear, as analysis of data collected will determine whether or not some of the interpreted structures in fact were structures. The same goes for undetected structures that might show up in the post-processing of the data. The known structures elevation suggests a shoreline dating between 8100-8400 uncal. BP with isobase 16 (Møller and Holmeslet, 1997).

The highest concentrations of polished stone axes were found at locality 11, and there was in general a very high concentration of finds at these structures. Large amounts of chert were clearly visible at the surface after de-turfing and cleaning, as well as a considerable amount of quartz crystal. Slate was also present, although to a lesser extent than chert. Other lithic types were also present.

Documenting the locality and its structures was not an easy task. Most of the structures were not visible when they were viewed from the ground. It was only after some initial testing of the photo pole had been done and some of the images had been stitched into a photo mosaic that the full extent of the locality became clear. But stitching the images by hand was far too time-consuming, as well as imprecise, to be of practical use. It was therefore decided to use PhotoScan to make orthographic photos. For this task it was decided to apply the photo pole at full extent (ca. 7m), making sure good overlap between images was achieved. For the latter purpose I implemented a “shift” principle when shooting the images by taking double or triple sets of images from the same position, with only a slight shift of angle to the right and left of the original position. By doing so I was ensuring that all images would achieve a high overlap (80% or more) with at least one other image.

The locality was documented during the entire excavation process, meaning that all structures were documented before and after excavation with PhotoScan. Unfortunately only parts of the locality were documented in one setting, so that not all of the images could be used with PhotoScan. Some structures were thoroughly topographical documented by the total station, but this was only done before excavating. It was found to be much too wasteful in terms of man hours spent and data returned.

At this locality there was one obstacle that was unique compared to the other localities. Through the middle of the field there was a high-voltage power line that could cause serious injuries or possible death to anyone coming in direct contact with the wires. The lines hung about seven or eight meters above ground, making the photo pole come dangerously close to the lines. It was therefore decided to have a person observing the pole whenever it was close to the lines, ensuring it did not touch them. When directly below the lines, the pole was lowered so as to be sure it did not touch it.

4.3 Inner Elgsnes background

Inner Elgsnes (Figure 4.6) is a small point on the west side of the mountain Elgen on Hinøyaoutside Harstad in Troms County. It is an idyllic location, with the steep mountain of Elgen on the one side and Kasfjorden on the other. The only ways of getting there is either by boat or by foot along a narrow patch of land between the steep mountain and the fjord. It is at the mouth of Kasfjorden, which extends about 4 kilometers south from the mouth of the fjord and is a little less than 2 kilometers across. Today there are only a handful of houses still standing, all of them used as vacation houses. A total of 22 burial cairns of different sizes have been registered at Inner Elgsnes, three of which are of considerable size: 18, 15 and 9 meters in diameter and 3, 2 and 1.5 meters high, respectively. A fourth cairn of considerable size is said to have been destroyed a long time ago.

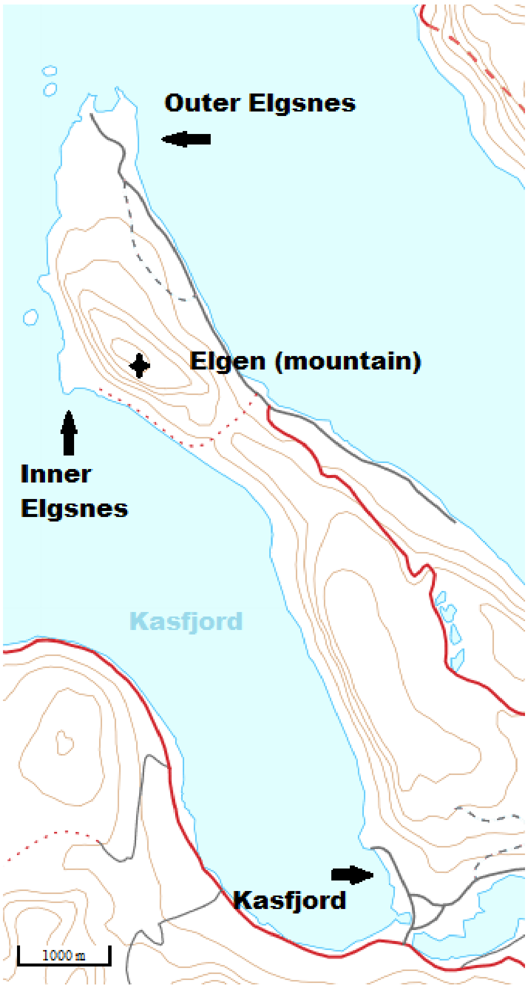

Figure 4.6 *Map of Elgsnes in relation to Kasfjord.*

Only the second largest cairn has been excavated in an archaeological context, by Olaus Martens Nicolaissen in 1922, but nothing was found in the cairn. It is quite possible that the cairn already had been plundered, as there was a depression in the middle of it before Nicolaissen investigated it (Munch, 1966:65). This is the only investigation done on Inner Elgsnes, so there is no conclusive evidence for dating the cairns. But the burial cairns have similar characteristics to the Bronze Age cairns in Western Norway (Sommerseth, 2010:76).

Nicolaissen did not find anything at Inner Elgsnes, but during the same year he investigated the remains of a burial cairn at Outer Elgsnes. There he uncovered the remains of a skeleton and a fragment of a polished slate knife blade. Munch has interpreted the knife on the basis of Nicolaissen’s description, as the blade was lost sometime after it was found at Elgsnes. Munch interpreted the knife as a “surviving” artifact from the Younger Stone Age, being deposited in the grave during the early parts of the Bronze Age (Munch, 1966:66-68).

There is one find from Inner Elgsnes relating to the burial cairns that is worth a mention. An 80 cm long, 4 cm wide Iron Age sword (Ts.2794) was registered in 1922 at the Tromsø Museum. It was reportedly found in an area where a human skeleton had been found some 50 years prior, but there are no indications that the skeleton was ever sent to the museum, nor that it was from the same period as the sword. It is not clear exactly when the sword was found, only that it was turned in the same year as Nicolaissen visited Elgsnes.

The fact that the skeleton was found around fifty years prior to 1922, i.e. 1872, coincides well with Hans Thøger Adolph Winther’s investigations in the area during the 1870’s. If the locals were uninformed about what the burial cairns were and what they could contain, it is not unlikely that they would search for valuables in the ground after learning about the value of such things from Winther. He had stated that the cairns had not been excavated or plundered prior to his visit in 1874 and that the locals had thought that the cairns were not in fact graves, but lookout posts or guard towers (Winther, 1874:12). Nicolaissen must have misinterpreted this, because he said that the cairns had in fact been plundered (Nicolaissen, 1922:11). In any case, the graves had been plundered long before both Winther and Nicolaissen investigated Inner Elgsnes.

As we can see, not much has been done regarding research on the prehistory of Elgsnes. The cairns are most likely burial cairns from the Bronze Age and probably the most northern examples of such. This assumption is purely based on visual similarities to burial cairns in Western Norway. However, the Iron Age sword does give some indication that Inner Elgsnes was a place where people were buried from as early as the Iron Age, which can give credence to a statement about Inner Elgsnes being a burial site in prehistoric times. Until further analysis is done, no clear evidence can be found to support an earlier date than the Iron Age.

4.4 Inner Elgsnes investigations

Right from the start of the project the plan had been to compare the practical applicability of digital photogrammetry as a tool for documentation in both excavations and in cultural heritage management (CHM). As an object for the CHM documentation test, I had chosen a burial cairn on Inner Elgsnes (Figure 4.7). The cairn itself is approximately 3 meters high and 18 meters in diameter. It was plundered sometime after its assumed construction in the Bronze Age, which left a large pit, about 4 meters across and 1.5-2 meters deep, in the center of the cairn.

Figure 4.7 *View of Inner Elgsnes from Elgen. Subject for my test is the uppermost cairn visible (arrow). Photo: Odd Harry Hanssen*

As this was to be a major part of my project, I began planning the trip early on. I had four assistants with me; Øystein Prytz, Johan Terje Hole, Kristine Haugen and Mikael Cerbing, as well as Lars Børge Myklevold, who was so kind as to let us stay at his house on the other side of Elgen. The initial plan was to be transported to the site by boat, but we were unable to obtain one at the time, which in turn meant that we only could bring with us a minimum of equipment. This was also due to limited transportation capacities from Tromsø. Because of these limitations, I decided it would not be pertinent for the project to use a photo-pole, but that the prism-rod (modified with a camera stand and some gaffer tape) would suffice as a substitute. The most crucial equipment was the total station, a Leica TPS 400, borrowed from the Institute for Archaeology and Social anthropology, University of Tromsø, as well as Johan Terje Hole's personal camera equipment. Other equipment can be viewed as non-essential and will not be listed.

The travel out to Inner Elgsnes was a short one hour walk over fairly easy (albeit steep) terrain. It was in fact so easy that I do not think bringing more equipment would have slowed the crew down or made it more hazardous[5]. After arriving and conducting a quick overview of the site we began setting up the total station and preparing the burial cairn for photographing. The slowest operation was plotting the topography with the total station, which took approximately three hours. Even with this amount of time we only managed to plot 178 points. This operation also required two persons, one for handling the prism rod and one for operating the total station itself. Compared to the other tests, this is a much more time consuming procedure to perform with a manual station than using a one-man robotic total station such as the Leica TPS1200. Due to the weather conditions as well as the time of day, we decided to pack up and head back to the house after completing the topographical measuring.

The next day we aimed to finish the remaining part of the test. The weather was good when we started, but as the day went on we could observe a rain front coming towards us. This meant that we had to be quick about our remaining tasks: making and placing photogrammetry markers (painted rocks placed on the cairn), shooting the photographs and measuring the points, all in that order. The images were shot with a Canon EOS 7D mounted on a tripod that was taped to the fully extended prism-rod, positioning the camera at a height of about three meters above ground. We did some preliminary tests to see what angle would yield the best results and decided that somewhere around 40 degrees would suffice. We photographed the entire cairn in a little more than 1 hour, including time spent on equipment failure (i.e. the remote control for camera not functioning half the time). Due to time constraints and worsening of the weather, I decided that we did not have the time to take any pictures of the entire mound from a distance. At the time, I did not see how it could be relevant for processing the images in PhotoScan.

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[5] If this had been a longer trek and the project had lasted more than a couple of days then it might have posed a problem to transport such equipment.

4.5 Summary of field tests

At the time of the test at Elgsnes I had no available portable computer that could run PhotoScan and thus could not test the images taken to see if they would be of any use. The tests at Tønsnes proved to be a great experience for me personally, as well for the project led by TMU. Before any of the results were analyzed, it was clear that this method was much more effective at producing orthophotographs than the traditional way of manually aligning the images in Adobe Photoshop. But since the excavation project only was interested in the orthophotographic data produced by this method, a thorough analysis of the spatial data is required to fully reveal the true potential this method could have for archaeologists.

5 Transforming photographs to 3D models

5.0 Introduction

My intentions with the Tønsnes data are to show how digital photogrammetry can supplement or even replace the methods we use today for documenting topographical data at excavations. In this chapter I will show how the data from Inner Elgsnes and Tønsnes can be converted from photographs to spatial data using digital photogrammetry. This data will then be compared with traditional telemetry data, using both quantitative and qualitative methods in the evaluation. In addition to this comparison I will show the cost of the different methods in terms of time consumption. The goal is to see whether the telemetry data can hold up to the photogrammetric data when quality and cost are combined.

I will also show how the data lends itself to visual presentation. Viewing three dimensional data on paper can be problematic and cause crucial elements to be lost in the presentation. By testing different methods for visually presenting the data, I will demonstrate for the reader that spatial data can be useful, even when viewed on paper.

To my knowledge, the data from Tønsnes is the first digitally processed photogrammetric data to be actively used in the field as an interpretation aid. The Tønsnes project used the orthographic images to assist in analyzing and interpreting areas for excavation, as well as delineating possible structures.

The photographs have been processed with low alignment and low quality, with the exception of the Inner Elgsnes data. The reason for choosing low settings is to show that even at these settings the data produced by PhotoScan will be superior to data gathered using total station. The low settings will also reduce the time spent processing the photographs, further increasing the gain from this method over traditional ones. For a detailed review of all processing parameters, see Doneus et al. 2011.

I have chosen to present the data from Inner Elgsnes first, as they are the least extensive.

5.1 Inner Elgsnes data

The test at Inner Elgsnes can be said to be a failure at many levels, but as a learning experience it was very valuable. Even if the test failed in regards to scientific data gained, it gave me personally immeasurable amounts of experience, which in turn lead to the tests at Tønsnes being successful.

The purpose of doing tests at both Tønsnes and Inner Elgsnes was to demonstrate the different possibilities that digital photogrammetry could offer archaeology. At Tønsnes the purpose was to show how it could be applied at an excavation, whilst the tests at Inner Elgsnes would display some of the possibilities for use of the method within cultural heritage management. But as I will now demonstrate, the test at Inner Elgsnes did not yield the wanted results, thus making a comparison of telemetry data gathered with the total station and photogrammetric data impossible.

5.1.1 Processing the data

Before the images could be processed, a visual inspection was performed to eliminating photographs which were inadequate (see standards in Chapter 3). After the selection, a total of 320 images remained, with dual images from each position, only varying slightly in angle to the object. Due to the large image volume it was decided to resize the images so that the processing time would be reduced. The resized images were then processed in PhotoScan at high alignment and lowest mesh detail. The total time spent processing the images was 49 minutes. Figure 5.1 shows the meshed model with camera positions.

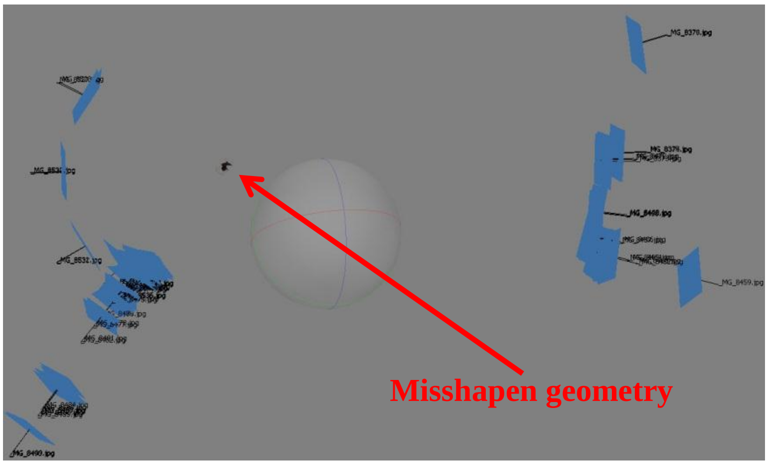

Figure 5.1 *Inner Elgsnes: result from resized images. Camera positions not correct, creating a misshapen geometric model. Blue squares indicate camera positions.*

An attempt was made with full size images with better results with regard to correct camera alignment and creation of the point cloud (Figure 5.2). Unfortunately this revealed a serious problem with the image series. In the model there is a clear gap between the first and second image sequence around the object. In addition to this gap, only 238 out of the total 320 photographs could obtain a fixed camera position. The outermost image sequence could not be matched with the rest of the model, creating an incomplete reconstruction of the cairn. The reason for this is probably a lack of overlap between image sequences, as well as a lack of any photographs with an overview of the entire cairn (Alexey Pasumansky, Pers. comm. 28.02.12). Another problem with the model made from full-sized images is that it took nearly four hours to make the alignment alone. This adds to the fact that the whole cairn could not be completely modeled, making any, eliminating the possibility for a volumetric assessment of the cairn or comparison with the spatial data recorded with the total station.

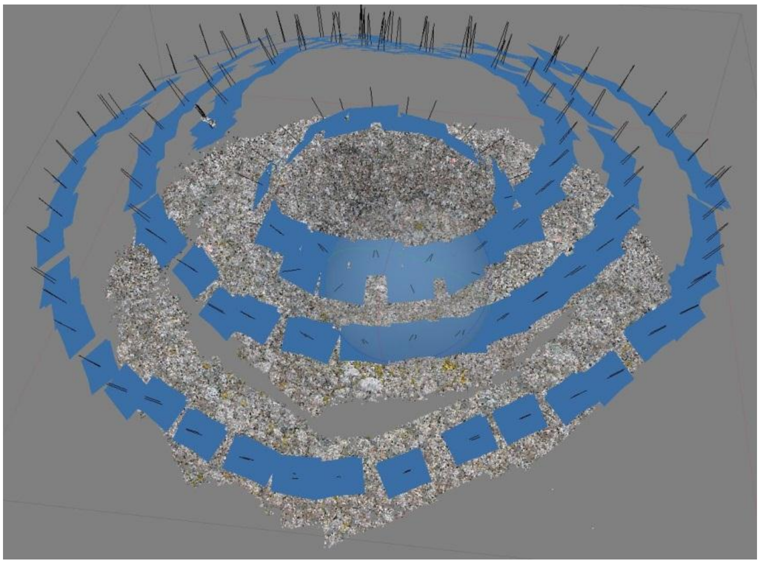

Figure 5.2 *Inner Elgsnes: 238 of 320 cameras aligned, full size images.*

Had the models been perfect and all cameras had aligned where they should, the models still could not be used for comparison. The reason for this is that the spatial data from the total station turned out to be faulty, despite every effort to extract and use the spatial data in ArcGIS. It is not even possible to use the reference points to properly scale the point cloud, because this would require accessing the data in ArcGIS to be able to identify which reference point corresponds to which point in the model.

5.2 Tønsnes data

A DEM, georeferenced orthophotography and a 3D model have been exported for all localities from PhotoScan. In addition to this, contour data has been extracted from both the PhotoScan and the total station data using QGIS. With the DEMs I have made use of the raster math toolkit in ArcGIS to determine how the different methods compared to each other quantitatively. Other than this, all comparisons are strictly qualitatively. I have also chosen to evaluate the cost effectiveness of each method, but only in the broader sense of time versus quality, not quality versus monetary cost in its strictest meaning.

All data from Tønsnes has been processed at high alignment and low geometry, with no mesh decimation and smooth reconstruction. The data has been tested first to get 100% camera alignment. The total station data has been converted from singlepoint shapefile to TIN and finally DEM raster using natural neighbors. A problem that was difficult to address was how to factor in time when using the total station. Both before and during recording, several steps that where not directly related to recording the data had to be factored in. These included setting up the station, contact issues between the station and the handheld device, work breaks and so forth. Keeping time was not something I predicted would be necessary before the tests began, so no records were kept. Therefore, 4 seconds per point measured has been used as a "qualified estimated" value.

5.2.1 Locality 8b

This locality was, as previously mentioned, interpreted as a possible grave before it was excavated. The stones, seen in Figure 5.3, stood out from their immediate surroundings, making them the prime object for documentation in this test. By documenting the stone formation with digital photogrammetry the grave could be better documented for posterity and thereby make it possible to use as a future reference for other investigations at similar sites.

	Locality 8b	Locality 10	Locality 11a
Images	54	91	59
Alignment processing time	5 minutes	241 minutes	116 minutes
Geometry processing time	8 minutes	24 minutes	16 minutes
Model resolution (in million) faces / vertices	1.4 / 0.7	17.8 / 8.9	19.4 / 9.7
Total processing time	13 minutes	265 minutes	132 minutes

Table 1 *Processing times and geometry resolution in PhotoScan of all tests at Tønsnes.*

Recording photographs and total station points at locality 8b was the fastest of all my test sites. This was partially because of the size of the structure, but also because I wanted to see at what speed a fairly precise spatial documentation could be done using the total station. The total time spent recording the structure was 10 minutes photographing (54 photographs), plus

13 minutes processing time (Table 1), and 48 minutes recording telemetry data (174 points) with the total station. No preparation time has been added to the photography step due to the use of a handheld Nikon D300 camera instead of a pole mounted camera.

Using my own formula, $Q = (100/R)^2$, an evaluation can be made of the DEM resolution that each method produce. At locality 8b, Q for the total station is 0.197, indicating a fairly low resolution when compared to the PhotoScan data, where Q is measured at 3.429. This tells us that, even though total time for the total station is only ten minutes more than that used for the photogrammetric model, Q gained per minute is only 0.007 for the total station, compared to 0.149 for PhotoScan. This gives an efficiency ratio of 21.3:1 in favor of the photogrammetric approach.

Photographs from 8b were not recorded with the same camera as locality 10 and 11a. Image resolution on photographs taken with the Nikon D300 are slightly larger (4288x2848 pixels) than the ones taken at locality 10 and 11a with the Canon G12 (3648x2736). However, there

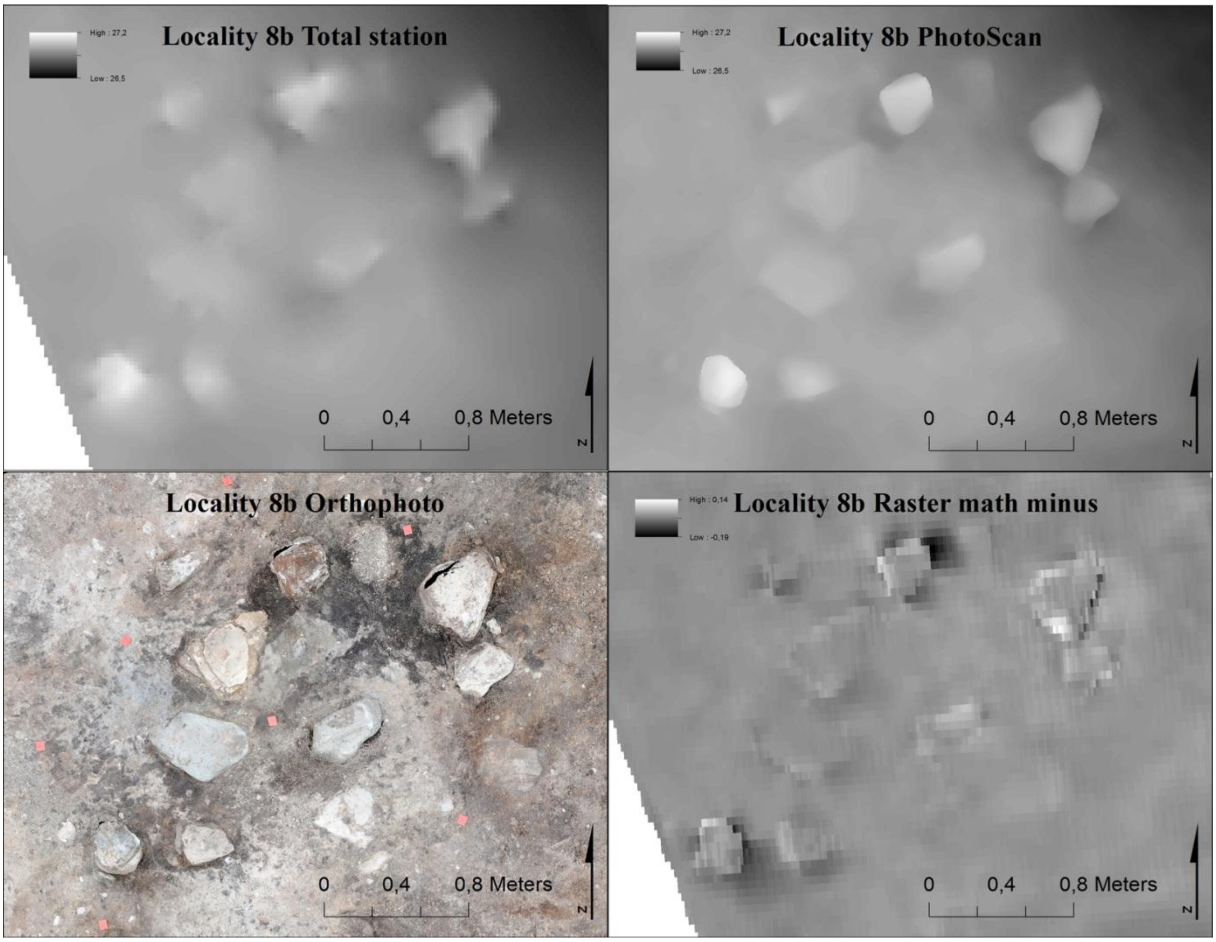

Figure 5.3 *Upper left: Total station DEM. Lower left: Orthophoto from PhotoScan. Upper right: PhotoScan DEM. Lower right: Raster math minus between total station data and PhotoScan data. Darker areas show negative discrepancy, lighter show positive discrepancy calculated from PhotoScan as base value.*

was no resolution loss experienced. Time consumption in the processing step is slightly elevated due to this, but the resolution of the finished model is also increased.

The subtracted DEM values in Figure 5.3 show that there is a significant difference between the two models in some areas, particularly around the large boulders. Tests have confirmed that the accuracy of PhotoScan is equal to that of laser scanners (Doneus et al, 2011:84). If the premise is that the PhotoScan model gives a highly accurate representation of the actual topography, then it is safe to say that the DEM generated from the telemetry data from the total station gives a more inaccurate representation of the structure, due to fewer measured points. This principle of using raster math to evaluate DEMs can also be applied to erosion monitoring, as mentioned in Chapter 3.

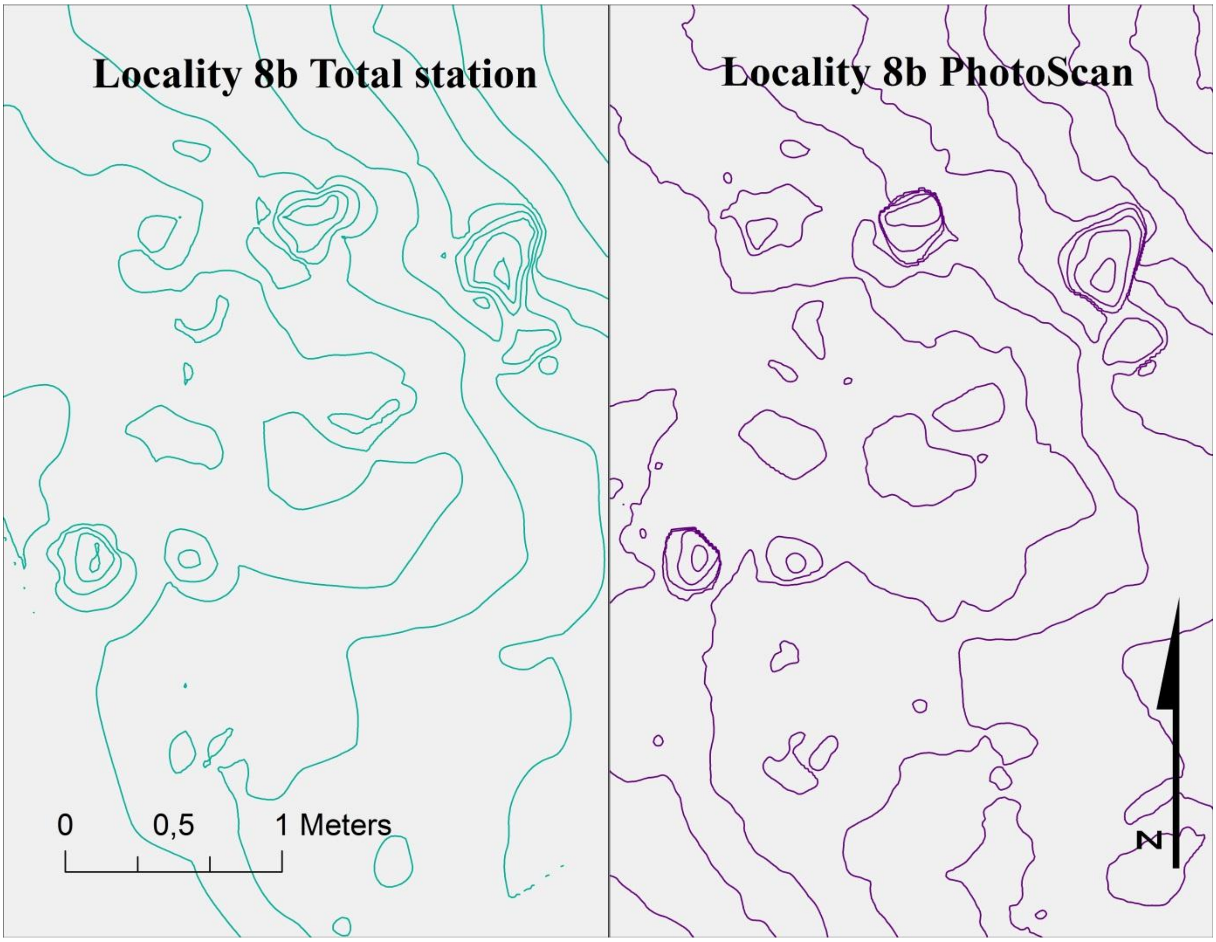

Figure 5.4 *Locality 8b: comparison of contour lines between total station data and PhotoScan data. 5 cm intervals.*

The contour lines extracted from both datasets show similar trends as the DEM (Figure 5.4). There is some distortion of the center part and to the north-west in the total station data. Interestingly, both methods show a lack of detail in the center, especially of the flat rocks.

However, this is a result of the selected height intervals, not of the data itself. But it does highlight a problem that can occur when choosing to use contour lines. If the contour creation is done without a simultaneous review of the orthophoto (or other photographic data) then the selections can skew the interpretation.

Adding hillshade to the DEM seems to distort the total station data more, as well as making it less reader-friendly (Figure 5.5). In the case of data from PhotoScan, the addition of hillshade seems to be working in favor of the reader, accentuating the microtopgraphical features even more than the plain DEM. This comparison shows that a fairly low number of points recorded with a total station can create unwanted feature disturbance.

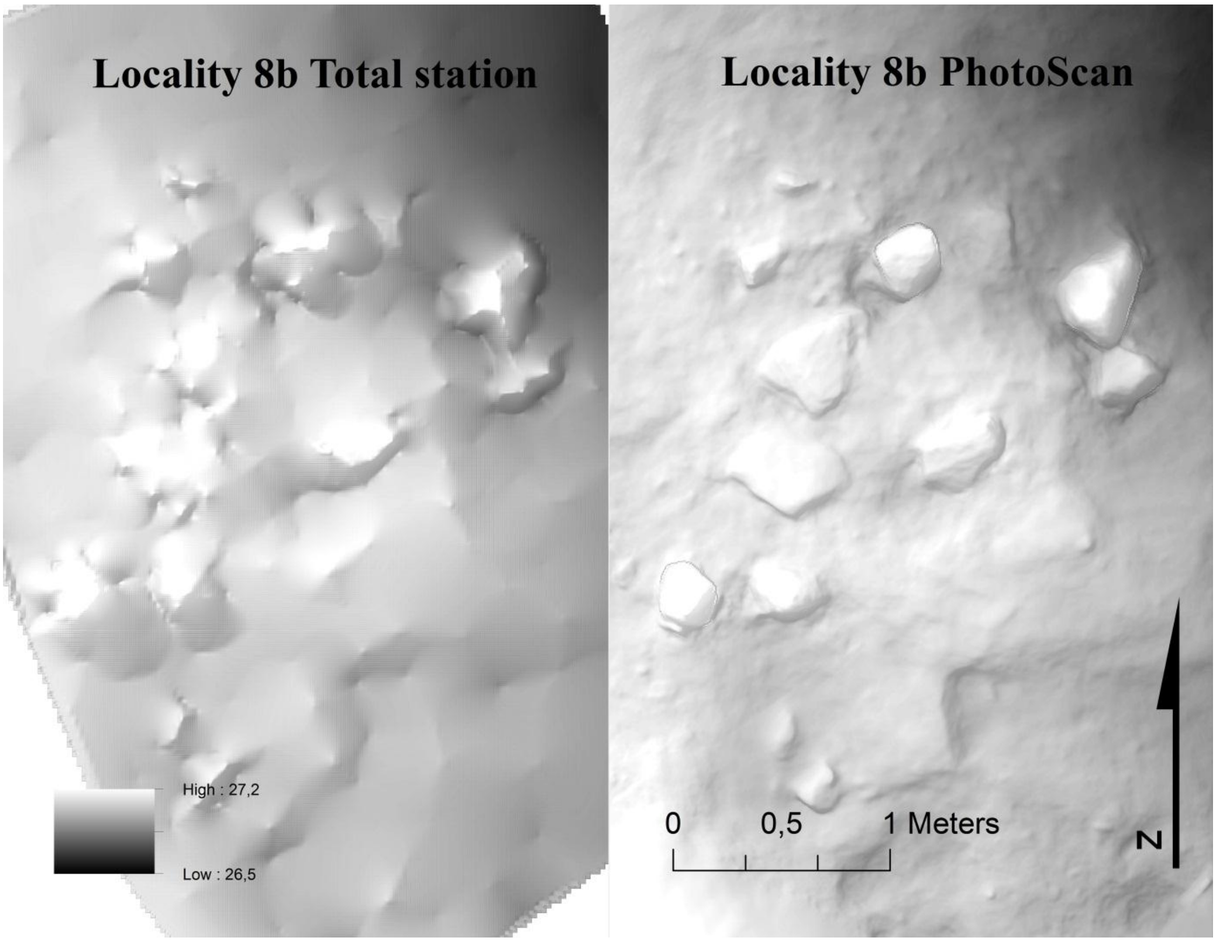

Figure 5.5 *Locality 8b: comparison of DEM with hillshade between total station and PhotoScan data.*

Figure 5.6 *3D model of locality 8b. Interactivity enabled in electronic version of thesis.*

Locality 8b is well suited for 3D visualization using the pdf format. Some of the features did not come across very clearly in either of the previous examples, such as an area where the excavator has dug through the top of the layer and into the red underlying layer. This is very clearly visible when viewing it from the “Damage view”[6] in the 3D pdf (Figure 5.6).

5.2.2 Locality 10

The assumed house structure at locality 10 demanded a different approach to documenting than locality 8b. The project management wanted detailed spatial documentation of the house, which made it possible to collect my data during working hours.

Photographing the site took 21 minutes (91 photographs), plus 265 minutes processing time (Table 1). Photographs were recorded using a pole mounted Canon G12. Recording the structure with the total station took two working days, or ca. 840 minutes. However, this only produced 4865 points, making an average time of over 10 seconds per point. One contributing factor for this could be that the total station had to be re-established after every

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[6] Only in the electronic version of the thesis. URL: http://munin.uit.no/

break for administrational reasons. But even if the average time per point had been 4 seconds, total recording time would amount to 344 minutes.

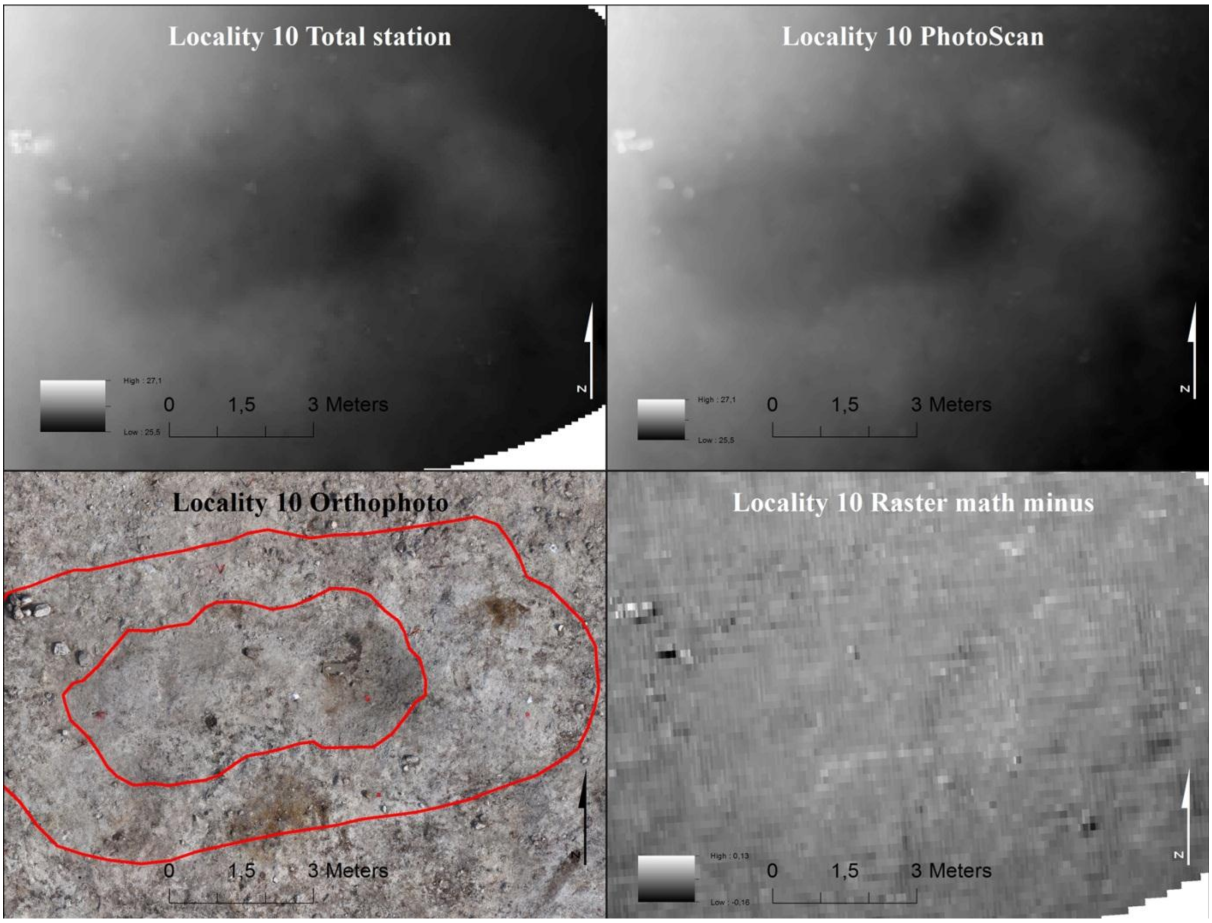

Figure 5.7 *Upper left: Total station DEM. Lower left: Orthophoto from PhotoScan w/outline of inner and outer wall limits. Upper right: PhotoScan DEM. Lower right: Raster math minus between total station data and PhotoScan data. Darker areas show negative discrepancy, lighter show positive discrepancy calculated from PhotoScan as base value.*

Evaluating the DEMs reveal a significant difference between the two recording methodologies. The Q value for the total station recording is 0.020, which indicates a fairly low density of points per square meter. The photogrammetric data produced a quality of 0.841, a near 1:1 ratio in resolution (pixel to square centimeter). Taking into account time as a factor, we see that Q per minutes is 0.00006[7] for the total station and 0.00317 for PhotoScan. This gives a performance ratio of 53:1 in favor of PhotoScan.

For locality 10 the subtracted DEM (Figure 5.7) values does not show the same large discrepancies as compared to locality 8b. This could be a result of a combination of a very detailed topographical registration with the total station and a lack of large boulders. The

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[7] Using the estimated 324 minutes.

discrepancies that can be found are located around the rock formation to the north-west of the house structure. It is worth noting that the discrepancy is both positive and negative in the area around the aforementioned rocks. Such differences could be misinterpreted as actual features and can be caused by poor judgment in regards to which points to record during the recording process. It is worth mentioning that the recording was done by me in this particular area, and that the selection of points was carefully assessed.

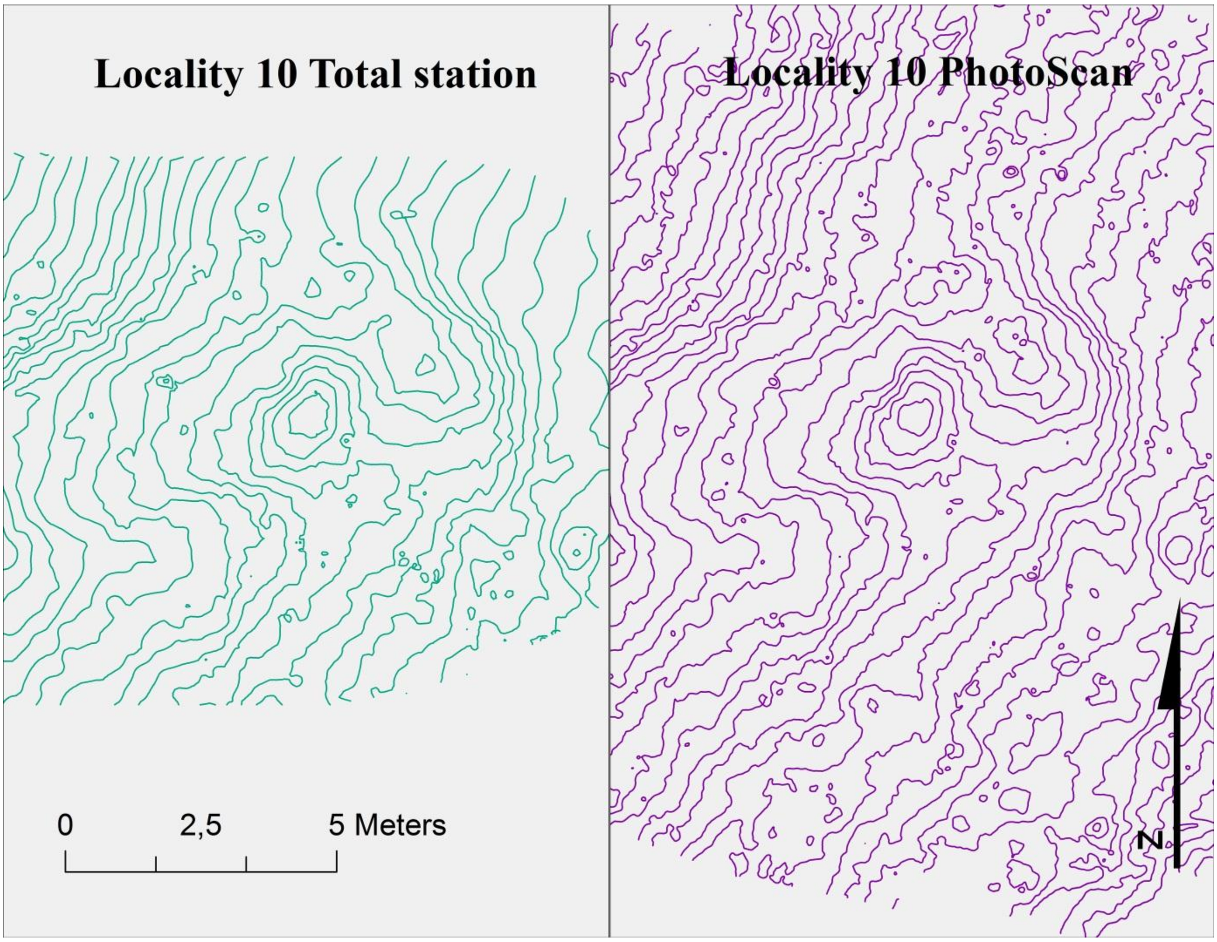

Figure 5.8 *Locality 10: comparison of contour lines between total station data and PhotoScan data. 5 cm intervals.*

The contour lines (Figure 5.8) did reveal some interesting features at locality 10 that were not as visible in the DEM. In the south-east “corner” of the structure, a possible entrance or perhaps air duct can be seen. It cannot be ruled out that this possible feature could have been produced by post-depositional processes, like erosion or modern human interference. This visualization does not reveal any significant discrepancy between the two methods. The question to ask is whether or not the time expenditure on the total station use is justifiable.

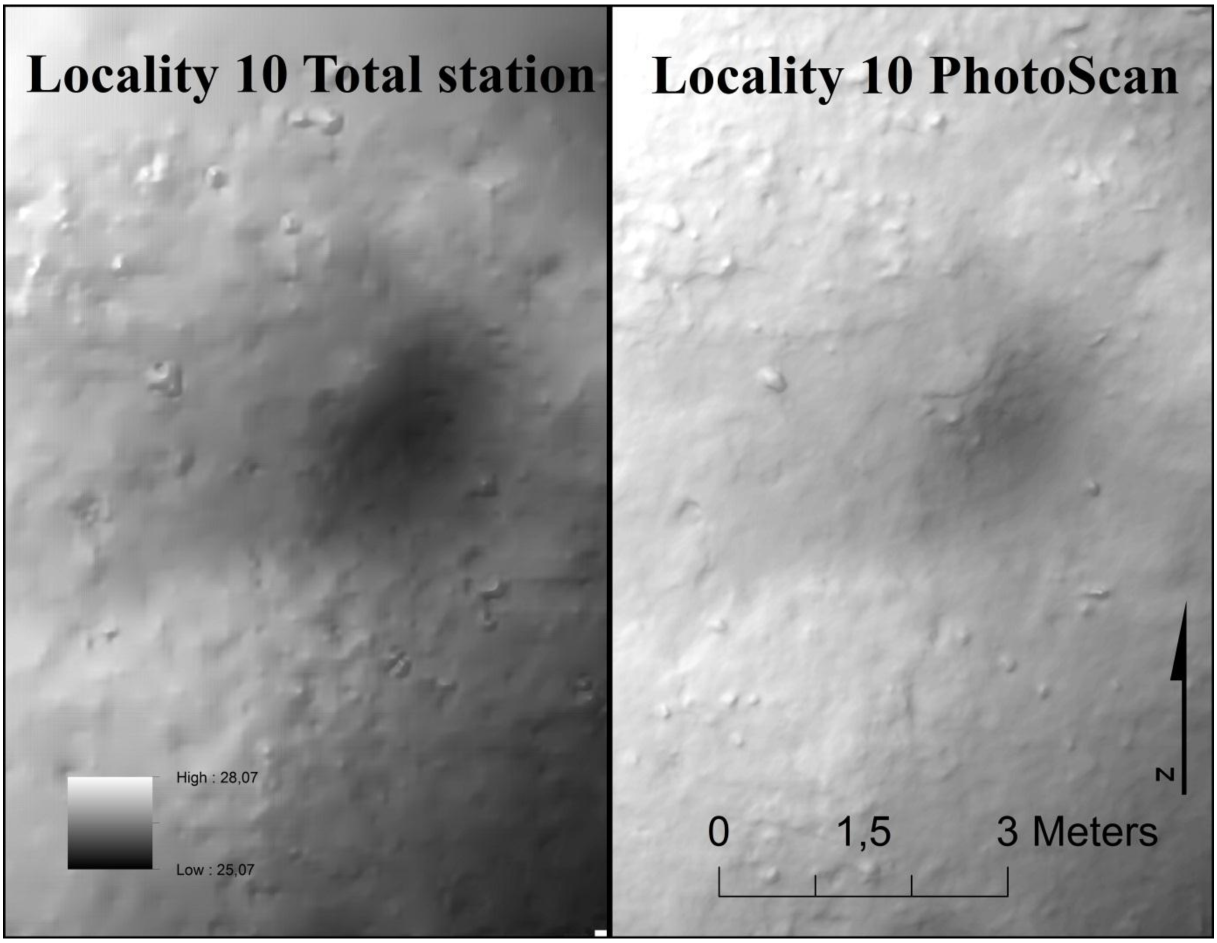

Figure 5.9 *Locality 10: comparison of DEM with hillshade between total station and PhotoScan data.*

The DEM from locality 10 with added hillshade effect gives a better view of the localities spatial dimensions than the unaltered DEM. Comparing the telemetry data from the total station to the photogrammetric data in this format provides a clear picture of the qualitative differences between the two methods (Figure 5.9). The telemetry data lacks the level of detail that is required to create a visually compelling three dimensional representation of the data. In particular, areas around rocks are less defined, thus creating poorer hillshade than what is the case with data from PhotoScan. The low detail of the total station data creates unwanted noise, thus making it the poorer choice of the two.

Figure 5.10 *3D model of locality 10. Interactivity enabled in electronic version of thesis.*

The structure at locality 10 is very well defined and was easy to spot during the field work. Due to its marked topography, I feel that it lends itself well to a 3D-pdf presentation. Both from a ground view and from a vertical view the model is compelling and easily understandable. It is also an excellent candidate for profile extractions (Figure 5.10).

5.2.3 Locality 11a

Locality 11a was not originally thought of as an object of interest on my part. But after an evaluation of the data after the excavation had finished, it became clear that the data could in fact be used in this thesis. There were however some limitations to the data, most notably a lack of complete coverage of the locality. The reason for this was that some parts of the excavation area at locality 11a were not considered for further investigations after initial cleaning and turf removal, thus eliminating the need for orthophotographic production of the entire locality. I have therefore only been able to model the northern part of the locality.

Recording data for locality 11a was, as mentioned in Chapter 4, a bit more challenging than at locality 8b and 10. This might also be a contributing factor to the holes in the spatial data, as seen in Figure 5.12. The total time spent recording locality 11a was 143 minutes photographing plus 132 minutes processing time (Table 1), and 164 minutes recording telemetry data (2464 points) with the total station. The time spent on recording the locality might be more or less than what has been calculated from the amount of points recorded, but since no records were kept of time consumption, only an estimate can be made. As with photographing the site, some issues had to be dealt with in regards to line of sight, but this was for the most part a problem at the southern part of the locality and would not affect time consumption for this test.

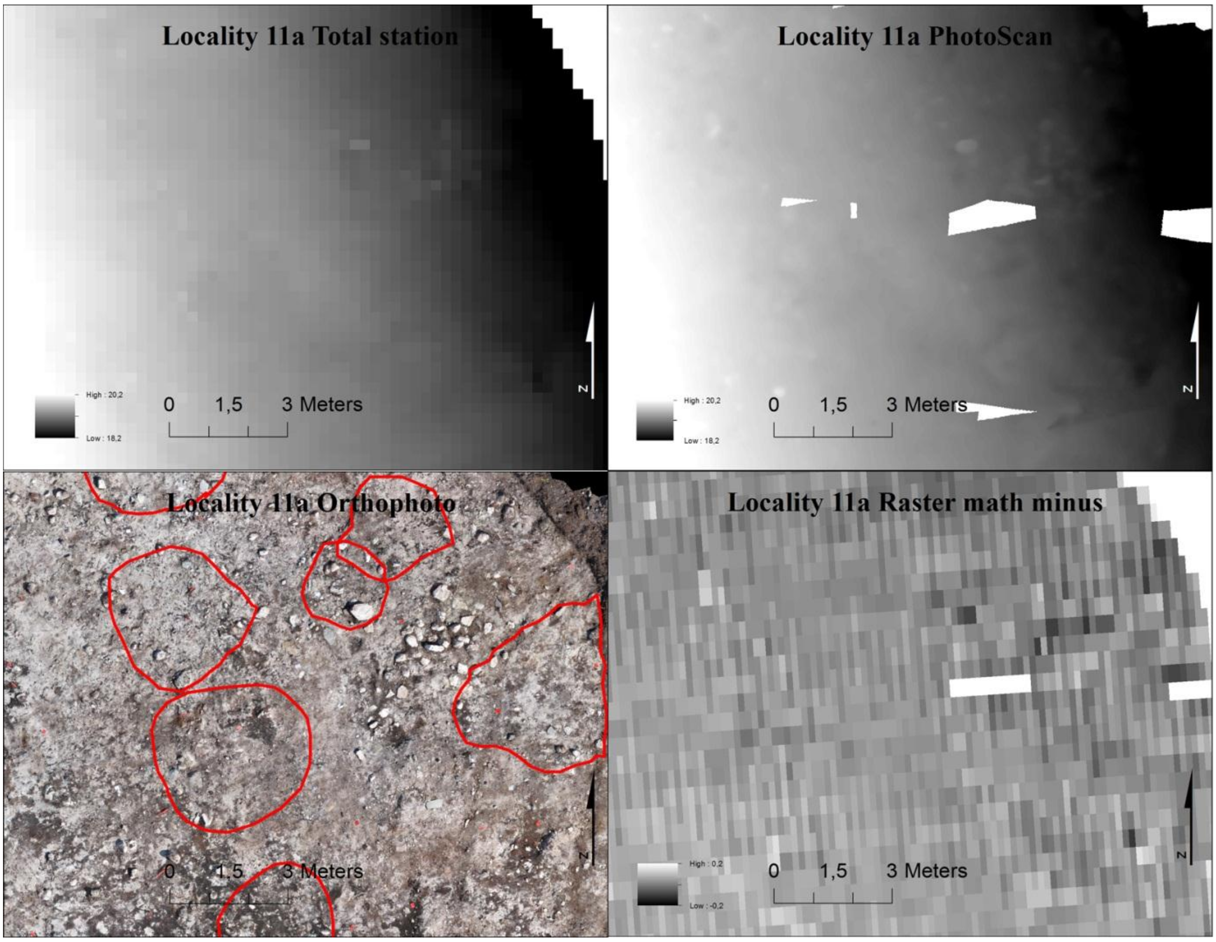

Figure 5.11 *Upper left: Total station DEM. Lower left: Orthophoto from PhotoScan w/outline of inner and outer wall limits. Upper right: PhotoScan DEM. Lower right: Raster math minus between total station data and PhotoScan data. Darker areas show negative discrepancy, lighter show positive discrepancy calculated from PhotoScan as base value.*

The DEMs produced from this data were not as easily readable as those from locality 8b and 10 in their default presentation mode (Figure 5.11). There are two factors that contribute to this; the area recorded is nearly 1000 m^2, and it stretches vertically over 4.5 meters. Another thing is the topography of the locality. It is a fairly flat, but sloping beach, of which its main constituent parts are sand, gravel and rocks. But for the purpose of evaluating quality, some observations can be made. The immediate impression of the telemetry data from the total station is that it is by and large inferior to the data from PhotoScan. The Q value for the total station is 0.001, compared to 0.395 for PhotoScan. Q per minute for the total station is a measly 0.000006, versus 0.002 for PhotoScan, making a performance rating of 333:1 in favor of PhotoScan. This further helps validate the trend, seen from the data at locality 8b and 10, that PhotoScan is a more productive method than traditional total station based methodology.

Subtracted DEM values (Figure 5.11) do not reveal any major discrepancies between the data sets. One reason for this might be that the general topographical trend in the area analyzed is fairly flat with few rocks or boulders of any significant size that make a visible difference in the topography. No noticeable depressions or other features can be detected either. Both methods give a fairly good representation of the topography.

For this locality, a visual representation of the terrain might be best presented using contour lines extracted from the models. As Figure 5.12 shows, no discernible differences can be detected between the methods. One noticeable difference between the two is that the

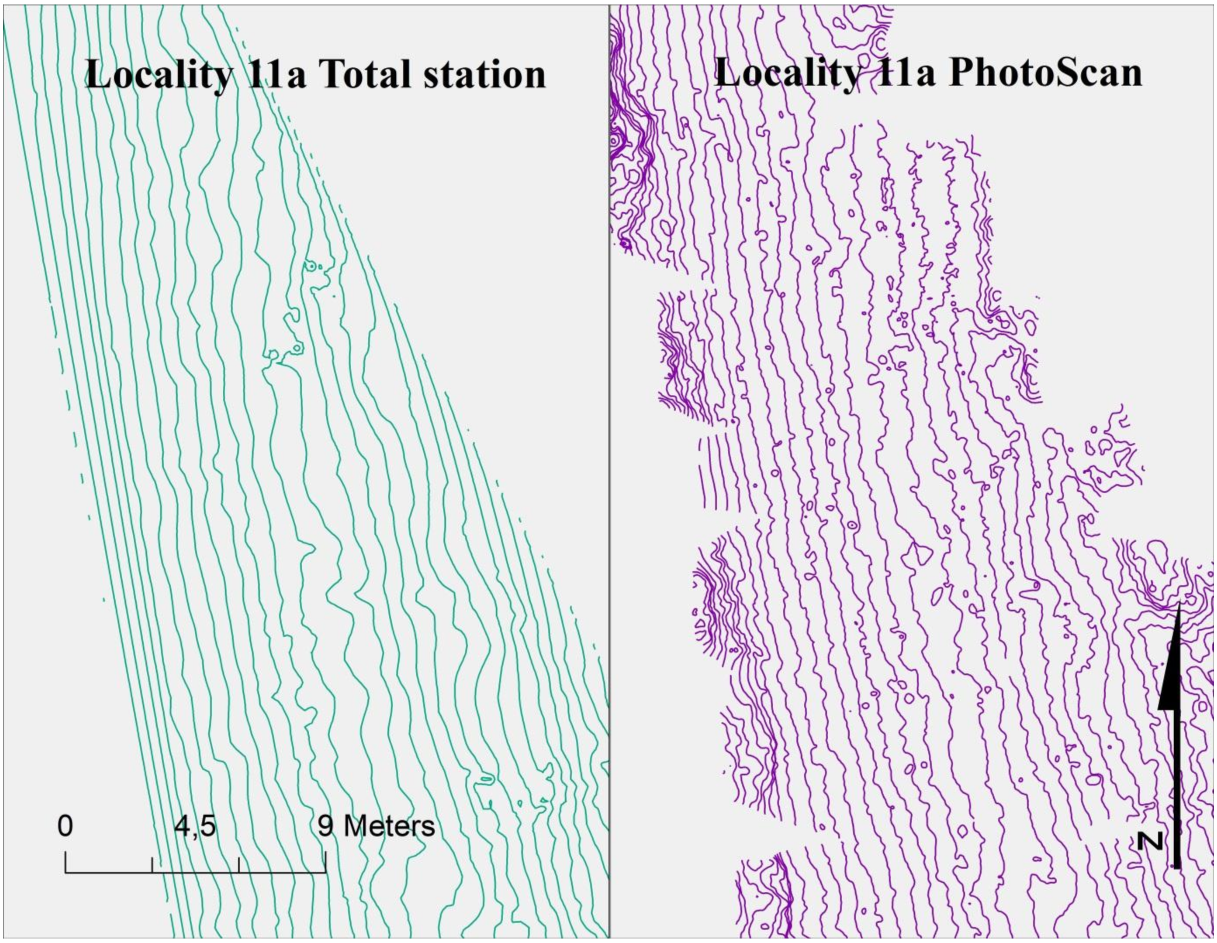

Figure 5.12 *Locality 11a: comparison of contour lines between total station data and PhotoScan data. 10cm intervals.*

PhotoScan model gives a perhaps too accurate representation of the excavated area. The contour lines extracted are so detailed that the even outlines of rocks get included in the map. This can however be avoided by using a lower resolution DEM from PhotoScan. This will also reduce the overall production time in PhotoScan.

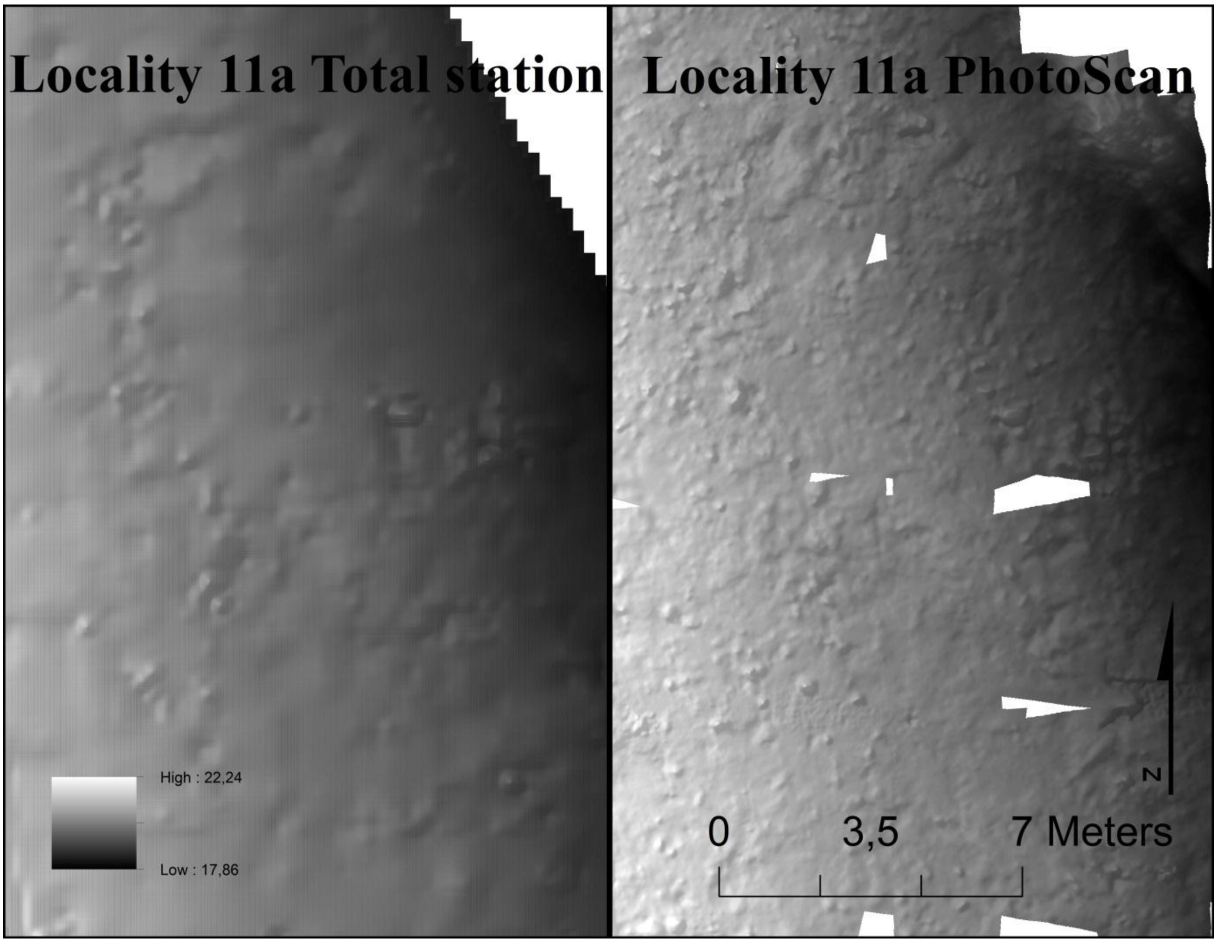

Figure 5.13 *Locality 11a: comparison of DEM with hillshade between total station and PhotoScan data*

For a visual presentation of the data, a DEM with hillshade effect is compelling in 2D form. As previously seen with the data from locality 11a, the plain DEM does not reveal any clear features immediately. But with the addition of hillshade effect, small and almost unnoticeable features become clearly visible. Slight changes in elevation can be seen, which can help confirm possible house structures. As seen in the PhotoScan DEM (Figure 5.13), features, such as rock-clustering or cleared areas, which were not discernible in the DEM without hillshade effect are now clearly visible. The same argument cannot be made for the total station model, as it is not detailed enough.

Figure 5.14 *3D model of locality 11a. Interactivity enabled in electronic version of thesis.*

Compared to data from both localities 8b and 10, 11a does not lend itself well to 3D visualization using 3D-pdf. One problem is the lack of clearly visible features; another is the lack of clearly defined stratigraphy in the texture. One possibility is to highlight the profile in the 3D-pdf as to show the relative inclination of the area (Figure 5.14). However, since the locality is very homogeneous in terms of micro topography, a profile of this would yield little, if any, information that could not be presented in a better way, such as hillshaded DEM.

5.3 Summary

In this chapter I have demonstrated the capabilities of a photogrammetric methodology as a spatial recording technique compared to traditional telemetry data recorded with a total station. It is clear that the quality gained when using a photogrammetric approach far exceeds that of the traditional total station, both by itself and when time is factored in. I have also shown some of the possibilities that photogrammetric data possesses in terms of both analyzing and visualizing the data in novel ways. These modes of presentation are of course not the only methods to display or analyze the data, but are some that might be easily accessible for general use.

From the test data it is clearly visible that the total station is not the most cost efficient method to use if the purpose is to gather topographical information of a site or structure. Even though the test at Inner Elgsnes did not produce the wanted result and no quantifiable data could be rendered from the test, some remarks can be made regarding the application at such sites. The models that could be produced show highly detailed topographical data which could be used to make an accurate volumetric assessment of the mound, something that would not be possible with a total station to the same extent.

A point that I have not touched upon here is the aspect of learning new methods and how that affect their applicability. This is a point that should not be underestimated, as learning new techniques can be troublesome and time consuming. But my personal experience with use of both total stations and photogrammetry techniques does not lead me to think that the one is harder to manage than the other. Even though almost every excavation in Norway involves total station use in some way, not every person on every excavation is trained in total station use, nor is such training expected. Training is given to those who need to be trained, which would be the cause with photogrammetry, if that was the preferred methodology. Quantifying training for either would be meaningless, because the training is not a recurring cost, but a one-time investment as well as being a subjective experience at an individual level.

6 Discussion

6.0 Introduction

The initial goal was to see how the methodologies compared to each other in terms of quality and cost efficiency. But as I will show, it quickly became apparent that a photogrammetric approach would generate far more detailed data than was possible with a total station in a much shorter time period.

In this chapter I will discuss the various pros and cons of the two methodologies in a rescue archaeology setting. An important element that needs to be assessed is how the performance ratio of each method compares against each other. I will use the test results from Chapter 5 to do so.

The fact that most of the equipment we use today is sufficient for applying a photogrammetric methodology to excavations would speak in favor of its use. We can simply add software to our existing arsenal of hardware that we use in the field to start applying this method. But in order for archaeologists in general to start using photogrammetry as a recording tool, it is crucial to establish the capabilities of the methodology. It is this fact that led me to write this thesis, and is my ultimate goal. By the end of this chapter it is my intention to have shown the most important elements of what photogrammetry is capable of producing and why it outperforms the common total station methodology in many respects.

6.1 Test results

The tests at Inner Elgsnes and Tønsnes served different purposes for testing the methodology. The goal of the test at Inner Elgsnes was to see if photogrammetry could be used for recording monuments and other permanently preserved archaeological sites and structures in three dimensions faster and better than what is possible with a total station. If such sites could be spatially documented with high resolution, then that data would present a better tool for researchers or heritage managers to do their work. Analyzing certain elements of the site could be done without even visiting the site, if the data was made available. Monitoring vulnerable heritage sites could be made more accurate and efficient if detailed data was available. These were some of the reasons why I chose to test the methodology on this particular site.

At Tønsnes, my approach to the test was to investigate the applicability of this methodology in a rescue excavation setting. I wanted to find out if a photogrammetric based methodology could reduce the amount of time spent on recording spatial data as well as increase the amount and resolution of the data that was being recorded, compared to the traditional way of recording with a total station. By testing the method on different localities which all had different properties in terms of topology, size and content, I hoped to be able to evaluate the applicability of the two methods in different settings. That being said, I did not, and do not, expect this method to be applicable to all excavations. If I am able to say anything conclusive, it will only apply to similar excavations under similar conditions in terms of cultural context, topography, geology, etc.

6.1.1 Results from Inner Elgsnes

As I have shown in Chapter 5, the test at Inner Elgsnes did not succeed in the way I had intended. But that is not to say that it was a complete failure; some remarks may still be made about the data and how the methodology could improve the recording process, as well as the stored record.

As I explained in Chapter 4, access to Inner Elgsnes was fairly easy. We were five people on the trip, each carrying some of the total station equipment. I did not have to pay any wages to my assistants, but if I had it would have posed a substantial extra cost. The same goes for the total station equipment, as I was able to loan it from the archaeology department. Renting a total station for three days would have incurred a significant cost. On the other hand, had I set out on this task by myself, I would probably have had to carry the equipment out to the site in several trips. In fact, this task would have been impossible to undertake alone, as the total station required two persons to operate. Had I only used camera equipment to record the site, it would probably only take one trip to transport all the equipment and myself to the site. If we imagine the trip to be ten times as long, then the choice of method becomes obvious.

If we had obtained the data, could this have had any significant impact on the understanding of prehistoric Elgsnes? Perhaps it would have been possible to make a volumetric assessment of the cairn and compare it to other cairns from the same period. This would require a systematic documentation of all cairns, or at least a representative selection of cairns, with the same documentation standards. But if such documentation had been available, then I believe it would be of great value to researchers.

There is no doubt that the reason for the test not working as I had planned was due to poor planning and lack of quality control in the field. This shows that the method is vulnerable to human errors, and that testing the data during fieldwork is of key importance. But at the same time, is this not the case for total station data as well? As it turned out, the data from the total station was almost as useless as the data from PhotoScan.

6.1.2 Results from Tønsnes

In contrast to the test at Inner Elgsnes, the tests at Tønsnes worked out as planned. Spatially, some of the data were somewhat incomplete, as seen in the example from locality 11a (Figure 6.1). However, this data was only intended for orthophotography production, not for the spatial data itself. Thus the overlap was not significant enough to generate complete spatial data for this locality. Even though there were gaps in the spatial data, it was still possible to generate orthophotographies from the data.

As seen from the quality gain calculations (Chapter 5), all of the tests produced significantly better results with PhotoScan than with the total station. The difference between the two methods is so great that it is, in my opinion, hard to find compelling arguments against the use of photogrammetry as a spatial recording tool. A quick look at the numbers reveals that for locality 11a PhotoScan produced 395 times more detailed data than the total station. When taking into account

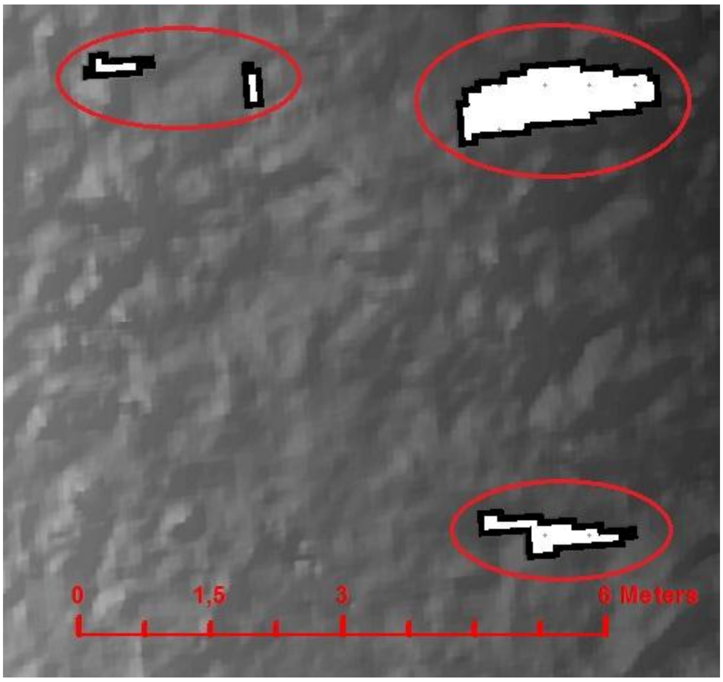

Figure 6.1 *Example of missing geometry at locality 11a.*

time as a factor, PhotoScan is shown to be 333 times more efficient than a total station at producing quality. This was the highest difference in performance rating of the three.

A prime example of how well PhotoScan performs compared to the total station is locality 10. One of the reasons why this is a good example is the location of the locality. As mentioned in Chapter 4 and 5, the locality was outside the “safe” area, where equipment could not be left unattended. This meant that the recorders would have to re-establish the station after each break, which meant that the total station would be unavailable for other operations for long periods of time. This was not an issue for the photo session, as the entire structure at locality 10 was recorded in less than 30 minutes, making it possible to do everything between breaks. One way of solving problems like these would be to plan better or have breaks on site. However, the total station does require that the reference system be re-established, or at least checked for tolerable errors within the established system, from time to time due to instability in the ground or other external factors, like weather.

Showing that one method produces more data at a faster pace does not necessarily mean that the quality of the data is of equal standard. A factor that is easily overlooked when investigating methodology, such as photogrammetry, is the archaeologists’ part in the recording process. When we record data, that record becomes a mediation between the past and the present. Recording features, stratigraphic layers or anything else for that matter will inevitably entail some form of interpretation No matter how objective we believe our data are, all documentation is at some level subjective (Lucas, 2012:215). In this context there might be some valid reason for the use of total station over photogrammetry when recording sites or

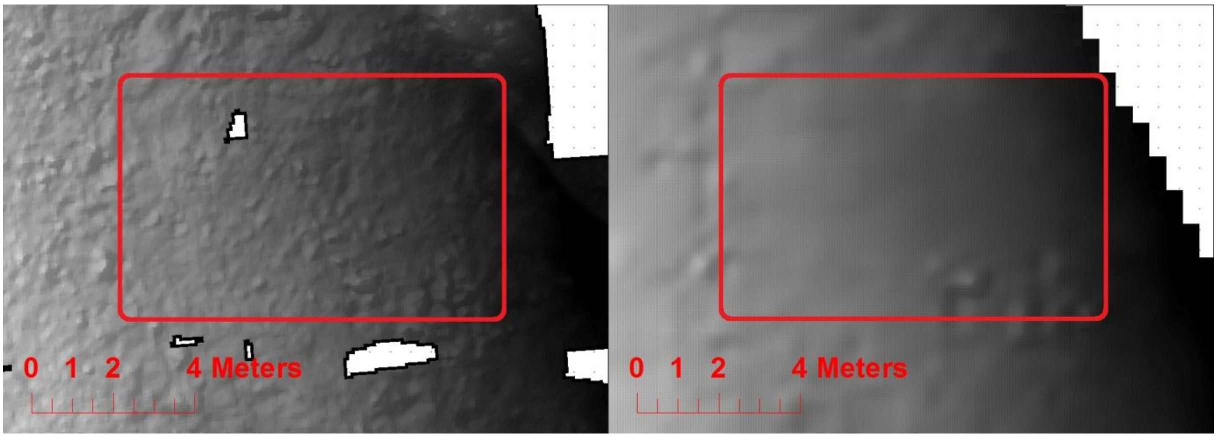

Figure 6.2 *Left: PhotoScan data from locality 11a. Right: data from total station of same area. The same area appears very differently in the two models.*

structures.

The data from locality 11a can be used to argue for both sides. In the comparison of the data at locality 11a we can clearly see a difference in both resolution and detail. The latter can be attributed to an interpretive (total station) rather than an objective (photogrammetry) approach. The archaeologist who recorded the site made a subjective evaluation of which rocks and other features to record in detail and which to leave out. The result of this is, as shown in Figure 6.2, a clearly “flattened” area of the locality present in the total station data.

The point of in-situ interpretation becomes moot. If we do argue that we as archaeologists can directly record an interpretation with the total station that would not be possible if we were to use photogrammetry, then we are missing the point. Generating higher quality data that contains more information about the excavated surface does not exclude important clues about our past, but simply increases the amount of re-useable data. Having experience with the data from start to finish, I know that it is not possible to interpret purely on the basis of either fieldwork or data.

I have not said much about the cost efficiency of the two methods. This is partly because I feel that the test results presented in Chapter 5 are convincing by themselves, but also because of the difficulties of quantifying the cost of each method. I have chosen not to deal with the monetary aspect because the variation of cost is dependent on so many variables that it would be hard to get any replicable results from such an investigation. However, I can make some general statements about the operating costs and investments. The cost of running a total station is the same as using a photogrammetric methodology as they are adjusted by the cost of manpower per hour. It is the initial investment that differs in cost. As shown in Chapter 2, a total station can cost anything in the range of 10,000-30,000 USD. The price for PhotoScan is currently 3,499 USD for a full commercial license, and only 549 USD for an educational license. The cost of a camera would not be an issue, as all excavations use photography as one of their main forms of documentation. Of course, training would also be a cost factor. But from my personal experience in both teaching myself how to use PhotoScan as well as teaching others, this is a far less “expensive” task than the learning process with a total station.

There are other methods being developed for field recording of data, such as the Nikon iSpace for Archaeology (Chapter 2), which might be as fast, or perhaps even faster at recording structures than photogrammetry. If methods like this can produce detailed topographical data as well as doing the traditional tasks of the total station, such as outlining structures and measuring finds, in a very similar fashion and at a faster speed, is there any real need of implementing a brand new way of thinking when it comes to recording data, such as photogrammetry?

Overall I would say that using photogrammetric methods to gather spatial data is far superior to traditional total station methodology in regards to time and quality. However, as I will point out below, we need to question if we really need this high precision data, as well as ask what it can be used for?

6.2 Applicability

If the data we are gathering today with current methods is satisfying enough for our needs, then is it really necessary to introduce novel ways of doing the same job? As I have shown in the previous chapter, the results produced from photogrammetry are decidedly better in terms of quality and cost. But does this alone justify introducing this methodology in a broad way? To investigate this I will give a brief review of how the data we get from photogrammetry can be used where traditional total station data cannot.

As I have focused on rescue excavations in my test material, I feel that it would be best to stick to this area of archaeology rather than exploring other areas where photogrammetry might be applicable. That is not to say that rescue excavations are where the methodology is best put to use. However, it would be an easy task to implement a photogrammetric standard to documentation requirements, as the only thing needed for this would be overlapping images. Looking at the pilot project for developing standards for documentation at the Directorate for Cultural Heritage in Norway (Dokumentasjonsstandard RA, 2011), the level of detail described there far supersedes those requirements that would be needed for a photogrammetric methodology.

If we look at how the emerging field of photogrammetry is developing in other parts of the world, a multitude of possible applications are being explored. In Pompeii it is being used as a tool for documenting the Forum spatially, so it can serve as a record for both professionals and the public (Guidi et al. 2009:1-2). If structures as complex as those in Pompeii can be recorded and made available for researchers and the public alike, is it not possible to apply the same standards to rescue excavations? This is perhaps more of an administrative and political issue that needs to be addressed at a higher level than in this thesis. I do, however, believe that there is nothing from the technical or methodological side that hinders this.

In this thesis I have presented different methods for analyzing and visualizing both total station data and photogrammetric data. As I have pointed out earlier, the methods I have presented are only some of the many possible methods available. Each method has its own strengths and weaknesses. For instance, with an orthographic DEM, analyzing changes between surfaces could be one application. For monitoring erosion of vulnerable cultural heritage sites, this could be a particularly helpful tool. The benefit that a photogrammetric approach would have over a total station approach would be in the resolution level. As I have shown in Chapter 5, the total station lacks the level of detail needed for this task, as the areas where points are not taken will be extrapolated as averages between points.

Sharing information about a site or structure can be a difficult task. Perhaps the most interesting application is the use of the 3D-pdf format. As I have shown in Chapter 5, this format is viewable in Adobe Reader, the most widespread software solution for viewing pdf files, making it a perfect platform for sharing information. One drawback with this method is that high resolution models are cumbersome and difficult to manage. Higher resolution entails a very large file size, making it problematic to share over e-mail. High resolution models are also difficult to view, as the high polygon count puts a strain on the graphics card and hardware in general. For instance, the models I have embedded in this thesis (Figure 5.6, Figure 5.10 and Figure 5.14) are decimated down to 500,000 polygons, keeping the file size relatively low (35-40 megabytes). This ensures that the viewer can view them without having the computer freeze under the strain. The problem is that when the models are decimated, some information is lost, as the decimation process “smooths” the geometry and generates a less defined mesh. For metric analysis this format may not be the best of choices, but will provide a general “feel” of the object or structure to the viewer.

6.3 Re-usability of data

As I showed in Chapter 5, there are many analytical as well as visual ways of using the data that has been recorded with photogrammetry. Although my main task is to evaluate the two methodologies against each other in a quantitative and qualitative way, some aspects of data value should be discussed as well. One aspect would be the re-usability of the data.

During the process of writing this thesis it has become clear to me that the goal of any excavation is to reveal as much as possible of the past as we are capable of doing with our current resources. In this work, a key component is how we document what we find for future generations. Quite often I have come across excavation data from the pre-digital era that are so inadequate that they are completely unfit for re-analysis. Poorly drawn sketches, lack of measurements, poor quality black-and-white photographs and so forth. And this kind of data is, most often, only available in summary form in publications, or, if one is extremely fortunate, excavation notes. So how can we, with our high-tech, fully digital data change this situation?

The process of recording is also interpretation. Structures that are being defined and outlines that are being drawn become the record that we as archaeologists will leave behind for future generations. But how can we make sure that the record that we are writing becomes as true to the real world as possible?

Documentation recorded in the field limits the data that we gather in terms of re-use. We can only re-interpret that which has been recorded. If the recorded data has a low resolution, then we as archaeologists will be limited to that resolution. At the same time, if we record a structure in the field using a total station or drawings on paper, then that data will be colored by the preconceived notions of the past. Structures or features that may have been widely accepted as one thing might turn out to be something completely different when viewed from a different source (Lucas, 2012:215-216). This kind of data is very hard to re-interpret, due to the lack of information about the unknown aspects. Having a “complete” record of spatial data, might it not be easier to re-imagine the site as seen by the excavators, and through this, re-interpret what they inferred about the site and its function?

It has been said that the essentially subjective experience of both fieldwork and post-processing is becoming more and more removed from the interpretive steps of the archaeological process (Chadwick, 2003:99). Methods like digital photogrammetry do separate the data from the actual process of excavation in the sense that it is a pure documentation of a surface, rather than an interpretation. But I see this as liberating for other researchers rather than an obstacle. This does however demand that the metadata that is being recorded is kept with the photogrammetric data in such a way that the link is clearly visible and readily understandable for those who did not partake in the recording process. If we can record things like differences in soil texture and link this metadata to the photogrammetric data, I believe that such efforts will make the re-usability of the data better for generations to come.

6.4 How we use our data: today and in the future

Analyzing archaeological data is a multi-sensory task. We do not limit ourselves to looking at a rock formation or color changes in the dirt when we decide how to interpret something. We look at things like moisture content, odor, color, compactness, and a multitude of other factors before we can decide whether what we have found stems from human influence or not. The problem is that we cannot record all this data due to the inherent complexity of nature. So how do we solve this? Currently, we do not.

In the 2008/2009 Tønsnes project, recording of microtopographical features was performed using a robotic Leica 1200+ TPS. This data was used to visualize features as well as assist in the interpretation of said features. However, the analyses were purely of a visual character. No attempts were made in regards to use the spatial data in quantitative interpretation of, for instance, layer thickness or stratigraphic affirmation. Three factors were detrimental to this: (a) the lack of discernible layers, (b) the hard pan that prevented complete excavation and (c) the lack of resources (Christian Roll Valen, Pers. comm. 16.04.12). But even if these factors had been absent, would the resolution of the data be good enough for this kind of analysis?

When comparing the different data sets from the 2011 excavation, a clear disadvantage of the total station data is visible. This data is finite (meaning the detail level cannot be improved upon) and lacks the fine details that can be found in the photogrammetric data. As shown in

Chapter 5, this is particularly visible in areas around rocks. The question that arises from this is whether or not our perception of these anomalies affects our analysis of the archaeology?

When a rescue excavation has been completed, a report is then produced and published. In such reports there are interpretations of the localities and structures that have been excavated, as well as images and other data. In addition, all raw data is stored at the museum. If someone in the future wishes to study the data, then it is simple to study the report and the data to make new or improved interpretations. But, is it really that simple? As I have tried to emphasize, the data that has been recorded is already covered by at least one layer of interpretation, which is the excavation process itself. So the data that is being recorded is already interpreted once, and is subjected to a second interpretation as it is being recorded. Finally the data will be submitted to a third layer of analysis during the report production. So there is a great deal that stands between the real world and the stored data.

An interesting aspect of the re-usability of data that I have deliberately avoided so far, is how we store our data. The data we produce is no longer limited by physical storage in the same way as non-digital data. We can carry with us all documentation from an entire excavation on a portable hard drive, reducing the demand for physical storage space to an absolute minimum. But what do we do if that hard drive is damaged? We can upload the data to large data storage facilities that have secure backup solutions, ensuring that our data is safe (as long as we pay the bill). But what if the servers are damaged? Well, the same problems would apply to all data, whether it is stored digitally or on paper. A question that is relevant and is more likely to have an effect on our data is the way the data is stored digitally. Today there is no problem opening a pdf file because of the widespread use of the format. But what happens to the data stored in pdf format when the format is no longer in use? There is no easy answer to this. The important thing is to be aware of the problem and proactive to find the best solutions for these issues. Fortunately, these issues are being taken seriously (see Baker et al. 2005 for key elements).

6.5 Pros and cons

Throughout this thesis I have demonstrated the capabilities of both methodologies in a rescue excavation setting. It has become clear that both methodologies are valid in terms of usefulness in an excavation process. In an attempt to quantify the benefits and drawbacks of each methodology, I will now give a brief summary of each methodology's pros and cons.

6.5.1 Digital photogrammetry: Pros

As my tests have revealed, digital photogrammetry is by far the superior methodology when evaluating efficiency and quality. The data produced with photogrammetry was between 17.5 and 333 times more efficiently recorded than with the total station.

Another factor that puts other methodologies, like the total station approach or even laser scanning, to shame is the cost of the equipment needed to produce equally good or superior data. The price factor gives low-budget archaeology projects the same opportunity to document spatial data in a highly detailed manner as well funded projects that are able to invest in equipment like total stations or laser scanners. Most of the equipment needed for digital photogrammetry is already a part of the field archaeologist's basic toolkit. If there is no money for (rather) expensive software solutions like PhotoScan, there are open source solutions that are free of charge.

A third important factor that makes the photogrammetric methodology a better choice is its mobility. Transporting heavy and cumbersome equipment, such as a total station, to a remote location is not always possible. The only equipment that is needed in the field for a photogrammetric survey is a camera and a tape measure to make it scalable. There is of course the need for a computer and software as well, but it is not crucial for field recording. It can be beneficial to have a computer in the field to make sure the image data has enough overlap, ensuring a model can be created. This can, however, be solved by being meticulous and systematic in the recording process. The Tønses data was only recorded once, which proves this point.

Finally, the biggest benefit of digital photogrammetry data over total station data, as I see it, is the re-usability. Images captured for this purpose are not "locked" to the output model in the same way as points recorded with a total station are to the final record. The possibility to remake photogrammetric models with better resolution at faster speeds in the future makes the re-usability of this methodology much greater than that of a total station.

6.5.2 Digital photogrammetry: Cons

One drawback is the lack of direct control over the recorded data. Photographs need to be in a complete, or at least partially complete, set before they can be processed in the software. This means that if you lack total coverage, as was the case at Inner Elgsnes, or that other factors make computation impossible, bad data cannot be recognized before processing has finished. If the user is unaware of this aspect of the process, in a worst case scenario the data may be unrecoverable. Again, Inner Elgsnes is a good example of just this, as I could not re-record the photographs due to time and financial concerns. But if the same thing had happened at Tønsnes, and no verification of the data had been undertaken, then the consequences might have been more serious, as it was a “live” excavation, where structures were being recorded and then excavated.

Another negative factor of this methodology is the sheer volume of data that comes with it. First there is the raw-data itself, i.e. the imagery. This should be of the highest possible standards to ensure its re-usability in the future. That means that recording needs to be done at high resolution with quality cameras. This, in turn, will lead to the production of massive amounts of data; data that does not need to be stored if we use more traditional means of recording. The data then needs to be secured properly so that it does not deteriorate over time. We also need to make sure that the data is readable in the future. All this adds to maintenance cost, as digital storage in secure locations (such as cloud services) is a monthly cost that will run until better permanent storage solutions are made available.

The biggest issue with photogrammetry, as I see it, is its limitations when dealing with moving or reflective surfaces. The method will not work if the object being recorded is moving, such as grassy fields, which would apply to field surveys. It is also difficult to document reflective surfaces, such as puddles of water. If the site is located in an area exposed to a lot of rain, chances are it is going to be difficult to get good image data.

6.5.3 Total station: Pros

When using a total station, the feedback of the recorded data is immediate. It is possible to confirm the data whilst recording, using the handheld device or on the total station itself, something that is not possible with photogrammetric recordings.

Assuming the recorder has an archaeological background and that he or she actively uses this expertise while recording, the extra layer of interpretation that the recorder applies to the data should work as a quality control of the excavated area. The recorder, drawing on knowledge from the entire site, might see things from a different perspective than the person who is excavating.

The greatest advantage of the total station is its ability to record points on the surface that are covered in grass or water. If pools of water have gathered on the surface it is still possible to do a topographical survey. The same goes for grass in motion, as the point of the prism pole can be placed below the visible surface of the grass.

6.5.4 Total station: Cons

The cost of purchasing a total station is very high (Chapter 2). Smaller projects seldom have the purchasing power to invest in equipment such as a robotic total station. The initial expense in itself is very high, but there is also the more or less hidden cost of upkeep and service.

The total station can become unstable in windy conditions, if the ground is unstable or if people interfere with it. If this happens, the total station becomes inactive during the time it takes to reset the station in the coordinate system. If it is inactive it is also unproductive, meaning a loss of time and money.

The total station only produces spatial data in the form of x, y and z coordinates. This data does not contain any texture data, meaning that a photographing of the structure or site is needed to obtain the same types of data as with photogrammetry.

The biggest drawback when using a total station is the low level of detail. Combined with the time factor, data from a total station cannot compete with that of photogrammetry. The total station data is also limited to those points recorded. No more spatial data can be retrieved from the site with a total station once the site is gone.

7 Summary and conclusions

7.1 Summary

In this thesis I have investigated the possibilities of digital photogrammetry as a methodology for spatial documentation in archaeology. From the late parts of the 19th century up to today, the development of spatial documentation has been phenomenal. But it is only in the last 10-20 years that we have been able to fully utilize the potential of digital recording methodology as a cost-efficient means of spatial documentation in archaeology. The most recent developments in field documentation methodology, such as digital photogrammetry, laser scanners and the like, especially have shown great potential for archaeology in general. New ways of using and interpreting the data gathered have started to make their impression on archaeology, although this is merely the beginning of a “digital revolution” in archaeology.

Both the data from Inner Elgsnes and from Tønsnes revealed some strengths and weaknesses of digital photogrammetry, as well as showing limitations and benefits of traditional total station surveying. At Inner Elgsnes the test data turned out to be of little or no scientific value, because of the lack of proper recording in the field that made it impossible to generate any spatial data from the images. This showed that careful planning of the recording process was necessary and that reviewing the data on-site would be beneficial. At Tønsnes I showed the true potential of digital photogrammetry in regard to spatially documenting a site compared to a total station approach. I was able to visualize the differences between the two methodologies in such a way that it became clear what the benefits and drawbacks each methodology entails.

My method for evaluating the data was not without flaws, but still yielded good results. I was able to show the potential of the data in regard to visualization and spatial analysis, although the latter only showed the absolute minimum of analytical potential in the data. My method for testing the two data types against one another also worked well, although I am sure that better methods for doing so could be devised. It showed that the photogrammetric data was far better in terms of both quality and processing speed.

Discussing my findings was quite difficult. Due to the overwhelming qualitative differences between the two methods I found it hard to argue against photogrammetry as a method for documenting topographical data from a site. The discussion also raised several questions regarding the usefulness of the data and its possible applications. Many of the issues raised there are things that always will be problematic for archaeologists to deal with, as they are so infused with everything from technological development to political trends.

7.2 Conclusions

Digital photogrammetry is by far a much more efficient methodology for documenting spatial data than total stations. Within the framework of my tests I have been able to show an improvement in efficiency of between 17.5 and 333 times from total station to photogrammetry. This is, in my opinion, an overwhelming advantage of digital photogrammetry as a field documentation methodology over traditional total station methodology. What sets digital photogrammetry further apart from total station methodology is the ability to generate models with varying quality at the user’s leisure. This enables re-interpretation of the data in a way never before seen. Also, the level of documentation for posterity will only be limited by image quality and hardware, not by the field recorder’s limitations or interpretations.

The most important lesson to take from this thesis is that digital photogrammetry is a new and effective tool in our archaeological field-toolbox. Digital photogrammetry is not a substitute for traditional methodologies, but an addition to our existing arsenal of tools. With this new tool we can improve our data qualitatively as well as speeding up the recording process, but only if the intended use of the data justifies the methodology. If we excavate in mechanical layers or if the stratigraphy is too homogenous to separate, then perhaps a total record is not needed, therefore removing the need for exact topographical data. We need to be able to evaluate the methodological requirements in the field so that we can minimize time expenditure and maximize data profit.

Working with this thesis has revealed a dire need for further research on the subject matter. This thesis has only explored the application of digital photogrammetry in a North-Norwegian Stone Age context. If archaeologists are to apply this methodology to other types of archaeology than the aforementioned, more testing would be required in order to be able to say anything conclusive about such applications. Only when we have made extensive evaluations on multiple types of sites, structures and contexts will it be possible to determine the full potential of digital photogrammetry as a field documentation tool. The same can be said about the analytical value of the data. Archaeologists need to catch up with the technology so that they can take advantage of the potential this kind of data brings with it. Archaeologists also need to take an active part in the development and not sit idly by while others set the standards of this technology.

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