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This dissertation is written as part of the three-article option offered by the Geography Department at UNC Greensboro. Each article addresses specific research issues within Remote Sensing, Photogrammetry, and three-dimensional modeling related structural and subsurface remote sensing of historic cultural landscapes. The articles submitted in this dissertation are both separate study sites and research questions, but the unifying theme of geographic research methods applies throughout.

The first article is titled Terrestrial Lidar and GPR Investigations into the Third Line of Battle at Guilford Courthouse National Military Park, Guilford County, North Carolina is published in the book Digital Methods and Remote Sensing in Archaeology: Archaeology in the Age of Sensing. Forte, Maurizio, Campana, Stefano R.L. (Eds.) 2016. The results of the research demonstrate the successful exportation of GPR data into three-dimensional point clouds. Subsequently, the converted GPR points in conjunction with the TLS were explored to aid in the identification of the colonial subsurface.

The second article submitted for consideration is titled “Three-Dimensional Modeling using Terrestrial LiDAR, Unmanned Aerial Vehicles, and Digital Cameras at House in the Horseshoe State Historic Site, Sanford, North Carolina.” There are two different research components to this study, modeling a structure and the landscape. The structure modeling section compares three different remote sensing approaches to the capture and three-dimensional model creation of a historic building. A detailed comparison

is made between the photogrammetric models generated from digital camera photography, a terrestrial laser scanner (TLS) and an unmanned aerial vehicle (UAS).

The final article, "Geophysical Investigations at the Harper House Bentonville Battlefield, NC State Historic Site" submitted focuses on the Harper House located in at the Bentonville Civil War battlefield. UNCG conducted a geophysical survey using a ground penetrating radar and gradiometer. The findings from the data were used to determine and pinpoint areas of interest for subsequent excavation.

REMOTE SENSING AND DATA FUSION OF CULTURAL AND PHYSICAL LANDSCAPES

by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Carl Sauer wrote, “We are concerned with the….interrelation of…….cultures and site, as expressed in the various landscapes of the world” (Denevan & Mathewson, 2009,p. xii). The following dissertation investigates various methods and data from a variety of remote sensing sensors for landscape studies. This research uses a combination of traditional remote sensing and geophysical remote sensing, both aerial and ground based, to study physical and cultural landscapes. As an emerging research topic this work not only investigates the subsurface landscape through nondestructive means, but looks to evaluate three-dimensional model generation from multiple platforms. This project examines the visualization of multidimensional data; these include Ground Penetrating Radar (GPR), Terrestrial LiDAR (TLS), aerial imagery, traditional photographic methods via digital camera (SLR) and from Unmanned Aerial System (UAS).

An objective of this study is to create a multidimensional representation of the landscape above and below the surface using multiple remotely sensed datasets (GPR, TLS, static digital cameras, and UAS imagery). Integration from multiple sources of data allows landscape features, that may otherwise be unseen, to be visualized realistically and provide a nonintrusive measurement option. Another goal is to compare the sensors quantitatively and qualitatively. Conducting this type of research will produce results that can be spatially integrated with other data relevant to archaeological, geographical and survey investigations to provide a comprehensive record of the site environment both below and above ground allowing for the creation of a localized geography (Watters, 2012). When completed what results is a more in depth understanding of the use of space and built environment over time and space (Thompson, Arnold III, Pluckhahn, & Vanderwarker, 2011).

Historically, maps are important and indispensable tools in the geographer's search for understanding of how human and physical processes act and interact on the Earth's surface (Goodchild, 2004). However, the paper map presents a static state of the world. With the advent of the internet, smartphones, and other personal digital devices the concept of the “map” is constantly evolving. These technological developments allow the creation of maps tailored to individual needs with ease (Parsons, 2013).

Remote sensing has also evolved greatly since the earliest photos taken from balloons in 1860s. With the boom in aviation technology to the first satellite launched into space, images have been taken capturing the Earth’s surface. Remote Sensing technology is ever evolving in development of sensors to the variety of uses these sensors can be applied to. Remotely sensed data is also experiencing a new age of visualizing and presenting information, moving away from the pixel paradigm to new means such as point clouds. Traditionally, remote sensing scientists had to accept the scale and resolution of the imagery they acquired due to the technical and financial limitations of such data. Scale, always an issue to any study, is becoming more attainable along with the range of what can be seen from great distances. Now, the field is becoming much more flexible and with new technologies continuously emerging the accessibility to define your own scale and resolution on the fly is becoming more the norm. The ability to determine and design remote sensing collection based on individual research needs is more common place. With the advances of the internet, imagery in a format that permits rapid web delivery, and intuitive navigation and changes in scale, have bypassed such barriers to delivery of imagery to a new audience (Campbell & Salomonson, 2010). The widespread availability of such systems creates an interface that is common to a broad community of users, thereby forming a large population familiar with its content and its functionality. This leads to the idea of creating your own localized geography. In this case the study sites are quite small in scale, but with these techniques and technologies we are not confined by the limitations of what traditional would define our study. Through applying traditional aerial imagery analysis in conjunction with scaling to a locally defined area using GPR, TLS, UAS, a more complete analysis of the landscape can be presented from the lowest scale to the highest.

Literature Review

The discipline of Geography not only brings techniques and fundamental methods to the research, but concrete theories that guide the study. A central tenet of geography is that "location matters" for understanding a wide variety of processes and phenomena. Indeed, geography’s focus on location provides a cross-cutting way of looking at processes and phenomena that other disciplines tend to treat in isolation (Board on Earth Sciences and Resources Commission on Geosciences, Environment, and Resources National Research Council, 1997). To understand location gives way to the understanding of place. Comparing places in a spatial context can provide a way of analyzing different physical and cultural features. Places are natural laboratories for the study of complex relationships among processes and phenomena. When such systematic analysis is applied to many different places, an understanding of geographic variability emerges. Of course, a full analysis of geographic variability must account for processes that cross the boundaries of places, linking them to one another, and also of scale (Board on Earth Sciences and Resources Commission on Geosciences, Environment, and Resources National Research Council, 1997).

The concept of landscape is important to this study. The idea that landscape is continuously produced is important to remember in historical settings. Rooted in the writings of Carl Sauer is the concept of landscape in terms of both cultural and physical aspects. Remote Sensing allows for that very repeated and systematic study of the effects of man on earth. This can be correlated with historical impacts of man on the surface measured through the sensors and fusion described in this research. In terms of geographic thought, it is notable that Sauer sought a more inclusive study of the landscape. He did this by adding the dimension of time to his inquiry in questing for understanding of man's occupancy of the earth.

Regarding the dissertation research, one aspect is the measurement and visualization of subsurface and surface historical features. The foundation of the research draws from Sauer's writings on landscape and the incorporation of landscape archaeology, including interest in how humans inhabited landscapes and generated socially inscribed notions of routes and places is similarly well informed by geospatial technologies (Llobera, 2011).

Persistent places are a fundamental concept in landscape studies. A persistent place, according to Schlanger (1992) and presented by Thompson, et al. (2011), is a locale that "is used repeatedly during the long-term occupation of a region". Understanding such places allows the researcher to develop links of usage with periods of population withdrawal and apparent abandonment (Thompson et al., 2011). The historical use of a place has bearing on how inhabitants negotiated past uses into something new. Traces/evidence is left in these places that are clues to the different uses of that site provide insight into how a landscape has been utilized and changed throughout time. Humans change their surroundings, but so do natural processes and these can also be measured and seen on the landscape. These cultural and physical remnants can come from different periods and can exist simultaneously enduring in a land for different lengths of time because there are variations in change. These variations and changes can be detected in multiple sensors and in this study highlighting, visualizing, analyzing, and presenting through these methods can help tell the story of past physical and cultural events occurring on the landscape.

Geophysical surveys are one of the key sources for subsurface data in this research. The fundamentals of archaeological geophysics lie in its ability as a prospection tool to locate map and produce images of buried cultural materials (Conyers, 2010). Non-invasive investigations of subsurface anomalies through geophysical surveys can provide archaeologists with valuable information prior to, or in-place of, the non-reversible processes of excavation (Yu-Min Lin, et al., 2011). The continued application and development of geophysical coverage for archaeological assessment has begun to introduce an alternative perspective into regional, or landscape archaeology (Kvamme, 2003). Geophysical surveys provide information on the structure and organization of a site enabling the study of spatial patterns and relationships relevant to research questions. In addition to the large-scale perspective of the site, geophysical survey results also provide a high-resolution focus on individual site features (Watters, 2012). These surveys provide advanced acquisition and processing techniques that can not only map the spatial extent of buried features precisely in three-dimensions, but also potentially determine specific material properties of the subsurface features such as stone, earth or brick. When these types of analysis are incorporated within a historical framework, ideas about the past can be tested and studied in ways not possible before (Conyers, 2010).

Ground Penetrating Radar (GPR) will be used as part of the geophysical surveys employed in this research. GPR transmits an electromagnetic pulse and measures a reflected signal that is dependent upon the dielectric properties of subsurface material. With GPR, it is possible to reconstruct high-resolution 3D data visualizations of the composition of the subsurface (Yu-Min Lin, et al., 2011). Most GPR equipment used in archaeology send nearly continuous pulses of radar energy into the ground along the full length of a survey transect. Identifying discontinuities in the subsurface, including stratigraphic contacts, walls, house or pit floors, rubble, or midden deposits, cause the radar energy to be reflected back to the surface (Kvamme, 2007). The velocity of this energy varies greatly, depending on dielectric properties of the subsurface materials.

If velocity can be estimated, then return times of echoes from pulses give information on depth, while amplitudes indicate something of the nature of subsurface changes (Kvamme, 2007).

An additional component to the data fusion and geovisualization of the research includes the use and exploitation of point cloud data collected from multiple sources. A point cloud is a collection of discrete three-dimensional locations (points) that can have additional metadata associated with each record. Point clouds appear realistic to even the most casual observer because of their three-dimensional nature. Technologies like laser scanning, standard digital photography and other visual technologies—not only produce images but extend our power to detect, record, and imagine landscapes (Mlekuz, 2013). These types of data can all be visualized in point clouds. Point cloud technologies fall into one of two categories: (1) active, where the sensor emits energy and uses its interaction with surfaces to construct the cloud and (2) passive, where the sensor collects energy reflected off of surfaces, observed from many different locations, and techniques from the discipline of photogrammetry are used to construct the cloud (White, 2013).

Active scanning technologies generate their own scanning energy and can record and even discover archaeological features at both site and landscape scales. These systems send out discrete pulses of light and record both how long it takes those pulses to return and how much of the original energy comes back. That information, when combined with data about where the sensor is positioned and how it is oriented with respect to the real world is used to construct the point cloud.

Each point in the cloud represents a location where the light pulse reflected off of a surface (White, 2013). The active system that is used in this research is the terrestrial laser scanner (TLS).

The term "laser scanning" describes any technology which accurately and repeatedly measures distance using laser pulse, by precise measurement of time needed for the laser pulse to travel from the object and back and transforms these measurements into a series of points, or a point cloud, from which information on the morphology of the object being scanned may be derived. (Mlekuz, 2013) Terrestrial laser scanning (also known as ground-based LiDAR) is increasingly used as a method of collecting spatial data, and when supported by digital photogrammetry, can render quantitatively accurate and visually impressive representations of land surfaces (Entwistle, et. al, 2009).

Terrestrial laser scanners can be used to create photo-realistic virtual copies of landscapes, and archaeological features, and offer the potential to improve our understanding of three-dimensional (3D) spatial relationships at study sites (Entwistle, et. al, 2009). Terrestrial laser scanning enables the researcher to quantify and integrate previously implicit knowledge-based field observations of topographic setting into a framework for interpreting an archaeological site and its characteristics (Entwistle, et. al, 2009). Passive scanning systems can be most easily thought of as standard digital cameras because, in fact, that is exactly what they are. When multiple images of the same scene are captured from different perspectives, the overlapping portions can be used to construct a three-dimensional representation of that scene (White, 2013). Two types of passive scanning systems are applied. Traditional static digital camera technology taken with a standard SLR digital camera. The overlapping static images are combined and converted to a point cloud. The second type of passive remote sensing for point cloud generation is captured with an unmanned aerial vehicle (UAS). UAS platforms are a valuable alternative and solution for studying and exploring our environment, in particular for heritage locations or rapid response applications (Nex & Remondino, 2014). Rotary or fixed-wing UASs, capable of performing the photogrammetric data acquisition with amateur or SLR digital cameras, can fly in manual, semi-automated, and autonomous modes (Nex & Remondino, 2014). UASs can be a complement or replacement of terrestrial acquisition (images or range data) (Nex & Remondino, 2014). The digital images can be used, beside very dense point cloud generation, for texture mapping purposes on existing 3D data, for orthophoto production, map and drawing generation, or 3D building modeling (Nex & Remondino, 2014). The dissertation utilizes UASs for both the structures, but also for the geophysical survey areas in order to create a "LiDAR-like" digital surface model.

Articles

As part of the nonstandard option for the doctoral requirements, three articles are presented. Each article focuses on a different site, objective, and remote sensing methodology. The first article is titled Terrestrial Lidar and GPR Investigations into the Third Line of Battle at Guilford Courthouse National Military Park, Guilford County, North Carolina is published in the book Digital Methods and Remote Sensing in Archaeology: Archaeology in the Age of Sensing. Forte, Maurizio, Campana, Stefano R.L. (Eds.) 2016. Guilford Courthouse National Battlefield Park is the location of a legendary Revolutionary War battle. A joint geophysical and archaeological field school was conducted near the third line action at the battle of Guilford Courthouse, located at the Guilford Courthouse National Military Park, Greensboro NC. The location of the third line is under debate by historians and archaeologists. A ground penetrating radar (GPR) survey revealed a linear feature approximately 50 cm in depth, varying in width and trending north south for approximately 68 m before entering a heavily wooded area. Excavation of a narrow trench towards the end of the field season revealed a colonial surface, possibly a road or gully, covered in fill dirt. Both a road and a gully have been discussed in the literature, and their discovery would yield important clues to the location of the third line. The surface of this buried feature was slightly concave. A team from Auburn University joined UNCG and NC A&T SU researchers with a terrestrial laser scanning (TLS) survey to see if a highly detailed elevation map could trace the surface manifestation of the feature into and through the wooded area. The results of the research demonstrate the successful exportation of GPR data into three-dimensional point clouds. Subsequently, the converted GPR points in conjunction with the TLS were explored to aid in the identification of the colonial subsurface. The TLS dataset has the capacity to discern the concave surface found in the dense overgrown and obstructed wooded area which could be a continuation of the subsurface feature seen in the GPR data.

The second article submitted for consideration is titled Three-Dimensional Modeling using Terrestrial LiDAR, Unmanned Aerial Vehicles, and Digital Cameras at House in the Horseshoe State Historic Site, Sanford, North Carolina. The House in the Horseshoe (Alston House) is located in Sanford, NC is 18th century property with a complex history of land use. This site was the scene of much smaller skirmish between North Carolinians loyal to the British crown and those in favor of independence. Unlike Guilford Courthouse Battlefield, a still extant structure is present with the original bullet holes to tell the tale. At this location the discovery of the unseen built environment from the Alston homestead is important, but as stated, this site has a more complex land use over time. In the 19th century, the site was plantation home of a NC governor encompassing much more acreage. The Alston House property at House in the Horseshoe State Historic Site provides a chance to examine exactly how much information can be derived from a combination of methods. There are two different research components to this study, modeling a structure and the landscape. The structure modeling section compares three different remote sensing approaches to the capture and three-dimensional model creation of a historic building. A detailed comparison is made between the photogrammetric models generated from digital camera photography, a terrestrial laser scanner (TLS) and an unmanned aerial vehicle (UAS).

An evaluation of the three methods demonstrates the ability of producing three dimensional models of the structure. Examining these differing methods can be used to draw conclusions as to the most viable means of model generation and dataset manipulation. The second component to the research focuses on landscape modeling which expands upon the structure modeling and further examines the immediate surrounding terrain. Historic aerial photography, total station survey data, UAS imagery and a generated digital elevation model (DEM) were all incorporated to determine the accuracy and discovery of new information that can be derived from the historic landscape.

The final article, "Geophysical Investigations at the Harper House Bentonville Battlefield, NC State Historic Site" submitted focuses on the Harper House located in at the Bentonville Civil War battlefield. The battle of Bentonville was a gruesome Civil War clash that covered tremendous acreage. The study is centered at the Harper House, the home turned hospital during the battle. An extensive geophysical coverage by the GPR was completed in March 2014 and an archaeological excavation was performed in June 2014 aiding in the validation of the results. The results of the excavation assisted greatly in the identification of both the physical and cultural subsurface features. UNCG conducted a geophysical survey using a ground penetrating radar and gradiometer. The findings from the data were used to determine and pinpoint areas of interest for subsequent excavation. Therefore, proving more effective and timelier than prospecting without such tools and techniques. The results of the survey allowed for the generation of maps to grid specific notable features for future excavation

CHAPTER II

TERRESTRIAL LIDAR AND GPR INVESTIGATIONS INTO THE THIRD LINE OF BATTLE AT GUILFORD COURTHOUSE NATIONAL MILITARY PARK, GUILFORD COUNTY, NORTH CAROLINA

This chapter is a manuscript published as in Digital Methods and Remote Sensing in Archaeology: Archaeology in the Age of Sensing. Forte, Maurizio, Campana, Stefano R.L. (Eds.) 2016

Introduction

Guilford Courthouse National Battlefield Park (GUCO) is the site of a pivotal 18th century Revolutionary War battle. In March of 1781 General Cornwallis leading the British army engaged American forces made up of militia units from North Carolina and Virginia as well as Continental line troops near Greensboro North Carolina (Figure 2.1). The courthouse was pivotal in the action over the contested land. There is agreement as to the general location of the first two lines of battle (Figure 2.2). The last action of the battle or third line was located near the courthouse. From this location General Greene directed the battle and finally had his army retreat along a north south trending road. While technically a victory for the British army the losses suffered in the battle caused its commander General Cornwallis to leave the Carolinas and move into Virginia and later defeated at Yorktown. The landscape of the Park from colonial settlement and county courthouse to battlefield to farm to historic preserve surrounded by housing developments has seen modification and reuse. The exact locations of the courthouse and the “retreat” road are an ongoing debate by various scholars and would help enhance the interpretation of this site (Babits and Howard 2009; Baker 1995; Coe and Ward 1973; Durham 2004; Cornelison et al. 2007; Hatch 1970; Hiatt 1999; Ward and Coe 1976; Stine and Stine 2013; Stine et al. 2003). The discovery of the courthouse location, the retreat road or other subsurface features may lead to an accurate placement of the third line of battle.

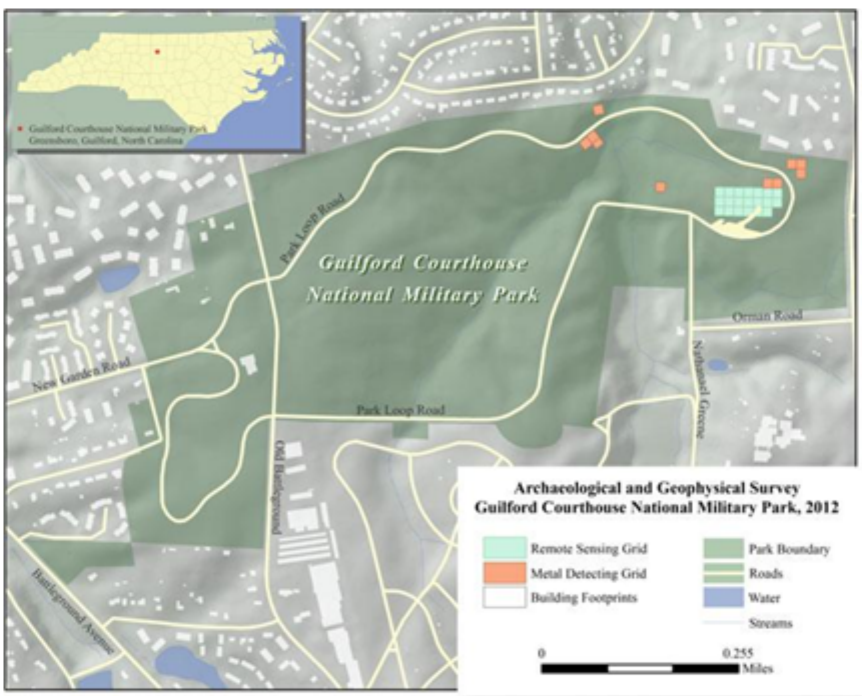

Figure 2.1 Guilford Courthouse National Military Park (Dr. Elizabeth Nelson)

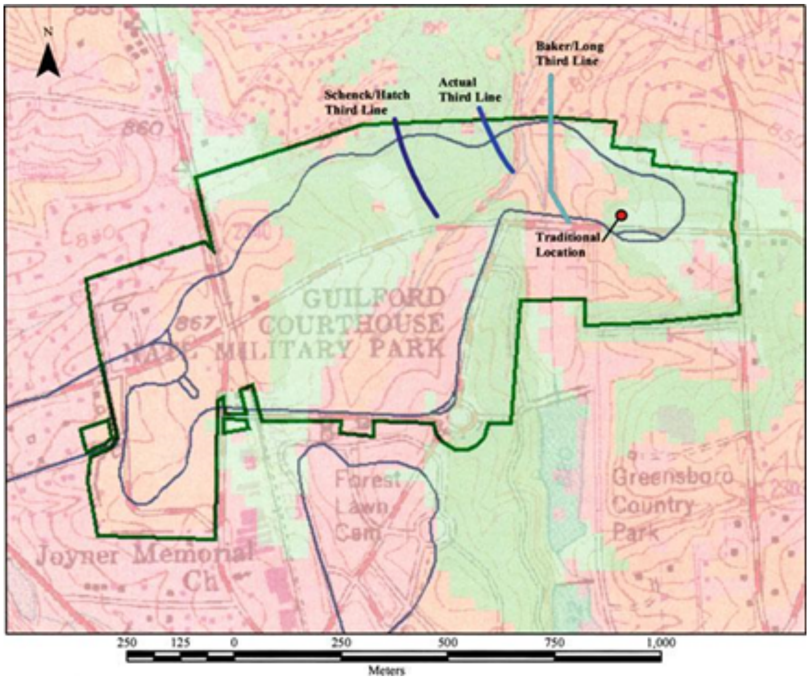

Figure 2.2 Disputed Location of the Third Line (Cornelison et al. 2007)

The environment surrounding one of the suspected locations of the courthouse is partially accessible, with mowed grass transitioning into secondary growth brush and trees with an undulating topography. Aerial and satellite imagery and traditional airborne Lidar have proved ineffective at determining the microtopography in this type of environment. Guilford Courthouse's unique blend of environmental conditions, both woody and grass provide a testing ground for utilizing other such methods of mapping similar forested sites. Applying the terrestrial laser scanning to certain subsets of the site can begin to answer questions about the landscape obscured by the woody environment (Fig. 2.3).

The overarching question of the larger research project involves the potential to combine multidimensional datasets from multiple sensors to produce an effectively fused above and below ground dataset. Drawing on historical archaeological data, GPR, TLS point cloud, and Total Station datasets, this paper focuses on the methods and results of the digital data fusion. In addition, the discovery and implementation of the most effective strategies to handle research sites with heavy vegetative cover and/or obstruction with regards to sensors selections and data fusion methodology are explored. Discovering the most beneficial way to visualize fusion datasets to aid in understanding historical landscapes is a major thrust of this study.

Figure 2.3 Wooded Study Site

Literature Review

Geophysical surveys are one of the critical sources of subsurface data in this research. The roots of archaeological geophysics lie in its ability as a prospection tool to locate map and produce images of buried cultural materials (Conyers 2010). Non-invasive investigations of subsurface anomalies through geophysical surveys can provide archaeologists with valuable information prior to, or in-place of, the non-reversible processes of excavation (Yu-Min Lin et al. 2011). The continued application and development of geophysical coverage for archaeological assessment has begun to introduce an alternative perspective into regional, or landscape archaeology (Kvamme 2003). Such surveys provide information on the structure and organization of a site enabling the study of spatial patterns and relationships relevant to research questions. In addition to the large-scale perspective of the site, geophysical survey results also provide a high-resolution focus on individual site features (Watters 2012). Applying advanced acquisition and processing techniques can not only map the spatial extent of buried features precisely in three-dimensions, but potentially can determine specific material properties of subsurface features such as stone, earth or brick. When these types of analysis are incorporated within a historical framework, ideas about the past can be tested and studied in ways not possible before (Conyers 2010).

Ground Penetrating Radar (GPR) was chosen from the geophysical surveys employed in this research to be used as the subsurface dataset. GPR transmits an electromagnetic pulse and measures a reflected signal that is dependent upon the dielectric properties of subsurface material. With GPR, the potential for the reconstruction of high-resolution 3D data visualizations of the composition of the sub-surface is possible (Yu-Min Lin et al. 2011). Identifying discontinuities in the subsurface, including stratigraphic contacts, walls, house or pit floors, rubble, or midden deposits, causes the radar energy to be reflected back to the surface (Kvamme 2007). The velocity of this energy varies greatly, depending on dielectric properties of the subsurface materials. If velocity can be estimated, then return times of echoes from pulses give information on depth, while amplitudes indicate some-thing of the nature of subsurface changes (Kvamme 2007).

An additional source of data for the visualization of above and below ground surface features includes the exploitation of point cloud data. A point cloud is a collection of discrete three-dimensional locations (points) that can have additional metadata associated with each record. Point clouds appear realistic to even the most casual observer because of their three-dimensional nature. Active scanning technologies generate their own scanning energy and can record and even discover archaeological features at both site and landscape scales. These systems send out discrete pulses of light and record both how long it takes those pulses to return and how much of the original energy comes back. That information, when combined with data about where the sensor is positioned and how it is oriented with respect to the real world is used to construct the point cloud. Each point in the cloud represents a location where the light pulse reflected off of a surface (White 2013).

The active system that is used in this research is the terrestrial laser scanner (TLS). The term "laser scanning" describes any technology which accurately and repeatedly measures distance using laser pulse, by precise measurement of time needed for the laser pulse to travel from the object and back and transforms these measurements into a series of points, or a point cloud, from which information on the morphology of the object being scanned may be derived. (Mlekuz 2013) Terrestrial laser scanning (also known as ground-based LiDAR) is increasingly used as a method of collecting spatial data, and when supported by digital photogrammetry, can render quantitatively accurate and visually impressive representations of land surfaces (Entwistle et al. 2009). Terrestrial laser scanning enables the researcher to quantify and integrate previously implicit knowledge-based field observations of topo-graphic setting into a framework for interpreting an archaeological site and its characteristics (Entwistle et al. 2009).

Ultimately, given enough observations of a densely-covered landscape by an active scanning system, some inevitably come from the ground beneath or next to the cover and can be used in conjunction with an extrapolation process to reconstruct the ground surface. The more ground observations you have, the better the surface reconstruction (White 2013). The 3D laser scanning data and GPR survey information also share common characteristics in that both can be broken down into a series of spot readings or sample rates, in other words the data can be treated as points. This is most familiar as the basic form of laser scan data, the point cloud.

However, for GPR the archaeological deliverables mostly come in the form of 2D images. By producing the results of the GPR as a list of X and Y coordinates based on the relative grid positions and sample spacing, and treating the calibrated depth as a Z the data could also be interpreted like a point cloud. In this case the signal response then becomes the Intensity value just like the reflection of the laser from the scanner (Watters 2012).

An essential part to this research is the data fusion and integration of all data collections. Construction of multi-scale models can be time-consuming, but this is offset by the following advantages: much improved regional context that is immediately accessible visually when analyzing and interpreting more localized field datasets (Jones et al. 2009). Employing a combination of methods over a survey area can help provide information as to the nature, or material, of an anomaly, thus providing insight for site interpretation. Mapping the distribution of disturbances over a site can assist in the recognition of such disturbances generated through cultural activities revealing the spatial distribution and association with site features (Kvamme 2003). These independent datasets are combined in 3D space through their geospatial orientation to facilitate the detection of physical anomalies from signatures observed across various forms of surface and subsurface surveys. The data types are variable in nature and scale, ranging from 2D imagery to massive scale point clouds (Yu-Min Lin et al. 2011). The data fusion process is able to establish interrelationships and patterns between multidimensional data sets, and therefore improve the identification and interpretation of surface and subsurface traces, that may otherwise go unnoticed (Ogden et al. 2009).

Geophysical surveys have been employed on a variety of locations at GUCO (Cornelison et al. 2007; Cornelison and Groh 2007; Stine and Stine 2013). A variety of subsurface anomalies and features have been located. Because of its protected status as a National Park few of these items have been excavated. Most recently Stine and Stine (2013) conducted a magnetometer survey which covered 4675 m^2 and the GPR survey that covered 2714 m^2 in an area thought to be the courthouse. Almost 160 anomalies were recorded and mapped. Stine and Stine were granted a permit to excavate in a specific location within the park. It is highly probable that 2–4 new structures (foundations) were located; one was excavated and showed to be a stone foundation. One of the most interesting features located by the GPR was a subsurface anomaly between 45 and 50 cm in depth and trended north/south for over 30 m before entering a heavy shrub and forest area with dense secondary growth. In the open area there was a slight depression on the ground surface. This area was near what Ward and Coe (1976) reported to be the Americans' retreat road. The small trench was excavated over the anomaly. There was a light scattering of recent material on the surface of the excavation then sterile clay fill for a depth of over 45 cm. The excavation revealed a tannish brown lens of sandy soil with Revolutionary War period ceramics such as pearlwares and creamwares as well as lead sprue, copper disks; and a piece of swan shot all falling within the colonial period (Stine and Stine 2013). It could not be determined if this was the historic retreat road based on the results of the 2011 field season.

At this same location the goal is to examine the microtopography to search for any deformation related to a possible retreat road and/or gully that were prominent features in the battle but have since disappeared from the landscape. A comprehensive geophysical survey using ground penetrating radar (GPR) combined with a terrestrial laser scan (TLS) helps identify key elements in modeling this historic landscape. This provides not only provide a more comprehensive view above and below the surface of this feature, but demonstrates a new method of fusing datasets from differing sensors.

The discovery of the third line would help place other military units and ultimately lead to the location of the courthouse, a major goal of the 2011 project. Using various remote sensing and geophysical surveying techniques the road or gully may have been identified in a comprehensive three-dimensional visualization. The fusion of datasets from very different sensors provides a new way of examining the cultural and physical landscape thought to be the third line. As an emerging research topic this investigation demonstrates the capability to discover landscape features through nondestructive means. The implementation of methodology for the visualization of three-dimensional data from different types of sensors; Ground Penetrating Radar (GPR) and Terrestrial LiDAR(TLS) begins to illustrate the usefulness of combining data.

Methodology

The GPR survey was conducted using a GSSI ground penetrating model DC 3000 equipped with a 400 MHz antenna was used to conduct the site survey. The total area coverage for the entire study site was 2714 m^2 with standard transects. Transects were collected in 50 cm with a dielectric constant of 8 and in 16-bit format. All pre-fusion processing was completed in Radan 7 software. A linear feature approximately 50 cm in depth, varying in width and trending from north to south for approximately 68 m before entering a heavily wooded area was identified in profile. In Figure 2.4 the red box indicates the area of interest. The higher the amplitude the return from the GPR signal the more intense the coloration shown. A linear feature that extends to the north begins to emerge with a high amplitude signature (Figure 2.5).

Figure 2.4 Excavation (2011) of Road/Gully Potential Location

For the TLS scanning help was provided by the team from Auburn University using a Leica C10 laser scanner. The scanner ran six 360 × 270° scans. Scan setups were spaced anywhere from 60 to 150 ft. apart, depending on the density of the forest surrounding the scanner. The scans were registered together using seven targets, a number of which were entered into the scanner at each setup. In order to improve accuracy of the terrain measurements, the scanner was placed on a seven-foot-high tripod.

The increased height reduced the angle of the return laser and lessened shadows from low-lying ground cover. The data were initially preprocessed in Leica Cyclone software. The point cloud was interpreted into x, y, z coordinates (Figure 2.6).

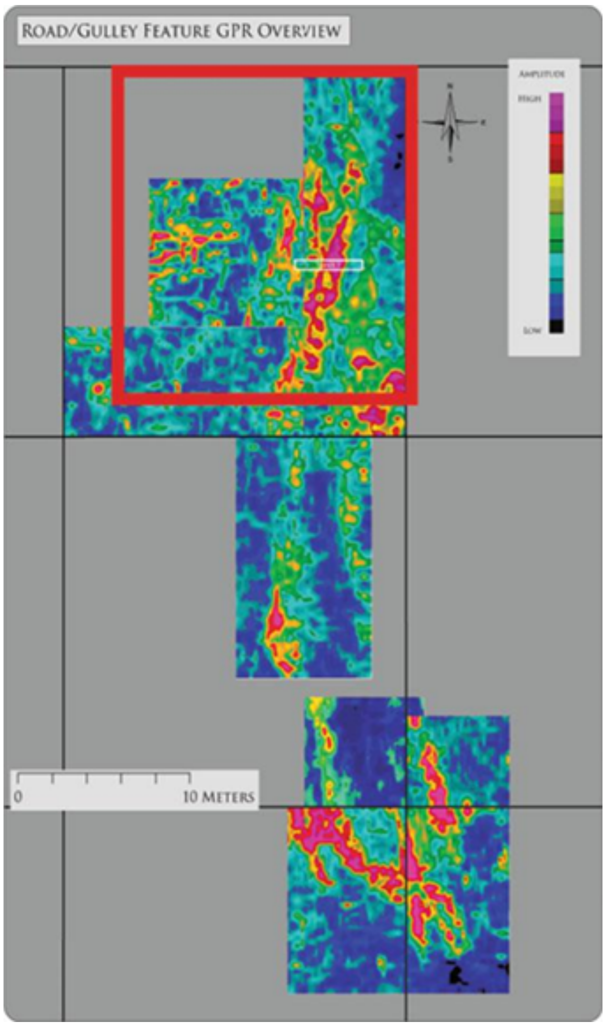

Figure 2.5 GPR Data Collection

Figure 2.6 Leica C10 TLS

In addition to GPR and TLS data collections, standard total station mapping was also conducted for registration of the two datasets. The deployment of a traditional total station survey provides accurate positioning for both data collections and for successful data fusion. A survey grade Topcon GR-3 Global Positioning System (GPS). The GPS antenna is capable of Real-Time kinematic (RTK) survey. The RTK survey method utilizes two GPS antennae: a stationary base that is set up over a point with known coordinates, and a manned, moveable, rover that optimally receives the same satellite signals as the base, but also receives instant correction via a radio link to the base antenna. This method enables a high level of positional accuracy that other GPS units cannot achieve. A traverse was begun by setting a GPS base station over Lincoln

Monument—a brass disk established by the North Carolina Geodetic Survey—using the Lambert Conformal Conic State Plane (feet) coordinates referenced to NAD83/86. A new datum point was then established with the rover positioned over semi-permanent marker such as a nail. The National Park Service requires all coordinate information in be completed in the Universal Transverse Mercator (UTM) projection and shown in meters. The projection and coordinates (including X, Y and Z) were, therefore, shifted to the UTM Zone 17, NAD83/86 using ArcGIS 9.3. Once the datum was established all additional datums, grid layouts and location points were completed using a Topcon GTS 233W total station with a Recon data collector equipped with Survey Pro 4.1.5.

The ground penetrating radar data is processed using GSSI Radan 7 software to normalize surface, velocity, and other standard corrections. After examining in the profile, an area of interest emerges indicating the road/gully feature previously discussed. These areas are then isolated by depth and are exported in the three-dimensional formatting of xyz. Where each depth slice of 10 cm to 1.50 m is exported with UTM NAD83 coordinates are represented as the x and the y with z being the elevation and a further attribute of amplitude return from the GPR antennae. In Figure 2.7 the yellow box indicates the area of the potential gully/road. In Figure 2.8, the area is isolated to show the point cloud derivative from the GPR used for exploration of fusion methods.

The terrestrial laser data was preprocessed at Auburn University in Leica Cyclone propriety software package. Once receiving the dataset from Auburn, the data converted to xyz formatting using Bentley Pointools. Since the fusion is based on the geographic coordinates of both the TLS data needed both georeferencing and registration of coordinates in order to fuse with exported GPR datasets. The TLS data had to be further clipped, gridded, and divided into multiple smaller subsets in order to be able to work within the computing power restraints. Georeferencing results in ESRIs ArcMap and LAStools proved unattainable due to computing power and software capability to handle such point clouds. Further attempts were taken Civil 3D CAD software and proved difficult. However, using the opensource software Cloudcompare allowed for partial alignment of small sections using previously collected total station ground points. Figure 2.9 illustrates the potential road area in the TLS point cloud.

The research goal was to determine if we could visualize in the datasets the road and attempt to fuse the GPR and TLS data together. Using Golden Software's Voxeler software package, both datasets can be imported multiple individual files to create three-dimensional point cloud. Taking a small area of the identified road feature and adding both sets of point clouds a preliminary proof of concept is achieved.

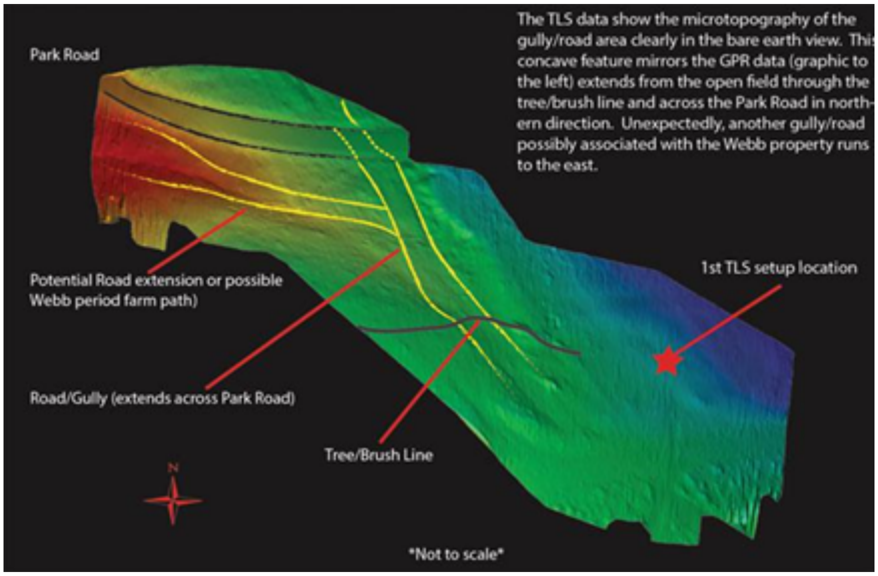

Figure 2.7 TLS Derived Elevation Model and Interpretation

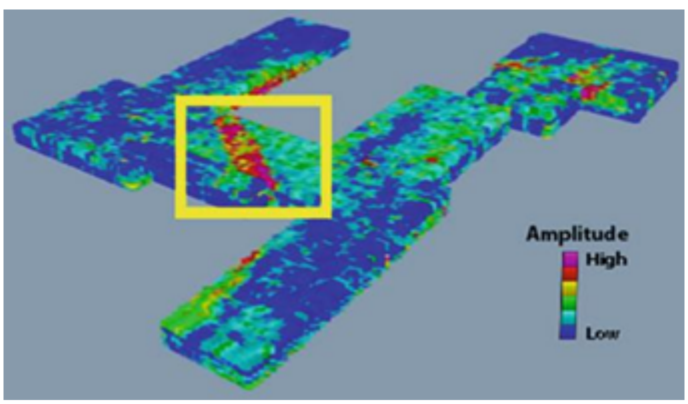

Figure 2.8 GPR in Point Cloud

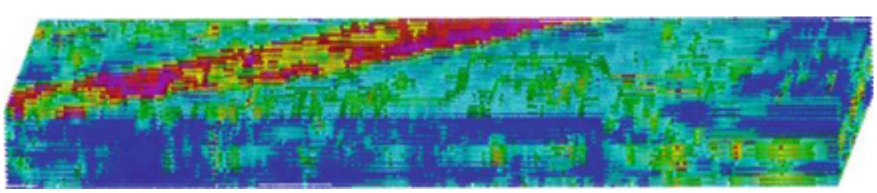

Figure 2.9 GPR in Point Cloud of Possible Portion of Road/Gully

Results

Initial results for the development of methods to export and fuse GPR and TLS data and create three dimensional files for modeling using Voxeler software proved successful. After exportation and alignment procedures were completed, Voxeler provides quick and easy to use visualization tools. The subsurface colonial road/gully can be visualized along the more open area of the site with its surface manifestation (the slight depression) mapped. Using the TLS data to follow the concave surface into the wooded area also proved successful. Figure 2.10 depicts the preliminary results from the data fusion using the coordinates and elevation as the attributes to match each point. The yellow box indicates the road/gully area of interest that appears in both datasets (Figure 2.11).

Working in wooded areas are challenging for these surveys. GPR data are attenuated by trees roots and moving the antenna through thick brush is not possibly. In some instances, cutting brush is an option but not on a protected site. The wooded areas surveyed contain dense brush and leaf litter, the methods using laser scanning resulted in a highly effective strategy for tackling such obstructed sites. The TLS data and post-processing measures did show a north south trending concave surface within the wooded area. The authors cannot of course state that this is a surface manifestation of the subsurface feature without excavation. The data and methods do however point to specific locations to test in the future. Methods from this research highlight the ability to take two different sensors and use them to examine subsurface and above ground landscape simultaneously. A further benefit from the research is the ability to achieve results from enormous datasets while operating with low level computing power found in traditional computer labs. Also, the results show what can be gained while working with opensource and low-cost computer packages.

Figure 2.10 TLS Point Cloud Highlighting the Potential Road/Gully

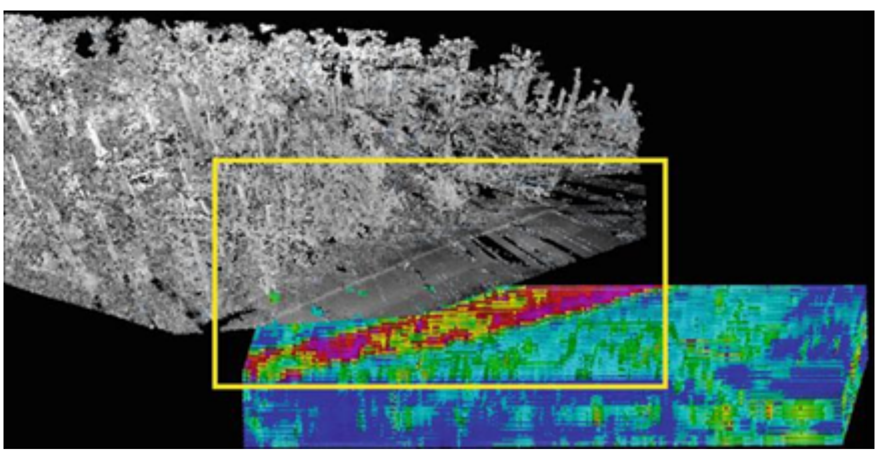

Figure 2.11 Data Fusion of GPR and TLS Datasets

Discussion

This research was to design to develop methods to fuse subsurface data collected by GPR with surface information provided by the TLS. Literature is lacking in methods to take these two widely used data sets and combine them to visualize the landscape above and below ground. Difficulties encountered by the authors included learning and integrating the variety of software used by the different researchers. The size and resolution of the datasets created, seamless transfer of the data created processing and storage issues on our computers. Each sensor required a variety of differing preprocessing software before the datasets can be exported for fusion to occur. The processes derived are considered as an initial step which we hope to develop in the future.

The research reveals that new and improved methods are needed to enhance future similar endeavors. Repeat collects and subsequent point cloud collects are needed to generate the needed coverage for the data fusion process. Alignment issues need to be further accounted for due to the lack of proper software and georeferencing. Difficulties arose due to the numerous software packages and multiple iterations were needed in order to export, fuse, and visualize all data. Topographic correction of the surface layer from the GPR data are needed to better represent the nature of the surface. Future efforts will involve building on the methods developed during this research and applying to other historic sites with spatial research questions. A critical component of future work would assess the accuracy of the point to point data fusion through the application of geostatistical methods. The value of future research would be to develop additional methods to address in the field registration, and enhanced processing of datasets through access to more powerful possibly supercomputing opportunities. Ultimately the authors would like to create an immersive dataset creating a virtual landscape of the historic site where the researcher and community can virtually navigate the site and examine all the features above and below ground.

The second research goal was to investigate the extent of the subsurface feature as in was seen to the open area of the site. Walking into the wooded area the concave feature quickly disappeared, thus ruling out the use of traditional total station survey, (it's hard to map what you cannot see!) The use of the TLS and the generated point cloud allowed the researches to identify areas that seemed to be a continuation of the subsurface road/gully. Hopefully future test excavations will be able to verify or reject this possibility.

Conclusion

This research investigated methods to fuse GPR and TLS data. The data are quite different one is generated from a radio wave the other from a light source. One arrives with discrete x, y, z coordinates the other must have the coordinates generated from a time slice. The initial work in this area has proved successful resulting in a fused dataset showing below ground, surface and above surface 3D points. The research also was successful in delineating a surface feature, easily seen in the open area but hidden by dense shrubs and leaf litter in the wooded part of the site. The TLS data collection and post-processing indicated the possible continuation of the feature and will hopefully be verified by future excavation.

The data fusion of the sensors allowed for detailed three dimensional above and below ground surfaces. The techniques have shown the ability to document archaeological features from more than one perspective and where traditional techniques (shovel testing and pedestrian survey) have proven less successful. The identification of a buried surface feature (road/gully) combined with the vague surface elements of the feature continuing in the woods creates an historic land-scape. The potential of this fusion means that future excavation of the area should reveal the exact nature and direction of the feature. Both the gully and the road are keys to unlocking the location of the elusive third line of battle at Guilford Courthouse; giving archaeologists, historians and geographers a more complete picture of the battlefield landscape.

The authors are continuing the application of multidimensional data fusion methodology from GPR and TLS to a variety of other archaeological and historical sites. The techniques are transferrable to any location that is looking to view above and below ground archaeological features and make them visible for interpretation in the context of the landscape. For example, current research is being conducted at the House in the Horseshoe (Alston House) State Historic Site located in Sanford, NC. The Alston house is an 18th century property with a complex history of land use. The property was the scene of skirmish between North Carolinians loyal to the British crown and those in favor of independence. Unlike Guilford Courthouse Battlefield, a still extant structure is present with the original bullet holes. Current work suggests that the visible topography has been altered. In the 19th century, the site was a robust plantation of a NC governor, including his household and the enslaved, encompassing much more acreage. The site provides a unique opportunity to study the landscape changes brought about over time by these varying scales of the property’s uses.

Fusion techniques at the House in the Horseshoe include an extensive geophysical survey using GPR, gradiometer and resistivity/conductivity. This survey has already provided insight into the buried features located on the property and results were coordinated with archaeological testing. In addition to the geophysical survey methods, the House in the Horseshoe site presents an opportunity to examine the historic structure of the Alston House through passive scanning. The Alston House is used to test the hypothesis that using a SLR digital camera to capture multiple images of the Alston House can provide an accurate point cloud. The structure is imaged through acquisition of multiple photos taken of the house from multiple angles.

Using software such as Structure for Motion (SFM), AGIsoft Photoscan, and Meshlab a three-dimensional point cloud can be created to create a realistic model. The goal is to implement this technique and then test the accuracy of the point clouds to the real-world points from a total station survey. Goals of the project would be to then compare the digital photography techniques to a traditional TLS collection, perform accuracy assessments, and ultimately conduct the data fusion process incorporating the geophysical survey data. The specific techniques defined in this research are being refined for different historical landscapes with different research questions. Archaeologists, geographers, and remote sensors interested in landscape analysis will find these techniques informative and relatively inexpensive. Fusing a wider selection of sensing data will hopefully allow for the discovery, identification and interpretation of below ground features and their surface interactions

CHAPTER III

THREE-DIMENSIONAL MODELING USING TERRESTRIAL LIDAR, UNMANNED AERIAL SYSTEM, AND DIGITAL CAMERA AT HOUSE IN THE HORSESHOE STATE HISTORIC SITE, SANFORD, NORTH CAROLINA

Introduction

High density surveys and measurements of a site, specifically a structure, provides detailed digital information on structural features, adds to the knowledge base and helps promote better methods to conserve and record a property. High-density survey and measurement (HDSM) refer to the range of technologies that provide the ability to measure, record, and analyze spatial and physical properties of landscape features with extreme precision and accuracy. (Optiz & Limp, 2015) The application of geospatial methods in geography, archaeological to historic sites has proven to be a valuable asset to various research projects worldwide. (Optiz & Limp, 2015, Torres J. et al., 2014, Fernandez-Hernandez et al, 2015) The ability to digitally model and measure historical features has proven highly valuable in preservation efforts, the study of historic sites over time, and the knowledge of a specific landscape. (Remondino F. , 2011)

Advancements in noninvasive technologies and methodologies f has provided researchers an array of powerful tools to investigate and understand historic sites. Among these new remote sensing tools are high resolution aerial and satellite imagery, airborne and terrestrial laser scanning (TLS), and imagery from unmanned aerial systems (UAS).

Regarding the UAS close-range photogrammetry provides a new way of viewing historically relevant locations (Fernandez-Hernandez et al, 2015). The Alston House property at House in the Horseshoe State Historic Site provided a chance to examine exactly how much information could be derived from a combination of methods. There are two different research components to this study, modeling a structure and modeling landscape. The structure modeling section compares three different remote sensing approaches to the capture and three-dimensional display of a historic building. A detailed comparison is made among the unstructured models generated from digital camera photography, a terrestrial laser scanner (TLS) and an unmanned aerial systems (UAS).

An evaluation of the three methods was performed to measure the accuracy, cost and ease of each for producing three dimensional models of the structure. Examining these differing methods can be used to draw conclusions as to the most viable means of model generation and dataset manipulation. It is important to note that in the modelling of the historic structure, the methods comparing the drone and the camera are uncontrolled.

Total station measurements were not taken from the locations of the photo capture, but are measured from the terrestrial LiDAR instrument. This comparison is a preliminary attempt at comparing data captured from a UAS, camera, and terrestrial LiDAR sensor. The measurements are relative to each other and future efforts would involve total station measurements.

The second component to the research focuses on landscape modeling which expands upon the structure modeling by examining the immediate surrounding terrain.

Historic aerial photography, total station survey data, UAS imagery and a generated digital elevation model (DEM) were all incorporated to determine their levels of accuracy and the forms of new information that could be discovered by their application in examining historic landscapes.

Literature Review

3D modeling is the process used to convert point cloud information into a more useful product such as a surface or geometric model. (Historic England, 2011) A point cloud is a collection of discrete three-dimensional locations (points) that can have additional metadata associated with each record. Point clouds appear realistic because of their three-dimensional nature. Terrestrial laser scanning, digital photography and unmanned aerial systems (UASs) imagery collect data while mapping and imagining landscapes. These technologies record relative x,y,z positions to create the form of the structure. (Optiz & Limp, 2015)

Two types of point cloud technologies exist, active and passive. Active collection involves the emission of energy to generate distance measurements from the reflection of that energy or signals off surfaces to generate the point cloud. Terrestrial laser scanning (TLS) or ground based Light Detection and Ranging (LiDAR) is an example of active point cloud collection. TLS sensors operate by transmitting of a pulse of light that bounces back back to the instrument which records the return time and a range calculation. The returned energy is displayed as intensity and an onboard camera system colorizes the point cloud with the traditional RGB schema. (Beraldin et.al, 2010)

Passive sensors, such as UASs and traditional hand-held digital cameras, record energy that is reflected off surfaces. Traditionally, photogrammetric principles would be employed in the processing and analysis of image data. Photogrammetric methods are able to provide detailed 3D information with estimates of precision and reliability of the unknown parameters from the measured image correspondences (tie points). (Remondino F., 2011) For UAS and digital camera collects, the data is not structured as in aerial imagery for photogrammetry. For this research, the data is known as unstructured data using structure from motion algorithms (SfM) instead of traditional photogrammetric processing. The SfM algorithm defines the camera's interior orientation and simultaneously calculates the exterior orientations using tie points identified on the input images in a process known as bundle adjustment (a reference to the bundles of light rays converging on the optical center of each camera). This allows SfM to minimize the projection errors between observed and predicted points. The camera calibration can be calculated by the software 'on the fly'. (Historic England, 2017 HistoricEngland.org.uk/advice/technical-advice/recording-heritage). The resulting 'model' will be in an arbitrary coordinate frame and at an arbitrary scale if no formal control is available. Therefore, having precise measurements with which to tie the model is important. In this case, both total station and the TLS data were used for survey control for the computed positions of the cameras and a check on the overall accuracy of the model.

Exploring the accuracy, ease of use, and cost effectiveness of these outlined techniques and sensors in the analysis historic spaces may allow for a more comprehensive understanding of these areas. Other benefits of three-dimensional historic modeling include the generation of accurate and realistic information of the size and shape of a feature located in a historic landscape as well as providing precise records and models of a building façade as in the case of the Alston House. (Historic England, 2017 HistoricEngland.org.uk/advice/technical-advice/recording-heritage)

Three-dimensional modeling provides not only the recording of a structure, but enhance preservation and conservation efforts as well. (Remondino F., 2011) When studying the built environment, three dimensional models allow for a more detailed analysis of the structure. This methodology for capturing structural data can better inform the study of historic events and the relation to the built environment. (Optiz & Limp, 2015). Research by Chiabrandoa et al., 2016, Kersten et al., 2015, Remondino & Rizzi, 2010, Xu et al., 2014 etc., demonstrated the usefulness of an interdisciplinary methodological approach between the Spatial Sciences and Archaeology fields.

Aerial and ground based remote sensing surveys are becoming more common and are proving increasingly valuable to the study of the historical landscape as well. Current instruments can provide a dense dataset for the examination and mapping of buried elements of the built environment. (Leucci, et al., 2015) As systems become more affordable, research is being conducted on how to best apply these methods aid our understanding of complex historic sites. For example, research by Turner et. al 2018, demonstrated that such geophysical surveys provide an opportunity to evaluate how each instrument captures structural remains through ground truthing for accurate confirmation. In terms of visualizing multi-sensor datasets in a three-dimensional model, Curry et al, 2016 outlined a methodology for the fusion of point clouds from GPR and TLS collects. Fernandez-Hernandez et al (2015) described a novel, low-cost, user-friendly photogrammetric tool for generating high-resolution and scaled 3D models of complex sites. The results obtained with unmanned aerial systems (UAS) photogrammetry of an archaeological site indicated that this approach is semi-automatic, inexpensive and effective. Arato et al. (2014) applied Ground Penetrating Radar (GPR) and UAS imagery along with historical maps in the search for possible submerged archaeological remains, with emergent methods for quick large-scale mapping. The authors clearly defined an effective method for data capture and collection. Uysal et al. (2014) detailed outcomes of a study showing that the data derived from UAS photogrammetry has adequate accuracy very near to Real Time Kinematic (RTK) GNSS data. The possibility exists to use the UAS photogrammetry in place of traditional ground surveying for map production and for other engineering applications with the advantages of being lower cost, more time effective, and greatly reducing field work.

Methodology

In 1772, the Philip Alston plantation complex became known as the House in the Horseshoe. The property is nestled along a horseshoe shaped bend of the Deep River in Sanford, North Carolina. On July 29, 1781, a legendary skirmish occurred between Alston, his fellow patriots, and a larger group of Tories loyal to the crown led by David Fanning. The Alston home was attacked leaving still visible bullet holes throughout the structure. The property, following Alston, was purchased by the future Governor of North Carolina, Benjamin Williams, who served four terms (1799-1802, 1807, and 1808).

Williams accumulated 103 slaves who worked approximately 300 acres of cotton annually. Currently, the site is a North Carolina State Historic Site managed by the North Carolina Department of Cultural Resources. (NC Historic Sites website, 2018)

The Alston House at the House in the Horseshoe State Historic Site presented an opportunity to model a structure for the purposes of testing techniques and methodologies, as well as assisting in the preservation and cultural resource management of an historically significant structure. The structural modeling component of this research examines multidimensional data from both ground-based and airborne remote sensing. The generation of high-density survey data in the form of point clouds allows for modeling of landscape features that may otherwise be unseen and provides a nonintrusive measurement option. Also, using point clouds to model the structure enables a one to one comparison of the various methods.

Figure 3.1 The Alston House, House in the Horseshoe

The property has seen various occupations overtime including revolutionary era skirmish. This historic home provided an ideal structure to evaluate the ground based and remote sensing techniques of this study. (Figure 3.1) For the second research question, landscape modelling, the side yard adjacent (northwest) to the structure was chosen as the area of interest. The area is an open plot consisting of a few medium sized trees scattered throughout and a thin tree line surrounding the outer edges. (Figure 3.2) The field gradually grades down to the river. A small subsection was designated as the region of interest. Using the remote sensing tools available, various methods were evaluated to view variations in the terrain.

Figure 3.2 UAS Orthophoto of Property

In the creation of the 3D models, software relying on structure from motion (SfM) was used. SfM is an approach that operates under the same rules as stereoscopic photogrammetry, whereas the structures can be recreated from a series of overlapping images (Westoby et al., 2012). Once general correspondence has been estimated within the collection of unstructured imagery, the next step is the creation of structure from motion (SfM). Estimating view points and recreating scene geometry is a classic problem in photogrammetry when dealing with image correspondence. Two or three images are typically used to reconstruct a reliable initial geometry which is then followed by a process known as bundle adjustment. Bundle adjustment is the process of minimizing the re-projection error through refinement of camera and point parameters and is applied as images or batches of images from the collection are added to the initial seed (Triggs et al., 1999). In the case of the global approach, the bundle adjustment is applied to the entire image correspondence set which is typically more efficient. The final product from this is a sparse point cloud which can then be used in the generation of a denser point cloud and mesh generation.

To generate the point clouds a series of photos taken by a handheld traditional Nikon D40 digital camera, costing $499, were acquired of both leaf off and on seasons. Unfortunately, the varying camera positions could always capture the same percentage of the façade. The imagery used for the model generation included 124 images taken sequentially around the structure. The total collection of images from both seasons took approximately 2 hours.

The software packages used to create the models included Agisoft Photoscan ($200), and Autodesk Recap360 Pro ($300 or free for students) Photoscan uses the structure from motion (SfM) process, whereas the imagery can be captured from any angle and the structure reconstructed only if features are present in at least two photos. (Agisoft User Manual, 2017) Agisoft Photoscan utilizes several stages of processing that lead to the creation of the final model. The first stage involves the alignment of the imagery or feature matching of common points resulting in the generation of a sparse point cloud. Feature matching refers to the capability of finding the same point or feature under different viewing and illumination conditions (Barazzetti, et. al, 2010)

In the next stage a dense point cloud is constructed from the estimated camera positions in relation to the images. Once the dense point cloud is available the mesh can be built showing the structure's geometric surface. The final step is the texturizing of the model. This gives the model a realistic look to replace the dense points. Ultimately, the editing of the outlying points and clipping of erroneous data is capable within the Photoscan software. The time for the initial creation of the model was 15 minutes.

Autodesk Recap Pro™ is a Computer-Aided Design (CAD) software for capturing and integrating three-dimensional laser scanner or point cloud data into CAD renderings. Recap360 Pro™ has a feature called "Photo to Model". The structure from motion algorithms are also used to create the model. Once the data were imported to the Recap™ software, the point cloud was accessible to edit, navigate, and measure. Processing of the images to create the model in Recap360™ took approximately 10 minutes. (Figure 3.3)

Figure 3.3 Digital Camera Photo Model

For the ground-based modeling of the structure, a terrestrial laser scanner was utilized. Laser scanning from any platform generates a point cloud: a collection of XYZ coordinates in a common coordinate system that illustrates the spatial distribution of a subject. (Historic England, 2017 HistoricEngland.org.uk/advice/technical-advice). The scanner deployed for this study was the Faro Focus3D X330 (total instrument coast of $18,350). The system is very portable and the setup used six targets (spheres) placed in six different arrangements surrounding the structure (totaling 36 controlled locations for registration). Placement of the targets and number of scans were determined based on the constraints and task requirements such as full coverage, overlap ratio, point density, and incidence angle. The ground control points for the survey were provided by the scanner's placement locations. All of the scans were viable and none were omitted from the final model. The points were colorized from the 17 photographs taken simultaneously on board the TLS system at each scanning station to complete the point cloud. The entire scanning process took roughly 7 hours to complete. (Figure 3.4)

Processing involved the alignment of the point clouds and the georeferencing of the target spheres. Each scan required registration through an automatic alignment using targets and a global alignment to tie the cloud together. (Remondino F., 2011). As stated the six spherical targets were placed six different arrangements to allow for accurate alignment of scans. The scans were pre-processed in the proprietary Faro Scene™ software. Using a combination of target and cloud to cloud registration, the point clouds were stitched together and the data were translated into NC State Plane coordinate system based on the positions acquired from the TLS's onboard Global Navigation Satellite System (GNSS) receiver. The results were indexed into the Autodesk Recap format. The resulting point cloud amassed more than a billion points. The final step in the creation of the TLS model was completed with Autodesk Recap360 Pro™ . Once the file was imported to the Recap software, the point cloud was easy to edit, navigate, and measure.

Figure 3.4 Terrestrial Laser Scanner (TLS) Model

The UAS used in the study was a quadcopter made by DJI called the Phantom 4 Professional (P4P). ($1499). The P4P is an electric, multirotor system fitted with a gimbal mounted 19.96-megapixel digital single-lens reflex (DSLR) camera. It has a mechanical shutter with a 1-inch complementary metal-oxide semiconductor (CMOS) sensor. The maximum image size of the camera is 5472 x 3648. Additionally, the UAS is equipped with a barometric altimeter and a navigation grade GPS receiver capable of using both the GNSS and GLONASS systems. (DJI, https://www.dji.com/phantom-4/info) A total of 324 images were captured in four rounds of collection around the structure with a resolution of 2.83mm and 484,857 tie points. For the generation of the UAS 3D model, Agisoft Photoscan™ was used. Photoscan utilizes a structure from motion (SfM) process as discussed previously. While the imagery can be captured from any angle the structure can be reconstructed only if features are present in at least two photos (Agisoft User Manual). Photoscan has several stages of processing that led to the creation of the final model. The first stage involved the alignment of the imagery or feature matching of common points resulting in the generation of a sparse point cloud. Feature matching is defined as the capability of finding the same point or feature under different viewing and illumination conditions (Barazzetti et al., 2010). In the next stage, a dense point cloud (69,483,772 points) was constructed from the estimated camera positions in relation to the images.

Once the dense point cloud was available, a mesh was built reflecting the structure's geometric surface. The final step was the texturizing of the model. This gave the model a realistic look to replace the network of dense points. All additional editing of the outlying points and clipping of erroneous data was achieved within the Photoscan software. (Figure 3.5)

Figure 3.5 UAS Model

In order to fully evaluate the three models, a test to see the “match” or accuracy between the three datasets was required. For the comparison, CloudCompare, an open source software was used. ($0) CloudCompare is a 3D point cloud editing software that allows for direct comparison of two models. The ultimate goal of comparing the three point clouds was to approximate the accuracy or “good match” between both models. In order to determine the accuracy, it was critical to scale and register the models to one another. It is important to note that for the scaling, registration, and comparison the TLS model was the reference model. Both the digital camera photo model and the UAS model were aligned to the TLS model for evaluation. The TLS model served as the reference model as it is equipped with survey grade equipment thus providing the most standard and accurate point measurements. The datasets have such large point clouds that for the comparisons only a portion of the models were processed for alignment, registration, and measurement. For the comparison, only a portion of the models processed for alignment, registration, and measurement. For this assessment two subsections were chosen, the chimney side (the southern chimney clear of vegetation) and the steps on the west of the house. These sections were chosen for their completeness in both models and as they contained angles from which measurements could be taken easily and consistently.

The UAS, TLS, and photo models (figures 3.3, 3.4, and 3.5) are visibly distant from each other in both study areas when initially loaded into the software. The goal is to scale the models and then complete registration for a more one to one comparison. The first step is to scale the point clouds in order to make them the same size. The next stepis to measure the length of this element (or the distance between the two specific points) on the entity with the larger scale. The following formula was used for scaling. Note that the TLS model was always the referenced model.

Sf = Dmax/Dmin

Sf = Scaling factor

D_{max} = TLS model measurement D_{min} = UAS model measurement.

D_{max} is the measured distance between two points on the TLS model. D_{min} is the measured distance on either the UAS model or the photo model at the same location on the structure (i.e. on the chimney or bottom corners of the house). Finally, the Sf (scaling factor) computed was entered into CloudCompare's multiply/scale tool, which resulted in the resizing of the two models so they could be viewed at the same size.

It is important to point out that the objective was to test the "match" or similarities between the UAS, TLS, and photos. The accuracy is relative to the TLS data as the base for comparison not actual location data. Next, using Cloud Compare's Iterative Corresponding Point (ICP) tool for fine registration, a registration of the models was completed to allow for comparison and ultimately a rough superimposition of one model onto the other. The ICP algorithm takes point cloud as the reference (TLS) and the points of the other model (source)are registered to best match the points of the reference data.

The algorithm iteratively revises the transformation (combination of translation and rotation) needed to minimize an error metric, usually a distance from the source to the reference point cloud, such as the sum of squared differences between the coordinates of the matched pairs. (CloudCompare, Chen & Medioni, 1993, Besl & Mckay, 1992) All clouds were finely registered through the algorithm's iterative process. For comparative purposes, the photo model and UAS model were also independently registered to the TLS model. A root mean square error (RMS)was generated for the fit of each model. An RMS is calculated by taking the squared distance between one-point cloud and it nearest neighbor in the reference cloud, divided through the number of points from data cloud and extract the root. The following table details the RMS for each model by sample area in comparison to the reference model (TLS).

Table 3.1 RMS of Photo and UAS Models Compared to TLS (Reference Model)

RMS of Photo and UAS Models Compared to TLS (Reference Model)		
Model	**Sample Area**	**Registration RMS**
Photo	Chimney	0.73
	Bottom Corner to Corner (House)	0.98
UAS	Chimney	0.17
	Bottom Corner to Corner (House)	0.65

The last stage of evaluating the various structural models, involved the determination of the closeness of the models. Once the fine registration was completed, the cloud to cloud distance measurements were taken. The point cloud to point cloud distances were computed in CloudCompare as well. Using the defaults given, CloudCompare searched the nearest point in the reference cloud and computed their Euclidean distance. (CloudCompare documentation) The distances were colorized and the following figure were generated for each model. Note that the points farthest away from the reference cloud are shown in red. (Figure 3.6)

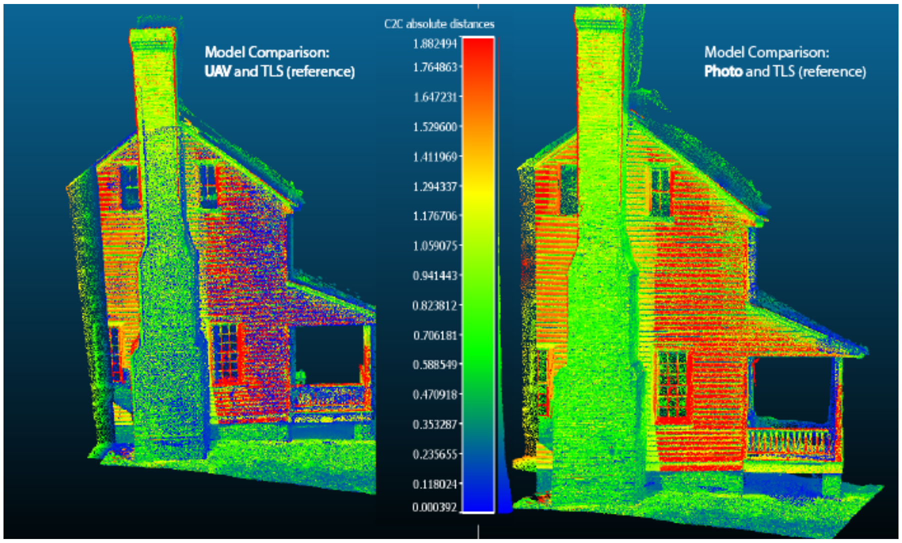

Figure 3.6 Cloud to Cloud Distance Comparisons (Chimney Sample Area in cm)

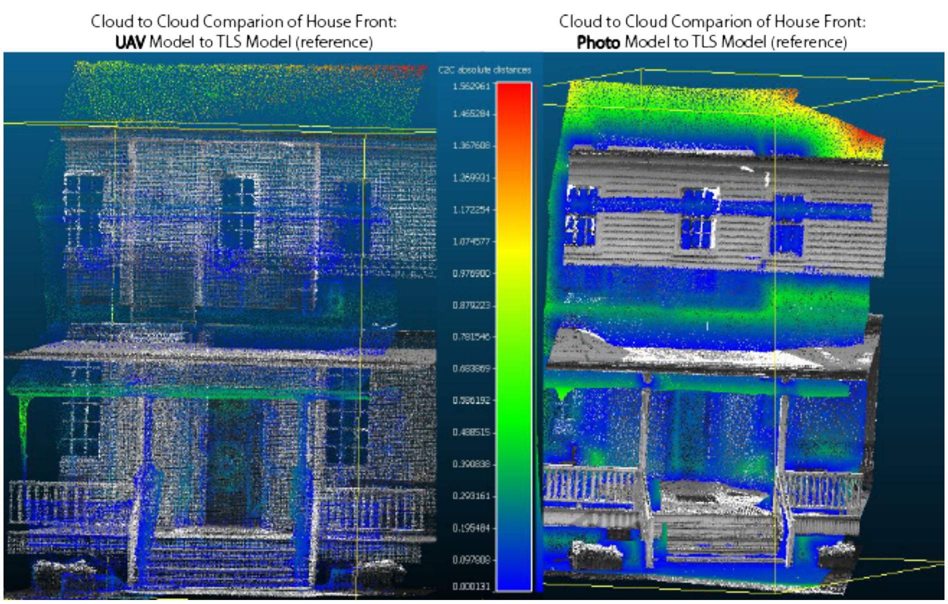

Figure 3.7 Cloud to Cloud Distance Comparisons of UAS and Photo Models of the Front of the House (Corners) to the TLS Reference Model

Results

The 3D models were compared to one another for visualization and completeness as well as the time and costs needed to create the model. The visualization factor was a qualitative measurement of how realistic was the depiction created by each sensor. Another key characteristic important to the viability of each model was the degree of completeness. More completeness included fewer smears, redundancies in points, erroneous points, and/or gaps in the datasets. Finally, each model was evaluated on the cost and the time necessary for creation.

The terrestrial laser scan method produced a robust point cloud enabling more of the structure to be visualized and measured. As with the camera model there could be some significant cleanup of holes and erroneous points, i.e. vegetation in the dataset. However, the rendering of the model was denser and more informative. The laser scanners were not as versatile as cameras with regard to capturing data, as they required far more time to scan the object, whereas a camera can capture a scene almost instantaneously. Laser scanning required line of sight to the object being recorded, meaning that it cannot see through objects (including dense vegetation), and it cannot see around corners. (Historic England, 2017 HistoricEngland.org.uk/advice/technical-advice/recording-heritage)

The results of the digital camera collection produced a viable 3D model in terms of visualization quickly and effectively. It is also noteworthy that there was obviously significant warping of some of the areas along the porch, roof, and upper middle window. (Figure 3.8). Further refinement of the various steps in the process and added images from more angles could alleviate these discrepancies. Imagery taken from cameras with highly accurate GPS embedded or tied in situ to a survey point would aid in decreasing gaps in the dataset. In the Recap360 model, gaps in the roof and porch were similarly present as in the Photoscan model. The model was realistic in that the structure was visible and has real world coordinates, but is visually incomplete and practically unusable. Clearly, the most effective way to remedy the level of incompleteness is with a denser collection of photos. Additional photos would eliminate more of the gaps. Further editing and feature matching may prove beneficial in eliminating the smears, gaps, and erroneous data points.

Figure 3.8 Photo Model Warping and Gaps in Data Coverage

The cloud to cloud distance comparison of the sample chimney and front of house areas produced mixed results. The chimney sample showed a closer alignment between the photo point cloud and the TLS reference point cloud than the front sample measurements. Neither was as efficient as the UAS model which would be expected. Furthermore, the large distances between points found only in the front of the house contributed to the decreased usability of the photo model. Although, having the photo model was valuable when making an initial model of the structure, when actually comparing the measurements of the point to cloud to a survey grade instrument, the ineffectiveness of the model became apparent. The UAS collection produced a more complete and full point cloud of the entire structure than the other methods. The ability to collect at high repetitions, multiple angles and heights with greater overlap created a model that more closely aligned with the TLS model while extending the coverage along the roof of the structure. Even with the dense point cloud, some areas were still not completely collected. Such areas included under eaves and along some window edges. Again, vegetation was partly to blame for the obstruction. The current work only allotted four levels of collections at four different consistent altitudes. To alleviate the gaps more levels of collection around the house at different altitudes is recommended, particularly more time spent capturing data from troublesome areas with obstructions. The cloud to cloud comparison of the UAS point cloud model to the TLS reference model illustrated a closer alignment between the two datasets. The chimney sample area was most demonstrative in highlighting the distances.

In the front of the house there was a close alignment along the front corners of the structure, but as the models moved higher up the structure the more the point clouds diverged. Further refinements of the individual models could be useful in enhanced alignment between the two point clouds. The second phase of the project was to examine the landscape using the UAS data collection of the property. High-density survey and measurement (HSDM), can capture the microtopography at the landscape scale providing a potential glimpse of embedded features and provide insight into discovery and preservation. Whether the methods of study are extensive or intensive neither provides the insight to the landscape on their own. Using HDSM sensors and methods of collection can answer some questions, and may also provide a new set of inquiries that would need to be addressed by more intensive surveys such as excavation. (Historic England, 2017 HstoricEngland.org.uk/advice/technical-advice/recording-heritage)

The research conducted in this phase utilized many types of datasets. Current and historically aerial imagery was acquired for comparative purposes. Fortunately for this site there was an extensive set of historical imagery that recorded what the site looked like at various times in the past which was used to visualize the change over time of the property. In the case of the study area, imagery from 1939 played a key role in assessing change in the property. It is important to note that in 1939, the imagery indicated a small structure located to the edge of the study area. This structure remained intact until the 1983 imagery. (Figure 3.9)

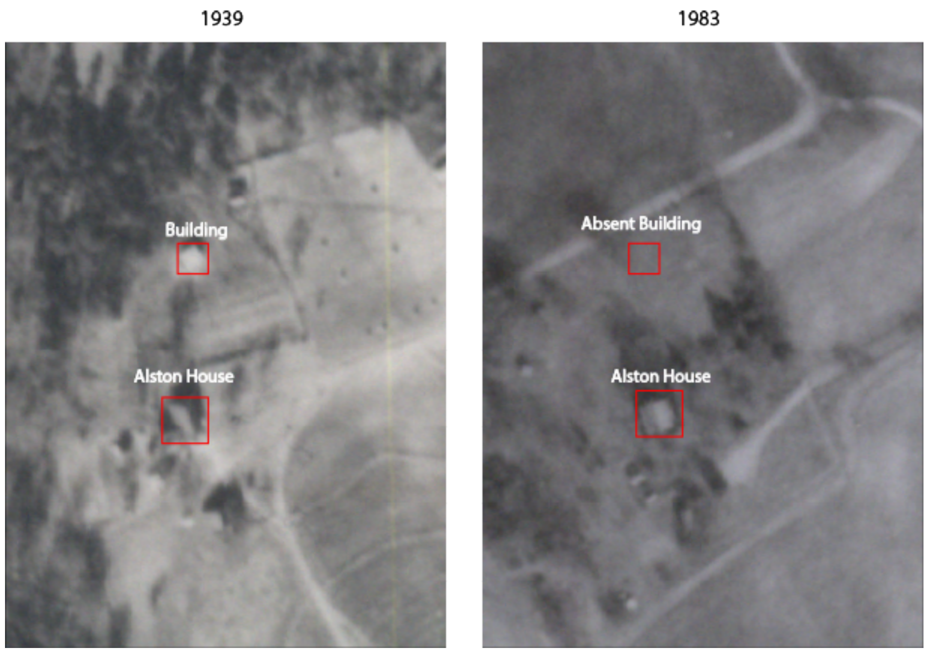

Figure 3.9 Historic Aerial Photography (1939 and 1983)

Some of the more traditional methods for creating digital elevation models (DEMs) can be costly, i.e. LiDAR and/or very time intensive total station surveys. However, the State of North Carolina has a wealth of LiDAR data that provides wall to wall state coverage. The decrease in cost and increase in availability and quality of UASs has provided a quick and more affordable means of generating DEMs. Close range photogrammetry from these platforms has enabled more robust studies of a wide range of study sites.

For the UAS collect, a flight plan was first created. This plan, based on the area of interest, was recorded on the map. Takeoff and landing points were designated as well as flight direction and height. After creating the flight parameters, the UAS was able to then perform an automated flight without user input. In this study the coverage area was

0.0357 km^2 or 8.82 acres with 65 total images acquired. The flight altitude was 62.9m, well above the tree line and 162,011 tie points were captured for generating the model.

Agisoft PhotoScan™ was used for all UAS data processing. The first stage was camera alignment. To do this PhotoScan searched for common points on imagery and matched them. By determining the position of the camera for each picture in the matched pair the software was then able to refine the camera calibration parameters. Once this was completed, a sparse point cloud and then a dense point cloud were generated. After the adjustment of these data, the 3D georeferenced point cloud was generated directly. The georeferenced sparse point cloud consisted of 162,011 points and the dense point cloud used for DEM generation had 36,604,315 points. (Figure 3.2)

In the next step a surface mesh was generated or in this case the DEM. This was a 3D polygonal mesh model that represented the objects surface based on the dense or sparse point cloud. A DEM represents a surface model as a regular grid of height values. DEMs can be rasterized from a dense point cloud, a sparse point cloud or a mesh. The resolution of the DEM for this study was a 9cm pixel calculated from the average point density. Once the DEM is created then it can be texturized generating an Orthophoto. The orthophoto is a high-resolution imagery product based on the source photos and reconstructed model. (Figure 3.11)

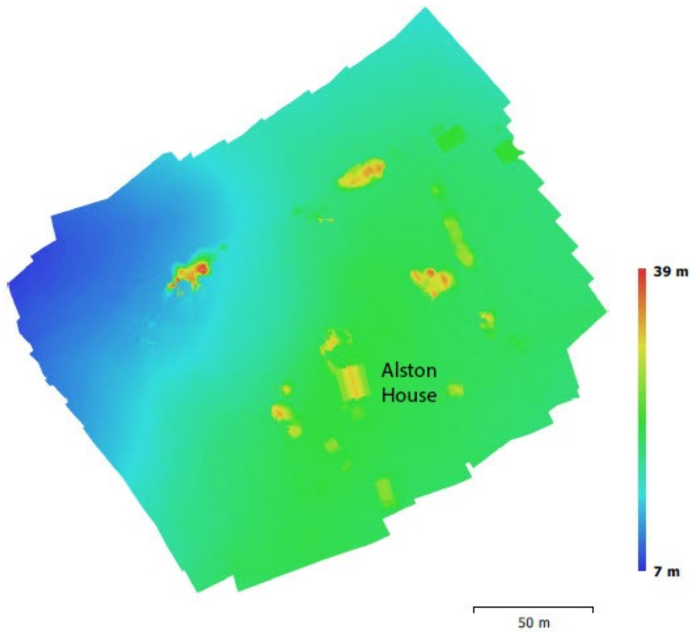

Figure 3.10 Digital Elevation Model

The final evaluation involved the UAS DEM accuracy compared to the total station survey. Using the total station points gathered from the research completed by Turner & Lukas (2016). A total of 28 test points to correspond to the DEM and generated from the UAS imagery. Both the datasets elevation (z) values were converted to cm. For the elevation error (z error) an RMS calculation was performed.

Dz = UAS Elevation

Tz = Total Station Elevation n= Number of samples RMS = sqrt ((Tz-Dz)^2/n)

The RMS for the study was 8.32 cm. The result, although higher than 1, is promising considering a number of factors. The total station data was collected using highly accurate survey grade instrumentation. The survey was conducted within a precise ground-based study that involved a large number of GNSS survey point collects. The total station points were also collected in 2013 for another study, so changes were possible. In contrast, the UAS data was captured in 2018 for the specific purpose of DEM formation. Despite the temporal, sensor, and objective purposes the degree of error between the two datasets is promising.

Conclusion

The objective of the study was to examine whether photo generating models could be compared effectively to traditional laser scans. Table 3.2 details the study's findings regarding visualization and completeness, cost, and time between a photo generated, professional terrestrial laser scan, and a UAS model.

Table 3.2 Comparison of the Three instruments for Creating Three-Dimensional Models

Comparison of the Three Instruments for Creating Three-Dimensional Models					
Instrument	Cost	Collection Time	Processing Time	Coverage	Model Accuracy (cm)
Terrestrial Laser Scanner (TLS)	$18,350	7 hours	1 day	Complete coverage with gaps on the roof	Reference
Unmanned Aerial Vehicle (UAS)	$1499	3 hours	1 day	Complete coverage of structure	0.18
Digital Photography	$499	1 hour	4 hours	Data gaps, noticeable towards roof and significant warping	0.73

Evaluation on these comparison factors clearly showed the photo models excelled in time and cost. However, the laser scan's completeness of coverage was still above and beyond the digital camera models. It is important to note that each project varies in terms of requirements needed to be met in order to be considered successful. The low-cost quick modeling could be useful for recording, preserving, and discovering or informing of an historic feature. The best scenario is to be able to perform a complete simultaneous total station survey with either the photo collection or TLS survey to produce the most accurate and complete model.

Further manipulation and evaluation of the models is recommended. Capturing more overlapping images with a digital camera could produce a significantly more accurate and realistic model. Editing of all datasets using a more robust editing software may help eliminate gaps and holes in the models. As mentioned, the simultaneous collect of accurate survey data along with the digital photography is highly recommended. This would help positioning of the images in the coordinate system more accurately which would allow them to be more easily manipulated with other data such as the TLS points. Finally, testing lower quality and cost cameras would be useful in evaluating the cost verses quality question.

No single sensor or method can capture every feature in a completed model. Complex geometries provide obstacles for modeling for both TLS and UAS systems. (Torres et al, 2014) However, obtaining both datasets allows for a more complete coverage. For example, where roof gaps are present in TLS data, UAS imagery can fill in. As for more detailed façade modeling TLS can fill in for UAS imagery. As seen in other studies (Remondino & Rizzi, 2010), despite combining several sensors, some gaps and holes were present in both 3D models formed in this study which required subsequent interpolation. However, this study's the visual examination both models through comparing their respective point clouds showed that the UAS methodology was a viable option compared to the high-end survey grade TLS system. The UAS data capture took one to two hours as compared to the six to seven hours needed for the TLS data collect. Also, it is important to note the lower cost of the UAS method as compared to the TLS.

Further efforts to model the structure should include simultaneous data capture from both aerial and ground based sensors along with detailed total stations survey of the structures. This step would allow a robust evaluation all accuracy values for an enhanced comparison. Future efforts should include a full data fusion of the TLS and UAS datasets.

The accessibility of so many datasets allows a more comprehensive understanding of the landscape. No one sensor can explain everything that is occurring on a site. However, the combination of sensors in conjunction with historic imagery can start to pin point areas of interest and areas that can be ruled out. Armed with such knowledge conclusions and plans can be made about what areas should be examined further. As an additional benefit, the ability to test the accuracy of the UAS DEM relative to the total station survey was of note. The DEM created from the UAS, used for this study site, generated a similar set of elevation data as that produced by the total station.

CHAPTER IV

GEOPHYSICAL INVESTIGATIONS AT THE HARPER HOUSE, BENTONVILLE BATTLEFIELD STATE HISTORIC SITE

Introduction

Bentonville Battlefield is a state historic site located in Johnston County, North Carolina. Spanning March 19 to 21 of 1865, Bentonville was the largest and one of the last battles fought in North Carolina during the Civil War. The conflict at Bentonville resulted in more than 4,000 casualties. The Union army, under the command of General William T. Sherman, met and defeated the Confederate forces led by General Johnston. Approximately 80,000 troops fought on what is now the Bentonville Battlefield State Historic Site in one of the final battles of this American internecine conflict. (NC State Historic Sites, http://www.nchistoricsites.org/bentonvi/)

Located on the property, the two-story farmhouse of John and Amy Harper, built around 1855, still stands. The Bentonville farm, like others in North Carolina, had slaves. By 1860, John Harper owned three slaves who may have been freed by General Sherman's army during the Battle of Bentonville. There is a reconstructed kitchen and slave quarters located adjacent to the house. Bentonville State Historic Site and the Office of State Archaeology posed several questions about these and other cultural features reported to be located in the lot behind the Harper House. In particular, the location of the Harper family's privy remained speculative. Numerous other potential structures related to the Harper family's occupation were reported to exist in the farmstead's heart [or nucleus], such as disposal areas, known archaeologically as garbage pits, surficial trash, kitchen middens, and general livestock buildings, lots, and fencing. (Stine, 2012)

On the first day of the Battle of Bentonville, Union troops commandeered the home to serve as the field hospital. Over 500 soldiers were treated during the battle in the lower rooms of the house. Based on historical accounts and photographs, the hospital has been documented as a nonsterile assembly-line, quickly moving patients through the house. As was the case in most field hospitals during the war amputations were quite common. Historical documentation shows the amputated appendages discarded through a window. (Robinson & Schneider, 2011) Significant Civil War battle reports of the time indicated a potential for finding pits used for the disposal of medical debris, including amputated limbs, buried at the time of the house's use as a temporary hospital.

Bentonville Battlefield State Historic Site management sought expanded information on the Harper family, their house, and the house's use as a hospital. The Office of State Archaeology (OSA) brought together the site managers and gave permission for site access. The University of North Carolina archaeology and geography faculty and students were charged to garner data to improve landscape management and cultural interpretation at the site with the help of OSA archaeologists, local volunteers, Bentonville staff, and UNCG undergraduates and graduate students.

The UNCG study conducted a targeted geophysical survey using ground penetrating radar and gradiometer. The findings from the data were used to determine areas of interest and allowed for the generation of maps to grid specific notable features for future excavation. The use of the ground penetrating radar and gradiometer technology proved more effective and faster than prospecting without such tools and techniques.

Literature Review

Geophysical remote sensing is a non-destructive method for discovering a variety of sub-surface archaeological features. It has been used to help prospect for hidden remains and speed up the testing process in archaeological surveys (Conyers 2004 and 2012; Hargrave 2006). Through the examination of features such as middens, gardens, structures, etc., a more comprehensive depiction of the cultural landscapes can be achieved. (Kvamme K. L., 2006). Kvamme stated that the best way to understand the subsurface features is through geophysical surveying. Geophysical survey techniques including magnetic gradiometer, resistivity, electromagnetic conductivity and GPR are commonly deployed to image historic sites. Of these technologies, Ground-Penetrating Radar (GPR) and magnetometers configured as gradiometers are commonly used in archaeological field work to aid in site interpretation prior to excavation (Conyers 2012; Kvamme 2003; Moore 2009; Perttula, Schultz, Walker 2008). Previous GPR surveys of other areas of the Bentonville Battlefield site conducted by Robinson and Schneider (2007). proved quite useful (Their research near the cemetery and memorial with the use of a GPR, was successful in the location and recovery of a previously unknown soldier.

Conyers explains that Ground Penetrating Radar (GPR) collects data in the form of reflections as the signal travels and interfaces with different subsurface substances, materials, and objects. The travel time between these "hits" and their return back to the data collector can be converted to depth readings to allow for isolation of where these reflections are originating. (Conyers, 2012). Both the three-dimensional slice maps and the individual profile readings generated from the GPR are important to utilize when interpreting a site. It is also critical to examine reflections in the profile and compare them to other similar profiles from other studies to identify potential feature interpretations. There are several factors, described by Conyers, that influence the collection and interpretation of the data, these include soil types, geologic stratigraphy, the actual movement of the energy from the radar and its interaction with the subsurface. Water distribution and saturation can affect results and penetration of the signal, and ultimately any cultural remnants situated in the subsurface can also influence results. (Conyers, 2012)

Gradiometery is a geophysical method that detects local variations in the strength of the earth's magnetic field. The magnetic gradiometer can be used to locate and highlight magnetic variations which can be historic or modern in nature. Bricks, rocks, metal, and burned areas are some examples of features that are easily seen in the data. The processed results from the data collected are seen in gray with the scale of variations measured in nanoteslas. Magnetic anomalies are frequently classified as either dipolar or monopolar, which can be used as a basis for describing various anomaly classes (Burks, 2004). Dipolar anomalies have distinct negative and positive poles which are visible on gradiometric maps, with both areas of increased (positive) and decreased (negative) magnetic field strength. Strong dipolar anomalies are often caused by the presence of ferrous metal objects. Dipolar anomalies can also be caused by the presence of ferrous sediment and/or rocks that have been heated in place to a high temperature. (Kvamme, 2006)

When these instruments are used together patterns emerge that can assist in the identification of areas of interest for further analysis and excavation. Cases exist where either the GPR or the magnetometer data is of limited use. Such cases include where the soil matrix, level of soil moisture, and/or electronic signal interference affects the GPR results. (Hargrave, 2006; Conyers, 2012 and Rogers et al., 2012). With gradiometric data the interference of electrical wires, rocks, and the soil matrix can all distort the results. This means that the geophysical survey map, while highly effective at narrowing down the location of potentially culturally significant features, should not be assumed to perfectly portray archaeological features (Hargrave, 2006). Therefore, an excavation is typically necessary to corroborate and expand upon the geophysical results.

Over the years, small-scale archaeological investigations have been conducted around the immediate area of the Harper house. These focused upon activities related to building repair and restoration (Babits 1976; Beaman 2000a; Harper 1997; Wilson 1984), landscaping (Carnes-McNaughton 1992, 1996a; Harper 1991; Wilson 1983a, 1983b), and site maintenance (Beaman 2000b; Carnes-McNaughton 1996b; Harper 1990). Each of these projects was limited to specific areas and the vast majority of artifacts recovered were related to post-Civil War activities, recent improvements, or modern visitation. (Robinson & Schneider, 2011).

Methodology

The geophysical instruments used for the Bentonville survey in this study included a GSSI 3000 Ground Penetrating Radar unit with a 400 MHz antenna and a Bartington Dual Gradiometer Magnetometer (Mag). Portions of the yard behind the Harper House were divided into grids and both instruments were employed to prospect for sub-surface cultural features. Geophysical grids were established to allow for both GPR and gradiometer coverage. Four 30m by 30m grids were placed on the back (north) side of the Harper House (Figure 4.1).

Upon reviewing the data in the post processing phase of analysis, it was clear that the third and fourth grid collections (nearest the visitors' center) were of very limited use in the interpretation of cultural features, due to subsurface wires and pipes. It is important to stress the use of historical imagery in the analysis phase. A complicating factor with determining historical magnetic changes observed in the sub-surface are the large-scale battle reenactments that occur yearly (figure 4.2). Particularly the disturbance from the reenactors many campfires which could mask or be confused with historical magnetic changes observed in the sub-surface.

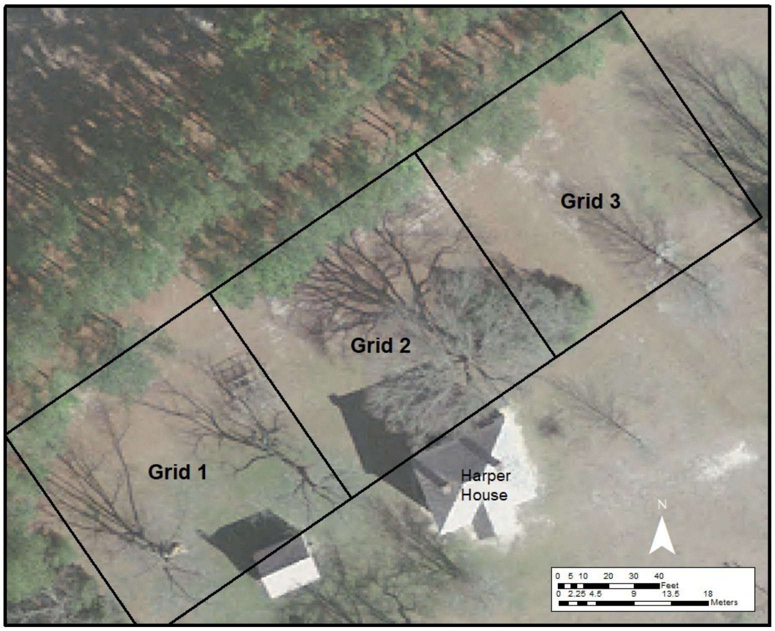

Figure 4.1 Harper House Geophysical Survey Grid

Figure 4.2 Harper House Battle of Bentonville 2005 Reenactors' Camp

The US Department of Agriculture Soil Conservation Service (1994) classifies 90% of the soils covering the Bentonville landscape as Wagram or similar soils. Wagram soils are very deep, well drained soils of the NC coastal plain. characterized by a sandy loamy nature. In the case of the Bentonville site, this soil type allowed for a greater penetration of the radar signal allowing for a high reading at great depths.

With the assistance of Dr. Jerry Nave of NC A&T, an extensive total station survey was completed for the site. A Topcon GR-3 Global Positioning System (GPS) was used in concert with a Topcon GTS 233W total station to tie the previously established grids to real-world coordinates. (Figure 4.3) All imagery and data were georeferenced to these survey points. Dr. Nave's expert survey of the site insured that the mapping was accurate and within the limits of the geophysical equipment. All the geophysical survey was conducted within numbered grids, and mapped and referenced to the corresponding grid number.

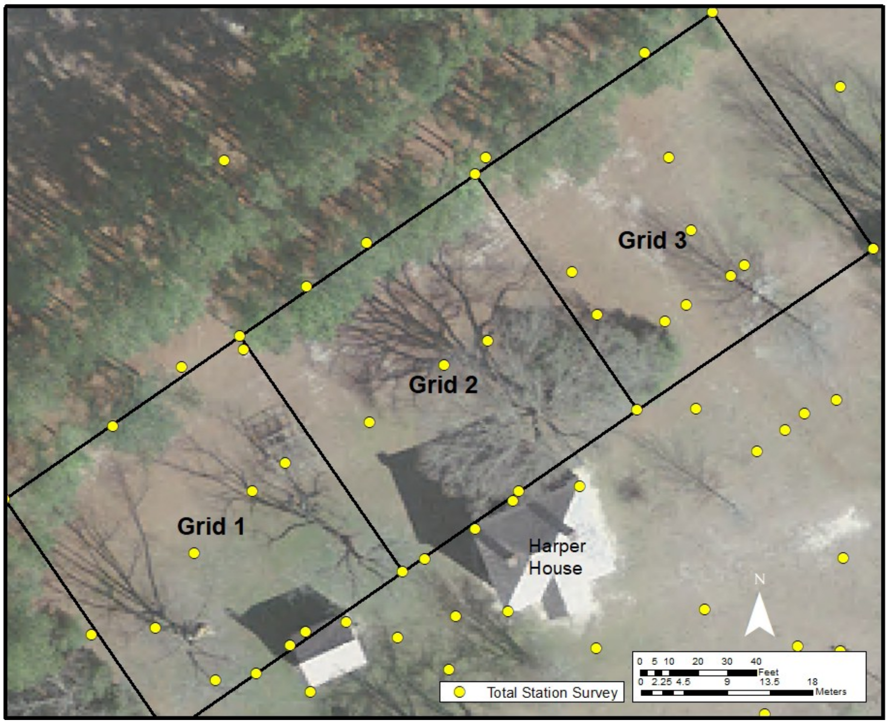

Figure 4.3 Total Station Points Collected

GPR

Grid 1 contained a grape arbor (located in the center area). Grid 2 contained the brush and heating/cooling units along with a large tree in the southeast corner and bordered the Harper House along the grid's southern edge. Grid 3 contained bushes in the southwest corner, and an old road bed along the eastern boundary. On the SE corner of Grid 3 and the NE corner of Grid 4 there was a power pole with a transformer. Grid 4, not shown, contained the road and the paved walk and signage and lay between the Harper House and the visitor center. A GSSI SIR- 3000 with a 400mhz antennae was used; data were collected in one direction along the X axis. In Grids 2 and 3 there are data voids due to obstructions by the large oak and shrubbery present around the house's air conditioning units in Grid 2. These appear as a solid void in the GPR slice maps and images. (Figure 4.4)

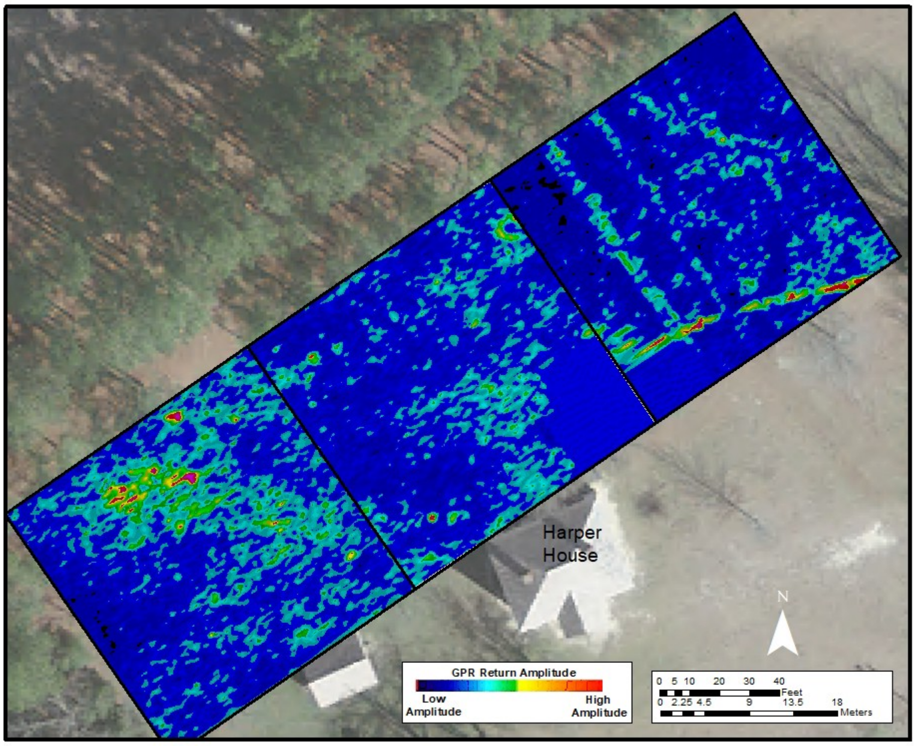

Figure 4.4 Ground Penetrating Radar (GPR) Collection

During the post-processing phase, the velocity correction for the dielectric properties was made to the data. This correction allows for more accurate depths to be identified for interpretation. All of the GPR data were post-processed and analyzed using Radan 7 software in the UNCG Geography Department's Remote Sensing Lab. The first post-processing step was to set the data to time zero; this allowed the creation of a profile with a true ground surface by removing the space generated by the antenna carrier. A background filter was then applied to help normalize the data and remove noise. Finally, the average relative dielectric permittivity (RDP) of the soils was determined for each collection date using hyperbolic reflections visible in the vertical profiles. This was accomplished using the migration tool. After fitting the curve to match hyperbolic shapes, the profile number and reflector distance from the transect start were recorded in a spreadsheet, along with the velocity estimated by the fitting tool. (Turner & Lukas, 2016) The RDP of the soils above each reflection was calculated in another column using the following formula. (Conyers, 2004)

K = (C/V)2

K = Relative Dielectric Permittivity

C = speed of light in a vacuum, .2998 m/ns

V = velocity of radar energy through soil, m/ns.

Following the calculation of RDP for each reflector, the mean RDP of the collection date was used to export the 2D slice maps. Each slice was examined at a .10 m thickness. Each grid was saved as a .tiff file and then georeferenced for excavation planning and dimensional analysis using ESRI’s ArcMap software (Conyers, 2004; Radan7 Users’ Manual, 2011). The resulting slice was then exported to a comma separated values (.CSV) file for interpolation via ordinary kriging in Surfer (Golden Software Inc. Golden, Colorado) before importing and georeferencing back in ArcGIS.

Magnetometer

A gradiometer detects objects near or at surface based on local variations in the earth’s magnetic field. Like the GPR, the gradiometer is nondestructive and does not disturb sub-surface features. A gradiometer shows magnetic features when objects or soils contain iron or are heated. A gradiometer is a specially configured type of magnetometer that measures variation in magnetism in the shallow subsurface, in units of nanotesla (nT) (Clay 2001, Aspinall et al. 2009). Magnetometry is confined to the uppermost 1 -2 m for most soil features and is limited to 3m for burned or iron masses. Interferences can distort the data and inhibit proper identification of relevant objects. Such interferences can include buried pipes, fencing, cell phones, animal burrows, pavements, landscaping, and passing automobiles. (Kvamme, 2006) For the Bentonville survey a Bartington 601 dual sensor gradiometer was deployed. Grids were traversed starting at the northwest corner at 0.50m intervals. In the lab, the data was processed in TerraSurveyor software (DW Consulting, Barneveld, The Netherlands) TerraSurveyor is specifically designed to acquire, assemble, process and visualize two-dimensional archaeological data (TerraSurveyor manual). The processed composite was then exported to ASCII raster format for import and georeferencing in ArcGIS. (Figure 4.5)

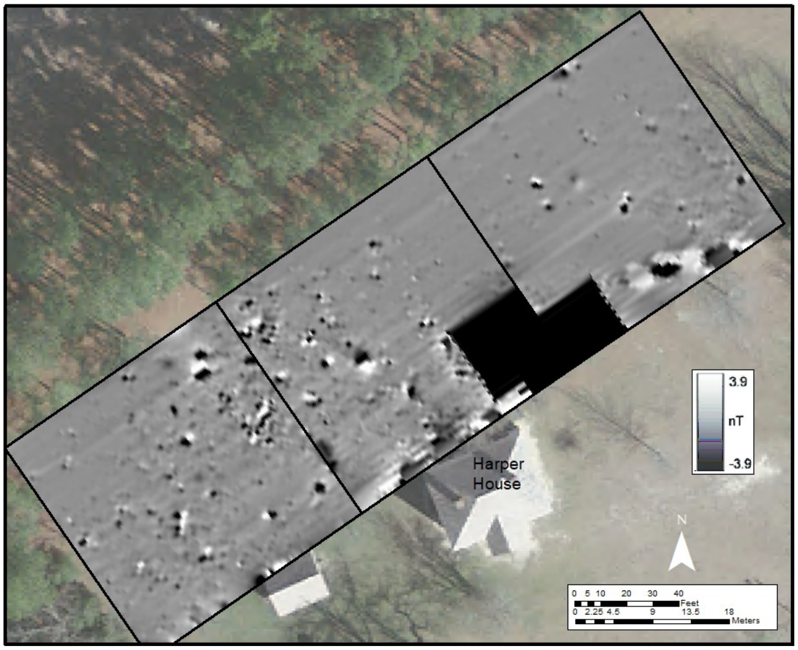

Figure 4.5 Magnetic Gradiometer Data Collection

Previous Excavation

Over the years, small-scale archaeological investigations have been conducted around the immediate area of the Harper house. These intermittently focused upon activities related to building repair and restoration (Babits 1976; Beaman 2000a; Harper 1997; Wilson 1984), landscaping (Carnes-McNaughton 1992, 1996a; Harper 1991; Wilson 1983a, 1983b), and site maintenance (Beaman 2000b; Carnes-McNaughton 1996b; Harper 1990). Each of these projects was limited to specific areas and the vast majority of artifacts recovered were related to post-Civil War activities, recent improvements, or modern visitation. (Robinson & Schneider, 2011).

Armed with the geophysical survey data and with gratitude to the Office of State Archaeology and the dedicated, knowledgeable management at the site, a public archaeology day was held in the summer of 2014. Visitors and volunteers were able to participate and learn how geophysical surveys aid in the location of archaeological materials. Within the grids established in the geophysical survey, test units and trenches were placed to validate and discover what the geophysical data was precisely indicating. Two trenches were opened using a backhoe to strip the topsoil and plowed trenches, the locations were chosen as they provided the best chance to define the detected anomalies within the study area. The test units were 50cm x 50cm, but in one case the test units were extended into two 50cm x 50cm units. The remaining soil, as well as the interface of additional subsurface layers or subsoil, was cleared through the use of schnitting (i.e., using flat shovels to skim the surface flat) and trowels to expose and define any features.

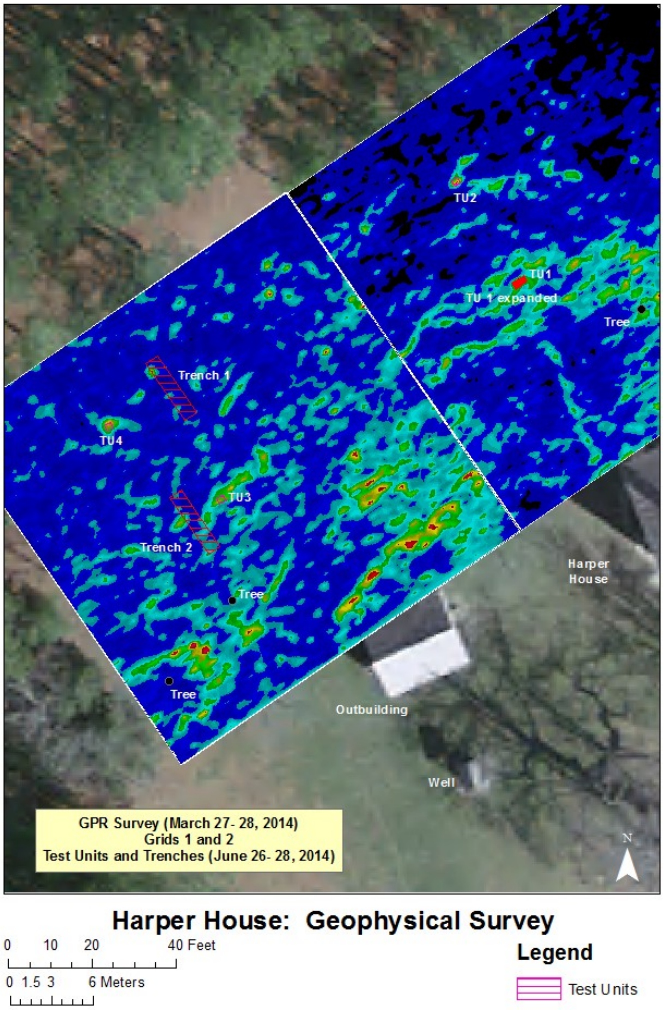

Figure 4.6 Excavation Test Units

Supervised by the OSA Deputy State Archaeologist and UNCG Archaeologists, graduate assistants and site staff screened soils using a ¼ inch hard-wire mesh. (Figure 4.6) All recovered artifacts were bagged separately by provenience and sent to the State Archaeology lab where they were identified and cataloged. (Emily McDowell, Research Laboratory Supervisor, Office of State Archaeology Research Center. 2017. Personal communication: email)

GPR Results

Grid 1 contained several high amplitude areas of interest. Depths of 0.55m, 1.61m, and 1.85m all indicated areas with moderately high amplitude undulating reflections in respective profiles. The high amplitude reflections recorded in the southern corners of Grid 1 were dismissed since they were associated with the extensive tree root system of the two large trees found there. However, in the center of the slice at 0.55m, an area of interest was presented in the profile as having surface characteristics.

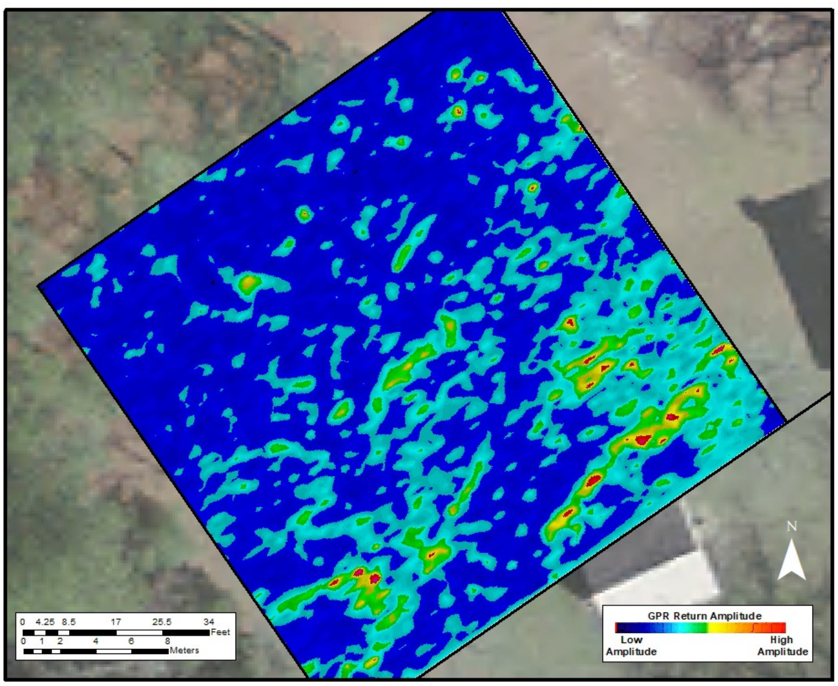

Figure 4.7 GPR Collection at 0.55m Depth

At 1½ meters, an elongated area emerged with moderate amplitude returns and undulating complex reflections in profile. Typically, a depth of 1.85m would not be significantly interesting to explore, but the soil characteristics of the site provided a greater penetration of signal. A high amplitude response was detected at this depth and was deemed worthy of investigation due to the shape and size.

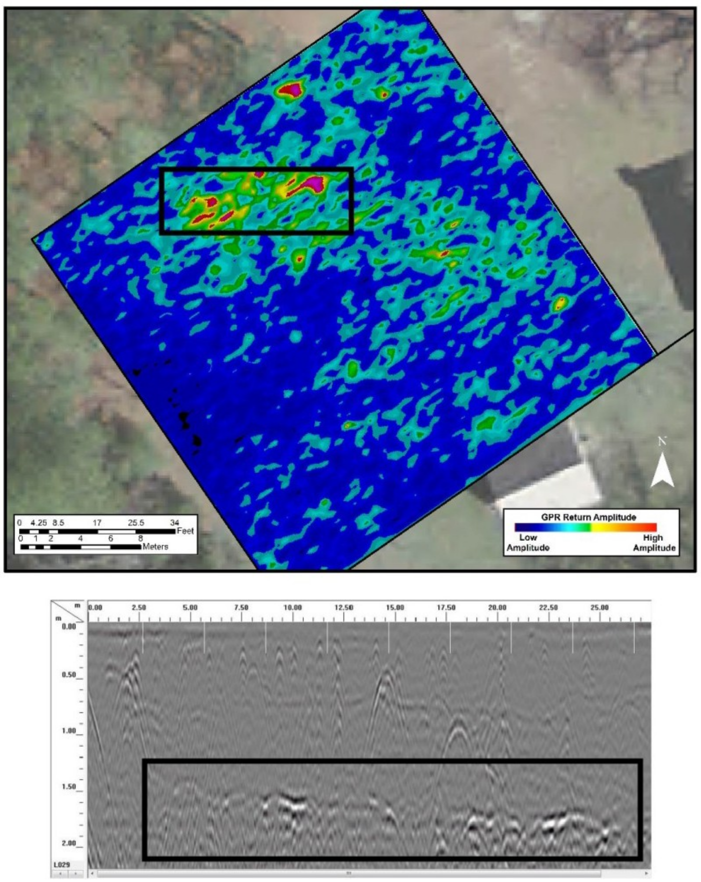

Figure 4.8 GPR Slice Map (Top) and Profile (Bottom) at 1.85m

Grid 2 contains a large tree and old grape arbor which provided high amplitude reflections from roots that need to be noted before further examination of the grid can continue. Towards the northern center of grid 2, another high amplitude response was present and depicted in profile. An overlaying signal response indicated several high reflective features. At a depth of 0.55m, a distinct linear feature was detected from the house to the middle of the grid terminating with a high amplitude response.

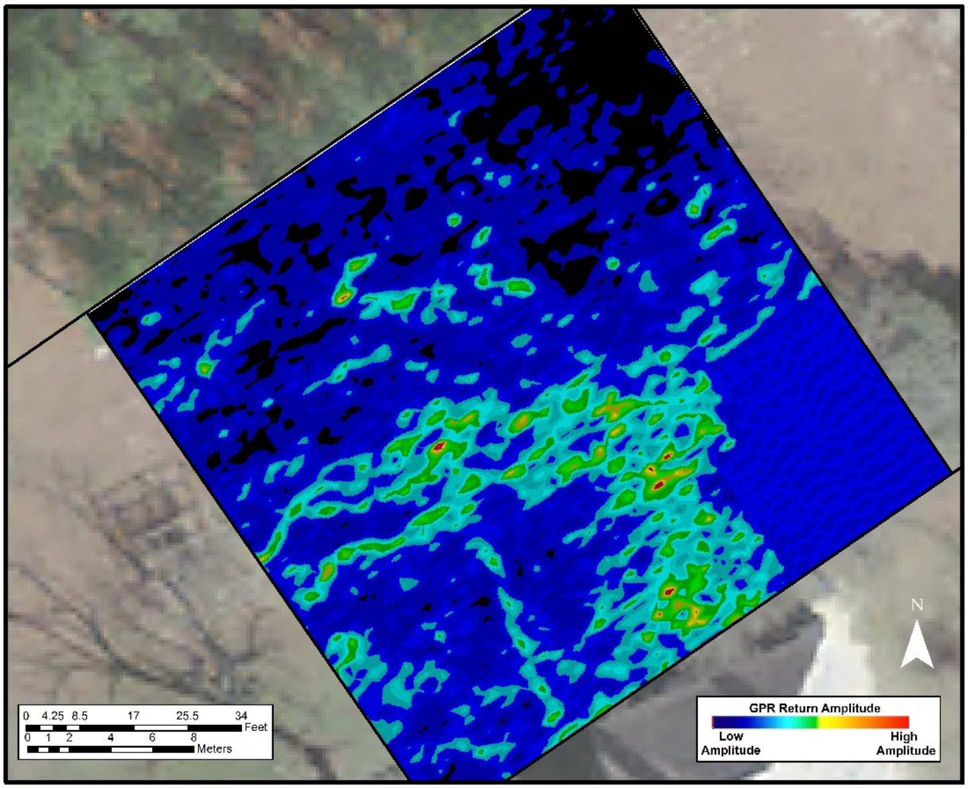

Figure 4.9 GPR in Grid 2 at 0.55m

Upon reviewing archival photography of the house, the feature shown in the southwestern part of the grid was thought to be an old pipe. However, it was deemed worthwhile to examine the termination point of the pipe for validation of the data, purpose of the pipe, and other potentially associated historical features.

Figure 4.10 Picture of Backside (North) of House with Pipe Extending Circa 1950s

Gradiometer Results

Using the same grids as the GPR, the gradiometer was also able to detect permanently magnetized thermoremnant features, in addition to those expressing temporary magnetic response in the presence of the earth's field. A few different types of responses were seen in the processed data. The most clearly visible are the dipolar discrete areas that appear with both highly positive and negative (white and black) nT values and are found in both Grids 1 and 2. These areas represent locations of magnetic objects, ferrous metals such as iron. The strong dipolar areas identify areas for further investigation. Another type of signal that is seen in the gradiometer data have strong mpositive discrete responses. Where the dipolar areas have both dark and light appearances, they are seen as dark areas surrounded by a “halo”. These discrete locations are often sites of thermoremenant features formed from intense burning. The final type of areas seen in the data from the gradiometer survey were the positive discrete spots. These do not present with such high values as the strongly positive, but appear as black areas dotting the landscape. These are often natural in origin and correlate to tree root disturbances and buried geologic formations such as rocks.

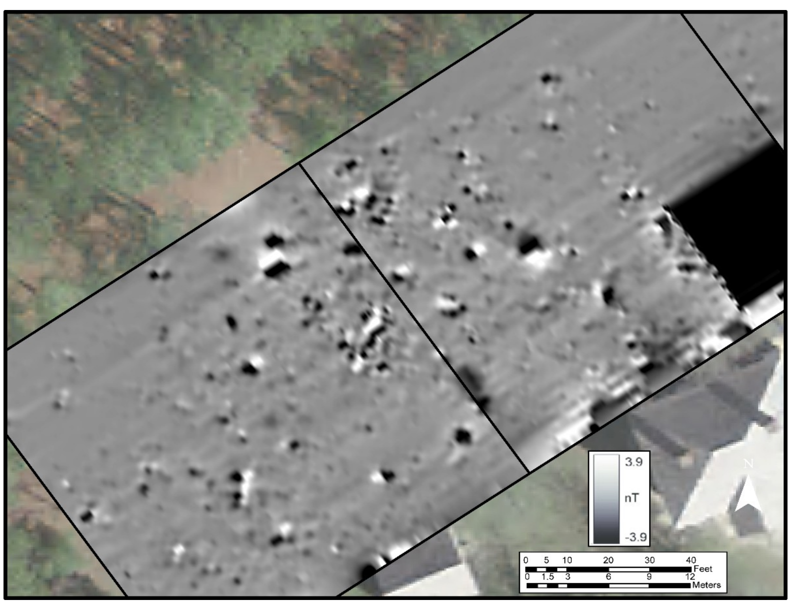

Figure 4.11 Gradiometer Data Analysis

Comparisons

The final step in evaluating the geophysical analysis was to see how the data compared. Overlaying the two data sets reveals similar information or identification of completely different features. The gradiometer data complements the GPR data in this study quite effectively. The feature edges as displayed in the GPR correlated with the gradiometer data. The results of the study demonstrate how GPR was successfully deployed in conjunction with a magnetic gradiometer.

A high amplitude reflection seen in the slice map and in the profile depicted an interesting reflection in the northernmost portion of the highlighted area. Looking at the gradiometer there is an anomaly in the same location with a strong dipole contrast indicating a change in magnetic fields. In grid 2, a similar comparison is made in the northern feature showing the gradiometer measurement at -3.9 nT. When compared to the GPR data, a direct correlation reveals the same shape and location of the feature.

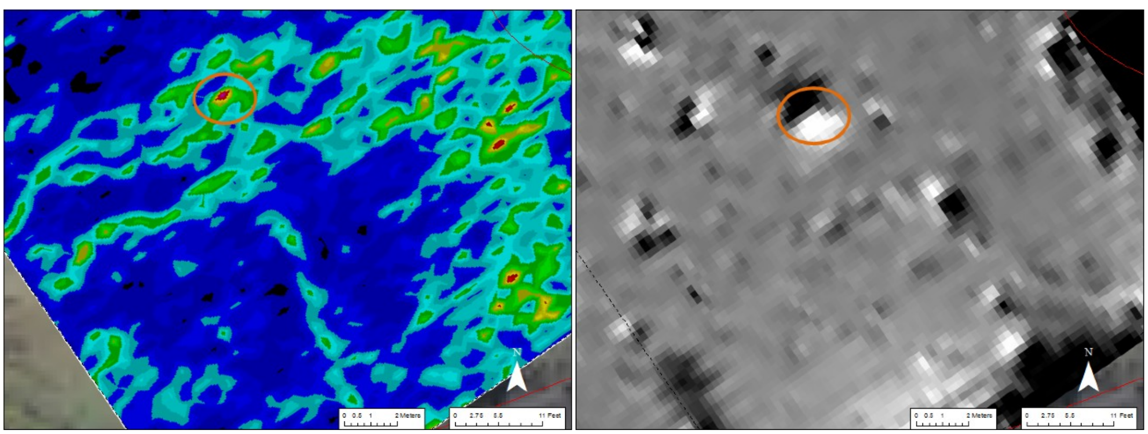

Figure 4.12 GPR Data (Right) Compared to Gradiometery Data (Left)

These comparisons were necessary in determining locations for further investigation, either with shovel tests or an excavation test unit as done in this study. It is important to consider that geophysical anomalies can be cultural or natural in origin. Besides possible historic features, the subsoil is very heterogeneous and there are many factors involved in measuring geophysical magnitudes used to characterize the contents of the soil. Any dataset obtained from a survey needs to be processed and interpreted to have a real-world application such as historic site management. (Sala et.al, 2012)

Excavation

In grid 2, test unit 1 was identified as the termination point of the linear feature seen in the GPR data previously discussed. The feature begins to appear approximately 0.30 -0.55m below the surface. The high amplitude returns with the "buried" surface indicated in profile warranted an investigation. Upon inspection a large pipe was found with a valve, as expected, this was a remnant of an historic utility for the house. Various artifacts located in the mix were cataloged by North Carolina Office of State Archaeology laboratory. The unit was expanded another 50cm x 50cm for further analysis.

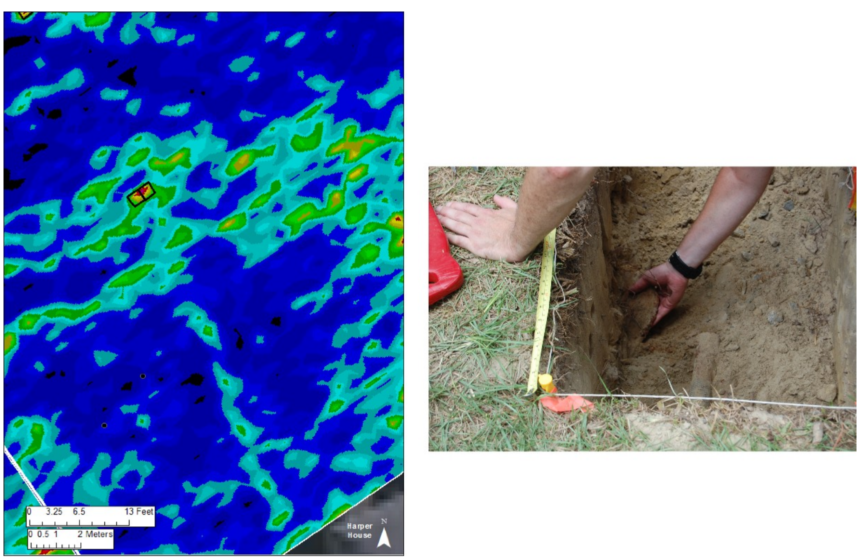

Figure 4.13 Grid 2 Test Unit 1

Test unit 1 yielded a total of 140 items the majority of the items were categorized as kitchen related or miscellaneous of unknown use. The lab was able to assign dates to 58 of the 140 artifacts. Almost all were dated 20th century in origin. This included an iron stove plate with knob handle that was recovered.

Test unit 2 was located in the northern part of Grid 2. The gradiometer and GPR indicated a feature appearing in the 0.35 – 0.65m sub-surface layer (fig 15). In the GPR data, the feature became visible quite shallow in the profile and proliferated until approximate 1m in depth. A total of 48 artifacts were recovered from this unit. Most of the items were either kitchen or ethnobotanical in nature. Of the 48 only 24 were dated by the lab. A large number of the 24 were deemed 20th century in provenance. In test unit 2, many iron nails dating from 1830-1890 were recovered along with a number of pieces of burned wood. The burned wood recorded by the gradiometer, most likely by the strong dipole persists in the survey data.

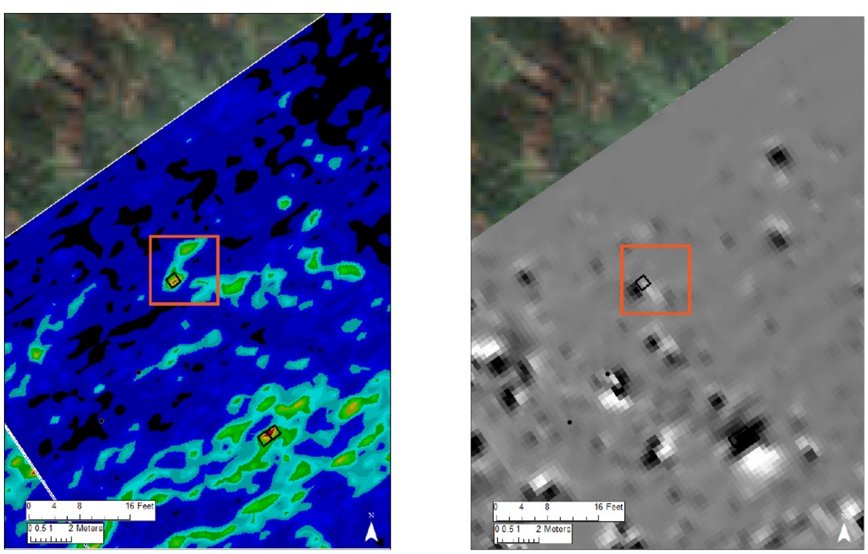

Figure 4.14 Grid 2 Test Unit 2

Grid 1 contained two trenches and two test units. Test unit 3, situated in the middle of the grid, was below surface between 0.40 -0.55m in the GPR data. It was chosen due to its semi-shallow visibility, making it suitable for a 50x50 unit. This unit produced 170 artifacts that were predominantly kitchen related items. 83 out of the 170 pieces were dated from the1830s to present. That determination led to considerable ambiguity in the origin of the material culture. Within the unit, a large number of pieces are Earthenware ceramics of varying time periods. Most of the ceramics were from the 1830s consistent with the house being built in 1855. Other items included a saucer fragment of undecorated Creamware dated 1762-1820. Along with ceramics, numerous bottles and glass of various ages were recovered. As with test unit 2, burned items were found, i.e. charcoal fragments. The burned material along with more iron nails of various time periods were clearly identified by the gradiometer data. However, as previously noted the charcoal could have been modern in nature related to reenactments campsites.

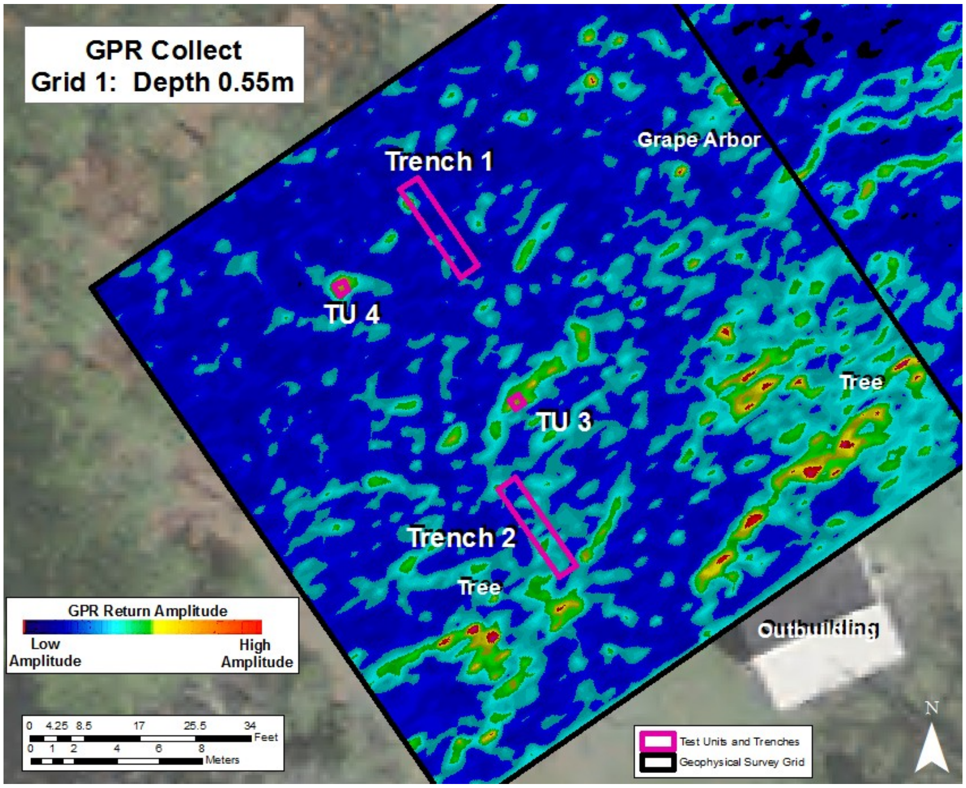

Figure 4.15 Grid 1 Trenches and Test Units

Test unit 4 was excavated in the northwestern corner of Grid 1. Appearing in the GPR data at approximately 0.30-0.65m in depth, unit 4 yielded very little. It was chosen due to its strong reflection in profile and contrast in gradiometeric data. The only items recovered were modern in nature and did not impact the historic interpretation of the site.

Trench 1 was opened in the northern edge of Grid 1. As previously mentioned, both the gradiometer and GPR identified a strong anomaly in this trench. The GPR indicated the feature in profile appearing 1.70-1.85m. This reflection was most likely the result from changes in soil profile and deep saturation levels recorded by the GPR. This “false” reading was nevertheless extremely valuable. Interferences by soil profiles and soil moisture are important to study to determine how the sensors will react and how we should interpret them. However, Trench 1 produced only 110 artifacts. Out of the 110, 94 were determined to be modern to present. Nearly 80% of the recovered items were kitchen related. Earthenware ceramics determined as Whiteware from the 1830s to the Present were dominant in the unit. Along with kitchen glass and ceramics, a Whiteware saucer with red, green, and blue floral motif dated 1765 to 1810 was recovered.

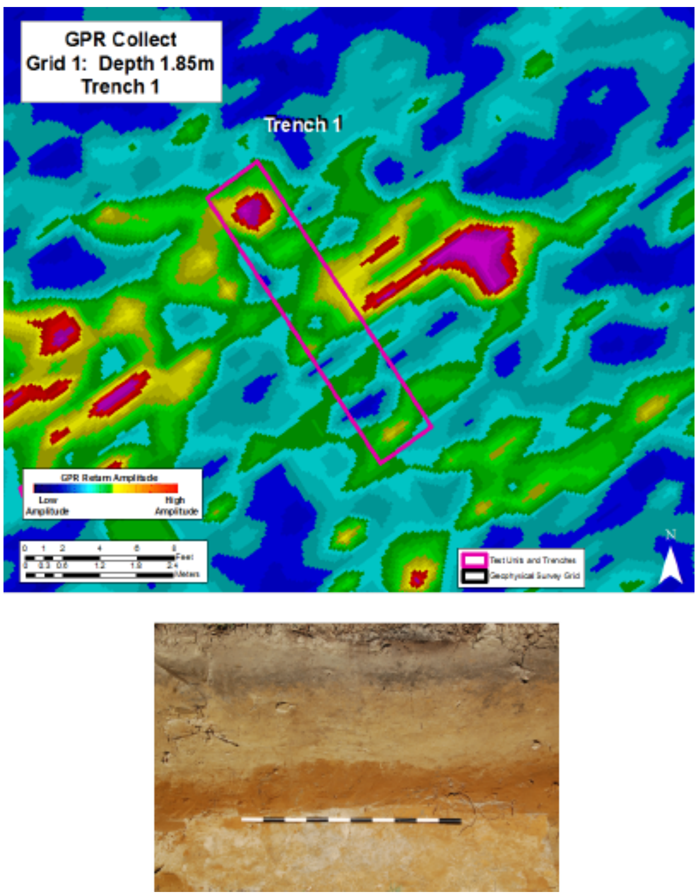

Figure 4.16 GPR Slice of Trench (Top) Excavation of Trench (Bottom)

In the lower central portion of Grid 1, a second trench was excavated. Trench 2 proved to be the most fruitful in terms of items recovered. A 50x50 grid was initially laid out, but due to the high number of period artifacts visually identified in the field by experts the unit was expanded to trench 2. A total of 632 items were found in Trench 2. The majority of them were kitchen related as with the other units on the property. 556 out of the 632 items were able to be dated. Most of the material came from three periods a 1870-1920, the 1830s, and 1762-1820. All of these dates correspond with the early occupancy of the house and farm. Additionally, numerous pieces of glass of various dates were found as well as Earthenware ceramics, both Creamware and Whiteware.

Fragments from the 1830s showing floral motifs in green were recovered along with royal patterned embossed motifs on fragments from 1762-1820. A dinner plate fragment dated 1765-1810 in a green, pink, and blue floral motif was discovered as well. Iron nails both wrought and cut were recovered. Most of the nails were dated 1830-1890.

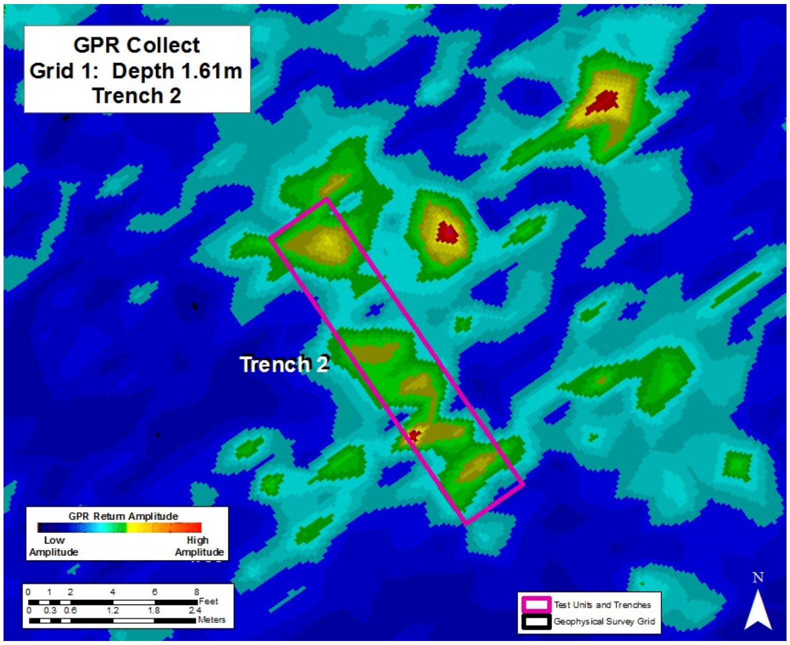

Figure 4.17 Trench 2

Discussion

The results of the geophysical survey show the usefulness of conducting such surveys. Through noninvasive tools and techniques, areas of interest were determined, enabling for more focused prospection. Within a two-day period, a large area was surveyed with both the GPR and the gradiometer and with the addition of high accuracy total station data collection to tie the grids in, a comprehensive survey was achieved. Post processing allowed for the generation of detailed maps that were then compared and evaluated. When data from both sensors were evaluated together, new areas for further investigation were identified.

The results of the geophysical survey provided a guideline indicating where a formal excavation would be most fruitful. In conjunction with UNCG, the State

Archeologist, and Bentonville State Historic Site an excavation of the predetermined locations was conducted. The excavation provided not only information for the site and researchers, but a chance for the public to learn about geophysical remote sensing techniques and archaeological excavation methods. The excavation was conducted as an event for the public to have hands- on exposure, and learn about the history of the site and geophysical archaeology. Over two days, the public was able to learn from experts not only traditional archaeological methods, but also geophysical tools and methodology that were used to determine the location for the test units. High school students and volunteers were overseen by professional archaeologists and graduate students from UNCG, with expertise in the application of geophysical tools and methodologies. Individuals from a variety of ages, backgrounds, and levels of experience were able to get a chance to learn how to excavate and recover artifacts. Integrating the public into the research helped generate greater interest and understanding of the historic site as well as making the subjects of Geography, Archaeology, and Geophysics more approachable.

One of the main questions originally posed for the site explorations was the location of hospital related artifacts and amputated limb burials. Unfortunately, the results of the excavation did not resolve this question. No evidence of the amputee pit was discovered during this excavation event. The overwhelming number of artifacts recovered were kitchen in nature. A large assortment of Harper family period kitchen items was retrieved. Architectural items, such as numerous iron nails were discovered. Based on the results of the artifacts found at these particular sites, it seems that these items were simply discarded over the years in the backyard of the house. It is also important to note the prevalence of modern items that can be associated with the numerous reenactments that have occurred over the years. Examining the distribution of the artifacts allow a story to emerge about land use during the various periods of occupancy. The space to the back of the house where the research was conducted yielded pieces from the typical farmstead life. Across the property and various generations of owners, a story of construction, disposal of used goods through burial and burning, and manipulation of the landscape for farming was seen. Many pieces were discovered relating to the primary period in question, the Civil War. Examination of the site revealed deposed ammunitions that correlated with the sites use as a field hospital.

While some questions regarding the hospitals use during the battle were not answered completely, the investigation did provide a more detailed history of the use of the property over time. In addition to the public education aspect to this study and the actual excavation results, this study also demonstrated the value of conducting the geophysical survey. The ability to combine both the data from both the GPR and the gradiometer on this site and subsequently "dig up" and see what the sensors recorded was critical in providing a better understanding of the technology. In most cases both sensors picked up on similar anomalies. These areas were then validated by the excavation, i.e. dipolar gradiometer readings, and changes in profile reflections in the GPR. As discussed previously, the GPR highlighted an area with significant undulations in the profile. Although not proving rich in artifacts, the GPR was reflecting subsurface changes in the geology. This result provides a chance to compare the natural reflections that the sensors can record versus reflections from material culture.

Conclusion

The Bentonville site has great potential for further research. Expanding on the work already completed near the back of the house and completing the geophysical survey around the entire structure to include the front of the house would be advisable. Within the confines of the backyard, other features that were visible in the geophysical survey could be further excavated. Other non-invasive technologies could also be utilized at the site. With the ease and affordability of unmanned aerial systems (UAS), a comprehensive study could be conducted over the entire site. Such a survey could generate several useful products. For example, data from a UAS survey could be used to build a digital elevation model (DEM) which could then be compared to the geophysical survey data. 3D modeling of the house from UAS imagery could be useful in future research and preservation of the structure. Finally, the deployment of a UAS to the surrounding wooded area (leaf off) could reveal evidence of battle related activities previously unknown. The site has unlimited potential for further investigations.

CHAPTER V

CONCLUSION

The research conducted for this dissertation combined traditional remote sensing and geophysical remote sensing, both aerial and ground based, to study physical and cultural landscapes. Using three different sites of historical significance to the state of North Carolina, this work not only surveyed the subsurface landscape through nondestructive means, but also evaluated three-dimensional model generation from multiple platforms. Methodology was developed from critical literature for the visualization of multidimensional data from Ground Penetrating Radar (GPR), Terrestrial LiDAR (TLS), aerial imagery, traditional photographic methods via digital camera (SLR) and from Unmanned Aerial Vehicles (UAS). An outcome of this type of research was the spatial integration with other data relevant to archaeological, geographical and geophysical investigations to provide a more robust record of the site environment and historical landscape.

In Chapter II, the first article submitted regarding Terrestrial Lidar and GPR Investigations into the Third Line of Battle at Guilford Courthouse National Military Park, Guilford County, North Carolina, resulted in the demonstration of the successful exportation of GPR data into three-dimensional point clouds. In conjunction with the TLS collected data, the GPR point clouds were explored to aid in the identification of the colonial subsurface. The initial work in thisarea has proved successful resulting in a fused dataset showing below ground, surface and above surface 3D points. Of particular interest a possible road or gully was identified in the point cloud dataset fusion as slightly concave buried surface. The manifestation of the feature could be traced into the wooded area with the help of the TLS collection. The gully and the road may be keys to unlocking the location of the elusive third line of battle at Guilford Courthouse, giving archaeologists, historians and geographers a more complete picture of the battlefield landscape. The TLS data collection and post-processing indicating the possible continuation of the feature and will hopefully be verified by future excavation. The data fusion of the sensors allowed for detailed three dimensional above and below ground surfaces. The techniques have shown the ability to document archaeological features from more than one perspective where traditional techniques (shovel testing and pedestrian survey) have proven less successful.

The second article, Chapter III Three-Dimensional Modeling using Terrestrial LiDAR, Unmanned Aerial System, and Digital Camera at House in the Horseshoe State Historic Site, Sanford, North Carolina, The Alston House property at House in the Horseshoe State Historic Site reported on an examination of the type and extent of the information that can be derived from a combination of remote sensing techniques and modeling methods. The first part of this study investigated various approaches to the collection of data and subsequent 3D modeling of historic and the second part of the study evaluated digital surface and terrain models of the landscape of the property created by remote sensing techniques and modeling methods. The structure modeling section compared three different remote sensing approaches to the capture and three-dimensional model creation of a historic building. A detailed comparison was performed on the different photogrammetric models generated from digital camera photography, a terrestrial laser scanner (TLS) and an unmanned aerial vehicle (UAS).

The objective of the study was to examine whether lower cost photo generating models could be used in place of the traditional laser scans. Examining these different methods enabled conclusions as to the most viable means of model generation and dataset manipulation. The evaluation clearly showed that the photo models excel in time and cost. However, the laser scan's completeness of coverage outperformed the digital camera models. The low-cost quick modeling could be useful for recording, preserving, and discovering information of a historic feature. The best scenario is to perform a complete simultaneous total station survey with either the photo collection or TLS survey to produce the most accurate and complete model. It was discovered that complex geometries provide obstacles for modeling from both TLS and UAS systems. However, obtaining both datasets provided for a more complete model around the entirety of the structure. For more detailed façade modeling, TLS can fill in for UAS imagery. Despite combining several sensors, some gaps and holes still existed in the final 3D model.

However, through the examination of the relative accuracy of both models by comparing their respective point clouds showed that the UAS methodology outperformed the high- end survey grade TLS system. The UAS data capture took only one to two hours as compared to the six to seven hours of time for the TLS data collect.

The second component to the research focused on landscape modeling which expanded upon the structure modeling by examining the immediate surrounding terrain.

Historic aerial photography, total station survey data, UAS imagery and a generated digital elevation model (DEM) were all incorporated to determine the accuracy and discovery of new information that could be derived from the historic landscape. Accessibility to a variety of datasets provided a more comprehensive understanding of the landscape, as no single sensor could explain everything that was occurring on the site. For highlighting areas of interest and areas that appear to be less valuable for prospection the combination of sensors with historic imagery proved an even more powerful approach. Armed with such knowledge, conclusions and plans can be made about what areas should be examined further. An additional factor evaluated was the quality of the UAS derived DEM relative to the one created from the total station survey. It was found that the DEM from the UAS for this study site, produced a similar set of elevation data as the total station. While the UAS dataset was not an exact mirror of the total station it does appear to be a valuable, low cost, time efficient, noninvasive data collection and mapping alternative.

The final article, “Geophysical Investigations at the Harper House Bentonville Battlefield, NC State Historic Site” presented in Chapter IV, focuses on the Harper House located on the Bentonville Civil War battlefield. At this state site, a geophysical survey used a ground penetrating radar and gradiometer. The findings from the data were used to determine and pinpoint areas of interest for subsequent excavation. The extensive geophysical coverage by the GPR and Magnetometer was conducted prior to the archaeological excavation which aided the validation of the geophysical results. The results of the excavation assisted greatly in the identification of both the physical and cultural subsurface features. The validation of the geophysical survey data was extremely valuable. The ability to combine both the GPR and the gradiometer on this site and subsequently "dig up" and see what the sensors recorded was critical in providing a better understanding of the potential and limits of the technology. In most cases both sensors picked up on similar anomalies. These areas were then validated by the excavation, i.e. dipolar gradiometer readings, and changes in profile reflections in the GPR. As discussed previously, the GPR highlighted an area with significant undulations in the profile. Although not proving rich in artifacts, the GPR reflected subsurface changes in the geology. This result allowed for a chance to compare the natural reflections that the sensors can record versus reflections from material culture.

Examining the distribution of the artifacts allowed a story to emerge concerning land use during the various periods of occupancy. The area adjacent to the back of the house where the research was conducted produced artifacts from a typical farmstead life. Consistently across the property, a story of construction, disposal of used goods through burial and burning, and manipulation of the landscape for farming are seen through various generations of owners. The primary period in question, the Civil War, was well recorded in the ground with pieces dating from that period. Further examination of the site revealed disposed ammunitions remains that were considered consistent with the site being active during the battle. Even though certain questions regarding the hospital use during the battle were not answered completely, the investigation allowed a more detailed history of the use of the property over time.

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