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The History and Use of Aerial and Space-based Remote Sensing and Ground Based Terrestrial Laser Scanning in Archaeology

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An overview of the history of aerial and satellite-based remote sensing in archaeology is given, from the initial technological development to a chronicling of the incorporation of each technology into the discipline. A discussion of some of the main questions involving the utilization of each technology follows, with specific emphasis on the issue of scale in relation to satellite and aerial photography. New incarnations of GIS are offered as a solution to this and other issues. A novel history of ground based terrestrial laser scanning is presented as well as a general description of the technology involved. Problems of implementation and utilization of ground based terrestrial laser scanning in archaeology are also discussed, with particular importance given to operational limitations faced in field scanning of cultural sites. The laser scanning workflow is examined and a step-by-step analysis from initial site assessment, to optimization of data capture, post-processing, and to final media deliverable is undertaken. Problems relating to individual steps are highlighted and discussed with different solutions presented. A general assessment of the state of the art of each technology will also be discussed, with each discussion based from archaeological case studies undertaken by the author.

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Chapter 1

Introduction

Archaeology as a discipline has undergone a significant transformation as a discipline from its first appearances as a Victorian infatuation with exotic anthropological artifacts to the modern scientific, theoretical and methodologically based study that it strives to be today. The transformation has been facilitated by the incorporation of progressive social theory development and has also come to be influenced by the increasing capabilities of science and technology. While consideration of the benefits and disadvantages of the incorporation of new science, technology, and theory is nothing new to archaeology, it is science and technology that continues to be one of the factors pushing excavation, documentation, and preservation capabilities into new frontiers. In the field of archaeology, the continual development of technology has also become one of the driving forces for theoretical evolution within the discipline, challenging theory to remain abreast of ever expanding technological potential. While the basic tasks of the archaeologist remains the same, "collection, classification, and interpretation" (Lock and Molyneaux 2006), the means by which these are done has changed significantly with the advent of these newer technologies. In the case of satellite and aerial-based archaeological prospection and laser scanning site documentation, new developments in technological ability have raised many questions and issues that modern archaeologists are just beginning to address.

Archaeology, as defined by the Society for American Archaeology (SAA), is "the study of ancient and recent human past through material remains" (SAA.org), but archaeology has not always enjoyed the current (but contested) perception as a scientific discipline. In fact, much of the public perception of archaeology is rooted in images from films such as the Indiana Jones series, which hardly stress the scientific recovery and documentation process that is taught in archaeological field schools and university programs today. While people have always held a fascination with the material culture of their cultural predecessors, (i.e., the Romans and their love of all things Greek, the Maya and their veneration of Olmec relics), it has only been within the last three hundred years, born as a result of Enlightenment thinking, that archaeology has undergone the process of becoming a scientific discipline. Although popular culture still portrays archaeology as romantic adventures, the reality is that there are now ranges of sub-specializations ranging from lithic and faunal specialists to digital archaeologists who specialize in technologies in archaeology. But beyond television and films, there is a more fundamental issue with the perception of archaeology that is tied into the manner in which archaeological research is conducted. "We associate most scholarly disciplines with a subject: Biology with the study of nature, geology with the study of the earth, and math with the study of numbers.… Archaeology is most often associated with an activity: digging in the earth" (Shanks and McGuire 1996: 58). But that public perception is antiquated and does not reflect the state of the art of the archaeological excavation process. Beyond the simple association with the trowel/shovel are the many modern tools that the archaeologist employs: cutting edge surveying equipment, digital cameras, global positioning systems, laser scanners, electronic resistivity meters, ground penetrating radar, LiDAR, satellite, sonar, and GIS to name a few. This list is hardly exhaustive but is gives insight into the many burgeoning areas of specialization in the archaeological subfield of remote sensing.

The archaeological subfield of remote sensing has long held much promise for cultural site identification and prospection. "Today the term remote sensing is generally understood as a technique for the acquisition of environmental data by means of non-contact instruments operating from various land, air and space based platforms" (Lyons 1977: 5). Aerial and space-based remote sensing were the first remote sensing technologies to be incorporated into regular use in the field of archaeology. This revolutionary category of remote sensing technologies has a colorful history stretching back over 100 years, but such tools are still underutilized by contemporary researchers. As the first group of remote sensing technologies to be used in the field, aerial and space-based remote sensing provides an important case study in when analyzing just how and to what extent remote sensing has come to be accepted within the archaeological community over time. A study of the history of aerial and space-based remote sensing will begin to answer questions such as what happens when a new subfield in archaeology is established, and if and how does it gain mainstream acceptance within the archeological community?

Moving past a simple history of aerial and satellite based remote sensing, a thorough analysis of the state of the art is needed. Beyond evaluating limitations and strengths of the technologies, questions must be asked and answered regarding what influence technological theory has in the role of the implementation and acceptance of technologies, and ultimately in the interpretation of the models that are created. Can we use technology without theory? Is it theory that has to keep up with technology or is it technology that needs to keep theoretical issues in mind? Can a historical analysis help to uncover just how archaeologists have dealt with the dialectical relationship between the two in the past?

In addition to aerial and space-based remote sensing, technologies have much more to offer the excavator and the researcher than simply telling us where to dig. The close-range sensing technology of laser scanning offers solutions to some of the most fundamental problems of archaeological excavation. Archaeological Excavation "is tantamount to the destruction of the site and can be thought of as a non-repeatable experiment" (Scollar 1990: 38). There are many implications to the "destruction of the site" that must be considered prior to excavation. The first is quite obvious yet important nonetheless; once a site has been excavated it cannot be recreated as it was due to the destruction of the stratigraphic layers. If a change in soil context is missed by the excavator, this crucial characteristic is lost forever to the site interpretation process. The only objective record of the past is destroyed at the moment the archaeologist's trowel enters the earth. The realization of the destructive nature of the excavation process has led to the development of new non-destructive techniques for site excavation and documentation. Remote sensing, close-range sensing, and geophysics have all been developed or adapted from other fields, to mitigate the damaging effects of excavation and documentation whenever possible. By digitally documenting the site throughout the excavation process from pre-excavation to each individual context, and finally to post-excavation, the site can be "reconstructed" in three dimensions and differences in soil color and consistency can be identified. This systematic approach of comprehensive digital documentation also allows for the excavation process to be verified or critiqued by other researchers (Forte *et al* 2001: 2).

Technologies in archaeology cannot be used practically without a theoretically informed, developed methodology. But the introduction of a new technology into the field raises certain questions; How is the accuracy and reliability of a new technology challenged within the field? Are there patterns of a general technological acceptance/rejection throughout the discipline and which steps can be taken to facilitate increased utilization? What processes prove most affective at disseminating technological awareness and know-how across the field? Many of the questions and dilemmas posed by the introduction of new technologies in archaeology can be answered by reviewing the history of the first technique of remote sensing in archaeology, aerial archaeology. These questions can be answered by looking at the birth and development of the use of remote sensing technologies in archaeology. While I will not attempt to answer the many questions that the introduction of new technology raises, I will discuss the history of the introduction of new technologies in an effort to shed light on the future of acceptability and utilization of new cutting edge technologies. Through the recording of past uses of remote sensing technologies in archaeology, it is possible to see which problems most often arise, and how methodology has adapted to overcome these issues. Chapter 2 includes an updated and synthesized history of aerial and satellite-based remote sensing in archaeology, paying particular attention to where implementation began, and following its gradual acceptance throughout the wider archaeological community; starting with a discussion of the oldest mode of remote sensing (aerial archaeology) and finishing with its closely related field of satellite photography. Chapter 3 addresses one of the looming issues that aerial and satellite-based remote sensing face, scale, and how other technological innovations (namely GIS) can offer solutions to this and other problems. In

Chapter 4 a brief but novel history of one of the newest forms of remote sensing, laser scanning, is provided. This will be followed in Chapter 5 by an analysis of the issues this new technology has faced in its relatively short history in the field and is concluded with an assessment of possible functions for the technology in the future. Finally Chapter 6 offers some general thoughts on the state of the art of remote sensing in archaeology and discusses problematic areas commonly encountered in research and fieldwork conducted with a strong technological focus.

As archaeologists, the history of our discipline has been rooted firmly to exploration delving into the earth and sea in an effort to divulge the details of past cultures, but perhaps the most exciting new frontiers of archaeology will be explored from positions based in the sky or in space. While the primacy of the trowel as the most utilized tool of the archaeologist appears unthreatened, it is the cutting edge technologies of geo-physics, lasers, and computer science (digital technologies) that will continue to usher archaeology into a new era. But before anyone envisioned such technological hardware could ever be used successfully in archeology, 100 years ago the first subfield of remote sensing, aerial archaeology, began its slow but steady influence of how we undertake archaeology.

Chapter 2

A History of Aerial and Satellite Based Remote Sensing

The history of aerial and space based remote sensing in archaeology began more than 150 years ago, long before the field of archaeology assumed its current manifestation. It was not long after the development of the photographic camera that archaeological enthusiasts began to explore the new technology's potential in site identification and understanding. Before the advent of remote sensing, site identification and exploration was limited to those sites that were obvious on the Earth's surface or were discovered through the chance digging of archaeologists or even those in other fields or industries. But the earliest archaeologists quickly realized that in order to better understand existing sites and find new ones, "one ought to be a bird in order to be a field archaeologist" (Deuel 1969: xviii).

In addition to a simple chronology of events, the history of this subfield of archaeological remote sensing can inform contemporary researchers about both the process of the acceptance of new ideas and technologies in the archaeological community. In addition, it can reveal mistakes that past advocates have made in selling the new technology as well as the successes. With ever-advancing technological capabilities that can be incorporated into archaeological methodology, it is paramount that the most successful model for integration be identified in order to further the discipline. While this chapter's purpose is not to provide a template for successful incorporation, the next logical step would be to formulate a methodology for successful integration of a new technology into the field. It is also a reference point to evaluate the degree of incorporation of technologies already in the process of being introduced to archaeologists. As the first attempt at incorporation of remote sensing (and arguably the most successfully), there is much to learn from a historical study of the topic.

The functionality of aerial and satellite-based remote sensing has also changed since the technologies first introduction to archaeology. Now, in addition to showing the excavator potential sites to excavate, photographs can also be utilized to determine how best to excavate a site, and conversely also help archaeologists decide where excavation may be more difficult or impossible. Also, in addition to use in intra-site analysis, imagery is now widely used to visualize inter-site relationships across great expanses of space and even time. Analysis of inter-site relationships through time is done by evaluating the relationships of various anthropogenic features, in the same geographic area over time. This capability is born from the new technology's inherent ability to document the macro-scale view of a site and the relationship to its surroundings a bit more clearly, and does away with the prevalent problem of previous archaeologists missing "the forest for the trees." Remote sensing is inherently a top-down approach, in that analysis is needed to proceed from the macro scale (aerial and satellite imagery is captured at the macro level) and proceeds through analysis to the micro level (Campana and Forte 2006).

One of the distinct advantages of Photography in general, is that it currently has the ability to capture more detail than any human generated map can. "An air photograph records not only the conventional plan of a countryside, as is drawn on a map, but also its actual state, including therefore not only real roads, railways, cottages, and towns, but also the crops, hedgerows, and ephemeral details which can never be distinguished on the most careful, general survey" (St. Joseph 1944). But photography also is superior to maps or drawings in another way in that it captures sites as they are, without occlusion and with limited amounts of human interference or agency so far as deciding the level of detail to include and exclude.

Aerial photographs of landscapes "amount to nothing less than historical records, and writing on aerial archaeology is, in the last analysis, also a writing on historiography", and therefore should be appreciated and conserved just as historical texts are today (Deuel xviii). Similarly to a book, a good archaeologist can 'read' the photograph of the earth's surface and convey the narrative that unfolds across the document. But like any historical book, the interpretation of the text will differ slightly from one archaeologist to the next.

The natural state of the Earth is a product of billions of years of geological change. Humans have through the course of living change the natural environment around them to varying degrees. Only within the last two hundred years, have we been able to develop technologies able to document those changes. If someone digs a hole thousands of years ago, "let men and the ravages of time fill it and pack it, let it be overgrown by weeds or make the plough run overt it for generations, the soil in the cavity will never be the same against as the surrounding undisturbed area" (Deuel 44). But it should also be stressed that in the case of aerial and space based remote sensing, archaeologists are not actually able to see beneath the surface of the earth, but rather are seeing impacts of subterranean features on the growth patters of plants, or the absorption level of soil.

Both the historical legacy and current maturation of the use of remote sensing and it applications in other fields such as geography, oceanography and other associated fields, as well as its current status as a mature have led some digital archaeologists to push to consider remote sensing and archaeology as two different fields, (Parcak, 2009). But a historical study of its use shows that the potential of remote sensing in archaeology is best realized when archaeologists trained in the methods of the technology apply it to their research process. Who better to tailor the use of the various techniques in archaeology, than those who have a general understanding of the subject area that the technologies will act upon?

The evolution of the capabilities of aerial and satellite based remote sensing and other remote sensing technologies have served to both expand and limit the range of usefulness for each technology. While archaeologists now have the capability to identity features on photographic imagery today that they never could have imagined of seventy-five years ago, when it comes to identifying intra-site features (as was one of the uses of imagery in the early phase of the technologies introduction) it is not be able to compete with geophysics or other remote sensing technologies. Remote sensing technologies have come to be categorized into different areas depending on the scale that they best serve to document. Aerial and space based remote sensing are best able to capture data at the macro level of landscape and inter-site analysis, while a remote sensing technology like electronic resistivity is best used to identify intra-site features at a much smaller scale.

Remote sensing entails an array of different technologies, each originating in different subfields of physics and computer science and relating to different technologies from lasers to radar and photography. Aerial Photography, geophysics, laser scanning, virtual reality, imagery analysis within geographic information systems (GIS), and satellite imagery analysis are all forms of remotes sensing. As an area of study, satellite remote sensing is the "specific application of satellite imagery (or images from space) to archaeological survey, which entails searching for ancient sites on a particular landscape at different scales", but in a more general sense all of these technologies "are concerned with identifying "anthropogenic" features in a landscape" (Parcak 2009).

There are many alternative names that have been given to Aerial Archaeology throughout history, aerial prospecting in archaeological research, archaeology from the air, archaeological air surveying, air photography for archaeological purposes, air archaeology and aerial aid to archaeology, but they all describe the basic function of using photographs obtained from aerial vehicles, to understand and identify the relationship of anthropogenic features at the inter/intra-site level.

For as long as people have shown an interest in uncovering the material remains of people from the past, they have used the geomorphic phenomenon on the earths surface to give them a clue as to where to dig. Whether is was earthen ramparts in the British Isles, or *Tells* looming throughout the Levant, people have looked with a suspicious eye at those geomorphic features which were large enough to be distinguished from the same plane, that of the earths surface. But people fortunate to live in landscapes with natural high vantage points, and where certain species of plant life grew, came to recognize that from those vantage points patterns in the vegetation growth could be discerned. To their surprise, those patterns correlated to subterranean anthropomorphic features that would be uncovered during farming practices or through simple investigation. The People of France came to refer to the variability in crop growth patterns over archaeological ruins as *danses de fees*; "according to popular belief, the agile spirits were responsible for leaving marks in crops from their midnight antics"

(Deuel 1969). But the incidents of archaeological discovery based on identification in vegetation patters observed from high vantage points were isolated, and a methodology of field crop interpretation was never developed, as these instances of detection owed more to chance, than a truly developed methodological style. It would take revolutionary developments in technologies for archaeologists to achieve their much-desired vantage point for site identification, in the sky.

The first recorded instance of pictures being taken from the air occurred in the month of October in 1858. Taken from a hot air balloon by Gaspard Felix Tournachon, they created a sensation upon their exhibition and sparked a rush by many enthusiasts to begin documenting large cities from the air (Deuel 1969). As is often the case, war further fueled the development and usage of the newfound practice of imagery capture. In 1861, during the American Civil War, Union soldiers began undertaking aerial surveys, using balloons, of the newly encountered territory. The surveys were instrumental to planning everything from supply logistics to battlefield planning (Miller 2008). But what began as simple aerial survey, eventually turned into the first systematic use of aerial photography (Deuel 1969). This military tradition of the usage of aerial photography may have started on the battlefields of the United States, but eventually it would be adopted by the British armed forces, where its use would grow and develop and eventually influence the first archaeologists to consider its use in identifying sites.

The development of aerial photography amongst the British proved to be an enduring effort that came to be implemented differently across the vast British Empire in accords with the unique challenges posed by each territory. "Major Elsdale was the pioneer of air-photography in the British Army, when between 1880 and 1887 he carried out experiments from free balloons" (Crawford 1928). Abandoning the idea of manned aerial photographic surveys in favor of free flying balloons that could be set up faster and were easier to transport, Major Elsdale radically changed the effectiveness and deployability of the new method of survey. His balloons were engineered to carry a camera up into the air, where several photographic plates were automatically exposed, after which the balloons would then release their internal gas and return to the earth. But while his efforts were successful in surveys of Britain, when similar survey units attempted to reproduce his methodology in the Survey of Indian in 1892, they proved ineffective in the new environment, and they technique was eventually abandoned for survey purposes.

While attempts at widespread usage of the technique proved to be too unreliable, some recognized its potential use on a limited scale. The British Colonel Sir Charles Close, who while serving in the British army in 1891 in northern India, got the idea to photograph the archaeological site of Agra (Deuel 1969). He is credited with formulating the first archaeological endeavor to specifically include aerial photography. Ultimately his plan would prove unsuccessful, a casualty of unfavorable weather conditions, but the realization by Colonel Close that aerial photography could contribute to archaeological understanding of a site, was groundbreaking.

The watershed moment for aerial archaeology transpired in 1906, when Lieutenant P.H. Sharpe took both a vertical and an oblique photograph of Stonehenge on the Salisbury Plain from a war balloon. The same photo was later published in *Archaeologia* (vol LX) by Colonel Capper, also of the British Army, and the world became aware of the potential of the new technological technique (Crawford 1928).

Although the photographic feat was groundbreaking, the only other parties capable of undertaking a similar endeavor at the time were other advanced militaries. In 1908 Italian Army engineers followed the lead of the British, when they began aerial documentation along the Tiber River. By 1911 they had gone on to complete aerial photographic documentation of the port of Ostia, and the Forum in Rome (Deuel 1969). But enterprising archaeologists, who could not support balloon surveys at remote sites, began to look to other means to capture imagery from the air. In 1914 Henry S. Wellcome used box kites with "specially devised automatic control cameras" for photographing his archaeological sites in the Sudan and in Egypt (Crawford 1928).

The driving force behind the evolution of remotes sensing can be identified best as the invention and evolution of the technology itself. It was firstly the invention of such technologies as photography and later the development of powered flight that led to the birth of archaeological remote sensing. While the Wright Brothers are credited with developing and flying the first powered, manned, heavier than air, and maneuverable aircraft (or airplane), at Kitty Hawk, North Carolina in 1903, it would not be until the rapid development and refinement of plane design during World War One, over a whole decade later, that aerial photography from airplanes would take off. Air photography was used pre-1915, but it was only with the occurrence of the First World War, the development of the airplane, and "the skills acquired by military air-observers that established the value and importance of air photography (Parcak, 2009).

The first to combine new advancement in camera technology with the airplane was the German archaeologist Carl Schuchhardt, who was able to secure German war photographs and use them in his interpretation of an existing Roman frontier wall in

Romania (Deuel 1969). In Europe, neither the Germans nor British were successful at identifying archaeological sites from the air, but in the Northern Sinai Desert, special German teams (Denkmalschutzkommando) were established with the explicit task of using military aircraft for identifying and mapping large scale archaeological ruins (Crawford 1928). Dr. Theodor Wiegand of the German archaeological task force is credited with publishing the first photographs taken from a plane explicitly for archaeological purposes when he published his photographs in 1920. Despite a concerted effort to employ the new methodology in the Sinai Desert and throughout the rest of the Middle East and North Africa, there was little progress in imaging terrain in the European Front. But the disparity between usage in France and Germany, versus the Desert of the Sinai, has more to do with the native topography and geography, and the ease of identifying features, than anything else (Crawford 1928). The relatively sparse open country allowed for more site identification and investigation.

The first aerial archaeological photographic survey to be undertaken with an accompanying explicit written analysis was conducted by the British Surveyor Lieutenant-Colonel G.A. Beazeley as he flew missions over modern day Iraq.

> "when the air photographs were printed they revealed the faint trace of a vast ancient city some twenty miles long as as much as two and a half miles wide in places, continuous except for a break such as Aski Baghdad, and if it was all built at the same time must have housed a population of about four million souls. As it appears to have been built all in one style the area may very well have been one vast town. The air photographs show up clearly the nobles' and rich merchants' estates along the bank of the Tigris, with their mansions, offices, summerhouses, and gardens; each estate being arranged on a different pattern according to the whim of its owner. The centre of the city seems to have been supplied by a system of *karezes* (underground water channels) in addition to supplies led in by canals." "Whereas when walking on the ground no trace was visible" (Deuel 1969)

Colonel Beazeley published the first archaeological accounts of an aerial survey of abandoned sections of the city of Baghdad in 1919 in the "Geographic Journal".

Unfortunately for the Colonel he was shot down and taken prisoner before he could conduct more extensive aerial surveys.

British pre-eminence in the field of aerial archaeology, all the way up to 1950, was due in part to the willingness of the Royal Air Force to participate in exploration. On training missions, the R.A.F. instructed its men to be on the lookout for archaeological sites, and to photograph them when they were observed (Deuel 60). Royal Air Force flights assisted Alexander Kennedy's Petra work in 1923-4, Nelson Glueck's survey of Transjordan and Palestine in the late 1920's, Berazeley's early aerial photographs over different parts of Mesopotamia, and O.G.S. Crawford's exploration of Iraq, Transjordan, and Palestine in 1928 (Parcak 2009). But archaeologists were eager to direct their own survey mission, but were finally able to in the mid 1920's. In May 1924, O.S.G. Crawford conducted the first archaeological aerial survey undertaken distinctly by an archaeologist, and not the R.A.F., over the English region of Wessex (Crawford 1928). Crawford would later go on to publish the seminal book, *Wessex From the Air* in 1928, which became the de-facto bible on aerial archaeology.

The early history of archaeology is punctuated with colorful, seemingly larger than life characters, be they the Earl of Elgin, Thomas Bruce and the Elgin Marbles, or Heinrich Schliemann and his excavations of Troy, and aerial archaeology is no exception. Osbert Guy .S. Crawford is credited as being the father of aerial archaeology. Where others had dabbled in the technique, it was Crawford, who while flying sorties over the Western Front in WWI Europe, realized the potential for the new technology as it relates to archaeology (Deuel 1969). Crawford dates the birth of aerial archaeology to 1922 when he reviewed photographs given to him by the British Royal Air Force. His reaction to the photographs and the archaeological remains they clearly contained was as follows:

> "I realized that air-photography was going to be an enormous help to archaeologists in unraveling the marks of all kinds of left in the ground and above it by prehistoric man. It was a dramatic revelation but I knew at that moment that a new technique had been found, and that I had the means of developing that technique and making it available to the world at large…" (Deuel 1969).

For Crawford the introduction of his paper "Air Survey and Archaeology: Discussion", was meant to "inaugurate what will prove to be a new epoch in the history of British archaeology" (Crawford 1923). In step with his vision, Crawford later went on to found *Antiquity*, where he published his own articles relating to aerial archaeology and served as editor. It was through his prolific writing on the topic of aerial archaeology, that Crawford came to be responsible for coining much of the terminology used in the field. Arguably, Crawfords most important contribution to aerial archaeology, was his treatise, "Air Survey and Archaeology: Discussion" which was the first attempt at establishing an optimal methodology for conducting aerial photography of archaeological sites. In the article, Crawford divided sites into three categories, Shadow sites, Soil Mark sites, and Crop Marks, and wrote and formulated a different methodological approach for each.

This first site classification that Crawford distinguishes are shadow sites. Shadow sites depend on light to create shadows to bring out features in the landscape. These most commonly include surviving large-scale ancient earthworks; "furrows, boundary banks, ditches, walls, ramparts, causeways, home sites, abandoned villages, and all sorts of barrows." The longer the shadows, the easier it is to distinguish the features from the surrounding terrain, and for this reason the early morning and evening hours are the optimal time to conduct the aerial survey. But Crawford also pointed out that if there is heavy agricultural production or some other type of prolonged disturbance of the soil then the chance of shadow sites appearing would be greatly reduced.

The second distinctive class of identifiable sites is those that are identifiable by soil marks. Crawford defines soil marks as “a coloration of the bare earth, appearing either lighter or darker than the surrounding undisturbed terrain”. When filling cuts in the earth (ditches, hollows, trenches, pits, canals) the soil is often filled with more organic matter, and it retains moisture far longer than the surrounding areas, which eventually leads to a darker appearance.

> “the silt, brick earth, and humus in buried pits and ditches collect and conserve surface moisture, and permit a greater root-penetration than in undisturbed subsoil, so that the growth of the crops is taller and more luxuriant than the average. Foundations and roads prevent root-penetration and the growth over such features will appear poor and stunted.“ (J,K. St. Joseph 1945).

Field ploughing can accentuate the features by raising undisturbed soil to the surface and providing a contrast in colors among the various soil types. Again, early morning and evening hours work best at identifying features of this variety. If a field is planted, it can eventually turn into the third kind of site classification, those identifiable by crop marks. It is for this reason that the best time of year to identify sites using this method is during the early spring, late fall, and winter months.

Crop Marks, or “subterranean disturbances that can either be detrimental or favorable to growth”, are the third and last class of sites identifiable by aerial archaeology. The irregularities in growth pattern are due primarily to the root structure of the plant; if a plant is rooted in a fill area, its roots are able to easily spread through the less compact earth. The fill soil also has the added benefit of being more moisture retentive and typically more nutrient rich than surrounding soil. All of this translates into more “luxuriant growth and thicker and taller plants” (Deuel 1969). Conversely it a plant is located over a wall, compacted floor or road, root system growth will prove to be more difficult leader to a smaller more frail plant specimen.

As Crawford was the first to begin a systematic testing of various techniques in search of those most successful, he was also quick to encounter the many circumstances that would trigger false positives in site identification. The application of pesticides and even crop diseases like fungus, often created the impression that archaeological features lay beneath their roots. Perhaps the most humorous false positive that Crawford encountered was then he thought he discovered a large Neolithic settlement, only to discover that it was the result of a farmer staking his goats into the grounds which resulted in a large patchwork of eaten grass (Crawford 1923). It was also in the same article, that Crawford published the observation that oblique angles are the most critical for viewing architectural remains as they preserve the three-dimensional representation that vertical views are not capable of providing. Crawford's newly developed methodology immediately proved effective when in 1925 he discovered another large Neolithic settlement, named Woodhenge, only two miles away from Stonehenge.

The period leading up to the Second World War witnessed the spread of aerial archaeology beyond mostly British endeavors to researchers from other areas. In the 1920's and 1930's, the French Jesuit Priest Antoine Poidebard, began one of the most comprehensive aerial landscape surveys outside of Great Britain, when he began to document the extensive Roman frontier in present day Syria, Jordan, and Iraq. After embarking on aerial survey missions to uncover the agricultural potential of arable land in northern Syria, Poidebard discovered an immense system of Roman ruins. In 1934, Poidebard published *La Trace de Rome dans le 22hotog de Syrie*, the culmination of years of aerial survey over hundreds of miles of Roman Forts, outposts, and way stations (Deuel 1969). The end result was a better understanding of the Eastern Roman frontier, as an intermediary between the Roman Empire proper and the Empires of Central Asia and the Far East. Despite his groundbreaking success in the Near East, Poidebard's work was not emulated back in France, or any other French province. It would not be until after the Second World War, that France would begin another major advance in aerial archaeology methodology.

The late 1920's also signaled the start of a developing tradition of aerial archaeology in the America's. In 1927, Charles Lindbergh made the first solo, non-stop, trans-Atlantic crossing from the United States to the European mainland in a fixed wing aircraft. But it was on a later expedition that the young airman would begin to contribute to the field of aerial archaeology. In 1929, while flying on a route between Havana and Panama City, Lindbergh made a detour over the Yucatan where he spotted "embedded in the verdant tropical foliage, a number of high, overgrown, pyramidal mounds from which protruded pieces of masonry" (Deuel 1969). Lindbergh's interest was peaked and when he returned to the United States he offered his plane and service to the Carnegie Institute to begin surveying the American Southwest and potential Maya sites in Central America. Lindbergh began aerial photography in the American Southwest and was successful at helping excavators uncover new sites as well as better understand existing excavations and their relationship with arable land areas, water sources, and easily defended positions in the vicinity (Deuel 1969). Both Lindberg and his wife were the first to photograph Chaco Canyon from the air, and document the extent of the main settlement and its related features in the surrounding landscape. While Lindbergh brought much notoriety for the new technology, it was actually the United States military; who began the first intentional aerial photographic surveys for archaeology, when in 1921 photographed the Cahokia Mounds in the Mississippi River basin (Deuel 1969).

With the growing awareness of the advantages of aerial archaeology becoming known to advocates of cultural preservation, it began to see employment in a number of projects mainly across the American Southwest. In 1930, one of the United States Senators from Arizona, Carl Hayden, was instrumental in getting the Salt and Gila Basins, in the Four-Corners region, recorded through aerial photography. Much of the complex irrigation system of canals and dams built by the indigenous inhabitants over a thousand years ago were being destroyed by increased urban and farming development and there was an immediate need to properly document the extensive irrigation system that stretched tens of miles in some cases. In California, George Palmer, an amateur pilot, discovered the "Intaglio Pictographs" when he viewed a human and animal figure (both about 100 feet long) north of Blythe California. Produced in the same manner as the Nazca Lines in Peru (Parcack 2009). After alerting authorities the US Air Corps of the US Army photographed them 1932 in a process that eventually uncovered two nearby sites. The University of Chicago's Oriental Institute was the first academic institution to sponsor an aerial photographic project when in 1935 it sent Erich Schmidt to begin aerial documentation of sites in Iran (Deuel 1969). His endeavors were not rewarded with a great deal of success due in part to his relative inexperience, lack of understanding of optimal survey conditions, and to the greatest extent meddling Persian officials.

The advent of the Second World War interrupted much of the progress in aerial photography as much of the Air forces of the world were embroiled in fighting one another. But the war did serve to train a whole new generation of pilots, as well as re-introduced some British and American pilots to areas with easily identifiable anthropomorphic features in the Middle East, and North Africa. The end of the war coincided with a boom for aerial archaeology. The Aerial Survey of Italy began in May of 1945 with the signing of the Armistice two RAF pilots and archaeologists in their private sector jobs John Bradford and Peter Williams-Hunt used their planes and equipment to photograph the Italian region of Apulia on the southern Adriatic coast (Deuel 1969). They were the first to take Crawford's British methodology to another country and successfully document its archaeological features. The two pilots were able to identify one of the first Neolithic farming settlements in Italy. Bradford later was able to identify over two thousand Etruscan Tombs simply by studying air photographs taken by RAF during World War Two.

Aerial archaeology also proved to be fundamental in the discovery and understanding of several important archaeological sites throughout the world, namely the Etruscan city of Spina, and the Nazca lines of Peru. The 'missing' city of Spina was an Etruscan and Greek influenced city that at its height in the fifth century B.C. traded with Greece, Egypt, and the Levant. In 1935 the cemetery of Spina, with more than 1200 tombs, was discovered but the location of city proper remained a mystery. The cemetery was rich with "granulated gold earrings and bronze candelabras of distinctly Etruscan cast, amber necklaces, Egyptian vessels of glass and alabaster" (Deuel 1969). In 1956 the city was finally identified using aerial photography in the Vale Pega. In 1941 the famed Nazca Lines were investigated for the first time using aerial photography conducted by

Paul Kosok of Long Island University. It was only after the first comprehensive aerial survey, that the full extents of the pictographs were revealed.

In 1947 Cambridge University inaugurated the Cambridge University Collection of Aerial Photographs that served as the first sustained foray by an academic institutions into the field of aerial archaeology, and demonstrated the growing importance of the new methodology in the world. During the waning years of the same decade, French Air Force Colonel Jean Baradez began the first government sponsored archaeological aerial reconnaissance work in southern Algeria (Deuel 1969). In yet another giant leap for the field, the first infrared photography was used in Barbeau Creek rock Shelter in North Carolina in 1954, unlocking tremendous new analytical capabilities for aerial photography. J. Buettner-Januch discovered that archaeological remains were more easily observable on IR film than on normal ones due in part to infrared films ability to decrease haziness, as well as its ability to highlight particular features from a background. While IR archaeology flourished, one of the main drawbacks that became apparent was the need for variable exposure rates of IR films, so the quality of the exposures could not be ascertained without first developing the film (Parcak 2009). While the introduction of improved multispectral imaging from the air increased the effectiveness of aerial photography, by the 1960's the age of satellites had began, and with this new era came improved and continual earth coverage and unique capabilities that aerial photography was hard pressed to match.

The story of space-based remote sensing in archaeology begins with the rise of launch vehicle technologies, or rockets, able to carry equipment payloads beyond the earth's atmosphere. Although planes were developed during the twentieth century, their innate handicaps (needing air to keep combustion in the engines going, and needing air to provide lift for the wings) rendered them of limited use in terms of launching space based satellite platforms. Rockets in comparison, actually work best in a space for a couple of reasons; space is a vacuum which has no air particles to interfere with ejecting gas out of the rocket nozzle and no air resistance for the rocket to encounter as it travels through space. The presence of air particles (an atmosphere) results in a loss of power, which translates to a loss of velocity and carrying capacity.

Satellite remote sensing begins in the 1940's with the development of the V-2 rocket by the Germans. While the first attempts to mount a camera yielded very poor quality pictures, but they showed the promise that the technology could achieve given adequate time to develop (Parcack 2009). The first documented use of rockets in warfare is found in the Ching Shih, which tells of their use against the Mongols at Kai-fung-fu in 1232 (Miller 2008). Roger Bacon, an English Monk, is credited with smuggling the formula for making gunpowder and rockets out of China in 1249, introducing the West to a technology that would revolutionize how were wars fought in Europe and eventually the world.

The development of liquid-fueled rockets by Robert Goddard in 1926 revolutionized the functionality of rockets. Rockets using liquid fuel are much more advantageous mainly because they are capable of producing much more energy than solid-fuel rockets, and they are more easily controlled as the burn rate can be manipulated by simply shutting off fuel to the rocket engine (Miller 2008). Suddenly rockets could be developed to carry much heavier payloads, and the Germans in the buildup to World War Two were quick to exploit this technologies new potential.

The final development of the V2 rocket in 1943, unleashed a wave of terror and destruction across the major European capitals of the Allied nations. But born out of this technology, developed by the Nazi armies to tip the scales in their favor, came the space age, and with it the capacity for archaeological satellite remote sensing. Following the end of the Second World War, both the United States and the USSR raced to improve designs of captured German V2 rockets. On May 10, 1946 the first instrument carrying rockets were launched by the United States to a height of 70 miles, with equipment to measure the intensity of solar rays. Several months later, the United States was also responsible for capturing the first photograph from space, which was taken aboard another V2 launched on October 24, 1946 (Miller 2008). While the United States looked to be ahead in rocket development, it was caught off guard when on October 4, 1957 Sputnik 1 was launched aboard an R-7 rocket (a multi-stage rocket whose design is based on the V2) by the Soviet Union. The ability to launch objects high enough to put them in a semi-sustainable orbit was only made possible by the development of multi-stage rockets. Multistage rockets are basically rockets stacked on top of each other or side by side. When one stage of the rocket is used up it falls away making the rocket lighter, which translates to faster speeds for the remaining stages and rocket payload. This is a much more efficient system than a single stage rocket which must deliver the weight of the emptying rocket fuel tanks, in addition to the payload, into space. The response of the United States, was to develop it's own multi-stage rockets, and did so with the creation of the Delta series rockets in the 1960's. These rockets served as the platforms on which all TIROS, Nimbus, LANDSAT and GPS satellites have been launched and put into orbit.

Before any satellite is launched, scientists must decide which the optimal orbit depending on the capabilities and desired informational output of the satellite. But deciding just what is that optimal orbit is a tricky process; the earth spins on roughly a north/south axis, so if a satellite were to spin on an equatorial orbit, it would fly over the same area every day. If the satellite was put into a polar orbit, or inclined orbit (in-between the two types) the whole earth will be covered over after a given amount of time. "It is possible to arrange the timing of a polar orbit so that the satellite will pass over the same spot at the same time of day each month. This allows scientists to accurately chart changes in specific areas on the Earth's surface" (Miller 53, 2008).

By the late 1960's, satellites were fully capable of capturing infrared (IR) and hyper spectral photographs from space. IR and hyper spectral photographs work by capturing light beyond the visible spectrum that provides better contrast, and in turn easier feature identification. In the seminal article "Archaeological Methods and Remote Sensing", George Gumerman and Theodore Lyons established IR photography and multispectral photography as the most comprehensive film techniques capable of capturing data on a slew of different subjects from soil composition to vegetation growth patterns (Gumerman and Lyons 1971). This works at a basic level by recording the reflected radiation from the surface of the Earth. Any variation in radiation level is the product of subsurface features, be they roads, walls, ditches, or pits. In this way, satellite remote sensing can act as an aerial geophysical sensor using multispectral data (Parcak 2009: 21). The ability to conduct multispectral and IR imaging of the Earth's surface was enhanced with the launching of the Landsat Satellite System in 1972, and later with the SPOT system which was begun in 1986.

Another pivotal moment in the development of space based remote sensing was the development of the Global Positioning System (GPS). In 1973 NAVSTAR, the first functional incarnation of GPS, was developed by combining all the different satellite systems from across the different branches of the military into one uniform system. Any position on the earth could be calculated by triangulation between any of three satellites in NAVSTAR system (although most GPS units use four to offset possible error). On July 14, 1974, the first satellite explicitly created for the NAVSTAR system was launched; additional satellite launches continued until the system was completed in 1994 with a total of 24 satellites (Miller 2008: 71). During the height of the cold war, on September 1, 1983, a Korean airliner was shot down after it strayed into Soviet Airspace. This prompted then-President Ronald Reagan to make GPS capabilities available to private airlines, a move that was followed later by opening of GPS to the public for free in the year 2000 (Miller 2008: 71).

In addition to image gathering, advances in technology also allowed for the gathering of highly accurate topographical data. Plane mounted side looking radar was used in 1977,1978, and 1980 to see through the jungle of the Maya Lowlands in Belize and Guatemala to map ancient Maya irrigation channels and causeways. In 1981, the SIR-A, or the Synthetic Aperture Radar Mission (SRTM), was undertaken by the space shuttle *Columbia*, and overflew and mapped most of the Earth. It was the start of various shuttle radar-mapping missions that continued until the latest mission onboard the space shuttle *Endeavor* in 2000. The 1981 mission was responsible for discovering in the Sahara "Radar-Rivers" the complex ancient river systems beneath the sands of the Sahara. The SRTM data were used to map the areas where vegetation and animals would have thrived, and as a consequence, locate the possible living sites of ancient humans who relied on them, “water was the single critical factor in determining the settlement system” and settlement would have corresponded to “any collection of water within the radar channels” (Wendorf et al 1987: 46). A ground survey of the Wadi Arid-the largest radar channel uncovered in the SRTM mission-led to the discovery of several hundred Neolithic sites that were more densely located along the depressions between the ridges of the desert landscape, where the SRTM showed the deepest channels, and where water and vegetation would have been most abundant and dense (Wendorf et al 1987: 58). Without the radar mission, it would have been impossible to see beneath the sands of the desert to the underlying geomorphic features, and in turn, nearly impossible to identify the Neolithic settlements.

The commencement of the use of LiDAR (light detection and ranging), in archaeology opened up whole new areas of terrain for site prospection; areas that had previously been too difficult to survey on foot or with other technological techniques. LiDAR works similar to radar, by emitting light-usually in the form of a laser-and measuring the wavelength of the reflected light, a very precise image of a surface is constructed. The ability to differentiate reflected wavelengths means that LiDAR can effectively edit out certain elements like trees, sand, and buildings. The possibilities for application in archaeology are enormous; not only to discover or document new sites, but also to correct information and remove contemporary features from digital elevation models (DEM’s) of sites already documented. For example in 2001, the utilization of LiDAR was used to correct the location of Stonehenge and make a DEM that did not include contemporary trees and structures (Parcak 2009: 77).

The methods of utilizing satellite imagery have not remained static as other technologies have been introduced into remote sensing, but rather, have continued to develop in new, ingenious ways. In 1992 Frederick Cooper located sites by identifying growth patterns of shrub oaks to find ruins. By analyzing free and reduced cost imagery from a different perspective, Cooper was able to move beyond identifying sites based on their more obvious impacts to the environment and, in the process, increase the potential for site prospection via satellite imagery. Satellite-based remote sensing in archaeology continues to flourish, with new spheres of methodological influence.

It is quite apparent that historically, certain patterns are present, with certain researchers from different parts of the world and select institutions serving as the standard-bearers for increased technological innovation and inclusion in archaeology. While institutions like the RAF, Cambridge University and Oxford University, Yale University, and the University of Chicago have significantly influenced the developed methodology for air and space based remote sensing, there are signs that the institutions advancing most rapidly are located beyond the list often considered. For example, in the 2000's China became the most advanced nation in terms of sponsoring satellite remote sensing for archaeology and was responsible for organized the first International Conference for Remote Sensing Archaeology in 2004. Cutting edge development in the field has shifted after a hundred years from Britain and the United States, to the rising powerhouses in East Asia.

In light of the shifting dynamic of aerial and space-based remote sensing, it is important to note that perhaps the most instrumental contributors to the field of archaeology have not been nation-states, corporations, militaries, academic institutions, or even professional archaeologists, rather innovators with other interests and from other fields. "Aerial archaeology owes some of its finest accomplishments to outsiders or amateurs, men [and women] who were driven by enthusiasm instead of professional or academic pressures" (Deuel 1969: 276).

From the start, aerial and space-based remote sensing has developed as an independent science and method, impervious to the shifting trends of archaeological practice over the decades of the twentieth century. What this has meant is that in the ever-evolving process that is archaeological investigation, remote sensing has come to serve as a cornerstone for thorough archaeological survey no matter the decade of work or excavator in charge. The functions for its use have stayed relatively constant, even as these technologies change the way that we approach the survey and excavation process. This fact is apparent in that long before there was any attempt at developing a standard excavation methodology, there was a keen interest by some to incorporate the use of technologies into the survey and excavation process. As a testament to the role that aerial and space-based remote sensing now plays in archeology, the most technologically advanced archaeological field schools are now offering training as part of the basic curriculum.

Chapter 3

Issues Involving Aerial and Satellite Based Remote Sensing

Some of the most pertinent questions to arise from the discussion of the use of aerial and space based-remote sensing in archaeology are: How is site identity formed within a landscape? How can we relate the material culture found within that site to its particular surroundings? While seemingly simple and straightforward, these two questions can be identified as core issues through which we can frame a discussion on the formation of site identity and inter-site relationships as they relate to landscape archaeology, the utilization of aerial and based-remote sensing, scale, and a host of other issues that arise when material culture is considered. A useful starting point in this discussion is to look at the underlying theoretical perspective guiding research, which ultimately influences both the questions that are asked, and how are answered. Anthropological-and in turn archaeological-theory is not unique in that it includes the perspectives shared by other humanities and social science disciplines. Much of the same social and individual factors have weighed on the discourse of archaeological thought, and so, the ideas and thought processes employed by contemporary archaeologists should not be alien to scholars in the other fields of the humanities and social science. A brief look at the history behind the current modes of archaeological theory is particularly relevant to orient ourselves in the present.

The century before 1960 has come to be known by historians of archaeology as the “long sleep” in terms of advancement of archaeological theory (Johnson 1999: 15). This period was characterized by archaeology that focused on the quantity of cultural objects found without much consideration for the methodology by which it was extracted or critical consideration of underlying cultural significances. David Clarke, in a scathing critique of the old way of practicing archaeology, wrote “every year (brings) a fresh crop of archaeological excavations, a new harvest of prehistoric artifacts... the archaeologists come and go, new names and sites outshine the old while hundreds of years of collected material overflows and submerges our museum storerooms” (Clarke 1968: 3). The accumulation of goods by archaeologists served little more purpose than keeping them out of the hands of grave robbers (an identifier some would argue that archaeologists of the time deserved as well). The artifacts that came to be discovered were analyzed and categorized into groups within a rigid framework that was limited in focus on large cultural groups. These “archaeological cultural groups” (comprised of grouped artifacts) came to be equated as a human culture “by making the assumption that artifacts are expressions of cultural ideas or norms” (Johnson 1999: 17). The old way of doing archaeology was flawed in that its rigid framework did not allow for expansion of understanding of culture accounting for the frustration and futility felt by many archaeologists like David Clarke. “Culture-historic archaeology, it was argued, lacked such rigorous procedures, and simply mapped its observations of the archaeological record onto a set of assumptions about how human being operated in the past” (Thomas 2004: 69). The “New Archaeology” movement of the 1960s sought to address many of the theoretical issues that archaeologists faced as they began to apply critical theories developed outside of archaeology to their discipline.

New Archaeology could be described more as a revolutionary movement against the old ways than as any one particular theoretical framework. “The weakness of traditional, culture-historic archaeology was that it operated on the basis of presumed and unproven human characteristics: a particular relationship between material culture and group identity, the manifestation of cognitive norms in material culture patterning, and so on" (Thomas 2004: 64). The goal of New Archaeology was to be more scientific and more anthropological, attesting to be "a set of questions rather than a set of answers" (Johnson 1999: 21). Particular importance was place on cultural evolution within societies-evolution that described cultural change as a process that was dynamic, even within one location and time, but still a product of outside influences ranging from neighboring cultures to its environment. Importance was often placed on the ideas of systems theory to explain the formation of culture. For new archaeology culture was a defined as "an intercommunicating network of attributes or entities forming a complex whole. Cultural systems are, at last in part, the way they are because they are adapted to an external environment, whether that is the surrounding natural environment or that of neighboring, competing social systems" (Johnson 2004: 68). With the acceptance of cultural evolution came the realization that the archaic, static model of relatively few compartmentalized cultures would no longer suffice. New ideas of what culture was and how it came to be influenced were a part of this new school of thought.

The New Archaeologists created revolutionary schema to contextualize within which to contextualize the world. The development of the systems theory set the stage for archaeologists to begin to take a broader view beyond simple sites into whole geographic areas. The new questions that began to be asked of the artifacts-and the archaeological record generally-reflected the changing theoretical paradigm. "Why pottery decoration zigs or zags are unimportant but the big picture flow of, say, market networks or other large scale issues" (Johson 2004: 25) can begin to be understood as archaeologists begin to ask "why" instead of merely "when." Another important shift in thinking, which would be a driving force later to utilize aerial and space-based remote sensing, was the desire to increase archaeological variability. The degree of representation of sites came to be a concern as historically speaking archaeologists have excavated the "biggest and best sites without looking at rural infrastructure; it became apparent that what was needed was a broader more inclusive large-scale view" (Johnson 2004: 26). The vast collections of archaeological artifacts that had been recovered only represented certain segments of certain societies at particular times and were missing the evidence that would be needed to create large-scale understanding of the flow of culture, goods, and ideas.

One of New Archaeologies main goals was to be more scientific and to achieve this goal, the archaeologists looked to the hard sciences of chemistry, physics, and biology as models from which ideas could be garnered to re-create archaeology as a legitimate science. This movement was not without opposition. Debate raged over whether the archaeology could ever be a hard science or if its mission to collect information on past peoples relegated it to the status of a historical or humanity study permanently. "The use of scientific technique no more makes archaeology into a science than a wooden leg turns a man into a tree" (Johnson 1999: 36) is a telling statement that was repeated by many who were skeptical of the new infatuation with science by many leading archaeological theorists. There was also skepticism among some archaeologists of the belief of New Archaeologists in the belief of essentialism, which posited that that all humans have the same inherent desires that are biologically endowed either to humans or to a specific sex. Discontent about the direction of New Archaeology let to a gradual countermovement by a school of thought dubbed post-processual archaeology, but for most of the 1960s and 1970s, much of American and European archaeology was dominated by the ecological functionalism of processual archaeology (New Archaeology). Processualist archaeology rejected the view that human history was determined by the actions of “great men” and “great women”, preferring to investigate the interactions of population, environment, resources, technology and climate over the long term (Thomas 2004: 119). Processual archaeology is best characterized as a broad ideological front rather than a particular set of ideologies and there are still many who adhere to its theoretical underpinnings. The rigidity of the structure of processual archaeology, and the disconnect, as seen by some, from the humanistic study of archaeology, would eventually lead to the creation of post-processual archaeology in reaction against the perceived shortcomings of the older theoretical model.

Post-processual archaeology counts among its many influences later generations of Marxist thought as well as the thinking of prominent post-modern scholars, most notably Ian Hodder, Michael Shanks, and Christopher Tilley. Several ideas around which post-processual archaeologists coalesce are that of the rejection of essentialism and the idea of ideologically free analysis. Michel Foucault advocated the idea that “humans do not have the same ‘baseline’ with which to compare desires across time with” (Johnson 1999: 166). If there is no essentialism, then it is wrong to assume that contemporary humans, as well as those people from times past, have certain innate desires to freedom, sex, etc. The urge to associate such feelings with peoples of bygone times is identified by Neo-Marxist thought as the acute politization of archaeology. Processual archeology’s attempts to solve the problem of impartiality through the utilization of the scientific method was viewed as a failure, as ideology is something we have yet to figure out how to completely remove from our methodologies and analytical processes. If we could use overarching scientific theories to explain just how people develop culture, (as some have done with through the approach of environmental determinism) it would make formulating ideas about past cultures more straightforward. Ultimately, however, people posses agency, which makes this endeavor all but impossible. Speaking of the rules prescribed by a particular environment, sociologist Anthony Giddens noted that people understand the rules of their environment and work to manipulate them creatively rather than follow them passively (Johnson 1999: 104). So if we wish to understand culture and a particular society then we should look at just how people manipulate those rules in their environment in the rituals of their everyday lives "as many argue that such routines embody what a society is" (Johnson 1999: 105).

In addition to the many scientific questions that can be posed in the study of aerial and satellite-based remote sensing, I would like to investigate other primary questions that aerial and space-based remote sensing pose to contemporary archaeologists; that of culture loss and gain in terms of changing scale. Before any questions can be addressed, I believe it is fundamental to look at which questions are being asked and why. It is impossible for me to consider that I can expect to reconstruct past culture based exclusively on cultural relics (be they pottery shards or building foundations observed in satellite imagery) or that I will ever be able to completely remove biases inherent within me given present time and location. What is commonsense to me may only serve to impede me as I seek to establish impartial results, *especially* given what I perceive to be the high level of subjectivity that is required as I conduct my research. It is imperative that the researcher refrain from being ethnocentric and assuming that the values and norms of their culture are universal to others across time. Given this frame of thought, it is important to identify the questions that should be asked to lead us to some appreciation of the issue of cultural understanding and its relationship to scale.

The question of whether cultural understanding within a site is gained or lost at various levels of spatial scale requires that we ask (and answer) many other questions before we can arrive at a point of agreement on this question. But first it is probably best to address if and why this question matters. Technology has greatly increased the capacity of archaeologists to locate and map potential archaeological sites throughout the world. Geographic Information Systems (GIS) allow the user to integrate data taken from multiple sources and at multiple scales and use them together in one seamless interface. But the technology that makes site identification and mapping so effortless also raises fundamental questions about objectivity and, ultimately, the role of GIS in archaeology. Are the scientific processes undertaken in remote sensing objective? Can we rely on technology to accurately and sufficiently depict a culture of a particular time and place in the form of a model? These questions must be addresses if we are to ascertain if results obtained following scientific procedures are relevant. To begin we will look at what steps comprise the process of space based satellite remote sensing.

The first aerial archaeological survey occurred in 1906 and was conducted on the Salisbury Plain of England by P.H. Sharpe in a plane (Parcack 2009: 24). Today archaeologists are able to rely on several satellite systems from which they can access photography ranging in type and resolution. The Ikonos, Landsat, Quickbird, and SPOT satellite systems have all provided archaeologists with accessible global coverage ranging from the 1970’s to the present. The resolution on the systems ranges from .8m to 150m in resolution (Parcack 2009: 63). Needless to say at a resolution of 150 meters, few objects on the ground will be discernable, on the other hand, at .08m, SPOT satellite imagery (which, as a result of its high resolution and limited coverage, costs significantly more) will probably show more detail than is actually needed. Once imagery has been acquired, that imagery must be formatted to be input into photo-manipulating software like ER Mapper, Photoshop, or a host of other image processing software. Imagery used to be only available on film, which had to be developed and then digitally scanned for manipulation. Now the process is kept digital at all steps, which safeguards the quality of the image. Once the image has been enhanced to the researchers satisfaction it can then be input into GIS software for incorporation into the holistic view that GIS creates. This simplified model will be an effective reference for future discussion of the challenges that the spatial archaeologist faces. While the model above may seem straightforward, there are many theoretical questions that underlie this process. Are we able to infer elements of a cultural group from the large-scale imagery that we utilize in spatial archaeology? If we are, how are the results applicable to archaeological culture studies in general? What can looking at cultural relics like artifacts and anthropogenic features at such a large (macro) scale reveal that we could not learn by looking at a small (micro) scale? Let us begin our evaluation with a discussion on scale.

What is scale? There are various definitions of scale, the result of the varying purpose of scale across different fields of study. While scale can be looked at as a measuring standard, "it is at the same time a concept, a lived experience and an analytical framework" (Lock and Molyneaux 2006: 1). Scale has come to be categorized into three separate types-cartographic scale, methodological scale, and being geographical scale.

Archaeologists work with all three scales. Furthermore scale can be classified as being spatial-or dealing with a measurement of area-or temporal, which deals with measures of time. Archaeology encompasses a timescale far larger than other social science or humanities disciplines. Whereas historians are limited by the formation of the written text, archaeologist's range of study dates back millions of years in some cases. We are forced to look at patterns over longer periods of time due to the limited existing archaeological record. When we are looking at a site, we can choose to focus on elements within it that relate to a short or long time-scale. A useful summation of what spatial scale denotes, is that it "represents a level of spatial representation, as commonly used in cartography, and defines the relationship between distance on a map image and the corresponding difference in reality" (Harris 2006: 42). Spatial scale consists of three measures of scale; macro (large scale), semi-micro(middle sized scale), and micro (small scale).

After just a cursory look at the definition and functions of scale, it quickly becomes apparent that scale is a rather complex idea. Scale is an issue that has perplexed other disciplines, and archaeology is not immune from its complexity. The complexity of scale has only increased with the advent of GIS and other technological advancements like satellite photography. Ignorance by many archaeologists of the impact of scale in archaeological studies only compounds the problems associated with scale. There are three major problems which arise from the issue of scale; the Earth is too large and "understanding its variability is an enormous task...geographic studies, including fieldwork, are restricted to relatively small areas, so linking them can be difficult...and finally there is the issue of standardization, which is concerned with the merging and integration of various types of geographical data from a range of environments into a coherent form" (Lock and Molyneaux 2006: 4). Identifying the many issues that arise from scale is easy, with the difficult task being finding a way to solve those issues.

The first problem that archaeologists face arises from the simple nature of the earth. "Because of the extent of and complexity of the Earth's surface, researchers must invariably sample, generalize, or aggregate data in order to comprehend reality" (Harris 2006: 39). The archaeologist is without a choice when it comes to the matter of determining if and when to use scale. The nature of the world that we call home and study mandates that we choose a scale simply due to its size and variability. Scholars, most recently geographers, have attempted to address these issues of geographic variability and scale selection, and much of their successes and failures have been transferred to archaeological studies. Because our understanding of scale comes largely from the use of "non-dynamic paper maps" the flexibility and dynamism of digital GIS represents new and significant challenges to the understanding of scale issues (Harris 2006: 43). It is not surprising that we struggle with the same problems as our predecessors in other fields.

The next issue that arises from a critical look at scale is linkage and visibility. Visibility actually has several meanings in the context of space-based remote sensing. It can refer to picture resolution or it can refer to appearance of cultural patterns at various levels. Scale and resolution are invariably interdependent. As scale is increased, so too is the resolution up to a point. As scale decreases, so does resolution. So resolution is another factor that must be considered when assessing features or artifacts within a landscape. Another important note is that scale of data capture and the scale of display are two different things. When a Landsat satellite captures a panchromatic (black and white) image of the Sahara Desert in southern Tunisia at a resolution of eight meters, that is its scale of data capture. When that image is incorporated into a map or simply viewed through a display of some kind, however, that image becomes its scale of display. If someone were to take that satellite image, digitally scan it, and then enlarge it, the scale of data capture has not been changed. That is, and will always remain, tied to the original resolution of eight meters. What has been changed is the scale of resolution of display. The other aspect of visibility alludes to observable cultural phenomena and the level of scale at which they either becomes apparent or lose relevance. "A common assumption is that shifting from one scale to another in space and time is a seamless process" (Lock and Molyneaux 2006: *iii*). It is at this point that linkage and the second type of visibility began to show their close relationship.

One of the powerful features of GIS is its capacity to integrate data captured at a variety of scales, but this is also one of the primary weaknesses of GIS. "In geographic investigation it is apparent that conclusions derived from studies made at one scale should not be expected to apply to problems whose data are expressed at other scales. Every change in scale will bring about the statement of a new problem, and there is no basis for assessing that associations existing at one scale will also exist at another" (Harris 2006: 46). If we cannot be sure that observations taken at large scales can be associated with those at smaller scales, then should we accept results derived from GIS or those taken from such macro scale surveys as satellite photography? This is a basic question that must be addressed if we are to figure if cultural understanding is gained or lost through movement between various scales. But scale is just one of many problems that confront the use of GIS; Generating data for GIS analysis invariably requires extensive effort and introduces a slew of issues associated with data capture, data accuracy, data resolution, error estimation, metadata, data structure, storage and compression, and data sharing to name but a few" (Harris 2006: 40).

Beyond the inherent difficulties of navigation of scale in terms of identifying the relationship between cultural artifacts, lies yet another problem; As humans, we are stuck in a concept of "body-scale" and "there is no guarantee that we can understand relationships in the larger and smaller worlds that these days technology allows us to visit or construct" (Lock and Molyneaux 2006: 30). So, even if it were possible to make cultural connections across scale, it may not be possible for humans to fully comprehend what those relationships signify, or appreciate their relevance in a cultural study. Even if we have the tools to properly link cultural information at various scales, there is no guarantee that the human mind is capable of adequately comprehending those connections due to our inherent body-scale projection on the world. Cognitive archeology tells us that people perceive space differently even from within the same cultural time and place (Renfrew 1994: 34). With the advent of aerial and space-based remote sensing as tools for the archaeologist, we are able to confront concepts of space and landscapes as past peoples never have. Conversely, we have also lost the ability to conceive of a place or landscape as past peoples-refereed to as the "dwelling perspective"-in various cultures (Ingold 2000, 153).

When we approach the issue of making cultural connections across different scales, it its best to employ a metaphor through which it may be easier to understand what exactly is going on. If an individual were able to climb a ladder, they would be able to see different things based on the position they were on the ladder. If the individual were on the ground, the immediacy of their surroundings would be most pressing and loom large in the conception of reality. With each step up the ladder, however, a new reality unfolds. Despite being in the same relative location on the Earth, the perspective and scale of view is changing. "It is important to emphasize that none of the sets of information or interpretation on this 'ladder' can operate too far up or down from the level at which their (researcher) data was captured and their perceptions formed" (Fairclough 2006: 2007). It is important to note this as archaeologists working who now must work with data captured from a variety of scales-from satellite photography to ground prospecting.

There is significant danger and shortsightedness in creating sweeping generalizations based on data received at particular levels of scale. The linkage of scales between high to low and low to high levels brings about concerns for ecological fallacy because "generalizations about patterns and processes at one level of scale may not hold true at another level" (Harris 2006: 42). When an ecological fallacy is created, people overemphasize the macro environment, leading to criticisms that environmental determinism is being overplayed. Conversely, "individualistic fallacy occurs when attempts are made to impute macro level, aggregate relationships from micro-level, individual relationships" (Harris 2006: 47). In this case, quite logically, the landscape and environment are ignored as influences at the macro-level scale, with emphasis put onstead on small scale issues as being overly deterministic. There is one last scale fallacy, and that is cross-level fallacy. Cross-level fallacy occurs when one makes inferences from one sub-population to another sub-population at the same level of analysis; these three fallacies rely on assumption that relationships observed at one level of population aggregation are a universal feature of that population. The fallacies could all be characterized as overgeneralizations, "however generalization should not simply be equated with less information, for generalization could add information rather than reduce it simply by the ability to display more features for a larger areal unit. Scale is thus intertwined with the issues of data measurement, data accuracy, and data resolution" (Harris 2006: 42).

Perhaps the best way to illustrate the above listed fallacies is to present them through another metaphor. The ocean represents a large body of water that covers most of the surface of the earth. It is obvious that a study of the behavior of tropical fish in the coastal waters of Costa Rica cannot give us a clear picture of the workings of the entire ocean system. And the study of the ocean's current flow will tell us little about the particular mating rituals of seahorses off the coast of the Big Island of Hawaii. Generalizations will need to be made to bridge the different levels of information at the different scales if they are ever to be relatable to each other and useful in a more holistic view. The same can be said for archaeology and its various subfields that conduct work at different spatial scales.

The question of how to solve the issues of cross-scale generalizations is an important issue yet to be resolved in archaeology. Different archaeologists have come up with different methods to deal with the issues of spatial scale. It is a telling fact of the enormity of the issue that "landscape archaeologists are guilty of selecting a large scale specifically to avoid being caught up in very local or site-based detail" (Fairclough 2006: 206). When archaeologists are going out of their way to avoid dealing with the pressing issue of scale, it says a lot about views on whether this problem is apt to be solved and how easily it can be done. "Most archaeologists are choosing to ignore issues of scale, or cede that scale reconciliation is an insolvable problem" (Harris 2006: 49). While this outlook may seem bleak and cast doubt on the "truthfulness" of cultural interpetations that cross scale boundaries, there are some archaeologists who are making initial movements to address the glaring issue in the discipline.

A solution to the problem of cross-scale archaeological analysis will need to create a "spatial scale for making the animal and its world 'comparable'" (Costall 2006: 23). By scrapping the conventional model of spatial scale-subdivided into three categories-we can create a new model which better takes into consideration the relationship of humans with their surroundings. There are no new proposals yet on just what that model would look like. A different take on a possible solution has been proposed by the landscape archaeologist Stefano Campana. Campana suggests the addition of new layers to the traditional model of macro, semi-micro, and micro scales. The inclusion of additional 'mid-scale' (Campana and Piro 2009: 5) measurements would significantly decrease the gap that cultural inferences would need to bridge when making generalizations. A different take on the addition of more mid-scale layers is proposed by Vuk Trifkovic, who proposes the creation of 'taskscapes' (Trifkovic 2006: 258). Taskscapes serve as link between the individual and the environment while taking into consideration the agency of the individual and its impact on the perception of the boundaries of environment (Ingold 2000: 178). Trifkovic elaborates further that taskscapes address agency 'in order not to treat people as little more than uniform and abstract templates we need to connect new perspectives on personhood with landscape inquiry and understand the mutually defining relationship between the two scales" (Trikovic 2006: 270). In the post-processual tradition, both agency and environment figure prominently in new ideas about scale, but the definition and meaning of landscape and its influence on culture is yet another subject that remains highly subjective and debatable.

"Landscape is an idea not a thing, although constructed by our minds and emotions from the combination of physical objects-here the scale issues are those of objectivity/subjectivity, top down/bottom-up approaches, and the range of views on the question of the reality and usefulness (or otherwise) of facts and data" (Fairclough 2006: 205). If landscape is a subjective creation of our minds, then it will be impossible to be able to recreate a landscape for an individual long since deceased, and the problem is only magnified-if not impossible-when trying to recreate the landscape of an entire bygone society. But to completely deny the relevance of landscape to an archaeological cultural study would be an error as well. "There can be no appropriate account of the body and embodiment without consideration of the mutually defining relationship between embodied agents and the landscapes surrounding them" (Trifkovic 2006: 258). The landscapes that we see around us are not simply empty space.

In between sites was not nothingness, In between any pair of group of settlements one finds the fields with their various crops, woodland, pasture, hunting areas, water sources, lagoons and ponds, quarries, mines, civil or religious administrative boundaries, streets and simple pathways etc. The majority of the features in the spaces between the settlements do not manifest themselves in the form of surface finds, and even when they do so the material is so difficult to interpret that it tends to be described as “off-site” [Campana and Piro 2009: 18].

What Campana and Piro are trying to say here is that the sprawling landscape that exists outside the parameters of the archaeological site has served to influence past people just as much as foreign good brought in through trade. But once again, we must find some balance between focus on scales in our research if we are to find the true perception of landscape of a person-through and for that “smaller scale regional overviews may well be the scale at which to capture community and cultural perception and identity” (Fairclough 2006: 212).

Several landscape assessment systems have been developed by archaeologists to deal with how to classify and interpret landscapes. The most prominent system is that of the Historic Landscape Characterization (HLC) that was developed in the 1990s in England do deal with landscape interpretation and analysis of the historic environment common throughout the country. HLC is GIS-based, which immediately introduces simple issues of spatial scale in three categories: input, output, and interpretation. HLC aims to create “area-based generalizations rather than detail for specific sites and features by its concern for the semi-natural and non-site components of landscape” (Fairclough 2006: 205). This shift in focus from the individual and cultural material to the inclusion of landscape offers an updated, better-rounded methodology with which to approach landscapes without being totally overwhelmed. With such a focus on the inclusion of landscape as a contributing factor to understanding the relevance of cultural objects and features, it becomes apparent that all of the landscape is actually a cultural relic. This is a revolutionary idea by which much of contemporary landscape can be viewed and interpreted.

Any discussion of the assessment of culture in past societies should include a consideration of how it is done. Archaeologists rely on various scientific methods to discover, date, and catalogue artifacts and contextualize them. What is important for our discussion is not necessarily the method by which scientific testing is carried out, but rather the place of science in archaeology. If pure science insists on the removal of self from the inquisitorial process, how can we ever hope to recreate cultural elements from the past without injecting some form of our own humanity into our research process? The exaltation of science has had critical implications for archaeology as a discipline; "The supposed inclusiveness of the scheme of physical science was achieved through a rhetorical trick, the claim that the new science covers everything, and so anything it fails to include must, evidently, fall beyond the scientific realm of things. Anything resistant to the methods of the new science could not, therefore, be truly 'real,' and hence, had to, instead, be purely subjective" (Costall 2006: 16). All that was excluded from coverage by the new science was much of the formative processes of past cultures. "Culture, through guilt by association with us, has to be banished from the "real' world, and subjectivized; it has to be located within a realm of individual or social re-presentations (Costall 2006: 17). Once culture has been marginalized, it is easy to dismiss. Without a clear understanding of past culture, artifacts lose their context and become nothing more than what they are in the present; articles of wood, clay, bronze, or stone. An archaeological interpretation reliant completely on scientific method misses out on some of the most sysynonym subimportant formative relationships between past peoples and the things that shaped them. "The word animal and environment make an inseparable pair. Each term implies the other. No animal could exist without an environment surrounding it. Equally, although not so obvious, an environment implies an animal (or at least an organism) to be surrounded. ...The mutuality of animal and environment [however] is not implied by the physical sciences" (Costal 2006: 20). To be human is to know that we are constantly being shaped and influenced by the environments that surround us. To forgo that observation is to miss out on achieving a higher degree of cultural understanding.

With most of the discussion of the theoretical problems associated with culture and scale touched upon, a look at a working case study may be the best way to gauge just how an understanding of culture is gained or lost across levels of scale. In order to create a more holistic understanding of the landscape being studied, Stefano Campana and his team of archaeologists and geophysicists are undertaking a broad landscape study in southern Tuscany, but implementing a wide range of near and remote-sensing technologies that operate in both the macro and micro-scale environments. I have had the privilege of working on two of his collaborative projects first hand, at Pievina and Pava during the summer of 2009. In two different publications-"Understanding Archaeological Landscapes: Steps Towards an Improved Integration of Survey Methods in the Reconstruction of Subsurface Sites in South Tuscany" and "From Space to Place: the Aiali Project (Tuscany-Italy)"-Campana outlines the various incarnations in which scale came to be addressed either explicitly or implicitly.

The size of the areas under investigation within the region of Tuscany varied from 40-450 sq km with an average of 150 sq km (Francovich and Campana 2007: 243). Given the enormous scale of the project-dubbed the Aiali project-it is immediately apparent that large-scale remote sensing prospection techniques would need to be employed to make assessments at the macro-scale level. So oblique photography was employed throughout the various research areas in southern Tuscany, with the results being particularly beneficial in the location of multiple potential sites for excavation. It was decided to take exploration one-step further, and multi-spectral IKONOS-2 imagery was purchased for landscapes under review. Use of IKONOS satellite imagery served to expand understanding of 14 sites identified by oblique and aerial photography in Tuscany and served to identify images that did not appear on aerial photography because of time of year and changes in surface characteristics, which is a trend that has great implications for "monitoring and exploring the archaeological heritage" (Francovich and Campana 2007: 243). Conversely, many of the archaeological discoveries that we made during field survey or in examining vertical air photographs are not visible on the satellite imagery.

While satellite imagery was employed to "provide a total, continuous and objective view of the whole of the land surface within the chosen survey area" (as it provides a "total recording") this macro scale approach is balanced by field walking surveys, and pottery analysis at the micro-scale site as in the analysis at Aiali (Campana et al 2006: 134). In Aiali, pedestrian survey results (micro-scale) were married with aerial photographs (macro-scale) to create a complete picture of the landscape that resulted in greater comprehension of ancient culture of the area. With Campana's designation of a new "local-level scale", there is now a platform by which intra-site questions can began to be asked and answered. The new level of scale serves to reduce the void present between macro and micro scale data. Campana's extensive experience traversing scale using technologies and making observations about the past cultures that inhabited the ancient landscapes enabled him to make the observation that;

> The transition from the micro to the macro level does not consist of a simple mathematical and graphical process of reduction, rather, it involves complex procedures of simplification, generalization and blurring of distinctions which have significant effects on the quality and quantity of the information transmitted. The transition in the opposite direction, from the macro to the micro scale entails even more complex problems" [Campana et al 2007: 5].

Here Campana establishes that in order to move between the various scales, generalization (or reduction in particular expressed observations) is key to making cultural evaluations that still remain true. Is there some loss of knowledge of the particulars of culture? Yes. But there is also gain in that sacrifice in knowledge of the particulars results in increased knowledge of the general. What is needed is to find a balance between the two scales. Campana asserts that in Italy, mapping solely at the macro level-using macro scale methodologies like satellite photography to observe surface manifestations-would only result in the discovery of five percent of the potentially surviving archaeological evidence. So relying solely on the macro-scale also serves to handicap the researcher from attaining a more complete understanding of the past inhabitants of the landscape being studied.

My own macro-scale study involved the utilization of Landsat-7 photography that was taken over the city of Xian, in the province of Shaanxi, China during various times in 2008. My problems with the imagery reflect problems encountered by most other archaeologists when receiving data. "The problem of identifying an appropriate scale of study when using GIS is compounded by the need to utilize, wherever possible, data created by others in order to reduce data duplication and replication and to minimize the cost of populating the GIS database" (Harris 2006: 40). The archaeologist must remain keenly aware that he/she is at the mercy of the previous handlers of data in terms of data manipulation and integrity. “Data at ‘sub-optimal’ scales are sometimes all that is available and GIS users must be very conscious of this constraint on the validity and quality of results” (Harris 2006: 43).

My work involved the creation of digital elevation models (DTM) from the Landsat photos which were then “draped” over topography data acquired during the Shuttle Radar Topography Mission (SRTM) that scanned portions of the earth with radar, thereby acquiring a topographical map of the Earth’s surface. I was fortunate in that there are SRTM data for the city and surrounding landscape of Xian, and that these data were free and readily accessible through NASA. Utilizing an ER Mapper algorithm that I found among the data I received (this algorithm also contained what few multispectral images were available), I manipulated the photographs to my specifications. What I sought to do in the photographs was to highlight (through color expression manipulation) significant large-scale geographical features such as mountains and plains in the photographs. I then imported geo-tiff SRTM data from NASA/USGS into ER Mapper (which automatically geo-references both the SRTM data and the Landsat photography utilizing the accompanying metadata) and draped the algorithm photographs on top for what came to be my first DEM creations (See Figure 1 and 2). While the SRTM data were captured during the 2000 space shuttle mission, the Satellite photos date from approximately eight years afterward. There is no way of knowing if large-scale geological features present in the SRTM data were manipulated in any way during those intervening eight years following which represent a possible area of inaccuracy.

What I took away from the process was the amount of subjectivity that any digital reconstruction entails. There are so many choices and points where the individual has discretion over what will be displayed. When a researcher finally decides there is a need for satellite imagery that researcher can decide to use old imagery found in digital libraries or purchase new images. There is a plethora of different satellite systems from which to choose and which promise varying degrees of resolution. The researcher can decide whether panchromatic (which usually has a higher resolution) or multispectral data should be used. Once the imagery data have been acquired, the researcher then has the choice to enhance particular features in the photographs by using photographic enhancement software like ER Mapper, or a plethora of other software. During the manipulation process most any feature can be enhanced or diminished. The SRTM data are also an area of variable accuracy. With a resolution of approximately 90 meters, nothing but the largest of geographical features will be distinguishable (El-Baz and Wiseman 2007: 17). SRTM data are also not perfect and have been subjected to "finishing" procedures that remove anomalies that appear during the acquisition process. Archaeologists are unlikely to be able to control the entire process of project data collection, compilation, management, analysis, and modeling. All of this subjectivity begs the question of just how accurate the DEM's are that I have created. The answer is that I cannot say precisely. Archaeology has yet to establish a method for establishing accuracy. For now, critique is instead leveled at methodologies.

Scale confronts the archaeologist with many problems that require critical thought in any research endeavor. When dealing exclusively with large-scale data such as satellite photography, it is quite tempting to engage in ecological fallacy. This is where the strengths of endeavors such as the Campana's attempt to map and catalogue sites in southern Tuscany come into play. Utilizing a consortium of specialists of both the macro and micro scale ensures that both levels receive adequate consideration during analysis of results. Such a research environment is conducive to sparking dialogue about the problem of scale. It is not surprising that one of the first attempts to create a solution to the problem (the creation of more intermediate layers of scale between micro and macro level) has come from such a collaborative environment.

Archaeologists are tasked with collecting, classifying, and interpreting (Lock and Molyneaux 2006: 1) artifacts from the past. To do so requires that we develop empathy for the people we study. In our consideration of the way people lived their lives, we become cosmopolitans of people from a past time and place. In our efforts to create sense of the people and culture that have come before us, we utilize the data available to us as best as we can. While we can only work with the data and software that are available to us, we must not forget the problems that are inherent within them. "Given the fundamental importance of space and scale in archaeology it is critical that archaeologists acknowledge and struggle with these concepts and refuse to work in perverse oblivion to the problems of scale" (Harris 2006: 49).

When I first began researching the impact of aerial and space-based remote sensing in archaeology, the issue at the forefront was the loss and gain of cultural understanding in relation to my macro-level study of satellite photography. Like most investigative undertakings while I did find some answers, I also found many more questions. It is undeniable that understanding of past cultures are gained and lost in different ways as we transcend scales. This is true because as archaeologists, we have yet to produce a perfect mechanism to translate the cultural relics found within that landscape accurately from one scale to the next. My work on macro-level data, has convinced me that what is needed is a paradigm shift in thinking about scale as our current models are no longer useful to us in our exploding technological age. Gary Lock states that "appropriate scaled reality is not achievable when we move beyond reality" (Lock and Molyneaux 2006: 4), but maybe the very technology that is serving to highlight our problems of scale will one day be able to create an alternative reality where issues of scale reconciliation among data sets and agency of the peoples past and present can be resolved.

Chapter 4

An Introduction and History of Ground-based Terrestrial Laser Scanning

The history of archaeology is filled with influential characters from outside the discipline that have introduced new frontiers and capabilities, such as digital documentation and possibility of fully immersible site reproducibility to the field of archaeology. Ground-based terrestrial laser scanning, the history of which is relatively brief in comparison to other remote sensing technologies such as aerial and space-based remote sensing, follows in that tradition. It owes its creation and development to professionals from the fields of engineering and surveying. Generally speaking, terrestrial laser scanning involves the use of a laser to take highly accurate distance measurements (and in some cases surface properties are also recorded) at the rate of many thousands per second, in effect creating a three dimensional cloud of "points" that records the contour characteristics of the surface being scanned. The incorporation of laser scanning into documentation methodology has alleviated many of the problems faced by cultural heritage preservation professionals and archaeologists, and the technology continues to create solutions in novel applications. Before exploring the history of the newest inductee into the archaeological remote and close-range sensing family, it is best to begin with an introduction of this recent technology involved in ground based terrestrial laser scanning.

The name *laser* is in fact an acronym that stands for a Light (that is) Amplified by Stimulated Emission of Radiation (LASER).

> Laser light is generated through the excitation of atoms causing them to emit energy as photons. A light source is used to stimulate the laser source, exciting electrons into a higher state. The new excited atomic structure is inherently unstable and the electron returns to its original state emitting energy as a photon of light. Where the emitted photon strikes an already excited atom, two photons of the same wavelength and direction are emitted. The emitted light radiation is reflected back into the laser source, further stimulating the photon emissions, which are allowed through one end of the laser source

> as highly coherent low divergence Light Amplified by Stimulated Emission of Radiation [Large and Heritage 2009: 24].

As is to be expected, the physical mechanism required to facilitate such an ordered process is one of the limiting factors both for the power and portability of lasers. Most generally, lasers "consist of a lasing material (crystal, gas, semi conductor etc.), a light or electrical current pump source and an optical cavity where photons are reflected back into the lasing material to amplify signal" (Heritage and Large 2009: 25). It has only been within the last 20 years that laser portability has opened up the technology to use by those in a wide spectrum of fields.

Scanners have become ubiquitous in the design and production of many of the goods that we consume. Lasers are divided into different classes based on their characteristics and capabilities, while lasers are broken down into four levels that are used to gauge the potential harm they can cause to humans. A Class I level laser is generally safe to the human eye and is used in laser applications that require constant human exposure. An example is a desktop scanner or copier. A Class II level laser elicits a blinking response from an individual if the eye is exposed, and the eyelid is barrier enough to avoid damage. Constant, direct exposure can lead to eye damage. A bar code scanner is an example of Level II laser technology in deployment. Class III lasers are potentially hazardous if viewed directly and should only be used with advanced eye safety gear with limited exposure to the skin. An example of a Class IIIb laser is a high speed DVD or CD writer. Finally, Class IV lasers have the ability to cause damage to the skin and eyes with exposure. Such lasers are used mostly in industrial or medical settings and extreme caution is needed in their use (3D Risk Mapping 2008: 14). In the mid-1990s, when Ben Kacyra (inventor of the first ground based terrestrial laser scanner) formulated his design for the laser scanner, he originally called for the use of a Class II laser system. Concerns about eye safety for the operator, and limitations that a more dangerous laser would impose on his new device, however, prompted Kacyra to finally opt for a level I laser in the Cyrax 2400 (Kacyra 1997). The Class I level laser used for most terrestrial laser scanners make them safe to operate in public spaces should a technician need to scan an intersection or an area of a facility that cannot be shut down.

The terrestrial laser scanners that are operated in the field of archaeology add a new layer of technology to the laser, and that is data capture. The data capture in this case refers to the documentation of reflected laser light signatures received while scanning in the field. Naturally, this is the point at which many questions arise regarding the difference between the make-up of laser light versus naturally occurring light, and the ability for terrestrial laser scanner sensors to distinguish the two. Terrestrial laser scanners work primarily through the basic concept of an emmittence of a laser pulse and subsequent documentation of the return signal. But just how does the laser scanner sensor receptacle distinguish between naturally occurring light and the light of the laser scanner? Electromagnetic radiation (which includes light) exhibits the properties of both waves and particles, but there are distinguishing characteristics between the two types of light (i.e. naturally occurring and laser light). Visible light occurs between the wavelengths of 400nm and 700nm, while the "laser range" extends into both the infrared and ultraviolet parts of the spectrum (Heritage and Large 2009: 22). Naturally occurring light is emitted in random directions at variable wavelengths and at variable amplitudes, with no phase correspondence. Laser light, on the other hand, is emitted in a single direction at a constant wavelength and amplitude with total phase correspondence. Thus it becomes possible for a sensor receptacle to distinguish the particular wavelength and amplitude of the laser light that has been emitted, despite the fact that there is naturally occurring light in the same wavelength. For a look at just how the technology has arrived at the state of the art, it is best to examine the historical development of the laser, and laser scanning in archaeology.

Terrestrial laser scanners have become categorized by the various principles of their operation. There are three basic types of laser scanning systems that have been developed; triangulation, time-of-flight and phase-based systems. In the case of triangulation scanners, the laser emitter shines a laser light onto the surface to be scanned, and then the device system relies on an optical sensor to look for the reflection of the laser's projection onto the scanning surface. The distance from the optical sensor to the object is calculated by using the known length of one leg of a hypothetical triangle (from the laser source to the optical sensor), and by using the recorded angle of the received laser light from the origin point (3D Risk Mapping 2008). Received points are then stored within a three-dimensional matrix established with the scanner as a zero point. In the case of time-of-flight scanners, this platform's operation is quite simple; it measures the difference in time between emitted laser light and its received echo. It is referred to as a phase-based system as it varies the power of the laser light emitted and measures the phase difference between the sent and received waveforms (Reindal 2009). Phase-based scanning works quite similarly to time-of-flight scanning, the difference being multiple lasers pulses are sent out, at different frequencies or colors, and then are measured by corresponding frequency or optic filters. Phase-based scanning has been characterized as slightly more accurate, faster, and capable of providing dense point clouds, but over shorter ranges (due to the ability to send many shorter and higher frequency bursts that register better at shorter distances), and most hardware producers have shifted to offer both (e.g. Leica Geosystems). In addition scanning systems can differentiated as either static or dynamic systems; Static systems are the group of ground-based terrestrial laser scanners I am working with, and dynamic being mobile mounted systems like LiDAR from a plane or automobile.

The information pipeline throughout the process of laser scanning is one that follows several formulated steps. Typically, it involves the following processes- acquisition of range and image data, point cloud processing, meshing, image processing, model texturing, and finally storage. In order to acquire accurate range and image data, the laser scanner operator must first take control point measurements, most commonly with a total station, with which to orient the later data. Some ground-based scanners come with the ability to attach a GPS antenna onto the unit, which makes geo-referencing a much simpler task (Drake 2002). Most types of professional post-processing software include the ability to incorporate the scan data into a specific coordinate system. Unfortunately, the hardware production industry has moved away from the GPS antenna as a built-in feature, as most industrial blue-print projects do not have a need to geo-reference their scan data. An example of fieldwork properly incorporating laser scanning, and geo-referencing equipment (total station-highlights how lengthy the process of proper site digital documentation is the case of the site documentation of Pichango Alto in Nasca, Peru. It took five days of fieldwork to accomplish the task of both scanning and taking the myriad of GPS data points. “First, an overview scan acquiring the whole area from an elevated position was conducted that later served as a reference to which the single scans were registered” (Lambers 2007). Once the overview scan has been completed it is possible to orient scans from other devices taken at different scales within the original scan matrix or grid. It is at this point that post-processing software, a critical element in the production pipeline, enters the picture.

When Cyra introduced the first commercial laser scanner, the 2400 model, it also released accompanying data processing software known as Cyclone (Salonia 2003). Cyclone was marketed as a complete, cleaning, registering, and meshing software, and even boasted plug-ins for AutoCAD. Cyra technologies set the precedent, and now hardware developers include their own proprietary software with their scanners for post-processing and hardware control. Registering the point clouds is usually carried out by matching the targets captured amongst the individual scans and aligning them to each other from each scan. The software provides a goodness of fit measure as registering involves the translation and rotation in three dimensions between the local coordinate systems of the scans being meshed (Drake 2002). Point cloud registration can either be done automatically, with the post-processing software recognizing standardized targets within the scans and matching them, or manually, with the technician selecting individual control points from which the software attempts registration. While automatic registration is the ideal method (requiring less time), it does not work 100% of the time (or can provide registrations with a higher than acceptable error percentage). Thus, technicians should strive to be adept at both methods. Once all the point clouds have been oriented to one another within a common matrix, then point overlap can be removed. The utilization of a point sampling tool (decimation algorithm) reduces the number of points from the many different scans where they overlap. This is a necessary function as it often time will dramatically reduce the size of the data file and leave the researcher with a more manageable file size that can be more easily stored. The sampling rate is important in another aspect, in that it is the deciding factor in the quality of the mesh that can be generated. If too many points are removed, the generated mesh geometry will be large and hide intricacies gathered by the scanner. Different types of post-processing software contain different mesh generating algorithms and, in addition to selecting the optimal software, the operator must also select the optimal mesh algorithm for the particular project.

Image data acquisition is another crucial step in the process of terrestrial laser scanning. The latest high-end laser scanners come with internally mounted cameras which automatically record color photographs that are properly oriented within the reference coordinate system or matrix. The texture mapping is thus automatic and uncomplicated. As the camera is calibrated the images are undistorted according to the obtained calibration parameters. However, there is a disadvantage to using internal cameras; "the main drawback of these integrated cameras is their low radiometric and geometric resolutions, as well as the non-parallax free color values they yield for close range measurements" (Lerma 2010: 501). Current system cameras range between four to five megapixels in terms of resolution. This is another indicator of the scanners industrial target industry, as there is little need for an internal high-resolution camera in generating 3D CAD drawings. Low-resolution photographs mean that end product digital recreations will also be of lower quality resolution. The current solution to this problem is the utilization of cameras capable of taking high resolution photographs that can then be draped over the mesh-model or relying on other remote sensing techniques like photogrammetry or computer vision to yield high-quality three dimensional outputs.

The history of laser scanning began nearly a half century ago, when "in 1959 two scientists, Charles Townes and Arthur Schawlow, suggested the potential for a narrow beam of very intense monochromatic radiation traveling over large distances that could be precisely directed" (Heritage and Large 2009). These first attempts at harnessing the power of amplified light were crude and cumbersome, and for the most part were relegated strictly to laboratory work in support of various weapons defense programs. The first solid-state ruby laser was developed in 1960, and emitted powerful pulses of collimated red light. The color of this first laser (red) has come to be associated with all general laser color since, despite the current trend away from ruby laser systems. With the establishment of an efficient technological footing, rapid development followed. The first laser distance-measuring instrument appeared in 1966, and the first alignment laser was marketed beginning in 1971 onward. The industrial applications for the new developments in laser technology brought about the increase of regular use in the private sector that would eventually lead to the use of laser technology in the environmental sciences and ultimately archaeology.

The story of the creation of ground-based terrestrial laser scanning of archaeology began even before the advent of the first laser, in the Middle Eastern country of Iraq. Born in 1940, Ben Kacyra was raised amid the archaeological rich land and developed a deep appreciation for cultural heritage. "My dad loved archaeology and he used to take me to all the ruins," explained the famous Civil Engineer in an interview to the San Francisco Chronicle (Abate 2007). It was this appreciation that would continue to influence Kacyra even after obtaining degrees in engineering at Jesuit College in Baghdad, later immigrating to the United States in 1964 and attending The University of

Illinois (Barton 2007). Even as Kacyra moved to the San Francisco Bay area and established his own successful civil engineering firm, he was brainstorming new ways to incorporate his expertise in engineering into in his childhood love of archaeology. As a civil engineer and inventor, he realized that many of the same problems experienced in surveying, if solved, could provide a solution to many of the issues faced in archaeology.

Prior to the advent of ground-based terrestrial laser scanning, surveyors tasked with documenting structures were forced to take a plethora of analogue measurements with which to characterize all of the main elements of the element being scanned.

> Traditionally, surveyors have been called in to produce accurate, as-built, drawings for buildings using the tools they've always used: steel tapes, theodolites and, for the intricate and otherwise untouchable or unreachable features, photogrammetry – a painstaking process of measuring accurate dimensions of complex shapes from photographs [Booth 2002: 2].

Before the invention of laser scanning the task of digital documentation required that "scads of people (be sent) into the plants with tape measures" in order to properly generate workable post-construction blue-prints for buildings (Abate 2007). This method of generating blueprints was as "labor intensive, time consuming and error prone" (Kacrya and Dimmsdale1997: 5). The implementation of EDM's (electromagnetic distance measurement, i.e., the use of lasers in instruments like a total station) was a groundbreaking step in improved accuracy, but EDM's have their limitations (Booths 2002). Points taken from a total station are incapable of comprehensively documenting the three dimensional geometry of a large space. An army of individuals armed with tape measures was still required to take the manual measurements, and while the error level was reduced, it still remained significant. Additionally, surface color and texture could still only be documented using a second step with a camera or video. Kacrya sought a way to simplify and improve this very complex and inaccurate data generation process.

In 1989, Kacrya sold his civil engineering firm and devoted himself to the production of a tool that would revolutionize the generation of digital three-dimensional blueprints.

In 1993, Kacrya founded Cyra Technologies with the aim of creating the first ground-based terrestrial laser scanner. "With his technology partner Jerry Dimsdale and wife Barbara Kacyra, partnerships with Massachusetts Institute of Technology and Los Alamos National Laboratory, and a significant investment by Chevron Corporation, Kacyra went on to succeed in developing the first long range laser scanner" (Barton 2007: 2). But the process was not easy, and much of the trio's success could be attributed to luck. Dimsdale characterized the endeavor as having three major challenges; developing the "scanning system, laser pulse generator, and the timing circuit for measuring the round trip travel time of the pulses" (Abate 2007: 2). Luckily for the team "much of this technology had been developed over many years at huge government expense, but was found languishing uncompleted" (Dimsdale 2005: 1). Perhaps the greatest asset the team commanded was naivety in gauging the enormity of the task they had set out to achieve, and despite the complexity, they were ultimately successful in introducing the Cyrax 2400 model in 1998.

Following the sale of Cyra Technologies to Leica Geosystems in 2001, Ben and Barbara Kacyra established the Cyark Organization in 2003 with the specific aim of facilitating the spread of laser scanning technology into the field of archaeology. The duo aimed for the comprehensive digital historic preservation of heritage sites across the world. The mission statement of Cyark-"Preserving cultural heritage sites through collecting, archiving and openly distributing data developed by scanning, digital modeling and other state of-the-art technologies" (Cykar.org)-reflects Kacyra's lifetime goal of giving back to the archaeological discipline with which he had held a fascination since boyhood. Inspired to take action following the devastating losses of the Bamiyan Buddha's at the hands of the Taliban in Afghanistan and the destruction of the mud-brick city of Bam in Iran, Kacyra realized just how significant digital documentation was (Barton 2007). Cyark functions much as an intermediary between private corporations and educational and non-governmental institutions, breaking barriers between the newest technologies and those who need their use the most. Cyark has worked to team up geomatic (surveying) organizations like the British firm Plowman Craven and Associates with academic institutions such as The University College London in archaeological projects including the digital documentation of the ancient central Asian city of Merv.

The Cyrax 2400 debuted to positive response most notably within the petroleum and oil refining industries. The large industrial plants associated with these industries often did not possess up-to-date plan drawings of rapidly evolving facilities. Laser scanning proved the perfect means by which to capture "as-built" blueprint data, as using the technology required only one or two operators, scanning could be done "remotely" from safe distances, and work did not necessitate a costly shutdown to perform (Booth 2002: 1). The success and growing demand for laser scanners was quickly noticed by rival technology companies who began to quickly buy out fledgling scanner startups, or started the process to develop their own in-house ground-based terrestrial laser scanner hardware. The market for laser scanners began to expand beyond the petroleum and refining industry to include diverse fields like forensics, geology, and mining, as well as the aviation and automobile industries. Immediately following the debut of the Cyrax 2400 in 1998, there was a rapid succession of new and improved scanners from varying competing companies. The Austrian tech hardware company RIEGL introduced its own laser scanner, in late 1998. Leading GPS hardware company Trimble acquired the French startup MENSI S.A. in 2003 and began its own laser scanning development. Faro technologies, once a producer for high tech robotic medical equipment, noticed the growing market and shifted its production line in 2005 toward laser scanning and related geomatic equipment. In addition to Trimble, Leica, and Faro, there are a multitude of other scanner hardware producers; Surphaser, Stienbichler, Zoller and Frohlich, Maptek, Optech, Amberg, and Topcon. When it comes to software, most hardware companies develop their own accompanying proprietary software, but there are also laser scanner 3D modeling software industry standards such as Polyworks and Rapidform. Perhaps the most exciting development on this front is the rapidly developing niche of open source software such as Meshlab (meshlab.org), who provide point cloud and mesh data processing capabilities without the steep $10,000 to $20,000 dollar (US) price tag of commercial software licenses.

Over the short period that scanners have been commercially available, their capabilities have seen rapid improvement, as a consequence of competition between the various hardware producers. The first scanners placed emphasis on long range, high precision machinery, while later generations (from 2004) concentrated on speed of data acquisition and shorter ranges. Companies such as Leica and Reigl now boast a whole line-up of various scanners, each optimized to work at specific ranges for specific industries such as mining or automobile design. All of the increases in data collection rate and precision now meant that the amount of data that was being collected was increasing almost exponentially. When Cyrax introduced the Cyrax 2400, the data collection rate for that instrument was roughly 100 points per second; in contrast, the latest models (depending on emphasis) can collect upwards of 500,000 points per second. Data storage is a concern that has developed alongside the increases in precision rates. The increased ability of scanners has brought a new emphasis on the importance of storage, and a shift in the perception of the land surveying process.

> As terrestrial laser scanning systems mature from state-of-the-art instruments to become standard practice for recording complex topography, a change of emphasis is required; moving from using the system simply as a method of data capture to its use within a systematic surveying framework with well-established data collection and analytical protocols [Heritage and Large 2009: 24].

From the development of the earliest light pulse systems in the early part of the twentieth century, through systems based on ruby lasers developed in the early 1960s, and up to the more recent development of semi-conductor lasers, the way has been paved for more portable, diverse types, and (quite importantly) eye-safe instruments. The proliferation of venues that utilize laser scanning-the oil and natural gas industries, petrochemical companies, forensic labs, and now cultural heritage managers-speaks to the versatility and effectiveness of the technology's basic design (3D Risk Management 2008).

The first utilization of ground-based terrestrial laser scanning in archaeology and heritage management was undertaken by the prominent British goematic firm Plowman Craven and Associates which pioneered laser scanning recording techniques of historic buildings and opened the door for other uses in archaeology and heritage management (Booth 2002). Today, ground-based terrestrial laser scanning is utilized on prominent archaeological sites across the globe and is the gold standard for comprehensive digital documentation. Perhaps the biggest sign of the acceptance of ground-based terrestrial laser scanning's acceptance is the attention that it receives from private industry. Every large private geomatic company (e.g. leading international groups such as Urbica

[France], Universal Survey Group [Canada], and of Course Plowman Craven and Associates [U.K.]) now boasts heritage documentation as part of their target business. This is the result of NGOs like Cyark, which are at the forefront pushing for the utilization this new comprehensive digital documentation technique at heritage sites big and small.

Although only 13 years old, the technology of ground-based laser scanning has come to have a tremendous impact in the field of archaeology and world heritage. The birth and evolution of scanner capabilities, although designed and created for other fields, has been an answer to many of archaeologies fundamental documentation dilemmas. Currently archaeology does not factor large in scanner hardware design, but that may change with growing awareness of the important role that scanning plays in providing a trusted comprehensive digital documentation method. With increasing capabilites, decreasing size and prices, and ease of use, the future looks promising for the continued incorporation of this technology into the archaeological excavation and documentation process.

Chapter 5
Application of Ground-Based Terrestrial Laser Scanning

Technology has come to offer various improvements to the quality of life for people and simultaneously increase our capabilities in a broad spectrum of fields. The increased work efficiency afforded by the continuing development of new technologies (and the utilization of existing technologies in innovative ways), has allowed archaeologists who have long struggled with the task of locating and documenting potential archaeological sites to finally develop wide-ranging excavation and documentation strategies. The archaeological sub-field of remote sensing has long held much promise for cultural site identification and prospection. "The term remote sensing is generally understood as a technique for the acquisition of environmental data by means of non-contact instruments operating from various land, air and space based platforms" (Lyons 1977: 5). Various technologies are used in this data acquisition process including geophysics, aerial and satellite photography, both ground and air based radar, LiDAR, computer vision, and laser scanning. While remote sensing has historically focused primarily on initial anthropogenic detection, comprehensive site documentation has been an area that has only begun to be explored within the last decade. It is through the utilization of the technology of ground-based terrestrial laser scanning that precise site digital documentation, in totality, can finally become attainable. But laser scanning in archaeology is not a methodological alternative that is free of problems, and a thorough evaluation of the role that the technology currently plays in the field, as well as its methodological shortcomings, is necessary.

Remote sensing has much more to offer the excavator and the researcher than simply telling us where to excavate. For example, laser scanning offers us solutions to some of the most fundamental problems of archaeological excavation. Archaeological Excavation "is tantamount to the destruction of the site and can be thought of as a non-repeatable experiment" (Irwin 1990: 38). There are many implications of the "destruction of the site'" that must be considered prior to excavation. The first is quite obvious yet important nonetheless-once a site has been excavated, it cannot be recreated due to the destruction of the stratigraphic layers and the removal of artifacts, ecofacts, and features from their position *in situ*. If a change in soil context is missed by the excavator, this crucial characteristic is lost forever to the site interpretation process. This means that only a very limited group of people-the on-hand excavators, and more generally the site excavation manager-are wholly responsible for how the site will be documented and presented to other archaeologists and, eventually, the world. The finality of the excavator's interpretative process, the decision as to what constitutes a new layer or feature, weighs all excavation and is best mitigated through experienced excavators and constant discussion among the excavation team. But again, various viewpoints, considerations, and expertise are left out of the interpretive process of excavation unless they are present and vocalized in the decision-making process.

While the limitations of viewpoints at the time of excavation may result in questions that archaeologists must address, the limited technological viewpoints is another problem whose solution can begin to help address those other limitations. The problem of limited technological information assessment is actually a product of both the conventional (and antiquated) site documentation process that is often implemented during archaeological excavations around the world and the shortcomings of current incarnations of Geographic Information Systems (GIS). Only recently has GIS come to begin to be considered a standard tool in most archaeological excavations, yet even still, its use is a cumbersome process rooted in the traditional system of site excavation. “Many commercial GIS include in general a 3D extension, namely a 3D inter-face for visualizing multilayered surfaces (vector and raster) but no one is aimed for articulated 3D interaction with all the archives of spatial data (bi-dimensional and 3 dimensional)” (Forte et al 2001: 2). Those archaeologists do use GIS still are not able to manipulate and view raster and vector data in a true three-dimensional immersive environment-a testament to the limitations of current incarnations of GIS. Researchers are not able to enter physically or virtually into a GIS map and visualize and interact with the terrain in a meaningful way. The position of an artifact or feature can be registered with GPS and input into a GIS, but the details of that artifact (i.e. the means used to produce petroglyph upon a rock) cannot be properly evaluated or fully appreciated in a shapefile, without locating and presenting the feature or artifact in the original environment in which is resided. But laser scanning is not in and of itself a foolproof solution to all of the documentation problems faced by archaeologists. With a basic understanding of the history and mechanics of laser scanning established in the previous chapter, it is now time to weigh the potential benefits and shortcomings of laser scanning in archaeological and evaluate the current methodological process associated with laser scanner utilization and the information pipeline.

Ground-based terrestrial laser scanning capabilities have increased seemingly exponentially in the roughly 13 since the technological platform was developed. Scanner hardware developers have overcome many of the problems that early users and have developed instruments on the market that are compact, quick, and capable of working in many different archaeological environments. But there are still many shortcomings to the technology that the archaeologist must keep in mind when contemplating the use of the remote sensing technology. The first is the composition of the material(s)-objects or features-to be scanned. When it comes to scanning objects or terrain, surface reflectance and transmissivity ultimately affect photon absorption, scattering, and passage. If the color of the object or terrain being scanned is the same as the wavelength of the laser light that is being emitted, then the receptor is unable to distinguish between the wavelength of the light being reflected from the object or terrain, nor the original laser emmitance. A related issue is experienced when scanning objects or terrain that are dark, when all or most photon energy is absorbed and not reflected back-resulting in little or no data capture. Similarly, if the surface of the object is too smooth or glossy, then the laser light is scattered in all directions with little light returning to the source to allow for registry. Scanning a polished metal or translucent surface like glass, for instance, is nearly impossible as the laser light scatters on contact with the surface or passes through without reflecting back. While glass, polished metal, or those surfaces that are colored red or green (the industry standard for all laser scanner devices) may not be the most commonly found surfaces in archaeology, dark-colored features or areas that are heavily in shadow are encountered frequently. Lighting and other atmospheric conditions can also severely affect the range and accuracy of a laser scanner. Just as too much darkness can affect light absorption, too much light can create noise or machine data confusion. A problem I frequently encountered when scanning exterior spaces, was the impact of the suns position on my scanning data. The sun altogether heats the surface being scanned, and bathes it in excessive light, while it can also act to interfere directly with the light receptor if it is within or very close to the scanning inclination window (area to be scanned). This is just one of the reasons that I have found that the best angle to scan varies from 45° to -45°, a standard that is comparable to other published reviews of optimal scanning inclination angles (Clark and Robinson 2004: 4). To avoid interference from the sun or other major light sources, a scanning inclination angle directly, or near to, the angle of the light source was avoided.

Perhaps one of the most important questions that ground-based terrestrial laser scanning and other remote sensing technologies pose to archaeologists is just where in the excavation and interpretation process they belong. Laser scanning has come to primarily fill a role tasked at documenting the final post-excavation stage (Lerma 2010: 501). While this is an important task and laser scanning is particularly adept at completing it, there is much more potential use for the equipment beyond its current accepted role. There are legitimate reasons for laser scanning currently maintaining such restricted use, namely the high cost of purchasing or renting the equipment (current mid-level time of flight scanners range in price from approximately $30,000 to $150,000), the training involved for the equipment operator, the time required for data post-processing, and the cost of post-processing software. For these reasons, it is understandable that a project director may only bring in the specialized equipment for site documentation, after the final stage of excavation, to limit costs or reduce the demand on equipment and operators, that may be shared between several different sites. But this adapted approach does much to limit site reproducibility as a 3D model, and in turn a loss of the general understanding of the site long after the excavation process is over.

As any site is excavated, the archaeological excavators are consistently moving through different layers, sediments, and/or components, and do not necessarily need to move far spatially to change to a different habitation zone temporally. For example, temporal difference of 100 years may be the difference of just 10 plaster layers only two centimeters in thickness, but each requires its own mental map, or perception of place through time. The same can be said excavating a Roman villa, where over the span of 400 years, there may be four or five different distinct villas with entirely different cultural affiliations and materials (Campana and Forte 2006). So when ground-based terrestrial laser scanning is incorporated into the final post-ex documentation, it is disingenuous to present the scan model as the comprehensive documentation of Villa X or Ritual Site Y since it is only one of the living surfaces that the structure or space may have supported.

"The landscape should be considered [to be the]… a result of a historical sedimentation process where events both naturally and human induced have interacted to form an interwoven and complex whole" (Campana and Piro 2009: 4). Naturally each layer of that sedimentation process tells a different story to archaeologists, a story worth documenting in as comprehensive a manner as possible for future generations of archaeologists and anthropologists to read and derive meaning from. Comprehensive individual layer documentation with ground-based terrestrial laser scanning equipment comes as close to achieving the goal of preserving that cultural unit intact as possible, far better than any other documentation method currently available. While this methodology is by no means free from reliance on the subjectivity of the excavators in terms of identifying new context layers or features, it is a tremendous step forward in increasing the transparency of the excavation process-by comprehensively documenting the excavation process through a digital model of each new layer or feature-and allowing more open access to the information by outside researchers-by providing that data in a single digital format which is readily transmittable-which is in line with attempts at facilitating multivocality, a perspective which all modern anthropological endeavors should attempt to incorporate into their methodology. 3D archaeological site reconstructions, hosted in an accessible digital space, can be multidisciplinary forums for experts in archaeology, anthropology, history, art history, and other social sciences to communicate and interact within (Forte and Piertroni 2009: 60).

Another important methodological question that faces every archaeologist utilizing a laser scanning system is whether a researcher in fact needs such large amounts of points from current scanners. Unfortunately, the archaeological field does not drive hardware development for laser scanning, but instead design is driven by demand from rich sectors such as the oil and natural gas industries. These industries use laser scanning to create highly detailed Autocad drawings of refineries and oilrigs. The emphasis on the hardware specifications are to produce ever more dense point clouds from which to generate the final Autocad plans for these facilities. These industries have little need to generate actual RGB maps from their scans, so laser scanner internal cameras are of poor quality or non-existent. Applying laser-scanning hardware that has been explicitly developed for other fields presents challenges that archaeologists must grapple with and manipulate finally to serve our own particular needs. In the archaeological sub-field of laser scanning, “there is now a mismatch between the ability of terrestrial laser scanners to provide data at an ever higher resolution, and the proficiency with which such data is utilized" (Reindal 2009: 245). This, then, begs the question of just when is too much enough information being gathered.

In the summer 2011 excavation season at, Turkey, I had the pleasure of serving as scanner supervisor for our team from the University of California, Merced. Our research project was titled "3D-Digging at Çatalhöyük" and was directed by Maurizio Forte. During the excavation process using various digital recording technologies were used in an effort to establish a more improved excavation methodology. Laser scanning was just one of the technologies used, while others included computer vision, and 3D photography and video. My worked entailed me using a Trimble FX Time of Flight/Phase scanner that was capable of capturing data at a resolution of up to 216,000 points per second (Trimble 2011). The primary goal of our research was to test the methodological question of whether scanning at each new soil stratum layer was a feasible practice or if the time required to scan interfered too much with the flow of the normal excavation process. It took approximately 30 minutes for the Trimble FX to scan and process the data to an exportable format for a room at the full capabilities of 360x270 (i.e. its highest resolution setting). While scanning a single layer or small anthropogenic feature would not take nearly as long, the question of resolution setting is one that I had to deal with, and an issue that any scanning operator will also need to face. My decision to scan at a lower resolution, roughly half of the scanners full capacity (and default setting), was based on multiple considerations that each needed to be careful weighed before the optimal setting was decided upon.

The first consideration that I focused on was the time needed to scan. A 30 minute break from the excavation process to allow for scanning for the remainder of my team was just not logistically feasible, since-as with any excavation-there is limited excavation time and any lost time ultimately translates into wasted funds or resources. Scanning at the lower setting reduced the time required by a little under half, which translated into about two to three scan stations per scan, once or twice per day for an average time of twelve minutes per total scanned area (six minutes per scan station with an average of two scan stations per unit/feature). In addition to the time constraints, I had to determine if my level of data capture was sufficient to support the desired output for our project. For this, I had to consider the surfaces I was scanning. Our excavation at Çatalhöyük involved the excavation of a 7,500-year-old Neolithic home-specifically Building 89, Space 379, in the East Mound's South Shelter. The material I was scanning were all natural materials, ranging from dirt and stone building infill to plaster-layered floors and walls. The material was neither reflective nor transmissive, and, thus, was ideal for high-resolution data capturing. The designs of the walls and adorning plaster decorations were organic in nature which did not demand extreme high resolution that more geometric shapes would have required to be properly defined three dimensionally. Again, the material properties and shapes lent themselves to scanning at a lower resolution.

The final consideration was data management and output. Even at lower scanning resolutions, file size and point cloud density was nearly unmanageable given constraints of the post-processing hardware and software available to me. A file size for a 360° room ranges from half a gigabyte, to upwards of a full gigabyte. Working with files this large push hardware and software to their working limit and make post-processing even more time consuming due to computer and software lag and malfunctions. Experimenting with creating various models from the same scan data allowed me to determine that even the reduced resolution scans could be sampled (reduced) much further and still provide a model of excellent quality (Thus, it is clear that for any project, the scanning team will first need to identify the ultimate objective and tailor their scan preferences appropriately to achieve that goal (Forte et al 2009: 190)). A similar heritage project, the digital documentation of Tambo Colorado, used a Leica HDS 3000 with a data capture rate of approximately 4,000 points per second. Scanner operators were forced to reduce their models by 90 percent (Forte et al 2005: 6). At Çatalhöyük, I worked with the Trimble FX that had capabilities 200 times that of the Leica HDS 3000 and I was forced to decimate my models by roughly 80 percent. Only after considering all of the above constraints was I able to determine that scanning at a lower resolution was the ideal scanning profile for the Çatalhöyük project.

Laser scanning can resolve many of the contextual interpretation issues that archaeologists face. Laser scanning affords the researcher a complete three-dimensional view of a site in its entirety. Laser scanning data for stratigaphic layers mitigates the issues of the lack of site reproducibility by allowing for the digital recreation of the site as it was excavated. While GIS can properly locate an object within an x,y,z coordinate system, only laser scanning is capable of 3D documentation of artifacts and anthropomorphic features *in situ*. Digital site reproducibility also provides other exciting possibilities to the archaeological community. For example, if another researcher other than someone of the dig team takes issue with the conclusions reached following the excavation, the scanning data can provide a minimally unbiased record to consult. A true three-dimensional model can bolster or undermine an interpretation offered by an archaeologist in a way that reviewing a site photo or a hand drawing with height levels cannot. Variations in molding detail or other tangible anthropogenic features cannot be as easily portrayed or observed as they could be using laser scanning documentation and 3 dimensional viewing. The scanning data also allow for the re-interpretation of sites excavated now, by future researchers who may develop more advanced techniques of site interpretation.

Much of the debate surrounding the effectiveness and practicality of laser scanning involves its comparison to the other, relatively newer, archaeological technology of photogrammetry. Photogrammetry can be described as the science and art of measuring and interpreting imagery in order to reconstruct objects in either two or three dimensions. "Close range photogrammetry usually applies to objects ranging from a few decimeters up to 200 m in size. If the orientation in space of one image is known, every image generates a bundle of rays that can be used to either texture models (standalone mode) or measure objects in space (if more than one image is available and intersect the bundle of rays coming from different pictures)" (Lerma 2010: 505). Photogrammetry has long been used in aerial and satellite photography to establish the extents of ruins and other large-scale archaeological features, and it is reliability of this technique, coupled with the speed and accuracy of terrestrial laser scanning that will provide archaeologists with the most effective method for comprehensive site documentation.

The combination of laser scanning and photogrammetry for three-dimensional modeling has proven to be particularly efficient and comprehensive. In the case of the documentation of the landscape in Pinchango Alto in Nasca, Peru, for example "different levels of resolution and different viewing angles of the two recording systems used, allowed the three dimensional models to be produced according to the specific requirements of archaeological analysis" (Lambers 2007: 9). Both technologies should be used in unison when the characteristics of the study area are complex, and of large dimensions, or when it is possible to find features or artifacts of a varying nature. "The laser scanning techniques and close range photogrammetry can offer two complementary sets of instruments and technologies able to answer to the specific requirements of architectural and archaeological survey" (Drap 2006: 337). But sometimes the incorporation of both techniques is unfeasible, while in some situations, utilizing one mode is more advantageous than using the other or both. When an object, artifact, or feature, is predominantly point or line based (e.g. a box), photogrammetry is the best tool to use as laser scanners cannot easily document sharp edges. On the other hand, when an object is irregular and complex, like a sculpture, tool, or other find with an uneven or porous surface, then laser scanning is the more appropriate technology to use. It is too difficult (if not impossible) to produce an accurate three-dimensional image of an object with an irregular or porous surface using photogrammetry (Lerma 2010: 503).

Terrestrial laser scanning is not the answer to all excavation needs. There are problems with laser scanners that must be identified and addressed according to the specific characteristics of the site. Areas that must be documented at a macro-scale cannot be adequately evaluated using ground-based time-of-flight scanners. Instead, aerial or satellite photos, airborne radar or LiDar, and/or photogrammetry might be more appropriate. Time is yet another factor that should be taken into account. While laser scanning counts speed as one of its strengths in documenting large areas, when a site becomes too big it may take too much time to adequately conduct the required scans.

Experience is also crucial. Given the long history of photogrammetry within archaeology, many feel more comfortable relying on it as the primary documentation technique. Conversely, experience can also be viewed as a barrier to utilizing terrestrial scanners. Becoming a proficient scanning technician is only part of the process, but knowledge of a range of post-processing software, the importance of which varies with the desired outcome of the project, must also be acquired. This requires not only a significant investment of money, but also of time. Inconsistencies in the orientation, resolution, and position of individual surveys-which can be caused by a lack of training-can require many hours of work to correct or can render some data useless (Reindal 2009: 246). The scanner operator should have the knowledge to work as efficiently as possible, selecting the fewest number of scanning stations to get total coverage of an area, selecting the fewest number of high resolution photographs with which to texture the model, and selecting a manageable scanning resolution. Experience is key to managing all of these factors.

Beyond the complexity of the scanner hardware and post-processing software, perhaps the most daunting problem that hinders widespread incorporation of laser scanners into current excavation methodology is the high price of the scanning equipment. When it comes to deciding which documentation method to employ, price becomes a significant factor in the decision. With the price in excess of 100,000 dollars for a current medium-range time-of-flight scanner, the cost alone is a deterrent for most researchers. Conversely, close-range photogrammetry has the benefits of being relatively cheap and easy to set up, and the portability of taking mainly the cameras (and tripods) to the different sites is an advantage that makes it appropriate for recording a large number of artifacts, features, and sites (Lerma 2010: 504).

The technology of terrestrial laser scanning offers archaeologists an opportunity to develop a new comprehensive site digital documentation methodology. But it would be wrong to assume that terrestrial laser scanning provides the complete solution. Each individual site must be considered separately, and researchers should assess available time, training, money, and site characteristics before deciding whether terrestrial laser scanning, photogrammetry, or a combination of the two would work best. As researchers, we must realize that although technology is improving, by itself it will not overcome the shortcomings of poor methodology. There is the inherent danger of overreliance on technology; “a danger exists, a direct, positive relationship between data quantity and data quality is often assumed in the recording of surfaces and there is a tendency to accept high-resolution data as being the most accurate representation” (Reindal 2009: 266). Laser scanning is often lauded as one of the most accurate documentation techniques available (and it currently is), but each researcher should always consider the product or informational output that is to be desired before employing laser scanning as the means for site documentation. If a simple representational model for general educational purposes is the end-goal, then employing an expensive scanning system and operator may not be the best solution, since there are cheaper ways to produce a detailed and accurate model. Documentation of a “critical” heritage site, or for higher academic purposes may be instances that require such precise instrumentation. A good researcher knows the limitations of the specific technology they employ and does not implement its usage where such technology is inappropriate. That said, archaeologists finally have a tool that allows for the three-dimensional digital preservation of artifacts, features, and cultural sites, which will in turn, allow research of such archaeological remains even after destruction. As an archaeologist, and even more simply just as a human, it is easy to see this is quite the achievement.

Chapter 6
Conclusion

Examining the history of remote sensing in archaeology reveals much about the practice of archaeologists. There has been a general tendency to eschew new technological methodologies in favor for more time-tested formulas. There has been a tendency of certain institutions (with corresponding geographic parallels) to be more receptive to remote sensing technologies, while others remain largely absent from the field. But perhaps this mindset is evolving at a more rapid pace, as illustrated by the accelerating acceptance of laser scanning within the archaeological community. Through documentation of the use of the technologies over time, it is also possible to see the challenges presented by the utilization of each technology, and how methodology has evolved to deal with these challenges. As was the case with aerial photography in archaeology, it is likely that laser scanning will only slowly increase in utilization in the field until issues related to cost, usability, and accessibility are addressed. As was the case with its remote sensing predecessors, the costs associated with laser scanning will decrease, and more open source software for post-processing will be developed. It is interesting to note that this is already happening at a more accelerated rate than was the case with aerial and space-based remote sensing. While aerial and satellite-based remote sensing took the better part of a century to become widely used, laser scanning has already gained acceptance since its debut 14 years ago. Again, if history is any predictor of the future reception of laser scanning, then there will be continued holdouts to the documentation method, and only a small minority of archaeologists will choose to become proficient in the technique.

Perhaps the most interesting reaction I had while studying the history of the utilization of aerial and space based remote sensing in archaeology, and then utilizing the technologies myself, was the number of practical questions that arose in response to my own work and research. Decisions about which type of terrain data were available and at what resolution, which resolution setting was best to capture scan data, and how many photographs to use to texture map a model all contribute to the subjectivity of the final product in remote sensing. The extent of the subjectivity during the data capture process and ultimately in the final product outcome took me by surprise, but I was most intrigued by the problems that I and other contemporary archaeologists face when incorporating these technologies into their site identification and excavation strategies. A thoughtful look into some of the problems that incorporation of aerial and space based remote sensing into archaeological practice is essential for any archaeologist both prior to and during use of such techniques. Beyond repeating facts about scanner accuracy, and camera pixel resolution, we must provide specific information about specifically which data within our model can lead to further understanding of which functions of the site. It is most disappointing to hear a model described in terms of the accuracy of the individual technologies used (and even this accuracy is diluted through post-processing) instead of the interpretive potential that it offers.

Once the archaeologist has made an adequate evaluation of just what types of anthropological questions can be addressed in the created model, he/she must also work to address what is missing. The many problems that the issue of scale presents to the archaeologist that are not easily reconciled, but perhaps the best policy the archaeologist can adopt is being forthright about just what the model does not include. Every archaeologist must determine limits for their representation, but those limits are certain to exclude both macro and micro data of some type. Our digital models are created to either document material cultural remains, or to better identify or understand such remains. No matter the resolution of the scanner or the quality of the images, we cannot hope to capture a complete picture of life in the past in a model and must look for ways to supplement the omissions that our models possess. Perhaps the most helpful step in this process is audience identification before any documentation process begins. Is the digital documentation undertaken to answer a specific research question, will it be transformed to serve a public media function, or will it need to serve both aims. An academic or professional audience will be in a position to appreciate small-scale (and even macro-scale) representations than the general public or even a more specific younger audience may miss. Concern for audience will help in determining which technology is most appropriate to use, as well as at what resolution documentation should occur. While this advance consideration will avoid some problems of scale and cultural representation we must acknowledge that we do not currently have a perfect system, and that our best hope may be new generations of GIS that may solve the issue of information loss and gain at various scales. For now, scale and resolution remains a fundamental problem in the generation of any model.

When a finished digital model is completed, be it in the form of an accurate DEM or a model of an archaeological structure or feature, the person who is best able to interpret that model is the creator him/herself. No one knows the deficiencies or strengths of the model better than the archaeologist whom has captured and manipulated the data. It is apparent that when it comes to digital prospection and documentation, the pressing need in archaeology is greater technological proficiency across all of the various subfields. This is not to say that lithic or faunal analysts should be experts on laser scanning, but it may serve a pottery expert well to have a general understanding of optical scanning so that digital scanning of sherds for better illustration/documentation purposes becomes a viable option for them. But even if work on digital surveying or digital documentation is 'subcontracted' out to digital archaeologists, it is in the best interest of the primary researchers to know the methods, strengths, and weaknesses of the prospection and documentation types employed. Only then can they truly understand exactly which documentation method is most appropriate and what exactly their delivered digital model (or final product) represents.

Conversely, it is the responsibility of digital archaeologists to ensure that they do not become too far removed from the fundamentals of archaeology; including knowledge and appreciation of the excavation process. It has been my experience that digital archaeologists (as many archaeological sub-specialists) have 'room to grow' in terms of understanding the excavation process and how sites arrive in form to the documentation point that most digital archaeologists experience them at. If a digital archaeologist only visits the site to conduct periodic laser scanning or take GPS points, they have a fundamental lack of knowledge of how features have been identified, and what patterns in soil consistency may mean and how they relate to one another, but most importantly have missed much of the discussion involved amongst excavators as to how all elements of the trench are inter-related. This lack of understanding handicaps the recorder and limits the understanding of just which features are which and how they should be emphasized or portrayed. It is also the responsibility of the digital archaeologist (as any type of archaeologist who begins work at a site) to understand the natural and cultural background of the landscape, site, features, and artifacts to be documented. At the point where the digital archaeologist is simply traveling from one archaeological site to the next creating digital models with no understanding of the cultural and natural context being studied, or not being involved in the interpretation process, then they have regressed to the level of simple technician and have precluded themselves from the real work of archaeology-that of studying past cultures and their relationship to the present.

It is an appreciation and understanding of the past cultures, (which should facilitate the digital documentation process) which ensures that we, as digital archaeologists, are adequately prepared to participate in the archaeological interpretation process. We must not be afraid to express our interpretations of the models we create, since oftentimes it is the digital archaeologist who has the greatest understanding of the end product. In a perfect archaeological research project, everyone could be classified as a digital archaeologist and could identify and then use the appropriate technologies to survey, or record their site or artifact. Of course there are significant barriers to achieving such a goal, not the least of which is the high cost of hardware, software, and training, but there are ways that these problems are being addressed. Partnerships between universities, NGO's and technology companies are already happening, reducing those barriers in the process. Open source software is another major innovative way that archaeological programs can incorporate state of the art technological processes into their curriculums. Using open source GIS software like GRASS (Geographic Resources Analysis Support System), and modeling software like MeshLab, researchers can minimize costs and work on platforms that are both cheap and readily available to fellow researchers around the world. The most technological innovative field schools in Italy are now offering aerial and space-based remote sensing as part of the basic training including GIS, GPS, laser scanning, geophysics, and other remote sensing technologies (Parcak 2010).

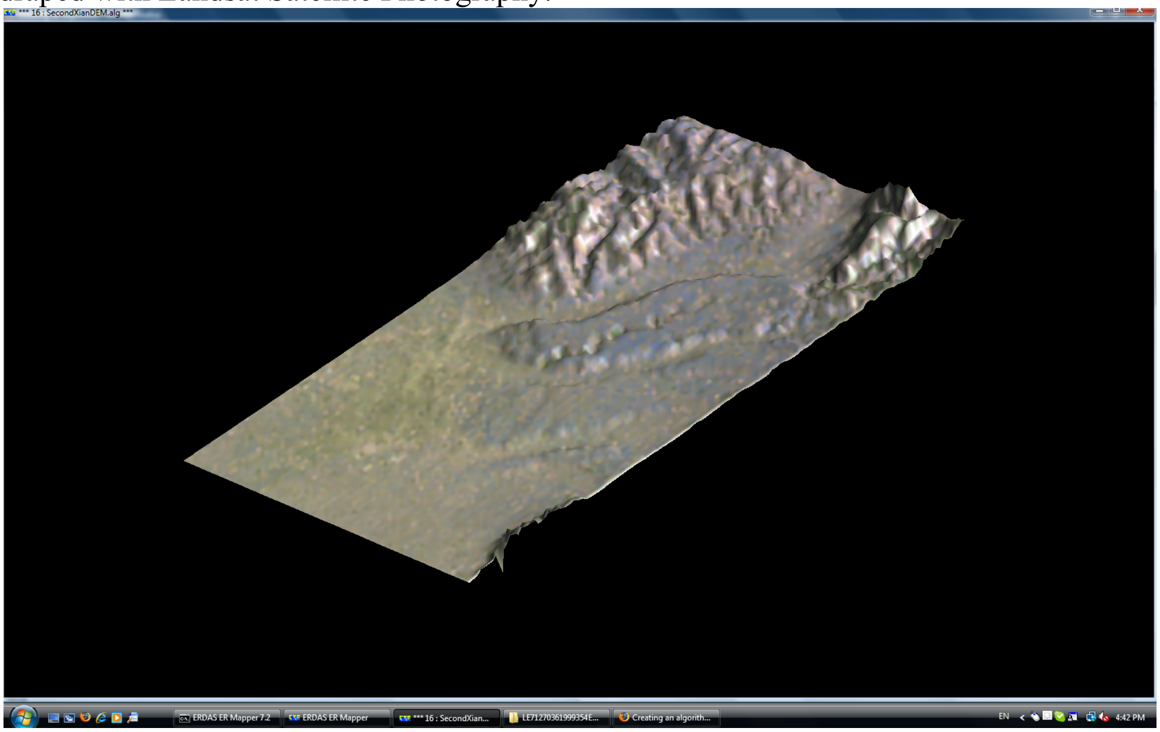
Advancements in computer vision and photogrammetry are making comprehensive digital documentation of a site as easy as taking a series of digital photographs and aligning them in ever more accurate software's. The possibility for all archaeologists to incorporate methods of digital archaeologists is rapidly progressing, toward a point in time where that distinction between the two becomes blurred, as it should be. A short passage written by Leo Deuel in his book *Flights into Yesterday: The Story of Aerial Archaeology*, quit succinctly sums up the responsibility of archaeologists who use aerial recording techniques, to the subject matter they study in their images or models.

> To derive the fullest benefit from the photographs and thus turn chance discoveries into a systematic analysis of the total landscape, the expert needs a real feeling for the setting-its physical geography, its history, and even its living people. Only through such intimate knowledge can he (or she) adapt his (their) methods to the genius of the place; concentrated on the significant, and on the abnormal rather than the normal; dissociate contemporary or recent features from those long abandoned; unwind and extricate the manifold marks that betray various past epochs; recognize their role within the given environment; and train (them) self to see not just a few obliterated earthworks but culture groups with their characteristic economies. Only thus will they be able to restore a buried landscape and people it with a whole sequence of humanity which has its origin in the distant dawn but continues into the present [Deuel 1969: 122].

The same responsibility applies to digital archaeologists broadly.

Figures and Illustrations

Figure 1. Screenshots of a DEM of the Chinese city of Xian. The DTM uses SRTM data draped with Landsat Satellite Photography.



Screenshots a Ground Based Terrestrial Laser Scan Model of Building 89. (Figure 3 and 4)

Figure 3

Pre-excavation laser scan textured mesh with aligned post-excavation laser scan mesh. Building 89, East Mound, Çatalhöyük, Turkey.

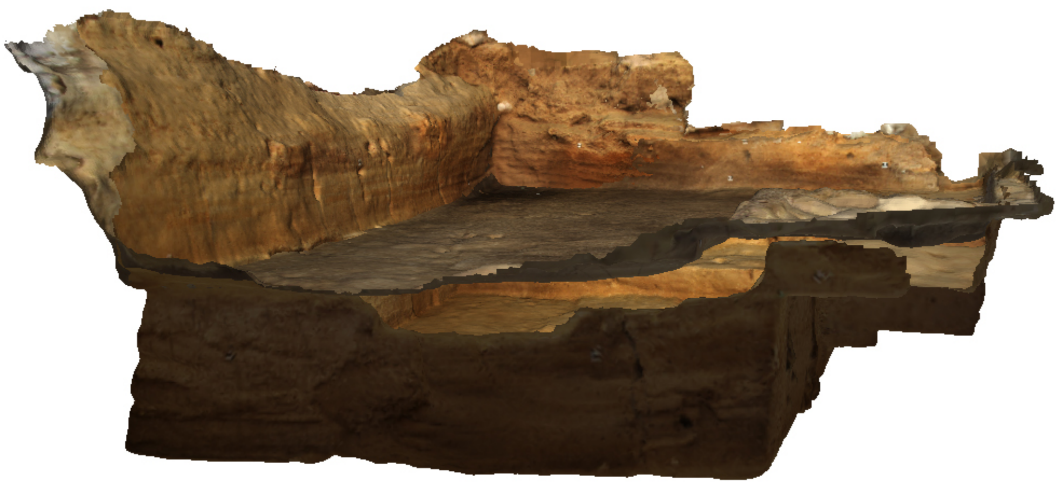
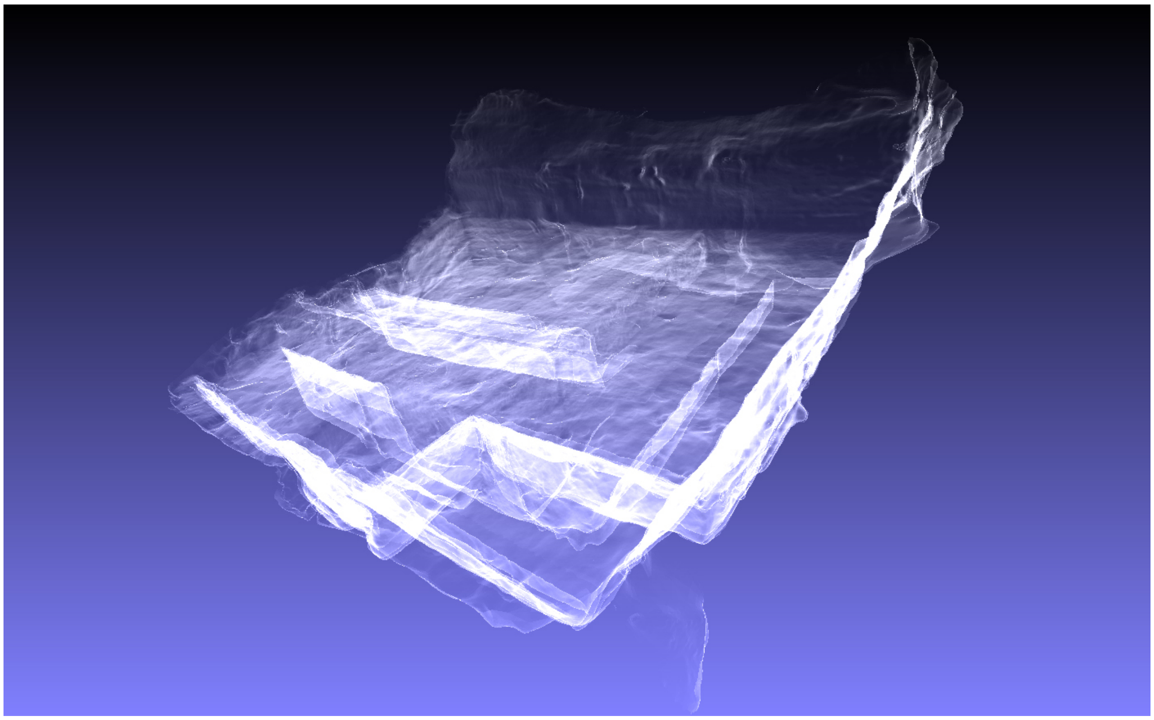


Figure 4

X-Ray view of aligned laser scan model of different Contexts encountered in building 89, East Mound, Çatalhöyük, Turkey.



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