DOCUMENTING MACKENZIE INUIT ARCHITECTURE USING 3D LASER SCANNING

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ABSTRACT

Laser scanning is currently being used in various areas of the world to document, preserve, and analyze ancient architecture. Laser scanners record the proveniences of numerous points on an object's surface. The resulting three-dimensional images can be used to test various building scenarios, analyze activity areas in a three-dimensional context, and digitally archive heritage resources threatened with destruction via erosion and industrial activities. Laser scanning may have applicability in the western Canadian Arctic, where archaeological research has become increasingly focused on the interpretation of Mackenzie Inuit architecture and the preservation of houses threatened by erosion. The use of laser scanning technology in an environment as remote and challenging as the Arctic provides an excellent case study for assessing the benefits of using this approach in a region associated with both complex architecture and excellent preservation. We conclude that laser scanning is feasible at isolated arctic field sites, but suggest that short-range, high-resolution scanners, similar to the one used in the study, are best suited to recording specific architectural details, rather than complete dwellings.

KEYWORDS: laser scanning; Mackenzie Inuit; architecture

INTRODUCTION

Variability in architecture and its relationship to cultural processes has been an important subject in anthropology since the very beginnings of the discipline (Mauss 1906; Morgan 1881). This is especially true in the circumpolar world, where the preservation of dwellings and other feature types is often excellent. The search for cultural processes in circumpolar architecture continues to spark interest in arctic archaeology and ethnography, and many recent publications on this topic attest to this interest (Dawson and Levy 2006; Dawson et al. 2007; Friesen 2004; Lee and Reinhardt 2003; Levy and Dawson 2009; Patton and Savelle 2006; Whitridge 2008). In the Mackenzie Delta region of the Canadian Arctic, for example, researchers have attempted to link variation in semisubterranean houses to changes in Mackenzie Inuit social organization (e.g., Arnold 1994a; Friesen 1999, 2006). Unfortunately, resolving these important research questions has been hindered by the erosion of archaeological sites, as well as inconsistencies in the methods employed to document and record Mackenzie Inuit architecture, both historically and in the present day.

The destruction of Mackenzie Inuit sites due to erosion caused by rising sea levels and storm surges highlights the fact that culture heritage sites throughout the world are currently threatened by time, natural processes, and human interaction. An organization dedicated to preserving and sharing the world's cultural heritage called Cyark has constructed an interactive hazard map with over eight hundred heritage sites, many of which are undocumented. The map illustrates each site's proximity to environmental threats such as rising sea levels due to climate change and earthquakes. Examining Cyark's interactive hazard map reveals that laser scanning has been used extensively in Europe and other areas of the world to rapidly and accurately document archaeological sites and heritage buildings under threat (see Giuffrida et al. 2005; Guidi et al. 2005 for examples). However, laser scanning has rarely been used for such purposes in North America. Instead, it has been confined primarily to recording small objects, such as paintings and sculptures (Blais et al. 2008).

The use of laser scanning in an environment as remote and challenging as the North American Arctic provides us with a unique case study for evaluating its suitability for recording archaeological features in more accessible areas. The Canadian Arctic presents some formidable obstacles because many sites can only be accessed by helicopters or fixed-wing aircraft. Laser scanning equipment is highly sensitive to dirt, moisture, temperature, and impacts. Maintaining a steady, reliable source of power is also critical, as are adequate light levels to obtain clear scans. Finally, the instrument needs to operate from a stable platform that is impervious to wind, and many arctic regions have few calm days.

In this paper, we describe how laser scanning was used to document precontact architecture at an archaeological site in the East Channel of the Mackenzie Delta during the summer of 2007. Even though extremely challenging, environmental obstacles unique to arctic environments can be effectively managed when laser scanning. We also demonstrate how recording architecture in three dimensions, and at high resolutions, allows researchers to visualize architectural features in ways that are simply not possible using two-dimensional line drawings. Once back from the field, for example, the entire site can be re-examined at levels of up to .3 mm accuracy. The resulting images can form the basis of three-dimensional computer reconstructions of scanned features, which can then be used to test various construction scenarios, interpret the domestic use of space, and excite public interest in archaeology. Laser scanning, for example, has played a major role in a recent exhibit completed for the Virtual Museum of Canada.[1] Scanned 3D images of various artifacts were placed inside a computer model of a Thule whalebone house as a means of recreating the domestic setting of a Thule household.

THE USE OF LASER SCANNING IN ARCHAEOLOGY

Many disciplines have benefited from the infusion of laser scanning technology. Since its inception, scanning technology has used representations of archaeological and architectural monuments as showpieces in its marketing materials. However, because of the inherent expense, it is not surprising that the majority of laser scanning applications have been in engineering, surveying, and manufacturing. The expense of purchasing and maintaining the instrument has prevented the use of this equipment from becoming commonplace in both historic preservation and archaeological fieldwork. Though the cost represents a barrier in many fields, over the last decade many notable archaeological projects concerned with significant heritage sites have relied on laser scanning.

A great deal of early laser scanning work in archaeology and conservation focused on capturing the images of smaller objects. In 1999, two research projects embarked on the scanning of Michelangelo's statues, including the Renaissance sculptor's famous depiction of David. One of the research groups, led by Marc Levoy of Stanford University, used a custom-designed triangulation laser built by Cyberware to scan Michelangelo's statues in Florence, Italy, including the David, the Prigioni, and the four statues in the Medici Chapel (Levoy et al. 2000). The

1. http://www.museevirtuel-virtualmuseum.ca/Search.do?ex=on&R=VE_1914

scans were of a high enough resolution to reveal the artist's chisel marks on the stone (Koller et al. 2004). Other examples include the laser scanning of ancient cuneiform tablets by Kumar et al. (2003) and of Da Vinci's Mona Lisa by the National Research Council of Canada (Blais et al. 2008). While small objects allow for high levels of resolution, it is often impractical to scan buildings and other larger scale objects in this way. High-resolution scanners, for example, have narrower scanning ranges, requiring multiple setups in order to capture an entire structure. As a result, issues of resolution and rate of capture, as well as accuracy and color depth, must be evaluated when determining the type of scanner needed for a project.

TYPES OF SCANNERS

Deciding what type of laser scanner to use is often determined by the size and scale of the object to be documented. There are three major categories of laser scanners: pulse (time of flight), phase (triangulation), and modulating light (Boehler et al. 2003). Time of flight scanners can have a range up to 800 m, but most work well in the 100–200 m range. These types of laser scanners are excellent for acquiring 3D images of buildings and large sites; they have a moderate degree of accuracy for a single point (1 cm to .5 mm depending on the distance to the object) and have a scan rate of approximately 2000 to 50,000 points per second. These pulse scanners operate by measuring the time of flight required for a laser pulse to reach the surface of an object and be received by the scanner. An important advantage in this technology is its ability to operate under any lighting conditions. With the introduction of self-rotating laser-emitting heads, the speed of data acquisition has been greatly increased. With fewer setup steps and less post-processing, this technology is ideal for reconnaissance and for establishing baselines of historic sites and archaeological excavations (Finat et al. 2005; Johansson 2002; Sternberg et al. 2004).

Triangulating laser scanners are a second type of instrument and come in single and double camera versions. Triangulating scanners generally offer high spatial resolutions (less than .3 mm) with low distance ranges (an order of magnitude less than time of flight scanners). Capable of acquiring data at speeds greater than 100,000 points per second, these scanners offer the archaeologist the ability to acquire highly accurate 3D images of artifacts and architectural details. Unlike time of flight scanners, however, light levels usually must be in a specific range. If light levels exceed the manufacturer's parameters, the camera will not function properly. In addition, surfaces that are very reflective under bright light will result in holes in the data set. This can be especially problematic in arctic environments, where the reflective surfaces of permafrost and ice encountered during excavation might cause problems. Single camera versions work on the principle used by range finders: a known baseline distance between the mirror and camera lens allows triangulation on a point. Triangulating scanners that employ a double camera are similar to the single camera but feature a light projector that produces a moving strip or static pattern. These patterns, when viewed by the camera at a fixed distance from the light source, can provide data used to determine the shape of the object. Although not capable of capturing data over a large area, they do provide accuracy in a range of .1 mm to .6 mm, depending on the distance to the object and the design of the unit. Bench-mounted versions of this scanner make it possible to automate data acquisition and facilitate transport and setup (Barnett et al. 2005; Cain and Martinez 2004; Díaz-Andreu et al. 2006).

Finally, there are scanners that use a modulated light source. By varying the amplitude of the light source, the camera can determine the distance from the target or object. Some of these phase scanners will split the laser beam into several components, each with a different wave length (Boehler et al. 2003). For example, the Faro laser scanner splits light into 76, 9.6, and 1.2 m wavelengths. The distance to the object is determined by registration of the shorter wavelengths against the longer cycles. The range of these scanners can exceed 70 m and provide resolution of .6 to 1.2 mm, depending on the distance to the object. One advantage of this type of scanner is that it is extremely fast. With point acquisition of over 120,000 per second and a 360-degree field of view, these scanners can provide a good alternative for general survey work. When faced with the problem of scanning objects that are both large and contain small details, the solution can be to use multiple scanners with different resolutions. A modulated light scanner, for example, can be used in combination with a triangulation scanner to capture large objects at different levels of detail (El-Hakim et al. 2005; Malinverni et al. 2003).

COLOR ACQUISITION

The color of an artifact or building surface is important in archaeology. However, acquiring accurate color information presents a unique set of challenges in 3D imaging. Although it is possible to capture color data with all types of scanners, very controlled lighting conditions of the target or site are required to capture consistent and accurate color data. This is often difficult when working outdoors under natural lighting conditions. With laser scanners, color values (RGB) are recorded for each point acquired from the surface of the object. This data can be converted into texture maps that are used to wrap the surface of a mesh, a process known as texture mapping. In creating 3D photo-realistic models, digital imagery can also be combined with laser scanning data. High-resolution digital cameras can be mounted directly onto a laser scanner. Using a software solution based on photogrammetric principles, it is then possible to select color values from the digital image for every point in the 3D image or point cloud. In general, a digital camera can also operate under a greater range of lighting conditions.

ENVIRONMENTAL CONDITIONS

Environmental controls are much easier to manage under lab conditions than in the field. Clean power, lack of dust and vibration, and excessive heat and cold do not concern the researcher in a lab compared to one in the field. Consequently, when selecting a laser scanner for fieldwork, issues of transport, reliability, and outside operating conditions must be considered. All scanners have operating limits. Ordinarily, scanners will not work in dusty, wet, excessively hot, or extremely cold environments. Although some scanners have been designed to minimize the impact of dust entering the unit through the use of heat sinks rather than fans, most units are sensitive to heat above 40°C and below 0°C. In the Canadian Arctic, summer temperatures are influenced by such factors as proximity to sea ice, snow or rock cover, and prevailing winds. Temperatures can dip to –12°C in some areas, posing potential problems for scanner operation. Operating in the rain is not advised or recommended for any scanner, which is again problematic for laser scanning in arctic regions, where rain, snow, and persistent fog are common during summertime. Though future scanners may not require a stable, fixed platform, today most scanners do (Blais et al. 2004; Neubauer et al. 2005). Given that scanners must have a clear line of sight to the target, placing a scanner on scaffolding that shakes under the use of the operator will result in unusable data.

For anyone who operates a scanner, transportation of the equipment to the site becomes a serious issue. There are only a few scanners whose size and weight allow them to fit on board in the overhead compartment or under the seat of an airplane. This is even more problematic in the Canadian Arctic, where smaller fixed-wing aircraft serve smaller communities. The use of G-force cases, though reliable, will likely not guarantee that the unit will avoid damage while being handled by cargo and airport baggage personnel. In addition, ancillary equipment such as targets, digital camera, laptop computer, connecting cables, uninterrupted power supplies (UPS), generators, tripods, tarps and tents must be transported to the site (Sternberg et al. 2004). Consequently, being self-sufficient in the field may require the transport of several hundred pounds of equipment, easily exceeding the normal luggage allowance for northern commercial airlines.

BUDGETARY CONSIDERATIONS

Although price may be a limiting factor in the purchase of a scanner, the type of data needed for the project should guide the final selection. In reality, one scanner may not be sufficient to achieve the research objectives of a specific project. Two scanners may be required: one for the general survey of the site and another for capturing detail including relief, architectural ornamentation, and artifacts. Ultimately, the expense of laser scanner acquisition may be so great that purchase is prohibitive. A better solution may be to contract with a firm that will charge several thousand dollars a day for data collection. While costly, contracting out may ultimately be more cost effective, particularly when working under time constraints or when the need to capture data is infrequent. As many first-generation scanners are now approaching ten years in age, a used market may soon emerge that will make acquiring equipment for research and teaching more affordable. Much of the older equipment captures data at the same resolution as newer ones, but at a lower speed, which in a teaching or research environment is not as critical as in industry.

USING LASER SCANNING IN REMOTE SETTINGS: THE MACKENZIE INUIT SOD HOUSE

The western Canadian Arctic presents us with an excellent case study to examine how laser scanning might be applied in documenting indigenous house forms in remote areas of northern North America. Over the past several thousand years, Inuit and their Thule-culture ancestors devised a series of remarkable house designs involving the innovative use of such materials as whalebone, sod, stone, ice, snow, hide, and driftwood. The robustness of these materials means that many archaeological sites contain dwellings in excellent states of preservation. This is especially the case for semisubterranean houses framed with driftwood and whalebone. Some of the largest and most complex dwellings were built by the Mackenzie Inuit of the outer Mackenzie Delta region, one of the most populous groups of Inuit in the circumpolar world of the nineteenth century. The Mackenzie Inuit built large semisubterranean, cruciform-shaped winter houses framed with local driftwood and covered with sod. These dwellings have been summarized extensively in the ethnographic literature by Franklin (1828), Nuligak (1966), Petitot (1876), Richardson (1828), Stefansson (1914), Stringer (Friesen 2004), and Whittaker (1937). Out of these observations emerges a dwelling "type" with a fairly standardized set of architectural features (Fig. 1). They are described as having three alcoves or sleeping platforms opening off of a central room designated as a main chamber. A fourth alcove, or extension, forms part of the entrance passage. Ethnographic accounts describe the main chamber as constructed with four corner posts outlining a square, with dimensions ranging from 2.4 m to 3.6 m on a side. The corner posts consisted of inverted tree trunks set into the ground with their roots serving as crotches for four stout logs, which formed the main ridgepoles of the structure. The inside height of these dwellings was recorded as 1.8 m, with the roof being constructed from split logs with the flat sides facing inward. The ceilings and walls of the alcoves consisted of split logs resting obliquely against the ridge poles, forming the four sides of the main chamber. According to Whittaker (1937), the lower ends of the logs were set on the earth about 60 cm (2 feet) beyond the square and leaned against the upper logs, until the spaces were filled. The structure would have then been covered with sod blocks for the purpose of insulation.

The alcoves served as sitting and sleeping places for family members as well as work spaces and storage areas. They were elevated from 15 to 60 cm (6 inches to 2 feet) above the floor of the main chamber. Although dimensions vary between authors, the alcoves are typically depicted as trapezoidal extensions from the two corner posts of the main chamber (Richardson 1828:216). The floors of the alcoves, which sometimes had a gentle inclination forward, were constructed of split logs with the flat surfaces facing up. Stefansson (1914) observed that these boards were of irregular lengths and rarely met up with the walls of the dwelling.

A long, narrow, slightly curved entrance passage, partially excavated into the earth and partly covered with blocks of ice, provided access to the winter house. This entrance passage, which was 4.5 m to 6 m long by .76 m wide led to a trap door in the slanted floor that was covered by a piece of fur (Stefansson 1914:159–160). Whittaker (1937) observed that "the best of such houses, built on a hillside,

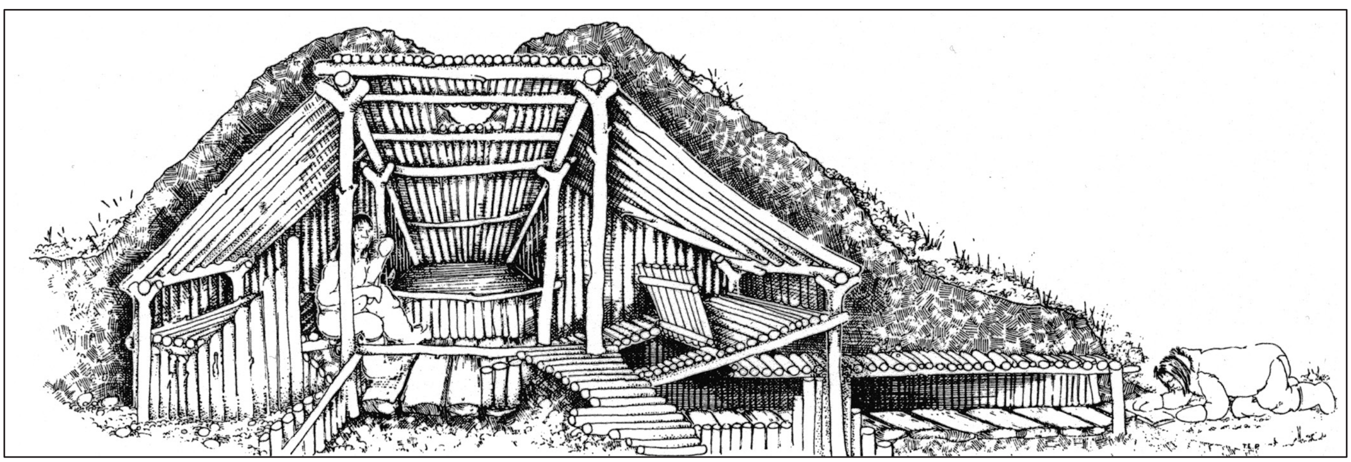

Figure 1. Artist's reconstruction of a Mackenzie Inuit house (by Terrence Pamplin, Prince of Wales Northern Heritage Centre).

would have the entry through a long passage, leading to a trap door in the floor" (Charles Whittaker, cited by Friesen 2004:229).

As mentioned previously, ethnographic descriptions portray Inuvialuit architecture as relatively homogeneous, emphasizing the cruciform house over all other variations. However, Petitot (1876), Whittaker (1937), Stringer (n.d), and Richardson (1828) all to acknowledge that while three-alcove houses were the norm, single- and double-platform dwellings were also constructed. Interestingly, it is in the archaeological record that significant variability begins to emerge, particularly in the number of alcoves observed, but also in other aspects of design and construction (Arnold 1994b; Friesen 1991, 1994; Friesen and Hunston 1994; McGhee 1988; Yorga 1980). In terms of house size, Arnold (1994a) has identified a developmental sequence for the East Channel with single-platform dwellings at Cache Point gradually being replaced by two-alcove structures at Pond and triple-platform dwellings at Gupuk. The number of platforms also seems to vary spatially, with cruciform-shaped houses dominating the major East Channel sites of Kuukpak and Kitigaaryuit, while this form becomes popular only during the nineteenth century at Nuvugak and the Anderson River sites. To the west on the Yukon North Slope and Herschel Island, only single- and double-alcove structures have been identified to date (Friesen 2006).

Arnold (1989:50) suggests that the cruciform design may have been adopted to improve structure efficiency, particularly in terms of sharing heat, light, and food. Friesen (1999), on the other hand, envisions the adoption of the three-alcove dwelling in the densely populated East Channel as a social strategy designed to reduce scalar stress generated by the structure of the resource, namely the spatial and temporal availability of beluga whales. He sees the efficient exploitation of beluga whales and subsequent participation in lucrative trade with the Hudson Bay Company post at Fort McPherson as contributing to the rise of large households in this area (Friesen 2006:183–184). In the nineteenth century, some powerful and ambitious lineage heads or *umialiit* of groups located east of the Mackenzie Delta adopted the cruciform-style dwelling to emulate their powerful neighbors in the East Channel. Alternatively, individuals with direct contacts to families in the East Channel may simply have decided to build cruciform houses at Nuvugak and in the Anderson River area using a familiar design (Friesen 2006:184).

The developmental sequence defined by Arnold (1994a) was based on samples of four excavated structures from Cache Point, five from Gupuk, but only two from Pond. Not only was the sample from the Pond site small, but chronological controls were somewhat limited. During the summer of 2003, one unexcavated structure at the Pond site was subjected to ground-penetrating radar in an attempt to identify the suitability of this remote-sensing technique in arctic environments and to explore the subsurface configuration of these semisubterranean features. During the summer of 2007, funding provided by the European Science Foundation and the Social Sciences and Humanities Research Council of Canada allowed us to return to the Pond site to conduct further excavations. The feature selected for investigation was the structure (House 3) previously examined by ground-penetrating radar, but we were also able to sample a second semisubterranean structure (House 4) nearby. Although our primary objective was to establish the number of alcoves present on individual structures and the date of site occupation at the Pond site, we were also interested in the architectural variability because the ethnographic and archaeological descriptions were difficult to reconcile in our virtual reconstructions of these winter houses. In particular, the floor plans and photographs compiled during excavations in the Mackenzie Delta were difficult to incorporate in the virtual representations of these structures. As a result, an additional goal of the project was to explore the suitability of laser scanning as a tool to document and analyze Mackenzie Inuit architecture as well as to explore the organization of interior domestic space. Documenting the architecture of an excavated dwelling digitally in high definition would allow us to construct an "as built" model of the house using 3D computer modeling software. This model would then serve as a virtual laboratory for testing different construction scenarios and analyzing activity areas in a three-dimensional context.

THE POND SITE (NITS-2)

Although high-resolution data could benefit the investigation of architectural variability and its relationship to social processes, the feasibility of using this technology to scan large semisubterranean features in the Canadian Arctic was untested, especially given the logistical and environmental challenges of transporting and operating scanners in a remote field setting. In order to assess the potential of this technology, we decided to laser scan a single Mackenzie Inuit dwelling at the Pond site (NiTs-2). The site is located on the west shore of Richards Island at 69° 20.6'N and 134° 03.3'W, approximately 3 km south of Kuukpak, which is remembered in oral histories as the main village of a regional group known as the Kuukpangmiut. The Pond site is adjacent to, and takes its name from, a creek-fed pond that flows into Kugmallit Bay near the mouth of the east channel of the Mackenzie River (Fig. 2). Several clusters of shallow depressions are visible on the surface, and bone can be seen eroding from the banks of the pond. Evidence from archaeology and Inuvialuit oral histories indicates that the shores of Kugmallit Bay were occupied since about AD 1300 by several regional groups of ancestral Inuvialuit.

The Prince of Wales Northern Heritage Centre carried out excavations at Kuukpak over the course of several field seasons in the 1980s. The remains of several semisubterranean driftwood and sod houses (*igluyuaruit* in Inuvialuktun) were excavated, ranging in age from approximately 500 to 300 years BP. With one exception, these houses had alcoves with raised sleeping platforms along three sides and a long tunnel entering into the dwelling at the fourth side. The Prince of Wales Northern Heritage Centre conducted excavations at two of the house depressions at the Pond site in 1989. The excavations revealed that both were the remains of fairly substantial driftwood and sod houses, but unlike the Kuupuk cruciform houses, the Pond structures appeared to have only two sleeping alcoves. Radiocarbon dates showed that the structures excavated in 1989 were approximately 600 years old, and therefore built about a century before the dated houses at Kuukpak. An interpretation advanced at the time postulated that the Pond site was abandoned sometime after 600 years ago, when a build-up of the foreshore flats that today separate the site from Kugmallit Bay interfered with hunting beluga whales in this area. As a result, the people are assumed to have abandoned this area and moved downstream to establish their winter houses at Kuukpak.

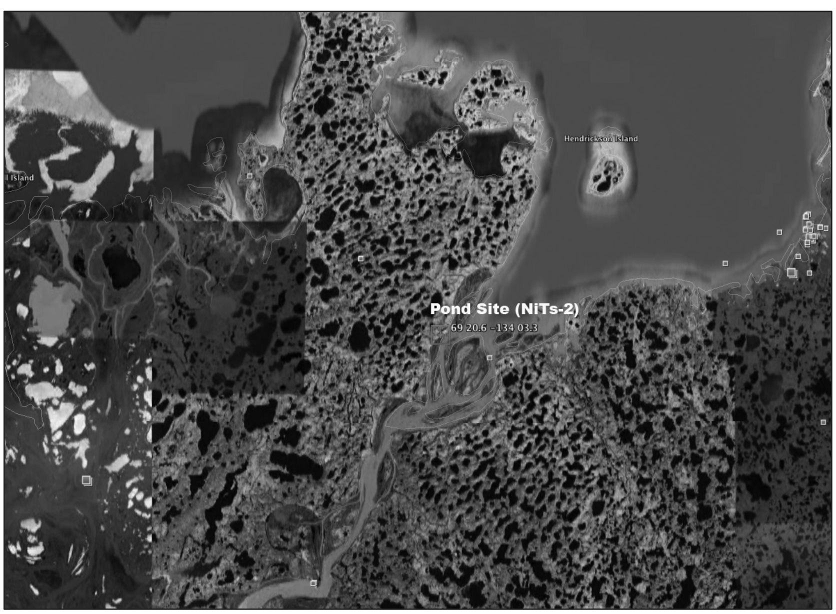

Figure 2. Map showing location of the Pond site (NiTs-2).

METHODOLOGY

1. LASER SCANNER SELECTION: IMPACT ON OPERATION

A single high-resolution, triangulating scanner (Minolta VIVID 710) was used to record the architectural remains of the two house features at the Pond site. Ideally, two scanners would have been chosen: one to quickly scan the area multiple times and the other to only scan detail as it emerged during the excavation. If two scanners had been selected, decisions would have had to be made on site concerning what was significant enough to dictate the use of the higher resolution scanner. One advantage of the VIVID 710 is that it guaranteed that the data captured of the entire excavation would be at a high resolution (0.3 mm). The advantage of having high-level detail of the entire site is that the significance of a particular area does not have to be determined on site, thus avoiding the problem of later discovering that data is missing for an area of interest.

The Minolta VIVID 710 is good for close-range work and scans fairly quickly. It is possible to scan an area approximately 30 cm by 30 cm at a distance of 2.4 m from the unit in a few seconds. However, given that the field of view for the Minolta is between 1.2 and 2.4 m, depending on the choice of lens, additional time should be reserved for scanning. Because significant overlap is needed for the registration of images, a meter square can require up to twenty-five scans. Furthermore, issues of occlusion may require considerably more scans in order to acquire faces of objects not visible from a single vantage point. Each scan can constitute several hundred thousand points and can be stored as a three to six megabyte text file. An area of a meter square can take several hours for data capture. This includes moving and setting up the equipment, refocusing, and moving any tarps needed to shield the area from direct sunlight.

Capturing color always presents significant issues during data acquisition. Under direct sunlight detail can be lost, especially when the materials are highly reflective. One solution is to use controlled artificial lighting. In a lab environment this can be accomplished fairly easily. In the field, shielding the site from direct light requires the use of tarps, tents, or temporary structures. One alternative is to set up a camera on a bipod that can be used to photograph a high-resolution digital image from overhead. Registration of the digital image with the 3D data can occur during post-processing. To assist in this registration, 3D targets should be used on the site. Small spheres placed on a grid can greatly assist in the registration of each scan using software designed to align and optimize 3D data sets.

2. LOGISTICS OF LASER SCANNING

As part of the logistical planning for this project, all equipment was moved by commercial airlines and helicopter to the site. The equipment included a laptop computer, the Minolta VIVID 710 laser scanner (weight 11.3 kg) in its protected Pelican box (model no. 1550, weight 6.1 kg), a Manfreto model tripod (weight approx. 11.3 kg), a daylight fluorescent light, tarps, targets, generator, and two uninterrupted power supplies (UPS). The advantage of the UPS units is that they provide clean, reliable power for the scanner. While one UPS is powering the scanner, the generator can recharge the other, thereby offering continuous scanning throughout the day. In addition to providing power to the scanner and laptop, a UPS can be used to power the portable daylight fluorescent fixtures. It is recommended that larger units (rated above 1200 va) be used for this type of work, providing power for several hours without any recharging.

3. SCANNING IN THE FIELD

In the field, a grid was first set up over each of the two features (House 3 and House 4) excavated in 2007. Using a Leica TCR301 total station, critical points were measured from an established datum within the site and this grid was used to locate the 2 m x 2 m excavation units and the targets. A Nikon digital camera with wide-angle lens mounted on a bipod was used to photograph the excavation units and to create a photographic montage of the structure. The laser scanning of excavated units in houses 3 and 4 required a total of eight hours to complete. For each house, laser-scanned data were acquired from three locations around each 2 m x 2 m excavation unit (Fig. 3). Even with good coverage achieved by scanning from multiple positions, some holes in the data were inevitable. To minimize potential data loss, several pie-shaped scan spaces were created from each scanner position. Rotating the scanner about 20 to 25 degrees created a new set of scans that later needed to be assembled into a single scan space.

Before the actual data are captured, the unit must be focused. Small adjustments in the focal range have a significant impact on data capture. A change as small as 10 mm can result in a scan with holes. Operators should be prepared to spend a significant portion of time on this basic operation. Scanning bright reflective objects can also be problematic. Hot spots can result in a complete loss of data or a "hole." Soil, especially dry soil, can be extremely reflective. Even soils that are kept damp by spraying water may be too reflective to achieve good results. During the course of this project, the sky was only dark for a few hours. Translucent plastic tarps were used to help shield the site from excessive glare from direct sunlight. A doubled-over blue plastic tarp reduced the light to within the operating levels needed by the Minolta.

Temperature and rain could have presented considerable problems. The Minolta VIVID 710 has an operating temperature of 10° to 40°C and should not be used when the relative humidity is greater than 65%.[2] Fortunately during the course of the scanning, the weather did not create any serious problems. The temperature range was not below freezing nor was there significant rain. However, during periods of strong winds two crew members were required to handle the tarps, taking them away from excavation duties.

The digital data obtained from scanning houses 3 and 4 were stored on 512 MB compact flash cards. Each card can store approximately 150 scans, which can later be downloaded to a card reader or to a PCMCIA card on a PC for backup and analysis. During the course of the project, approximately six hundred scans were saved on

2. http://www.konicaminolta.com/instruments/products/3d/non-contact/vivid710/specifications.html

Figure 3. Using the Minolta laser scanner to capture an image of House 3.

these compact flash cards. These scans were then checked in the field on a PC loaded with Polyworks10,[3] an application designed for assembling and processing the 3D images. It is always advisable to check data for integrity in the field as soon as possible. If holes in the data are found due to issues of occlusion or lighting, additional scans can be completed.

4. PROCESSING 3D IMAGES

Acquiring data in the field is the first step in creating a 3D virtual image of a site. With PC technology it is now possible to assemble large 3D data sets into a single registered image. However, with large data sets, there are still some limitations on the ultimate size of the point cloud that practically can be assembled on today's PC. Working with the Minolta VIVID 710 scanner over the course of several days produced over one hundred million points for both house features. The process for assembly of the data requires that each scan be registered or positioned to within the tolerance of the point accuracy of the scanner. The process is relatively simple in principle, if ultimately time-consuming. In our research, Polyworks Version 10 was used on a Dell Precision 650 Pentium with dual Pentium IV 3.05 Ghz CPUs and a NVIDIA Quadro FX 3000 G card. After the first scan is brought into the workspace, each subsequent scan is opened and registered to the base scan using known targets in both scans as control points. It is helpful if overlap is sufficient to virtually see the same three targets in both scans. When this is not possible, applications like Polyworks can register a set of images by identifying the same points in each scan. For example, the end of a stick or small rock was used to more tightly match the two images. Usually, a minimum of three points will be needed in both images to begin the matching process. Polyworks can merge each image within one standard deviation of point accuracy. Once this step is completed, subsequent images can be registered by repeating this process. Polyworks eliminates points in the overlap region, creating a more efficient 3D representation of the site.

3. http://www.innovmetric.com/Manufacturing/what_overview.asp

With large data sets it is possible to exceed the computational capability of a PC. Rather than assemble scans of the entire site, one strategy is to assemble separate sections. Once each section is complete and optimized they can then brought together as a single model. Ultimately, the question of purpose must be considered in processing a 3D image. Researchers may need as accurate a model as possible for taking measurements, as is required in comparative architectural analysis, or in testing possible construction scenarios. Most imaging processing applications will intelligently remove points where they are not needed and still maintain the integrity of the object. However, for archaeological data requiring a high level of detail throughout the site, this strategy may result in the loss of important features. One solution is to use applications that allow point clouds to be resampled on the fly. This gives access to high-resolution point clouds within the resolution of the screen display without forfeiting detail. High-performance video cards designed for computer-aided design (CAD) will permit the greatest access to these larger data sets.

Once the point cloud is registered, a mesh can be created for all or part of the feature. This surface can consist of a triangulated irregular network (TIN) of connected points. In Polyworks, as in most image-processing applications, this mesh is optimized and reduced in complexity for viewing the data set in 3D. One limiting factor we found in creating optimized mesh files for houses 3 and 4 was the number of individual objects located within individual excavation units. These features include small pebbles, rocks, and the texture of the wood, with its open grain and cracks. Preserving all the objects sets a lower boundary on how many polyfaces can be removed during the process of optimization. Another factor in optimization is the number of small holes that exist in the assembled data set, due to the occlusion of objects by other objects. This can result in noncontinuous mesh files, increasing the complexity of the form. In this work it was possible to produce a file for House 4 that consisted of approximately 200,000 polyfaces that could serve as an armature for texture mapping. Texture mapping can add a realistic impression to the site, making building materials such as rock and wood appear true to form. Using digital images from a Nikon SLR taken in normal daylight offered a more realistic model when compared with the color data from the laser scanner. Because a blue tarp was used to shield light from the site, color data capture with the Minolta had a bluish-purple hue.

RESULTS

Fig. 4 is a photo composite of all units excavated in House 3 during the 2007 field season. Areas shaded within the excavated area highlight some of the architectural details scanned using the Minolta VIVID scanner. The laser scans of units D and E are presented as examples of the processed images. It is worth mentioning that the architecture of House 3 was somewhat anomalous, as compared with other features previously excavated at the Pond site. Much of the roof frame, for example, appeared to be absent. While a few logs were found adjacent to the edges of alcoves and on the central floor space, the intact floor was missing from the dwelling. We surmised that House 3 contained two alcoves or sleeping platforms and a possible cooking area, identified as a hearth, in the central room. The absence of substantial driftwood architecture, usually common in Mackenzie house depressions, is difficult to explain. It may have been removed at some point following the abandonment of the house. Alternatively, House 3 may have been some sort of hybrid structure, more lightly constructed than a typical semisubterranean house, perhaps for use during warmer months. Ongoing analysis of faunal remains recovered from House 3 may provide seasonality indicators that will allow us to confirm this possibility.

Even though many of the excavation units scanned contained only minimal amounts of architectural information, the resulting images clearly demonstrate the potential of laser scanning to capture details that might be overlooked when relying on simple two-dimensional line drawings. By way of illustration, Unit D (Fig. 5) captures a large cluster of broken pottery with associated faunal material. One can see the orientation and superpositioning of the different sherds as well as the horizontal and vertical relationship of the vertebra to the central cluster of ceramic sherds. Further, the scanned images of individual units can, unlike 2D line drawings, be rotated 360 degrees along the x, y, or z axis, allowing the researcher to reorient and zoom in and out of areas of interest (Fig. 6). Similarly, the highly detailed 3D image of Unit E captures the spatial relationships of the driftwood, faunal remains, and rock relative to the edge of the entrance tunnel (Fig. 7). Unlike House 3, our test excavation of adjacent House 4 did reveal a classic Mackenzie Inuit log floor in an excellent state of preservation. Fig. 8, the scanned 3D image of this unit,

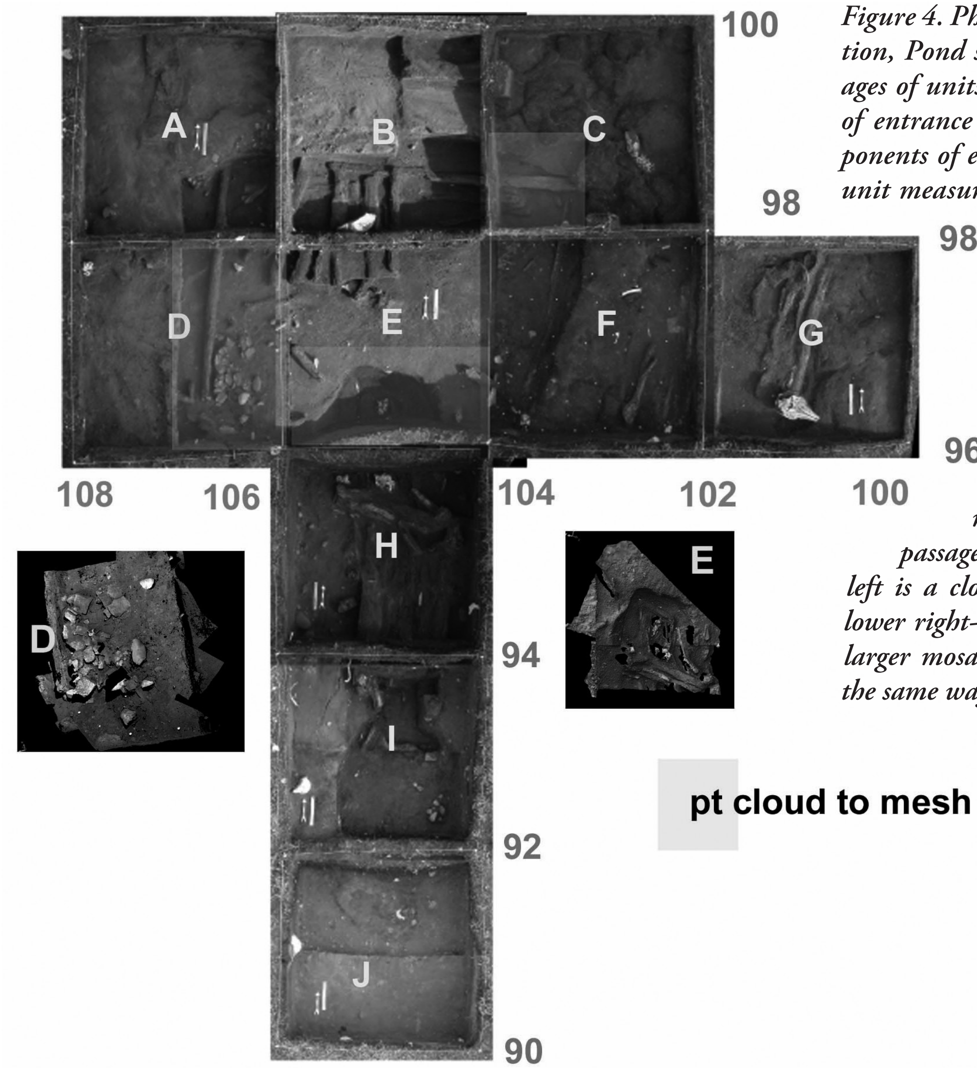

Figure 4. Photo composite of House 3 excavation, Pond site. Processed laser-scanned images of units D and E, shown on either side of entrance passage, illustrate specific components of each unit in greater detail. Each unit measures 2 m x 2 m and the long axis of the image is oriented north to south.

The laser scanned image on the right shows details of the entrance tunnel located in the bottom center of unit E. It is oriented the same way but shows materials uncovered near the bottom of the entrance passage. The laser-scanned image on the left is a close-up of potsherds found in the lower right-hand quadrant of unit D in the larger mosaic. Again, the image is oriented the same way.

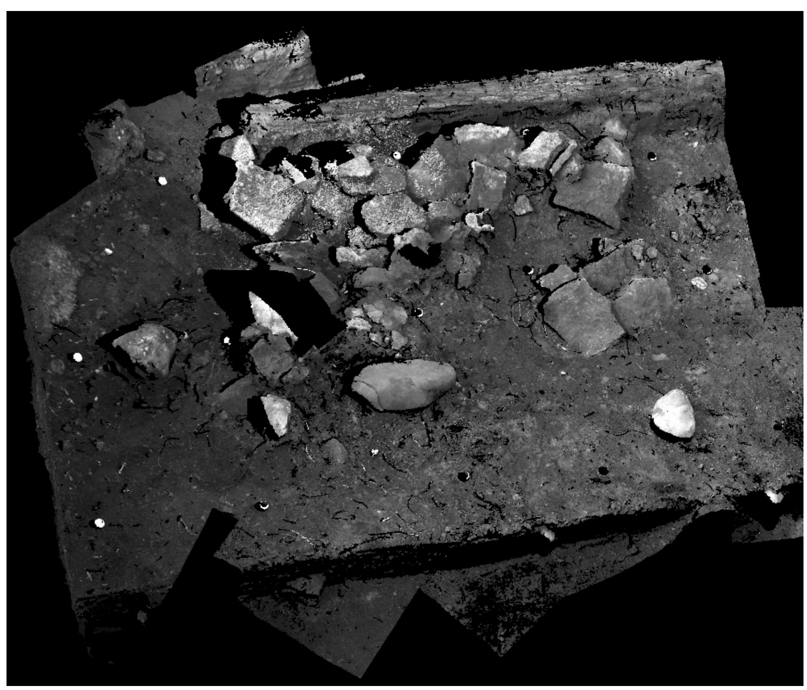

Figure 5. Scanned image of pottery cluster in unit D (see Fig. 6). Long axis is approximately 1 m.

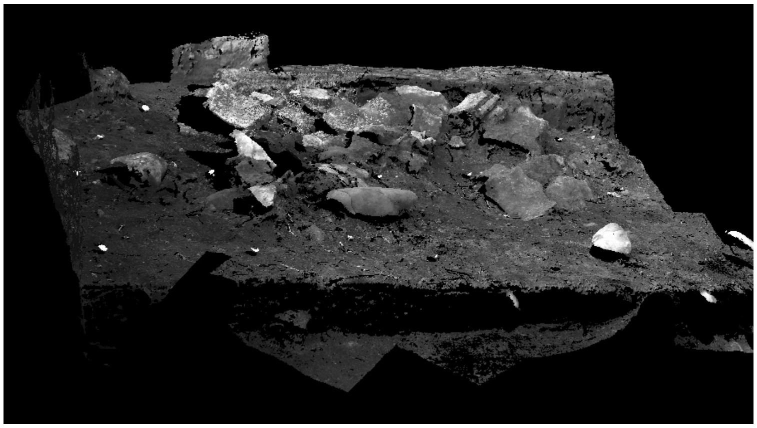

Figure 6. Rotation of 3D image in Fig. 5.

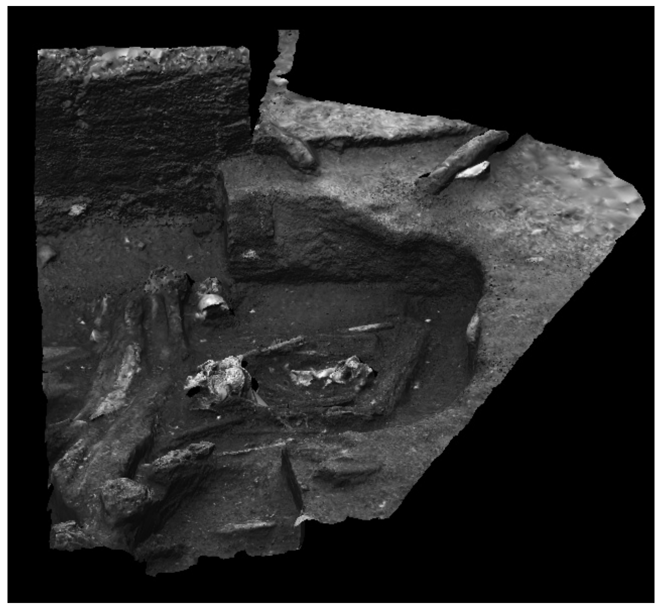

Figure 7. Scanned image of unit E, showing architectural details.

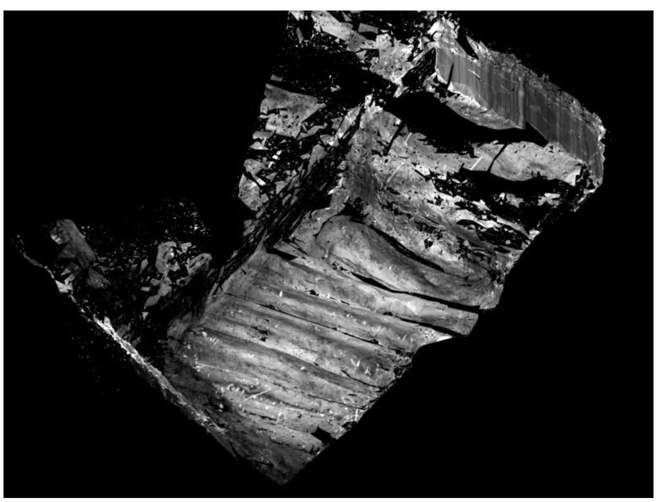

Figure 8. Scan of test unit in House 4, capturing the log floor.

nicely illustrates the ability of the scanner to capture significant architectural details when more substantial wooden pieces are present.

Given the unusual nature of House 3, the greater amount of architectural information obtained by the laser scanner may provide us with more insights into how this dwelling was constructed and used. These data will eventually form the basis for a 3D computer reconstruction. Reverse engineering once-standing structures from archaeological data is often challenging, and we have found such models useful in testing various construction and design scenarios. Furthermore, 3D models constructed from laser-scanned data can be used to examine the organization of domestic space (Levy et al. 2009). The recent construction of computer models of an Inuvialuit sod house and a Thule whale bone house has proven extremely valuable in analyzing design and building processes, visualizing interior space, and forming hypotheses about the organization of domestic space (see Dawson and Levy 2006; Levy et al. 2004 for some examples). Such models can also be used to develop products, such as interactive web pages and games, which both educate and excite public interest in archaeology.

CONCLUSIONS

In the past, arctic archaeologists have relied primarily on two-dimensional line drawings and photographs to document the preserved remnants of Mackenzie Inuit architecture. The floor plans of each successive layer are often drawn and photographed, thus compiling a record of the architectural components exposed during the course of an excavation. Unfortunately, the quality and accuracy of the drawings are highly variable, ranging from simple sketch maps to detailed plan views in which architectural features, such as floor boards and posts, are recorded using a system of Cartesian coordinates (x, y, z). We have found that laser scanning constitutes a more efficient and more accurate approach to the collection, interpretation and presentation of preserved architectural data in the Mackenzie Delta region.

Because we are still assembling the scans made of houses 3 and 4, processed images of several scanned 2 m x 2 m excavation units have been presented here as "proof of concept." As mentioned previously, one of the advantages of using the laser-scanned image rather than the more commonly used line drawings is that the architecture can be examined in three dimensions, and at a .3 mm level of accuracy. Once back in the lab, the researcher can rotate these images and zoom in and out of areas of interest, using applications such as Quicktime VR. The flexibility of this approach may eventually provide us with greater insights into the unusual architectural attributes of House 3 at the Pond site. After the processing of the House 3 scan images has been completed, for example, we will be able to explore the feature exactly as it appeared in the field. Analyzing architecture in this way might reveal architectural detail that was overlooked in the field, and therefore not recorded in more traditional line drawings of the feature.

Another purpose of this paper has been to outline our experiences using a laser scanner to record Mackenzie Inuit architecture at the Pond site. Our results illustrate that laser scanning can be used to successfully capture architectural data from remote sites at high levels of resolution. Though issues of logistics will always present challenges, laser scanners are able to withstand the jolts and shaking of travel when placed in G-force cases. Once on site, it is possible with UPS and generators to operate in the Arctic during the summer months. Having two scanners, one for general site description and one for scanning artifacts and details, would have made data collection and processing quicker. However, it was possible with a single higher resolution scanner to capture a detailed 3D image of an archaeological excavation. In conducting this research, however, several lessons were learned.

We had only recently acquired the Minolta VIVID 710 prior to its use in the field. Greater experimentation with the use of targets would have simplified the assembly of the final data set. In our work we used small glass spheres placed on a grid of approximately 20 cm. Unfortunately, the spheres were too reflective, leaving a hot hole in the data. In the future, these small spheres will be coated with a nonreflective paint. Also, if the spheres had been painted several different colors, their identification during data processing would have been easier. Furthermore, given the need to reduce the direct light over the entire feature, a portable shelter could easily be transported to the site. These portable structures are commercially available and come in sizes from 3.6 to 4.8 m wide and lengths of 6.10 m. Assembled from small sections, they are ideal for transport by helicopter. Made of metal or plastic tubing covered with a plastic-coated fabric, they can be staked to the ground. Commercial versions of this type of shelter can survive extreme conditions and create an enclosed space where equipment is safe from dust, rain, and snow. Having such a shelter at the Pond site would have made it possible to create the necessary controlled lighting conditions, thereby optimizing data capture. Using an array of daylight fluorescent lights would result in better color and fewer shadows and hot spots. Although it would add at least four to six hours in setup, use of these portable shelters would save time in the long run and would guarantee better data capture.

In conclusion, having demonstrated that laser scanning is feasible and of benefit in recording archaeological sites in remote areas, the time is ripe to explore how this technology can be used to document cultural heritage sites in areas of the North American Arctic currently threatened by erosion and human interaction through development. Outside of northern Canada, laser scanners could be used to record petroglyths, geoglyphs, medicine wheels, as well as the remains of a variety of precontact and historic structures. The expense of laser scanning, coupled with the technical expertise required to process the images once captured, mean that this approach is likely not suited for every project. However, as the technology advances, costs will likely come down and image processing will become more automated.

REFERENCES

Arnold, C. D.
1989 Vanishing Villages of the Past: Rescue Archaeology in the Mackenzie Delta. *The Northern Review* 1:40–58.
1994a The Importance of Wood in the Early Thule Culture of the Western Canadian Arctic. In *Threads of Arctic Prehistory: Papers in Honour of William E. Taylor, Jr.*, edited by David Morrison and Jean-Luc Pilon, pp. 269–279. *Archaeological Survey of Canada Mercury Series* Paper 149. Canadian Museum of Civilization, Hull, QB.
1994b Archaeological Investigations on Richards Island. In *Bridges Across Time: The NOGAP Archaeological Project*, edited by Jean-Luc Pilon, pp. 85–93. *Canadian Archaeological Association Occasional Paper* 2. Canadian Museum of Civilization, Hull, QB.

Arnold, C. D., and E. Hart
1992 The Mackenzie Inuit Winter House. *Arctic* 45:199–200.

Barnett, T., A. Chalmers, M. Díaz-Andreu, G. Ellis, P. Longhurst, K. Sharpe, and I. Trinks
2005 3D Laser Scanning for Recording and Monitoring Rock Art Erosion. *International Newsletter on Rock Art* (INORA) 41:25–29.

Blais, F., M. Picard, and G. Godin
2004 Accurate 3D Acquisition of Freely Moving Objects. Paper presented at the Second International Symposium on 3D Data Processing, Visualization and Transmission, Thessaloniki, Greece. September 6–9, 2004.

Blais, F., J. Taylor, L. Cournoyer, M. Picard, L. Borgeat, G. Godin, J. A. Beraldin, M. Rioux, and C. Lahanier
2008 Ultra High-Resolution 3D Laser Color Imaging of Paintings: The Mona Lisa by Leonardo da Vinci. In *Lasers in the Conservation of Artworks: Proceedings of the International Conference LACONA VII, Madrid, Spain,* edited by M. Castillejo, pp. 435-440. CRC Press, Leiden. National Research Council Canada #49854, Madrid, Spain.

Boehler, W., M. Bordas, and A. Marbs
2003 Investigating Laser Scanner Accuracy. Proc. CIPA XIXth Int. Symposium, pp. 696–702, 30 Sept.–4 Oct., Antalya, Turkey.

Cain, K., and P. Martinez
2004 Multiple Realities: Video Projection in the Tomb of Ramsses. In *Beyond GIS: Mindscapes, VR and Cultural Landscapes*, edited by M. Forte, pp. 1–14. University of California, Berkeley.

Dawson, P., and R. Levy
2006 Constructing a 3D Computer Model of a Thule Whalebone House Using Laser Scanning Technology. *Journal of Field Archaeology* 30(2005):443–455.

Dawson, P., R. M. Levy, D. Gardner, and M. Walls
2007 Simulating the Behaviour of Light Inside Arctic Dwellings: Implications for Assessing the Role of Vision in Task Performance. *World Archaeology* 39(1):17–35.

Díaz-Andreu, M., C. Brooke, M. Rainsbury, and N. Rosser
2006 The Spiral that Vanished: The Application of Non-Contact Recording Techniques to an Elusive Rock Art Motif at Castlerigg Stone Circle in Cumbria. *Journal of Archaeological Science* 33:1580–1587.

El-Hakim, S. F., J. A. Beraldin, L. Gonzo, E. Whiting, M. Jemtrud, and V. Valzano
2005 Hierarchical 3D Reconstruction Approach for Documenting Complex Heritage Sites. In the XX

CIPA International Symposium. NRC 48229, September 26–October 1, 2005. Torino, Italy.

Finat, J., J. Fernandez-Martin, J. Martnez, L. Fuentes, and J. I. Sanjose
2005 Some Experiences in 3D Laser Scanning for Assisting Restoration and Evaluating Damage in Cultural Heritage. Paper presented at the Lasers in the Conservation of Artworks LACONA VI Proceedings, Vienna, Austria, Sept. 21–25, 2005.

Finat, J., M. A. Iglesia Santamaría, J. Martínez Rubio, J. J. Fernández Martín, L. Giuntini, I. San José Alonso, and A. Tapias
2005 The Roman Theatre of Clvnia: Hybrid Strategies for Applying Virtual Reality on Laser Scanning 3D Files. Paper presented at the Proceedings of the ISPRS Working Group V/4 Workshop 3D-ARCH 2005, Mestre-Venice, Italy, August 22–24, 2005.

Franklin, J.
1828 *Narrative of a Second Expedition to the Shores of the Polar Sea in the Years 1825, 1826, and 1827*. J. Murray, London.

Friesen, T. M.
1991 Qikiqtaruuk 1990: Archaeological Investigations on Herschel Island, Yukon Territory. North Coast Heritage Research and Protection Project, Heritage Branch, Government of Yukon, Whitehorse.
1994 The Qikiqtaruk Archaeology Project 1990–92: Preliminary Results of Archaeological Investigations on Herschel Island, Northern Yukon Territory. In *Bridges Across Time: The NOGAP Archaeological Project*, edited by Jean-Luc Pilon, pp. 61–83. *Canadian Archaeological Association Occasional Paper* 2. Canadian Archaeological Association, Victoria.
1999 Resource Structure, Scalar Stress, and the Development of Inuit Social Organization. *World Archaeology* 31(1):21–37.
2004 Kitigaaryuit: A Portrait of Mackenzie Inuit Life in the 1890s, based on the Journals of Isaac O. Stringer. *Arctic Anthropology* 41(2):222–237.
2006 Architectural Variability in the Mackenzie Delta Region: The Role of Social Factors. In *Dynamics of Northern Societies*, edited by Jette Arneborg and Bjarne Grønnow, pp. 177–186. National Museum of Denmark, Copenhagen.

Friesen, T. M., and J. R. Hunston
1994 Washout—The Final Chapter: 1985–1986 NOGAP Salvage Excavations on Herschel Island. In *Bridges Across Time: The NOGAP Archaeological Project*, edited by Jean-Luc Pilon, pp. 39–60. *Canadian Archaeological Association Occasional Paper* 2. Canadian Archaeological Association, Victoria.

Giuffrida, A., M. Liuzzo, C. Santagati, and S. Andreozzi
2005 The Laser Scanner for Archaeological Survey: Le Terme Dell Indirizzo in Catania. In CIPA 2005 XX International Symposium, 26 September–1 October 2005, Torino, Italy. http://cipa.icomos.org/fileadmin/papers/Torino2005/316.pdf.

Guidi, G., L. Micoli, M. Russo, B. Frischer, M. De Simone, A. Spinetti, and L. Carosso
2005 3D Digitization of a Large Model of Imperial Rome. Paper presented at the Fifth International Conference on 3-D Digital Imaging and Modeling, Ottawa.

Johansson, M.
2002 Explorations into the Behaviour of Three Different High-Resolution Ground-Based Laser Scanners in the Built Environment. In *Proceedings of the CIPA WG 6 International Workshop on Scanning for Cultural Heritage Recording*, edited by W. Boehler.

Koller, D., M. Turitzin, M. Levoy, M. Tarini, G. Croccia, P. Cignoni, and R. Scopigno
2004 Protected Interactive 3D Graphics via Remote Rendering. In *SIGGRAPH Conference Proceedings*, pp. 695–703. Association for Computing Machinery, New York.

Kumar, S., D. Snyder, D. Duncan, J. Cohen, and J. Cooper
2003 Digital Preservation of Ancient Cuneiform Tablets Using 3D Scanning. *3DIM* 2003:326–333.

Lambersa, K., H. Eisenbeiss, M. Sauerbier, D. Kupferschmidt, T. Gaisecker, S. Sotoodeh, and T. Hanusch
2007 Combining Photogrammetry and Laser Scanning for the Recording and Modelling of the Late Intermediate Period Site of Pinchango Alto, Palpa, Peru. *Journal of Archaeological Science* 34(10):1702–1712.

Lee, M., and G. Reinhardt
2003 *Eskimo Architecture: Dwelling and Structure in the Early Historic Period*. University of Alaska Press, Fairbanks.

Levoy, M., K. Pulli, B. Curless, S. Rusinkiewicz, D. Koller, L. Pereira, M. Ginzton, S. Anderson, J. Davis, J. Ginsberg, and J. Shade
2000 The Digital Michelangelo Project: 3D Scanning of Large Statues. In *SIGGRAPH Conference*

Proceedings, pp. 133–144. Association for Computing Machinery, New York.

Levy, R. M., and P. Dawson
2009 Using Finite Element Methods to Analyze Ancient Architecture: An Example from the North American Arctic. *Journal of Archaeological Science* 36(10):2298–2307.

Levy, R. M., P. Dawson, and C. Arnold
2004 Reconstructing Traditional Inuit House Forms Using Three Dimensional Interactive Computer Modeling. *Visual Studies* 19(1):26–35.

Levy, R. M, Dawson, P. Dickson, B. Mackay, G. Arnold, C. and G. Oetelaar
2009 The Third Dimension of Place: Representations of Activities in Inuvialuit Homes. Paper presented at the 42nd Annual Chacmool Conference: Identity Crisis: Archaeology and Problems of Social Identity. University of Calgary. November 13–15, 2009.

Malinverni, E. S., G. Fangi, and G. Gagliardini
2003 Multi-Resolution 3D Model by Laser Data. Paper presented at the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 5/W12. DARDUS Università Politecnica delle Marche, Via Brecce Bianche, Ancona, Italy.

Mauss, M.
1906 *Seasonal Variations of the Eskimo: A Study in Social Morphology*. Routledge and Kegan Paul, Boston.

McGhee, R.
1988 Beluga Hunters: An Archaeological Reconstruction of the History and Culture of the Mackenzie Delta Kittegaryumiut. *Archaeological Survey of Canada Mercury Series* 139. Canadian Museum of Civilization, Hull, QB.

Morgan, L. H.
1965 [1881] *Houses and House-Life of the American Aborigines.* University of Chicago Press, Chicago.

Neubauer, W., M. Doneus, N. Studnicka, and J. Riegl
2005 Combined High Resolution Laser Scanning and Photogrammetrical Documentation of The Pyramids at Giza. Proceedings of the CIPA 2005 XX International Symposium, Torino, Italy, Sept. 26–Oct. 1, 2005. http://cipa.icomos.org/fileadmin/papers/Torino2005/470.pdf.

Nuligak
1966 *I, Nuligak*. Simon and Schuster, Toronto.

Patton, A. K., and J. M. Savelle
2006 The Symbolic Dimensions of Whale Bone Use in Thule Winter Dwellings. *Etudes/Inuit/Studies* 30(2):137–151.

Petitot, E.
1876 *Monographie des Esquimaux Tchiglit du Mackenzie et de L'Anderson*. E. Leroux, Paris.

Richardson, J.
1828 Narrative of the Proceedings of the Eastern Detachment of the Expedition. In *Narrative of a Second Expedition to the Shores of the Polar Sea in the years 1825, 1826, and 1827*. J. Murray, London.

Stefansson, V.
1914 The Stefansson-Anderson Arctic Expedition of the American Museum: Preliminary Ethnological Report. In *Anthropological Papers of the American Museum of Natural History* vol. 14, part 1, New York.

Sternberg, S., T. Kersten, I. Jahn, and R. Kinzel
2004 Terrestrial 3D Laser Scanning—Data Acquisition and Object Modelling for Industrial As-Built Documentation and Architectural Applications. Paper presented at the ISPRS TH-17 Laser Scanning Acquisition and Modeling Techniques, XX ISPRS Congress, Istanbul, Turkey, July 12–23, 2004. http://www.isprs.org/congresses/istanbul2004/comm5/papers/183.pdf.

Whittaker, C.
1937 *Arctic Eskimos*. Seeley and Service, London.

Whitridge, P.
2008 Reimagining the Iglu: Modernity and the Challenge of the Eighteenth Century Labrador Inuit Winter House. *Archaeologies* 4(2):288–309.

Yorga, B. W. D.
1980 Washout: A Western Thule Site on Herschel Island, Yukon Territory. *Archaeological Survey of Canada Mercury Series* 98. National Museum of Man, National Museums of Canada, Ottawa.