New Opportunities in Digital Archaeology: The Use of Low-Cost Photogrammetry for 3D Documentation of Archaeological Objects from Banks Island, NWT

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Arts

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NEW OPPORTUNITIES IN DIGITAL ARCHAEOLOGY: THE USE OF LOW-COST PHOTOGRAMMETRY FOR 3D DOCUMENTATION OF ARCHAEOLOGICAL OBJECTS FROM BANKS ISLAND, NWT

(Thesis format: Integrated Article)

by

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Graduate Program in Anthropology

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts

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Abstract

This thesis investigates the use of low-cost three-dimensional (3D) modelling programs (Agisoft Photoscan and 123D Catch) to create and disseminate digital replicas of archaeological features and artifacts in the context of the Ikaahuk Archaeology Project, a community-based archaeology project on Banks Island, Northwest Territories. It aims to 1) assess the benefits and challenges of low-cost photogrammetry for in-situ documentation of hunter-gatherer archaeological features; 2) determine the usefulness of low-cost photogrammetry for replicating small-scale artifacts in comparison to 3D scanning methods; and 3) explore how Internet media can be used to disseminate 3D models. This thesis demonstrates that low-cost methods of 3D modelling are sufficiently able to replicate many types of archaeological objects, and are accessible due to their low cost, ease of use, and compatibility with online dissemination. As a result low-cost 3D modelling has a promising future in archaeological documentation, conservation, and engagement with non-specialist audiences.

Keywords

3D modelling, photogrammetry, Arctic archaeology, community archaeology, digital archaeology
Acknowledgments

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Table of Contents

Abstract ........................................................................................................................................ ii

Acknowledgments .................................................................................................................. iii

Table of Contents ................................................................................................................ iv

List of Tables ........................................................................................................................ vii

List of Figures ....................................................................................................................... viii

1 Chapter 1: Introduction .................................................................................................... 1
   1.1.1 3D Modelling in Archaeology ............................................................................. 2
   1.1.2 3D Modelling Technologies ............................................................................. 2
   1.1.3 Applications of 3D Modelling in Archaeology ............................................... 4
   1.1.4 Public and Community Engagement in Archaeology through 3D Models .... 6
   1.1.5 Banks Island Archaeology ............................................................................... 11
   1.1.6 Geographic Context ....................................................................................... 11
   1.1.7 Archaeological Context ................................................................................ 12
   1.1.8 Ikaahuk Archaeology Project ........................................................................ 14
   1.1.9 Thesis Objectives .......................................................................................... 15
   1.1.10 Thesis Materials ........................................................................................... 15
   1.1.11 Sample 1: In-situ Archaeological Features from Field Investigations..... 15
   1.1.12 Sample 2: Museum Artifacts from the Prince of Wales Northern Heritage Centre .......................................................... 18
   1.1.13 Online Dissemination ................................................................................... 20
   1.1.14 Thesis Organization ..................................................................................... 21
   1.2 References ................................................................................................................ 22

2 Applications of Low-Cost Photogrammetry to Replicate and Disseminate Archaeological Features īn-situ on Banks Island, NWT ......................................................... 32
   2.1.1 Background Information ............................................................................... 33
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.2</td>
<td>3D Modelling in Archaeology</td>
</tr>
<tr>
<td>2.1.3</td>
<td>Problems in Archaeological Applications of Photogrammetry</td>
</tr>
<tr>
<td>2.1.4</td>
<td>Materials and Methods</td>
</tr>
<tr>
<td>2.1.5</td>
<td>Ikaahuk Archaeology Project</td>
</tr>
<tr>
<td>2.1.6</td>
<td>Archaeological Features Recorded</td>
</tr>
<tr>
<td>2.1.7</td>
<td>Photographic Recording</td>
</tr>
<tr>
<td>2.1.8</td>
<td>3D Model Generation</td>
</tr>
<tr>
<td>2.1.9</td>
<td>Online Dissemination</td>
</tr>
<tr>
<td>2.1.10</td>
<td>Results</td>
</tr>
<tr>
<td>2.1.11</td>
<td>Photoscan and 123D Catch in in-situ Field Recording</td>
</tr>
<tr>
<td>2.1.12</td>
<td>Photogrammetry for Recording Hunter-Gatherer Archaeological Features</td>
</tr>
<tr>
<td>2.1.13</td>
<td>Disseminating 3D Models</td>
</tr>
<tr>
<td>2.1.14</td>
<td>Discussion and Implications for Future Research</td>
</tr>
<tr>
<td>2.1.15</td>
<td>Photogrammetry for in-situ Documentation</td>
</tr>
<tr>
<td>2.1.16</td>
<td>Photogrammetry for Hunter-Gatherer Archaeology</td>
</tr>
<tr>
<td>2.1.17</td>
<td>Disseminating 3D Models with a Community or Public Audience</td>
</tr>
<tr>
<td>2.1.18</td>
<td>Conclusions</td>
</tr>
<tr>
<td>2.1.19</td>
<td>References</td>
</tr>
</tbody>
</table>

3 Comparison of 3D Scanning and Low-Cost Photogrammetry to Replicate Small-Scale Artifacts from Museum Collections

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1</td>
<td>Background Information</td>
</tr>
<tr>
<td>3.1.2</td>
<td>3D Modelling in Archaeology</td>
</tr>
<tr>
<td>3.1.3</td>
<td>3D Modelling in Archaeological Engagement</td>
</tr>
<tr>
<td>3.1.4</td>
<td>3D Models and Social Media</td>
</tr>
<tr>
<td>3.1.5</td>
<td>Materials and Methods</td>
</tr>
<tr>
<td>3.1.6</td>
<td>Digital Replicas and the Ikaahuk Archaeology Project</td>
</tr>
</tbody>
</table>
### 3.1.7 3D Scanning

3.1.8 Photogrammetry

3.1.9 Disseminating 3D Models

3.1.10 Assessing 3D Models and Methods

3.1.11 Results

3.1.12 3D Scanning

3.1.13 Photoscan

3.1.14 123D Catch

3.1.15 Dissemination of 3D Models

3.1.16 Discussion

3.1.17 Advantages and Disadvantages of High- and Low-Cost 3D Replication Methods

3.1.18 Advantages and Disadvantages of Online Dissemination Methods

3.1.19 Implications for Future Research

3.1.20 Digital replicas and Community-Based Archaeology

3.1.21 Conclusion

3.1.22 References

### 4 Conclusion

4.1.1 Objective One

4.1.2 Objective Two

4.1.3 Objective Three

4.1.4 Considerations for Future Research

4.1.5 References

### Appendices

4.1.6 Appendix A: Examples of 3D Models
List of Tables

Table 1: Sites investigated by Ikaahuk Archaeology Project and approximate dates of occupation ............................................................................................................................... 38

Table 2: Comparison of Average Number of Computed Faces of 3D Models Created with Photoscan and 123D Catch at Medium and High Quality Target Levels .............................. 54

Table 3: Comparison of Average Processing Time (Minutes) of Meshes in 3D Models created with Photoscan and 123D Catch at medium and high target quality levels. ............ 55

Table 4: Comparing Average Number of Computed Faces According to Archaeological Feature Type in Models Created in Photoscan and 123D Catch at Medium Target Quality. 58

Table 5: Comparison of the average file size of PDFs and videos generated in Photoscan and 123D Catch, respectively ....................................................................................................... 59

Table 6: Artifacts scanned with 3D3 White Light Scanner. Table compares artifact material, artifact size, scans recorded, and the number of computed faces in original and decimated scans. ....................................................................................................................................... 97

Table 7: Recorded time required to capture data and build 3D models with the 3D3 White Light Scanner, Photoscan, and 123D Catch ........................................................................... 99

Table 8: Artifacts replicated with 3D3 White Light Scanner, Photoscan, and 123D Catch. Table compares artifact material, artifact size, and the number of computed faces for 3D models. ........................................................................................................................................ 100

Table 9: Average file sizes for 3D models in formats used in dissemination (OBJ, PDF, and Video) ............................................................................................................................................... 104
List of Figures

Figure 1: Location of Sachs Harbour and Banks Island. ........................................................ 12

Figure 2: Timeline of Occupation on Banks Island since 4000 BP ........................................ 13

Figure 3: Map showing location of sites on Banks Island where features were photographed. ................................................................................................................................................. 17

Figure 4: Map showing location of archaeological sites where artifacts replicated in this study were recovered. ............................................................................................................. 20

Figure 5: Map showing the location of Sachs Harbour and Banks Island in Canada............ 39

Figure 6: Map showing the locations of study sites: Cape Kellett (OlRr-1), Agvik (OkRn-1), and Seal Camp (OkRn-2) ........................................................................................................ 40

Figure 7: Sod houses from Cape Kellett. Left: House 1. Right: House 3 .............................. 42

Figure 8: Caches from Seal Camp. Left: Cache 5. Right: Cache 21. ..................................... 42

Figure 9: Tent Rings from Seal Camp. Left: Tent Ring 3. Right: Tent Ring 9. ..................... 43

Figure 10: Isolated artifacts. Left: Artifact 1 from Seal Camp. Right: Pottery from Agvik... 44

Figure 11: Photograph in pre-processing with Photoscan. Mask is applied to hide the water, sky, and insects in the photograph. ................................................................. 46

Figure 12: Image showing the 3D model of Cache 5 at the four workflow stages of Photoscan. Top left: sparse point cloud generation after photo alignment. Top right: dense point cloud. Bottom left: 3D surface (mesh). Bottom right: 3D surface with texture. ........... 47

Figure 13: Cache 5 after processing in 123D Catch. Areas with stretched mesh and large holes are still visible along the edges of the 3D model, and can be trimmed before the model is exported. ......................................................................................................................... 49

Figure 14: Ikaahuk Archaeology Facebook Page ................................................................. 51
Figure 15: Average Percent of Photographs Aligned in Photoscan and 123D Catch .......... 53

Figure 16: Textured Meshes of Cache 5. Top left: 123D Catch, medium target quality. Top right: 123D Catch, high target quality. Bottom left: Photoscan, medium target quality. Bottom right: Photoscan high target quality................................................................. 54

Figure 17: Comparison of Average Processing Time (Minutes) and Quality (Computed Faces) of 3D Models created with Photoscan and 123D Catch. Data points are labelled with their respective software program and target quality level.................................................... 56

Figure 18: Average Percent of Photographs Aligned in Photoscan and 123D Catch According to Archaeological Feature Classification ................................................................. 57

Figure 19: Unsuccessful 3D model of sod house (House 3) in Photoscan ....................... 58

Figure 20: PDFs generated at different target qualities for 3D models of Cache 5 generated in Photoscan. Left to right: High quality, high quality with decimated mesh, and medium quality. ...................................................................................................................... 60


Figure 22: 3D Model of a Tent Ring by Tim Rast (2012), created with 123D Catch........... 64

Figure 23: Map showing the location of Sachs Harbour ..................................................... 80

Figure 24: Map showing location of sites included in this study ...................................... 88

Figure 25: Scan of decorated harpoon head (PWNHC 982.50.362). Left: Original Scan. Right: Decimated Scan with Texture.......................................................... 90

Figure 26: Example of BMP image used in texture mapping. Image is the texture map for the decorated harpoon head (PWNHC 982.50.362). ......................................................... 90

Figure 27: Typical method of photographing artifacts for use with photogrammetry. PWNHC 982.50.603..................................................................................................................... 91
Figure 28: Left: Awl (PWNHC 982.50.154). Right: Lure (982.44.003). The geometry of the lure was more complex than the awl, requiring more scans to fully capture it. ......................... 96

Figure 29: The average number of computed faces in 3D models generated by the 3D3 White Light Scanner (original and decimated scans), Photoscan, and 123D Catch. ......................... 101

Figure 30: Awl (PWNHC 982.47.009). Left: 3D3 White Light Scanner. Mesh decimated. Center: Photoscan. Mesh processed at high quality with a dense point cloud. Right: 123D Catch. Mesh generated at Maximum Quality. ................................................................. 102

Figure 31: Kamik (boot; PWNHC 982.50.173). Left: Photoscan. Right: 123D Catch. 109
Chapter 1

1 Chapter 1: Introduction

This thesis investigates the use of low-cost three-dimensional (3D) modelling programs to create and disseminate digital replicas of archaeological features and artifacts in the context of the Ikaahuk Archaeology Project, a community archaeology project on Banks Island, Northwest Territories (NWT). Research over the last two decades has indicated that 3D modelling, or documenting and visualizing archaeological objects digitally in 3D, is valuable in archaeological research, conservation, and presentation to broad audiences as it can create realistic and accurate digital copies of archaeological objects. In the past, 3D modelling technologies were prohibitively expensive and too technologically specialized to be incorporated in most archaeological projects. However, developments in computer science and digital photography in the last ten years have resulted in several low-cost and user-friendly options for 3D modelling using photogrammetry, a technique that builds 3D models using 2D digital photographs of real-world objects. While low-cost photogrammetry has been successfully applied in a limited number of archaeological applications, its potential still remains largely untapped. This thesis will explore three relatively unexplored areas where low-cost photogrammetry could be valuable to archaeologists. It aims to: 1) assess the benefits and challenges of using low-cost photogrammetry for in-situ documentation of typical hunter-gatherer archaeological features; 2) determine the usefulness of low-cost photogrammetry for making 3D replicas of small-scale artifacts in comparison to expensive 3D scanning methods; and 3) explore the ways that social media and other web resources can be used to host and share 3D models. This introductory chapter provides an overview of low-cost photogrammetry and its relationship to archaeology, and further background on Banks Island archaeology and the Ikaahuk Archaeology Project, the case study explored in this thesis.
1.1.1 3D Modelling in Archaeology

1.1.2 3D Modelling Technologies

Digital 3D models are one way that archaeologists digitize, replicate, and represent archaeological objects, including landscapes, sites, features, and artifacts. A 3D model is a mathematical representation of an object, consisting of a triangulated network (“mesh”) or textured digital surface that can be viewed in 3D using specific software or in two-dimensions through a 3D rendering process (Remondino and El-Hakim, 2006).

Archaeology and heritage applications generally favour reality-based 3D modelling techniques, which extract data from the surfaces of real-world objects in order to build meshes, since this method creates 3D models that most closely match the original objects (Remondino and Rizzi, 2010). Improvements in 3D technologies in the last 25 years allow archaeologists to make digital replicas of archaeological objects that are accurate, high-resolution, and quick to produce (De Reu et al., 2014; Dellepiane et al., 2011; Kersten and Lindstaedt, 2012; Scopigno et al., 2011).

Currently there are two main types of 3D modelling techniques that archaeologists use to create digital replicas of sites, features, and artifacts: 3D scanning and photogrammetry. 3D scanning refers to the use of highly specialized equipment that measures and reconstructs the surface of an object using technology based on stereovision, light wave, or sound wave distance measurement (Lerma et al., 2010; Remondino and El-Hakim, 2006; Remondino et al., 2008). 3D scanners collect information in the form of a 'point cloud', or a series of points, which are then used to create a digital “mesh” surface that matches the surface of the original object (Boehler and Marbs, 2004). Alternatively, photogrammetry methods extract information from 2D photographs to reconstruct objects in 3D (Doneus et al., 2011; Lambers et al., 2007; Verhoeven et al., 2012). This technique, also known as image-based 3D modelling, uses structure-from-motion and stereo-reconstruction algorithms to identify and match shared points from overlapping photographs to create point clouds and meshes representing the surface of an object.

Until very recently, 3D technologies were not accessible to many archaeologists. Most 3D techniques required fragile and expensive equipment as well as specialized
knowledge and training to use it (Boehler and Marbs, 2004; Scopigno et al., 2011). Only archaeologists with backgrounds in computer science could personally utilize 3D technology, and very often outside companies were hired, at great expense, to design the software and hardware for a project and then perform the 3D modelling (Fryer, 2007). Currently, archaeologists no longer need to have hardware or software custom-built for their projects, as both are more commonly produced and less expensive than their predecessors (Kersten and Lindstaedt, 2012; Remondino and El-Hakim, 2006; Wurtz, 2011). Nevertheless, 3D scanners and professional photogrammetry software remain relatively expensive and still tend to require specialized training and knowledge to use. Since the mid-2000s, advances in photogrammetry have opened up the technology to a broader user base. A variety of low-cost, free, and open source programs and web services now allow users to create 3D models using digital photographs taken using off-the-shelf digital cameras with no additional specialized equipment. Several of these programs are also partially or fully automated, carrying out the steps of identifying and matching points in photographs, building point clouds and meshes, and applying texture to 3D models with little to no manual input from users. A few archaeologists have already recognized the potential of inexpensive, user-friendly photogrammetry software, and have begun exploring the efficacy of several programs. While as recently as ten years ago photogrammetry did not create content that was as high in detail or quality as that of 3D scanners (Boehler and Marbs, 2004), recently-developed low-cost programs such as Blender (Kersten and Lindstaedt, 2012), Autodesk 123D Catch (previously known as Autodesk Firefly during beta; Brutto and Meli, 2012; Kersten and Lindstaedt, 2012; Nguyen et al., 2012; Santagati et al., 2013), and Agisoft Photoscan (De Reu et al., 2014, 2013, 2013; Doneus et al., 2011; Verhoeven et al., 2012) are steadily improving, and can provide results that are comparable in detail and accuracy to 3D scanning (Doneus et al., 2011; Kersten and Lindstaedt, 2012).

Since low-cost photogrammetry is still relatively new to archaeology, there are several areas where its use remains unexplored. Since different 3D modelling techniques are more or less useful depending on the size, complexity, shape, and texture of the objects that are being scanned, (Kersten and Lindstaedt, 2012; Pavlidis et al., 2007) it is
important to continue testing the use of these technologies on new types of archaeological objects (Nguyen et al., 2012). For example, low-cost photogrammetry has been successfully applied to document historic sites with substantial architectural features such as monuments or temples, stone foundations of buildings, and large, complex excavation pits (De Reu et al., 2014, 2013; Plets et al., 2012; Santagati et al., 2013), but the technology remains unexplored in the context of hunter-gatherer archaeology, where archaeological features are comparatively smaller and less geometrically complex. Similarly, low-cost photogrammetry can document large, complex areas, but few examples use low-cost photogrammetry to make 3D models of small-scale artifacts (Kersten and Lindstaedt, 2012; Nguyen et al., 2012).

1.1.3 Applications of 3D Modelling in Archaeology

Further exploration of different 3D modelling technologies is necessary because of the broad range of contexts where 3D modelling can benefit archaeological research. In archaeological investigations, 3D modelling has been used as a way to document archaeological investigations (Benko et al., 2004; Doneus et al., 2011; Plets et al., 2012), rock art (Chandler et al., 2007; Lerma et al., 2010; Simpson et al., 2004), artifacts and statues, (Dellepiane et al., 2011; Karasik and Smilansky, 2008; Kersten and Lindstaedt, 2012; Scopigno et al., 2011; Stanco et al., 2011), and landscapes (Eisenbeiss et al., 2005; Lambers et al., 2007; Landry et al., 2014). 3D modelling has advantages over traditional 2D means of recording, such as photographs and manual drawings, as it can fully capture the 3D shape and detailed texture of archaeological features (De Reu et al., 2014; Plets et al., 2012). As a recording technique, 3D modelling is also quicker and more accurate than manual drawing (Doneus et al., 2011). In documenting the excavations of a building foundation, De Reu et al. (2014) found that 3D recording allowed them to capture all of the metric information about the site that would have been recorded with traditional documentation methods, but at a quicker pace and with added information about the texture and shape of the objects that would otherwise have been lost during excavation.

Archaeologists have also used 3D modelling as a type of digital conservation of archaeological sites or objects. Archaeological sites in many parts of the world are in danger of destruction from cultural or natural forces, the latter of which are particularly
threatening in areas with extreme climates, such as the circumpolar regions (Barr, 2004; Dawson et al., 2013; Remondino and Rizzi, 2010). 3D technologies have been used in recent years to make copies of threatened archaeological sites or objects before they are further damaged so that future stakeholders will have access to these objects in a digital, if not physical, form. For example, Dawson et al. (2013) used laser scanners to document historic Fort Conger on Ellesmere Island in northern Nunavut, which is a historically important site in danger of destruction from rising sea levels, storms, and coastal erosion related to climate change. While the original Fort Conger remains at risk of destruction, there is now a high-resolution and accurate digital replica that will remain available for study in perpetuity.

In addition, objects that are already partially destroyed can be digitally reconstructed or restored through manipulation of digital replicas in 3D modelling programs (Koller et al., 2010; Stumpfel et al., 2003). This allows archaeologists to create fully-restored replicas without altering or damaging the original objects. With individual artifacts, archaeologists can digitally reassemble broken pieces of artifacts, or create replicas of incomplete artifacts with missing areas restored artificially. Compared to physical restoration, digital restoration has the advantage of being able to quickly create multiple replicas to propose and test multiple hypotheses about the original shape, colour, or materials of missing parts of objects without altering the original form (Dellepiane et al., 2011). For example, Arbace et al. (2013) were able to digitally reconstruct the Madonna of Pietranico, a terracotta statue that was severely damaged in a 2009 earthquake, by 3D scanning the individual pieces of the statue and reassembling them using 3D modelling software. Besides restoring the shape of the object, the team was also able to digitally restore the paint on the surface of the statue that had been damaged both during the earthquake and naturally over time.

Furthermore, 3D modelling can be used to make information from archaeological research more accessible to other scholars and public audiences. In some cases 3D models are created as a way to allow users to have access to distant archaeological sites or artifacts that are difficult and/or expensive to visit in person (Boeheler, 2005; Patias, 2007). For example, the Digital Michelangelo Project at Stanford University created
digital replicas of 10 well-known statues, including the David, and made them available upon application to established scholars in an online database, so that scholars who could not travel to Italy could access the statues in a digital form (Levoy et al., 2000). Similarly, Betts et al. (2011) created the Virtual Zooarchaeology of the Arctic Project, a database of 3D models of skeletons of animals typically found in the Arctic. These 3D models allow zooarchaeologists anywhere in the world to compare their faunal specimens to those in the online collection. Without such digital access, they would have to travel to visit museum or university reference collections in person.

Using 3D models to engage public interest in archaeology is also frequently cited as a priority in applying 3D modelling in archaeology. Within museums, heritage professionals have been utilizing 3D technologies as a way to engage public audiences since at least the 1990s. Some early projects included creating 3D models as a part of online museum exhibitions (Hawkins et al., 2001; Koshizuka and Sakamura, 2000; Rushmeier et al., 2003). These early projects were often designed as augmented reality environments using video gaming engines, where users became active participants in immersive environments (Jones and Christal, 2002; Sylaiou et al., 2009). In more recent years, some museums have created online databases of individual 3D objects for the purposes of public consumption and education. For example, the Smithsonian X 3D project was recently initiated with the goal of digitizing 10% of the 137 million objects in the collections of the Smithsonian museums and research centers (Waibel, 2014). 3D models of objects can be viewed using a web browser, where they can be manipulated through zooming and rotating the object, as well as editing the object's surface properties, taking measurements, and creating cross-sections. High resolution copies of 3D objects can be downloaded for use on personal computers or for physical replication using a 3D printer, and printed copies of 3D files are also available for purchase through the Smithsonian X 3D for educational purposes.

1.1.4 Public and Community Engagement in Archaeology through 3D Models

To date, public engagement using 3D models has largely been carried out within museums, rather than by archaeologists. Despite the participation of many archaeologists
and other heritage professions in 3D modelling throughout the 2000s, technical restrictions and financial costs restricted most from sharing their work online (Koller et al., 2010). With advancements in Internet technologies, there are now more ways for archaeologists to share their 3D models online. For example, most Internet browsers are now compatible with common 3D file formats such as X3D, a standard and royalty-free XML file format that displays computer graphics in browsers (Berndt et al., 2010). Several websites have also been developed that allow users to upload 3D models in a variety of different file formats, which can then be viewed and manipulated or edited online. Some sites, such as 3DVIA (http://www.3dvia.com/), SketchFab (https://sketchfab.com/), and 3Dfile.io (http://3dfile.io/) provide some options for free accounts, whereas others such as Babel3D (https://www.babel3d.com/) require a paid membership. Further, new 3D formats have been developed in order to make 3D files accessible on computers without 3D modelling software. The most common universal file type is the 3D PDF, which embeds 3D models in U3D format and can be used across multiple operating systems and open-source applications. 3D modelling programs are increasingly incorporating features to facilitate the sharing of 3D models, either through the ability to export 3D models in XML, U3D, or PDF format, or through directly uploading versions of 3D models to hosting websites.

Increased opportunities for sharing 3D models online can be particularly beneficial for archaeologists who work with non-specialist groups, especially in the context of community-based research. Community-based archaeology has developed over the last three decades as a diverse set of archaeological themes, methods, and practices based on engagement, communication, and collaboration with local or descendant communities (e.g. Brighton, 2011; Moser et al., 2002; Smith and Waterton, 2009; Tully, 2007). This form of archaeology grew out of the concerns of both the archaeologists who wished to make their research relevant to modern society and the growing dissatisfaction of local and descendant communities who were routinely excluded from heritage management and decision making surrounding archaeological projects (Atalay, 2012; Merriman, 2004).
The theoretical approaches and methods of community-based archaeology projects are diverse, though they share a few common goals and themes. In most instances, these projects aim to collaborate with communities in all aspects of the research, including project planning, developing research questions, obtaining funding, collecting and analyzing data, interpreting data, disseminating results, and curating the data (Atalay, 2012; Moser et al., 2002). Common practices among community-based archaeology projects include training and employing community members in research methods, publicly presenting research, interviewing and recording oral histories, providing educational resources, and making archives accessible to the community (Moser et al., 2002; Smith and Waterton, 2009).

Digital replicas of archaeological sites, features, and artifacts can contribute to several of these goals. First, they can make archaeological sites and artifacts accessible to communities. Access to archaeological objects such as sites and artifacts is valued in community-based archaeology, since these items often hold deep and significant meaning for local, descendant, or Indigenous communities. As the tangible aspects of the archaeological record, artifacts, sites, and places on the landscape are often the means through which people understand and engage with the past (Lyons et al., 2010; Stewart et al., 2004; Tully, 2009) Objects such as artifacts can serve as visual representations of other times, places, stories, and emotions (Lyons, 2013). As identified by Tully (2007, p. 160) in her analysis of community-based archaeology methodologies, heritage objects such as artifacts “not only act as a bridge between past and present but can encourage the retelling of folklore, strengthen notions of identity and revive a pride in community heritage.”

In-person access to archaeological sites or artifacts may be desirable, but is not always attainable in practice. Archaeological sites are sometimes too remote for community members to visit, and artifacts are sometimes inaccessible because they are stored in museums located away from communities. Additionally, in some cases the community with whom an archaeologist collaborates does not live in a single area, but is dispersed among different parts of the world (Atalay, 2012; Singleton and Orser Jr, 2003). Through 3D modelling, archaeologists can create replicas of important objects that can be used by
community members who live anywhere, as they can be made accessible online. For example, González-Tennent (2010) opted to create a digital museum and 3D replica of the archaeological remnants of the town of Rosewood, Florida, a black majority town that was destroyed in a race riot in 1923. He did so because the descendants of Rosewood community members currently live in many parts of North America. A digital access point ensures that their project is accessible without requiring anyone in their main target audience to physically travel to the original site.

In a digital form, 3D models may also be a more engaging way to share information about archaeology with communities in comparison to traditional methods of archaeological dissemination. The audiences for whom archaeologists usually publish their research include archaeologists within the academic community, professional archaeologists with ties to cultural resource management, and various community and public audiences (Atalay, 2012). However, archaeologists in general have not been successful in in their attempts to convey archaeological information to the community and public audiences, as they tend to disseminate their research only in ways that are accessible to their peers (Merriman, 2004). Typical forms of dissemination do not work well in a community-based archaeology project, as communities often do not have access to scientific journals, and scholarly writing is often jargon-filled and difficult for non-specialists to understand (Merrifield, 1993).

Digital representations of archaeology provide a more effective means of disseminating archaeological research to a community or non-specialist audience. Several forms have been used successfully to engage non-specialist audiences, due to their ability to enhance the level of connectedness that users identify with objects (Antoniou and Lepouras, 2009; Chim et al., 2003; Lepours and Vassilakis, 2004; Sylaiou et al., 2009). A greater sense of connectedness with artifacts through digital replicas may help to draw the interest of communities, and even promote the sharing of knowledge between generations within a community. An exhibit created by Dawson et al. (2011) for the Virtual Museum of Canada, for example, consisted of a 3D re-creation of a Thule-Inuit whale-bone house. The 3D model was presented to Paatlimiut Elders as part of a virtual immersive environment by using 3D “theatres” created with Cave Automated Virtual Environments
(CAVEs) and 3D projectors. Dawson et al. (2011) found that some Paatlirmiut Elders preferred the 3D model of the Thule house in comparison to written literature describing it. One Elder responded: ‘It’s hard to imagine something if you’ve never seen it before and something like this makes it so much easier to imagine what life was like in the old days than just reading about it in a book’ (Nunia Qanatsiaq in Dawson et al., 2011, p. 395). Another Elder felt that this reconstruction would be a more effective way to engage youth to learn about traditional lifeways than other forms of learning: ‘A lot of young people don’t seem too interested in learning about the old ways, but I think they would with something like this. It’s a new way for them to learn and that is always valuable’ (Mark Kalluak in Dawson et al., 2011, p. 396).

When shared online, digital replicas also have the potential to promote participation in archaeological interpretation, which is essential to multivocal interpretations of the past. Both social media websites and traditional websites with forums have been noted for their potential to achieve ‘liberation’ or ‘democratization’ of knowledge, where non-archaeologists have the opportunity to alter, manipulate, or create content, and to readily provide their own stories, opinions, and interpretations of archaeological materials (Boast and Biehl, 2011; Brown and Nicholas, 2012; Goskar, 2012; McDavid, 2004). Morgan and Eve (2012), for example, worked towards an open-access form of archaeology through digital media at the Prescott Street excavations, where they used the social media site Flickr (www.flickr.com) to upload all of their site documentation information. Here, anyone interested could view information and also tag photographs and leave comments to share their thoughts, ideas, and stories regarding the history and archaeology of the site. In one example, a user who was otherwise unrelated to the project found a photograph through Flickr and was able to identify the building that was being excavated and share a story about a great-great-grandfather who once lived in it.

Furthermore, the act of creating digital replicas can involve the participation of both archaeologists and community partners. Participation of community members in all stages of archaeological research is one of the most important aspects of community-based archaeology. As such, many projects strive to include local volunteers and employees. While in the past 3D modelling required extensive training and background
knowledge in computer science, modern low-cost photogrammetry is user-friendly enough that it can easily be incorporated into archaeological investigations by crew members without background knowledge in computer science. Specialized equipment is not necessary, as photographs can be taken with regular digital cameras and most smartphones. As a result, archaeologists and community members can work together to create 3D models that are engaging and accessible resources documenting archaeological sites, features, and artifacts for communities. For example, the HeritageTogether project at Bangor University, which aims to document stone monuments in Wales using photogrammetry, uses a crowd-sourcing approach to data collection (Roberts, 2014). As a community-based project, they work directly with community members to collect photographs, and also encourage users to independently take photographs of stone monuments and then upload them to the HeritageTogether website for 3D modelling.

1.1.5 Banks Island Archaeology

1.1.6 Geographic Context

The archaeological features and artifacts documented for this thesis all originated on Banks Island, NWT (Figure 1). It is the westernmost and fourth-largest island in the Canadian Arctic Archipelago, covering 70,028 km$^2$. Sachs Harbour, a hamlet of around 100 people on the south coast, is the only permanent settlement on the island. Most of the island forms the Banks Island Lowland ecoregion of Canada, which is classified as having a mid-arctic ecoclimate, with a mean annual temperature of approximately -16°C and an annual precipitation range of 100-200 mm. Wetlands extend over much of the ecoregion, and marshes are common along the coast and low-lying areas. Wildlife on the island includes muskox, caribou, arctic hare, arctic fox, snowy owl, raptors, polar bear, seal, whale, seabirds, and waterfowl. Vegetation on the island consists of mosses and mixed low-growing herbs and shrubs such as purple saxifrage, *Dryas spp.*, arctic willow, kobresia, sedge, and arctic poppy.
1.1.7 Archaeological Context

Previous archaeological research suggests that Banks Island has been occupied intermittently over the last 4000 years (Figure 2). The Arctic Small Tool Tradition (ASTt; 2500 BC-1500 AD) represents the first human occupation of the Canadian Arctic, and in the Canadian Low Arctic is divided into the Pre-Dorset (2500-500 BC) and Dorset (500 BC-1500 AD) periods. Evidence of ASTt occupation on Banks Island is limited to a few sites. The earliest evidence of occupation comes from a cluster of Pre-Dorset muskox-hunting sites, including the Unimgmak site (PjRa-2), in the northern interior of the island.
near Shoran Lake, which date to about 1800 BC (Hodgetts; 2013a; Schledermann, 1976; Taylor, 1967). The next known occupation falls in a transitional phase between Pre-Dorset and Dorset times, which has several different regional expressions across the Canadian Arctic (Bielawski, 1988; Fitzhugh, 1980, 1972; Knuth, 1967; Maxwell, 1973; McGhee, 1976; Riddle, 2010). In the western Canadian Arctic, Transitional ASTt is known as the Lagoon Complex and dates to about 500 BC (Arnold, 1980; Le Blanc, 1994). The poorly-understood Lagoon Complex is known from only two excavated sites in the Western Canadian Arctic (Arnold, 1980; Le Blanc, 1994) and appears to represent a local development from Pre-Dorset groups influenced by Dorset groups to the east and to a lesser degree Norton Tradition groups from the west. The type site, the Lagoon Site (OjRI-3), on the south coast of Banks Island, has evidence of a mix of coastal and inland resource exploitation. Recently, two additional sites on the north coast of Banks Island have been dated to the Lagoon phase (Cary, 2012; Hodgetts, 2013a). Several other possible ASTt sites on the island remain undated.

Figure 2: Timeline of Occupation on Banks Island since 4000 BP

During the later Thule-Inuit Period, ranging from 1200 AD to European contact, Banks Island appears to have been occupied more frequently and in more areas of the island. The Thule-Inuit are the ancestors of the modern Inuit peoples, who first appeared in the Canadian Arctic around 1200 AD when they migrated eastward from Alaska, eventually reaching as far as Greenland and Labrador (Friesen and Arnold, 2008; Morrison, 2000, 1989; Taylor, 1963; Whitridge, 2001). Banks Island has evidence of some of the earliest Thule-Inuit occupation in Canada, with the Nelson River site on the southern coast of the island dating to about 1250 AD (Arnold, 1986; Friesen and Arnold, 2008), which was likely a winter camp for marine hunting while the Thule-Inuit were migrating east. After the initial migration, the Thule-Inuit continued to occupy at least the southern coast of Banks Island until at least 1600 AD (Hodgetts et al., 2014).
Occupation continued from the Thule-Inuit period into the 19th and 20th centuries in some parts of the island as well. During this period Innuinait (Copper Inuit) groups used the northern interior and east coast to intensively hunt muskox and gather supplies from the *H.M.S. Investigator*, a British ship that was abandoned in Mercy Bay in 1853 (Hickey, 1984, 1979; Hodgetts, 2013a; Morrison, 1987; Toews, 1998; Webster, 1996; Will, 1986). Recent survey suggests that occupation in the northern interior was not limited to the *Investigator* exploitation period, but likely extended from Thule-Inuit times into the 20th century (Hodgetts and Eastaugh, 2009, 2010; Hodgetts, 2013b). Beginning in the 1920s and 1930s several fox trappers arrived on the island, living in various places along the south coast including the modern-day Sachs Harbour (Gray, 1997). In the 1950s several Inuvialuit families from Sachs Harbour and Victoria Island occupied the southeast of the island around DeSalis Bay, hunting polar bear, seals, and other animals (Nagy, 1999). After the 1950s the families living in DeSalis Bay relocated to Sachs Harbour or Uluhaktok on Victoria Island (Nagy, 1999).

1.1.8 Ikaahuk Archaeology Project

This research was carried out as a part of the Ikaahuk Archaeology Project, an ongoing investigation of the human history of Banks Island that is building a collaboration between the University of Western Ontario and the Inuvialuit community of Sachs Harbour. Community members have raised concerns about archaeological research on Banks Island. They feel that researchers from multiple disciplines who work on the island have not effectively shared their results with the local community. They are also concerned that artifacts from local archaeological sites have been removed from the island and are not accessible to people living in Sachs Harbour. We are attempting to address these concerns by creating digital replicas using low-cost 3D modelling methods that can be shared with Sachs Harbour residents online.

Online methods of dissemination through social media were chosen because they are already very popular means of entertainment and communication in Sachs Harbour. Most families have high-speed Internet connections and computers, as well as smartphones and other mobile devices. Internet and computers are also available at the Inualthuyak School in Sachs Harbour, which teaches kindergarten through grade nine. Furthermore, the use
of social media is not restricted to youth, but is popular among most generations, including some Elders. Finally, there are many people who are part of the Sachs Harbour community who do not currently reside in the hamlet. Though online means of dissemination, we are better able to engage with the broader community.

1.1.9 Thesis Objectives

The overall goal of this research is to explore the efficacy of using low-cost photogrammetry to make 3D models that can be disseminated online to multiple audiences, the most important of which are Sachs Harbour residents and other Inuvialuit, but also include other Indigenous groups, and anyone with an interest in archaeology and cultural heritage. Specifically, the goals of this study are to: 1) assess the benefits and challenges of using low-cost photogrammetry for in-situ documentation of typical hunter-gatherer archaeological features; 2) determine the usefulness of low-cost photogrammetry for making 3D replicas of small-scale artifacts in comparison to high-cost 3D scanning methods; and 3) explore the ways that social media and other web resources can be used to host and share 3D models.

1.1.10 Thesis Materials

To meet the goals of this research project, two sets of archaeological materials were used:

1.1.11 Sample 1: In-situ Archaeological Features from Field Investigations

The first set consisted of archaeological features encountered during the 2013 field season of the Ikaahuk Archaeology Project. Archaeological features and artifacts were photographed in-situ and then reconstructed later in Sachs Harbour and at Western University using Photoscan and 123D Catch, two popular low-cost photogrammetry packages. The materials documented in-situ include stone caches, tent rings, surface artifacts, and sod houses remains. They were documented at three archaeological sites (Figure 3), which are described below:
1.1.11.1 Cape Kellett (OlRr-1)

Cape Kellett is a Thule-Inuit site located on the southwestern tip of Banks Island, consisting of nine Thule dwellings oriented parallel to the coastline facing the Beaufort Sea. It was first recorded by T.H. Manning during a Defence Research Board Expedition in 1952, and his party partially excavated at least three of the dwellings (Manning, 1953). Investigations by the Ikaahuk Archaeology Project in 2013 involved mapping the surface features including the dwelling remains, two associated middens, one tent ring (likely recent) and the remains of a historic wooden shack (Hodgetts et al., 2014). The winter dwellings are typical of those from other Thule-Inuit sites. Originally, these semi-subterranean dwellings would have been constructed with whale bone and/or driftwood supporting posts and beams for the walls, roof, and entrance tunnel, which were then covered with sod (Savelle and Habu, 2004). They currently consist of low mounds of earth with central depressions, remnants of whale-bone supports, and often have linear depressions extending away from the mounds representing their entrance tunnels.

Currently, several of the dwellings show evidence of surface erosion and damage, from both natural and cultural sources, including the original excavations by Manning.

The dwellings appear to represent more than one occupation at the site. The radiocarbon dates and the material culture found in Houses 8 and 9 together indicate an early use of the site in the 12th-13th centuries AD (Hodgetts et al., 2014). As at the Nelson River site (Arnold, 1986), this early occupation is likely associated with the initial migration of Thule peoples eastward from Alaska. Other radiocarbon dates suggest that some of the dwellings at the site were used later in the mid-14th century AD (Hodgetts et al., 2014).

1.1.11.2 Agvik (OkRn-1)

Agvik is a Thule site located on the south coast of Banks Island approximately 30km east of Sachs Harbour. The site is located on a high bluff adjacent to a gully that leads down to the beach. It was first identified by Manning (1953) and revisited recently by Arnold (2010) and by the Ikaahuk Archaeology Project (Hodgetts et al., 2014). It is made up of at least 11 Thule winter dwellings, consisting of low mounds with central depressions and sometimes also entrance tunnel depressions. There is also a pile of whale bone and wood
at the site, as well as several scatters of animal bone and surface artifacts. Three of the houses are under immediate threat due to erosion in the gulley, and it is likely that other houses will be impacted by either the gully or the eroding bluff face within the next decade. Radiocarbon dates from Arnold (2010) and Hodgetts et al. (2014) suggest that the site was used between 1400 and 1600 AD and may have had multiple occupations.

1.1.11.3 Seal Camp (OkRn-2)

Seal Camp is a Thule site about 2 km east of Agvik, consisting of numerous stone features spread over 700 m across two ridges overlooking the Beaufort Sea. The stone features include 18 caches, nine tent rings, and ten arrangements of stone with unknown functions. The tent rings and caches suggest that the site was used in the warmer months. Recent radiocarbon dates suggest that the site was occupied around 1400 AD, though it is unclear whether the site was used briefly or occupied repeatedly over a longer period (Hodgetts et al., 2014).

![Figure 3: Map showing location of sites on Banks Island where features were photographed.](image-url)
1.1.12 Sample 2: Museum Artifacts from the Prince of Wales Northern Heritage Centre

The second set of archaeological materials consisted of artifacts that are currently held in the Prince of Wales Northern Heritage Centre (PWNHC), the territorial museum of the Northwest Territories. In 2013 a total of 18 artifacts were loaned and digitized using a 3D3 White Light scanner at the Sustainable Archaeology Facility in London, Ontario. A sample of these artifacts was also modelled using Autodesk and 123D Catch. Three additional artifacts that were too fragile to transport were also photographed at the PWNHC and reconstructed using low-cost photogrammetry methods. Following suggestions from community members in Sachs Harbour, I selected artifacts representing a broad range of activities related to sewing, cooking, hunting, fishing, and living on the land. The artifacts from the PWNHC collections were from the following four sites on Banks Island: the Lagoon Site (OjRI-3), Nelson River (OlRr-1) and two small sites on DeSalis Bay (OiRe-2 and OiRe-9; Figure 4).

1.1.12.1 Lagoon Site (OjRI-3)

The Lagoon Site is a transitional Arctic Small Tool tradition site investigated by Charles Arnold (1980) in the 1970s, and the type site for the Lagoon Phase. It is located adjacent to a saltwater lagoon southeast of the mouth of Masik River on the southeast coast of Banks Island (Arnold, 1980). The site comprised several concentrated accumulations of cultural debris, distributed across several hundred meters of the shoreline (Arnold, 1980). While there were likely dwellings associated with this site originally, the only documented features include a midden, butchering area, and surface lithic scatter (Arnold, 1980). The recovered faunal assemblage suggests occupation in the late spring or early summer and is dominated by snow goose (*Anser caerulescens*), ptarmigan (*Lagopus* sp.) and ringed seal, with secondary emphasis on muskox (*Ovibos moschatus*) and Arctic fox (*Alopex lagopus*) (Arnold, 1980, 1977). The radiocarbon dates from this site suggest that it was used around 395 BC (Arnold, 1980, p. 421).

The artifacts recovered from the Lagoon Site display a unique mixture of traits from several cultural groups in the Arctic. Some parts of the assemblage, namely the
microblades, large bifaces, and extensive use of quartzite, have parallels on other Pre-Dorset sites in the western Canadian Arctic, including Pre-Dorset sites from Shoran Lake in north-central Banks Island (ca. 1500 BC) and the Ekalluk River sites on nearby Victoria Island, which were occupied during the late Pre-Dorset period (Arnold, 1980). Other artifacts including burin-like tools and side-notched end blades display similarities with those from Dorset sites in the Ekalluk region and elsewhere (Arnold, 1980). Finally, some Lagoon artifacts, such as stone lamps and harpoon heads with lashing slots, resemble those from the Norton and Choris complexes of the post-ASTt of the Yukon and Alaska (Arnold, 1980). Due to its unique artifact assemblage, Arnold (1980) suggested that the Lagoon site was a late regional Pre-Dorset manifestation that had influences from the western Arctic. Though the connection to Choris and Norton sites was tentative, it was influential in ASTt studies, as prior to the investigation of this site it had been assumed that there was little to no contact between the western and eastern Arctic regions during ASTt times (Arnold, 1980; Maxwell, 1980).

1.1.12.2 Nelson River (OgRi-1)

The Nelson River site is an early Thule-Inuit archaeological site on the southeastern tip of Banks Island. It was investigated first in the 1980s by Charles Arnold (Arnold, 1986; Friesen and Arnold, 2008). The site consists of a single two-room dwelling with a tunnel entrance built with driftwood posts and beams, adzed planks, and boulders. Arnold (1986) interprets it as a single occupation given the homogeneity of the artifact assemblage and the lack of evidence for rebuilding in the structure. This site is frequently cited as the earliest evidence of Thule occupation outside their Alaskan homeland, based on radiocarbon dates which cluster around AD 1200 and the presence of Sicco and Natchuk harpoon heads typical of late Birnirk culture of Alaska (Friesen and Arnold, 2008; Morrison, 2000).

1.1.12.3 DeSalis Bay (OiRe-2, OiRe-9)

Several artifacts in the study assemblage come from two small archaeological sites in DeSalis Bay, a large bay south of Prince of Wales Strait, which was occupied in the historic period by several Inuvialuit families (Nagy, 1999). Both sites are classified as
historic Inuvialuit campsites that consist of the remnants of rectangular tent structures, faunal debris, and artifacts. There are no absolute dates for these sites, but the material culture and the oral histories of local Inuvialuit people (Nagy, 1999) suggest that they were used between the 1930s and early 1950s.

Figure 4: Map showing location of archaeological sites where artifacts replicated in this study were recovered.

1.1.13 Online Dissemination

As the ultimate goal of this project was to make 3D models that could be accessed by members of the Sachs Harbour community, finished 3D models were shared online. A page for the Ikaahuk Archaeology Project was first created at the beginning of the 2013 field season on the social media site Facebook (www.facebook.com) in order to share 3D files with community members. Three formats were used to share 3D models through Facebook. Videos which showed 3D models were uploaded through a project YouTube (www.youtube.com) account and then linked to Facebook. Next, PDFs of individual 3D models were uploaded as files within the Ikaahuk Archaeology Facebook page. Finally,
3D models were uploaded to the online hosting site SketchFab (www.sketchfab.com) and then linked to Facebook. These methods were chosen as they were the most straightforward options to both create and share. They did not require the use of any additional software besides the initial programs used to create 3D models, and the online accounts used did not require the Ikaahuk Archaeology Project to pay for any web-hosting space. Furthermore, these formats were chosen because they can be displayed either online or on a user’s personal computer without specialized 3D programs. Videos, PDFs, and online hosting methods were utilized to determine which could best represent the 3D models made in Photoscan and 123D Catch, and were most compatible with Facebook.

1.1.14 Thesis Organization

The body of this thesis consists of two independent research articles intended for publication in peer-reviewed journals. Each chapter contains specific objectives, relevant background information, methods of analysis, and descriptions of the archaeological materials used in the study.

Chapter Two explores the use of low-cost photogrammetry to document archaeological features in-situ and create 3D models that can be shared online. It considers the advantages and disadvantages of the photogrammetry software programs Photoscan and 123D Catch as tools in field research in a remote location and compares the successes and shortcomings of each program for replicating several types of archaeological features, including sod houses, tent rings, caches, and isolated artifacts. It also explores the relative merits of these programs for creating 3D models suitable for online dissemination to a community audience.

Chapter Three compares low-cost photogrammetry with high-cost 3D scanning methods for creating digital replicas of artifacts in museum collections. It compares the quality of the 3D models created through both methods, and considers the relative benefits and challenges of these techniques from the perspective of an archaeologist with limited background in computer science. It also explores the merits and drawbacks of several
means of online dissemination of 3D models created with each of the low- and high-cost methods, including videos, PDFs, and online hosting.

Chapter Four summarizes the objectives and conclusions of the previous three chapters and discusses the contributions of the research to the broader discipline of archaeology. It also explores possible future directions for the use of low-cost 3D modelling and its implications in archaeology.

1.1.14.1

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Chapter 2

2 Applications of Low-Cost Photogrammetry to Replicate and Disseminate Archaeological Features in-situ on Banks Island, NWT

Advances in 3D modelling technology in the last two decades have created new opportunities for archaeological research and conservation. Though used in many disciplines, 3D modelling has particular value in archaeology and heritage studies, where objects such as archaeological sites, features, and artifacts are of interest to many stakeholder groups but are often inaccessible in their original form or are in danger of deterioration or destruction from natural or cultural forces (Boehler, 2005; Patias, 2007). In these contexts where access to original archaeological objects is difficult or impossible, 3D modelling can be used to make readily accessible digital copies. However, many common forms of 3D scanning are prohibitively expensive and their use requires specialized knowledge, restricting it to a limited number of archaeological professionals. An alternative is photogrammetry, a technique that uses 2D photographs to extract geometric data and create 3D copies of objects. Newly-released photogrammetry software is becoming increasingly inexpensive and user-friendly, and represents the first opportunity for archaeologists without specialized backgrounds in computer science to take an active role in creating and incorporating data from 3D modelling into their research.

As low-cost and user-friendly photogrammetry is relatively new to archaeology, the benefits, challenges, and limitations of this technique have not been fully explored in the archaeological literature. This paper will address some of these issues, including: 1) the use of photogrammetry to record in-situ archaeological features during field investigations; 2) the utility of photogrammetry in the replication of small-scale features typical of North American hunter-gatherer sites; and 3) the online dissemination of the results of 3D modelling to public audiences. This paper explores these issues by comparing the relative merits of two low-cost photogrammetry programs, Agisoft
Photoscan (Photoscan), and Autodesk 123D Catch (123D Catch), to record hunter-gatherer archaeological features on Banks Island, NWT and the use of Internet resources and social media to share the completed 3D models with a public audience as part of a community-based archaeology project. The results suggest that both photogrammetry programs are valuable tools for in-situ documentation, though Photoscan is better able to process photographs taken in less-than-ideal field conditions and 123D Catch processes photographs more quickly. Furthermore, low-cost photogrammetry is a viable option for documenting some hunter-gatherer archaeological features, but features that are less discernible differentiated from their surrounding landscapes are more challenging to document and less likely to result in accurate or realistic 3D models. Finally, both photogrammetry programs are appropriate for creating content that can be used in online dissemination. 123D Catch is particularly useful as it processes 3D models quite quickly and is more compatible with dissemination through social media.

2.1.1 Background Information

2.1.2 3D Modelling in Archaeology

3D modelling, or the acquisition and digital reconstruction of 3D information of an object’s surface, has been used within archaeological research since at least the 1980s (Koller et al., 2010). There are two main types of technology that archaeologists have used to digitally record archaeological materials: 3D scanning and photogrammetry. 3D scanning technology uses specialized equipment to acquire 3D spatial information from an object’s surface using technologies based on stereo vision, light wave, or sound wave time-of-flight distance measuring (Lu and Pan, 2010). 3D scanning technologies have been used in archaeology since the mid-1990s (Bertani et al., 1995; Wurtz, 2011), and are accepted as the best 3D modelling technology for creating accurate, precise, and high quality digital replicas of geometrically-complex archaeological materials (Boeheler, 2005; Lambers et al., 2007; Lerma et al., 2010).

Photogrammetry, alternately, reconstructs objects in 2D or 3D by extracting information from 2D photographs. This technique, also known as image-based 3D modelling, uses structure-from-motion and stereo-reconstruction algorithms to identify and match shared
points from overlapping photographs of an object and then uses those points to create
dense digital meshes representing the surface of that object (Doneus et al., 2011; Lu and
Pan, 2010). The technology behind photogrammetry has changed significantly along with
developments in imaging technology. The process of using 2D photographs to represent
objects in 3D has been used since as early as the mid-19\textsuperscript{th} century, and what is now
known as ‘digital photogrammetry,’ or the use of modern computing technology to
reconstruct objects in 3D, was developed in the early 1990s (Fryer, 2007). Methods of
digital photogrammetry in the 1990s and 2000s were found to be effective for accurately
reconstructing objects in 3D, but they were criticized for being inaccessible to non-expert
users (Remondino and El-Hakim, 2006). Until recently, both the software programs and
the photography equipment required for photogrammetric reconstructions were
specialized and expensive, and required that users had extensive backgrounds in
computer science to operate them (Fryer, 2007; Koller et al., 2010; Lerma et al., 2010;
Patias, 2007; Pavlidis et al., 2007). Despite these challenges, several archaeological
projects incorporated the use of high-end commercial photogrammetry programs into
their research, documenting rock art (Chandler et al., 2007; Lerma et al., 2010; Simpson
et al., 2004) relief art (Boehler and Marbs, 2004), aerial survey data (Bewley, 2003),
architecture (Boehler and Marbs, 2004; Eisenbeiss et al., 2005; Lambers et al., 2007;
Remondino, 2011), and statues (Boehler and Marbs, 2004).

Within the last ten years, several new commercial and open-source software packages
and web services have been released that offer potential alternatives to the costly and
specialized photogrammetry programs of previous years. These programs and web-
services are inexpensive or free and do not require the use of metric cameras or other
specialized equipment to process photographs. They are also more accessible to users
who do not have prior knowledge in computer science, as they are usually partially or
fully automated, requiring little to no manual input from users. Several researchers have
already recognized the potential of these programs in archaeology, and have begun to
investigate the usefulness of inexpensive user-friendly photogrammetry within
archaeology. Comparisons among low-cost photogrammetry programs in documenting
archaeological excavations (De Reu et al., 2014; Plets et al., 2012), architecture, (Brutto
and Meli, 2012; Santagati et al., 2013) and monuments (Kersten and Lindstaedt, 2012)
have found that low-cost photogrammetry programs have improved significantly in recent years, and are now comparable to those from both 3D scanners and more expensive photogrammetry software packages.

2.1.3 Problems in Archaeological Applications of Photogrammetry

Though archaeologists have established the usefulness of low-cost photogrammetry techniques in several areas of archaeological research, there remain some contexts where the benefits, challenges, and limitations of the technology are unexplored. The first issue is related to the application of photogrammetry to document archaeological features in-situ during field work. Boehler and Marbs (2004) established that photogrammetry is advantageous as a 3D modelling technique during field research, as it is relatively quick and requires minimal equipment. However, field conditions present several challenges. In order to create 3D models through photogrammetry, the algorithms require that areas under documentation have consistent lighting, static backgrounds, and distinctive textures.

While these conditions can be achieved easily in a laboratory setting, they are more difficult to ensure in a field setting, where fluctuations in weather, wind, and other environmental factors can rapidly change scene lighting and backgrounds, and areas without distinctive textures, such as skies and bodies of water cannot always be avoided in photographs. While some archaeologists (Patias, 2007) are able to plan their research around seasonal weather patterns, or return when conditions are ideal, archaeologists who work in remote areas or have limited time to spend documenting archaeological sites may have little choice but to photograph features in relatively poor conditions. As photogrammetry is a popular technique in disciplines with outdoor field work, such as aerial survey, mapping, and architectural planning (Fryer, 2007), many professional and high-cost programs have features that can account for fluctuations in environmental conditions and still produce usable results, usually through manual assignment and checking of data points (Mitchell, 2007). However, as many low-cost alternatives are automated and do not have the full features of more expensive programs, they are not necessarily able to produce high-quality results for archaeological features that are documented in-situ in less-than-ideal conditions.
Secondly, relatively few archaeologists have used photogrammetry to document the kinds of ephemeral features common on hunter-gatherer archaeological sites. Though photogrammetry has demonstrated utility in other settings, the effectiveness of different 3D modelling techniques depends on the size, complexity, shape, and texture of the objects that are being modelled (Kersten and Lindstaedt, 2012; Pavlidis et al., 2007). Many of the successful applications of photogrammetry in archaeology to date deal with historic sites from Europe (Brutto and Meli, 2012; De Reu et al., 2014; Santagati et al., 2013), with monumental architecture, stone building foundations, and large and complex excavation areas. These objects consist of complex shapes, colours, and details on their surfaces, and are described as feature-rich (De Reu et al., 2014; Pavlidis et al., 2007). Photogrammetry works well with these types of archaeological features, as software programs are significantly more likely to be able to calculate reference points and geometry among feature-rich objects, while objects with less complex surfaces are less likely to model well in 3D (Kersten and Lindstaedt, 2012). Though there are exceptions, archaeological objects from hunter-gatherer sites in North America and elsewhere tend to be smaller and less complex in their geometry and texture. The utility of photogrammetry in documenting these simpler hunter-gatherer features remains largely explored in archaeology.

Finally, little work has addressed the dissemination of 3D models to a public audience in detail. Heritage professionals have acknowledged the potential of digital replicas of archaeological objects in the context of public dissemination and stressed the importance of making 3D models widely available online (De Reu et al., 2013; Koller et al., 2010; Patias, 2007). However, there are few examples of Internet databases that make 3D digital replicas of archaeological objects publicly available. Several factors contribute to this dearth of publicly-disseminated 3D models. There are technical issues related to creating 3D files that are suitable and compatible for online display; files are often so large that they cannot be displayed without a significant loss in quality, and Internet browsers are not always able to display 3D files (Berndt et al., 2010). In addition, internet repositories can be expensive to create and maintain, and some pilot projects that host 3D models online have been taken down after a short period due to a lack of funds (Gourley and Viterbo, 2010), which is an issue common to online databases in archaeology.
generally (Kansa and Kansa, 2011). Due to these challenges and others, there is a considerable disconnect between the number of archaeologists and other heritage professionals who use 3D scanning in their research and the state of digital curation on the internet (Koller et al., 2010).

Despite these valid concerns with digital databases, it is worthwhile to explore diverse ways of sharing 3D models using online resources. The ever-improving state of computing and Web technology can allow archaeologists to move creatively past the challenges of online dissemination. Research indicates that presenting archaeological information in the form of an interactive, digital display is significantly more engaging and evocative to audiences of non-archaeologists than traditional means of disseminating archaeological research (Bonacchi, 2012; Dawson et al., 2011; Goskar, 2012; Jeater, 2012; Sylaiou et al., 2009). Aside from technological advancements, changes in the overall online presence associated with Web 2.0 indicate that Internet resources are becoming more collaborative and interactive, and the boundaries between the roles of online producers and consumers are less clear than in previous decades (Kansa, 2011).

Increasingly, archaeologists have found success using non-traditional online means of dissemination, such as social media photo-sharing sites and video games rather than academically-minded databases in order to make archaeology relevant to a range of non-specialist audiences (Kalfatovic et al., 2008; Morgan and Eve, 2012; Pett et al., 2012; Richardson, 2012).

This research was carried out as a part of the Ikaahuk Archaeology Project, which is an ongoing investigation of the human history of Banks Island in Canada’s western Arctic. This community-oriented project involves researchers from the University of Western Ontario and Inuvialuit community members in Sachs Harbour (Figure 5), and is working towards meaningful, balanced, collaboration between these groups at all stages of the research process. We are exploring the potential of photogrammetry to address community concerns about the failure of researchers (from a range of disciplines) to share their results with local residents. Specifically, this study set out to compare two low-cost photogrammetry programs, 123D Catch and Photoscan in terms of: 1) the advantages and disadvantages of photogrammetry for use in in-situ field recording in
remote locations, 2) the utility of photogrammetry as a means to document hunter-gatherer archaeological features typical of the Canadian Arctic, and 3) the benefits and challenges of using online means to share the resulting 3D models.

2.1.4 Materials and Methods

2.1.5 Ikaahuk Archaeology Project

Our fieldwork in the summer of 2013 targeted three archaeological sites on the southern coast of Banks Island (Figure 6), all from the Thule-Inuit period (Table 1). The Thule-Inuit are the direct ancestors of the modern Inuvialuit and other Inuit, who migrated into the Canadian Arctic from Alaska around 1200 AD (Friesen and Arnold, 2008; Morrison, 2000, 1989; Taylor, 1963; Whitridge, 2001). Cape Kellett and Agvik were likely occupied in the winter and each consists of multiple semi-subterranean sod houses and scatters of animal bone. Seal Camp, on the other hand, is a warm season site, consisting of several dozen tent rings, caches, and other stone features, as well as animal bone scatters and surface artifacts.

<table>
<thead>
<tr>
<th>Site</th>
<th>Approximate Dates Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Kellett (OIRr-1)</td>
<td>1250-14700 AD (Hodgetts et al., 2014)</td>
</tr>
<tr>
<td>Agvik (OkRn-1)</td>
<td>1350-1670 AD (Hodgetts et al., 2014)</td>
</tr>
<tr>
<td>Seal Camp (OkRn-2)</td>
<td>1370-1550 AD (Hodgetts et al., 2014)</td>
</tr>
</tbody>
</table>
Figure 5: Map showing the location of Sachs Harbour and Banks Island in Canada
Photogrammetry was used at these sites both as a way to gather information quickly and to create content to share with the community of Sachs Harbour. These Arctic sites are quite remote, which makes access expensive for researchers based in the south, and they can only be documented during a relatively short period in the summer when they are free of snow. Additionally, two of the visited sites (Cape Kellett and Agvik) are being impacted by coastal erosion (Hodgetts et al., 2014), which is accelerating as a result of climate change (Barr, 2004; Dawson et al., 2013). As such, the sites needed to be documented in as much detail and as quickly as possible.

Photogrammetry was also used as a means to make archaeology more accessible to non-specialists. As a community-based project, the Ikaahuk Archaeology Projects aims to include the local Inuvialuit community in all stages of archaeological research and aims
to bring together Western and Indigenous methodologies to create a more multivocal and reflexive interpretation of the past (Atalay, 2012; Jensen, 2012; Smith and Waterton, 2009; Tully, 2007). At community meetings and consultations, community members raised several concerns regarding archaeological practice on Banks Island. While many community members expressed a strong interest in local history, many felt that archaeologists and other researchers who had previously worked on the island had not sufficiently consulted with local people or shared the results of their research with the community. We responded by exploring the use of photogrammetry to create digital 3D models as one way of sharing the results of field investigations with community members who could not visit sites in person, in a way that is more accessible and engaging than conventional means of disseminating archaeological research, such as written reports.

2.1.6 Archaeological Features Recorded

Four categories of archaeological objects were recorded on the surfaces of the three archaeological sites investigated: sod houses, caches, tent rings, and isolated artifacts. These were chosen as they are common on archaeological sites in the Canadian Arctic. In addition, they represent a diversity of sizes, shapes, textures, and overall geometric complexity, all of which affect their suitability for replication using photogrammetric modelling techniques. At each site, these features were also documented using conventional archaeological recording techniques (record photographs and total station mapping). We wanted to explore the potential of photogrammetry to collect more detailed information about the individual archaeological features at each site.

2.1.6.1 Sod Houses

Two sod house mounds were documented at the Cape Kellett site (Figure 7). The remains of these Thule-Inuit winter dwellings consist of low mounds of earth with characteristic central depressions and remnants of whale-bone posts. Often, they also have a linear depression leading from the mound towards the coast, the remains of entrance passages. Of the two houses documented, one (House 1) was located on the gravel beach of the site, while the other (House 3) was located on the vegetated tundra. Both were likely originally built on tundra vegetation, which is eroding away to expose the gravel beach.
Though the sod house mounds ranged in diameter from 3-10 meters, their surfaces were smooth and homogeneous, and their surface texture was similar to that of the surrounding landscape.

Figure 7: Sod houses from Cape Kellett. Left: House 1. Right: House 3.

2.1.6.2 Caches

Two stone caches were documented at Seal Camp (Figure 8). These features consisted of roughly circular piles of stones ranging from 1-1.5 m in diameter and 50-75 cm in height. These features have a complex shape and texture: the caches were built with stones of varying shapes, sizes, and colours and the features themselves are easily differentiated from the surrounding gravel landscape.

Figure 8: Caches from Seal Camp. Left: Cache 5. Right: Cache 21.
2.1.6.3  Tent Rings

Two tent rings were documented at OkRn-2 (Figure 9). Each consisted of several stones in a roughly circular arrangement approximately 1-2 m in diameter. Though they were constructed of the same kinds of stones as the caches of OkRn-2 and located on the same gravel surface, the tent rings were less complex in terms of their overall shape. While caches consisted of large numbers of stones clustered together and raised well above the ground surface, tent rings consisted of only a single ring of more widely spaced stones resting directly on the ground surface and were less easily differentiated from their surroundings.

![Figure 9: Tent Rings from Seal Camp. Left: Tent Ring 3. Right: Tent Ring 9.](image)

2.1.6.4  Isolated Artifacts

Two isolated artifacts surface artifacts were also documented (Figure 10). One was a fragment of worked bone or antler that was resting on the gravel surface of OkRn-2, while the other was a fragment of a ceramic vessel that was partially exposed on the surface at Agvik. Both were much smaller than the recorded features. The worked bone/antler was about 10 cm in length while the exposed pottery was roughly rectangular in shape and about 15 cm in width. Because of their small size, neither of the isolated artifacts was overly distinct in shape from its substrate, but both were sufficiently distinct and complex in texture and colour to be suitable for modelling with photogrammetry.
2.1.7 Photographic Recording

All features were photographed in-situ using a non-metric Nikon D3200 24 megapixel digital camera with an 18mm lens. Photographs were taken in two sequential loops surrounding each feature, the first loop from kneeling height facing the object at a normal angle, and a second from standing height at a high angle. Additional photographs were also taken to capture the detail of more geometrically complex features, to ensure that all details of the shape and texture of the feature were documented. The number of photographs taken varied between 30 and 50, depending on the size and geometric complexity of the target object. Photographs were taken from a distance of about 1-5 meters from a given feature, depending on the size of the feature. It was not necessary to take photographs from a precise or fixed distance from documented features, as the selected photogrammetry programs automatically derive reference points from shared features in photographs to build geometric information.

2.1.8 3D Model Generation

We investigated the relative merits of two photogrammetry programs for generating 3D models: Photoscan and 123D Catch. These programs were chosen as they have been successfully utilized in other archaeological projects, and they represent the range of available options for low-cost photogrammetry. Photoscan, created by the Russian company Agisoft, is a low-cost software program aimed towards 3D designers that is more expensive ($179 for Standard Edition, $3499 for Professional Edition; Agisoft
LLC, 2013), whereas *123D Catch*, available for free from Autodesk, is a web service that is designed for use by both professionals and the general public (Autodesk, 2014). Processing of photographs began in Sachs Harbour in July 2013 and was completed at Western University. An Internet connection was not available at field sites on Banks Island. However, while working at Cape Kellett we returned to Sachs Harbour each night, and we also spent several days in the hamlet at the beginning and end of the field season, where we were able to use the Internet for processing data with *123D Catch* and disseminating models online. Processing was carried on an ASUS™ X53E laptop computer with an Intel® Core i7-2630QM processor, DDR3 1333(O.C.) MHz SDRAM, 4 GB, 2 x SO-DIMM memory, 64-bit operating system (Windows 7), and an Integrated Intel® HD Graphics 3000 graphic card.

2.1.8.1 Photoscan

*Photoscan* (Standard Edition, version 1.0.1) allows users to create 3D models in a four-step automated workflow: (1) image alignment and sparse point cloud generation, (2) dense point cloud generation (3) 3D surface generation, and (4) texture mapping (Agisoft LLC, 2013; De Reu et al., 2014; Verhoeven, 2011). *Photoscan* requires that photographs are taken using a camera with at least 5, but preferably 12, megapixels in a sequential loop surrounding an object with at least 60% overlap between sequential photographs (Agisoft LLC, 2013). Before the first step is started, images can be manually pre-processed to ensure that they will be aligned sufficiently. Users can mask areas of photographs that are irrelevant to the object that is being modelled, or where “moving objects” such as shadows will interfere with the program's workflow (Figure 11). Areas of photographs where there is minimal information about texture or where there is little variation in texture, such as skies or water, can also be masked. Masked areas of photographs will not be used at any point in the 3D model generation process. Though not a mandatory step, pre-processing images before beginning the four-step automated process can have a positive effect on quality of the finished models (Agisoft LLC, 2013; Verhoeven, 2011).
Following pre-processing, the four steps of the automatic workflow can be started (Figure 12). During the first step, photographs are aligned and a sparse point cloud of the object's geometry is produced using a structure-from-motion approach, and the relative orientations and internal parameters of the camera are computed. In the second step, a dense point cloud is computed. Based on the information computed in the first step, *Photoscan* creates a more detailed point cloud, similar in density to LIDAR (light detection and ranging) point clouds (Agisoft LLC, 2013). In the third step, the 3D geometry, or the surface mesh of the object, is generated using multiview stereo-matching algorithms. Users can choose whether to build this geometry using the sparse or dense point cloud. Finally, a texture can be computed and mapped onto the mesh based on the inputted photographs to give the model a more photo-realistic appearance. During each of these steps users can choose a desired level of quality for the finished output; choosing higher quality results in the most detailed 3D model, while choosing lower quality significantly reduces the required processing time. Though the steps are
automated, users can intervene at any time to assess and rectify any issues encountered in the workflow.

There are several options for post-processing before final models are saved and exported. Agisoft also recommends that meshes are decimated to make files compatible with other programs, as *Photoscan* tends to create meshes with excessive geometry resolution (Agisoft LLC, 2013). For use in other programs, users can export the sparse or dense point clouds, or the models themselves into a range of formats (OBJ, 3DS, WRL, DAE, PLY, DXF, U3D or PDF).

![Figure 12: Image showing the 3D model of Cache 5 at the four workflow stages of Photoscan. Top left: sparse point cloud generation after photo alignment. Top right: dense point cloud. Bottom left: 3D surface (mesh). Bottom right: 3D surface with texture.](image)

### 2.1.8.2 123D Catch

*123D Catch* (desktop, version 2.2.3.377) creates 3D models in a simple and entirely automated process that can be accessed online ([www.123dapp.com/catch](http://www.123dapp.com/catch)), or through an app on a desktop computer, iPhone or iPad. Prior to using *123D Catch*, users must create
an Autodesk ID profile, which allows them to access their models from anywhere with an Internet connection. Users must be connected to the Internet at all times while creating and editing 3D models, as 123D Catch uses cloud computing for all processing. To create a 3D model, users upload at least five photographs surrounding an object in a sequential loop. Photographs should overlap by at least 70% and must be uploaded in sequential order (Santagati et al., 2013). Photographs are uploaded through the app to the Autodesk cloud, where a point cloud and surface mesh are computed. After processing, users can improve the appearance of models in a few ways. Holes, stretched patches of mesh, or other poorly-generated areas of mesh can be ameliorated by manually stitching photographs together. To manually stitch photographs, users must identify and match the same point in three different photographs, after which the entire project is submitted to the Autodesk cloud again for processing. Poorly-generated areas of mesh or areas with erroneous data can also be trimmed from the final mesh to give it a neater appearance.

Meshes are automatically generated at Standard Quality, but can be regenerated at a lower density (Mobile Quality) for viewing with mobile devices or at a higher density (Maximum Quality) for use in other 3D editing programs (Figure 13). Both point clouds and meshes can be exported (DWG, FBX, RZI, OBJ, IPM, or LAS formats). Alternately, users can create videos (AVI format) showcasing objects, which can then be exported or uploaded through 123D Catch to a designated YouTube account.
In order to compare the potential capabilities of both Photoscan and 123D Catch to quickly create accurate 3D representations of archaeological features, models were generated in each program at both medium and high target quality levels. In Photoscan, medium target quality consisted of models that were processed using a sparse point cloud, but with the most detailed mesh quality available. High target quality was achieved using a dense point cloud and the highest quality output settings for mesh construction. In 123D Catch, medium target quality refers to meshes produced at Standard Quality, while high target quality consisted of meshes generated at Maximum Quality.

2.1.9 Online Dissemination

In order to make the completed 3D models of archaeological features readily available to the community of Sachs Harbour, they were shared using the social media websites Facebook (Figure 14) and YouTube. Facebook was chosen as the primary online means of sharing all research, as it is a very popular means of both entertainment and communication in most households and among most generations, including Elders, in
Sachs Harbour. We created the Ikaahuk Archaeology Facebook page at the beginning of the field season in 2013, where it began to generate traffic among Sachs Harbour residents, as well as other archaeologists and members of the public. After one year, the Ikaahuk Archaeology Facebook page has 132 ‘likes,’ meaning that 132 people have chosen to receive updates about the project in their newsfeeds. According to the demographic data generated through the Page Insights function of Facebook, 18 of the 132 likes are from residents of Sachs Harbour, and an additional 19 are from people living in other nearby areas of the Northwest Territories (Inuvik, Tuktoyuktuk, etc.). Of the total likes, 107 live in Canada, 16 in the United States, and nine in Europe. Women (53%) are slightly more represented than men (44%), and the most common age group active within the page is 25-34 years old.

In order to disseminate 3D models quickly, we chose 3D file formats for dissemination that were available within Photoscan and 123D Catch and that did not require the use of any additional 3D modelling or design software. Within Photoscan we converted 3D models into PDF (portable document format) documents and within 123D Catch we created videos of 3D models and uploaded them to YouTube. The methods used in this study were also chosen due to their user-friendly nature for a non-specialist audience. Whereas some 3D file formats (e.g. OBJ, PLY, or LAS point clouds) would be preferable for dissemination to other professionals familiar with 3D modelling, they would also require that users have specialized or expensive 3D modelling software programs or Internet browser extensions to view them. In contrast, PDF files and videos can be viewed using a free PDF reader or a generic Internet browser, respectively.
2.1.10 Results

3D models were successfully generated using both Photoscan and 123D Catch for seven of the eight archaeological objects in this study. Though all models had at least some issues with the quality of the finished product, such as holes (areas without data) or stretched areas of mesh (areas with insufficient data points to accurately replicate the original object), models were considered successful if all parts of the original features were adequately represented in the completed mesh. This section further explores the advantages and disadvantages of Photoscan and 123D Catch for use in in-situ field recording, the utility of photogrammetry applied to hunter-gatherer sites, and the ability of each photogrammetry program to create content that is compatible with dissemination through online social media.
2.1.11 Photoscan and 123D Catch in in-situ Field Recording

Both Photoscan and 123D Catch had advantages and disadvantages in the context of recording archaeological features in-situ. The photographs used to construct these 3D models were taken in less-than-ideal conditions during field work. Though we followed the recommended procedures of Photoscan and 123D Catch for photographing objects as closely as possible, there were many environmental factors that could not be controlled during field recording. When possible, photographs were taken on days when the weather was overcast, but lighting was often inconsistent and shadows fell across parts of the documented features. Additionally, given the open tundra setting, bodies of water and skies were usually present in photographs, and movements in the background of photographs were difficult to avoid. Wildlife was also a challenging factor, as the large numbers of insects on warm days often blocked the subjects of interest in both the foreground and background of photographs. Processing of data using 123D Catch was an additional challenge in Sachs Harbour, as the program requires a reliable high speed Internet connection. We had no internet access at our field sites and Internet service in Sachs Harbour is often interrupted, which caused delays in generating models.

Despite these challenges, both software programs produced 3D models that effectively captured the original features, with the exception of one sod house. Here, we compare the models from both programs based on the numbers of aligned photographs, the number of computed faces and overall processing time. The number of aligned photographs quantifies how well each program is able to locate shared points in overlapping areas of photographs, and determines how many shared data points can be generated in later stages of the workflow. As this is the first step in the workflow of both Photoscan and 123D Catch, the ability to align a higher percentage of photographs strongly influences the quality of finished models. We had similar results with both programs (Figure 15), but the average percent of photographs aligned was slightly higher in Photoscan (88%) than in 123D Catch (76%). Haukaas attempted to manually align photographs that were not aligned automatically in 123D Catch. However, this was a time consuming endeavour that added at least 10-20 minutes of additional cloud processing time for each manual
point. Points that were aligned manually also tended to result in more problematic meshes (i.e. more holes, stretched mesh, less detail of mesh geometry).

![Average Percent of Photographs Aligned in Photoscan and 123D Catch](image)

Figure 15: Average Percent of Photographs Aligned in Photoscan and 123D Catch

The average number of computed faces generated in 3D models is a measure of their overall detail. Photogrammetry programs, along with most conventional surface reconstruction programs, recreate surfaces of objects as triangular networks, known as “meshes” within computer graphics literature and as “triangulated irregular networks (TIN)” in geographical information technology terms (Remondino and El-Hakim, 2006). These surfaces consist of thousands or millions of faces and the vertices that connect them. Meshes that have a higher number of computed faces can provide a more complex and detailed digital representation of an object’s surface. Models generated at high target quality in Photoscan had the highest number of computed faces, while models generated at medium target quality in 123D Catch had the lowest number (Table 2). Models created at medium target quality produced similar results in both programs, while high-target-quality models created in Photoscan had significantly higher numbers of computed faces than those created at the same target quality in 123D Catch. A comparison of medium- and high-target-quality 3D models made with each program is shown in Figure 16.
Table 2: Comparison of Average Number of Computed Faces of 3D Models Created with *Photoscan* and *123D Catch* at Medium and High Quality Target Levels

<table>
<thead>
<tr>
<th>Program</th>
<th>Target Quality</th>
<th>Average Number of Computed Faces</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Photoscan</em></td>
<td>Medium</td>
<td>42587</td>
</tr>
<tr>
<td><em>Photoscan</em></td>
<td>High</td>
<td>1761410</td>
</tr>
<tr>
<td><em>123D Catch</em></td>
<td>Medium</td>
<td>47626</td>
</tr>
<tr>
<td><em>123D Catch</em></td>
<td>High</td>
<td>667507</td>
</tr>
</tbody>
</table>

Processing time is another important factor to consider when evaluating the merits of both programs, as it determines how quickly archaeologists using photogrammetry as part of their field research will have usable results for immediate dissemination to outside parties or as a basis for deciding how field work should proceed (e.g. if 3D models are used to guide excavation plans (De Reu et al., 2014)). Programs that take much longer to process the data can hinder research in such contexts, especially when generating large numbers of 3D models, while programs that process data very quickly may not result in models of sufficiently high quality. On average, models created at high target quality in Photoscan took significantly longer to process than any other models, with an average computing time of nearly two hours (Table 3). Alternately, models generated in 123D Catch at high target quality or in either program at medium target quality could process much more quickly. Figure 17 compares the processing time required compared with the average number of computed faces, and shows a strong relationship between required processing time and the quality of finished 3D models.

Table 3: Comparison of Average Processing Time (Minutes) of Meshes in 3D Models created with Photoscan and 123D Catch at medium and high target quality levels.

<table>
<thead>
<tr>
<th>Program</th>
<th>Target Quality</th>
<th>Avg. Processing Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoscan</td>
<td>Medium</td>
<td>11.26</td>
</tr>
<tr>
<td>Photoscan</td>
<td>High</td>
<td>114.97</td>
</tr>
<tr>
<td>123D Catch</td>
<td>Medium</td>
<td>15.25</td>
</tr>
<tr>
<td>123D Catch</td>
<td>High</td>
<td>27.38</td>
</tr>
</tbody>
</table>
2.1.12 Photogrammetry for Recording Hunter-Gatherer Archaeological Features

The models were also assessed to determine which types of archaeological features common in the Canadian Arctic could be best reconstructed using photogrammetry. Completed 3D models were separated into groups by feature type and then evaluated using the measures outlined above. First, the average number of aligned photographs was compared in each category. The results of this comparison indicated that both programs had 100% success aligning isolated artifact photographs. *Photoscan* also had 100% success aligning photographs of caches and tent rings, and *123D Catch* had reasonable success with these features as well. Neither program was particularly successful aligning photographs of sod houses (Figure 18).
Next, the average numbers of computed faces for 3D models generated at medium and high target quality levels were compared (Table 4). As previously noted, 3D models were generated for all eight features documented in this study, though only seven were successful. For one sod house both programs at both target quality levels were only able to generate a mesh for a very small portion of the feature (Figure 19). For both programs at both target levels, sod houses had the lowest number of computed faces and tent rings had the second-lowest. At medium target quality, isolated artifacts had the highest average number of computed faces and caches had the second-highest in both programs, while at high target quality these two features were reversed, with caches having the highest average number of computed faces and with isolated artifacts having the second-highest.
Table 4: Comparing Average Number of Computed Faces According to Archaeological Feature Type in Models Created in Photoscan and 123D Catch at Medium Target Quality

<table>
<thead>
<tr>
<th>Feature Type</th>
<th>Photoscan (average number of computed faces)</th>
<th>123D Catch (average number of computed faces)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Target Quality: Medium</td>
<td>Target Quality: High</td>
</tr>
<tr>
<td>Sod House</td>
<td>35786</td>
<td>1116463</td>
</tr>
<tr>
<td>Tent Ring</td>
<td>37803</td>
<td>1170276</td>
</tr>
<tr>
<td>Cache</td>
<td>47882</td>
<td>2643130</td>
</tr>
<tr>
<td>Isolated Artifact</td>
<td>49322</td>
<td>1692943</td>
</tr>
</tbody>
</table>

Figure 19: Unsuccessful 3D model of sod house (House 3) in Photoscan.

2.1.13 Disseminating 3D Models

The overall goal of this project was to make 3D models available online through Facebook, as Facebook is already a popular means of sharing information in Sachs Harbour. We explored two different approaches for dissemination, PDF files and videos, which were made available through the Ikaahuk Archaeology Project Facebook page. Interactive PDF files were created for all of the 3D models created in this study using Photoscan. PDFs were simple and very quick to create with Photoscan, and they had the added benefits of being interactive for the user (through zooming and rotating 3D
objects). As they must be saved to a personal computer to view, they could be used after the initial download without Internet access.

However, a number of challenges surfaced when attempting to share 3D models online. PDFs of 3D models generated at high target quality were generally large and difficult to work with, an issue that is acknowledged by Agisoft (Agisoft LLC, 2013). Though they could be exported into PDF format, the PDF files were slow to load and difficult to manipulate within a PDF reader. Not only did the large files inhibit the interactivity of the 3D models, they were too large to upload to Facebook. The PDFs generated from high target quality were an average of 116 MB, which greatly exceeds Facebook’s current maximum file size of 25 MB. Following Agisoft recommendations (Agisoft LLC, 2013), Haukaas reduced the meshes to around 200,000 computed faces and generated new mesh textures. This reduced the file sizes of PDFs to an average of 13 MB each, making them compatible with Facebook requirements (Table 5). The reduced file size made 3D models in these PDFs easy to manipulate (zoom and rotate), and the appearances of their surfaces are similar to those created from high-target-quality models. PDFs generated from models created at medium target quality were an average 7 MB. The 3D objects in these files are the most easily manipulated within a PDF reader, though they do not show the same level of detail in the surface geometry as those created using high-target-quality models (Figure 20). In addition, at this time most free mobile PDF browsers are not compatible with 3D files, limiting their use to personal computers.

Table 5: Comparison of the average file size of PDFs and videos generated in Photoscan and 123D Catch, respectively.

<table>
<thead>
<tr>
<th>Target quality of 3D model in Photoscan</th>
<th>Video Setting in 123D Catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High with decimated mesh</td>
</tr>
<tr>
<td>116</td>
<td>14</td>
</tr>
<tr>
<td>Average file size (MB)</td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>14</td>
</tr>
<tr>
<td>461</td>
<td>1033</td>
</tr>
</tbody>
</table>
Next, we created videos of 3D models in *123D Catch* and shared them on Facebook using YouTube. Videos took the form of a camera following a path that slowly circles the 3D object and then zooms to show detail. *123D Catch* can create an automatic animation path that follows the order of the photographs as they are uploaded. However, the videos created from automatic animation paths are choppy and unattractive. Instead, we created custom animation paths that made three loops around an object: one at a high angle, a second at a high angle zoomed in, and one showing an eye-level view to illustrate the vertical geometry of the object. *123D Catch* exports videos only as AVI files, though users can choose from several quality levels ranging from lower quality that is suitable for sharing with mobile devices, to high-definition videos at standardized 720p and 1080p settings. We found that videos had to be exported at either 720p or 1080p in order to fully capture the detail of the geometry and texture of the 3D object (Figure 21).
In order to make videos available online to residents of Sachs Harbour, they were shared using YouTube. We created a YouTube account for the Ikaahuk Archaeology Project through which videos were uploaded, and then linked to the Facebook page. Though Facebook does allow users to upload video internally, video files are restricted to a maximum of 1024 MB (1 GB), making it impossible to post some of the higher-quality videos generated through 123D Catch. We had more success uploading the videos to YouTube, as it has a higher file size limit (2 GB). In addition, YouTube allowed us to track how many times each video had been viewed, whereas Facebook did not. Uploading videos online required a steady Internet connection, which was not always available in Sachs Harbour. As such, uploading videos could take as little as 20 minutes when the Internet connection was reliable, but up to several hours when it was not. Once uploaded, videos could be viewed on YouTube in any Internet browser on a variety of personal computing devices, including computers, tablets, or smartphones.

2.1.14 Discussion and Implications for Future Research

The goals of this study were to investigate photogrammetry in archaeology through the comparison of two photogrammetry programs, 123D Catch and Photoscan, with reference to three issues: 1) the advantages and disadvantages of Photoscan and 123D Catch for use in in-situ field recording, 2) the utility of Photoscan and 123D Catch to document archaeological features typical of hunter-gatherer sites, and 3) the feasibility of using online means to share the finished 3D models from Photoscan and 123D Catch through social media. Overall, models created through Photoscan were higher in mesh quality than those created in 123D Catch, while 123D Catch was more effective for sharing results with a public audience as it processes models more quickly and facilitates their dissemination using social media.

2.1.15 Photogrammetry for in-situ Documentation

Both Photoscan and 123D Catch are useful for in-situ documentation, but they each have different strengths. Photoscan is more useful for processing photographs taken in less-than-ideal field conditions, as there are options for masking shadows, skies, bodies of water, insects, and other objects that would otherwise interfere with the generation of 3D
data. *Photoscan* can also work without an Internet connection, which makes it an ideal choice in remote field contexts where Internet is unavailable. If quick web dissemination was desired but Internet was unavailable or limited, 3D models could still be produced, and then shared as soon as an Internet connection was made. *Photoscan* had the longest processing times in this study, but the average processing time recorded in this study (about two hours per 3D model with version 1.0.1) is still quicker than previous versions of the same program, where processing a single 3D model required at least overnight processing or up to 26 hours (De Reu et al., 2014; Nguyen et al., 2012). Alternately, *123D Catch* has fewer options for manual intervention and manipulation of data. Though users can manually match data points in *123D Catch*, this prolongs processing time without providing significant benefits in overall mesh quality. *123D Catch* is better suited than *Photoscan* for situations where time in the field or time needed to process and share models is limited, since the former produces results more quickly. In any case where the aim is to create and share 3D models in “real-time,” *123D Catch* would be an ideal choice, as it processes quickly and models can be readily shared through YouTube.

2.1.16 Photogrammetry for Hunter-Gatherer Archaeology

3D models were generated successfully for most types of archaeological features in this study, indicating that low-cost photogrammetry is a viable option for documenting at least some of the more ephemeral feature types produced by hunter-gatherers. In this study, objects that were smaller (e.g. isolated artifacts) and more distinct from their surrounding landscape in terms of shape and texture (e.g. caches) resulted in higher quality 3D models that were more accurate representations of the original. In contrast, features that “blended in,” or were broadly similar in shape and texture to their surroundings (i.e. tent rings and sod houses), resulted in less detailed meshes. Meshes of tent rings, though lower in their overall quality as defined by the number of computed faces, were still largely representative of the original features. However, a successful and representative mesh was only generated for one sod house. This house, as discussed above, was situated on a gravel beach and was therefore more distinct from its surroundings than the second, which was covered in the same vegetation as the adjacent tundra.
The results of this study indicate a promising future for low-cost photogrammetry in the archaeology of hunter-gatherers, not just in the Arctic but in many parts of the world. There are many other types of archaeological features found on hunter-gatherer sites that display a distinct shape or texture from their surrounding landscape (if located on the modern ground surface) or their matrix (if located in an excavation unit). Such features could include shell middens, shell rings, hearths, post-holes, house pits, butchering areas, bone beds, and artifact or faunal scatters, all of which are found in North America (Jefferies et al., 2005; Lightfoot, 1993; Sivertsen, 1980), Central and South America (deFrance et al., 2009; Fitzpatrick et al., 2009), Australia (Lourandos, 1997, 1980), and elsewhere. In addition, archaeological features that did not model as successfully in this project may have better results in another context. For example, Rast (2012) used 123D Catch to create a 3D model of a tent ring for his blog Elfshot (Figure 22). In comparison to the tent rings documented in this study, the one documented by Rast consisted of stones that were much more distinct from their surrounding landscape in their geometry and texture, resulting in a realistic and representative 3D model.

![Figure 22: 3D Model of a Tent Ring by Tim Rast (2012), created with 123D Catch.](image)

Furthermore, while this research was focused on making 3D models of individual archaeological features, the results suggest that low-cost 3D modelling may be useful for documenting larger features, sites, or landscapes in future studies. In other projects,
professional or high-cost photogrammetry has been used to document large
archaeological sites or landscapes in combination with other 3D capture techniques. For
example, some projects have used 3D laser scanners to capture the geometry of a site and
then photogrammetry to capture its texture (Lerma et al., 2010). In other projects,
researchers have alternated 3D scanning and photogrammetry for different parts of an
archaeological site, depending on which method would best capture its geometry and
texture (Apollonio et al., 2012; Drap et al., 2003; Guidi et al., 2007). Given the ability of
the low-cost methods used in this research, it is likely that they could be also be
combined with 3D scanning methods to create high resolution and realistic 3D models of
larger areas of archaeological sites or entire archaeological sites in future projects.

High-cost photogrammetry has also been used to make 3D models of archaeological sites
using aerial photographs. Photographs taken by archaeologists in aeroplanes (Verhoeven
et al., 2012) or from cameras mounted in unmanned aerial vehicles (UAVs) (Eisenbeiss
et al., 2005; Lerma et al., 2010), have been successfully used to document large
archaeological sites or to survey landscapes for archaeological prospection. Using
additional equipment to take photographs covering larger areas from above, ranging from
poles and ladders to UAVs may allow archaeologists to cover larger areas with their
photographs (Plets et al., 2012). However, it is important to note that at this time most
low-cost photogrammetry programs are suitable only for creating visualizations through
matching data points and creating models. 3D models created with photogrammetry can
be used for mapping and prospecting archaeological areas in similar ways to how LiDAR
data or other aerial survey methods are used (Chase et al., 2012, 2011; Landry et al.,
2014; Verhoeven, 2011), but the features required to georeference 3D models and create
orthophotos are currently restricted to professional photogrammetry software. 3D models
of large archaeological sites or landscapes created with current low-cost options would
require further manual measurement and identification of ground control points within
professional photogrammetry or mapping software, which is usually expensive and time-
consuming (Verhoeven et al., 2012). Currently the Professional Edition of Photoscan
allows for the identification of ground control points and GPS coordinates for camera
locations within its work process, making it an ideal but expensive option for recording
broad sites and landscapes. Given the rate of improvement with low-cost
photogrammetry in the past ten years, in-program georeferencing abilities may be available in the future.

2.1.17 Disseminating 3D Models with a Community or Public Audience

The finished 3D models from photogrammetry were also valuable tools for sharing information with a non-specialist audience. Whereas 3D models created from other forms of 3D scanning, such as laser scanning or LiDAR, can require weeks of post-processing using specialized computers and software before they are ready for dissemination, 3D models created through these low-cost photogrammetry programs could be shared with interested members of the Sachs Harbour community in a much shorter period of time. When in Sachs Harbour with an unreliable Internet connection, all steps of creating a 3D model in 123D Catch, converting it to video form, and uploading it online could be carried out in a few hours in the evening after the day’s field work. This is quick compared even to other forms of modern photogrammetry (Verhouven, 2011), but as we had limited access to the Internet in the evenings during field work, it meant that usually only one 3D model could be processed each evening that we were in Sachs Harbour, limiting the number of models that could be shared during field work overall. However, even in limited numbers we were able to use the 3D models created in the evenings as a part of ongoing community engagement both in person and online via Facebook as soon as our field work started.

Though both 123D Catch and Photoscan are able to export 3D files into formats compatible with other 3D processing software, they also include options for easily sharing models without using additional software. This is especially the case with 123D Catch, whose developers both heavily utilize social media for promotion and product support, and encourage users to share their 3D models using the Autodesk network. Photoscan, while not as closely linked to social media or other Web 2.0 applications, also has practical options for disseminating 3D models. Their option for exporting in PDF format is particularly valuable, as it utilizes open source software and can run on multiple platforms (including Windows®, Mac OS, and mobile platforms including Android™ and iOS for iPhone and iPad), although there are no free options for mobile PDF readers at this time. Further, after the course of this research, a new version of Photoscan was
released that includes an option to upload 3D models directly to either of the 3D file hosting websites SketchFab (www.sketchfab.com) or Verold (www.verold.com), suggesting that Photoscan will be increasingly more compatible with online dissemination in the future.

Beyond online dissemination, low-cost photogrammetry programs can also play a greater role in engagement with communities in community-based archaeology projects, or any other projects where archaeologists wish to include non-experts in archaeological fieldwork. In this project we created 3D models that could be shared with a community audience, but community-based projects aim to include community members in the all stages of archaeological research (Atalay, 2012; Moser et al., 2002; Tully, 2007). Since the overall the process of taking photographs and processing them to create 3D models is straightforward, it could easily be an activity that archaeologists and community members can do together. Furthermore, since photogrammetry programs do not require special equipment or software that is expensive, community members who wish to document the archaeological phenomena that they encounter can do so without the presence of archaeologists, similar to the HeritageTogether project where independent community members photograph archaeological features for reconstruction with photogrammetry (Roberts, 2014). In areas where environmental conditions threaten the preservation of archaeological sites, one solution has been to mobilize local residents to monitor and record archaeological sites before they are destroyed, such as with the SCAPE Trust project, in which local residents regularly locate, monitor, and record archaeological sites in Scotland that are being destroyed due to coastal erosion processes (Lausanne, 2014; SCAPE Trust, 2014). With the increasing threat of climate change to sites in the Arctic (Barr, 2004; Dawson et al., 2013), including those used in this study (Hodgetts et al., 2014) the mobilization of communities may similarly help to document sites before they are lost, ultimately contributing to a greater understanding of the archaeology of the region.

2.1.18 Conclusions

Overall, this study has found that the low-cost photogrammetry programs Photoscan and 123D Catch have much to offer archaeological investigations of hunter-gatherers and
community-based archaeological research. Both programs are able to create 3D models fairly quickly for a range of archaeological features that are common to hunter-gatherer sites, whereas features that “blended” into their landscapes in this study did not model well. While photogrammetry is potentially useful for documenting a broader range of hunter-gatherer feature types such challenges will no doubt persist. This study has also suggested that low-cost photogrammetry has a promising future in engagement and outreach efforts. Both Photoscan and 123D Catch can create 3D models that are compatible for quick sharing with social media and both have the potential to be used in collaboration with communities or public audiences in future projects because they are user-friendly and require no specialized equipment. Given the rapid advancements since the mid-2000s, it is likely that low-cost photogrammetry techniques will continue to improve and become more accessible for the average archaeologist, opening up the use of 3D modelling to a more diverse range of archaeological research projects. In so doing, we must carefully consider the ethical implications of opening up access to these materials. It may not be desirable to make access to all objects and features public, and as such it is important work closely with Indigenous communities and other stakeholders when using Internet media to disseminate archaeological information. Through careful engagement with stakeholders, low-cost 3D modelling techniques as explored in this paper present an exciting and useful tool in democratizing archaeological research.

2.1.19 References


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Chapter 3

3 Comparison of 3D Scanning and Low-Cost Photogrammetry to Replicate Small-Scale Artifacts from Museum Collections

Advances in digital 3D technologies in the last two decades have provided new opportunities for archaeologists to document and visualize archaeological objects. 3D scanning techniques, which use a variety of means to create highly detailed copies of objects, have been the most common forms of 3D reconstruction in heritage since the 1990s. This technique is expensive and requires that users have prior expertise in computer science. In contrast, newly-released photogrammetry programs, a technique that uses data from 2D photographs to reconstruct objects in 3D, are inexpensive and user-friendly, opening up opportunities in 3D modelling to a broader range of archaeologists. Low-cost photogrammetry already has demonstrated utility in replicating large-scale archaeological and heritage materials, such as architecture, statues, and excavation sites. However, its potential and limitations in reproducing small-scale artifacts have been explored in less detail.

Digital representations of archaeology have been used to effectively engage with public and non-specialist audiences in several contexts, and are often created with this aim in mind. Social media applications related to Web 2.0 have also been used effectively to disseminate information about archaeological research to broad audiences. Their digital form makes 3D models of archaeological objects well-suited for use in public engagement using social media, but the methodological and technical challenges involved in sharing them online has not been thoroughly explored in the archaeological literature. This project explores the benefits, challenges, and limitations of using both high-cost and low-cost methods of digitally replicating small-scale objects, and examines the relative merits of the available means of making them accessible to a non-specialist audience through social media.

This research was carried out as a part of the Ikaahuk Archaeology Project, which aims to understand the history of Banks Island, NWT through collaboration between
archaeologists and the Inuvialuit (western Canadian Arctic Inuit) community of Sachs Harbour (Figure 23). At multiple community meetings and in individual conversations, community members have expressed a strong interest in artifacts from local archaeological sites, several of which have been excavated since the 1950s. They are concerned that these artifacts are held in far-away museum collections in Yellowknife and Ottawa. Despite attempts by several archaeologists to provide replica artifacts to the community, they have been lost or kept in buildings that community members seldom visit, and there is a general sense in the community that archaeologists’ promises of replica artifacts have remained unfulfilled. Digital replicas represent one way of making some of those artifacts that would otherwise be inaccessible in museum collections available in a digital form to community members in Sachs Harbour. Haukaas digitized a total of 21 artifacts from collections at the Prince of Wales Northern Heritage Centre (PWNHC) in Yellowknife, NWT, and they were shared through the Ikaahuk Archaeology Facebook page using a variety of formats, namely PDFs, videos, and an online embedded 3D object viewer.

The specific goals of this project were to a) determine the advantages and disadvantages of using high-cost 3D scanning and low-cost photogrammetry software to scan small-scale museum artifacts and b) to explore the ways that digital 3D replicas of artifacts can be hosted and shared online through social media to make them easily accessible to a non-specialist audience using a variety of Internet browsers and devices. We found that 3D scanning was far more effective than photogrammetry in replicating the complex geometry of small-scale items. However, photogrammetry was quicker, easier to use, more cost-effective, and as the technology was more mobile, we could use it to digitize museum artifacts that were too fragile to transport to a 3D scanner, or too large to fit in one. Furthermore, we found that 3D models created using low-cost methods were easier to disseminate using social media. Videos and embedded 3D objects were the most compatible with Facebook and were most versatile across Internet browsers and devices. PDFs, on the other hand, were able to retain more detail of the original objects, but were not compatible with mobile devices and were also not ideal for sharing with social media. Overall, we found that while 3D scanning technology still creates more accurate and
detailed replicas of small-scale artifacts, low-cost photogrammetry is increasingly effective and has many benefits related to engaging non-specialists in archaeology.

![Map showing the location of Sachs Harbour](image)

**Figure 23: Map showing the location of Sachs Harbour**

### 3.1.1 Background Information

### 3.1.2 3D Modelling in Archaeology

3D technology is increasingly useful in archaeology and cultural heritage management, as it allows archaeologists and other heritage professionals to create precise, high-quality digital copies of real-world archaeological materials, such as archaeological sites, features, landscapes, architecture, and monuments. Several methods exist to acquire 3D data and reconstruct objects digitally in 3D, but the most commonly used in replicating heritage objects are 3D scanning and photogrammetry. 3D scanning refers to the use of a 3D scanner, or specialized equipment that uses stereovision, light wave, or sound wave distance measurement to acquire information about an object's surface (Lambers et al.,
Though there are many types of 3D scanners, those that use non-contact measurements and thereby pose the least potential harm to the surface of the object are preferred in heritage applications, including laser scanners and structured light scanners. These scanners project light onto the surface of an object, which allows them to measure and capture geometric information in the form of a 'point cloud', which can then be used to reconstruct the surface of the object digitally. The technology of 3D scanners was first developed in the 1960s, and the first scanners were available commercially in the 1980s (Lu and Pan, 2010).

Photogrammetry, on the other hand, extracts information from 2D photographs to reconstruct objects in 3D. The technology of photogrammetry has changed significantly alongside developments in imaging technology. This technique, also known as image-based 3D modelling, uses structure-from-motion and stereo-reconstruction algorithms to identify and match shared points from overlapping photographs of an object and then uses those points to create dense digital meshes representing the surface of that object (Doneus et al., 2011; Lu and Pan, 2010, p. 41). Until the late 2000s photogrammetry software packages were expensive to purchase and required the use of metric cameras, photogrammetric scanners, or other specialized equipment (Fryer, 2007).

Since at least the 1980s, archaeologists have been incorporating various types of 3D technologies into their research as they are developed. Early 3D techniques were often experimental, and preferentially used by archaeologists who had prior experience in computer science (Remondino and El-Hakim, 2006). In the early 2000s, increasingly more archaeologists and heritage professionals were designing research projects that utilized 3D technologies to recreate archaeological sites (Benko et al., 2004), heritage architecture and monuments (Boehler et al., 2004), and artifacts (Pieraccini et al., 2001). The 3D methodologies in these projects tended to use hardware and software programs that were custom-built, expensive, and difficult to use (Fryer, 2007; Nguyen et al., 2012). These methodologies were highly specialized, and as such they were only utilized by a small subset of archaeologists and heritage professionals with computing expertise. However, these projects laid the groundwork for future explorations of 3D technologies in archaeology.
Within the last five years, the state of 3D technology has changed significantly, requiring less computing skill and thereby opening up new opportunities to a broader variety of archaeological applications. 3D scanners are still relatively expensive ($3000-300,000 USD), though their results have consistently improved and have been used to successfully document a variety of archaeological objects, ranging from large architecture (Apollonio et al., 2012; Lerma et al., 2010) to rock art (Wurtz, 2011) and small artifacts (Karasik and Smilansky, 2008). Available professional photogrammetry packages also remain beyond the means of most non-specialists ($1200-5000 USD). Within photogrammetry, several open-source, free or inexpensive web services and software packages have been released in recent years, many of which are designed to be automated and easily used by beginners in 3D technology. Several researchers have already recognized their potential within archaeology. Evaluations of low-cost, user-friendly photogrammetry programs in documenting large-scale objects such as complex excavation pits (De Reu et al., 2014), and standing buildings and monuments, (De Reu et al., 2013; Kersten and Lindstaedt, 2012; Santagati et al., 2013) have found that they have improved significantly in recent years, and the accuracy and quality of their finished products are now comparable to those from both 3D scanners and more expensive photogrammetry software packages.

With a few exceptions, the use of low-cost photogrammetry software to replicate small-scale objects, including artifacts, has not been explored in detail (Kersten and Lindstaedt, 2012; Nguyen et al., 2012). Successful applications of low-cost photogrammetry in archaeology tend to focus on monumental architecture, which consists of complex shapes, colours, and surface details (De Reu et al., 2014; Pavlidis et al., 2007). Photogrammetry works well with these types of objects, as software programs are significantly more likely to be able to calculate reference points and geometry for such “feature-rich” objects (Kersten and Lindstaedt, 2012). Smaller artifacts are less likely to be complex and detailed in their shape and texture than such large objects, resulting in fewer reference points with which photogrammetry software can calculate geometry and generate successful 3D models. Here, we explore the relative merits of 3D scanning and two low-cost photogrammetry programs in creating 3D artifact replicas.
3.1.3 3D Modelling in Archaeological Engagement

Digital replicas of artifacts are an important avenue for exploration in archaeology, as artifacts are valuable to a range of different stakeholder groups. While archaeologists continue to look to these objects to research the past (Fryer, 2007), they are also increasingly acknowledging the interests of other groups in heritage objects. Acknowledging stakeholder interest in archaeology has become especially important in the context of community-based archaeology projects, which aim to include local, Indigenous, or descendent communities in all stages of research (Atalay, 2012; Jensen, 2012; Moser et al., 2002; Tully, 2007). As identified by Gemma Tully (2007, p. 160) in her analysis of community-based archaeology methodologies, heritage objects “not only act as a bridge between past and present but can encourage the retelling of folklore, strengthen notions of identity and revive a pride in community heritage.” Accordingly, facilitating access to heritage objects has increasingly become a priority in community-based archaeology and community museology projects in the last two decades (Atalay, 2006; Killion, 2008a; Smith and Waterton, 2009).

Enabling public or community access to heritage objects in their original form or context, though desirable, is often a complicated task. There are several circumstances where original heritage objects are not available to interested stakeholders, whether archaeologists, communities, or public audiences. In many countries, for instance, items from archaeological sites must be curated in designated facilities with environmental controls, where access to them is limited to support preservation (Killion, 2008a). Objects in-situ, such as archaeological sites or monuments, as well as items in museums may be too distant from people who wish to visit them (Boehler et al., 2004; Patias, 2007). This is especially true in parts of the world with colonial histories, where artifacts and other cultural items are often held in museums and other institutions rather than with their associated descendant communities (Kuprecht, 2014). While many Indigenous groups continue to advocate for the physical repatriation of objects in museums (Ferguson, 1996; Killion, 2008b), others have explored digital repatriation. Digital representations of heritage objects, including 3D models but also photographs, audio files, and digitized documents, have been successfully integrated into some recent community-based
archaeology and heritage projects, where they have been utilized to evoke memories and perceptions of the past, and relate knowledge of the past to new generations of a community (Christen, 2006; Dawson et al., 2011; Ngata et al., 2012).

It should be cautioned, however, that digital replicas are themselves problematic as representations of heritage objects. As new digital and computing technologies are introduced into archaeology, they are sometimes viewed as objective, neutral, research tools that are free from theoretical assumptions, when in reality digital technologies and the products that they create are not inherently free from the assumptions and biases of the researchers, and are understood differently (Dallas, 2009; Morgan and Eve, 2012; Zubrow, 2006). This is particularly important to consider when working with heritage materials in a community-based archaeology context, as perceptions of digital representations of archaeological materials can also differ significantly between the Western scientific community and the local, descendant, and Indigenous communities with whom they collaborate. For example, while Western archaeologists are more likely to view reproductions of artifacts as 'copies' that share only aesthetic qualities with their originals, some Indigenous groups in North America feel that copies hold the same esoteric or spiritual qualities as the original artifact (Brown and Nicholas, 2012; Isaac, 2011).

3.1.4 3D Models and Social Media

Since 3D visualization was first available to archaeologists, presentation to public audiences is an oft-cited justification for integrating 3D technologies into archaeological projects, especially using Internet resources (Dawson et al., 2011, 2013; Fryer, 2007; Koller et al., 2010; Patias, 2007). Despite this acknowledged benefit, relatively few published articles address the methodological processes and challenges of sharing 3D models online (Berndt et al., 2010; De Reu et al., 2013), and one study found that only a small subset of heritage professionals who had created 3D models by 2007 had attempted to share them online at all (Koller et al., 2010). This limited dissemination of 3D models online stems from several causes, including technical challenges of hosting 3D files in websites (Berndt et al., 2010) and for the cost of hosting large databases of 3D models (Gourley and Viterbo, 2010).
Meanwhile, there are growing numbers of archaeologists who strongly advocate for the use of popular web resources to disseminate archaeological information in order to make research more transparent and accessible to public, non-specialist audiences (Jeffrey, 2012; Morgan and Eve, 2012). Increasingly, archaeologists and other heritage professionals have found success using online media associated with Web 2.0 to engage with multiple audiences and disseminate archaeological information, using media such as social media photo-sharing sites and video games (Kalfatovic et al., 2008; Morgan and Eve, 2012; Pett, 2012; Richardson, 2012). Some of the technological restrictions that limited sharing 3D models on the Internet in the past are being overcome and there are now more options for sharing 3D models online. Here, we explore the challenges and potential limitations of sharing 3D models through videos, interactive PDFs, and embedded 3D object viewers. These methods were chosen to explore a range of 3D files that do not require the acquisition of specialized software or browser extensions, in order to make them as accessible as possible to non-specialist audiences.

3.1.5 Materials and Methods

3.1.6 Digital Replicas and the Ikaahuk Archaeology Project

This research is a part of the broader Ikaahuk Archaeology Project, which aims to understand the history of Banks Island through partnerships with the local community of Sachs Harbour, NWT. At community meetings and consultations, local Inuvialuit have expressed a strong interest in having access to artifacts that originated on Banks Island but are currently stored in museum collections away from the community. According to the Northwest Territories Archaeological Sites Regulations, which came into force June 15, 2001, all artifacts recovered from archaeological investigations must be submitted to the Prince of Wales Northern Heritage Centre in Yellowknife, NWT. Local community members would be welcome to visit these original artifacts at the museums, however air travel to these locations is beyond the means of most Sachs Harbour residents. Some community members wished to have original artifacts returned to Banks Island, but the community does not have a museum or other facility with climate-controlled conditions appropriate for artifact storage.
Several community members requested artifact replicas to have as resources for public education and appreciation of the history of the island. Ultimately, we will ask the community to select a small number of artifacts for which we will commission physical replicas. However, physical replicas are problematic. They are expensive to commission initially, and they further require a designated space to be stored and someone within the community to take primary responsibility for them. Furthermore, if they are kept in a designated space in Sachs Harbour, they will only be accessible to those currently living within or visiting the community. Alternatively, digital methods of artifact replication can be relatively cost-effective. With a limited budget for artifact replication, and a large number of previously excavated artifacts in museum collections, we wanted to maximize the numbers of replicas that we could produce. We employed both high-cost 3D scanning and low-cost photogrammetry techniques to generate the digital replicas, in order to determine which method could create the highest number of artifact replicas in the shortest amount of time, while still producing high-quality results. Digital replicas can also be stored without a designated physical space. Many people who do not currently live in Sachs Harbour still identify as members of the community, though they have travelled elsewhere to find work, attend school, and for family and other reasons. Creating a digital access point allows Sachs Harbour community members, as well as other Inuvialuit and people who are interested in Arctic history to access the replicas as well.

A total of 21 artifacts were replicated as part of this project. All are curated at the PWNHC, the territorial museum of the Northwest Territories. At the request of community members in Sachs Harbour, we selected artifacts representing a variety of tasks related to living on the land, including sewing, cooking, hide processing, hunting, and fishing. We prioritized the replication of finished and complete artifacts in a good state of preservation. Three artifacts were documented only at the PWNHC for reconstruction using photogrammetry, while 18 artifacts were loaned from the PWNHC and taken to the Sustainable Archaeology Facility in London, Ontario, where Haukaas digitized them using a 3D3 White Light Scanner. Artifacts loaned from the PWNHC varied in size and material type, but tended to range from about 4-17 cm in length (Table 6) and included stone, bone, antler, metal, and wood. Artifacts that were only
documented at the PWNHC (Table 8) tended to be slightly larger and more fragile, both of which made transportation for replication with a 3D scanner problematic.

The artifacts came from three archaeological sites representing three different periods of occupation on Banks Island (Figure 24). Ten artifacts originated from the Lagoon Site (OjRI-3), which is located on the southern coast of Banks Island near the Masik River and was occupied around 500 BC. It is part of the poorly-understood Lagoon Complex (Arnold, 1980), known from two sites in the Canadian Arctic. It represents a local development from Pre-Dorset groups in the Western Canadian Arctic that was influenced by Dorset groups to the east and Norton Tradition groups from the west (Arnold, 1980; Le Blanc, 1994), and is one of several distinctive regional transitional phases between the Pre-Dorset and Dorset periods of the Arctic Small Tool tradition (Fitzhugh, 1980, 1972; Knuth, 1967; Maxwell et al., 1976; McGhee, 1976; Riddle, 2010). Five artifacts were from the Nelson River site (OlRr-1), which is a Thule-Inuit site located on the southern coast of the Island that was briefly occupied around 1250 AD (Arnold, 1994; Friesen and Arnold, 2008). The Thule are the direct ancestors of the modern Inuit occupants of the Arctic who migrated eastwards from Alaska around 1200 AD (Friesen and Arnold, 2008; Morrison, 2000). Nelson River is one of the earliest known Thule sites in the Canadian Arctic (Arnold, 1994; Friesen and Arnold, 2008; Morrison, 2000). Finally, three artifacts were recovered from two related archaeological sites on DeSalis Bay (OiRe-2, OiRe-9) on the southeastern coast of the island. This region was used by several Inuvialuit families from Banks Island and Victoria Island between the 1930s and 1950s for hunting and trapping (Nagy, 1999; Toews, 1998). These two sites have not been absolutely dated, but were most likely used in the 1950s.
3.1.7 3D Scanning

3.1.7.1 Data Collection

Artifacts were scanned using a 3D3 White Light scanner with a Large FOV (field of view) kit at the Sustainable Archaeology research facility in London, Ontario. This scanner consists of a projector with two cameras on a mounted tripod that project a fringe pattern over an area of an object. While scanning, the fringe is modified in width and phase, allowing the 3D scanner to extract multiple sets of 3D coordinates by calculating the returned patterns on the surface of the object. During scanning, artifacts were placed on pedestals of foam on a rotary table. The table rotates the object so that the 3D scanner can collect 3D coordinates from multiple angles on the surface of the object. The cameras of the scanner were calibrated daily and the rotary table was calibrated several times daily to ensure that the cameras were accurately collecting data. Using the program Flexscan3D, data collected from the scanners as point clouds are converted into mesh form (PLY format). Generally multiple scans from different perspectives are required to
capture the full geometry of the object being scanned. At this stage, scans are manually edited in Flexscanned to remove unwanted areas, such as materials that were used to support the object during the scanning process. Meshes created from multiple perspectives are then combined to create a finished scan, which is processed to reduce “noise” (erroneous data points) and fill small holes in the geometry using FlexScan3D.

3.1.7.2 Data Processing

The 3D models were further processed in external software programs to finish meshes and apply textures. Finished objects were first imported into the 3D processing software Geomagic Studios™ in OBJ format where further corrections were made in the mesh to account for holes and noise. 3D models created using this method represent the geometry of objects, but not their texture or colour. In order to make models as realistic and accurate as possible, textures were added using texture mapping (Figure 25). This method draws from techniques in 3D animation, and projects texture information from high-resolution photographs onto the surfaces of 3D models (Betts et al., 2011). Artifacts were photographed using a high resolution digital camera with a macro lens. Usually four to six pictures were sufficient for each artifact to fully represent all aspects of its surface. Photographs were then mapped onto 3D objects using the program Zbrush at the Sustainable Archaeology Facility. 3D models were processed to create UV maps, 2D representations of 3D models as if the models were cut along seams and laid on a flat surface. After textures were applied to 3D models they were saved as Bitmap files (BMP), which are 2D images that correspond to the UV map of the original 3D model (Figure 26).
Figure 25: Scan of decorated harpoon head (PWNHC 982.50.362). Left: Original Scan. Right: Decimated Scan with Texture.

Figure 26: Example of BMP image used in texture mapping. Image is the texture map for the decorated harpoon head (PWNHC 982.50.362).
3.1.8   **Photogrammetry**

3.1.8.1   **Data Collection**

Artifacts were recorded in sets of high-resolution photographs for the purposes of creating 3D models using photogrammetry. Artifacts were photographed using a non-metric Nikon D3200 24 megapixel digital camera with a 35 mm lens. In order to facilitate image stitching by the photogrammetry programs, artifacts were propped on curation-quality foam that was marked with geometric symbols, which was then placed on top of newspaper surrounded by objects of varying sizes and colours (Figure 27). A ‘busy’ background with complex colour and geometry facilitates data point matching between photographs and results in more accurate models.

![Figure 27: Typical method of photographing artifacts for use with photogrammetry. PWNHC 982.50.603](image)

Photographs were taken in at least four sequential loops surrounding each object. The first set of photographs included a loop at a mid-angle facing the object followed by a second loop at a high angle. These photographs documented the entire scene, including the artifact, its foam pedestal, and the objects used as aids. The second set of photographs included one loop each at mid and high angle as in the first loop, but only capturing the
artifact on the top of its foam pedestal and not the surrounding objects. The number of photographs taken varied between 40 and 80 for each artifact, depending on its size and complexity. It was not necessary to take photographs from a precise or fixed distance from the target objects, as the photogrammetry programs used in this study automatically derive reference points from shared features in photographs to build geometric information.

### 3.1.8.2 Data Processing

We generated 3D models with two photogrammetry programs: *Photoscan* and *123D Catch*. Using *Photoscan* (Standard Edition, version 1.0.1), we processed photographs at the highest quality setting in each stage of the program’s four-step 3D modelling process. In *123D Catch*, we generated meshes at Maximum Quality. Full descriptions of both programs and their 3D modelling processes are available in Chapter Two (pp.32-77).

### 3.1.9 Disseminating 3D Models

As the overall goal of this project was to create content that could be shared with a community audience, it was important to make 3D models available in a file format that can be viewed without any specialized software programs or computers. We were already using our Ikaahuk Archaeology Project Facebook page to disseminate our research, to members of the Sachs Harbour community within the hamlet and elsewhere in the Northwest Territories, as well as archaeologists and other members of the public, as discussed in Section 2.1.9 (pp.49-50). However, Facebook currently does not support the internal embedding of any 3D files. Instead, we utilized three methods of disseminating the 3D models, videos, 3D PDFs, and embedded in-browser 3D model viewers, all of which were shared with Sachs Harbour community members and the broader public via the project’s Facebook Page.

First, we created videos using *123D Catch* for 3D models created within that program. Videos were generated in AVI format and usually took the form of a camera following a path that slowly circles the 3D object, showing different angles and then zooming to show detail. *123D Catch* exports videos only as AVI files, though users can choose from several quality levels ranging from lower quality (Mobile and Large settings), to high-
definition videos (720p and 1080p). Videos can be saved or directly uploaded to a designated YouTube account from within 123D Catch.

Second, we created PDFs of 3D models generated using 3D scanning and Photoscan. These files display a 3D object that can be rotated or zoomed using the mouse and they can be viewed using any modest computer with Adobe Acrobat or most other free PDF readers (Betts et al., 2011). Unfortunately, PDF readers that can display objects in 3D are not currently available for free for mobile devices. PDFs were created for artifacts scanned using the 3D3 White Light scanner in two steps. They were saved in OBJ format with texture in BMP files, and then those files were loaded into Adobe Photoshop CS6 Extended and exported as Universal 3D format (U3D) files, which were then converted into PDF files in Adobe Acrobat X Pro. PDF files were generated for 3D files created in Photoscan using a feature within the program.

Third, 3D files created with all three methods were uploaded using the web-hosting site SketchFab. This site allows users to create free profiles and upload 3D files in a variety of formats, which are then available for viewing and manipulating (rotating and zooming) on the SketchFab website. Additionally, users can embed 3D files into other websites that are uploaded into SketchFab. We uploaded files to the SketchFab site and then linked to them through Facebook.

3.1.10 Assessing 3D Models and Methods

In order to determine the advantages and disadvantages of low-cost and high-cost 3D replication methods we compared the quality of the 3D models and the time required to complete them. Quality measures the success of each method in modelling small-scale objects and was assessed by comparing the number of computed faces in the finished models. 3D scanning and photogrammetry, along with most conventional surface reconstruction programs, recreate surfaces of objects as triangular networks known as “meshes” within computer graphics literature and as triangulated irregular networks (TIN) in geographical information technology (Remondino and El-Hakim, 2006). These surfaces consist of thousands of connected faces and the vertices that connect them. Meshes that have a higher number of computed faces can provide a more complex and
detailed digital representation of an object’s surface. The time required for 3D modelling is important when, as is often the case, there are time constraints on researchers’ access to either the objects (often in museum collections) or the scanning equipment (users often have to pay for instrument time). We calculated time to completion based on the time required for data collection, 3D model generation, and texture mapping.

We also assessed the methods of online dissemination to determine how effectively the videos, 3D PDFs, and embedded objects in websites could present the 3D models, and how compatible they were with dissemination through Facebook across multiple Internet browsers and mobile devices. We also compared how much the original meshes of 3D models had to be reduced in quality in order to be compatible with the online dissemination methods and suitable for use with a modest, non-professional quality computer.

3.1.11 Results
This study investigated the benefits and challenges of low-cost photogrammetry in comparison to high-cost 3D scanning for digitally replicating small-scale artifacts, and ways that digital replicas can be shared with a community audience using online resources. We found that 3D scanning was better able to capture the complex geometry of small-scale artifacts, but the 3D modelling was time-consuming and required the use of several expensive and non-user-friendly devices and software programs. Low-cost methods, alternatively, were very user-friendly but were limited in their ability to replicate very small artifacts. For dissemination methods, PDFs were able to capture the detail of the original 3D models but they were the least compatible with social media and mobile platforms. Videos on YouTube and embedded models on SketchFab were more versatile across multiple platforms and compatible with sharing through social media.

3.1.12 3D Scanning
A total of 17 items were successfully scanned using the 3D3 White Light scanner. In order to capture the full geometry of the objects in question, we used a rotary table and set the 3D scanner to collect 3D coordinates every 30 degrees, so that the surface of each artifact was scanned 12 times during each rotation. Objects were scanned from a
minimum of three positions, meaning that each object underwent scanning for three rotations on the rotary table in two different positions and the scanner collected a total of 36 scanning images. Artifacts with more simple geometry, such as the awl in (Figure 28), needed as few as four scanning positions, whereas artifacts with more complex geometry, including incisions or drilled holes, such as the lure in the same figure, required scanning in more positions (12 in the case of the lure). Artifacts that required more scans had more detailed meshes, though the average number of computed faces for all 3D models of artifacts was 751,546 before objects underwent texture mapping (Table 6). The only artifact that could not be scanned successfully using this method was a bone needle that was approximately 2 mm in width and 5 cm in length. Due to its small width its geometry was difficult to capture. It is likely that scanning from several more positions would have resulted in sufficient data collection, but we did not want to risk damaging the fragile artifact so we did not complete additional scans.
Figure 28: Left: Awl (PWNHC 982.50.154). Right: Lure (982.44.003). The geometry of the lure was more complex than the awl, requiring more scans to fully capture it.
Table 6: Artifacts scanned with 3D3 White Light Scanner. Table compares artifact material, artifact size, scans recorded, and the number of computed faces in original and decimated scans.

<table>
<thead>
<tr>
<th>Artifact No.</th>
<th>Site</th>
<th>Artifact Description</th>
<th>Artifact Material</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Approx. Surface Area (cm²)</th>
<th>Number of Scans</th>
<th>Original Scans</th>
<th>Condensed Scans</th>
<th>Decimation as % of Original Scans</th>
</tr>
</thead>
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<tr>
<td>982.50.174</td>
<td>Lagoon</td>
<td>Awl</td>
<td>Bone</td>
<td>11.26</td>
<td>1.36</td>
<td>0.59</td>
<td>9.02</td>
<td>48</td>
<td>350630</td>
<td>17666</td>
<td>5.04</td>
</tr>
<tr>
<td>982.50.69</td>
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<td>Burin</td>
<td>Lithic</td>
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<td>2.73</td>
<td>0.77</td>
<td>10.04</td>
<td>48</td>
<td>403364</td>
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<td>50</td>
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<td>Projectile</td>
<td>Bone</td>
<td>12.81</td>
<td>0.95</td>
<td>0.46</td>
<td>5.55</td>
<td>36</td>
<td>580994</td>
<td>24998</td>
<td>4.3</td>
</tr>
<tr>
<td>982.50.154</td>
<td>Lagoon</td>
<td>Harpoon Foreshaft</td>
<td>Bone</td>
<td>14.08</td>
<td>1.31</td>
<td>0.60</td>
<td>11.03</td>
<td>48</td>
<td>345968</td>
<td>345968</td>
<td>100</td>
</tr>
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<td>982.50.362</td>
<td>Lagoon</td>
<td>Decorated Harpoon Head</td>
<td>Bone</td>
<td>11.55</td>
<td>1.72</td>
<td>0.66</td>
<td>13.17</td>
<td>48</td>
<td>681580</td>
<td>272628</td>
<td>40</td>
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<td>Blad</td>
<td>Lithic</td>
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<td>2.08</td>
<td>0.88</td>
<td>13.17</td>
<td>36</td>
<td>824245</td>
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<td>Needle Blank</td>
<td>Bone</td>
<td>10.88</td>
<td>0.74</td>
<td>0.57</td>
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<td>36</td>
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<td>Pendant</td>
<td>Bone</td>
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<td>1.94</td>
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<td>36</td>
<td>550710</td>
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<td>Lithic</td>
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<td>0.64</td>
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<td>476024</td>
<td>100012</td>
<td>21.01</td>
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<td>Awl</td>
<td>Wood</td>
<td>9.28</td>
<td>1.76</td>
<td>1.58</td>
<td>25.78</td>
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<td>Wood</td>
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<td></td>
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<tr>
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<td></td>
<td>Tip</td>
<td>Metal</td>
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<td>144424</td>
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<td>982.40.611</td>
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<td>Harpoon Head</td>
<td>Bone</td>
<td>8.03</td>
<td>2.91</td>
<td>2.46</td>
<td>21.61</td>
<td>60</td>
<td>1326383</td>
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<td>Bone</td>
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<td>Ulu blade</td>
<td>Lithic</td>
<td>16.93</td>
<td>1.81</td>
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<td>Ulu Handle</td>
<td>Wood</td>
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<td></td>
<td></td>
<td>751546</td>
<td>129416</td>
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</table>
In order to perform texture mapping and prepare scans for dissemination online, the meshes of completed scans had to be decimated, or reduced in their overall number of computed faces. Decimating meshes is often necessary when broadly disseminating 3D models, as only computers with advanced graphics processing capabilities are suitable for working with 3D models that have very large numbers of computed faces (Betts et al., 2011). For this project, decimation was completed using Geomagic Studios™ 2012. Meshes were decimated as little as possible, because decimation reduces the detail in their shape and texture. However, models that had exceptionally large numbers of computed faces had to be reduced substantially order to attain file sizes suitable for online dissemination and for use with average computers. Meshes were reduced to an average of 23.24% of their original state resulting in an average of 129,416 computed faces.

Creating 3D models using this method was difficult and time-consuming. To begin, several days of training prior to beginning the scanning projects were required in order to learn how to use the hardware and various software programs used in this method. Scanning with the 3D3 White Light scanner was carried out initially over a total of 27 hours. Each artifact required between 30 and 60 minutes to scan, depending on its complexity. The additional time was required to calibrate the scanner and rotary table and to allow troubleshooting during occasional hardware or software malfunctions. Texture mapping required a further 26 hours, including the time needed to collect and process photographs to build texture maps. In total, 53 hours were required to scan the 18 artifacts, resulting in an average of 177 minutes (2.95 hours) of manual processing for each artifact (Table 7).
Table 7: Recorded time required to capture data and build 3D models with the 3D3 White Light Scanner, Photoscan, and 123D Catch

<table>
<thead>
<tr>
<th></th>
<th>3D3 White Light Scanner</th>
<th>Photoscan</th>
<th>123D Catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Time</td>
<td>1620</td>
<td>160</td>
<td>3628</td>
</tr>
<tr>
<td>Average Time per Artifact</td>
<td>90</td>
<td>23</td>
<td>518</td>
</tr>
</tbody>
</table>

3.1.13 Photoscan

A total of seven items were modelled using Photoscan, four of which were also scanned using the 3D3 White Light scanner (Table 8). Items were processed using the highest-quality settings in all steps of the automated workflow of Photoscan, and masks were applied as needed to facilitate photo stitching. Photoscan was able to create fairly dense meshes for each of these objects, with an average number of computed faces of 182,668. Photoscan also generated a detailed and realistic-looking texture for each of the objects. It created significantly fewer computed faces than the original scans from the 3D3 White Light Scanner, but more computed faces on average than the white light scans that were decimated for texture mapping and disseminating online (Figure 29).
Table 8: Artifacts replicated with 3D3 White Light Scanner, Photoscan, and 123D Catch. Table compares artifact material, artifact size, and the number of computed faces for 3D models.

<table>
<thead>
<tr>
<th>Artifact No</th>
<th>Artif</th>
<th>Site</th>
<th>Artifact Description</th>
<th>Material</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Approx. Surface Area (cm²)</th>
<th>White Light Scanner</th>
<th>Photogrammetry</th>
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<td>982.50.174</td>
<td>1</td>
<td>Lagoon</td>
<td>Awl</td>
<td>Bone</td>
<td>11.258</td>
<td>1.362</td>
<td>0.588</td>
<td>9.016</td>
<td>350630</td>
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<td>982.40.671</td>
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<td>Nelson River</td>
<td>Ulu Blade</td>
<td>Lithic</td>
<td>8.617</td>
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<td>1.295</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>Handle</td>
<td>Wood</td>
<td>9.278</td>
<td>1.76</td>
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<td>Metal</td>
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<td>982.50.603</td>
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<td>982.47.010</td>
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<td>DeSalis Bay</td>
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Despite the fairly dense meshes generated by Photoscan, capturing an object’s full geometry in order to create a ‘floating object’ 3D model (which represents the entire artifact independent of the surface it rests on) was problematic, as Photoscan relies on a fixed, unmoving scene in order to identify data points and generate point clouds. As such, the object must stay in the same position during documentation. As a result, the portion of its surface on which it rests during documentation is not captured. In addition, portions of the artifacts that measured less than 1 cm in any orientation usually resulted in meshes with erroneous data points and were not effectively replicated in the models. For example, the tip of the awl (PWNHC 982.47.009) in Figure 30, which measures 0.48 cm, is distorted in the 3D model created through 123D Catch, whereas it is replicated sufficiently with the 3D3 White Light Scanner and Photoscan.

In comparison to 3D scanning, Photoscan was relatively simple to use. As the process of 3D modelling is mostly automated, it required little input from the user besides loading photographs, masking unwanted areas of photographs or point clouds, and choosing mesh
quality levels. Collecting data through photographing artifacts was relatively quick (average of 23 minutes) and additional input required an average of 12 minutes per model to mask photographs and assess the data. The automated processing was, alternatively, quite time consuming, requiring an average of 518 minutes (8.63 hours) of automated processing time, resulting in a total of 553 minutes (9.22 hours) for each model when processing at the highest quality settings (Table 7).

![Figure 30: Awl (PWNHC 982.47.009). Left: 3D3 White Light Scanner. Mesh decimated. Center: Photoscan. Mesh processed at high quality with a dense point cloud. Right: 123D Catch. Mesh generated at Maximum Quality.]

3.1.14 123D Catch

The items modelled using Photoscan were also modelled in 123D Catch. Meshes were first processed at the default Standard Quality and then again at Maximum Quality. 123D
Catch resulted in meshes with the fewest number of computed faces, with an average of 51,198 (Table 8). Like Photoscan, 123D Catch was unable to generate accurate meshes for smaller objects or parts of objects measuring less than 2 cm, resulting in inaccurate and poorly-generated meshes. In contrast, the larger (at least 10 cm) objects documented only with photogrammetry resulted in higher-quality meshes that were more representative of the original objects, but less detailed than those created through Photoscan. Like Photoscan, 123D Catch relies on a static background to build meshes, and presented similar challenges in capturing the entire geometry of an item to create a ‘floating object’.

We found that overall 123D Catch was the simplest and quickest method for generating 3D models. In each case it took an average of 23 minutes to collect photographs and then an additional 47 minutes to process them. Almost no user input was required beyond uploading photographs, selecting mesh quality to generate, and inspecting meshes, which took an average of five minutes per object. The total time needed to create models was 75 minutes (1.25 hours) per artifact including data collection (Table 7). However, technical issues were very common during processing. While 123D Catch will load a maximum of 80 photographs, it often terminates processing if more than 30-40 high-resolution photographs are loaded, which resulted in longer processing times and poorer-quality geometry in the 3D models, as sometimes photographs had to be left out in order for 123D Catch to process a model.

3.1.15 Dissemination of 3D Models

In order to demonstrate 3D models created with 123D Catch, we created videos that consisted of a custom animation path following two loops around each artifact, with one loop zoomed in to show fine details of the 3D model. Videos that were lower in quality did not necessarily represent the detail in the original 3D models, while videos exported in high definition at either 720p or 1080p were better able to capture the detail of the geometry and texture of the 3D model. The meshes of the 3D models did not have to be decimated to convert them to video format. In order to make videos available online to Sachs Harbour residents and others, they were uploaded to YouTube and then shared via Facebook. Creating video files at higher quality levels required about 15 minutes of
processing time within 123D Catch, and then an additional 20-30 minutes to upload onto YouTube.

Models created with 3D scanning and Photoscan were exported successfully as PDF documents. These PDF files display the 3D models, retaining the quality of geometry and texture of the original 3D models, and can be manipulated by the user. However, PDFs were the most problematic file type to share through Facebook. The 3D models generated through Photoscan and 3D scanning resulted in large PDFs that are slow to load and difficult to manipulate within a PDF reader. Furthermore, Facebook requires that uploaded files are less than 25 MB. In order to create PDFs that can be easily loaded and manipulated on an average user’s computer and meet the Facebook file size requirements, we had to reduce meshes to a maximum of 200,000 computed faces, and preferably fewer than 100,000. These restrictions produced PDFs that averaged 5-10 MB in size, well within the Facebook parameters and still able to load on an average computer. The average file sizes of PDFs were 9.2 MB for files created with the 3D White Light Scanner and 9.52 for 3D models generated through Photoscan (Table 9).

To host 3D models online through SketchFab, we saved them as OBJ files with textures in JPEG format and uploaded these together into SketchFab. With a free account on SketchFab, we were restricted to uploading file sizes of no more than 50 MB. The 3D models created through 3D scanning in OBJ format with texture were an average of 15.88 MB each, whereas OBJ files from Photoscan with texture averaged 22.35 MB. Though the 3D models from both methods met the Sketchfab size requirements, we found that models with more than 100,000 faces or with file sizes greater than 20 MB were slow to load and difficult to manipulate using SketchFab on an average computer with a high-speed internet connection.

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<th>3D3 White Light Scanner</th>
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<th>123D Catch</th>
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<td>OBJ with Texture</td>
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<td>Average File Size (MB)</td>
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3.1.16 Discussion

3.1.17 Advantages and Disadvantages of High- and Low-Cost 3D Replication Methods

Through this case study we were able to identify several advantages and disadvantages of high- and low-cost methods of creating 3D digital replicas of artifacts. Artifacts created with the high-cost 3D scanner displayed the highest overall quality. They had the highest number of computed faces in their meshes prior to being decimated for dissemination, and they better represented the original shapes of the artifacts. The 3D scanning method was better able to represent artifacts because it allowed for objects to be scanned from multiple perspectives, which captures more visible surfaces of the original artifact. The scanner was also able to capture even very small (<5 mm) details, and more successfully reconstructed geometric complexities, such as cracks, incisions, or drilled holes.

Nonetheless, there were numerous disadvantages to the 3D scanning method. It required the use of very specialized technology, including both the scanning equipment and the software needed to process the data, which are expensive and difficult to learn to use. Even when we were familiar with the process of 3D scanning, it still required several hours of constant manual input. Additionally, while the meshes created through 3D scanning were very high in quality, they had to be decimated significantly in order to create files that were compatible with online dissemination methods, resulting in meshes that were more similar in terms of the number of computed faces to those created through the photogrammetry methods. Finally, in this case study, artifacts were transported from PWNHC in Yellowknife to the 3D scanner at the Sustainable Archaeology Research Facility in London, Ontario. This restricted the range of artifacts that could be scanned, as it meant that items that were too large or fragile to be transported could not be digitized.

The low-cost photogrammetry methods were not able to create 3D models that were as detailed as those created through 3D scanning. We found that Photoscan was a better option than 123D Catch for modelling very small artifacts because it offered more options for manually intervening in the 3D generation process to mask photographs and also because it created meshes with higher numbers of computed faces. However, even
with *Photoscan* very small artifacts or details of artifacts less than 1 cm in size could not always be modelled accurately. Both *Photoscan* and *123D Catch* more successfully modelled artifacts (and elements thereof) that were larger in size (at least 5 cm). Smaller artifacts resulted in poorer-quality 3D models in comparison to the larger artifacts that were only documented using photogrammetry methods, most likely because they had less surface area and were less complex in their shape and texture, resulting in fewer opportunities for the photogrammetry programs to identify and match data points between photographs.

Even though the quality of meshes in 3D models generated using the low-cost photogrammetry programs was not as high, these techniques had several advantages over the 3D3 White Light scanner. In particular, *123D Catch* could process data to create models very quickly, with a turnaround time of less than one hour from photography to a completed 3D model. Processing time with *Photoscan* was longer, but the results of this study show a significant improvement in comparison to older photogrammetry programs, including those recorded with older versions of *Photoscan*, where processing batches of 20 images could require up to 26 hours (Nguyen et al., 2012). Both of these programs were simple enough that we could create 3D models with them without any prior training or prior experience with photogrammetry or 3D modelling, making these processes significantly more user-friendly than 3D scanning. Finally, while creating 3D models and preparing them for dissemination using the 3D3 White Light scanner method required several steps using multiple programs, both *Photoscan* and *123D Catch* created textured 3D models that were ready to be shared using only internal features of the programs, making the photogrammetry programs even more cost-effective and convenient for the average user. In this study, we found that *Photoscan* was a more effective photogrammetry program for use in replicating small-scale items, because it could process larger batches of photographs without technical challenges, it could replicate smaller artifacts more accurately, it could show more detail in both mesh and texture. However, *123D Catch*, due to its quick processing speed and ease of use, may be of more use to users with limited experience with 3D modelling or users with stricter time restrictions for processing models.
3.1.18 Advantages and Disadvantages of Online Dissemination Methods

Similarly, each of the methods for sharing 3D models online has strengths and weaknesses that make it more or less well-suited in particular contexts of use. The videos retain the details in shape and texture of the original 3D models, though they are less interactive for the user than the other dissemination methods, which allow users to zoom and rotate 3D models. PDFs are more interactive for users, though the quality of 3D models has to be reduced in order to create files that can be shared and used online. Further, users are required to download the PDF files to their own computers in order to view them, and there are currently no free PDF readers for mobile devices. Though the ability to save files to a personal computer means they can be accessed later without an internet connection, downloading several large files individually is a time-consuming process. 3D models uploaded to SketchFab had the advantage of being both interactive and quick to access for the user, with a more generous file size allotment per 3D object. SketchFab and YouTube videos were also advantageous for sharing with Facebook, as both websites already promote sharing with Facebook. YouTube videos embed and play within a Facebook page and links to SketchFab show a large thumbnail image with a direct link to the interactive 3D model, which make them more readily available to Facebook users.

The challenges of dissemination identified in this study, especially regarding file size limitations, are dependent on the context in which they are shared online. Within this project, we oriented our dissemination methods to be compatible with Facebook, according to the wishes of our primary target audience, the community of Sachs Harbour. Through Facebook, we were able to quickly share 3D models in a free, online space that was already familiar to our audience, though we were also met with certain restrictions on what we could share, in terms of file sizes and formats. Were we sharing through other forms of social media (Twitter, Flickr, etc.), we would encounter similar restrictions. Hosting 3D models in a more traditional website format would provide more flexible opportunities to host a variety of file formats and sizes, but might generate less traffic than our Facebook page.
3.1.19 Implications for Future Research

The results of this study indicate that low-cost photogrammetry methods have a valuable place within 3D modelling of archaeological objects. We identified limitations with both Photoscan and 123D Catch; they are not as effective as high-cost methods for accurately documenting artifacts or parts of artifacts that are small (less than 5 cm in any direction) and they do not always capture the entire geometry of an object since it must rest on a fixed, unmoving background, which can be problematic depending on the shape of the object. However, low-cost photogrammetry is still a potentially valuable tool for replicating artifacts and other heritage objects in museum collections. Photoscan and 123D Catch can both create realistic 3D models of artifacts larger than 5 cm, and they require a relatively short amount of time with the original artifacts. This feature can allow archaeologists to make 3D models of artifacts that cannot be transported to be documented at a 3D scanner, such as very large, heavy, or fragile items. While the ‘floating object’ issue applies more strongly to documenting very small objects, it is less pertinent when documenting certain types of artifacts, such as those that would normally be placed with one side resting on a surface, or objects that are too fragile to be frequently moved from their curated position, such as the child’s kamik (boot) in Figure 31.
This study has considered only low-cost photogrammetry software and dissemination via digital media, but current developments in 3D replication technology suggest that low-cost options will likely continue to expand. Photogrammetry has become significantly more affordable and user-friendly since the mid-2000s (Boehler and Marbs, 2004; Kersten and Lindstaedt, 2012; Remondino and El-Hakim, 2006), and 3D scanners are similarly following this trend. Several desktop and handheld 3D scanners, such as the Fuel3D (http://www.fuel-3d.com/), the Makerbot Digitizer (http://store.makerbot.com/digitizer), and others that are in development may provide another comparatively low-cost ($1250-3000 USD) alternative to expensive 3D scanners that cannot be transported in the future.

Furthermore, low-cost photogrammetry may be combined with 3D printing technologies in future research. 3D printing technologies allow users to create physical replicas from digital 3D files, and already these have been utilized by archaeologists who wish to make objects from museum collections more widely accessible. For example, the Smithsonian X 3D project (http://3d.si.edu/) has begun to digitize heritage objects using 3D scanning technologies, with the intention of allowing users to make physical copies of them using 3D printers (Waibel, 2014). Some 3D printers can now be attained at a relatively low
cost, such as the Makerbot Replicators (http://store.makerbot.com/) which range from $1375-$2799 USD, and individual replicas can be ordered from retailers such as i.materialise (http://i.materialise.com/) and Shapeways (http://www.shapeways.com/). Autodesk currently supports 3D printing primarily through their program 123D Make (http://www.123dapp.com/make), though physical replicas or 3D models can be ordered directly through 123D Catch as well. The ability to quickly create high-quality and accurate physical copies of artifacts for a relatively low cost has untold potential for archaeology, especially in cases where access to original artifacts is limited.

3.1.20 Digital replicas and Community-Based Archaeology

Digital replication of artifacts using low-cost methods can play an important role in community-based archaeology projects. Many communities wish to have access to artifacts that are in museum collections, but the repatriation of original objects is often a complex, political, and expensive process (Killion, 2008b; Kuprecht, 2014). This study has indicated that when the repatriation of original items is not possible, digital replication can be an accessible alternative. Digital copies can be shared online using social media platforms with which community members are already familiar (in this case Facebook), and the copies can be shared online not only with multiple and dispersed communities (e.g. diasporic communities; Atalay, 2012, Singleton and Orser, Jr, 2008).

In addition, since the photogrammetry programs used in this study are inexpensive and do not require specialized equipment, they can be used in collaborative endeavours between communities and heritage professionals, or by communities themselves. Community-led heritage documentation has been successful in some other projects (Roberts, 2014; SCAPE Trust, 2014), and has the potential to make a particularly large contribution to our understanding of archaeology in remote regions such as the Arctic, where many archaeological sites remain undocumented but are known to local people who travel on the land. A tool such as 123D Catch can be used by community members to record artifacts in-situ on Arctic archaeological sites, where they are common due to the limited soil development in the tundra environment. Documentation through 3D modelling may be a useful way of preserving and sharing knowledge about archaeological sites while leaving sites intact, as an alternative to collecting artifacts and bringing them home,
which is a common issue in archaeology in many parts of the world. Given that the Arctic archaeological record is also increasingly threatened by climate change, which is accelerating coastal erosion and driving permafrost melt (Blankholm, 2009; Chapman, 2003; Goetz, 2010; UNESCO, 2007), photogrammetry could be effectively utilized in a community-based program to document threatened Arctic sites. It could also be deployed in existing community-based programs designed to document sites threatened by coastal erosion, such as SCAPE (Scottish Coastal Archaeology and the Problem of Erosion; SCAPE Trust, 2014), and in new initiatives designed to mobilize concerned publics to deal with climate change-related and other threats to the archaeological record worldwide.

Similarly, low-cost 3D technologies may be of use in future community-based museum projects, where museums aim to collaborate with local, descendant, or Indigenous communities to develop exhibits or care for heritage objects (Atalay, 2006, 2008; Killion, 2008b). Community-led projects that intend to digitize heritage information for their communities, such as the Te Ataakura project led by the Maori tribal organization Toi Hauti (Ngata et al., 2012) would likely benefit from user-friendly and inexpensive tools for 3D replication.

However, it is important to consider the many ethical issues related to the replication of artifacts and other heritage objects. While some communities have actively pursued digital replication of heritage objects (Ngata et al., 2012), there are others that do not wish to make some or all of their heritage objects publicly available due to the esoteric or intangible qualities of the objects (Boast and Enote, 2013). Furthermore, concerns of intellectual copyright of artifacts should always be carefully considered when publicizing heritage objects, especially when using online forms of hosting and sharing information. Ongoing discussions with community stakeholders regarding which types of artifacts can be replicated, which can be placed online, and who can access them are all crucially important.
3.1.21 Conclusion

This study broadly compared the use of high-cost 3D scanning and low-cost photogrammetry software to replicate small-scale museum artifacts. Overall, we found that 3D scanning techniques were more effective in capturing the complex geometry of small artifacts, but the methods were difficult to learn and relied on the use of expensive and specialized hardware and software. On the other hand, the photogrammetry methods were able to effectively replicate the geometry and texture of artifacts with a minimum measurement of 5 cm or greater. Furthermore, photogrammetry was much more accessible to the average user, as it is inexpensive, simple to use, and mobile, since it does not require equipment beyond a digital camera and computer. This study also explored means of disseminating 3D models to non-specialist audiences through social media. We found that 3D models created using low-cost methods were easier to disseminate using social media, as the programs were able to create content that was ready to disseminate without the use of additional software. Videos and embedded 3D objects were the most compatible with Facebook and versatile across Internet browsers and devices. PDFs were able to retain the most detail of the original objects, but were not compatible with mobile devices and were also not ideal for sharing with social media. Due to their accessibility and ease of use with social media, photogrammetry programs have the potential to be used in a more diverse range of archaeological projects than was possible with 3D modelling technology in the past (Remondino and El-Hakim, 2006), such as the documentation of large or fragile objects in museums or activities based on participation with communities or other non-specialist groups. Further advances in low-cost 3D modelling technologies will likely result in further improvements to the accessibility of 3D modelling software, the quality of finished results, and the compatibility of 3D models with social media indicating that low-cost methods of digitally replicating artifacts will continue to be a viable option for archaeological research.

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4 Conclusion

This thesis investigated the use of inexpensive 3D modelling methods to create and disseminate digital replicas of archaeological features and artifacts from Banks Island, NWT. The project aimed to assess the potential of new low-cost photogrammetry programs for replicating in-situ archaeological features and small-scale objects, thereby extending their archaeological application beyond standing buildings and other large monuments. It further explored the range of options for disseminating these models to non-specialist audiences using online media. The following sections summarize the main conclusions derived from this research, followed by some suggestions for further work.

4.1.1 Objective One

The first objective of this thesis was to assess the benefits and challenges of using low-cost photogrammetry for *in-situ* documentation of typical hunter-gatherer archaeological features. Low-cost photogrammetry methods have primarily been used to replicate complex and large-scale archaeological objects, such as heritage architecture, monuments, and excavations, and their applicability for replicating smaller and less complex features, particularly in remote field locations, remains relatively unexplored. To meet this objective I replicated a series of *in-situ* archaeological features (sod houses, caches, tent rings, and isolated artifacts) at three archaeological sites (Cape Kellett, Agvik, and Seal Camp) on the southern coast of Banks Island in 2013 using Photoscan and 123D Catch. The photogrammetry programs were able to effectively replicate all archaeological features except for one sod house, indicating that the software programs are better able to generate 3D models for archaeological features that are complex and distinct in their shape and texture from the surrounding landscape. I determined that photogrammetry methods were practical choices for *in-situ* documentation in comparison to methods such as terrestrial laser scanning or LiDAR (Dawson et al., 2011; Landry et al., 2014; Wurtz, 2011) that are reliant on equipment that is difficult to transport to the
field and sensitive to outdoor weather conditions. The photogrammetry methods require only the use of a digital camera for data collection.

When comparing the specific photogrammetry programs used, I found that Photoscan was an ideal choice for documenting hunter-gatherer features in-situ, as it was less influenced by less-than-ideal field conditions (changeable weather, insects, skies) that interfere with the 3D modelling process, can be used in field locations without an Internet connection, and creates 3D models that are higher in overall quality than 123D Catch. 123D Catch is less useful for in-situ documentation in remote field locations as it requires an Internet connection, though it can still create realistic-looking 3D models within a relatively short time-span when Internet is available.

4.1.2 Objective Two

The second objective of this thesis was to determine the usefulness of low-cost photogrammetry for making 3D digital replicas of small-scale artifacts in comparison to expensive 3D scanning methods. Previous work demonstrates that 3D scanning methods can create high quality, accurate, and realistic-looking digital copies of artifacts or other small-scale archaeological items (Betts et al., 2011; Karasik and Smilansky, 2008). Though there are a few notable exceptions (Kersten and Lindstaedt, 2012; Nguyen et al., 2012), the suitability of new low-cost photogrammetry methods has not been explored in as much detail for the replication of small-scale objects. To meet this objective, I used both high-cost (3D3 White Light scanner at the Sustainable Archaeology research facility) and low cost (Photoscan and 123D Catch) methods to replicate a total of 21 artifacts held in museum collections in the PWNHC. 3D scanning was more effective in replicating the complex geometry of small-scale items, as Photoscan and 123D Catch had difficulty replicating the geometry of very small artifacts or parts of artifacts (< 5 cm). However, the photogrammetry programs were able to effectively replicate the larger artifacts considered in the study (>10 cm), and required no specialized equipment, were easier to use, more cost-effective, and more mobile than the 3D3 White Light scanner.

Of the two photogrammetry programs used in this study, Photoscan was able to create more detailed and representative 3D models of the artifacts. 123D Catch was not able to
replicate small artifacts or parts of artifacts in as much detail, though the program was still valuable for slightly larger items, as it was more user-friendly and could create 3D models much more quickly than *Photoscan*.

4.1.3 Objective Three

The final objective of this thesis was to explore the ways that social media and other web resources can be used to disseminate 3D models to non-specialist audiences. Public engagement is a frequently-cited reason for using 3D modelling within archaeology, but relatively few authors have discussed the methodological challenges of sharing 3D models online (Berndt et al., 2010; Koller et al., 2010). I addressed this issue by exploring different formats for 3D model dissemination via the Ikaahuk Archaeology Facebook page, namely 3D models in PDFs, videos posted to YouTube, and embedded 3D models posted to the online hosting site SketchFab, in order to learn which best represented the 3D models and which were most compatible with social media across multiple computing devices. I found that while PDFs were interactive and representative of the original 3D models, they were problematic to share using social media due to both file size and format restrictions and because users must download PDF files before viewing them. Another problem is that users must purchase mobile PDF readers that are compatible with 3D files in order to view them on mobile devices. These limitations suggest that PDFs may be better suited for use in formal reports or databases than social media. Alternatively, videos and embedded 3D models are most compatible with sharing through social media, as YouTube and SketchFab are already oriented towards social media dissemination, and users can view the 3D models on any computer or mobile device within an Internet browser, without the use of any additional software.

Among the 3D replication techniques used, the low-cost photogrammetry methods were the most compatible for sharing through social media. Whereas the 3D models created with the 3D3 White Light scanner required processing with several software programs in order to create content in the correct format for online dissemination, 3D models created with *Photoscan* and *123D Catch* required no additional software. *123D Catch* was particularly useful for sharing through social media, as it facilitated the uploading of videos to YouTube from within the program.
4.1.4 Considerations for Future Research

Overall, this thesis demonstrated that low-cost photogrammetry can be a valuable tool for creating 3D models of several types of hunter-gatherer archaeological features and artifacts and disseminating them online using social media. The results indicated that low-cost photogrammetry is becoming increasingly more accessible to a wide range of archaeological projects than 3D modelling techniques in the past, because it is inexpensive, easy to use, and does not require specialized equipment. Further investigations of low-cost 3D technologies with a variety of archaeological objects and in various research contexts will contribute to a greater understanding of the benefits and challenges of using the technology within the discipline of archaeology. First, more types of archaeological features can be documented using low-cost photogrammetry in order to fully understand the potential benefits and limitations of low-cost photogrammetry within archaeology. Documenting more types of artifacts and archaeological features of varying geometric shapes, textures, and sizes will be necessary to determine the limitations and best practices of low-cost photogrammetry within archaeological research. In addition, the broader-scale in-situ documentation of features or sites can be investigated using other means of data collection, such as aerial photographs, or the integration of low-cost photogrammetry with other means of 3D capture and visualization, including professional photogrammetry, terrestrial laser scanning, or LiDAR.

Second, additional investigations of low-cost 3D modelling technologies are needed within archaeology. This thesis investigated two popular low-cost photogrammetry methods (Photoscan and 123D Catch), but there are many other types of low-cost 3D replication technologies that are in development, including hand-held or desktop 3D scanners such as the Fuel3D (http://www.fuel-3d.com/), and the Makerbot Digitizer (http://store.makerbot.com/digitizer), which may be highly useful for archaeologists in future years. Similarly, the development of 3D printing technology will likely be essential to future archaeological research. Already the Smithsonian X 3D project (http://3d.si.edu/) has begun to digitize heritage objects using 3D scanning technologies, with the intention of allowing users to view copies of objects digitally or to make physical copies using 3D printing technologies (Waibel, 2014). New developments in 3D
scanning and printing would help to address a range of archaeological research problems, but could contribute in particular to overcoming issues of restricted access to artifacts within museums or other institutions.

Finally, further explorations of engagement through low-cost 3D modelling are necessary. This project determined that online dissemination of 3D models through social media can be a quick and effective way of making 3D models available to a non-specialist online, but there can be technical limitations related to the hosting and presentation of 3D files in some types of social media, in this case Facebook. Given the current opportunities for online dissemination of 3D models that were unavailable in the past (Koller et al., 2010), it is prudent to continue exploring new 3D formats and avenues of disseminating them online, though other social media sites, websites, or formal databases. Furthermore, the photogrammetry programs used in this study can be valuable in other ways to community-based research projects, where collaboration between archaeologists and other stakeholders is necessary to build partnerships and achieve a more multivocal interpretation of the past (Atalay, 2012; Tully, 2007). Because of their low cost and user-friendliness, Photoscan and 123D Catch can be used by archaeologists and community members alike within field research and museum activities to create and disseminate digital replicas of archaeological objects. Similarly, the ethical implications of replicating and publicizing artifacts or other heritage items require further exploration. A close working relationship between archaeologists and other stakeholders is necessary in any project, but the broader implications of artifact reproduction and publication using social media in the context of intellectual property and copyright warrant ongoing investigation as well.

4.1.5 References


Wurtz, M.D., 2011. Recording a Vanishing History: Three-dimensional Scanning of Petroglyphs at Writing-on-stone Provincial Park, Alberta, Canada.
Appendices

4.1.6 Appendix A: Examples of 3D Models

Examples of videos of 3D models are available on the Ikaahuk Archaeology Project YouTube page (https://www.youtube.com/user/IkaahukArchaeology).

Examples of embedded 3D objects are available on the Ikaahuk Archaeology Project SketchFab page (https://sketchfab.com/ikaahukarchaeologyproject).

Decorated harpoon head (PWNHC 982.50.362). 3D model created using 3D3 White Light scanner at the Sustainable Archaeology research facility.
Cache 21 from Seal Camp (OkRn-2). 3D model created in *Agisoft Photoscan* at high target quality. Mesh decimated for publication.
Curriculum Vitae

Name: Haukaas, Colleen

Post-secondary Education and Degrees:

University of Lethbridge
Lethbridge, Alberta, Canada
2008-2012 B.A.

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2012-2014 M.A.

Honours and Awards:
Social Science and Humanities Research Council (SSHRC)
Joseph-Armand Bombardier Canada Graduate Scholarship 2013-2014
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Related Work Experience:
Teaching Assistant
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