Seeing is Believing
Investigating the influence of photogrammetric digital 3D modelling of underwater shipwreck sites on archaeological interpretation

Madeline McAllister
Bachelor of Archaeology (Flinders University)
Master of Maritime Archaeology (Flinders University)

This thesis is presented for the degree of Doctor of Philosophy of The University of Western Australia
School of Social Sciences
Archaeology
2018
THESIS DECLARATION

I, Madeline McAllister, certify that:

This thesis was substantially accomplished during enrolment in the degree.

This thesis does not contain material, which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution.

No part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of The University of Western Australia and where applicable, any partner institution responsible for the joint-award of this degree.

This thesis does not contain any material previously published or written by another person, except where due reference are made in the text. All figures are my own unless otherwise cited.

This work is not in any way a violation or infringement of any copyright, trademark, patent, or other rights whatsoever of any person.

This thesis does not contain work that I have published, nor work under review for publication.

Signature:

Date:

24.10.2018
Photography is a powerful tool for the communication and dissemination of information. Indeed, visual media infiltrate almost every aspect of archaeological research. These aspects include locating, recording, analysing, interpreting, preserving, archiving, critiquing, communicating, managing and contextualising archaeological data. This often includes photography, artefact illustrations, site plans, virtual reconstructions and digital three-dimensional (3D) models. Archaeology’s reliance on visualisation to convey meaning can be traced through time. With the recent rapid widespread application of cutting-edge digital 3D modelling software, the reliance within archaeology on visual media as a means to communicate meaning and knowledge is increasing. The introduction of new digital visualisation tools is potentially changing the way that archaeologists approach sites and incorporate visual media within overall archaeological practice.

From a maritime archaeological standpoint, visualisation (particularly photography) has long played a central role in recording underwater sites due to the complexities of working at depth. The emerging trend is for underwater 3D recording and digital modelling. However, does this relate to the wider use of visual imagery in archaeology? What are the implications of a rapidly advancing, user-friendly technology, both methodically and theoretically? This thesis makes extensive use of a relatively new technique I am calling ‘photogrammetric digital 3D modelling’, to generate digital 3D models of real-world underwater shipwreck sites from a series of photographs of those sites. Two underwater archaeological sites in Western Australia are the focus, James Matthews (1841) and Batavia (1629). By applying this technique, a critical method-based approach is undertaken to determine the deeper influences that image-based digital models have on the archaeological process. Adding a fourth dimension (time) expanded this critique by experimenting with photogrammetric modelling of legacy photographic data.

The results indicate that viewing an underwater shipwreck site in a digital 3D medium can influence a viewer’s perception of the site and enhance a viewer’s understanding of the site geometry. Additionally, the realistic presentation of image-based 3D models increases the subjective influences and bias involved in creating these visualisations, which are often hidden from the viewer. An analysis of the history of imagery within archaeology highlights the problems of ocularcentrism and the rhetoric of imagery that have often accompanied scientific principles of objectivity and truth. The current
application of detailed, accurate image-based digital 3D models encourages a reliance on vision to convey meaning.

To embrace current and future developments influenced by digital realism, further discussion is needed to better understand the ways that technology and associated methods operate on archaeological interpretation. This thesis proposes that seven themes are embraced to aid this discussion: *paradata, methodological rigour and transparency, accuracy and authenticity, legacy data, purpose, complementarity* and *sustainability and access.*
# Table of Contents

Thesis Declaration ........................................................................................................... ii
Abstract ............................................................................................................................ iii
Table of Contents ............................................................................................................. v
List of Figures ................................................................................................................... vii
List of Tables .................................................................................................................... xii
Acknowledgements ............................................................................................................ xiii
List of Figures .................................................................................................................... xii
Abstract ............................................................................................................................ iii
Thesis Declaration ........................................................................................................... ii

## 1. Introduction .................................................................................................................. 1
  1.1 Research topic ............................................................................................................ 5
    1.1.1 Aims ..................................................................................................................... 7
    1.1.2 Limitations .......................................................................................................... 8
    1.1.3 Outcomes ............................................................................................................. 9
  1.2 Theoretical framework .............................................................................................. 10
  1.3 Related terminology and definitions ........................................................................ 10
    1.3.1 Photomosaics ...................................................................................................... 11
    1.3.2 Orthophotographs ............................................................................................ 12
    1.3.3 Stereo-photography versus stereo-photogrammetry ....................................... 12
    1.3.4 What is Photogrammetry? .................................................................................. 13
    1.3.5 Close-range photogrammetry ............................................................................ 15
    1.3.6 Photogrammetric reconstruction ....................................................................... 15
    1.3.7 3D triangulation software: AutoCAD, Rhinoceros 3D and Site Recorder ..... 17
    1.3.8 3D reconstruction software: PhotoModeler, VirtualMapper and Rhino .......... 17
    1.3.9 Agisoft PhotoScan 3D reconstruction software ................................................. 18
    1.3.10 Photogrammetry versus photogrammetric 3D modelling ................................ 20
    1.3.11 Photogrammetric 3D reconstruction versus photogrammetric 3D modelling ..... 20
  1.4 Thesis structure ......................................................................................................... 21

## 2. Archaeology, imagery and objectivity ......................................................................... 23
  2.1 Early depictions of antiquity: classical period to the 18th century ......................... 25
  2.2 The Renaissance: new approaches for knowledge .................................................. 30
  2.3 The Scientific Revolution and 17th century antiquarians ...................................... 34
  2.4 The Enlightenment: early foundations for archaeological illustrative language .... 37
  2.5 The 19th century: foundations of modern archaeological depiction ...................... 39
  2.6 Photography: a catalyst for achievable objectivity? .................................................. 44
  2.7 The 20th century: archaeology and mechanical objectivity ..................................... 48
  2.8 Computers, GIS and virtual reality: a new age for archaeological visualisation ...... 53
  2.9 Archaeological digital 3D modelling ....................................................................... 63
  2.10 Ocularcentrism and the rhetoric of imagery ............................................................ 64
  2.11 Reflexivity and representation ................................................................................ 67
  2.12 A redefined notion of objectivity and realism in archaeological visualisation ........ 71
  2.13 Legacy data: revisiting primary archaeological data ............................................. 73
  2.14 Summary .................................................................................................................. 81

## 3. Underwater archaeology and photographic recording ............................................... 83
  3.1 Limitations of underwater archaeological photography ......................................... 83
  3.2 A history of photographic recording for underwater archaeology ......................... 87
  3.3 Documenting underwater archaeological sites in digital 3D ................................... 101
    3.3.1 Digital cameras and 3D modelling: Tektaş Burnu ........................................... 102
    3.3.2 P3DM of underwater site: Pavlopetri ............................................................. 105
    3.3.3 PhotoModeler to PhotoScan: Mazotos ............................................................ 108
6.2 How does P3DM of underwater shipwreck sites fit within a review of the history of archaeological recording? ..................................................................................................... 237
6.3 Summary................................................................................................................... 241

7. Conclusions and future research ............................................................................. 243

References.................................................................................................................... 252
Appendix A.................................................................................................................... 270
Appendix B.................................................................................................................... 277
Appendix C.................................................................................................................... 280
Appendix D.................................................................................................................... 283
### List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>An illustrated drawing of the Nuzi clay tablet (Meek 1935b: Tablet 1)</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>Example of a Marshallese stick chart (Romm 2015:np)</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>Drawing of Severan Marble Fragments showing the Circus Flaminus, Rome (Popkin 2015:Figure 2)</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>The Peutinger Map: segment 9 of 11 showing Cappadocia across the middle (Talbert and Unger 2008:Plate 1)</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td>1591 portrayal of Tumuli at Jelling Denmark, Drawn for Henrik Ratzau (Trigger 2006:Figure 3.2)</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Lucas De Heere’s 1574 painting of Stonehenge, note the perspective and inclusion of people and a horse for scale (Piggott 1978:10)</td>
<td>32</td>
</tr>
<tr>
<td>7</td>
<td>William Camden’s Stonehenge from the 1600 edition of Britannia (Camden 1610:252)</td>
<td>33</td>
</tr>
<tr>
<td>8</td>
<td>Ole Worm’s Cabinet of Curiosities (Musei Womani Historia, 1655) (Bahn 1996:36)</td>
<td>35</td>
</tr>
<tr>
<td>9</td>
<td>Example of artefact illustration indicating scientific realism, The Dal Pozzo Paper Museum (RL 10269r) (Moser 2014:70)</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>John Aubrey’s plan of Avebury (Monumenta Britannica c. 1675) (Piggott 1978:41)</td>
<td>37</td>
</tr>
<tr>
<td>12</td>
<td>Oscar Montelius’s typology of Bronze Age fibulae (Montelius 1886:28)</td>
<td>41</td>
</tr>
<tr>
<td>13</td>
<td>Pitt-Rivers plan drawing of Barrow 27 (Piggott 1978:54)</td>
<td>43</td>
</tr>
<tr>
<td>14</td>
<td>Example of diffusion of the ‘heliolithic’ culture from Egypt, Map 2, (Smith 1929:14, Map 2)</td>
<td>44</td>
</tr>
<tr>
<td>15</td>
<td>Lithograph print of the Temple of Edfou, Egypt, 1842 [note: original drawing by David Roberts, subsequent Lithograph is by Louis Hague (Roberts et al. 1842-49)]</td>
<td>46</td>
</tr>
<tr>
<td>16</td>
<td>Example of Conze’s high quality images, the Archway of Samothrace, Plate 3 from Conze’s 1880 report (Dorell 1989:5)</td>
<td>47</td>
</tr>
<tr>
<td>17</td>
<td>Wheeler and Gordon’s site plan, Maiden Castle, Dorset 1934-7 (Piggott 1978:58-9, Figure 41)</td>
<td>50</td>
</tr>
<tr>
<td>18</td>
<td>Wheeler’s 1922 stratigraphic recording at Segontium (Piggott 1965:175)</td>
<td>50</td>
</tr>
<tr>
<td>19</td>
<td>Example of a photographic tower (the Pratt-Mitchell photo turret) used in the 1960-70s (Sterud and Pratt 1975:161, Figure 12)</td>
<td>52</td>
</tr>
<tr>
<td>20</td>
<td>Cutting up a photograph before laying out a photomosaic (Sterud and Pratt 1975:164, Figure 14c)</td>
<td>52</td>
</tr>
<tr>
<td>21</td>
<td>Gary Lock’s depiction of the relationship between technological development and theoretical advances (2003:8, Figure 1.2)</td>
<td>57</td>
</tr>
<tr>
<td>22</td>
<td>A timeline of archaeological visualisation</td>
<td>73</td>
</tr>
<tr>
<td>23</td>
<td>Use of imagery terms in selected archaeological journals</td>
<td>77</td>
</tr>
<tr>
<td>24</td>
<td>A 1987 edition of National Geographic featuring the Uluburun excavation (National Geographic Society 1987)</td>
<td>84</td>
</tr>
<tr>
<td>27</td>
<td>Ivanoff-Rebikoff water correcting lens diagram (Valentine and Rebikoff 1968:967)</td>
<td>88</td>
</tr>
<tr>
<td>28</td>
<td>Pre-excavation site photomosaic (Bass and Throckmorton 1967:25, Figure 6)</td>
<td>92</td>
</tr>
<tr>
<td>29</td>
<td>Post-excavation site photomosaic (Bass and Throckmorton 1967:26, Figure 7)</td>
<td>92</td>
</tr>
<tr>
<td>30</td>
<td>Divers completing triangulation measurements at Cape Gelidonya (note: the datum point marked with the stadia pole) (Bass and Throckmorton 1967:27)</td>
<td>93</td>
</tr>
</tbody>
</table>
Figure 31. The photomosaic strip and site plan derived from the images (Bell 1986:112, Figure 2) ................................................................. 99
Figure 32. Partial Batavia photomosaic (Baker and Green 1976: Figure 2) ................................................................. 99
Figure 33. Individual frame models of the amphorae and partial view of the rendered 3D site plan (Green et al. 2002:287) ................................................................. 104
Figure 34. Stereo-rig is used with a guide line for navigation (Henderson et al. 2013:247) ................................................................. 106
Figure 35. Depth map, texture and conventional site plan (Henderson et al. 2013:250) ................................................................. 108
Figure 36. Example of a) the 3D point cloud and b) final 3D site plan from Mazotos, indicating enhanced investigation of an anchor (Demesticha et al. 2014:145) ................................................................. 113
Figure 37. Perspective view of Gnačić shipwreck, via Sketchfab https://sketchfab.com/models/945cfaa9b1664187a57ba43441d7953f (Torres 2016) ................................................................. 116
Figure 38. Sony Alpha-7 II in a Nauticam housing ................................................................. 123
Figure 39. Example of coded targets, laminated and attached to the aluminium plates ................................................................. 124
Figure 40. Recommended swimming path for recording with coded targets (Yamafune 2016:28) ................................................................. 125
Figure 41. Plan view of a recommended recording technique for best P3DM based on Yamafune (2016), modified using a test frame in a swimming pool ................................................................. 126
Figure 42. PhotoScan window for alignment settings ................................................................. 129
Figure 43. PhotoScan window for dense cloud settings ................................................................. 131
Figure 44. Settings window showing options selected to create the mesh ................................................................. 133
Figure 45. Settings used for texture building ................................................................. 134
Figure 46. Exporting orthophoto window ................................................................. 137
Figure 47. Brigantine ship similar to James Matthews (c.1841) (WA Museum, http://museum.wa.gov.au/research/research-areas/maritime-archaeology/treasures-from-the-deep/james-matthews) ................................................................. 142
Figure 48. Woodman Point (ArcGIS) ................................................................. 143
Figure 49. Woodman Point with the James Matthew site highlighted (ArcGIS) ................................................................. 144
Figure 50. Diver operating the stereo-photogrammetry tower (WA Museum) ................................................................. 146
Figure 51. Mapping out the site plan from scale measurements and photomosaic strips (Henderson & Baker 1976:235) ................................................................. 147
Figure 52. James Matthews site plan with the excavation grid numbers (courtesy of the WA Museum) ................................................................. 148
Figure 53. Surface view of the road crash barriers encircling James Matthews (courtesy of the WA Museum) ................................................................. 149
Figure 54. The bow end of the site in 2014 after the shade cloth was torn off (courtesy of the WA Museum) ................................................................. 150
Figure 55. Working example of masking the grid frames within PhotoScan ................................................................. 153
Figure 56. Image set 489 unmasked high - showing more success in aligning the images [Output: Cameras (19/20), TP (15,636), DC (4,303,484), Pol. (286,897)]. ................................................................. 154
Figure 57. Image set 489 masked and aligned at medium accuracy [Output: Cameras (19/20), TP (7,836)] ................................................................. 155
Figure 58. Image set 489 masked and aligned at high accuracy [Output: Cameras (19/20), TP (12,744)] ................................................................. 155
Figure 59. Indication of a successful reconstruction due to the horizontal accuracy of the grid bar ................................................................. 156
Figure 60. Example of an original negative that required masking of non-useful data around the edges ................................................................. 157
Figure 61. Image set 480 final P3DM with texture [Output: Cameras (6/6), TP (6,659), DC (1,059,821)] ................................................................. 158
Figure 62. Image sets 490 & 495 P3DM (mesh only), [Output: Cameras 35/35, TP (12,4380), DC (4,536,395)] ................................................................. 158
Figure 63. Image sets 490 & 495 P3DM (texture) [Output: Cameras 35/35, TP (12,4380), DC (4,536,395), Pol. 1,366,193)] ................................................................. 159
Figure 64. Image sets 490 & 495 P3DM texture profile view [Output: Cameras 35/35, TP (12, 4380), DC (4,536,395), Pol. 1,366,193] ................................................................. 159

Figure 65. Image sets 492, 493 & 494 P3DM (mesh only) [Output: Cameras (81/83), TP (6,593), DC (11, 266,395), Pol. (2,253,276)] ................................................................. 160

Figure 66. Image sets 492, 493 & 494 P3DM texture [Output: Cameras (81/83), TP (6,593), DC (11, 266,395), Pol. (2,253,276)] ................................................................. 160

Figure 67. Image sets 492, 493 & 494 P3DM texture profile [Output: Cameras (81/83), TP (6,593), DC (11, 266,395), Pol. (2,253,276)] ................................................................. 160

Figure 68. Grid #10 I3DM [Output: Cameras (45/45), TP (28,802), DC (4,630,769), Pol. (926,149)] ........................................................................................................ 161

Figure 69. Dense cloud of the slate mound [Output: Cameras (147/147), TP (218,086), DC (19,885,092), Pol. (1,331,184)] ................................................................. 164

Figure 70. Profile view of the slate mound indicating texture [Output: Cameras (147/147), TP (218,086), DC (19,885,092), Pol. (1,331,184)] ................................................................. 164

Figure 71. Final orthophoto of the slate mound [Output: Cameras (147/147), TP (218,086), DC (19,885,092), Pol. (1,331,184)] ................................................................. 165

Figure 72. Chunk 1 [Output: Cameras (33/33), TP (9,651), DC (3,864,129), Pol. (257,603)] ................................................................. 166

Figure 73. Chunk 2 [Output: Cameras (3/3), TP (496), DC (456,272)] ........................................................................................................ 166

Figure 74. Chunk 3 [Output: Cameras (11/321), TP (529), DC (330,074)] ........................................................................................................ 167

Figure 75. Mesh for chunk 1 [Output: Cameras (66/66), TP (33,917), DC (7,079,619), Pol. (471,971)] ........................................................................................................ 168

Figure 76. Texture for chunk 1 [Output: Cameras (66/66), TP (33,917), DC (7,079,619), Pol. (471,971)] ........................................................................................................ 169

Figure 77. Chunk 2 mesh model [Output: Cameras (548/548), TP (381,850), DC (91,529,641), Pol. (6,129,234) Decimated (599,999)] ........................................................................................................ 169

Figure 78. Chunk 3 mesh model [Output: Cameras (115/115), TP (119,924), DC (22,737,987), Pol. (600,000)] ........................................................................................................ 170

Figure 79. Chunk 4 dense cloud [Output: Cameras (21/23), TP (25,751), DC (3,619,800), Pol. (241,314)] ........................................................................................................ 170

Figure 80. James Matthews site plan – updated as of November 2015, indicating swim trajectory ........................................................................................................ 172

Figure 81. Showing correction of colour due to white balance overcompensation ........................................................................................................ 173

Figure 82. Orthophoto of the bow end with coded targets [Output: Cameras (1359/1360), TP (864,618), DC (140,746,033), Pol. (9,432,131) Decimated (599,999)] ........................................................................................................ 174

Figure 83. Chunk 1 Dense Cloud [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (241,314)] ........................................................................................................ 175

Figure 84. Chunk 1 Mesh model HIGH (not decimated) [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (1,668,480)] ........................................................................................................ 176

Figure 85. Chunk 1 Mesh HIGH perspective view [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (1,668,480)] ........................................................................................................ 176

Figure 86. Chunk 2 [Output: Cameras (11/11), TP (2,868), DC (180,423)] ........................................................................................................ 177

Figure 87. Chunk 3 [Output: Cameras (14/14), TP (2,110), DC (295,665)] ........................................................................................................ 177

Figure 88. Chunk 4 [Output: Cameras (6/111), TP (1,249), DC (82,169)] ........................................................................................................ 177

Figure 89. July 5 P3DM Orthophoto [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (1,668,480) Decimated (600,000)] ........................................................................................................ 178

Figure 90. Example showing the colour quality of the images, no colour correction was necessary before processing ........................................................................................................ 180

Figure 91. Workspace menu showing various chunks and merged sets from James Matthews model ........................................................................................................ 181

Figure 92. Chunk 1 [Output: Cameras (675/675), Markers (8), TP (524,308), DC (77,559,164)] ........................................................................................................ 182

Figure 93. Chunk 2 [Output: Cameras (523/523), TP (618,881), DC (229,397,641)] ........................................................................................................ 182

Figure 94. James Matthews dense cloud [Output: Cameras (1298/1298), Markers (11), TP (1,250,378), DC (365,870,498), Pol. (24,391,366)] ........................................................................................................ 183
Figure 95. *James Matthews* original high quality mesh [Output: Cameras (1298/1298), Markers (11), TP (1,250,378), DC (365,870,498), Pol. (24,391,366)].................................184
Figure 96. Orthophoto of the final *James Matthews* I3DM ..................................................185
Figure 97. Wallabi Group, Abrolhos Islands (ArcGIS, Landgate). ...........................................187
Figure 98. Site plan showing only the recorded remaining cannon and anchors – (Green 1975:44), modified by K. Kasi (2016). .............................................................................189
Figure 99. Mermaid Reef and the *Batavia* shipwreck site on the southeast of the reef (ArcGIS) .............................................................................................. 190
Figure 100. Close-up view of the *Batavia* shipwreck site (note: the white sand patch) (ArcGIS). ............................................................................................................. 190
Figure 101. Example of image from the 2015 set showing the amount of fish .........................191
Figure 102. Example of close-up images swamped by fish .................................................... 191
Figure 103. Chunk 1 example dense [Output: Cameras (65/67), TP (13,623), DC (13,449,847)] ............................................................ 192
Figure 104. Chunk 5 example [Output: Cameras (14/33), TP (3,301), DC (3,804,276)] ..........193
Figure 105. Screen shot of the PhotoScan working window during processing (note separate and merged chunks). .................................................. 194
Figure 106. Orthophoto of the final I3DM [Output: Cameras (134/142), TP (31,816), DC (31,541,232), Pol. (2,102,748) Decimated (600,000)] ............................................ 195
Figure 107. Flipped coded target on *Batavia* ...................................................................... 197
Figure 108. Example of a chunk (southern end of the site) before merging ......................... 198
Figure 109. The red encircled areas show the dense points to be cropped from the model for further processing................................................................. 198
Figure 110. Showing placements of point markers (#8) and the end of a cannon ................. 199
Figure 111. Close-up of manual placement of a point marker in the centre of a coded target. 199
Figure 112. Close-up of the placement of a point on the coded target .................................... 200
Figure 113. Partial site plan of *Batavia* showing merged chunks (red outline) and areas where merging was an issue (grey) (K. Kasi – modified by M. McAllister). ......... 201
Figure 114. Complete *Batavia* model showing the sparse point cloud [Output: Cameras (1204/1217), Markers (29), TP (828,578)] ............................................. 201
Figure 115. *Batavia* complete model as dense cloud [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403)] ............................................. 201
Figure 116. Mesh settings for initial *Batavia* mesh ................................................................. 202
Figure 117. Sparse point cloud of *Batavia* ...................................................................... 202
Figure 118. Example of the dense point cloud. ..................................................................... 203
Figure 119. Close-up of dense point cloud ....................................................................... 203
Figure 120. Initial mesh created with arbitrary settings ...................................................... 203
Figure 121. Close-up of the mesh showing the gaps in the geometry data ......................... 204
Figure 122. Texture layer showing the holes ...................................................................... 204
Figure 123. Orthophoto of the complete mesh for original 3D model – note the holes/gaps [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)] ........................................ 206
Figure 124. *Batavia* extrapolated mesh showing the markers as well as extent of extrapolation [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)] ........................................ 207
Figure 125. *Batavia* profile mesh showing the extent of extrapolation outwards from the dense point cloud [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)] ........................................ 207
Figure 126. *Batavia* extrapolated mesh showing the same area as the original mesh ........ 208
Figure 127. Orthophoto of extrapolated mesh for 3D model [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)] ........................................ 209
Figure 128. Reflectance of sunlight on a coded target on *James Matthews* ....................... 215
Figure 129. *James Matthews* orthophoto (ArcGIS) ........................................................... 215
Figure 130. GIS images of the varying stages of overlap of the 2D orthophotos (ArcGIS) .... 236
Figure 131.  *James Matthews* site plan with legacy I3DMs referenced over the top..................237
Figure 132.  Refined epistemology of archaeological visualisation based on Daston and Galison’s (2007) *Objectivity* (modified by M. McAllister) ........................................240
List of Tables

Table 1. Stages of photogrammetry development (Foster and Halbstein 2014:7) ..................... 14
Table 2. Overview of visualisation of archaeological sites through time (Bahn 2014; Greene and Moore 2010; Trigger 2006) ....................................................................................... 24
Table 3. Results of keyword searches within archaeological journals ........................................ 76
Table 4. Photographic recording on underwater archaeological sites ........................................ 90
Table 5. PhotoScan settings to mask features from image alignment .......................................... 136
Table 6. Data collated from (Henderson 2008a) ........................................................................ 141
Table 7. Total legacy image sets and amount of images per set .................................................. 151
Table 8. Results from the high settings for camera alignment ..................................................... 153
Table 9. Showing the resulting successful image sets and corresponding data results. .......... 158
Table 10. Output data for the Grid #10 I3DM ........................................................................... 162
Table 11. Dives and number of images collected per dive. ......................................................... 163
Table 12. Settings for alignment phase of processing the James Matthews images .................. 180
Table 13. Final data for 5 December James Matthews P3DM .................................................... 186
Table 14. Data results for final model of Batavia 2015 ............................................................... 193
Table 15. Description of the themes for analysing I3DMs. ............................................................ 213
ACKNOWLEDGEMENTS

There aren’t enough words of thanks or praise to those who have stood by me over the last four years and helped me to get through the biggest challenge of my life but hopefully this does some justice.

First of all thank you to Al Paterson, my primary supervisor. You put up with endless reviews, questions and gave me guidance at the toughest of times. Thank you for providing me with this chance in the first place and getting me over the line.

To Jeremy Green, one of the best mentors I have had, thank you for never, ever telling me I couldn’t do something and for letting me push the boundaries and do some fantastic research.

I could not have completed the technical aspects of this thesis without the guidance of two experts in the field. So, thank you Paul Bourke for patiently guiding me from the beginning, and thank you Andrew Woods for stepping in and strengthening my research.

To Deb Shefi – you’re my unacknowledged supervisor and I most definitely could not have gotten here without your proofreading, patience and advice. Thank you, thank you! Also, thank you to the WA Museum and the team in the Department of Maritime Archaeology – Ross Anderson, Mack McCarthy and Corioli Souter. Your help with fieldwork, planning, guidance and advice allowed me to get out and record James Matthews and Batavia. Thank you to the other members of the department for all of your support: Myra Stanbury, Patrick Baker, Nicolas Bigourdan, Kalle Kasi, Jon Carpenter and Vicki Richards.

Thank you to the Archaeology discipline staff and students at UWA. Early help and advice from Jo McDonald and Sven Ouzman will always be appreciated. Thank you to the team that works behind the scenes to get us through: Ines Bortolini, Moilet Mtandwa, Steven Maras and Emma Piggott. I’m not sure I could have finished this thesis without the help from my fellow PhD students: Sam Harper, Laura Mayer, Lucía Clayton-Martinez, Carly Monks, Wendy Reynen, Kane Ditchfield Abhirada (Pook) Komoot, Megan Berry and Emma Beckett.

Lastly, I dedicate this thesis to my family
To my parents: Mum for you endless love, Jim for your support, Dad for your unwavering interest and being so proud and Natt for helping me get across the line. To all of you, I don’t have enough words to thank you for picking up the pieces when I needed it most and always, always supporting me in following my dreams. Thanks to my sister Ally for always being there when I needed you, reading draft after draft and putting in an entire weekend editing the last draft with me. Thank you xx
Funding & Awards

Many thanks also go to the Women Divers Hall of Fame (WDHO) for awarding me the funds to get out to the *Batavia* shipwreck site and complete an essential stage of photographic recording.

This thesis research ran in conjunction with the Australian Research Council Linkage Project ‘Shipwrecks of the Roaring Forties: a maritime archaeological reassessment of some of Australia’s earliest shipwrecks’ (LP130100137, Lead CI: Alistair Paterson). The Roaring Forties Project aims to significantly contribute to our understanding of 16th and 17th century European activities in the Indian Ocean and the Western Australian region. By reassessing maritime archaeological sites and examining how approaches to these sites have changed over time, this project contributes to our understanding of this time through new research questions and new technologies (LP130100137). As a result, this thesis took some guidance from the ‘Shipwrecks of the Roaring Forties’ aims by reinvestigating legacy archives within the Western Australian Museum.

This thesis was supported by an Australian Government Research Training Program (RTP) Scholarship.
Abbreviations

3D – three-dimensional
2D – two-dimensional
ARC – Australian Research Council
ARPENTEUR – Architectural Photogrammetry Network Tool for Education and Research
AutoCAD – Computer Aided Design, software program.
CD – Compact Disc
CD-ROM – Compact Disc Read-only Optical Memory Device
CI – Chief Investigator
DEM – Digital Elevation Model
EOS – Electro Optic Systems™
GCPs – Ground Control Points
GIS – Geographic information systems
I3DM – Image-based digital 3D model
JPEG – Joint Photographic Experts Group file format
LP – Linkage-Project
LZW – Lempel-Zilch-Welch lossless compression
NURBs – Non-uniform rational basis spline
P3DM – Photogrammetric digital 3D modelling
PhotoScan – Agisoft PhotoScan™
PNG – Portable Networks Graphics
RAW – Original, uncompressed image file formats
Rhino – Rhinoceros 3D™
SfM – Structure from Motion
TIFF – Tagged Image File Format
TV – Television
UEC – Underwater Explorers Club of Western Australia
US – the United States of America
UV – ultra-violet light
VOC – Verenigde Oostindische Compagnie, The Dutch East India Company.
VR – Virtual Reality
WA – Western Australia
WAM – Western Australian Museum
1. Introduction

Visual media techniques are powerful tools for communicating ideas, arguments and theories. Indeed, visualisation is an significant aspect of archaeological data recording and production, encompassing journals, field logs, artefact illustrations, photography, site plans, maps, section drawings, virtual reconstructions and digital three-dimensional (3D) models. Specifically, visualisation of sites, such as site plans, maps and large-scale photographs, enable the communication of detailed theories and ideas while also allowing individuals to understand complicated archaeological information (Moser 1992). Photography plays a core role in such visualisations, particularly now that digital cameras are readily available. Additionally, advances in semi-automated software programs coupled with computer vision now allow for the creation of increasingly realistic digital visualisations of archaeological sites and objects based on photographic data. These advances are rapidly increasing the ability to record high levels of detail and create realistic site visualisations with ease. In recent years, techniques and software have been increasingly applied to underwater archaeological sites, in an attempt to increase the accuracy of recording within dynamic environments. However, the rapid application is encouraging archaeologists to overlook significant issues about objective recording and the resulting interpretations. In this thesis, I argue that archaeology has taken a step sideways by re-embracing the ideal of ‘mechanical objectivity’ through digital technologies. To understand how the advances in digital visualisation are affecting the way that underwater archaeologists approach and record sites it was essential that I first review visualisation over time within the wider discipline of archaeology.

While reviewing the role of visualisation in archaeology, the significance of how various forms of visual media influence the creation of knowledge and archaeological interpretations became clearer. In particular, I focused on the role of imagery to convey objectivity and realism, which has roots in the earliest depictions of monuments and sites throughout the 16th to 17th centuries. Additionally, as I traced the development of visualisation from antiquarians (16th and 17th century scholars interested in archaeological sites and artefacts) to the development of the profession of archaeology in the 19th and 20th centuries, the link between advances in visualisation tools and theoretical stances strengthened. Two philosophical positions arose in the late 20th century that are relevant to the discussion put forth in Chapter 6. They are: ocularcentrism
(the privileging of vision over other senses) (Jay 1988, 1994; Tyler 1984), and, the rhetoric of imagery (the reliance and subconscious acceptance of visual imagery as objective and reliable tools for recording) (Barthes 1964) (see Chapter 2 for detailed description). These positions are significant to highlight. As I argue in this thesis, archaeology is currently in a phase of ‘digital realism’ that can be linked to the rapid application of digital 3D modelling (see Chapter 6), and these theoretical debates about ocularcentrism and the rhetoric of imagery provide critical perspectives on the implications of this in a longer perspective. Advances in technology and seemingly realistic results are swaying the mindset of archaeologists, and the wider public, by encouraging a reliance on the ‘truth’ and ‘objectivity’ seemingly portrayed by image-based digital 3D models (I3DMs) (see section 1.3.10 for further description). To understand the reliance archaeologists have on the mechanical objectivity of recording tools, we must understand the general ethical principles of archaeological recording.

An essential aspect emphasised in this research is that methods and techniques used in archaeology to record and excavate cannot be reproduced on the same data originally collected throughout an excavation, as is expected of repeatable scientific research (De Reu et al. 2013; Drap et al. 2013). Given this condition, it is an ethical requirement for archaeologists to ensure that the best standards of recording are upheld to make sure that the original work can be interpreted ex situ (De Reu et al. 2014; De Reu et al. 2013; Skarlatos et al. 2012). As a result, professional archaeological and cultural heritage associations have standards, guidelines and codes of ethics that their members are required to abide by and support (AAA 2012; AIA 2008; AIMA 2014; IFA 2008; NAS 2007). Some examples of responsibilities advocated for in the field of archaeology include accurate recording and representations of sites, reliable and repeatable methodology, and ensuring dissemination of work and research results to the public.

While these ethical standards promote the idea of recording a site to the highest possible standard, rapid advances in technology caused the standards of such associations to fall behind. However, standards and guidelines for cultural heritage applications increasingly regulate the use of digital technologies and virtual reconstructions in archaeological research. Two crucial examples are the London Charter (Denard 2009) and the Principles of Seville (IFVA 2011). The London Charter for the computer-based visualisation of cultural heritage, published in 2009, aims to work towards a consensus regarding guidelines and a recognition of issues for those working to create digital ‘environments’ for archaeological visualisation. The Charter originated from an earlier article (Beacham et al. 2006) that
conceptualised the rationale and continued discussions on the problems of hyperrealism from earlier publications (Frischer et al. 2000; Roberts and Ryan 1997; Ryan 1996). Following on from here, The Principles of Seville international principles of virtual archaeology (2011) took the basic rules set out in the London Charter and refined them specifically for digital and virtual reconstructions of the past. An issue discussed later in this thesis (Chapters 2 and 6) is that although both documents indicate the future best practice for codes and rules for archaeological associations, they are yet to be reflected in the wider archaeological practice.

In addition, the UNESCO Convention for the Protection of Underwater Cultural Heritage (2001) is a guiding document and the standard for underwater archaeological practices around the world. Interestingly, the Convention prioritises public engagement. There is a very significant reason for this. Underwater cultural heritage (UCH) sites are different to land archaeological sites. The majority of UCH sites are located in environments that most people can never access. Underwater sites are restricted to access by divers and, even then, deeper sites that lie beyond the limit of SCUBA diving remain completely out of reach. The ability to create highly engaging, detailed visual representations of UCH sites is a ‘game changer’ for archaeology. These visual tools provide a way for the public to understand UCH sites and engage with them on a level that they might never be able to achieve. Widespread public engagement of UCH through these visualisations would potentially encourage further understanding of the significance of these sites and encourage respect for this cultural resource. However, there is still a lot that we, as archaeologists, need to understand and prioritise to truly put these engaging tools in practice.

Recent advances in algorithms from the fields of computer science, machine vision and photogrammetry, plus increases in processing power, are facilitating the generation of increasingly sophisticated digital 3D models developed only from a series of photographs (De Reu et al. 2014; McCarthy 2014; McCarthy and Benjamin 2014; Olson et al. 2013; Plets et al. 2012b). Software programs widely available for semi-automated processing of these models provide the potential to record and capture archaeological sites in a manner that helps eliminate potential bias from conventional manual recording (Frischer 2008; Pierrot-Deseilligny et al. 2011; Remondino and Rizzi 2010). Previous discussions of 3D recording methods (McCarthy 2014; Pierrot-Deseilligny et al. 2011), outlined a range of successful and potential uses. These include historical documentation, digital preservation and conservation, cross-comparisons, monitoring shape and colour, simulating structure
deterioration, virtual realities, 3D repositories and catalogues, Web-based visualisations, computer-aided restorations, multimedia museum exhibitions and archaeological interpretation. The perceived benefits of 3D modelling in archaeology are further strengthened by the publication of recent research into the application of image-based recording of small and large-scale archaeological sites showing increasingly effective application of the above noted potential uses (Balletti et al. 2016; De Reu et al. 2014; Dell’Unto et al. 2015; Galeazzi 2016; Lercari 2017; Olson et al. 2013; Remondino and Rizzi 2010). The argument for the benefits of 3D modelling is strong and continual advances in technology are likely to increase the application of digital visualisation in archaeology and more widely. Determining if the same benefits apply to digital 3D modelling of underwater archaeological sites is essential given that the primary data for these models — photographs — have been the central method for recording and surveying a site in detail since the early days of underwater archaeological excavations (c. 1950s).

Photography is widely acknowledged as one of the archaeologist’s most significant and frequently used tools (Baker and Green 1976; Bass 1973; Bass 1986; Bass et al. 1984; Bass et al. 1989; Bass et al. 1967; Cederlund and Ingelman-Sundberg 1973; Green et al. 1967; Harp 1975:4; Plets et al. 2012b; Talliez 1965; Wheatley 2011). Essentially, it fulfils one of the key ethical requirements of conducting archaeological work to the highest possible standard of detailed recording. Over four decades ago, Baker and Green (1976) emphasised that the greatest value in recording with photographs is the vast level of detail recorded, potentially surpassing even the best archaeological site drawings. Due to an often hazardous marine environment there are two essential criteria for underwater archaeological recording: speed and accuracy (Green et al. 1971). As such, advances now allow us to apply photogrammetric digital 3D modelling (P3DM) to underwater sites.

Using P3DM we can create super realistic site visualisations for enhanced interpretation. The success of P3DM relies on high-quality images that capture multiple oblique and horizontal aspects of the site. One of the biggest achievements of P3DM software is the incorporation of algorithms that estimate the lens and camera distortions present in photographs while also providing reliable corrections (Skarlatos et al. 2012; Telem and Filin 2010). These algorithms not only provide visually accurate and detailed site recordings but can also compile large-scale digital 3D site ‘photomosaics’ (see section 1.3.3 for explanation) with reduced distortion issues. Additionally, this can broaden current methods of communicating a site’s significance and physical appearance to peers and allow the public to virtually ‘dive’ on a digital shipwreck site that they may otherwise
never get to experience (see the previous work on virtual dive trails by: Historic England [https://historicengland.org.uk/get-involved/visit/protected-wrecks/virtual-dive-trails/]; The Thistlegorm Project [http://thistlegormproject.com/]; and the Defiance shipwreck [https://thunderbay.noaa.gov/shipwrecks/defiance.html]).

Another aspect evaluated within this study is the potential of reinvestigating existing images for future research. As noted above, there is a wealth of visual media associated with archaeological research. Most surveys or excavations now produce a large amount of digital image data due to the ever-increasing capabilities of cameras and the size of memory cards. Even pre-digital research produced noteworthy collections of image negatives that are mostly housed in associated museums and institutions. What happens to the majority of these legacy images? Is there anything else we can learn from them? As photography is a key tool within underwater archaeological site recording, I explore how legacy images could be P3DM to provide new insights on previous archaeological excavations. It is possible that conventional photographing techniques used to capture legacy images could mean that not enough information is available for digital 3D modelling. I reinvestigate legacy photographic data to determine the potential for enhanced understanding gained through P3DM processing and resulting legacy I3DMs.

The technical advances that now allow us to P3DM both new and legacy photographic data of underwater archaeological sites represent a significant juncture in archaeological recording. The seemingly realistic representations will enable archaeologists to communicate complex site information to peers, colleagues and the public. However, enhanced levels of photographic recording, and the site visualisations that arise, open up a myriad of potential issues for improved interpretation (see section 1.3.10 and 1.3.11 for description of the P3DM technique).

1.1 Research topic
This study explores the impact and influences of P3DM and I3DMs on recording, communicating and interpreting archaeological data. I specifically focus on two WA underwater shipwreck sites, James Matthews (1841) and Batavia (1629). In recent years, the application of affordable user-friendly software and developments in digital cameras have enabled archaeologists to undertake increasingly complex computing and photogrammetry processes previously only done by skilled specialists. The widespread application of P3DM seems to encourage archaeologists to overlook issues of how completed I3DMs affect our interpretation and the creation of knowledge, which is only
enhanced by the apparent ease and reliability of this software and techniques. Although there is an increase in archaeological discussion regarding the relationship between images, the archaeological process and interpretation (Bateman 2000; Bonde and Houston 2013; Moser 2012, 2014; Olsen 2012; Shanks 2013; Shanks and Svabo 2013; Shanks and Webmoor 2013), it appears to have not filtered down to the application of P3DM and, specifically, to underwater shipwreck sites. My review of the literature suggests that there are seven key themes that should be a part of the broader application of I3DMs within the archaeological process. These themes were devised from initial recommendations within both the London Charter and the Principles of Seville but were then refined and adapted to suit my study of underwater archaeological sites. The revised themes are:

1. Purpose
2. Methodological rigour and transparency
3. Authenticity and accuracy
4. Legacy data
5. Complementarity
6. Sustainability and access
7. Paradata

My study aims to contribute to the future applications of underwater archaeological research and associated methods and theory. This is done by testing and refining a methodology for accurate and repeatable P3DM of shipwrecks and a critical analysis of the role it plays in a theoretical discussion of imagery in archaeology. This thesis aims to provide a theoretically informed method for the detailed, accurate and informative digital visualisation of underwater sites for archaeological interpretation. The approach adopted in this thesis is to conduct case studies at two WA underwater archaeological sites, *Batavia* (1629) and *James Matthews* (1841). Both shipwrecks were subject to previous extensive archaeological recording including excavation, on-going monitoring, and as a result have a wealth of legacy data housed at the Western Australian Museum (WAM).

Each site also provides variation in terms of recording in different marine environments. *James Matthews* is located close to the Perth metropolitan area, in a shallow sandy bay. *Batavia*, on the other hand, represents the typically dangerous and dynamic reef sites that are home to a multitude of shipwrecks off the WA coast. The two sites were selected to provide examples of P3DM in different environments. *James Matthews* was also chosen due to its accessibility for field recording.
In light of the above information, the research questions for this thesis are:

1) How can the creation of I3DMs provide new insights into the enhanced understanding of underwater archaeological sites and future applications of photogrammetric digital 3D modelling?

2) Why is it important to identify how the process of P3DM of underwater shipwreck sites fit within the history of archaeological recording?

3) How can the current technique of P3DM be further refined into a reliable way of representing archaeological data?

1.1.1. Aims
The primary aims of this research are:

1) To research and critically analyse the use of imagery within archaeological interpretation, focusing on the development of archaeological visual techniques and with a focus towards underwater archaeology.

2) To refine a method for P3DM of underwater shipwreck sites by application to two underwater sites incorporating both legacy and new visual data.

3) To discuss where P3DM and I3DM fit regarding the overall archaeological process, using both the understanding gained through applying P3DM and the insights from the review of imagery and archaeology.

4) To provide recommendations for the future of P3DM in archaeology, with particular reference to applications within underwater archaeology.

The first part of this project involves a thorough review of literature about visualisation and imagery within archaeology over time. This study focuses on an analysis of the way that archaeology has evolved with visualisation at its core and the current debates around the impact that technology and digitisation has on the discipline. This review aims to highlight the theoretical position I apply in the overall approach of this study. The next stage is an in-depth review of photography as a recording tool in underwater archaeology.
Additionally, Chapter 3 aims to identify methods and techniques from the current practices of P3DM that contribute to the proposed method in Chapter 4. Ultimately, the methodology adopted for this study involves an initial review of existing approaches and the development of a tailored technique for underwater P3DM in WA.

A primary factor taken into account is the well-established professional guidelines from the *London Charter* and the *Principles of Seville* that respectively focus on standards for digital heritage and the application of the *London Charter* to virtual archaeology. By reviewing past archaeological studies and consulting the *London Charter*, a method for the P3DM of underwater sites is developed and applied with a primary focus on the implications the results have in archaeological research. A large part of this investigation focuses on the application of the P3DM software, Agisoft PhotoScan™ (PhotoScan), to legacy data from past archaeological site recording. This application is a crucial aspect of my method, and the study takes on a critical reflexive process, with the aim of pointing out the many discrepancies and issues that are currently not a focus in underwater archaeology. The reflexive aspect incorporates a refined set of themes in the style of the *London Charter* and is the first step in a wider debate and overall recognition of the implication of P3DM methods and techniques to archaeological research.

### 1.1.2. Limitations

This study had minor limitations in terms of equipment, software and accessibility to sites. Fieldwork was limited to trips involving the WA Museum (with their vessels, qualified dive supervisors, supports and first aid equipment) and the sites they access throughout the Shipwrecks of the Roaring Forties Linkage-Project (LP). I had access to limited equipment owned by the Department of Maritime Archaeology, WA Museum and extra equipment able to be purchased through funding opportunities. *Batavia* is only accessible with optimal weather and during annual fieldwork trips. The *James Matthews* is close to Perth and accessible all year, however there are only rare days when visibility is adequate for photographic recording, due to ongoing sediment dredging nearby.

This study was further limited by a focus on archaeology with its ingrained ideals and theoretical approaches that are dominated by Western culture and schools of thought. As such, the following review of the history of archaeology and the development of archaeological science and imagery focuses on literature and studies published in English.
1.1.3. Outcomes

One major result of this research is an assessment of the potential for the application of legacy photographic and site-based data in an underwater 3D paradigm. The ability to re-study this data and potentially provide a new medium for archaeological interpretation is valuable for global underwater archaeological research. In a way, this can be thought of as archaeology of the archaeological record. Modelling of the legacy data specifically addresses some of the aims of the Shipwrecks of the Roaring Forties Project in particular, ‘…returning to shipwreck sites excavated over 40 years ago to examine how approaches to maritime archaeological sites have changed over time regarding both new research questions and new technologies’ (LP130100137).

A further outcome of this study is the critique of a process where a highly accurate and reliable 3D model (I3DM) can be studied, measured and interpreted by archaeologists. Essentially, this technology requires archaeologists to use new ways of looking at a site and its related archaeological information. As the I3DMs themselves cannot be shown or understood on paper (in a 2D format), this presents a new paradigm for archaeologists accessing information. The results may contribute to the body of knowledge in underwater recording techniques and methods with a focus on proposing the best-suited equipment and digital 3D modelling algorithms. A major outcome of this project is the contribution to current standards for archaeological recording of underwater shipwreck sites. The potential result of increased accuracy and detail may have future value in on-going site management and assessment of site formation processes, identification of structures and artefacts and reconstructing the site ex situ.

It is necessary to undertake a significant critical synthesis of all relevant literature on visualisation in archaeology to understand both the P3DM method and the wider influence of imagery in archaeology. This synthesis of literature addresses the conceptual issues related to visualisation, digital recording and representation of archaeological data. The results will potentially be a useful reference for future research in this area of archaeology. Additionally, a possible outcome for the I3DMs includes public exhibitions and museums that have the potential for the development of exhibits allowing the public to become familiar with a shipwreck site in a manner previously unattainable.
1.2 Theoretical framework
This thesis investigates a broad range of aspects related to archaeological interpretation and recording methodologies such as archaeology, underwater photography, photogrammetry, imagery, illustration, objectivity and interpretation. The inclusion of photogrammetry and P3DM, combined with underwater archaeological sites are placed within the context of how archaeological research developed through the lens of visualisation techniques over time. It should be noted that there are other complementary techniques for capture of imagery data of underwater sites. For example, reflectance transformation imaging (RTI), a surface characterisation technique, was recently successfully tested in underwater environments on small-scale artefact recording (Selmo et al. 2017), however, this thesis focuses on digital photogrammetric recording. As such, it is appropriate to include the earliest instances of illustrated antiquities, as well as the development of the natural sciences and a parallel development in archaeology.

For the main discussion (Chapter 6), I focus on the overarching theoretical approach of the significance of imagery in archaeology and mechanical objectivity. My approach is inspired by the work of Stephanie Moser’s ‘Making expert knowledge through the Image’ (2014), Lorraine Daston and Peter Galison’s Objectivity (2007) and Andrew Jones’s Archaeological Theory and Scientific Practice (2011). Consequently, the framework for this study begins by reviewing the development of the scientific image within archaeology and how the quest for objectivity is significant to the development of visual media in the discipline. I apply the general presupposition that visualisation is a tool and is closely linked to how we observe, record and classify to find meaning. This argument is particularly significant given the ideal that users are taught certain conventions to acquire a way of seeing. A detailed analysis of the use of imagery to convey meaning throughout history leads into a discussion and understanding of how P3DM fits in the archaeological process now. Lastly, a dual approach of objective (methodological rigour and transparency) and subjective (self-reflexive analysis) theoretical positions are employed to adequately use and understand the potential for P3DM and enhanced interpretation of underwater archaeological sites.

1.3 Related terminology and definitions
The rapid and recent uptake of P3DM software resulted in the need to review the terms and phrases associated with photogrammetry and digital 3D modelling. First, photogrammetry and the various sub-categories are presented before providing the reasoning and motives behind the jargon and concepts used within this study.
1.3.1. Photomosaics

The term ‘photomosaic’ is used by archaeologists to describe a technique for creating one large two-dimensional (2D) image of a site from multiple smaller images. Photomosaics have traditionally been considered to be a 2D process that produces a flat 2D depiction of an area. By using the P3DM techniques described in this thesis, it is conceivable that a ‘3D photomosaic’ could be created, however for the purpose of this thesis the term ‘photomosaic’ will be considered 2D only.

Photomosaics provide a solution to issues of limited visibility when attempting to record an entire archaeological site underwater with photographs (Bowens 2011:78). It is difficult to capture an entire site in one photograph underwater due to limitations with water depth and visibility. Green (2004:168) outlines this issue clearly, ‘…for example, an overall vertical photograph of a 30-m long wreck site is taken using a Nikonos 15 mm lens (in reality, underwater this is a 20 mm lens), a camera-to-subject distance of more than 16 m is required’. The probability of capturing a clear and accurate image, which shows details of an entire site from 16 metres above the seafloor, is exceedingly rare, if possible at all. As a result, the next best thing is to capture multiple images of the site at a closer distance and overlap them together to create one single image of the entire site.

There are issues with the geometric reliability of photomosaics. Due to perspective distortion towards the edges of images, it becomes harder to match the images as you progress outwards from the centre. Consequently, there are larger spatial errors with increasing images required to record an entire site (Green 2004:168-169). When the camera shifts position, an object becomes displaced between image frames, causing perspective distortion. (Wolf 1983:159). On sites where there are high relief structures, or a large Z (depth/height) value relative to X and Y (horizontal) values, it is almost impossible to create a photomosaic. Ensuring that a control scale is visible in every photograph (i.e. a metal/rigid square grid, grid tape measure lines or a fixed, stationary metal grid) as well as maintaining consistent diver heights and keeping the camera consistently horizontal are essential (Bowens 2011:137; Green 2004:169). Consequently, photomosaics created with film cameras and manual merging were challenging and time-consuming, although ultimately capable of creating a complete site image for interpretation and reference. An early example of using photomosaics to record a site is the archaeological excavation of the Bronze Age shipwreck at Cape Gelidonya in 1960 (Bass and Van Doorninck 1971). In that project, photomosaics (called ‘montages’ in the 1960s) were compiled by
triangulation. Large pieces of concreted cargo were measured and then removed before being plotted into an overall site plan (Throckmorton and Bullite 1963).

With the growing application of both computers and digital photography, photomosaics are most often created using programs such as Adobe Photoshop (Martin and Martin 2002), Hugin (Hugin 2017), or other panorama stitching software. Images from a digital camera, or scanned from film, can be processed using these types of software. These programs enable multiple images of a scene to be transformed and merged to generate a complete visualisation of the site (Martin and Martin 2002:145). As a photomosaic is essentially a 2D process, it is most accurate when the site is completely flat, but when the site has high relief 3D features (topography or distinct protruding objects) the photomosaic will incur various inaccuracies associated with perspective distortion. Consequently, photomosaics are never accurate planimetric representations (especially on sites with the varying height of features on the seafloor) and can only be used to gain an understanding of overall site dimensions and spatial layout with some accepted error (Wolf 1983:212).

1.3.2. Orthophotographs
An orthophotograph (orthophoto) is similar to a photomosaic, except that objects are in their true orthographic positions. Orthophotos are created from perspective photographs with differential rectification applied to eliminate image displacements from the tilt of the camera and topographic relief (Wolf 1983:324). Experimentation to create orthophotos began in the 1950s when the United States (US) Geological Survey began to construct equipment capable of rectifying perspective images (Wolf 1983). Orthophotos were not traditionally employed in underwater archaeology as the equipment, expense and skill needed to create them was beyond the capabilities of those working in most projects. Instead, photomosaics and drawing completed the level of recording required. In this study, P3DM software is used to generate I3DMs from which an orthophoto can be created. The creation of orthophotos is now a common practice within archaeological research (see Chapter 3 for more information).

1.3.3. Stereo-photography versus stereo-photogrammetry
Stereo-photography (stereoscopic photography or 3D photography) is a technique that uses a dual camera system to take pairs of photographs of the same scene at the same time. Although the stereo-pair images are essentially of the same scene, they differ in parallax angle. The resultant stereoscopic image pair (stereo-pair) captures the scene with
increased depth perception when compared to regular single 2D images. Stereo-
photography was applied to the archaeological recording of shipwrecks since early
archaeological excavations in the Mediterranean during the 1960s (Bass et al. 1984:272).
Early stereo-photographic techniques involved mounting a pair of cameras to a bar, which
was in turn connected to a photo-tower that ran along fixed grids at the base of the tower
and across the excavation (Bass et al. 1967; Bass and Van Doorninck 1971). The resultant
stereo-pairs could be viewed in stereoscopic 3D using a range of techniques and display
hardware (e.g. stereoscope, 3D TV, anaglyph) that can provide enhanced visual depth
perception of the site images (Woods 2009).

A subsequent benefit of stereo-photography is that the images can be processed to obtain a
digital representation of depth information (Paparadotis and Dissard 2002). Parallax
equations could be applied to gain 3D information about the structures captured in the
images (Green 2004; Woods 1993). Additionally, by taking a series of overlapping stereo-
images and processing the images using photogrammetry techniques, a topographic plan
could be generated (Green 2004).

In contrast to stereo-photography, stereo-photogrammetry specifically refers to processing
stereo-pair images using photogrammetry techniques with the intention of acquiring
accurate 3D measurements of real life objects (Wolf 1983). As a single photograph is only a
2D projection of a 3D surface, accurate depth information cannot be gathered from one
single photograph. At least two or more images are necessary to extract depth information
(Lichti 2008). The measurement process of stereo-photogrammetry specifically relates to
the use of only two camera images.

1.3.4. What is photogrammetry?
Photogrammetry is the applied scientific field of analysing two-dimensional images to
acquire three-dimensional information about an object, specifically it’s shape and location
(Garrison 1992; Kemp 2008; Luhmann et al. 2006; Martorelli et al. 2014; McCarthy 2014).
The mathematical basis of photogrammetry is projective geometry based on work by
Lambert (1728-1777), and later Poncelet’s 1822 treatise (Hannavy 2013:1081). The
techniques used in photogrammetry are directly linked to trigonometry and the principle
of collinearity (Garrison 1992:25). Collinearity refers to the direct linear relationship
between points in a photographic image to the same points in the real world. By the end of
the 19th century, photogrammetry was a widespread practice for topographic surveys
(Hannavy 2013). With later advances in computer science and machine vision in the 20th
century, the processes became increasingly automated, allowing non-specialists to undertake higher standards of P3DM and analysis (Table 1) (McCarthy 2014; McCarthy and Benjamin 2014; Yamafune 2016).

Table 1. Stages of photogrammetry development (Foster and Halbstein 2014:7).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Date (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photography &amp; plane tables</td>
<td>1850-1900</td>
</tr>
<tr>
<td>Stereo-plotters &amp; Aeroplanes</td>
<td>1901-1950</td>
</tr>
<tr>
<td>Computers &amp; Mathematical models</td>
<td>1951-1971</td>
</tr>
<tr>
<td>Digital &amp; Computer Vision</td>
<td>1972-Present</td>
</tr>
</tbody>
</table>

The earliest form of photogrammetry was the manual method of measuring individual points and distances in a scene. This technique required images to be photographed from a height (e.g. on a rooftop, from a kite or balloon) and used linear perspective and simple mathematical equations to compare known heights within images, which enabled measurement of unknown distances or points within the images (Foster and Halbstein 2014). An example of a manual method for acquiring these measurements often requires the application of plane tables (Luhmann et al. 2006). A plane table is a levelled table on a tripod with a sheet of paper which is attached to the surface and an alidade (a ruler with a telescopic sight) is used to attain measurements (Clancy 2013).

The next stage introduced a more technical piece of equipment for semi-automated photogrammetry. Stereoscopic plotting instruments (stereo-plotters) were commonly employed to measure points and distances from analogue photographs (Wolf 1983:264). Stereo-plotters project overlapping transparencies (from oblique or horizontal negatives) that create small-scale 3D models, from which measurements and mapping of the projected stereo-images are completed (Wolf 1983). A simplified description of a stereo-plotter is that they have three distinct systems: a projection system, a viewing system and a measuring system (Wolf 1983:266). If calibrated correctly, stereo-plotters ensure highly precise measurements from overlapping image sets. Although stereo-plotters are currently rarely used, they are included here to provide insight into the skill, expertise and experience required to acquire 3D information from 2D images before P3DM. Advances in the construction and use of aeroplanes provided further opportunity for aerial stereo-photogrammetry (Foster and Halbstein 2014).

The introduction of computers enhanced the capabilities and accuracy of photogrammetry. Analogue devices, combined with quicker calculation and processing performed by computers resulted in greater accuracy of measurements than stereo-
plotters could achieve (Foster and Halbstein 2014). Known as analytical photogrammetry, this stage represents the application of computers to provide semi-automation for some calculations and, importantly, enhanced reliability of the photogrammetric processes (Konecny 2014; Luhmann et al. 2006). As computers became more available and increased in processing capabilities, the results for digital photogrammetry expanded.

The field of photogrammetry comprises of specialised sub-disciplines related to technique, equipment and context. For example, by the camera position and object distance (satellite, aerial, terrestrial, close range and macro photogrammetry), by the number of measurement images (multi-image or stereo-photogrammetry) by the method of recording and processing (analogue and digital), by the availability of results (real-time, off-line and on-line photogrammetry) and lastly, by the specialist area (for example: engineering, architecture, forensic and industrial) (Luhmann et al. 2006:5-6). The most common types of photogrammetry adopted by archaeologists (satellite, aerial and close-range) are defined below. In addition, various terms are applied and used to describe P3DM and the following section aims to clarify the definitions of terms used throughout this thesis from both a photogrammetric and archaeological point of view. The following terminology section first defines close-range photogrammetry and then outlines the advances with software and digital photogrammetry.

**1.3.5. Close-range photogrammetry**

By definition, close-range photogrammetry refers to images taken at a distance of less than 300 m (Luhmann et al. 2006:5). For archaeological purposes, close-range photogrammetry can be defined as less than 10 m distance from the object, although this is adapted to the particular site recorded. For underwater archaeological sites, close-range is considered to be less than 5 m as quality images rely heavily on clear visibility, which is often around 2-4 m above a site through the water column (Rosencrantz 1975:270).

**1.3.6. Photogrammetric reconstruction**

The process of projecting areas in a 3D form through photogrammetry is called photogrammetric reconstruction (Lichti 2008:340). Photogrammetric reconstruction relies on the combination of numerous images to reconstruct large areas with high accuracy. Typical characteristics include, an overlap between images (of approximately 60% from image to image and 20% from strip to strip), and the presence of some known ground control points (GCPs) to register the final reconstruction within a particular coordinate system (Lichti 2008:341). Previously, (e.g. pre-2000) photogrammetric reconstruction of
archaeological sites was not often completed due to the complex analytical plotter equipment required and the high level of skill needed to operate them (Konecny 2014:170-174). Recent development and application of algorithms for computer vision have enabled faster, semi-automated digital computation of this process.

The Bundle block adjustment (Bundle) is an algorithm developed in the 1950s and refined in the 1970s (Schmidt 1958, Brown 1958, Ackerman et al. 1970, Brown 1976, Luhmann et al. 2006:21). Now incorporated in software programs, the Bundle algorithm is a vital tool for simultaneous photogrammetric triangulation, enabling relatively fast, automated calculation of interior and exterior orientation parameters and object point coordinates of a surface (Konecny 2014:218; Kyle et al. 2013:326; Luhmann et al. 2006:11&21). Often referred to as self-calibration, Bundle works by using tie points from bundles of rays (single images) to merge into a global model in which the object surface is reconstructed in 3D (Luhmann et al. 2006:229). Luhmann et al. (2006:21) note that the significance of Bundle cannot be overstated. As a method, it poses no restrictions on the position or orientation of cameras and does not have a limit to the central projection of the object. Furthermore, it is the most powerful and accurate method of image orientation and point determination owing to the fact that all measured values and all unknown parameters are taken into account with one single calibration (Luhmann et al. 2006:229). In general, a 3D wireframe and surface models of the object are created with a texture surface available from the original photographs (Grussenmeyer et al. 2002:305). Bundle is mainly used for close-range photogrammetry, and has resulted in a decline in the use of close-range stereophotogrammetry (Garrison 1992:97).

Even with the help of algorithms like Bundle, semi-automated P3DM can be a computationally intensive process. The process is completely algorithmic and involves multiple computational steps briefly described below (McCarthy 2016):

(a) Feature Extraction: mathematically unique visual features in the images are extracted.

(b) Feature Matching: matching features between pairs of images are identified.

(c) Bundle Adjustment: the matched feature points are fed into the bundle adjustment algorithm, which calculates the position and orientation of the camera locations.

(d) Point Cloud Calculation: once the camera locations are known the 3D location of all the matched feature points can be calculated, which in turn forms a 3D point cloud of matched feature points.
(e) Mesh Generation: a mesh of triangles is draped over the outer surface of the dense 3D point cloud.

(f) Texturing the Mesh: the original photographs are projected back onto the mesh to form a visually accurate textured digital 3D model.

1.3.7. 3D triangulation software: AutoCAD, Rhinoceros 3D and Site Recorder
Three-dimensional reconstruction of sites for archaeological purposes is not a recent occurrence. Both manual and software methods were applied to record information on underwater archaeological sites. Most often this is completed when specific details on the stratigraphy of a site are essential in understanding ship construction or cargo and cannot adequately be recorded with plan site maps. AutoCAD is a common software program for computer aided design (CAD) and site plan construction in a digital form. Essentially, AutoCAD is a computer-aided drafting program with a range of capabilities to complete scaled plans of sites, buildings and artefacts. Measurements of archaeological sites can be transferred into CAD format to enable digital drawings of site plans. Rhinoceros 3D (Rhino) is a lesser-known software program applied by underwater archaeologists in the early 2000s. Like AutoCAD, Rhino is a computer aided drawing software program that allows archaeologists to digitally draw-up site plans from measurements. It is based on a mathematical model that determines precise representation of curves and shapes called the non-uniform rational basis spline (NURBS) (Liu et al. 2015:1241), and is employed to create detailed 3D site plans (Green 2004:202). Lastly, Site Recorder is a Geographical Information Systems (GIS) program designed specifically for maritime archaeological projects. It enables digital mapping, recording and finds handling for maritime, freshwater and intertidal sites (Green 2004; Holt 2017).

1.3.8. 3D reconstruction software: PhotoModeler, VirtualMapper and Rhino
PhotoModeler, VirtualMapper and Rhino were some of the software programs employed from the late 1990s to create digital 3D reconstructions of underwater sites and artefact assemblages. Another notable software program implemented for archaeological 3D research is the Architectural Photogrammetry Network Tool for Education and Research (ARPENTEUR). ARPENTEUR is a web-based photogrammetric tool box created for use in marine biology and archaeology, although not as easy to use (Drap et al. 2004). The use of 3D plans in archaeology is best known as tools for public dissemination and promotion. Although on underwater sites, 3D plans are often the only method that can document complex, densely packed artefact assemblages (Demesticha et al. 2014).
The following describes the software programs employed in previous underwater archaeological 3D modelling. PhotoModeler is a commercial computer program produced by Electro Optic Systems (EOS) for phototriangulation of object geometry from photographs (Eos Systems 2016; Green 2004:187). Although little is published on its application to underwater sites (e.g. Franke (1999) Green et al. (2002) and Richards et al. (2008)), PhotoModeler was applied to archaeological projects in 1997 and, successfully implemented on the Tektaş Burnu shipwreck site in the early 2000s. This application is reviewed in detail in Chapter 3 (Demesticha et al. 2014; Green et al. 2002). Basically, the software uses images from a calibrated camera to measure the ray paths from the principal point of the camera, from the photograph, to various points on the site utilising Bundle (Green 2004:187). The software is most suited to mapping precise targets and looking at objects on sites over time (Green 2004). The version employed in these studies did not have the capability of creating digital elevation models (DEMs) or surfaces, although a recently updated version (i.e. PhotoModeler Scanner, 2016) now has the ability to create dense point clouds for surface mapping. Although PhotoModeler is still utilised in some aspects today, Skarlatos et al. (2012:5) note that PhotoModeler ‘…could not fulfil the requirements of, speed, automation, good 3D modelling and non-expert involvement, as it is, after all, a complete photogrammetric software.’ The recent availability of PhotoScan combines the majority of characteristics of the above programs into one user-friendly program.

In the early 2000s, VirtualMapper and Rhino were used in conjunction with PhotoModeler to create contour plans of the sites and plot the 3D artefacts onto the plan. VirtualMapper is a stereo-photogrammetry software that requires two overlapping photographs taken at the same time, processed into an epipolar file and viewed with stereoscopic glasses (Green 2004:194). On Tektaş Burnu, the software was used to reconstruct the site depth contours when conventional tape trilateration and PhotoModeler were possible yet time-consuming (Green 2004). Currently, VirtualMapper is an open source application with more digital capabilities for viewing stereo-photogrammetry. Lastly, Rhino is a free-form digital 3D modelling software (Associates 2017). Rhino is used within archaeology to plot 3D objects and artefacts (in the form of wire meshes) onto digital site plans (Green 2004).

1.3.9. Agisoft PhotoScan 3D reconstruction software
The amount of archaeological published research utilising PhotoScan reflects the popularity of the software program for this discipline. Specifically, many articles focus on either the software, the P3DM method or the use of the complete I3DMs (De Reu et al.
First released in 2010, PhotoScan is a P3DM program that ‘…create[s] quantifiable data in the form of x, y and z point data from which the software can generate a mesh and finally a fully textured 3D-model’ (Demesticha et al. 2014:138). The combination of multi-image photogrammetry and computer vision fulfils the need for fast acquisition of data and implementation of algorithms that allow archaeologists to extract accurate 3D spatial data, without the previous need for skilled specialists in the field of photogrammetry (Plets et al. 2012a:887). PhotoScan is a user-friendly, cross-platform software program that can enable non-specialist archaeologists to employ the use of P3DM techniques on archaeological sites.

It is pertinent to briefly discuss the other software options available for digital 3D photogrammetric modelling. There is a wide range of 3D photogrammetric modelling software programs available which all have the aim of producing detailed 3D models from collections of images. The various packages include: RealityCaptureÔ by Capturing Reality (Capturing Reality 2018). Autodesk Reality Capture (Autodesk 2018), Autodesk ReCap 360, Autodesk 123D Catch (now discontinued), Zephyr (3Dflow 2018), VisualSFM, Pix4D, Bentley Systems ContextCapture, Adam Technology 3DM Analyst, iWitnessPRO, and more. The list of photogrammetric software continues to grow as both the demand for them and the computer vision and processing capabilities advance. The underlying algorithms that each package use vary from one package to another, however because most of the packages are commercial closed source, it is not possible to know what algorithms are actually used, but they may include SLAM (Simultaneous Localisation and Mapping), SIFT (Scale Invariant Feature Transform) and others. It was beyond the scope of this thesis to perform a detailed comparison of these various packages, for technical, financial and time availability reasons.

At the time that this research began, PhotoScan was the most commonly used package at UWA and the WA Museum, so there was a great deal of expertise available in the use of that package. Consequently, PhotoScan (Professional Versions 1.2.4 [March 2016] to 1.3.0 [February 2017]) was selected as the only photogrammetric software program employed for this study. In addition the package is easy to use, affordable and creates digital 3D models, orthophotos and DEMs that can be exported to other formats. As such, it is a desirable tool for archaeologists, given there is no need for detailed knowledge of photogrammetric principles and computer processing. The detailed processes and steps used within PhotoScan are discussed within this body of work.
1.3.10. Photogrammetry versus photogrammetric 3D modelling

Throughout this thesis, I have chosen to use the term ‘photogrammetry’ to define the discipline of photogrammetry and the general definition of the photogrammetric process. To be concise and avoid multiple meanings of the phrase, I use the term ‘photogrammetric digital 3D modelling’ (P3DM) to describe the process of creating digital 3D models from photographs. The final result, that actual model, I am defining as ‘image-based digital 3D models’ or I3DMs. Terminology in this field is still evolving and a range of different terms is in common usage to refer to what I am calling P3DM in this thesis. Other terms include: multi-image photogrammetry, image-based 3D reconstruction, and structure from motion (SfM). The difference between reconstruction and modelling is outlined in section 1.3.11.

In addition, it is important to describe a platform that is commonly adopted by those wishing to share and publish their I3DMs. Sketchfab™ is a website platform that allows users to upload their I3DMs so that they can be viewed on a personal device, tablet, laptop or even virtual reality headset (Sketchfab 2018). Many websites also now have the ability to embed Sketchfab™ models. This platform will be referred to occasionally throughout this study and, at the time of writing, is a main way of publishing and viewing I3DMs.

1.3.11. Photogrammetric 3D reconstruction versus photogrammetric 3D modelling

In general, the term reconstruction is used widely within the disciplines of geographic information science, photogrammetry and computer vision. Although for use within underwater archaeology, there needs to be a slight change in the phrase to accurately portray the results. Within archaeology, the term reconstruction infers that the creator has reconstructed the site as is, instead of utilising data to illustrate a site’s 3D geometric form through a semi-automated process. The deeper theoretical implications within this discussion are defined and developed within Chapter 2 and Chapter 6. For now, it is sufficient to note that the term P3DM is used throughout this thesis (as opposed to photogrammetric 3D reconstruction) as modelling does not carry the connotation of recreating reality, instead implying modelling from real data.

The definitions and descriptions of photogrammetric phrases provide insight into the uses and specific details of each technique while also clarifying the terminology used throughout this study. Ultimately, P3DM is used to refer to the process of creating I3DMs of underwater shipwreck sites.
1.4 Thesis structure

The background to archaeological research and theoretical approaches to optics and visualisation within the discipline are explored and reviewed within Chapter 2. Initially, a review of the role of archaeological visualisation and the implications for interpretation over time is provided. This covers antiquarians right through to contemporary computer visualisation. I then explore the central problem of ocularcentrism in the discipline of archaeology and the theoretical approaches discussing how ocularcentrism affects, limits or biases archaeological interpretation. The overarching theoretical approach identified in this chapter will be returned to in Chapter 6.

Following on from Chapter 2, I provide an outline and background to previous studies involving underwater photography for site recording within Chapter 3. Core focuses are the main developments in current practices employing photogrammetric recording for 3D visualisation. The purpose of this chapter is to provide the background and basis for the proposed method for recording WA shipwrecks presented in Chapter 4. Subsequently, Chapter 4 sets out the P3DM method employed throughout this study. It outlines the specific equipment, settings and techniques employed while also introducing the analytical methods used to assess the results.

I present the results of the applied P3DM method for both James Matthews and Batavia within Chapter 5. Initially, I provide a brief historical and archaeological background for both of these case studies before moving into the results of the application within this study. In particular, the results of the legacy data application to James Matthews are presented here.

Chapter 6 further expands on the findings given in Chapter 5, while leading into the discussion and analysis of the overall results. Throughout this chapter I explore what did and did not work regarding the method applied to the sites. A core aspect of this chapter is a presentation of a refined method for P3DM of underwater sites in WA. In light of the experience of implementing the method to shipwrecks in WA marine environments, Chapter 6 revisits the theoretical approaches outlined in Chapter 2. The aim of this chapter is to engage in an enhanced approach to underwater visualisation and interpretation through I3DMs. I present an analysis of the results that aims to contribute to a wider discussion regarding visualisation in archaeology. Ultimately, I focus on sparking debates that will encourage archaeologists within the sub-discipline of underwater archaeology to
embrace the theoretical debates surrounding archaeology and optics. Lastly, I outline the conclusions gathered from the research in Chapter 7. The findings situate the results and discussion within the wider discipline of archaeology, and the unresolved issues pave the way for future work.
2. Archaeology, imagery and objectivity

Archaeological visualisation ‘…involves the construction of technical cryptograms and, as in all ciphers, these must be made according to rules carefully observed by both transmitter and receiver.’ Piggott (1965:165)

There is an age-old problem regarding archaeological subjectivity and the image. Essentially, the issue is this — does an image depict reality? There is a wide-body of archaeological literature that addresses the problem of archaeological visualisation and the subjectivity of the image that is explored throughout this chapter (Adkins and Adkins 1989; Bateman 2005; Harp 1975; Moser 1992; Moser 2012, 2014; Moser and Gamble 1997; Piggott 1965; Piggott 1978; Shanks 1997; Shanks and Svabo 2013). To truly understand the role imagery plays, the historical uses of visual media in archaeology are considered. This chapter provides an extensive analysis of the forms of visualisation in archaeology over time. Specifically, I consider how archaeologists relied on visual media and how this can limit and mould our understanding of archaeological data. In addition, this chapter synthesises a discussion about the theoretical principles and positions that relate to archaeology’s developing and changing relationship with objectivity and imagery. In fact, the depictive conventions archaeology would rely on can be traced to earlier developments in the medieval period.

This chapter explores the development of archaeological visualisation tools, practices and theoretical positions. In particular, I begin with the influence of illustration development in the natural sciences played before specifically focusing on the adaptations and changes in archaeological and theoretical positions for interpreting the archaeological record. Significant concepts covered involve the changes in theory and techniques from the scientific revolution and true-to-nature representations, through to the 19th and 20th centuries and the quest for objectivity. True-to-nature is defined by Daston and Galison (1992) as the attempts of early antiquarians and natural historians to record the utmost detail and capture reality as they saw it.

The invention of photography brought an underlying mentality of mechanical objectivity to visualisation in scholarship. Particularly within archaeology, the ideal of mechanical objectivity and accompanying development of archaeological photographic language is vital in understanding how visualisation has influenced interpretation. Additionally, and more recently, digital archaeology and enhanced computer vision has similarly led to
significant changes in archaeological thinking, whereby realism and objectivity are felt to be more accessible through technology. To contextualise this, I consider the various theoretical literature related to the use of imagery in archaeology against a chronological history of archaeological illustration. Table 2 summarises key figures, sites, and developments, providing an overview of the history of archaeological visualisation. The following sections delve into the key debates and thinking regarding visualisation and interpretation, with particular attention to the rhetoric of imagery, ocularcentrism and the potential for reflexive archaeology and P3DM.

Table 2. Overview of visualisation of archaeological sites through time (Bahn 2014; Greene and Moore 2010; Trigger 2006).

<table>
<thead>
<tr>
<th>Time period</th>
<th>Illustration/visual techniques</th>
<th>Theoretical notions</th>
<th>Key people</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6th CE – 15th CE</strong></td>
<td><strong>Classical phase</strong></td>
<td>Interest in ‘old’ things. Evidence of collection of artefacts and some noted ‘excavation’ of ancient building remains</td>
<td>Ancient Greece, Rome – Elite classes</td>
</tr>
<tr>
<td></td>
<td>Hand produced images</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>16th CE</strong></td>
<td><strong>Renaissance</strong></td>
<td>Enlightenment: fascination in the Classical Era for guidance in philosophy, art and architecture</td>
<td>Elite class, an understanding of the Classical Era was seen as a respected education William Camden</td>
</tr>
<tr>
<td></td>
<td>Text, manuscripts and the ‘great philosophers’. All depictions of artefacts/sites were realistic and aesthetically pleasing. Most depictions contained errors and were likely based on verbal accounts. European invention of printing – wood block press/Lithography</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>17th CE</strong></td>
<td><strong>Scientific Revolution</strong></td>
<td>The birth of scientific illustrations in the style of the natural sciences. Collecting and classification of artefacts, shells and plants etc.: ‘Cabinets of Curiosities’ (by elite class)</td>
<td>John Aubrey (Late 17th – sites) Isaac Newton Galileo Galilei Descartes Francis Bacon</td>
</tr>
<tr>
<td></td>
<td>Introduction of early standard illustration elements. Drawings became ‘warped’ to highlight the characteristics deemed significant.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>18th CE</strong></td>
<td><strong>Enlightenment</strong></td>
<td>Analytical reasoning by studying the age and formation of sites. Systematic studies of ‘ancient’ sites.</td>
<td>William Stukeley (Early 18th)</td>
</tr>
<tr>
<td></td>
<td>Realistic recording: inclusion of scales, north arrow and plan view Romanticism – early tourism and representation of dramatic landscapes and ‘noble’ primitive man.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>20th CE</strong></td>
<td><strong>Modern Archaeology</strong></td>
<td>Culture-History Archaeology and the rise of Processual archaeology latter 19th BCE post-processual archaeology</td>
<td>Sir Mortimer Wheeler O.G.S. Crawford Gordon Childe Lewis Binford Ian Hodder</td>
</tr>
<tr>
<td></td>
<td>Modern illustration. Application of conventions for appropriate archaeological depiction – solidifying the ‘language’ of archaeological illustration Introduction of computers and GIS.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A comprehensive understanding of archaeology requires awareness of the ways that imagery is central to data gathering, interpretation, and communication over time. Thoroughly reviewing the development of archaeological illustration and related theoretical approaches indicates that they are closely linked to the development of what we would now call the early natural sciences from the 14th century CE. As Moser (2014:59) concisely states, ‘Early traditions of antiquarian illustration were closely related to the development of scientific illustration, where graphic delineation of natural history specimens and ancient artifacts followed remarkably similar paths’. The general aim of science to present objective, true-to-nature observations and conclusions, has echoes within the development of archaeology.

### 2.1 Early depictions of antiquity: Classical and Medieval

A significant form of visualisation in archaeology is plans and maps. The history of cartography then is significant because it provides a deeper understanding of the modern conventions and uses for archaeological site plans and maps. Maps, of many forms and styles, communicate information about places, space and time for both literate and preliterate cultures (Thrower 2008). Map-making, as a form of representation, has its foundations many thousands of years ago with symbolic and figurative representations of the world often for spiritual and ceremonial purposes (Robinson 1995:22-3). For example, the Nuzi clay tablet is one of the oldest known maps to have survived dated to approximately 2300 BCE (Figure 1) (Thrower 2008:15). It was discovered during the 1930-1931 archaeological excavations at Yorghan Tepe, Iraq (Clark and Black 2016:28). The small fragment of clay most likely depicts a landscape of a small settlement surrounded by mountains with a river nearby. The style of the map is indicative of Mesopotamian cartography at this time (Thrower 2008).
Most significant to note about the use of maps and charts before the mass production and use of paper, is that both literate and preliterate or non-literate people could use them. This is a significant point in itself as it indicates the power of visualisation as a tool to transfer knowledge without necessarily requiring text. However, maps successfully communicate information about landscapes, space and time if given the user understands the cartographic conventions employed in relation to reality. One example is Marshallese stick charts that are still used by Marshallese people today (Figure 2) (Thrower 2008). The stick charts are made of palm fronds and shells. They allow the user to understand the patterns of swell and waves caused by winds, with islands identified by shells (Thrower 2008:16). Although confusing to those unaware of the culturally embedded conventions, the stick charts are accurate tools for communicating seafaring knowledge — the key is a trained user.
Other early graphic depictions of the world can be traced to Roman and Greek times. A notable figure of these eras is Claudius Ptolemy (100-170 CE) the Greek mathematician, astronomer and geographer credited with introducing mathematical cartography to the West (Skelton 1972:10). One example is a carved marble scaled map of the imperial city of Rome (c. 203-11CE) known as the Severan Marble Plan or *Forma Urbis Romae* (Talbert and Unger 2008:18). This map, now only remaining in broken pieces, portrayed 13.5 km squared of the city in detail (Figure 3) (Talbert and Unger 2008:67-8), and the fragments represent Roman mapping conventions of the time (Trimble 2008). Some of these conventions include lines marking out streets, buildings and open courtyards. In addition, staircases are noted by a ‘V’ symbol and the map generally has a scale of 1:240 (Trimble 2008:71). Greek and Roman map-making represent a well-defined set of conventions for depicting geographical landscapes and indicate the use of maps to easily comprehend distances and space.
There is some evidence that classical maps influenced map-making throughout the late medieval period (13th to 15th CE), although it should be noted that very few maps of antiquity survived into medieval times. For example, the oldest nautical charts and earliest post-Roman era maps come from the 13th century and are thought to be styled on earlier Roman or Byzantine graphic originals (Skelton 1972:7). A famous example from this period is the Peutinger Map (Tabula Peutingeriana), drawn c. 1200 CE. The Peutinger Map is comprised of a parchment roll (approximately 7 m x 0.32 m) and depicts Britain to Sri Lanka including Roman roads, sites and mileage (Figure 4) (Albu 2008:111). Raleigh A. Skelton (1972:7), a cartographic historian, argued that the 13th century represents a change in epistemology with the general recognition of scholars that ‘…a graphic design will communicate geographical relationships more efficiently than a written document’. Early maps, such as the Peutinger Map, are examples of visual representation enhancing our understanding of the world. Large areas could be presented in a form that was easily observed from one perspective. The development and use of maps allowed viewers to visualise and comprehend spatial relationships between places, information that was otherwise only conveyed through text or oral sources. This is particularly important to note when discussing how visualisation structured landscape and site interpretation during this time.
Christianity, a religion that values textual sources for information and knowledge, dominated Western thought throughout the medieval period. Due to the reverence of Christian ideologies, interest in the past focused on the Bible and was locked into largely biblical explanations of the origin of humans and the age of the earth (Robinson 1995:23). Consequently, perceptions of the past were largely structured by religious thinking, which precluded the consideration of material evidence for the accurate age of human cultures (Gamble 2015a; Manley 2014; Trigger 2006). In addition, independent thinking was deemed heresy, as doubting God and Christian beliefs offended the Church and related officials (Greene and Moore 2010). Pilgrimages to religious sites increased and often involved the collection of ancient artefacts and scripts or texts. The majority of objects collected during this time were housed in large libraries within monasteries (Bahn 2014; Elsner and Rutherford 2005; Greene and Moore 2010). Consequently, access to knowledge about the past was confined to those who had access to such places, and the ability to read.

Towards the end of the medieval period, scholars began to question Christian views on creation. The widespread recognition that knowledge was learnt by reading second-hand observations through someone else’s writings was no longer accepted. The 16th century
brought a new approach to understanding the world around us through technological advances and the European voyages of discovery.

2.2 The Renaissance: new approaches to knowledge

The Renaissance represents a movement across Europe spanning the 13th to 17th centuries. Areas of scholarship including art, music, technology and astrology were all affected by a new approach to study, to re-embrace concepts from the Classical era, as well as promoting new ideas and approaches (Hunt 1999:1). Specifically, there are key events that occurred during from the 16th century, which are significant to the visualisation of archaeological sites in Europe. Primarily, scholars began to turn to classical texts held within libraries and monasteries to understand more about the world than was possible through the Bible. In addition, the ‘Age of Discovery’ of the Americas and other places brought knowledge of new and different cultures. Sprawling civilisations and vastly different hunter-gatherer cultures defied the information provided by the Roman Church (Greene and Moore 2010). Lastly, the invention of the print press in Europe allowed for the reproduction of both text and graphic representations.

The Renaissance represents a definitive step by Western societies to understand the world around them. In terms of cartography, vital techniques were invented that enhanced precision and projection in mapping. One significant invention included triangulation (first described by Gemma Frisius in 1533), a technique that enhanced place fixing through intersecting lines. Additional equipment such as the plane table (drawing maps whilst simultaneously recording angles, Leonard Digges in 1571) and the pendulum clock (first described by Galileo, Christian Huygens built one in 1657 the first precise time keeping tool) (Thrower 2008:91). Most of these techniques would be adopted by antiquarians, and much later by archaeologists.

Renaissance map-making was heavily influenced by the translation of Claudius Ptolemy’s Geographia from ancient Greek into Latin (Thrower 2008). Thirteenth-century refugees from Constantinople brought Ptolemy’s guide to making maps with them when they fled the Turkish invasion. By 1410, the book was a popular reference for scholars in Florence, Italy, a centre for mathematics and geography, and, consequently, it spread across Europe from there (Thrower 2008:91). Thrower (2008) claims that the influence of Ptolemy’s Geographia cannot be over exaggerated. Geographia contains instructions for map-making projections that provided a base and a comparison for all progress in cartography and geography (Bagrow 1945; Keuning 1955).
Detailed research of the Classical scholars became more achievable with the dissemination of knowledge that accompanied the introduction of printing (through lithographs and wood engravings) to Europe in the late 15th century (Thrower 2008:91). The printing press was invented in Europe circa 1449 by Johan Gutenberg and the technology rapidly spread throughout the following decade (Barbier 2016:116). Printing enabled the reproductions of texts in a generally cheaper form (with some exceptions). In particular, the printing press was vital for reproduction of an exact copy of an illustration or map. Subsequently, information about sites, artefacts and past cultures could be printed and copied for mass circulation (Thrower 2008).

Ancient monuments were significant as Renaissance scholarship ‘included an emphasis on learning through recovery and translation of classical Greek and Roman texts, and architectural movements that sprang from the study of classical antiquities, particularly the ancient buildings of Rome itself’ (Manley 2014:4). Scholars, artists and architects looked to Classical cultures for inspiration as they sought to regain the perceived level of civilisation represented by the majestic monuments and scholarly culture of Classical Europe (Greene and Moore 2010). Scholars began to learn from ancient texts housed in monasteries, such as the works of renowned classical philosophers (e.g. Socrates, Plato and Aristotle) (Greene and Moore 2010). Significantly, Renaissance scholars used visual media, in particular illustrations of monuments, sites and artefacts, as tools for deeper understanding and communication (Pyle 2000:72). Knowledge of the ‘arts’ became a status of wealth, but by the end of the Renaissance it was no longer enough to read about ancient monuments and architecture — visiting and recording the sites became a focus (Trigger 2006:54).

Ancient monuments and artefacts were depicted visually, primarily through drawings, paintings and sketches (Gamble 2015a; Greene and Moore 2010; Trigger 2006). A visual portrayal of tumuli (grave mounds) and rune stones at Jelling, Denmark in 1591 (Figure 5) and a well-known 14th century manuscript that depicts Merlin erecting Stonehenge are some renowned examples of early antiquarian illustrations (Adkins and Adkins 1989:2; Trigger 2006:82-3). Portrayals of structures such as tumuli and Stonehenge suggest an interest and reverence of monuments and ancient sites. By the late 16th century, techniques for the visualisation of monuments advanced as topographical viewpoints become popular. An example is Lucas de Heere’s Dutch pen-and-wash drawing that depicts Stonehenge from an artificial projection enabling better communication of the
overall site (Figure 6) (Piggott 1978:10). The inclusion of humans and animals in these illustrations (like the person in Figure 6) were devices used to communicate details like perspective and to potentially inspire awe (Piggott 1978; Trigger 2006).

![Figure 5. 1591 portrayal of Tumuli at Jelling Denmark, Drawn for Henrik Ratzau (Trigger 2006:Figure 3.2).](image1)

![Figure 6. Lucas De Heere’s 1574 painting of Stonehenge, note the perspective and inclusion of people and a horse for scale (Piggott 1978:10).](image2)

A significant Renaissance figure was English statesman and scholar William Camden. Camden is most famous for his 1586 publication *Britannia*, in which he combined archival information with recorded knowledge of sites gathered whilst travelling extensively though England and Wales (Bahn 1996:36; Greene and Moore 2010). *Britannia* is a map-based description of Britain in the 16th century and is considered the first comprehensive guide to antiquities. The work highlights some core traits of an antiquarian from this time.
These traits include a reverence for ancient monuments and sites, a focus on Classical period history to identify the origins of Britain in Classical Rome and, lacking acknowledgement of any associated prehistory cultures (Figure 7) (Trigger 2006). Camden’s publication was essentially nationalistic as he sought to prove that the monuments in Britain were linked to the prestigious Classical cities of ancient Rome (Greene and Moore 2010; Murray 1999). The visual elements of Britannia played a core role in inciting interest and wonder of Britain’s ancient sites to the public. They communicated details that could not be described in words and encouraged wider interest and interpretation of ancient sites through visual depictions. Britannia was updated and revised in numerous editions both during and after his lifetime, signifying the impact of this publication (Trigger 2006).

![Stonehenge illustration from the 1600 edition of Britannia](image)

**Figure 7.** William Camden’s Stonehenge from the 1600 edition of Britannia (Camden 1610:252).

In the last decades of the Renaissance, English philosopher Francis Bacon (1561–1626) pushed for an understanding of the world through observation, instead of reliance on ancient texts (Trigger 2006:97). This new scholarship focused on a criticism of Classical culture being superior to the culture at the time (Trigger 2006). Now known as ‘Baconian
Francis Bacon’s approach is one of the first accepted practices of inductive reasoning — basing knowledge on observations of reality. This approach of observing reality to gain truth and facts defined the next era of scholarly thought and indicates a deepening reliance on visually observing the real world to obtain true knowledge.

2.3 The Scientific Revolution and 17th century antiquarians

The increasing divide between science and religion throughout Western Europe culminated in the 17th century with the Scientific Revolution. Mathematicians, physicists, natural philosophers and other scholars were no longer content by only learning through the written word of others (Ede and Cormack 2016; Trigger 2006). The Scientific Revolution was characterised by the exploration and investigation of the natural and cultural world by observing reality itself (Greene and Moore 2010:3). Modern science has its foundation during this period. Science is essentially defined as a system of knowledge gained by understanding that nature acts regularly enough to be described and interpreted by a set of laws and rules (Helibron 2003). This is relevant to the development of scientific objectivity, as sensory observations were seen as providing true knowledge of the world. Entrenching the ideal that seeing something with your own eyes provides more strength and truth then reading any other text. Therefore, this scientific method grew as a renowned, reliable way of learning the truth of the world through visual observations.

As interest in the study of natural sciences and antiquity increased, more specimens and artefacts were collected. The images in collections enticed scientists and antiquarians to begin classifying and recording to understand more about objects (Renfrew and Bahn 2012:22). Artefact illustrations were originally completed to document the objects held within these collections so that types or styles of artefacts could easily be identified and published. From here, descriptive visual records created by antiquarians and natural historians alike for documenting specimens increasingly relied on developing conventions for depiction within the drawings (Moser 2012:294).

Visual depictions of artefacts during the 17th century indicate how material objects were the core data for understanding the past and archaeological sites. There is a significant stage of collection, observation and recording of small objects (both natural specimens and cultural artefacts), that links modern scientific study and visual representation to early understandings of the past. As the study of Classical literature and philosophers was mainly a pastime of the rich and elite, so too was a hobby of collecting objects that evoked curiosity and represented rare or exotic finds. The collections of geological, archaeological,
religious and natural history specimens became known as ‘cabinets of curiosity’ and represent the beginnings of modern Museums (Figure 8) (Greene and Moore 2010; Manley 2014). At this time, a collective understanding began to be entrenched — that knowledge of the world around us could best be presented through visual illustrations (Moser 2012:293). The techniques and mediums for the visual representation of material culture during the Scientific Revolution further highlights the role that visual media played in structuring the ways that artefacts and ancient sites were interpreted.

![Figure 8. Ole Worm’s Cabinet of Curiosities (Musei Womani Historia, 1655) (Bahn 1996:36).](image)

A significant study by Moser (2014) ‘Making Expert Knowledge through the Image: Connections between Antiquarian and Early Modern Scientific Illustration’, highlighted the significance of artefact illustration during this time. Using examples of Italian and French antiquaries, Moser observed the changing ways that artefacts were depicted from the Renaissance to the 17th century. Super realistic, highly detailed and technical drawings were replaced by simplified distorted representation of objects. These drawings emphasised characteristics deemed significant for a further, more broad, study: ‘by highlighting the key attributes of artifacts, illustrators went beyond mere recording, transforming drawings of antiquities into interpretative statements’ (Figure 9) (Moser 2014:59). Using artefact illustration examples in catalogues called ‘Paper Museums’ (specifically, Dal Pozzo, Bonanni, Montfaucon and Caylus, Figure 9), Moser (2014:99) notes that the conventionalised illustrations portray early modification of visual depictions. Instead of attempting to illustrate an object as accurately to nature as possible, they contained visual codes highlighting features that were significant to those studying
them. This indicates that visual language was already becoming an essential aspect for recording and communicating information about artefacts in the 17th century.

![Illustration of artefacts](image)

**Figure 9.** Example of artefact illustration indicating scientific realism, The Dal Pozzo Paper Museum (RL 10269r) (Moser 2014:70).

The 17th century marked the beginning of a formal study of ancient sites in England (Figure 10). John Aubrey, a celebrated 17th century antiquarian, spent most of his career recording monuments in the county of Wiltshire, and is most renowned for his work at the prehistoric stone ruin complex at Avebury, 1649 (Trigger 2006:106). Aubrey’s principle of gathering information for information’s sake provided a thorough set of data for archaeological sites (Greene and Moore 2010:14). The site plans that Aubrey created are not illustratively detailed — in terms of modern recording — but they appear to be approximately scaled and include a north arrow as well as numerous descriptive notes (Trigger 2006). Around the time that Aubrey was recording monuments across England, tourism of ancient sites began to increase and a general public push for more information and descriptions of these sites probably inspired the work of antiquarians.
2.4 The Enlightenment: early foundations for archaeological illustrative language

The mid-17th to 18th centuries are often described as the period of Enlightenment, a refinement of post-Scientific Revolution ideals (Elliott 2010; Hankins 1985). Scholars turned to human evolution and increasingly developed new explanations for the answers presented in long-held religious theories on creation (Greene and Moore 2010). Famous individuals associated with this cultural shift include Galileo Galilei (1564-1642), René Descartes (1596-1650) and Isaac Newton (1642-1727) (Hankins 1985). The core of the Enlightenment is a shift away from seeing the Classical period as a superior culture, to acknowledging the contemporary achievements of the time.

During the Enlightenment, technical advances influenced the ways that ancient sites, monuments and artefacts were represented. The invention and availability of mass-produced paper replaced expensive rarer parchment, and provided the means for a more affordable way to disseminate publications (Pettegree 2010:18). Books and texts were no longer only available to the elite ruling class and monasteries (Adkins and Adkins 1989). Mass printing enabled publishers to reproduce the same image on a large scale, as opposed to originals created for every text or, reprints using more expensive parchments.
During the 18th century antiquarians applied visualisation techniques that suited the ideologies of the time. An excellent example of an Enlightenment antiquarian is William Stukeley. Stukeley conducted fieldwork on structural foundations and burial mounds (Trigger 2006:108). Stukeley surveyed Avebury, Stonehenge and Silbury in the 1720s, concluding that they are all connected together and linked to Druids (Greene and Moore 2010:16). Although not drawn to scale, the drawings that Stukeley completed of Avebury (published in 1743) are detailed as they include related site plan features and additional detailed notes and (Figure 11). Stukeley’s main reasoning for attributing the sites to ancient Druids was based on his deduction that the sites were pre-Roman, as Roman roads cut through some of the monuments (Greene and Moore 2010). Although his hypotheses about Druids were based on little evidence, Stukeley’s visual recordings of these monuments have long proven valuable, as much of these sites are now destroyed or drastically altered. For example, he recorded an avenue of stones leading from Stonehenge to the River Avon (now known as Stonehenge Avenue) that was only rediscovered with aerial photography (Greene and Moore 2010:16).

![Figure 11. William Stukeley’s depiction of Avebury, 1724 (Abury[sic] 1743) (Piggott 1978:41).](image)

Stukeley added classification of monuments to a growing repertoire of antiquarian characteristics, like linear earthworks or various types of burial mounds (Trigger 2006).
This illustrates the progress of antiquarians in adding and improving ‘standards’ for fieldwork. What we see in the period leading up to the early 18th century is the grounding of visual media as a powerful tool for both recording and communicating information about archaeological sites. Techniques and tools for discovering more information about the past were limited to recording sites and artefacts. Further information was learnt through classical texts and it would be some years before advances in the technology and excavation methods encouraged a change in the way information was gathered (Manley 2014). Antiquarians of the time focused on a political push for nationalism and a reverence of the past that aimed to provide further knowledge on the cultures that created them.

Overall, developments in techniques for visualising antiquities from the 16th to 18th centuries identify particular reasons for the technical characteristics of the illustrations – truth-to-nature and scientific realism. In the early Renaissance, scholarly depictions attempted to convey natural and historical objects using as much detail as possible so that reality was presented accurately (Moser 2014). Scientific approaches, such as true-to-nature and scientific objectivity, indicate how developments in visual techniques represent stages in archaeological history and are inherently linked to continued development in archaeological approaches. Moser (2014) highlighted this by outlining how the 17th century illustrative techniques represent a definitive stage in the representation of archaeological sites and material. Antiquarians simplified drawings the detailed drawings from the early Renaissance and highlighted characteristics that were deemed significant, instead of attempting to create representations that are as accurate to reality as possible. Essentially, these site and artefact illustrations became accurate depictions of reality for scientists and antiquarians but would not appear present the same information to those who did not understand the conventions with which they were drawn. We see a change from realistic portrayals of artefacts to an early transition of simplified illustrations that highlighted essential conventions for the interpretation of significant details.

2.5 The 19th century: foundations of modern archaeological depiction

Archaeology developed as a distinct discipline with ethical principles, methods and theoretical arguments throughout the 19th century. Two major theoretical developments at this time influenced the ways that artefacts were recorded and thus depicted. Danish scholar Christian Jürgensen Thomsen’s ‘Three-Age system’ (1836) and English naturalist Charles Darwin’s theory of Evolution (1859) were theoretical approaches that greatly influenced how archaeologists studied the archaeological record (Greene and Moore 2010; Manley 2014).
The ‘Three-Age System’ was developed by Thomsen in 1819 to organise artefacts into coherent categories in the Danish National Museum (Bahn 2014:20). Thomsen (1836) later published a guidebook in Danish on the ‘Three-Age System’ that grouped artefacts in material types. The system aimed to specifically classify and temporally order a large collection of prehistoric stone and metal artefacts within the Danish Museum. Although it is likely that there were similar practices in other museum around Europe (Heizer 1962). For example, the three-ages are the stone, bronze and iron age, with stone representing the earliest era (Manley 2014:12). The Three-Age System approach to classifying artefacts became popular after it was verified by Jens J. Worsaae, a Danish archaeologist (Worsaae 1849). Worsaae excavated a site using stratigraphy as a comparison for Thomsen’s system and confirmed that the dating by type was generally accurate (Heizer 1962:259). Eventually, this system was applied throughout Europe to identify changing proportions and material of artefacts over time, with the simplest representing the earliest period and more complex objects representing more modern stages (Bahn 2014; Manley 2014). Most notably, this system of classification relied on a visual depiction technique that highlighted characteristics of artefacts, as well as material type. The Three-Age System reinforced archaeology’s focus on visualisation of artefacts to convey information about archaeological sites and material, an approach that was further enhanced with evolutionism.

With Charles Darwin’s 1859 publication of *On the Origins of the Species*, ideas about the developing complexity of artefacts relating to the evolution of humans rose in popularity. Darwin’s proposed natural selection argument turned the focus of scientific study to identifying the stages of evolution. Natural selection is the idea that a population advances due to variations in the genetic make-up of each proceeding generation but, that it is not always progressive (Gamble 2015b; Scott and Marshall 2009). Archaeologists adapted evolutionism as a theory for identifying the early stages of humans and explaining them as an example of natural selection (Manley 2014). For example, John Lubbock (known as Lord Avebury) (1870) published *The Origins of Civilisation and the Primitive Condition of Man* and argued that primitive cultures are closely linked to the ancient human cultures as they lacked the evolutionary advances made by civilisations. This approach provided the foundation for justified racism at this time, which was accompanied by illustrative sketches identifying the features of primitive peoples. Evolutionism is significant here as it further highlights the influence that visual depictions, of both artefact and humans, have on conveying arguments and presenting interpretations. While evolutionism mainly
influenced archaeological studies that focused on the different stages of human adaptations and cultural change (Gamble 2015b), it also filtered through to material object analyses (Renfrew and Bahn 2012).

Evolution influenced theories about the development of artefacts and specifically led to arguments about the evolution of object styles and forms that are the foundations for typological classification of artefacts (Renfrew and Bahn 2012:27). These theoretical developments influenced artefact illustration, particularly in the standardised conventions for communicating the form, style and material of objects. For example, Figure 12 shows Swedish scholar Oscar Montelius’s study of Bronze Age artefacts as an example of categorising by type to determine development over time (Montelius 1886:28; Renfrew and Bahn 2012). Although there were other emerging theoretical perspectives about archaeology throughout this period, the primary influences on artefact illustration were, arguably, evolutionism and the ‘three-age system’. Another influential development for archaeology at this time was the significant advances in excavation techniques and principles, combined with the development of recording equipment such as photography. The implication of these developments and advances in ideas of the past and identifying human origins led to a more standardised type of artefact and site recording. Combined with advances in technology and equipment, reviewing the 19th century is significant in understanding the developments in visualisation in archaeology.

<table>
<thead>
<tr>
<th>Period I</th>
<th>Period II</th>
<th>Period III</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Fibulae" /></td>
<td><img src="image2" alt="Swords and Daggers" /></td>
<td><img src="image3" alt="Axes" /></td>
</tr>
</tbody>
</table>

**Figure 12.** Oscar Montelius’s typology of bronze age fibulae (Montelius 1886:28).
By the late 19th century conventions for archaeological recording and illustrations had developed further as archaeologists adopted rules and conventions for quality site excavation and classification. In particular, the skills developed for technical drawings of equipment and machines in the Industrial Revolution (c 1740–1840) and conventions such as orthographic view (projection) drawings formed the basis for what we define today as archaeological illustrations (Piggott 1965; Rovida 2012:81,120). One particular archaeologist is renowned for the application of detailed and accurate field methods, combined with technical drawings. The work of General Augustus Lane-Fox Pitt-Rivers (1827-1900) is often described as the turning point for archaeological field recording (Adkins and Adkins 1989:5; Piggott 1978:9; Thompson and Renfrew 1999:377). Pitt-Rivers set the standards for precision in archaeological illustration. His requirements for accuracy, detail and scale were unmatched at the time and indicated a general shift towards ensuring that recording methods were dependable tools for communicating archaeological finds (Bowden 1991:167; Manley and Campbell 2014:14; Piggott 1965:175).

Notably, Pitt-Rivers was also the first archaeologist to focus on illustrations (both site plans and artefact drawings) within his publications, as opposed to only including a minimal amount of illustrations (Figure 13) [see Volumes I-IV (Pitt-Rivers 1888)] (Piggott 1965:174). In addition, Pitt-Rivers advanced the quality of section drawings (i.e. a cross-section of the trench showing the features in profile) (Bowden 1991). Although it is now accepted that his ideals of excavation are not as we would expect today, his military background bought accuracy to the excavation techniques and his publications are filled with multiple illustrations and tables that are still of value today (Greene and Moore 2010). The use of visual images in the work of Pitt-Rivers represents the establishment of visualisation as a core tool for both recording, interpreting and communicating data within the archaeological process.
In archaeology, culture-history grew in popularity throughout Europe from the late 19th to the early 20th centuries. The cultural-historical approach began in Germany through the late 19th century as a way to describe the classification of recurring groups of artefacts and settlements into distinct types of people, social groups or cultures (Greene and Moore 2010). For example, John Abercromby (1841–1924) used the term Bell-Beaker culture to describe a collection of early Bronze Age beaker pottery (Herring 1938; Trigger 2006). Abercromby believed that the Beaker people had migrated across Europe and the specific style of the beakers was evidence (Trigger 2006). The Marxist archaeologist, Vere Gordon Childe (1892-1957), made culture-history popular throughout Europe during the 1920s (Childe 1929; Greene and Moore 2010) with the publication of his 1929 book *the Danube in Prehistory* in which he defined culture as a set of material cultural objects with associated traits. A core aspect of cultural-historical thought is the focus on forms, types and characteristics of artefact material that could be grouped together in cultural assemblages (Trigger 2006). Culture-history both reiterated the importance of typologies (such as Montelius’s bronze fibulae, Figure 12) and expanded upon the level of detail and different assemblages. In addition, diffusion is a concept that provided cultural-historians with a way of explaining the transferral of similar material culture and settlements across space (Renfrew 2005). At its core, the cultural-historical approach relied on empirical data to ‘speak for itself’ (Lock 2003:2). In order to allow this, cultural-historians often explained the information about social cultures through both visual typologies and diffusion maps with devised boundaries for the cultural groups of an area of interest. For example,
Grafton Elliot Smith’s (1929:14) (Figure 14) map the diffusion of the ‘helioithic’ culture (sun/solar deity worship) from Egypt to the rest of the world, whereby the ideas of diffusion are conveyed through arrows and shading of different parts of the world.

Figure 14. Example of diffusion of the ‘helioithic’ culture from Egypt (Smith 1929:14, Map 2).

It is evident that advances in archaeological illustration techniques and accompanying theoretical approaches increased the abilities of archaeologists to convey meaning and detail through visual media. In particular, the use and development of different styles or techniques for depicting material culture and sites, along with technological advances (e.g. mass printing and paper), increasingly encouraged reliance on visualisation as a strong and useful tool for accurate recording, interpreting and communicating information. Changes in imagery techniques throughout the following centuries further indicate an increasing reliance archaeologists placed on visualisation as one of the quick and easy tools for understanding data. However, it would be the invention of photography that would radically change the ways archaeologists used visual media.

2.6 Photography: catalyst for achievable objectivity?
Photography was invented in 1838 when Louis Jacques Daguerre designed and created a process for recording an image on silver copper sheets (Dorrell 1989). Only a few years
later, William Henry Fox Talbot patented the ‘calotype’; equipment that allowed a
negative image to be printed onto silver chloride impregnated paper (Dorrell 1989).
The invention of photography was a catalyst that pushed archaeology into a new era of
mechanical recording methods (Downing 2006; Olsen 2012). Photography had far reaching
effects on recording, visualisation and interpretation of archaeological material. The first
use of photography for archaeology is thought to be by Richard Lepsius in Egypt, 1842,
not long after Talbot’s invention (Olsen 2012:47). However, early photographic equipment
was not yet suitable for fieldwork and archaeological uses. Setting up the equipment was
expensive as supplies for photographic printing, combined with printing negatives were
costly. As such, illustration and printing continued to be the primary from of recording
and visualisation (Olsen 2012). The older technique of lithography was still often applied,
as it was easier and affordable.

Although lithography was invented before photography, the technique was used to make
lithographic engraved copies from original photographs to increase reproduction of
imagery (Daston and Galison 2007:137). Lithography is essentially a chemical process that
involves a flat stone with engravings. Ink is only retained on the engraved image (or
pattern) and when pressed onto paper creates a lithograph print (Figure 15) (Britannica
2014; Weaver 1964). Advances in reproduction included the Woodburytype, a term for
both a process and the completed image that became popular around 1875. The
Woodburytype is a photomechanical process through which high-quality monochrome
images are made from an original photographic print, producing copies often used for
book illustrations (Krauss 1978:296). However, a reliable field set-up for archaeological
photography occurred with the invention of the halftone process, which enabled easier
and affordable reproducibility of images (Dorrell 1989; Olsen 2012). The Halftone process
used a screen to break up the original image into dots of varying sizes that simplified and
recreated the original photograph (Cook 2002:146). Advances in photomechanical
processes, such as the halftone screen, allowed more affordable photographic reprinting
and increased the dissemination of photographs through publications.
The first extensive use of photography during an archaeological excavation was by Alexander Conze — an 19th century German archaeologist — during work at Samothrace, Greece. Published in 1880, Conze’s printed photographs (not lithographs) appear very much like contemporary archaeological images. Conze included stadia rods/measuring poles to give a scale and each image is crisp and sharp (Figure 16) (Conze et al. 1880; Dorrell 1989). Other notable applications of archaeological photography in the late 19th century were William H. Jackson’s photographic images of Mesa Verde and other American pueblos throughout the 1870s and Alfred P. Maudslay, Edward H. Thompson and Teoberto Maler’s photographs of buildings and monuments in Mexico during the 1880s (Dorrell 1989:6-7). Overall, the late 19th and early 20th centuries was an era in which photography increasingly became available as a standard and reliable (although still costly) tool for archaeologists (Dorrell 1989:7). However, the benefits of greater affordability and expertise with photography by archaeological site recorders did not occur until after World War II.
Although the developments of photographic techniques are notable in the 20th century, the foundations for how photographs are perceived are based in the late 19th century. At this time archaeologists could only adequately visualise specimens and artefacts through illustration, and the invention of photography seemed to provide an answer to the idea of reducing one’s own creative speculation (Daston and Galison 2007:124). The ability to capture a moment with photography and provide autonomous objective images appealed to the scientific aims of unbiased recording and decreased the potential for misdirected free will (Daston and Galison 2007). From the mid-19th century, machines were seen as ever alert, lacking bias or speculation, and ignorant of theory. As Frederick Bohrer (2011:8) stated at the beginning of his book, *Photography and Archaeology*, that archaeology and photography came of age in the 19th century. As such, the premise of the time, that ‘Photography offers the possibility of an effortlessly archaeological way of seeing, sliding present into past while remaining tethered in objectivity’ (Bohrer 2011:7), significantly impacted the way that archaeological material was recorded. Mechanical objectivity, through photography, continued to be touted for many decades, instilling a subconscious acceptance that photographs represented true reality and were the most detailed form for recording reality.
2.7 The 20th century: archaeology and mechanical objectivity

Site recording and artefact drawing styles were refined and standardised throughout the late-19th and early 20th centuries. The use of the pictorial conventions mentioned above further indicates that visual depictions began to be used in conjunction with text to make stronger arguments (Moser 1992:832; Piggott 1965:165) As Adkins and Adkins (1989) reinforce in their study of archaeological illustration, drawings have always been favoured as a recording technique because of the ability to highlight significant traits and characteristics. Increasing application of visual media, evident in more photographs printed within archaeological publications, indicated the reliance archaeologists have on these visual tools to translate ideas, theories and arguments into easily understandable visual summaries (Moser 1992). In addition it gradually became essential for the conventions, signs and symbols within archaeological visualisation to be understood by both the archaeologist creating the image and those who would interpret them.

Photography enhanced the recording abilities of archaeologists and played a major role in the conventions of site plans and surveys. The development of aerial photography in the late 19th and early 20th centuries was essential to the improvement of photographic surveys and photogrammetry in archaeology. Aerial photographs of archaeological sites were completed as early as 1879 in Persepolis, Iran (by Friedrich Stoltze) (Nöeldeke et al. 1882). Further notable examples include: Giacomo Boni’s photographs of the Roman Forum in 1899 using hot air balloons and, Colonel John E. Capper’s images of Stonehenge in 1906 (Capper 1907; Ceraudo 2014:11). In the following years until the outbreak of World War I, aerial photography slowly continued to develop. During WWI, aerial photography was essentially a reconnaissance tool to provide information about enemy occupied territory. As a consequence of increased experience in aviation and reconnaissance, techniques for aerial photography improved, as did the experience of pilots and photographers (Bourgeois and Stichelbaut 2009:4; Ceraudo 2014:12; Dorrian and Pousin 2013:5). In addition, camera equipment was refined to suit aerial photography, specifically the improvement of camera lenses (Reeves 1936:102). At the end of the war, archaeologists would quickly determine another benefit of the reconnaissance flights, a wealth of aerial images covering landscapes across Europe (Ceraudo 2014; Stichelbaut 2015).

Throughout the 1920s and 1930s, archaeological aerial photography was increasingly applied in countries across the world, such as Egypt, Palestine, South America and Central America (Reeves 1936). Numerous documents from this time provide guidelines for site photography from the air. Philip L.O. Guy (1932) compiled an article, ‘Balloon
Photography and Archaeological Excavation’, describing his experience with aerial photography using balloons. Guy (1932) details his success with certain techniques, while also highlighting what not to do when acquiring quality site photographs. Significantly, Guy (1932:148) noted that aerial photography ‘…enabled me to examine a number of sites from the air, discovering such things as the complex of buildings buried by sand inside the enceinte of the Crusaders castle of Athlit.’ It is evident that archaeologists understood the significance of having a view of the site from height, as it provided a much better perspective and enhanced understanding of a site’s spatial layout.

In 1936 Osbert G.S. Crawford published an article ‘Archaeological Photography’ (1936) describing his camera equipment and recommendations for quality images. Crawford stated that good photography was more to do with patience and perseverance than expertise or skill (Crawford 1936:352). American photographer Dache M. Reeves, was a pioneer in early reconnaissance aerial photography and balloon photography during World War I, becoming well-known for his archaeological site photography (Reeves 1936). Reeves argued for aerial photography (with either aeroplanes, balloons or kites) as a reliable method for discovering new archaeological sites and surveying known ones. The increased application of photography to archaeological research in the 1930s represents a growing reliance on a tool that appeared to objectively record reality. The combination of advances in equipment and expertise from WWI encouraged a wider use of aerial photographs for archaeological purposes. Significantly, it represents the beginning of an era of reliance and acceptance of photographic recording for objective recording.

Post WWI Europe witnessed further development in the rigorous standards for archaeological illustration and recording, best highlighted by the work of Sir Mortimer Wheeler (1890-1976) who brought his military background to his archaeological work (Adkins and Adkins 1989:5). Wheeler’s application of stratigraphic principles, scaled site plans and detailed descriptions of sites improved the recording standards introduced by Pitt-Rivers in the late 19th century (Hawkes 1982:86). Most notable were Wheeler’s forward planning in excavation and the degree of technical precision he demanded in excavation and site recording (Figure 17) (Sudeshna 2003:4). Indeed, it is argued by Piggott (1965:175) that Wheeler’s stratigraphic recording of Segontium can be considered a benchmark for archaeological illustration, as it was the first illustration to contain all of the information essential to understand the stratigraphy determined through excavation (Figure 18). Archaeological illustrations became a primary tool to convey information about sites and enhance understandings. The combination of photography and
illustrations indicates that archaeological visualisation was recognised as a dependable and consistent tool for communicating the ideas and interpretations of the archaeologist.

Figure 17. Wheeler and Gordon’s site plan, Maiden Castle, Dorset 1934-7 (Piggott 1978:58-9, Figure 41).

Figure 18. Wheeler’s 1922 stratigraphic recording at Segontium (Piggott 1965:175).

Like World War 1, World War II produced a large amount of new photographic images for archaeologists to study and identify sites after the war. Improvement of techniques and equipment for printing photographs leading up to and during World War II saw an increase in the application of aerial photography and the identification of numerous new archaeological sites after the war ended (Palmer 1947; St. Joseph 1945). Post WW2
archaeological photography continued to develop as a result of a mix of disciplines and principles.

The belief that site photography could capture every aspect of an excavation was first proposed and insisted on by Wheeler’s site photographer, Maurice B. Cookson, in the 1940s and 1950s (Cookson 1954; Thornton and Perry 2011:104). Although they rarely achieved the perfect results they sought, Wheeler and Cookson’s idea of complete capture through photography continued to be foremost in archaeology (Shanks and Svabo 2013). Cookson, a professional photographer, would go on to pioneer training in archaeological photography at the University College of London’s (UCL) Institute for Archaeology (Thornton and Perry 2011). Throughout the 1940s and 1950s, Cookson argued for the importance of quality, accuracy and clear archaeological site photographs. Cookson’s seminal publication *Photography for Archaeologists* (1954) is renowned as the original guide for archaeological photography and significant for the praise of objective, detailed photographic capture of information (Thornton and Perry 2011:104).

The post-war spread of aerial photography paved the way for photogrammetry as a technique for recording and enabled further detailed site plans and land surveys (Hannavy 2013). Although photogrammetry had previously been applied to archaeological research (e.g. (Baudouin 1902; Wastl 1933)), the development of towers, ladders, and stands enabled testing of close-range photogrammetry to archaeological sites throughout the 1960s and 1970s (Figure 19) (Sterud and Pratt 1975). Archaeologists were attracted to the time saving process of photogrammetric recording on sites (both on land and underwater), as well as the immense detail captured for later interpretation (Cooper 1979; Rosencrantz 1975; Vibe-Muller 1975; Whittlesey 1966; Wölpert 1964).

The process for acquiring measurements from the images themselves, however, was still a lengthy process that required skilled users and expensive plotting equipment. For example, Sterud and Pratt (1975:163) highlight how photographs had to be scaled appropriately for printing, a time consuming process before the developing stage. After this, cutting and placing photographs together was required to create scaled photomosaics of a site (Figure 20). However, the use of reliable photomosaics added another highly accurate recording tool to archaeology. Indeed, the authors praised the use of photomosaics as allowing increased accuracy, reproducibility, and saving money and labour, despite the added amount of time (Sterud and Pratt 1975:167).
At the same time photogrammetry also increased in use within archaeological fieldwork although it had been utilised since the early 20th century, as detailed below (Anderson 1982; Bannister et al. 1998). By the 1970s, it was a common tool applied in the field and continues to be to this day (Borchers 1977; Clouten 1974; Scogings 1978; Solveig et al. 1979). Most popular at this time was stereo-photogrammetry, which involves two cameras taking overlapping images and, when viewed together, the stereo-pair of images give an enhanced understanding of depth and dimension when viewing an artefact or site than is possible with a single 2D image (Bevan 1975:259). Richard Anderson compiled a detailed review of general photogrammetry in his 1982 article *Photogrammetry: the pros and cons for archaeology*. Although now out-dated, this article praised stereo-photogrammetry’s ability to record all visible surfaces with high accuracy and objectivity. Anderson begins by compiling a list of the positive implications for photogrammetric use within archaeology. According to Anderson (1982:200-1), photogrammetry was: 1) honest and ‘completely objective’, 2) accurate, 3) passive, 4) records in 3D, 5) provides a durable record, 6) allows for genuine re-interpretation of the archaeological record and, 7) is a useful photographic record for other research purposes. Although Anderson’s viewpoint was typical of a processual archaeologist (discussed in detail in section 2.3), he succinctly noted the key traits of photogrammetry that further encouraged archaeologists to believe in the objectivity of photography. In contrast, Anderson also noted some drawbacks of employing this tool for recording that were not yet a main point of discussion within archaeology. Apart from the generally accepted drawbacks of expense and the
requirement of skilled specialist operators, Anderson (1982:201) suggested that employing photogrammetry only records the visible and that it lacks the ability to directly interpret what it sees. It is vital to note that at the beginnings of the 1980s archaeologists were starting to understand some of the automation issues. Furthermore, Anderson (1982:204) predicted that the application of computers would reduce the laborious plotting and processing work within photogrammetry. In recent decades advances and development of algorithms for computer vision have significantly impacted the field of archaeological visualisation and documentation, seeing Anderson’s prediction come true.

2.8 Computers, GIS and virtual reality: a new age for archaeological visualisation

Computers, GIS, digital photography and digital 3D modelling all fall under the category of ‘digital archaeology’. There is a widely encompassing view that digital technology is a new age or revolution, as computers, tablets and a constant connection to the Internet are omnipresent factors of daily life. The perception of a digital revolution is slowly changing (Daly and Evans 2006), and the digital era, as a subject of study, is emerging in art and design with the concept of ‘post digital’ (Berry and Dieter 2015; Berry 2015). The rapid application of advancing digital technologies within archaeology is forcing archaeologists to seriously critique what the application of these techniques achieves. The influence of digital technology within archaeology is evident in the extensive growing literature debating how archaeologists employ digital tools. For example, the compiled publication, Thinking beyond the tool: archaeological computing and the interpretive process, provides insight into the ways that archaeologists are employing digital technologies (Chrysanthi et al. 2012; Eiteljorg 2000; Evans and Daly 2006; Frischer and Dakouri-Hild 2008). In general, there are two different schools of thought regarding digital archaeology:

1. Simply a tool that we employ (and therefore has no direct impact on our overall results and interpretations), or,
2. It influences us at every step, more so than simple, manually created visual media has previously. Digital technology pervades our everyday lives as well as the archaeological process and definitely influences what we see and how we interpret things. As a result it influences our interpretations (Zubrow 2006:10).

In my mind, digital archaeology is a combination of both of the above arguments, it provides tools for recording, analysing and interpreting data while also influencing the very way that we interpret this data. One way to understand the influence of digital archaeology on the archaeological process and visualisation is the analysis of changes in theoretical approaches over time.
During the mid-20th century, the approach to archaeological research began to change. Archaeologists were no longer satisfied with the inductive reasoning put forward by the cultural-historical approach and sought to bring forms of scientific rigour to the discipline (Binford 1962; Lock 2003; O’Brien et al. 2005). ‘New Archaeology’ (known now as Processual archaeology) dismissed the empirical approaches of culture-history and focused on the success in the natural sciences (e.g. Hempel 1965) at the time (Lock 2003). Archaeologists took up an empirical approach and began to use direct observations, such as measuring, photographing and drawing to retrieve data that would allow them to answer hypotheses about sites and cultures (Renfrew and Bahn 2012; Trigger 2006). The aim of the new, scientific archaeology was to create a worldwide standard in methodologies, and align archaeology to the principles of anthropology (Binford 1962; Chenhall 1967, 1968, 1971; Clarke 1968; Cowgill 1967; Whallon 1972; Wilcock 1973). A key element that enhanced and guided the new processual archaeological approach was the computer (Moffett 1991:34).

The application of computers to archaeology began in the late 1950s to the 1960s when computers were installed in universities for academic research. Processualists favoured quantitative approaches and advocated the use of computers for data processing and for the application of statistical approaches to research (Chenhall 1968, 1971; Cowgill 1967). As in other fields, archaeologists were no longer reliant on the manual processing of data, and over time the increasing processing power computers provided completed this work faster and more accurately (Djindjian 2009). As a result, the application of computers was best used within the archaeological research of those favouring mathematics and quantitative approaches to understanding the past. One example of the earliest applications of computers to archaeological research is James Deetz’s (1965) book *The Dynamics of Stylistic Change in Arikara Ceramics* from research conducted in 1960. Deetz’s publication highlights the use of computers at the time, investigating sequences and data of archaeological material by plotting the stylistic distribution of ceramic rim potsherds from an American Indian site using an IBM 704 computer (Deetz 1965). George Cowgill (1967:18) a specialist in archaeological computing, further reiterated the general focus of computer application during the 1960s by stating that ‘Most archaeological applications of computers fall roughly under the headings of data storage and retrieval or of multivariate statistical analyses’. Significantly, even at this early stage of computer use within the field of archaeology, Cowgill (1967:18) criticised some of the rapid uses of computers as a hasty reaction to the novel and fashionable attraction of a new machine. Broad discussions on
digital archaeological theory and method are best embodied by the creation of the Computer Applications in Archaeology (CAA) group in the 1970s. The CAA started with a small team of archaeologists and mathematicians in the UK and eventually grew into an international conference by 1992 (Andresen et al. 1992). The early foundation of CAA highlights constant and rigorous attempts by archaeologists to continually discuss and debate the implications that computer applications have on research, a point that is reiterated further on in this chapter.

Archaeologists from the 1950s and 1960s could only access the processing power of a computer while actually visiting the location that the large mainframes were housed (Scollar 1982). Consequently, although large computer mainframes were available within institutes, the invention of the microprocessor in 1971 was the first stage in reducing the size of computers and increasing their processing speed, culminating in microcomputers by 1975 (Lock 2003:11). The first commercially available computers, such as the Apple II and the IBM, were increasingly used in areas of archaeological research by the late 1970s (Lock 2003:11). Significantly, the application of computers to archaeology paved the way for large data storage, management, and processing, further enabling visualisation software and programs capable of producing graphic representations from the late 1980s and early 1990s onwards into the current digital age (Daly and Evans 2006).

A key aspect of processualism is the empirical approach to data and that all observed data presents an objective truth about reality. The core argument for processualists is that objective data exists and can provide understanding about the past if it is carefully researched and tested against hypotheses (O’Brien et al. 2005). Although early processualists did not actively critique visualisation and imagery, I argue here that visual data represented objective truth to processualism and essentially provided the ‘mechanical objectivity’ that scientists sought from microscopes and other technical equipment (Daston and Galison 2007). Consequently, advances in computer processing and computer vision enhanced archaeological reliance on visual data as it became more and more realistic and easily malleable (Reilly 1989; Reilly and Rahtz 1992). The dependence on digital visual tools and data is best appreciated by analysing the next significant technical development, Geographical Information Systems (GIS), as a case study.

GIS are programs that allow numerical, text-based and graphic data to be displayed in a visual environment (Green 2004:211). GIS software are mapping and spatial analysis computer programs enabling users to store, analyse and manipulate spatial information
through graphical layers (Maliene et al. 2011; Wheatley and Gillings 2005). The application of GIS to archaeology fundamentally improved the way that spatial analyses were approached by archaeologists and is often labelled as the biggest step in handling geographical information since cartography (Allen et al. 1990; Maschner 1996:301; Renfrew and Bahn 2012:88). The introduction of GIS to geography in the 1980s indicated the massive analytical power the software provided for spatial data, and archaeology quickly followed suit (Brown and Rubin 1982; Gill and Howes 1985; Kvamme 1985, 1986; Lock 2010). In a similar response to the application of computers, the rapid, enthusiastic and widespread use of GIS as a tool for archaeological research also sparked theoretical debates about the analytical implications.

In contrast, some saw the widespread use of computers as an extended application of data modelling and argued that the importance of the individual in the archaeological record would be lost in a sea of automated data processing and modelling. Debate and criticism arose with those who saw this as a failure of processual archaeology and sought to look beyond the statistics and embrace human agency within the past. Consequently, a new approach, post-processual archaeology, rose to popularity in the late 1980s becoming a favoured theoretical standing for archaeologists (Booth et al. 1984; Gaines and Gaines 1980; Graham 1979; Hodder 1985; Lock 1985; Lock and Wilcock 1987; Reilly and Rahtz 1992; Richards 1991, 1998; Richards and Ryan 1985; Ross et al. 1991; Shanks and Tilley 1987). In simple terms, post-processual archaeology is a collective approach by archaeologists who critique the objective beliefs expounded by processualists (Lock 2003). One of the core post-processual values highlighted from the late 1980s is that knowledge of the past is an interpretive discourse between subject and object (Hodder and Hutson 2003; Shanks and Tilley 1987). All interpretations made by archaeologists are affected by subjective biases from our own backgrounds and we create meaning from material culture (Johnson 1989; Shanks and Tilley 1987).

Unlike processualism, post-processualism is not one integrated school of thought (Lock 2003:11). Instead, post-processualism includes a wide variety of theoretical approaches that are united in the criticism of the processualist hypothetic-deductive approach. Subsequently, Lock (2003:11) points out that assessing the use of computers throughout post-processualism is difficult, however, a general understanding of the post-processualist reaction to computers can be determined through a review of the core arguments in the decades of advances in computers. For example, how advances in equipment and
technology sparked resurgence of objective ideals to archaeological site recording and a contrasting argument of interpretive approaches (Figure 21).

![Diagram](image)

**Figure 21.** Gary Lock’s depiction of the relationship between technological development and theoretical advances (2003:8, Figure 1.2).

From the 1990s, GIS programs were increasingly applied to archaeological research and the strengths of the software (e.g. the ability to store, integrate and visualise large amounts of data) were widely acknowledged (Harris and Lock 1992; Lock 2010). It is evident from the countless spatial recording and visualisation techniques employed that archaeologists have long been aware of the significance of recording spatial data. As a result, the popularity and continued application of GIS software is linked to the ability to manage and analyse data within a visual and spatial format — key themes of archaeological research.

Most of the discussions throughout the 1990s revolved around accepting the visualisation and modelling power of GIS, whilst also striving to understand what the application to archaeology would mean for long-term research and rigour in methodological practices (Allen et al. 1990; Barceló et al. 1998; Miller and Richards 1995). The first significant
publication discussing GIS and archaeology was compiled in Kathleen Allen, Stanton Green and Ezra Zubrow’s (1990) edited book *Interpreting Space: GIS and archaeology*. Within this compilation of essays and case studies the application of GIS was critically reviewed and discussed for the wider benefit of archaeology and the future. Significantly, Allen et al. (1990:383) noted that the enthusiasm for GIS as a new technology should not overlook deeper impacts and that, ‘…in any bandwagon effect we must maintain our critical edge.’ We need to be cautious with new technology and awareness is an important factor of introducing a new tool or technique to archaeological research.

Allowing a powerful methodology to drive the practice of a discipline can also be a pitfall for any academic research (Allen et al. 1990:383). For example, Allen et al. (1990) continue by pointing out that ‘elegance’ and a user-friendly interface does not necessarily mean that unskilled users can operate software successfully. Skill and experience of a user is always needed for the best outcome of any analysis. This was discussed a few years later in Maschner’s (1996) *New methods, old problems: geographical information systems in modern archaeological research*. This study concentrated on detailed descriptions of techniques and analytical tools within GIS, offering more information and demonstrating the abilities for archaeological work. Focusing on three main areas of GIS abilities, (i.e. data analysis and visualisation, cost surfaces viewshed or line-of-site analysis and site location and environmental modelling), the edited book compiles all of the potential for GIS to aid archaeological research. Maschner (1996:302) concludes the collective publication with a discussion on theoretical approaches to GIS and stresses the limitations and problems of GIS for archaeological research.

Moreover, Wheatley and Gillings (2005:1) point out that widespread growth in availability of GIS software has often not been replicated by adequate skill and knowledge for use by archaeologists. As GIS is now an ingrained tool for research within archaeology, issues arise with a lack of knowledge and understanding of the exact data required for proficient use and analysis of information through GIS (Wheatley and Gillings 2005). Perhaps this is a result of using tools and techniques that were originally designed for other disciplines and purposes. Indeed, most courses and textbooks teaching adequate skills and capabilities for GIS cater for other disciplines (such as geographical information science and geophysics) and often include irrelevant information. The result is that data collected for integration to GIS is often gathered in the field by individuals who may not truly grasp the principles of GIS and, when applied to the software, the data can create misleading conclusions (Wheatley and Gillings 2005:1). This point is argued further by Huggett
who states that archaeologists simply borrow computer software (i.e. GIS) from other disciplines without actually understanding the inner workings of what is created at the other end. The ubiquitous computer has become a tool of which only computer scientists truly understand the inner workings and machinations of the processing stages (Davis 1995:6). In recent years this problem was mitigated with the introduction of GIS programs designed by and for archaeologists, as well as books relating specifically to the application of GIS to archaeology (Agugiaro et al. 2011; von Schwerin et al. 2013).

Throughout the 2000s, the application for GIS developed into new small-scale applications that are essentially intra-site spatial databases. Due to the availability of portable computers combined with higher processing and graphic capabilities, using GIS within fieldwork became an accepted and powerful aspect of daily data management and interpretation (Lock 2010). A key attribute was the spatial nature of archaeology, as expressed by Lock (2010:1296): ‘[a]rchaeology is a discipline that has the understanding of space at its core and the tremendous power and flexibility of GIS goes a long way toward meeting its spatial needs.’ Archaeological data is not merely two-dimensional but inherently three-dimensional, and GIS responded to this fact. The first attempt at creating an intra-site 3D GIS database was from Katsianis et al. (2008) at the Paliambea, Kolindros, Greece. In this study archaeologists worked towards a combination of conventional recording and GIS with 2.5D rasters and 3D vectors in Esri ArcGIS. Another example of pioneering work on the integration of 3D and GIS is from Koehl and Lott (2008) at the Abbey in Niedermunster, France. They incorporated topographical surveys with photogrammetric plans and laser scanned point clouds to create a 3D GIS for intra-site documentation and analysis. However, both of these studies were slightly too early for the advances in semi-automation of photogrammetry and computer science that occurred in subsequent years.

Following on from the widespread adoption of computers and GIS, the advent and availability of digital cameras transformed the way the archaeological site recording and visualisation with photography was conducted. It is important to stress here, however; that the level of critical assessment of the use of digital photography for archaeological research never matched the initial critiques of computers or GIS. The first digital camera was developed by Kodak in 1975, mainstream digital cameras were not available until the 1990s (Prakel 2009:1). Digital cameras were increasingly employed in archaeology throughout the mid-1990s and, although they were seen by some as an expensive luxury, they were valued for removing the manual aspects of film photography (e.g. processing
film negatives, printing and scanning) to simply taking the photograph and uploading it to a computer (Hall et al. 1997:249). The improvements in digital camera equipment, mechanics, image processors and memory storage over the next two decades not only improved the quality of images produced but also made digital cameras more affordable and integrated into research.

These advances ensured that photographs were no longer limited to the 12, 24 or 36 images for each negative filmstrip. Instead, digital photography is capable of capturing many thousands of images in one session and only limited by the file type and size of memory card. As Shanks and Svabo (2013:103) state, ‘[p]hotography has never been so instantaneous or so disposable, one click to capture and another to delete’. To understand the apparent rise and infiltration of digital photography, a comparison of film versus digital cameras purchased from 2002 to 2008 showed interesting results. In 2002 a total of 27.5 million digital and 63 million film cameras were purchased, by 2008 digital camera purchases amounted to 119 million and film cameras were practically obsolete (Hand 2009:2; Lyman and Varian 2003). As a consequence of the accessibility, price, speed and reliability of digital cameras numerous possibilities for image-based archaeological recording were opened up.

The rise in popularity of digital photography had interesting implications for both photographic techniques and knowledge of traditional photographic equipment. Once again, the issue of skill and experience of a user becomes a part of the discussion. As Long (2013:xix) indicates, the automatic features of digital cameras reduced the requirement to understand the intricacies of camera equipment and how to take good quality photographs. The automatic settings of digital cameras have removed the need for users to understand photographic principles such as aperture and focal length. As such, digital photography grew in popularity, as it was no longer necessary to be highly skilled and knowledgeable in camera settings.

An important point to note is that unlike the level of sustained critical debate within archaeology regarding the application of computers and GIS, there has not been a similar level of debate and critical reflection regarding the effects and repercussions of incorporating digital photography into archaeological research. The reasons for this are not clear, however; I argue that it is the result of archaeologist’s longstanding acceptance of photography as objective. When exploring the effects of digital photography within archaeology, research for this chapter revealed that, in comparison to the large amount of
literature regarding the computers and GIS in archaeology, there are fewer publications in archaeology detailing the theoretical and methodological implications that digital photography may have on the archaeological process. Certainly there are influential publications by the likes of Moser (2012, 2014), Shanks (Shanks and Svabo 2013; Shanks and Webmoor 2013) and Molyneaux (2013) [expanded upon later in this chapter], but these works focus on photography and images as a broader facet of visualisation. I argue here that although GIS is ultimately something very different to a digital camera, the same level of debate and criticisms should have occurred with the incorporation of digital photography in archaeology. The application of digital cameras as highly manipulable pieces of equipment changed the way that photographic recording of archaeological site is completed. Digital cameras have dramatically increased the numbers of images created by archaeologists, enabled greater manipulation of images, decreased the processing time for uploading images, are increasingly readily available and affordable tools and, are valuable tools acquiring spatial information. It is surprising then that the significant influence that digital cameras have had on the archaeological process has not been met with sustained critical debate to ensure a thorough understanding of the changes digital imaging has wrought on the overall archaeological process. This oversight is more significant considering the other forms of digital visualisation that became available to archaeological research, and often incorporate digital photography as a core tool for data collection, such as virtual reconstructions and 3D digital modelling.

Virtual reconstructions created on a myriad of digital platforms aid in experimental exploration of what past life was like (Gabellone et al. 2013; Guidi et al. 2012; Haydar et al. 2011; Johnson and Ouimet 2014; Morgan 2009; Sanders 2014; Stanco and Tanasi 2013; Teichmann 2009; von Schwerin et al. 2013). For example, VR and gaming engines are common features within archaeological research as tools for illustrating and communicating ideas about past landscapes, cultures and individuals (Ch’ng et al. 2011; Ch’ng and Stone 2006; Dawson et al. 2011; Sanders 2014; Teichmann 2009). Gillings (2005:224) debated the implications of virtual reality in the chapter ‘The real, the virtually real, and the hyperreal[sic]: the role of VR in Archaeology.’ His focus was how virtual reality tools were quickly applied (whether for creating experimental reconstructions or reality-based reconstructions) and that a critical discussion has either been an apparent afterthought to justify the use of, or, left out altogether (Gillings 2005). For example, he states that ‘…archaeologists have to date tended to apply VR techniques first and then think about them later.’ (Gillings 2005:224). Gillings (2005:225) further argues that in order for VRs, such as P3DMs, to be truly useful to the discipline of archaeology, there needs to be a
There have been significant attempts to develop sets of protocols (as introduced in Chapter 1) to deal with the developments of digital and computing technology particularly regarding digital visualisations, namely: (1) The London Charter for computer-based visualisations of cultural heritage and (2) The Principles of Seville. Both sets of protocols aim to codify guidelines and provide recommendations for practitioners conducting computer-based visualisations within cultural heritage and the practice of virtual archaeology. Devised in 2006, the London Charter aimed to initiate a level of widespread integrity and reliability of computer-based visualisations for cultural heritage. It built upon the foundations of research and debates from the mid-1990s, during which those within cultural heritage began to critically question the impact of incorporating virtual 3D spaces within their research (Barceló 2001; Frischer et al. 2000; Roberts and Ryan 1997; Ryan 2001; Ryan 1996). This Charter aims to amalgamate all of the pertinent points and issues into one central document to be used as a guideline and catalyst for further discussion. One further aim was to ensure that computer-based visualisations move forward as a well-respected, reliable technique for archaeological research (Beacham et al. 2006). The London Charter promoted a foundation for all future research in this area, particularly through methodological and intellectual rigour and accessible results (Denard 2009:4). To do this six key principles were devised that inform the best practices in heritage visualisation across disciplines: implementation, aims and methods, representation, documentation, sustainability and access (Denard 2012). These are used as a basis for discussion in this thesis and are thus considered in further detail here.

The first principle, implementation, recommends that a ‘London Charter Implementation Strategy’ be applied to any project using computer-based visualisations (London Charter 2012:5). This strategy requires that a project designs or adopts a coherent conceptual framework that refines the London Charter to specifically relate to a field or discipline. ‘The Principles of Seville: International Principles for Virtual Archaeology’ is an example of implementing the ‘London Charter Implementation Strategy’. The Principles of Seville offer a further eight principles that relate specifically to experimental digital reconstructions of archaeological sites. These principles are: interdisciplinarity, purpose, complementarity, authenticity, historical rigour, efficiency, scientific transparency and training and evaluation (See Appendices E and F, the London Charter and the Principles of Seville included as a supplementary reference). Each principle aims to combat significant
problems that are encountered with computer-based visualisations of cultural heritage. For example, historical rigour aims to ensure that the virtual reconstructions are based on extensive historical research and are as accurate as possible (IFVA 2011:7). These principles are presented to assist cultural heritage practitioners to increase the applicability of the London Charter to other facets of cultural heritage. At the same time, the document enables practitioners to tackle issues that currently result in unreliable or incorrect virtual reconstructions of heritage.

The London Charter currently provides the best guidelines for ensuring that rigorous methods are used and that reliable computer-based visualisations are developed in archaeology. While there are certainly shared aspects of both the London Charter and the Principles of Seville that can be applied to image-based digital 3D modelling, they are not suited specifically to P3DM of archaeological sites. Some principles such as documentation, aims and methods, sustainability and access can all be applied when discussing aspects of P3DM. In contrast, research sources focuses on the sources used to create ‘reconstructed’ digital visualisations of the past and does not apply to digital 3D modelling. What this highlights is the need for a set of principles following the benchmark set forward in the London Charter that are compatible and complementary to image-based recording and digital 3D modelling of archaeological sites.

2.9 Archaeological digital 3D modelling

In the field of digital 3D modelling, there are constantly new tools and techniques, many of which are taken up by archaeologists. For example, archaeologists have quickly adopted new techniques like laser scanning and photogrammetry given their significant potential to record sites more comprehensively, accurately and thoroughly, and the potential that they will enhance interpretation and communication (Berggren et al. 2015; Bruno et al. 2013; Dell’Unto et al. 2013; Dell’Unto et al. 2015; Demesticha et al. 2014; Landeschi et al. 2016; Olson et al. 2013; Plets et al. 2012a; Quartermaine et al. 2014). While digital 3D models are growing in popularity as recording and communication tools that potentially improve the archaeological process (De Reu et al. 2014; Galeazzi 2016; Landeschi et al. 2016), Frankland and Earl (2011) warn that this current trend may not mean improved archaeological work. They stress that archaeological 3D visualisations are deceptive because of their apparent ability to provide authenticity, accuracy and objectivity. For example, photorealistic 3D visualisations of the past can seem to convey ‘historical truth’ to viewers (Frankland and Earl 2011:63). Instead, they argue that we should accept visualisations, such as digital 3D models as a means to view a site (or object)
from multiple angles and distances (Frankland and Earl 2011:63). In their thinking they are a form of subjective archaeological interpretation and should be treated as such.

This study reveals the changing meaning and significance of visualisation over time in archaeology. Early artefact illustrations and depictions of ancient monuments and landscapes began with a focus on capturing reality and representing the objects as close to the truth as possible. As scientific methods developed, theoretical positions changed and the aim of visual representation changed to reflect the scientific revolution and realism. Simplified line drawings of objects and natural specimens became warped to highlight features deemed significant for characterisation or classification. However, the introduction of photography brought back the mentality of mechanical objectivity and once again baited the ideal of capturing reality. Photography presented archaeologists with a highly detailed, seemingly objective way to record all manner of archaeological material. The promise of mechanical objectivity reignited archaeologist’s goals of objectively recording realism to the highest level. Additionally, perspectives once again changed to criticising the application of scientific objectivity and processualism. The underlying influences in photographic recording and the abilities of the photographer to influence the final depiction were brought to the forefront of archaeological debates. The digital age has since brought a new threat, that of analytical power, realism in representation and automation of high level processes for modelling. The recent widespread application of P3DM and increased use of I3DMs for archaeological visualisation brings old and new theoretical arguments back to the forefront of archaeological interpretation. The following sections delve into the primary theories surrounding visualisation and interpretation focusing on the rhetoric of imagery, ocularcentrism and the potential for reflexive archaeology and P3DM.

2.10 Ocularcentrism and the rhetoric of imagery
Archaeologist’s inherent dependence on visual media stems from over five hundred years of depicting material culture, sites and archaeological interpretation using an ingrained set of conventions and protocols for ‘accurate’ representation. This is a problem as it encourages the belief of objective representation through photography and enhances reliance on visual media for communication. The term ocularcentrism came to the front of visualisation debates with the work of Martin Jay, a scholar and historian whose research focuses on social and cultural criticism such as vision and understanding. Ocularcentrism is the privileging of vision over all other senses (i.e. smell, touch, hearing and taste) in order to understand or comprehend something (Jay 1988, 1994; Tyler 1984). In his 1988
paper ‘The Rise of Hermeneutics and the Crisis of Ocularcentrism’, Jay investigated the idea and prevalence of it within Western cultures.

Reliance on visual media relates to Descartes’ theory of vision equalling a simultaneous mode of perception; understanding a view in an instant (Thomas 2008:7). ‘Cartesian Perspectavilism’ is an ideology that reinforces the view of ‘seeing is believing’. Thomas (2008:2) summarises this as a particular facet of sight (the mind acquiring information through an ocular apparatus) that came to be the norm for understanding and accepting reality. We can find further elaboration in Jay’s 1993 *Downcast eyes: The denigration of vision in twentieth-century French thought* where he specifically refers to the biological mechanics of the eye. Jay highlights ideas of seeing with the eye, as a light sensor that turns light into impulses and then the mind transforms these impulses into imagery. Hence, ‘seeing is believing’ is perhaps more accurate as seeing is comprehending (Thomas 2008:4). However, what the now accepted and ongoing discourse aims to explore is the notion that ‘seeing’ is much more than the mechanical process outlined by Jay (1993). In terms of archaeology, ocularcentrism is particularly fitting given the culminated information already presented in this chapter — archaeology, a western practice, is also clearly an ocularcentric discipline.

For decades, the seemingly realistic photograph and ingrained way of recording and communicating through visual media implied that photographs represent reality and copy exactly what is seen in an objective manner (Harp 1975:iix). As Bateman (2008:192) explained, the technical nature of photography has endeared it to archaeology’s scientific aims and underpins the false or misunderstood notion of objectivity in the recording process when, in reality, it is far more subjective (e.g., Shanks (2013:153)). Like microscopes to the hard sciences, cameras and photography are technical tools for highly accurate recording and, as such, it is easy to forget that in reality photographs are often highly influenced by the photographer (Bateman 2000:1). Dechert (1975:351) reiterates that the photographer is trained to look at a particular subject with the presentation of specific data for a particular audience. They will likely take a photograph with the attributes that appear to make such data the most apparent. In so doing, attributes that are equally vital for another audience may be missed, which creates a conceptual bias. This is a vital point about how we interpret what we see, often forgotten when discussing archaeological photographs and visualisations.
Notably, Moser (2012:292) stresses that archaeologists remain largely unaware of the highly complex ways in which visual media influence the production of archaeological knowledge. Similarly, the conventions and technical language of archaeological visualisation shapes what is recorded and represented in the imagery. Moser (2012:296) most succinctly outlines the use and limits of the process of archaeological visualisation:

The process of archaeological visualization [sic] refers to the agency of the products ...and how they perform as key interpretive and explanatory tools in our discipline. While archaeological visualizations [sic] serve as a critical “gateway” through which disciplinary knowledge can be accessed by non-professionals, they also enable our own professional exploration of ideas and concepts that are difficult to identify and articulate through textual discourse.

As stated above, the conventions encourage archaeologists to use visual media — particularly photography — as a critical gateway for the exploration of theories and data. These visual tools allow us to elaborate and communicate ideas and data, which are difficult to do so in a textual form. Despite the acceptance that photography and visual media are one of the archaeologist’s most frequently used tools, there is an apparent ignorance of the relationship between visual representations of archaeological material and their impact on our understanding of the sites (Moser 2012:292; Moser and Gamble 1997:185). Outlining the true impact and potential limitations of being ocularcentric requires exploration of how visual media affects our understanding, in particular, the rhetoric of imagery.

The ‘rhetoric of imagery’ as developed by Barthes is relevant here. Barthes (1964) first highlighted and elaborated the persuasive effect that the codes, signs, languages and narratives of imagery have on influencing understanding and promoting certain values. Barthes semiotic approach to imagery and photography aimed to investigate the cultural codes for both creating and viewing photographs (Emerling 2013). Shanks (2013) further suggests that we take images for granted and accept what they depict as reality without questioning motives or bias. Archaeologists are increasingly becoming aware of the influences that visual media have on the creation of knowledge and our understandings of sites (Moser 2014; Shanks 2013; Shanks and Svabo 2013; Shanks and Webmoor 2013). It is well known that a visualisation is one of the core tools for communicating knowledge and interpretations, such as site plans, photography, charts, illustrations, diagrams and maps. Recognition of the need for theoretical research into the role of imagery and optics in
archaeological interpretation gained strength throughout the 1990s and continues today (Elkins 1997; Jay 1993; Moser 1992; Moser and Gamble 1997; Ouzman 2001; Shanks 1997; Shanks and Webmoor 2013). Studies conducted over recent years have shown a gradual understanding of the inherent problem with the use of visual media for communication and explanation of ideas and data, and that there are larger and deeper implications of accepting visualisations at face value (Cochrane and Russell 2007; Molyneaux 2013; Shanks and Webmoor 2013).

2.11 Reflexivity and representation

Archaeology relies on visualisation to convey information and meaning, but also often overlooks the implications of imagery in interpretation. The use of P3DM, with completed highly realistic I3DMs, is only going to increase ocularcentrism. How can this reliance on visual media be remedied? This section addresses the potential to combat the rhetoric of imagery through a reflexive process for image-based recording and digital 3D modelling. Ian Hodder (1999:92) — a pioneer in the field of postprocessual archaeological theory — used the term ‘archaeology at the trowel’s edge’ to refer to the cultural biases and contextual influences that influence the interpretations that archaeologists make about artefacts and sites. Excavation conventionally involves uncovering layers of sediment and evidence of habitation/use, recording the contextual relationship and removing significant artefacts before removing that layer of sediment in order to access the next layer, and so on. The problem with archaeology is that knowledge is ultimately formed by fundamentally changing and displacing the context behind the material culture that is being studied – through excavation, we destroy the very material that we wish to learn more about (Gregory et al. 2012; Olson et al. 2013; Shanks and Webmoor 2013). When an excavation is completed, all that typically remains of the context of an archaeological site are drawings and plans, data forms, samples and photographs – essentially a 2D record of a 3D site at the time it was excavated (De Reu et al. 2013).

Making this situation more complicated, Hodder’s (1999:92) argument is that all recording of the original context of a site is affected, influenced and biased by the cultural background of the person who is undertaking the recording. Consequently, while archaeological surveys are generally accepted as a measured geometric document, they are also equally an interpretation (Drap 2012:111). Archaeologists are active participants in site recording and will record what they deem important, what they are able to record and, inevitably miss out some details. As a result, the ability for archaeologists to make more future interpretations or inferences from the archaeological material will now
forever be influenced by the primary interpretations made; the ‘archaeology at the trowels’ edge’ (Hodder 1999:92).

One answer to this problem is to employ more self-critiquing methods and techniques within the overall archaeological process, also known as being self-reflexive or reflexivity (Berggren 2015; Hodder 2003; McAnany and Hodder 2009). Applying a reflexive process to archaeological research establishes a way to record the choices, reasoning and context for certain decisions. The London Charter recommends that the ‘[d]ocumentation of the evaluative, analytical, deductive, interpretive and creative decisions...should be disseminated in such a way that the relationship between research sources, implicit knowledge, explicit reasoning, and visualisation-based outcomes can be understood.’ (Denard 2009:8). The charter uses the term ‘paradata’ to encompass all forms of choices, decisions and reasoning. Bentkowska-Kafel and Denard (2012:1) note that, like many others, this term has been borrowed from other disciplines and in general it describes the process of documenting interpretation. In terms of understanding the way in which visual media influences our interpretations, paradata and reflexivity are essential features that should be included in archaeological research to gain a better understanding of the reasoning behind decisions.

Furthermore, Hodder (1999:84) aptly states that archaeological data is a dynamic, dialectical, and unstable relationship between objects, contexts and interpretations. Two of the main post-fieldwork losses are the context of objects within the site and interpretations made at the time of survey or excavation. With the availability of digital technology, the quantity of data recorded is increasing and the ease of storing it in a digital form is seen as a benefit to the ethical ideology of archaeologists (i.e. recording to the best possible detail and the highest level of accuracy for future research). Unfortunately, we are now experiencing a case of ‘drowning in data’ (Backhouse 2006; Thomas 1991) and Shanks and Webmoor (2013) argue that data stored in digital form is now beginning to lose its context and, as information archives, they can lose value. In an ideal world, archaeologists would be able to revisit a site at any stage of an excavation allowing the next generations of archaeologists to devise their own primary interpretations of the context and relationships between artefacts at ‘the trowel’s edge’. What is needed is a more cognitive, accessible, navigational site or project archive that actively encourages fresh experiences and constant refinement of interpretations and the exploration of different hypotheses. Some notable examples are considered in the remainder of this chapter.
As Hodder (1999:126) argues, the answer to the problem may lie in a 3D digital model of a site, ‘[p]otentially, users will be able to move through the site exploring information, and coming to their own decisions about the ‘data’ at different levels.’ However, a digital 3D site model should not aim to be a true copy of the original but, a mediation (Shanks and Webmoor 2013:105). Essentially, this is a way to provide a medium for contextualising essential archaeological information that is far more useable than the highly codified and objectified data found in traditional databases. One of the most recent and seminal examples of work similar to this is the lengthy archaeological project at the Neolithic city of Çatalhöyük, and the recent push to incorporate and embrace digital 3D recording and reflexive analysis of interpretations. If this type of documentation and communication is intertwined with a thorough and reliable paradata documentation then the choices and motivations for employing certain techniques and issues can be retraced and understood in a more cognitive way.

The work at Çatalhöyük within the ‘3D Digging Project’ is perhaps the most advanced and largest example of integrating digital recording and visualisation into the archaeological process (Hodder 2006:13). A recent and extensive period of excavation (since the 1990s) enabled in-depth investigation into many different theoretical and technological advances in archaeology by multinational teams (Berggren et al. 2015). Prominent is the Hodder’s approach of reflexive archaeological practices (Hodder 1997a; Hodder 2000).

The 3D Digging Project started in 2009 with the aim of recording every phase of excavation in one specific site, Building 89, in 3D using varying technologies (Forte 2014:1). The end goal as Forte (2014:1) describes it, is to make an archaeological excavation virtually reversible, allowing for new interpretations and yielding new research questions. Since 2009, Building 89 has been the testing ground for integrated 3D visualisation (laser scanned and image-based), an entire team-based digital diary, intra-site GIS, online data storage and communication and immersive VRs (i.e. the DiVE) (Berggren et al. 2015; Forte 2014). The extensive implementation of digital 3D recording at Building 89 during the archaeological excavations allowed the team to test the accuracy and scale of 3D models by laser scanners, and develop and thoroughly test a digital workflow (Forte 2014:13-14).

Undoubtedly, the benefits of a digital 3D recording approach are extensive. Recent publications suggest that the advanced reflexive processes shown by all team members of a project (including both field and laboratory staff) are enabling an expansion of the original reflexive objectives set out in the early 1990s (Berggren et al. 2015:447). Others
have stated that the 3D recording and visualisation allowed for a holistic vision of the excavation contexts and stratigraphic levels, beyond the conventional and somewhat restraining Harris matrix and single context systems (Forte and Gallese in press:7). Berggren et al. (2015) have clearly stated that the biggest influence in integration of data and the breaking down of barriers between different teams and staff was the implementation of personal computer (PC) tablets in the field. This is intrinsically linked to the ‘intrasite GIS’ (e.g. ESRI ArcGIS) that is now the overarching virtual space to hold all datasets, an integrated digital archive, that is available instantaneously on each PC tablet (Berggren et al. 2015:441-2). The application of digital 3D recording technologies within Building 89 at Çatalhöyük shows promising results in terms of efficiency, data integration, communication and reflexive visualisation methodologies in the archaeological process.

What is not apparent within ‘The 3D Digging Project’ is a focus towards integration of legacy data. Decades of research at Çatalhöyük produced an extensive amount of written, drawn, photographed and now digital data (Hodder 1996; Lloyd 1967; Mellaart 1967). However, the core focus of the 3D project was not to incorporate legacy data but to determine the success of a digital reflexive approach. Deeper cognitive understandings of Çatalhöyük may occur from the incorporation of all possible data collected over the years for each area of the site, coming one-step closer to a digital 3D and spatial archive.

Another project that both explores the applications of 3D recording and visualisation within a complete intra-site 3D GIS and incorporates legacy data is the ‘Swedish Pompeii Project’. This project began in 2000 jointly run by the Swedish Institute in Rome and Lund University. The aim was to document an entire city block (insula) of Pompeii, Insula VI, and investigate an encompassing method to record as many different aspects of the area and buildings as possible. At 1330 sqm, Insula VI is a large area to document (Dell’Unto et al. 2015:6). Unlike Çatalhöyük in both scale and focus, The Swedish Pompeii Projects’ main aim was to create an innovative framework for employing 3D GIS as an exploratory platform for visual analysis, rather than focus on the implication of digital technology within a reflexive archaeological process (Landeschi et al. 2016). Esri ArcGIS was selected as the software platform for this research for a multitude of reasons: familiarity within archaeology, user-friendly interface and the ‘3D Analyst’ ArcGIS extension allowing the incorporation of 3D data (Dell’Unto et al. 2015). Whilst GIS enabled the incorporation of a multitude of different data types, such as raster, vectors and 3D models, it was not seen as
enough and the team took the project a step further by including all of the legacy data associated with the project from 2000 onwards.

In 2011, researchers from Lund University employed a new 3D approach, P3DM that became part of the wider sub-project, ‘Pompeii Revived’ (Dell’Unto et al. 2013). Pompeii Revived aims to apply 3D documentation and interpretation for Insula V1, in the form of laser scanners and, from 2012, the introduction of photogrammetry (Dell’Unto et al. 2013). After a few years of applying and refining techniques for both recording with 3D techniques and integrating within a GIS system, the results and workflow as well as the accompanying discussion on the impacts of their research present a seminal piece of archaeological research. The innovative framework for employing 3D GIS as an exploratory platform for archaeological analysis will be a valuable reference for future archaeological excavations and research. Significantly, the framework showed that the combined use of 3D photogrammetry (and laser point clouds) could be effectively incorporated into a platform, which also employed legacy data in the form of site plans and façade recordings of the walls and vertical structures (Dell’Unto et al. 2015). Providing a basis for future archaeologists to have access to ‘all of the information’ they can to devise different theories and visualise multiple patterns in the data (Dell’Unto et al. 2015:3).

Like Çatalhöyük, the implementation of a GIS database provided a platform for archaeologists to constantly update data and have access to information from other teams within the project, fostering further validation of interpretations and context. Perhaps most importantly, the Swedish Pompeii Project showed that the integration of a 3D GIS database further deepens the cognitive and reflexive aspects of archaeological research, and it can be seen as an analytical tool for measuring a site within an understandable and navigable framework (Dell’Unto et al. 2015:20). To date, the discussion reveals how archaeological visualisation is linked to the archaeologist’s ability to record and communicate archaeological information. Essentially, as technological developments advanced so too did archaeologists reliance on imagery as a core tool for communicating knowledge.

### 2.12 A redefined notion of objectivity and realism in archaeological visualisation

The theoretical framework of this thesis is partially based on Daston and Galison’s (2007) seminal publication *Objectivity*, which presents a methodical outline and argument for the development of vision to convey objectivity and realism within scientific disciplines. They argue that scientists have changed the ideals of visual depiction over time, as is
highlighted in this chapter. As I have argued here, this can be simplified as a transition from true-to nature (illustrating as close to reality as possible), to mechanical objectivity (believing in the objectivity of photographs), to employing relevant conventions to the creation of images. While this argument resonates within the discipline of archaeology, I argue that there are slight changes that need to be made to fit Daston and Galison’s themes into the history of archaeology and imagery.

As explored above, throughout the 20th century archaeological methods and techniques developed increasingly rapidly. Like in the sciences, the 19th century invention of the camera and the scientific ideal of a truly mechanically objective tool for both recording and communicating data encouraged archaeologists to believe that they were recording data as it truly is in reality. By the 1970s, it was the era of post-processualism and archaeologists were well and truly aware of the bias and subjective influences all humans have in recording ‘what they see’. From the 1990s until now, archaeology has become a digital discipline (as with almost all disciplines). Archaeologists embraced the introduction of computers with the added influences of GIS and processing capabilities although continuing a critical reflection of the influence of this software on the way that archaeologists work and understand information. This implies that archaeologists require a trained understanding of the information they created and used within computers and related software. While this generally follows the flow of Daston and Galison’s premise, I argue that the next stages in archaeology’s history are not yet critiqued in the same way.

The use of digital cameras combined with advanced computer processing capabilities is ensuring that super realistic digital 3D models of archaeological sites and objects are rapidly being adopted. The discussion throughout this chapter has indicated that our current and fast adoption of P3DM is being done without the same discipline wide rigorous critique as previous digital tools. Archaeology is in an era of digital realism. The increasingly realistic representations currently being used are created with very few standards or guidelines for interpretation and use. Figure 22 illustrates how archaeology is in a critical phase, moving beyond digital realism, and towards enhanced ideal of trained judgment. I argue that an approach to P3DM, that is theoretically aware of issues like ocularcentrism and the rhetoric of imagery, encourages more detailed, reflexive and critical assessments of archaeological site recording. Consequently, this will also refine and enhance the understanding we have of archaeological sites by encouraging further awareness of our own practices and bias when recording. This idea is revisited in Chapter
6, taking into account the experiences of creating I3DMs from current and legacy photographic data.

**Figure 22.** A timeline of archaeological visualisation.

### 2.13 Legacy data: revisiting primary archaeological data

As time goes by, archaeology continues to solidify its place as a refined, engaging discipline. The archives of cultural heritage organisations, institutes and archaeological departments continue to expand with archaeological material and data. Legacy data (as defined in Chapter 1) is a term that succinctly defines all previous archaeological data from a site, most often items such as: site plans, photomosaics, artefact drawings, context and stratigraphy drawings, photographs and video. Before investigating photographic legacy data within this study, a review of previous archaeological research is essential to understand how current archaeologists approach all legacy data today. The following section identifies the gaps in our understanding of primary data and highlights potential beneficial uses in the future.

Archaeologists aim to record archaeological material to the highest possible standard as the sites we study are often destroyed by excavation. Consequently, the only remaining information, apart from artefacts and samples, to place objects in their original context is the data recorded during excavations. Recording as accurately and as detailed as possible ensures that future archaeologists can make interpretations through the recorded information. Primary archaeological data is employed within post excavation reports and research articles that disseminate the findings and interpretations of archaeological investigations. While there is the ethical argument for detailed, accurate recording, I believe that the same cannot be said of revisiting and readdressing legacy data.

As a starting point, general reference to studying legacy data can be found in introductory archaeological fieldwork textbooks and handbooks (Carver 2013; Drewett 1999; Grant and Gorin 2008; Green 2004). For example, Greene and Moore (2010:109) note that a search of previous records may uncover unpublished finds and reports that should be carefully studied before continuing with new research. The use of legacy data as background information for a new project begins generally aims to delineate previous excavations,
areas that could be a new focus, or what type of archaeological material to expect (Grant and Gorin 2008). Renfrew and Bahn (2012:71) also suggest that there is a wealth of potential rich and rewarding material locked away in museums and stores that can be analysed with innovative techniques and technology. Yet, apart from this small reference, they offer no other information or guidance on the use of legacy data for archaeological research, like the majority of other archaeological textbooks.

Advances in digital technology provide wider accessibility and a potential opportunity for future assessment of archaeological legacy data (Drewett 1999). The idea that digitisation is increasing the use of legacy data is suggested in the second edition of an archaeological textbook, *The Archaeologist’s Field Handbook: The essential guide for beginners and professionals in Australia* (Burke et al. 2017). This revised edition notes that legacy data is one of the most valuable sources for archaeological research, for example “[a]ll relevant previous datasets should at least be considered as a potential source of data for your research project.” (Burke et al. 2017:34). More than just referring to the prospective reassessment of legacy data, the authors continue by noting three significant limitations found when approaching legacy data (Burke et al. 2017:35). First, the aim for collecting the legacy data is most likely different to the new project, so the data may not be perfectly suited. Second, the quality of the dataset cannot be controlled (e.g. accuracy, detail, reliability etc.). Lastly, that the legacy data may have limitations in terms of the technology available at the time of recording (e.g. pre-satellite coordinates greatly reduces accuracy). Although Burke et al. (2017) highlight the potential uses of legacy data and denote some expected limitations, further discussion is missing.

Despite these general references, archaeological literature does not provide much guidance regarding revisiting legacy data. Overall, it appears that previous archaeological approaches to legacy data are only included as a way to provide background information for new surveys, excavations and investigations without deeper analysis. In addition, they only contain minimal suggestions for enhancing the potential of readdressing ‘old’ data in books. Moreover, there are no examples of reference to archaeological research that has a primary aim of readdressing legacy data.

A survey of the use of the concept of legacy data in archaeological literature was undertaken, with the aim of understanding whether there was a change over time in the recognition of the potential use of legacy date. However, in undertaking this survey the phrase ‘legacy data’ only recently came into common usage. This may suggest that
archaeologists are not actively focussed on using legacy data in their work. To widen the investigation, I included a range of sources and terms within this search to better review that use of legacy data over time. In addition, selecting appropriate keywords that encompass legacy data proved to be a challenge. The keywords had to cover both current phrases for legacy data as well as potential terms employed previously to mean the same thing. In this case, the searches employed a selection of keywords such as, ‘original photomosaic’, ‘initial site plan’ and ‘photographic archive’. The inclusion of other common phrases (e.g. photograph, photomosaic and site plan) provided both a comparative control and further useful insight into the visual media generally within each journal. Inferences from these results do provide comprehension of the study of legacy data in archaeology. The following list of keywords was searched in each journal (including title, abstract, body and keywords):

- Legacy data
- Primary data
- Photomosaic
- Original photomosaic
- Initial photomosaic
- Photograph
- Original photograph
- Initial photograph
- Site plan
- Original site plan
- Initial site plan
- Orthophoto
- Orthophotograph
- Photographic archive, and
- Archaeological archive

In an attempt to survey the key ways that legacy data are being described in archaeological research five journals were selected: World Archaeology, The International Journal of Nautical Archaeology (IJNA), Antiquity, Internet Archaeology and The Journal of Maritime Archaeology (JOMA). Each journal is either a well-known archaeological publishing body or represents a topic of this study (i.e. digital archaeology and underwater archaeology). Each journal was limited to a given period for ease of comparison. The last 20 years (1997–2017) provides coverage of two decades and relates to most digital databases for journals (with the exception JOMA, established in 2006). The results are summarised in Table 3.
Table 3. Results of keyword searches within archaeological journals.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy data</td>
<td>1 (book review)</td>
<td>1</td>
<td>6</td>
<td>1 (book review)</td>
<td>0</td>
</tr>
<tr>
<td>Primary data</td>
<td>6</td>
<td>10</td>
<td>72</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td>Photomosaic</td>
<td>61</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Original photomosaic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial photomosaic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Photograph</td>
<td>1049</td>
<td>24</td>
<td>4</td>
<td>1666</td>
<td>52</td>
</tr>
<tr>
<td>Original photograph</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial photograph</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Site Plan</td>
<td>358</td>
<td>45</td>
<td>4</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Original site plan</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial site plan</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Orthophoto</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Orthophotograph</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Photographic archive</td>
<td>21</td>
<td>0</td>
<td>16</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Archaeological archive</td>
<td>34</td>
<td>100</td>
<td>7</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1542</strong></td>
<td><strong>181</strong></td>
<td><strong>116</strong></td>
<td><strong>1739</strong></td>
<td><strong>379</strong></td>
</tr>
</tbody>
</table>

A significant finding of this review is that ‘legacy data’ is a term rarely used within these journals. *Internet Archaeology* returned the highest hits, mainly due to a special volume (Issue 24: Dealing with Legacy Data, 2008) dedicated to the use of legacy data and GIS. This volume is particularly insightful, as a journal issue with a focus on legacy data, as it indicated the themes and interest in 2008. The sub-theme to this issue is GIS, with each article encompassing more specific topics such as social behaviour and social use of space through landscape modelling, large-scale site investigation, and architecture and legacy data (Allison 2008; Robert 2008; Steven et al. 2008). Within this issue, legacy data incorporates books, maps, ancient descriptions, excavation reports and notebooks. Further legacy data is not limited to purely archaeological research; it also includes text and material from antiquity (e.g. Pausanias’ 2nd century CE writings about sailing around Piraeus port in Greece) (Allison 2008; Smith 1995). However, there is also the connotation that legacy data only refers to non-georeferenced geographical source data. Other archaeological data is employed but the focus is on ancient text and maps or excavation plans made before georeferencing was widely accepted.
An interesting insight from this review is the result of keyword ‘photograph’ across the journals. Mainly, both *IJNA* and *Antiquity* use ‘photograph’ over 1049 and 1666 respectively during the 20-year period, while *World Archaeology*, *Internet Archaeology* and *JOMA* do not get above 55 hits. These results indicate that both the higher scoring journals contain more research that uses a significant percentage of visual media to convey information (Note: the totals at the bottom of Table 3). The comparison between journals provides a fascinating insight into the trends that each journal has and significantly, that some journals have a minimal publication of keywords associated with visual media (Figure 23).

![Imagery in Journals](image)

*Figure 23. Use of imagery terms in selected archaeological journals.*

This brief survey of the use of language associated with imagery gives insight into how different journals employ visual media or, perhaps more correctly, the techniques for communicating information. There is the limitation that the keywords used in this assessment are not all encompassing when discussing legacy data, the selected terms cover a decent amount of potential terminology. The results presented through the keyword searches imply that only a minimal reassessment of legacy data occurs in archaeology. An extensive set of terminology further reinforces the lack of engagement with primary forms of archaeological data. Overall, this suggests that archaeologists are not engaging with legacy data in general, let alone with new digital mediums and reassessment. The incorporation of visual legacy data within this thesis aims to readdress
the original site photomosaics with new P3DM software to determine the use of legacy data within an I3DM context and the potential for enhanced interpretation.

A result of this survey is the identification of individual articles that do address legacy data. More specifically, these articles are embracing the positive and negative uses of legacy data and highlighting future results of revisiting this data. Ellis (2008), in an important article from the Internet Archaeology issue ‘Dealing with Legacy Data’, critically assesses the impact of using legacy data gathered during early archaeological research. Steven Ellis’s (2008) ‘The use and misuse of ‘legacy data’ in identifying a typology of retail outlets at Pompeii’ makes a valid assessment of the wealth of legacy data of archaeological research about Pompeii. In particular, Ellis discusses misinterpretations over the years and potential misidentification of the use of some structures in the archaeological site. Further, he insists that primary data is often not used appropriately; instead, secondary misinterpreted research is often perpetuated and can become the norm. Ellis argues that revisiting primary data — the actual legacy data — ensures a better understanding of sites.

Ellis (2008) strengthened his argument by revisiting the primary archaeological data (from both on-site surveys and excavation records) to make a more secure and thorough identification of the different shops. Apart from digitisation, Ellis did not change the form of the legacy data; instead, he assessed the potential for ingrained errors through the reuse of incorrect interpretations of primary data (Ellis 2008). Although only focusing on an analysis of legacy data, this article does introduce a critical approach to the current application and benefits of revisiting legacy data.

Another article of this issue of Internet Archaeology, Penelope Allison’s (2008) ‘Dealing with Legacy Data — an introduction’ points out some general ideas of legacy data and enhanced understanding of archaeological sites. In particular, Allison’s (2008) introductory article proposes both benefits and problems of incorporating legacy data within archaeological research. For example, one benefit associated with legacy data is that previous excavations were often far more extensive, providing a large dataset for analysis. Unlike current standards, that argue for smaller test-trenches to answer particular research questions, early archaeological excavations often uncovered entire sites (Bahn 1996; Trigger 2006). Although original recording may not be as accurate as is standard today, the wealth of primary data provides a useful dataset for analysis (Allison 2008:np). Another factor is that the legacy data may be the only remaining information about a site that no longer exists. An example of this is the work of antiquarian William
Stukeley, mentioned in Chapter 2, completing the detailed recording of an avenue of stones from Stonehenge to the River Avon, which no longer exists (Greene and Moore 2010:16; Piggott 1985:92). Or, it may simply be that a site has degraded since the initial surveys and excavations. Consequently, the legacy data from earlier investigations can provide vital information.

On the other hand, Allison (2008) identifies a set of possible problems with interpreting legacy data. An overarching issue is that legacy data can be difficult to employ and often needs manipulation to be useful for current investigations. For example, Allison (2008:np) identifies issues in differences of scale between current studies and legacy data. Not only have archaeologists reduced the size of excavated areas but also, the smaller areas are recorded intensely with far higher accuracy than earlier excavations (Allison 2008).

Allison (2008:np) also identifies the prospect of assessing primary data without having essential knowledge gained through recording and collecting that data. Apart from remaining field books and journals, insights from the first archaeologists are most likely unavailable. As a result, interpretations made by revisiting legacy data will lack the inherent knowledge gained by the archaeologist that recorded the primary data. Although this is a limitation that deserves to be investigated further, it does not completely constrain the use of legacy data. In fact, it serves as a useful reminder to be critical and self-reflexive when interpreting archaeological data. Consequently, archaeologists readdressing legacy data should do so with caution and an understanding of the limitations discussed here.

A recent article by Alison Wylie (2017), ‘How archaeological evidence bites back: strategies for putting old data to work in new ways’, presents a large and detailed analysis on the epistemic values of readdressing legacy data. Notably, the article delves into the ‘shadowy’ nature of archaeological data and presents strategies that aim to help archaeologists approach legacy data with a critical eye. Wylie (2017:208) focuses on three ways of addressing legacy data: secondary retrieval of primary data, re-contextualisation of primary data and, experimental simulations based on old data. The first two strategies are adopted by Wylie and based on already established approaches (Currie 2014:194). All three strategies are worth briefly investigating here before discussing the overall approach of the article.

Secondary retrieval can be defined as extracting new data from the old (Wylie 2017:208). This technique is characterised by the application of new technology to legacy data that
enables more information to be discovered than previously possible. An example that Wylie explores is the Diaspora Communities in Roman Britain Project run by the University of Reading, UK (Eckardt et al. 2009). The project used trace element and stable isotope analysis to analyse the dental enamel of late Roman period burials in the UK (Wylie 2017:208). The results redefined the authors’ understandings of the Roman Empire at this time, proving that the populations were far more diverse and mobile than previously believed (Eckardt et al. 2009; Leach et al. 2009). Consequently, revisiting previously collected archaeological data with new technology provided a secondary set of information about the Roman Empire in the UK, that realigned known ideals initially gathered from the primary data. Recontextualising data is a similar way to revisit old data, but focuses on resituating legacy data within newly recognised contexts (Wylie 2017:211). For example, redefining long held typologies for classifying Roman Egyptian houses or realigning the radiocarbon dating chronologies based on revised information about the nature of the process (Wylie 2017:211-5). Essentially, recontextualising legacy data is a form of reflexive analysis and criticism that reduces the strength of entrenched understandings.

Lastly, experimental simulation with legacy data is a strategy that can provide insight about the past through explanatory, heuristic and potentially evidential roles (Wylie 2017:207). Although the evidential aspects can provide a point for debate (Currie 2014:189), Wylie (2017:219) argues that they enable a form of revisiting archaeological legacy data. Experimental simulations based on legacy data assist the expansion of ideas, boundaries and, question previous interpretations. Wylie (2017:219) rightly opposes the notion that experimental simulations provide new evidence, and rather argues that they are robust exercises in critical analysis and reasoning of old data and interpretations. The strategies and discussion provided by Alison Wylie form a strong basis for future epistemic analysis of the way in which archaeologists engage with legacy data.

Revisiting photographic legacy data forms a core aspect of this thesis and aims to provide insight into the potential for legacy I3DMs in the future. The review of current archaeological journals and the use of legacy data, as well as other language associated with visual media, returned some interesting results. There is an obvious lack of engagement with legacy data within archaeology, despite a significant attempt in 2008 by Internet Archaeology. In addition, Wylie’s (2017) article represents a turning point in archaeological research, as Wylie engages with wider theoretical implications of old data and identifies strategies for approaching varying forms of legacy data. The issues
presented by both Wylie (2017) and Allison (2008) are discussed in terms of the results of legacy photographic data in this study in the later chapters of this thesis.

Although the keywords employed in this review may not encompass all the terms that archaeologists use to refer to legacy data, a total of 15 phrases give valuable insight. Interestingly, there is a trend in the use of visual media terminology across the five journals — some rarely use it, and others contain over a thousand results for general keywords such as ‘photography’. This implies that some journals employ greater visual media in communicating data over others. Issues encountered include changes in scale from early to modern archaeological excavations and, difficulties in acquiring an appropriate scale to compare new and legacy data, particularly for application within GIS-based software. A problematic issue is reassessing primary data without the inherent knowledge of the archaeologists who recorded it. This secondary interpretation results in a potential loss of detail and context that may never be regained. However, this could potentially be balanced by adopting critical, reflexive methods when employing legacy data, ultimately ensuring caution in the overall process of modifying the medium of legacy data. The core result of this review indicates that legacy data is in the early stages of investigation in archaeology and there is still much to be learnt from revisiting legacy data and incorporating primary data into new mediums for interpretation.

2.14 Summary
Archaeologists’ work is influenced by research in other areas of knowledge and increasingly affected by ubiquitous digital technologies. Consequently, every endeavour should be made to be aware of the effect technology has on the archaeological process. Advances in digital camera image sensors, computer science and machine vision, as well as algorithms for high level processing are opening up new possibilities for highly advanced recording and visualisation of archaeological data. In particular, the field of P3DM offers the possibility to record a site, trench or excavation at any given time, capturing detailed colours, textures and importantly, geometric structure.

Undeniably, archaeology is a visual discipline. The information and review of literature presented in this chapter shows an engrained culture of visualisation of archaeological sites and material data for over 500 years. Every aspect of data collection that archaeologists produce, whether it be a field journal or published article, typically includes a large amount of visual media to communicate interpretations or simply better describe a site to the reader/viewer. What is taken for granted by most archaeologists is
the reliance we have on current methods to objectively communicates results and interpretations. Illustrations, site plan drawings, photographs and videos all have inherent degrees of bias. As Moser set out, photography is perhaps the worst of all the visual media we employ. Given its very technical nature, it appears objective and the images we use are not adequately criticised for what they really are – interpretations. The same can now be said of digital 3D models and virtual realities.

What is apparent from this review of visualisation and imagery in archaeology is that archaeologists are moving beyond the testing phase of new technologies and seeing them as just a tool, and into the realm of a deeper understanding of how the application of these new technologies affects our interpretation. When the current research into the same area of digitally recording underwater sites (explored in the next chapter) is examined, it is very clear that archaeologists are still testing and refining ways to accurately record and create the same level of digital 3D models. What is lacking is a deeper investigation into how these techniques will affect or influence the way we interpret an underwater archaeological site. The conclusions from the above survey of literature indicate that a reflexive process is a vital tool archaeologists should employ to understand how tools influence the research process. What is not yet clear is whether the ‘silent power’ of the visual image is lost or enhanced when merged into the digital 3D world.

Overall, this review has shown that the wider discipline of archaeology is in the midst of theoretical debates surrounding archaeology and visualisation. The application of exciting new P3DM software and the fast, semi-automated processing images into geometrically accurate 3D models has briefly escaped the debate, but is now becoming a focus. When looking at the same applications of photogrammetry in underwater archaeological research, the same is potentially not true. Examples of current approaches to underwater 3D digital recording are discussed in the following chapter.
3. Underwater archaeology and photographic recording

The above review identified successful digital 3D visualisations incorporated within archaeological research, but what happens when you add water to the mix? Conducting archaeological research on underwater sites requires adaptation of existing methods within often challenging environments. I begin with a brief discussion of the limitations of underwater photography and the challenges often faced throughout investigations. Understanding these limitations provides valuable insight for the next stage, reviewing photographic recording for archaeological research on underwater sites. This provides the foundation for a discussion of the development and application of 3D modelling techniques in archaeology, detailing contemporary applications of P3DM and the impact of PhotoScan in recent years. Overall, I discuss the different approaches previously used to successfully apply P3DM as a visualisation and recording tool, starting with the first applications to underwater archaeological sites and ending with some of the most recent applications.

3.1. Limitations of underwater archaeological photography

Working underwater requires experience and knowledge of a variety of environmental factors that can affect the success of research. Archaeological divers are faced with characteristics that differ to those encountered on land. For example, water visibility, depth of work, tidal or current strength and water temperature are all factors archaeologists deal with when underwater (Bowens 2011). The underwater environment is a hazardous place for the human body (Opatz and Gunga 2015:138) and environmental factors can lead to dangerous situations for humans working on underwater sites, such as exhaustion, equipment malfunction, disorientation and entrapment or entanglement (Bowens 2011:41). In addition, physiological challenges experienced by the body include: shrinking of the lung volume, nitrogen narcosis and decompression illness caused by the formulation of inert gas bubbles when returning to the surface (Opatz and Gunga 2015:142). Even with risk management precautions and the experience, skill and knowledge of a diving team, the speed of archaeological work underwater is limited by water depth and the ability to dive multiple times in one day. Consequently, underwater archaeological research is often expensive and time consuming. As Richards et al. (2008:39) stated ‘[a]ny underwater archaeological surveying technique must satisfy two contrasting requirements: speed and accuracy’.
Due to time limitations and environmental restrictions of working on archaeological sites underwater, photography proved to be a tool of choice for underwater archaeologists due to its technical reliability, speed, and ability to capture details of a site for audiences who would never be able to physically visit the site themselves. For example, the Uluburun shipwreck was brought to the world’s attention through a highly visual article in the National Geographic magazine (Figure 24). Before discussing the successes and uses of underwater photography for archaeological recording, it is essential to note that, like humans have to adapt to working underwater, photography is also hindered by some limiting factors that characterise the physical environment of working in water. Understanding the capabilities of photographic equipment and resulting photographs has connotations for the method for P3DM of shipwreck sites in Chapter 4. The following limiting factors are described below: water density and diffusion of light, loss of colour and light refraction.

![Figure 24. A 1987 edition of National Geographic featuring the Uluburun excavation (National Geographic Society 1987).](image)

Water acts like a giant light filter that presents many challenges for photography. Because water is approximately 600 times denser than air, the visual colour spectrum behaves
differently across distance in water (Frink 1995:38; Roll 2001:21). As depth increases, sunlight decreases with the first colour (red) disappearing after one metre followed by the other colours at the warmer end of the light spectrum (oranges and yellows) until eventually just the blue/green end of the spectrum remains (Frink 1995:40; Munn 2012:8). To solve this issue, photographers use artificial lights to capture true colours at depth, however, this also means that the further away the light source is from the subject the less colour is obtained. Comparatively, black and white photography is not concerned with colour and therefore flash lighting for colour compensation is generally not necessary. Although, compensating lights may be required where the levels of overall light are reduced. When applying artificial light while taking photographs, the presence of particles and suspended matter within water — backscatter — can also be an issue (Frink 1995:39; Roll 2001:21; Zhukovsky et al. 2013:719). As a result of these limitations, the rule of thumb within water is to take a photograph as close to the subject being photographed as possible to reduce backscatter.

The refracting properties of water are a challenge for accurate recording and measuring of archaeological material. Light waves travel along a straight line when moving through one single medium and when another is added — such as travelling first through air and then water — the light waves bend. This is called refraction and results in the magnification of what you photograph underwater (first through air like a camera housing, then through water) (Bass et al. 1967:23). For flat-port lenses, the index of refraction is 1.33 or a magnification of approximately 33% (Roll 2001:21-22), resulting in an object looking like it is closer to you then it actually is. Refraction causes the focal length of a camera to also be increased by approximately 1/3. For example, normal lenses become telephoto and wide-angle lenses become normal (Bass et al. 1967:23). Focal length issues are mostly solved by using wide-angle water-correcting lenses (described in section 3.2) that enable a diver to photograph a large area from a short distance away (this also helps with reduced visibility) (Bass et al. 1967). In addition, dome port lenses can be used as the shape of the dome eliminates the effect of refraction on the image (Somerville 2017). However, the use of these lenses creates greater distortion towards the edge of each image.

Wide-angle lenses generally create radial distortion within images. Radial distortion can be divided into two general types: pincushion or barrel distortion. Pincushion distortion is best described as the horizontal and vertical lines of an image curving inwards to the centre. This type of distortion is caused by an increasing focal length moving outwards from the centre of the image (e.g. Figure 25) (Kroon 2012; Yongtao et al. 2004).
Contrastingly, barrel distortion is caused by the focal length decreasing from the centre of the image towards the edges (Kroon 2012). Barrel distortion makes the edges of images curve away from the centre, as if draped over a barrel (Figure 26) (Ridpath 2012). The affects of refraction and radial distortion are reduced by the application of specific lenses for underwater photography. Details of water-correcting lenses are described as they were invented throughout in the following section.


The limitations caused by environmental and physical factors indicate that there are challenges that must be overcome to capture quality photographs when underwater. A combination of challenging environmental conditions (often present at underwater archaeological sites), the complex way that diving at depth affects the human body and the physical affects on photographic equipment reflects the different way that archaeologists must adapt to working underwater in comparison to on land.
3.2. A history of photographic recording for underwater archaeology

To understand the application of current photographic techniques, I review the history of recording underwater archaeological sites with a focus on the development of key tools and techniques for underwater photography. Reviewing the development of archaeological photographic techniques gives an insight into the application of P3DM techniques today. The review is intended to provide further understanding into the history of underwater archaeology, the sites and practices that led to developments in methods for underwater recording, and the implication of these methods for archaeological interpretation.

Due to the refractive qualities of water differing from those of air, the invention of water-correcting lenses for underwater photography was essential for accurate spatial representation and eventual photogrammetric mapping methods for underwater sites (Rebikoff 1972b:224). In 1893, Louis Boutan developed the first camera to expose photographs underwater (Rebikoff 1972a; Valentine and Rebikoff 1968). Initially, he designed a housing for a small glass plate box camera followed by a reverse camera that entirely flooded when submerging the air lens (Anon. 1923; Rebikoff 1972a:898). Although the plate was also submerged, the photographic emulsion worked just as well as if on land (Rebikoff 1972a:898). However, it was not until 1931, when French naval optical research engineer A. Dratz, recognised the need for water refraction correcting lenses to increase the quality of photographs taken through the air of a camera housing and the water environment (Rebikoff 1972a:196). Dratz’s solution to this problem ultimately proved unreliable, as he deployed hemispherical dome port set-ups that were inaccurate and expensive (Rebikoff 1972a). A key step in the invention of water-correcting lenses was the ‘Ivanoff-Rebikoff’ correction lens. The Ivanoff-Rebikoff lens — put simply — made water invisible when photographing underwater using a complementary set of two lenses with airspace in between and aligned with the camera’s lens within the housing (Figure 27) (Valentine and Rebikoff 1968:968). Valentine and Rebikoff (1968:968) describe the lens as a complementary set of lenses (convex and concave) separated by an air space and mounted forward of the camera lens (Figure 27). Invention of this lens provides one of the best options to eliminate distortion issues experienced by a flat air-water boundary (like radial distortion and refraction described in section 3.1) (Knight 2012).
Further advances in underwater archaeology were enabled with Jacques-Yves Cousteau’s and Emile Gagnan’s 1943 invention of the pressure regulator, referred to as the ‘Aqua-Lung’ (Drap et al. 2013:98; Throckmorton 1967:19). The Aqua-Lung enabled humans to access deeper waters and operate without the cumbersome, heavy and restricting hard-hat equipment previously needed. The effect on access to shipwreck sites is evident with Phillip Tailliez’s motion picture film of shipwrecks, ‘Épaves’ or ‘Wrecks’. This black and white motion picture film (35 mm) was the first time that underwater shipwrecks were filmed and its fame pushed Cousteau into the spotlight (Rebikoff 1972a:197). The following decade saw a dramatic increase in the amount of amateur divers exploring the seabed and the late 1950s introduced the first large-scale excavation of shipwrecks by diving specialists.

The first excavation of a shipwreck with SCUBA divers occurred from 1952 to 1957, when Jacques-Yves Cousteau and Fernand Benoit excavated the Grand Congloué shipwreck in France (Benoit 1958, 1961a, 1961b; Cousteau 1954; Throckmorton 1967:19). Although they attempted to excavate as thoroughly as possible, many issues arose (Throckmorton
1967:19). Primarily, Throckmorton (1967:19) notes that while there was an archaeologist (Benoit) in charge, he did not dive and the excavation was directed by intermittently viewing the progress through an underwater television and directing the divers. Difficulties arose, as the divers were inexperienced in archaeological methods and shipwreck interpretation (Benoit 1961a, 1961b; Throckmorton 1967). As a result of the methods employed no site plan was created and it is still unclear if there was one shipwreck or two (Bass 1966a; Benoit 1961b; Throckmorton 1967). Although the salvage of Grand Conglué may not be seen as archaeological due to a lack of appropriate recording, it represents a key phase of maritime archaeology. Despite the drawbacks of this excavation, the work on Grand Conglué highlighted the difficulties that can occur when employing non-archaeological divers and the resulting site interpretation (Girault 1965).

Photography of underwater shipwrecks would soon prove to be a valuable tool for site recording through the use of photomosaics. In 1957, Phillipe Tailliez, commander of the Group Etudes Recherches Sous Marines of the French Navy, led a large-scale underwater excavation of the *Titan* shipwreck in France (Bass 1966a:106; Benoit 1958:5; Tailliez 1965). This excavation represents the first instance that a photomosaic was created to record the shipwreck site, although the exact methodology details (e.g. use of grids/control points etc.) were not reported (Bass 1966a; Tailliez 1958). Despite this excavation being a project that was not run or controlled by archaeologists, it is an important example of the early reliance on photography for recording underwater shipwreck sites. Unlike Grand Conglué, appropriate site recording for this time was completed even with non-archaeological divers completing the work.

It was increasingly clear that archaeologists needed to become divers to ensure that the excavation was conducted to the highest archaeological standards at the time, given the limitations of archaeological recording and excavation of the Grand Conglué shipwreck and the *Titan*. Drap et al. (2013:99) argue that this was the turning point for archaeologists and the study of underwater sites. Consequently, the discovery and recording of some of the most famous underwater archaeological sites throughout the 1960s in the eastern Mediterranean at Cape Gelidonya would see significant developments in underwater methods across different sites. The shipwrecks are known as Cape Gelidonya, Yassi Ada 1 and 2, and Kyrenia (see Table 4 for a detailed summation of the underwater archaeological sites discussed in the following section). I review each site, as they required a different recording methodology based on the archaeological requirements.
Table 4. Photographic recording on underwater archaeological sites.

<table>
<thead>
<tr>
<th>Date &amp; Site</th>
<th>Key people</th>
<th>Photographic recording method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1935-7 Tyre (Harbour), Lebanon</td>
<td>P. Poidebard</td>
<td>Underwater helmet divers to take first photographs underwater for archaeology. (Tchernia 1978)</td>
</tr>
<tr>
<td>1952-7 Grand Congloué, France c.200-100 BCE</td>
<td>J. Cousteau, F. Benoit</td>
<td>Full-scale salvage of an underwater shipwreck site. First time Aqua-Lung used. No recording completed. Unknown if the site is 1 or 2 shipwrecks. Archaeologist directed divers from the surface. (Bass 1966b:88)</td>
</tr>
<tr>
<td>1954 &amp; 1957 Titan, France c.100-0 BCE</td>
<td>P. Tailliez</td>
<td>First documented photomosaics created to present the site in its entirety. Limited archaeological recording.</td>
</tr>
<tr>
<td>1960 Cape Gelidonya, Bronze age, Turkey c.1200 BCE</td>
<td>G. Bass, P. Throckmorton</td>
<td>1960 complete excavation. Site plans recorded by removing lumps of concreted cargo. (Bass et al. 1967; Throckmorton 1967)</td>
</tr>
<tr>
<td>1961-4 Yassi Ada 1, Turkey, c.300 CE</td>
<td>G. Bass, P. Throckmorton</td>
<td>Deep site (130 ft, 37 – 43 m) Experimentation and evolution of methods best recording (photogrammetry) on sites at depth. Grids and photographic towers used to plot and map site. (Bass 1972:48)</td>
</tr>
<tr>
<td>1962 Cape Spitha, Greece, c.200-300 CE</td>
<td>P. Throckmorton</td>
<td>Underwater archaeological excavation with accurate measurements and mapping of giant columns. No photography used as deemed too distorted underwater. (Bass 1966b:112)</td>
</tr>
<tr>
<td>1967-8 Porto Cheli &amp; vicinity, Halieis and Pavlopetri</td>
<td>M.H. Jameson, J.G.D. Clark &amp; G. Daniel, J. Whittlesey &amp; E. Whittlesey</td>
<td>Over two seasons across a variety of different sites, aerial photography (via balloon apparatuses) enabled wider depiction and understanding of submerged archaeological sites in the Mediterranean.</td>
</tr>
<tr>
<td>1968 Kyrenia, Cyprus 325-315 BCE</td>
<td>J. Green, P. Baker</td>
<td>Survey of the site found in 1967 with metal detectors and probes. Outlining the importance of preliminary surveys before excavation begins. (Baker and Green 1976)</td>
</tr>
<tr>
<td>1972-82 Madrague de Giens, France, 75-60 BCE</td>
<td>P. Pomey, A. Tchernia</td>
<td>Stereo-photogrammetry (utilising a moveable bar set-up) and manual mapping of the site. Photomosaics also created of both plan and elevations views (Tchernia 1987)</td>
</tr>
<tr>
<td>1971-6 Batavia, Australia, 1629 CE</td>
<td>J. Green, P. Baker</td>
<td>2D large and small-scale site photomosaics created during the excavation of the hull remains (Bass 1966b:118).</td>
</tr>
<tr>
<td>1977-80 Santa Antonio de Tanna, Mombasa, Kenya, 1697 CE</td>
<td>R. Piercy, J. Kirkman</td>
<td>Poor visibility and limited camera lenses (Nikonos with 28 mm lens) created difficult photography. Later use of a 15 mm lens allowed the creation of full site photomosaics. (Kirkman and Bentley-Buckle 1972; Piercy 1978; Piercy and Piercy 1977, 1979, 1981)</td>
</tr>
<tr>
<td>1984-94 Uluburun, Turkey, c.1320 BCE</td>
<td>G. Bass</td>
<td>1984 season not mapped with photogrammetry as the steep descent/slope of the overall site hindered a constant camera height. Manual triangulation was used instead (Bass 1972).</td>
</tr>
<tr>
<td>1999-2001 Tektaş Burnu, Turkey, 440-425 BCE</td>
<td>D. Carlson, G. Bass</td>
<td>First focus on photogrammetry as the primary aim of recording the site. Initial use of film cameras and multi-tape trilateration, subsequent seasons introduced digital cameras and PhotoModeler.</td>
</tr>
</tbody>
</table>
In 1958, local sponge diver, Kemal Aras, informed Peter Throckmorton of a shipwreck site in Anadolu Burnu, Turkey (Throckmorton 1967:15). Under the direction of Peter Throckmorton and George F. Bass, the University of Pennsylvania and the London Institute of Archaeology started excavations at the site in 1960. At the time, Bass was an archaeologist with a brand new SCUBA qualification (Bass 2005:48). This was a significant moment as it is the first example of terrestrial excavation methods successfully adopted for application underwater (Barstad 2002:5). Although, the research involved extensive testing to determine the best method for recording and excavating, photography proved to be invaluable from the start.

Two ‘photographic montages’ or photomosaics were created during the excavations at Cape Gelidonya (Bass and Throckmorton 1967:25). One was completed at the beginning (Figure 28), before the removal of sand and artefacts, and the other was completed at the end of the excavation (Figure 29). Both mosaics were not created with the intent of measuring distances but provided a reliable reference for artefact distribution and drawing up the site plan (Bass and Throckmorton 1967:26). Bass and Throckmorton (1967:25) employed a single camera set-up on a levelled bar (with a wide-angle lens) from which a diver took photographs along a rope guide to keep an approximate straight line. Each image was taken at a fixed height off the seabed using a plumb line that extended from the bar to the seafloor, keeping a constant height. To control the resizing of images a two metre long bar marked with 20 cm intervals was used as a scale within every photograph (Bass and Throckmorton 1967:25). A high level of overlap ensured that perspective distortion between images was minimal and any remaining distortion in images was cropped as only the central part of the photograph was used to generate the mosaic (Bass and Throckmorton 1967:25).

One issue identified during recording was the fact that the seabed was not perfectly flat, but irregular in form. As a result, the relative scale of the same sized object differed, given
that they were at different distances from the camera. This problem sometimes prevented
the seamless joining of images when creating the mosaics (Bass and Throckmorton
1967:26). Presumably, this distance error was present throughout the photomosaic given
the fact that the seabed would rarely be truly level, and would thus distort the scale in
every image that was used to build the mosaic.

Figure 28. Pre-excavation site photomosaic (Bass and Throckmorton 1967:25, Figure 6).

Figure 29. Post-excavation site photomosaic (Bass and Throckmorton 1967:26, Figure 7).
To reduce dive time, archaeologists removed large pieces of concreted cargo from the site, which were brought to the surface to be excavated (Bass 1966a:136-7, 1972:45). Prior to removal each concreted mass was marked in several locations, surveyed by ‘triangulation’ to permanently fixed points established within the site, and also photographed *in situ* (Bass 1963:244; Bass and Throckmorton 1967:27) [note: Bass and Throckmorton refer to the survey method as triangulation. This is now commonly called trilateration and shall be referred to as such from here onwards]. Trilateration is an efficient manual method for recording structures and taking measurements underwater, involving two tape measures to record distances from known datum points to an object or feature. When these measurements are drawn on a site plan the overlap — or arc where the two distances meet — is the location of that point (Figure 30) (Bowens 2011:160). Consequently, each concreted mass could be placed accurately within the overall site plan.

Figure 30. Divers completing trilateration measurements at Cape Gelidonya (note: the datum point marked with the stadia pole) (Bass and Throckmorton 1967:27).

Due to the depth of water at the Cape Gelidonya shipwreck, the light absorbing affects of water impacted colour representation in photographs. Visibility on the site could be exceptional, Bass and Throckmorton (1967:23) state that on clear days snorkelers at the surface could see divers working 26 to 28 m below them. The issue of colour loss on the
site was reduced by the use of a camera flash attached by a short arm to the camera housing (Bass and Throckmorton 1967:24). However, they noted that using flashes on days when visibility was reduced created a large amount of backscatter within images. In comparison to colour photography, there was generally enough daylight for black and white site photography.

As a result of these methods, the excavation of a Bronze Age shipwreck at Cape Gelidonya revealed that underwater photography was a suitable method for creating complete site images for interpretation and reference. Diving archaeologists could attain better understandings of the site from an archaeological point of view and ensure that the most appropriate and effective recording for that time was completed. Notably, the combined recording techniques of trilateration and photomosaics during excavations enabled the completion of a large-scale site plan of Cape Gelidonya for archaeological interpretation. It is significant to highlight the fact that the photomosaics were not reliable as a tool for measuring but rather as a check for comparison to the site plan. In addition, the application, issues and results of the photographic recording at Uluburun were included in a 1967 publication by Bass et al., Cape Gelidonya: a Bronze Age Shipwreck, which described the background, excavation and research in detail. This is one of the first instances that photographic techniques were described in detail and that included photomosaics to communicate site details within the publication (see Figures 28 and 29).

Underwater archaeological recording methods progressed with the 1961 excavations at Yassi Ada 1, a shipwreck site once again reported by the local sponge diver Kemal Aras to Peter Throckmorton. George Bass from Texas A&M who led the project was particularly focused on developing and refining underwater archaeological methods and techniques (van Doornick 2005:92). The remains of the shipwreck at Yassi Ada 1 presented itself largely as an array of cargo, with hundreds of amphorae distributed over a 20 m x 10 m area at a depth of 37-43 m (Throckmorton 1972:206). These depths reduced the time that SCUBA divers could operate each day and, as such, any methods and techniques that could increase productivity underwater were desirable (Bass 1963:248; Green 2004:185). The same rigid steel frames with wire grids used for Yassi Ada 1 were placed over artefacts on the seabed and these were mapped into the site grid. Photographs of each square within the grid were also taken as a record (van Doornick 2005:92). Each square was itself trilaterated into the overall wreck site. In the second year of work, in 1962 this method was modified. Nine grid frames, (each one 2 m x 6 m) were permanently fixed in
place over the wreck site in the form of individual steps following the downward slope of the site (Bass 1963:248).

On top of each of these, a photographic tower constructed from a lightweight metal was bolted on to ensure that accurate images were taken on a level plane (Bass 1963:250; Throckmorton 1972:206). Each tower was four metres high and had a two metre square base with a grid set out in stretched elastic cords in 20 cm intervals (Bass 1966a:110). Radial distortion was minimal due to the application of high quality, appropriate cameras. However, the authors noted that the ‘architect’ (person completing the site plan drafting) corrected images before using them to create the plans and section drawings, although the intricate details of the image correction process were not included in the publication (Bass 1963:250).

Excavations were undertaken with each grid-by-grid section, and a photographic record was taken from the tower. Bass states that the quality of each image was exceptional, although the variation of objects on different levels of the seabed meant that each photograph could not be used to trace dimensions directly onto the scale plan (Bass 1966a:110). Only the centre of each photograph shows the true relation of the object due to radial distortion towards the edges. This resulted in each grid being drawn with objects ‘moved’ in conjunction with the measured distance below the grid (Bass 1966a:110). This is a time-consuming technique for drawing accurate site plans. Another problem described by Bass (1966a:110) was the pincushion distortion from not using water-correcting lenses, although this as partially rectified by the inclusion of grids in the recording process. Including the grids in images gave a visual comparison for the distortion towards the edges of each image.

In 1963 and 1964, Julian Whittlesey — a photogrammetric adviser for the project — and his wife Eunice, experimented with underwater stereo-photogrammetry by mapping Yassi Ada 1 with photogrammetry (Bass 1966a:112). This further reduced the time taken to map and record the site. Over the last two years of excavation (1963-4) at Yassi Ada 1, a system was developed involving a single camera set-up on a floating horizontal bar (van Doornick 2005:93). The camera was suspended on a gimbal and could be moved along the bar at calibrated intervals to create stereo-pairs of images (van Doornick 2005:93). The application of stereo-photogrammetry allowed archaeologists to have a visual impression of the depth and 3D appearance of the site.
It is important to note here the other photographic work that the Whittelseys took part in across other underwater archaeological sites in the Mediterranean. Namely the use of balloon apparatuses to take aerial photographs of submerged ruins at Helieis, Pavlopetri and Porto Cheli throughout 1967 and 1968 (Clark and Daniel 1968; Jameson 1969, 1974). The aerial photography was completed during the morning when light was suitable and the sea conditions were usually calm and clear (Clark and Daniel 1968:11). In general, the application of aerial photography via balloon apparatuses enabled a comparison with conventional techniques and refinement of large-scale site plans, provided spatial measurements, gave a notion of the wider extent of a site and, notably, identified remains which has previously gone unnoticed by divers (Clark and Daniel 1968:18; Jameson 1969:333, 1974:112). The application of balloon photography is important as they produced some of the first ‘plan’ photographic views of underwater archaeological sites (albeit in comparatively shallow water to the early application of photography to shipwreck sites) using these methods.

The experiment driven development of underwater archaeological recording continued with the archaeological excavation of Yassi Ada 2, in 1967 and 1969 (Bass and Van Doorninck 1971:27). The same methods employed at Yassi Ada 1 were replicated here. Yassi Ada 2 is a 19-metre long late Roman (4th CE) shipwreck site that sits next to Yassi Ada 1, but in deeper water at 40 to 50 metres. A new machine was employed on this site, the submersible Asherah, a highly manoeuvrable vehicle that could fit two people inside and reach depths of 180 m and remain there for approximately 10 hours (Bass 1965:7). It was built by the University Museum of Pennsylvania specifically for search and survey of deep-water shipwrecks. The main reason for employing Asherah for archaeological surveys is extended time that the two passengers could remain on a site. For example, the maximum bottom time of 10 hours greatly improves a divers maximum daily bottom time of 45 minutes on Yassi Ada (Bass 1965:7; Bass and Katzev 1968:166). Asherah’s primary use on Yassi Ada 2 was to conduct stereo-photogrammetric recording but it also allowed the archaeological directors time to observe and monitor the progress of the excavation from the submersible (Bass and Rosencrantz 1972). From the submersible, the directors were able to give directions to excavators through a communications system (Bass and Rosencrantz 1972:274). In 1967 the submersible was employed to record the partially excavated hull of Yassi Ada 2, and the resulting photomosaic and stereo-pairs of images show great detail of the site and proved to be a reliable way to record (Bass 1965). Ultimately, while useful on a site of this depth, employing a submersible is an expensive
piece of machinery and, in 1969 Asherah was sold due to financial issues (Bass 2006:8; Bass and Rosencrantz 1977).

By 1969, the archaeologists determined their preferred method for photographic recording. This method, mentioned above, involved attaching a camera to a horizontal floating bar and taking photographs at set increments along the bar (Bass and Van Doorninck 1971:28). While this method had been developed for Yassi Ada 1, at Yassi Ada 2 the equipment had seen technical advances. For example, a motorised Nikon F camera was used inside a housing with a hemispherical port that greatly aided in reducing the amount of distortion noticed in images (Bass and Van Doorninck 1971:28). Bass and van Doornick (1971:28) state that this method captured stereo-photographs specifically intended for making plans of the site and that it aided in reducing the dive time for recording as photographic recording was completed in less time then trilateration. The images were processed onto glass plates and could be viewed through a ‘Multiplex’, a stereoscopic instrument designed to produce accurate topographic maps from aerial images (Bass and Van Doorninck 1971). Unfortunately, they found it difficult to operate the ‘Multiplex’, as it proved to be too time-consuming, with Bass and Van Doornick (1971:28) likening it to ‘…a musical instrument: one may understand its theory perfectly but cannot play it well without many hours of practice’. However, when used successfully, the Multiplex aided in reducing distortion from the photographs and completing more accurate site plans.

The increasing accuracy of recording underwater sites with photographic equipment appealed to the ethical requirements of archaeology in general. However, the developments in the application of photography for underwater archaeological excavations and recording techniques in the 1960s, as detailed here all occurred at deep, clear water sites in the Mediterranean. In following decades the number of archaeological projects on underwater sites grew, particularly in the Mediterranean: archaeological excavation involving underwater photography was applied to significant sites such as Uluburun (Bass 1986; Pulak 1997, 1998), Serçe Limani (Bass et al. 1989; Pulak 1988; Pulak et al. 1987), Ma’agan Mikhael (Rosloff 1991), Molasses Reef Shipwreck (southeast of the Bahamas) (Keith and Simmons 1985), Spargi (Roghi 1959, 1965) and Madrague de Giens (Formenti et al. 1978; Pomey 1978; Tchernia 1978), amongst many others (for excavations dates see Table 4).
Beyond the Mediterranean shipwrecks were being found in open seas or more challenging underwater environments. In these locations, archaeologists adapted the photographic recording techniques first devised in the Mediterranean to combat the difference in environments. Two examples from the pre-digital era should suffice: the San Juan site in Canada and the Batavia site in Western Australia. Each reveal the central role for photography and the limits posed by site conditions. From 1980 to 1985 extensive underwater excavations were undertaken on a 16th-century whaling shipwreck, San Juan, in Red Bay, Labrador, Canada (Grenier et al. 2007). The cold water temperatures and sheltered bay preserved the remains of the Basque whaling ship, including extensive cargo (Morgan et al. 1992). Over five years, the 24 m long well-preserved wooden shipwreck was excavated in situ and recorded at a 1:10 scale by hand (Waddell 1986; Waddell 2007:120). The hand measured site recordings were complemented with photographic techniques, including a combination of photomosaics and stereo-photogrammetry that provided a total of approximately 53,000 images over 830 hours of diving (Waddell 2007:129). An interesting aspect of this research was the implementation of stereo-photogrammetry as a structural recording tool. The use of stereo-photogrammetry aimed to compare the accuracy, time and cost of recording the site with the hand drawn methods. Two Nikonos underwater cameras with 15 mm lenses, as well as a Hasselblad camera in an underwater housing, were calibrated in the underwater conditions. The two Nikonos cameras were mounted at a fixed distance apart on a photo tower (Bell 1986:113). The results over a 2 x 8 m section suggested that there was a total error of less than 0.05% when comparing stereo-photogrammetry (completed with a stereo-plotter) and hand drawing the site (Figure 31) (Bell 1986; Waddell 2007:131). Applying photogrammetric recording to this site indicated that understanding the variation of marine environments requires a tailored photographic approach to each individual site (Bell 1986:114). This study indicated that stereo-photogrammetric recording provided an additional, detailed form of mapping an underwater site along with the manual mapping. Ultimately, the research at this site showed that successful stereo-photogrammetry was completed that achieved a high level of spatial accuracy and provided a permanent record of the structure in situ.
Conditions faced on the margins of large oceans, like the Indian Ocean, are often severe and dynamic. The majority of shipwrecks on the Western Australian (WA) coastline are situated on shallow, turbulent limestone reef systems. Due to the turbulent, dynamic and shallow environment, techniques successfully applied in the Mediterranean are not suitable for recording there. One significant example is the wreck of *Batavia* wrecked off Western Australia in 1629 (for more details on the history of the wreck and discovery see Chapter 5, section 5.2). The site is located in 2-9 m of typically turbulent water in the Houtman Abrolhos (a chain of remote islands in WA’s Midwest region). The environmental conditions on *Batavia* prohibit the use of a floating bar, photographic towers or the placement of fixed square gird systems. As they considered working on *Batavia*, Baker and Green (1976:144) noted that a combination of a turbulent, high-energy environment and the inability to accurately record using manual recording techniques, left only one choice for the recording of the site — photography. To photograph the site, a single camera carried by a diver was determined to be the most effective method or capturing images suitable for the creation of scaled photomosaics. Both a 50 m long rope with lines marked at regular intervals, and a 2 m long rigid rod were included as scaled controls to aid in merging photographs into the photomosaic (Figure 32) (Baker and Green
Photographs were taken by one free-swimming photographer staying at approximately the same height (3.5 m) across the site, although the diver’s height was only an estimate due to the strong surge conditions (Baker and Green 1976:144). Photographs were processed in the purpose-built dark room set-up at the base camp.

![Figure 32. Partial Batavia photomosaic (Baker and Green 1976: Figure 2).](image)

During the excavation of the wooden hull remains, photomosaics of the excavation process were also competed in the same fashion just at a smaller scale, with different scale controls. As the site was excavated, 3 to 4 m sections of the hull were uncovered. Each timber was tagged with a number, the area was photographed, and then the timbers were removed (Baker and Green 1976:146). The resulting photomosaics provided valuable information by showing each timber *in situ*, including orientation and context. This technique provided adequate on-site recording as well as ensuring creation of a reliable photomosaic (Baker and Green 1976:146). The photographic recording at Batavia proves that underwater photography is a reliable and accurate method for archaeological recording in dynamic, environmental conditions (Baker and Green 1976:148).

The developments of the 1960s, 1970s and 1980s in underwater archaeological recording suggested that while conventional 2D photographic recording and visualisation were valuable tools, relying on them can also limit the recording abilities of often-complex
underwater shipwreck sites. Comparatively, 3D documentation and visualisation enabled a dynamic and holistic recording approach that best suits the study of some shipwreck aspects, such as cargo arrangement and site formation processes (Demesticha et al. 2014). Although there were already techniques for recording in 3D (such as understanding 3D depth through analogue stereo-photography), the availability of computers and processing power since the 1990s provided a new way to use photography for 3D visualisation. Throughout the remainder of this chapter, I review the developing application of digital 3D documentation of underwater sites and argue that P3DM and I3DM visualisation enables further flexibility, enhanced spatial accuracy and interpretation for post-excavation analyses.

3.3. Documenting underwater archaeological sites in digital 3D

Digital 3D visualisations became possible with advances in computing and the introduction of digital photography. Throughout this section I focus my review on photogrammetric processing programs that are increasingly employed for recording such as PhotoModeler, VirtualMapper, PhotoScan and 123D Catch (Eos Systems 2016; Ewins and Pilgrim 1997; Franke 1999; Green 2002; Green et al. 2002; Inc. 2017; Plets et al. 2012b; Richards et al. 2008). Early use of photogrammetric software programs (c. late 1990s to early 2000s) for underwater archaeological recording often required the combined use of a triangulation survey program with the photogrammetric software. Improvements in computers enabled the creation of trigonometric software for the triangulation of tridimensional points through computer software programs such as AutoCAD, Rhino and Site Recorder (Associates 2017; Green 2004; Green et al. 2002; Richards et al. 2008). Although not technically image-based processing programs, AutoCAD, Rhino and Site Recorder are included in this discussion as they often play an additional amalgamation role for the early photogrammetric programs as well as more extensive recording for detailed excavations (Green et al. 2002).

In the early 2000s, photogrammetric applications such as PhotoModeler and VirtualMapper required extensive manual camera calibration and the presence of control points before beginning a photographic survey (Green et al. 2002; Richards et al. 2008; Yamafune et al. 2016). Additionally, the programs, particularly PhotoModeler, were designed as true photogrammetric processing software with complicated, specialised settings and stages of use (i.e. not specifically for users skilled in photogrammetry). More recent advances in software and technology reduced the necessity for onsite camera calibrations and control points resulting in an increased use of P3DM to create I3DMs of
underwater archaeological sites (Fussell 1982:157; Green 2004:165). The use of different software and photogrammetric recording techniques as they developed is presented through a review of seminal underwater archaeological projects including Tektaş Burnu, Pavlopetri, Mazotos and the Gnalić shipwreck. A detailed description of each software, capabilities and general use is given in Chapter 1 — this section discusses each method’s specific application to underwater archaeological sites.

3.3.1. Digital cameras and 3D modelling: Tektaş Burnu
Tektaş Burnu represents one of the first archaeological excavations of a shipwreck in which digital photography and digital 3D models were essential recording techniques (Carlson 2003). The site is situated in the Mediterranean at a depth of 30-42 m, in relatively calm water off Turkey and often experiences visibility of at least 10 m (Green et al. 2002). When discovered in 1996, it was clear that the visible layer of 250-300 amphorae, combined with a steep slope, required a careful recording approach to successfully understand the complex site formation process and reconstruct the potential cargo assembly within the original vessel (Green et al. 2002). The site was excavated from 1999 – 2001 under George Bass and Deborah Carlson of the Institute of Nautical Archaeology (INA) (Green et al. 2002).

The first season (1999) combined conventional multi-tape trilateration and photogrammetric techniques to record the amphorae within the site (Green 2004). PhotoModeler was initially selected as a trial photogrammetric software, but test runs highlighted the increased speed of recording amphorae in comparison to multi-tape trilateration on each dive (Green 2004:188). The necessary process adapted for PhotoModeler on this site involved an innovative application of small targets on artefacts to record the exact orientation of each amphora as well as the coordinates in a 3D space (Green et al. 2002:286). White plastic discs designating the artefact number and depicting black triangular targets were attached to the mouth of each amphora. The discs created an artificial target for the PhotoModeler software to identify and recorded the position and orientation of each amphora (Green et al. 2002). In addition, further permanent control points were placed around the site so that they were visible in any photograph and allowed PhotoModeler to triangulate the exact position of that artefact within the shipwreck site.

One limitation of the photogrammetric process was the use of film for the first seasons in 1999 and 2000. In 2000, two Nikonos camera systems with 15 mm lenses were employed,
one calibrated with PhotoModeler and the other calibrated to predetermined permanent points, and proved to have exceptional optics qualities (Green 2004:193). Although photogrammetry sped up recording during each dive, the processing time post-dive proved to be lengthy. At the end of each dive, the films were removed, and the negatives processed, then dried before cut to size, scanned and uploaded to PhotoModeler (Green 2004:192). This process often required a total of 24 hours before the coordinates for the amphorae were available and the excavation could proceed, whereas post-processing of multi-tape trilateration was relatively faster (Green 2004:192). For the first two seasons, a combination of both photogrammetry and multi-tape trilateration continued to be used to record artefacts across the site and allow for timely excavation to continue.

In the third and final season, a digital camera replaced the film camera system for photogrammetry. Photogrammetric recording then used a pre-calibrated 3.3 megapixel Olympus Camedia with a custom built Willis underwater housing and a wide-angle lens and correctional dome port (Green 2004:193). The use of a digital camera removed the lengthy post-processing of film cameras from the photogrammetric process. Instead of 24 hours, preliminary coordinates were available in approximately 30 minutes (depending on the total number of images) (Green 2004:193). Additionally, the semi-automated use of the digital camera, with excellent low light capabilities, resulted in an almost ‘point and shoot’ ability for the photogrammetric recording, which reduced the stresses of underwater recording at that depth (Green 2004:194). The overall recording process was also improved to easily record small finds. A one-metre grid square was used as a secondary control framework within the network of permanent control points for PhotoModeler to provide reliable reference for smaller artefacts (Green 2004:190; Green et al. 2002:284). Significantly, the application of digital cameras in this methodological pathway removed the need for multi-tape trilateration recording, as the photogrammetric process was found to be sufficiently accurate and time effective.

PhotoModeler only supplied the coordinates for each object. To be able to interpret and understand these coordinates they were entered into the 3D software Rhino to create an 3D site plan. Rhino provided an interactive medium for exploring models, various ways of importing different data types and simple spatial analyses (Green et al. 2002:283). As the amphora were all very similar in form and size, a basic digital wire frame amphora was created and used to orient each amphorae to the coordinates provided through PhotoModeler. From here the wire frame was scaled to fit each amphora and a texture was created from the digital photograph and overlaid for the final digital 3D model (Green
This technique proved beneficial to a large-scale excavation as newly unearthed and recorded amphorae could easily be added to the appropriate 3D space in Rhino (Figure 33).

Additionally, VirtualMapper enabled recording and digital depiction of the topographic layout and contour of the overall site at Tektaş Burnu. VirtualMapper was used to plot the undulating surface underneath the site using stereo-photogrammetry (Drap et al. 2002; Drap et al. 2007; Ewins and Pilgrim 1997; Franke 1999; Green and Gainsford 2003; Green 2004:187; Ludvigsen et al. 2006). To complete this, a diver swam at approximately 10 m above the site taking a series of stereo-pair images (Green 2004:194). The stereo-pairs were downloaded post-dive and emailed to a processing facility in Australia that converted the TIFF images into digital epipolar files (Green 2004:194). From here, the epipolar files were sent back to the base camp at Tektaş Burnu where they were loaded into VirtualMapper, enabling both the identification of topographic structure coordinates and tracing of contour lines of the site’s surface (Green 2004:194; Green et al. 2002:286). Although sending the files to Australia for conversion also added unwanted time to the recording phase (24 hours), the method produced a contour plan that was then imported to the Rhino site plan (Green et al. 2002:286). The site plan provided essential information of the site’s surface and allowed for inferences about the site formation process (Green et al. 2002:287). Overall, VirtualMapper enabled recording of the geographical features that could not be completed by Rhino or PhotoModeler. Using this software enabled recording and visualisation of the site geography, which was vital in interpreting the overall site formation process.

Despite the successes in photogrammetry, there were issues noted with the overall photogrammetric recording process on Tektaş Burnu. For instance, Green (2004:197-8)
stated that the biggest problem was storing the daily influx of digital data, as each object had hundreds of related points recorded by the PhotoModeler program. If a stringent digital data recording system was not followed, measurements could easily be lost within unlabelled digital files (Green et al. 2002:286). In addition, there were problems with recording artefacts that were not amphorae, or amphorae that had no visible mouth to attach the plastic identification card (e.g. upside-down or broken) (Green et al. 2002:287). Creating individual 3D models of the amphorae, incorporating these into Rhino and adding the contour plots from VirtualMapper consequently added a considerable amount of time to the post-processing period (Green et al. 2002:289). However, the specific conditions and characteristics of Tektaş Burnu, combination of depth (30 – 42 m) and steep sloping topography, required a new 3D approach to both photogrammetric recording and visualisation of this site (Carlson 2003:581; Green et al. 2002:283). Overall, the site could now be viewed in 3D and rotated around to perceive different perspectives which, as Green et al. (2002:287) stated was ‘...an extremely useful way of analysing the composition of the site and how it had been formed’ (see Figure 33).

A detailed, critical review of the outcomes and use of the digital 3D models of Tektaş Burnu provides insights into the development and application of new technologies and equipment, as well as refinement of procedures to suit a complex site. Applying both triangulation and photogrammetric software to record stages of the excavation ensured valuable knowledge of the exact positions for artefacts within the spatial layout of the site was available for later interpretation. This work is historically significant to the development of digital 3D modelling applications within underwater archaeological recording as it represents a clear turning point in the focus of photographic recording and visualisation. Digital photography and digital 3D modelling became a priority for the archaeologists. Moreover, the success of the digital 3D modelling is evident in the use of images across the publications cited here that communicate the research results. For example, the use of the digital 3D models enhanced the way that the complexity of Tektaş Burnu could be understood (e.g. Figure 33). Employing digital 3D modelling on this Mediterranean site, is a unique example as its shows the transition from film to digital camera photogrammetry, and demonstrates a comparison of multiple triangulation and photogrammetric software programs as a combination being applied to this project.

### 3.3.2. P3DM of an underwater site: Pavlopetri

In 2010, the Underwater Archaeology Research Centre at the University of Nottingham and the Australian Centre for Field Robotics at the University of Sydney revisited
Pavlopetri, a submerged Bronze Age town off the coast of Laconia, Greece. This project aimed to survey and understand the site, although one particular technique was employed, stereo-vision photogrammetry, that enabled the creation of a 3D visualisation of the entire site (Henderson et al. 2013). The study at Pavlopetri represents an innovative stage for the use of UW recording and the creation of geometrically accurate I3DMs, or as the authors called them 3D ‘photomosaics and plans’, from stereo-pairs (Henderson et al. 2013:243)

A stereo-vision diver rig was designed specifically for digital image and sensor data collection, adapted from the designs and equipment of autonomous underwater vehicles (AUV’s) and remotely operated vehicles (ROV’s). The diver rig consisted of two cameras, lights, depth and GPS sensors, instrumentation and a power source. The entire set-up sat on a modified rigid carbon fibre frame to be propelled by divers or snorkelers (Figure 34) (Harding et al. 1969; Henderson et al. 2013; Mahon et al. 2011). The method used to record Pavlopetri did not require the use of numerous control points around the site itself due to the application of Simultaneous Localisation and Mapping (SLAM), an algorithm which allowed the images and resulting 3D model to be accurately geo-referenced from GPS sensor data (Henderson et al. 2013:246).

![Figure 34. Stereo-rig in use with a guide line for navigation (Henderson et al. 2013:247).](image)

The stereo-photogrammetry results for 3D reconstruction at Pavlopetri were promising. A large area (approximately 7000 sqm) was recorded with exceptional (centimetre) spatial accuracy, resulting in a high-resolution and georeferenced I3DM of the site (Henderson et al. 2013:244). The accuracy allowed site features to be traced in Photoshop to create a
traditional 2D site plan. In addition, the final I3DM is a detailed, easily understandable and navigable method for dissemination of information to peers and the public. This was a pioneering step in digital archaeological recording techniques for underwater sites. The results from this project show that high accuracy survey/mapping and recording can be completed more quickly with these methods on a shallow site when compared to conventional methodology such as triangulation or permanent control points (Henderson et al. 2013:254; Mahon et al. 2011:2319). Significantly, an outcome such as this seems to fulfil the ethical needs of recording archaeological sites to the highest standard possible.

However, most sites are not as calm and shallow as Pavlopetri. As the site is located on a relatively flat seabed in shallow water, with clear visibility and minimal swell or current, it provides excellent conditions for photogrammetry. In addition to excellent marine conditions, the archaeological structures lent themselves to accurate recording; the building outlines are straight lines and sharp edges that can be easily identified by photogrammetric software (Figure 35) (Henderson et al. 2013:254). The archaeologists state that future work at this site involves modifying the diver rig to reduce the amount of drag and weight in the water (Henderson et al. 2013:254). While ultimately a success, the method applied here is not reproducible across most underwater archaeological sites. For example, deeper sites and those affected by heavy swell as a submerged diver would not be able to use the surface GPS sensor or rely on a rope line for guidance in swell. Despite this drawback, the work at this site is significant to discuss as it represents another step towards more accurate digital 3D modelling of underwater sites. At the same time, Pavlopetri also represents an increasing reliance on digital site visualisations for both recording and interpretation.
3.3.3. From PhotoModeler to PhotoScan: Mazotos

The following example reinforces the argument that underwater archaeologists increasingly relied on digital 3D modelling as a way to record sites and communicate information. The work on a shipwreck in the Mediterranean, Mazotos, indicates a reliance on photogrammetric software packages – PhotoModeler and PhotoScan. In 2006, divers located the Mazotos shipwreck lying on a sandy seabed at a depth of 44 m near Larnaca, Cyprus. The site itself composed of approximately 800 amphorae (mainly hidden under the sea floor) and presented a well-preserved array of amphorae still in the stowage position. As sites in this condition, undisturbed and well-preserved, are rare, there was an immediate need for detailed recording, archaeological excavation and protection before it could be illegally salvaged (Demesticha 2011:40). This was the first underwater archaeological project by the University of Cyprus and the Department of Antiquities in Cyprus (Demesticha 2011:39). Between 2007 and 2009, surveys were conducted to understand the scale, state and archaeological potential of this site (Demesticha 2011). These early surveys indicated the need for a detailed understanding of the site formation processes associated with this shipwreck that would allow further interpretation of the stowage layout and styles within the vessel. Accordingly, a primary aim for fieldwork was the detailed and accurate recording of every artefact, particularly the location and orientation of each amphora as well as recording the depth, or height, of features on the
site. To date there have been six seasons of work, although the archaeological work at Mazotos is currently ongoing.

Given the success of previous 3D recording at underwater archaeological excavations (e.g. Tektaş Burnu) and the complexity of Mazotos site, 3D recording provided the opportunity to understand the issues of hull capacity and stowage of amphorae. From the start, the aim for recording at Mazotos was to primarily use digital photogrammetry as an accurate and reliable method for complete site recording and visualisation. In this discussion I review the techniques employed over the history of fieldwork at this site to date, to provide insight into the very recent developments in underwater photogrammetric recording and modelling, and to explore the benefits and shortfalls of certain photogrammetric software and techniques that have been recently used.

The pre-disturbance surveys and recordings from 2007 to 2009 faced many initial challenges and issues. The first surveys occurred over three dives, from 2007 to 2008, with a total of 350 photographs recorded. A Canon A620 camera with 35 mm lens and an Ikelite underwater housing were employed in these early dives (Vlachaki 2010:16). A combination of photogrammetry and manual recording were applied to appropriately map the site. Calibration of the cameras and orientation of the photographs were completed in PhotoModeler, and from there the positions of the amphorae were plotted into AutoCAD for 3D modelling of the site (Vlachaki 2010). Although each amphora was photographically recorded, conventional manual measurements ensured that the scale, size and style of each object were known. Multi-tape trilateration of several key points and the fixed control points around the site were completed as a back-up if the photogrammetric processing did not work (Vlachaki 2010). These manual measurements were recorded in Site Recorder and eventually also added to the 3D site model in AutoCAD (Vlachaki 2010:17).

Pre-disturbance recording with PhotoModeler proved to be a lengthy and challenging process as operators had to be skilled specialists with the photogrammetry tools (Demesticha et al. 2014:137). The artefacts were not removed until recording via photogrammetry and tape-trilateration were completed. Consequently, any delays in processing caused delays to the excavation (Demesticha et al. 2014:141). Application of PhotoModeler on Mazotos proved that it could not fulfil the essential requirements needed for this project. For example, the software needed to be suitable for non-expert users, speed and automation of processing and creating a final reliable P3DM. Skarlatos et
al (2010:4) stated that this is purely due to the true photogrammetric characteristics of PhotoModeler as a product aimed at photogrammetric specialists. In addition, although it was evident that PhotoModeler fulfilled the requirements for P3DM and creating a final I3DM, the lengthy implementation process caused too many delays in the excavation and did not suit the demand of working on a deep water archaeological site (Demesticha et al. 2014:142).

In 2010, the photogrammetric recording technique was enhanced with a new specific focus on digital photogrammetry and computer vision methods (Skarlatos and Rova 2010:1). For the 2010 season, priority was not only placed on creating a reliable site photomosaic but also incorporating an ensemble of open-source software that would provide a reliable, repeatable recording method (Skarlatos et al. 2010; Skarlatos et al. 2012; Skarlatos and Rova 2010). The decision was made to use PhotoModeler Scanner for camera calibration and orientation, while machine vision open-source tools for mosaicking and Bundle block adjustment were used to compensate for the limitations of PhotoModeler Scanner (Skarlatos et al. 2012:3; Skarlatos and Rova 2010:2). Additional software employed included Enblend and Smartblend (for the photomosaic) (PTGui 2017), Integraph’s SSK photogrammetric software (for Bundle block adjustment) (Integraph 2017) and Hugin Panorama Sketcher (Hugin 2017) (Skarlatos and Rova 2010).

The software programs were customised and extensively used for the 2011 field season to ensure that an open-source method was employed (Skarlatos et al. 2012). A complete open-source approach was employed here for a range of reasons, including: application regardless of budget, installation on a range of computers and that it could set a standard for archaeological recording (Skarlatos et al. 2012:20-21). For the Bundle adjustment, Bundler was used (see section 1.3.6 in Chapter 1 for a detailed description), while the dense point cloud extraction was completed using the Clustering Multi-view Stereo (CMVS) and Multi-view Stereo (PMVS) methods (Bundler 2017). Lastly, Meshlab was used to view and edit the point cloud (see section 1.3.6 in Chapter 1 for descriptions) (Furukawa et al. 2010; Furukawa and Ponce 2010) (Cignoni et al. 2008). Excavations focused on a 4 x 4 m area of the site, and the majority of photogrammetric recording also covered this area with approximately 60 to 70 photographs taken daily (Skarlatos et al. 2012). Processing the images with a variety of mainly open-source software showed that computer vision and photogrammetry were successfully in creating detailed spatial representation using 3D dense point clouds of the ongoing excavations (Skarlatos et al. 2012:12). Additionally, the method could be reliably applied to other underwater archaeological sites. Unfortunately,
this method still required experienced specialists to complete the processing, although it was noted that archaeologists with an understanding of photogrammetry and PhotoModeler could be taught to complete the process (Skarlatos et al. 2012:15).

From the 2012 season, the photogrammetric approach differed greatly to previous recording methods. Despite the low cost of the method presented for the 2010 to 2011 field seasons, the necessary incorporation of multiple programs for varying stages still required specialists to create reliable results. In 2012, the decision was made to use PhotoScan as the primary software for all stages of photogrammetry, as the easy-to-use interface successfully removed the need for photogrammetric specialist supervision (Skarlatos et al. 2012:21). The combination of PhotoScan and Rhino facilitated a detailed photogrammetric recording, I3DM and an eventual digital 3D site plan.

The application of PhotoScan came with various advantages. There was no longer the need to calibrate the cameras before photographing the site, as PhotoScan contains algorithms to complete this stage automatically (Demesticha et al. 2014:142). Additionally, relatively unexperienced photographers could complete the photogrammetric recording removing the need for specialist photographers. Single photographs would still allow metric measurements, as long as they overlapped. It also removed the need for specialist post-processing (Demesticha et al. 2014:147). The excavation process was no longer hindered by significant delays with processing, and photogrammetric recording was completed more often enabling timely recovery of artefacts. Significantly, the 3D data generated with PhotoScan was more accurate, less noisy (patches of discoloration, variation of brightness in images etc.) and much more detailed than previously created with PhotoModeler (Demesticha et al. 2014:147).

To interpret the P3DM results, an underwater reference system was essential for georeferencing all final I3DMs. One of the challenges for the team was the lack of features and the visually homogeneous sandy sea floor that made the selection of visual reference points difficult. A large aspect after 2010 was the creation of fixed control points for referencing within the site. Consequently, a focus at Mazotos involved developing a reliable underwater reference system (Skarlatos and Rova 2010:8). The flat, sandy seabed proved to be a difficult environment in which a permanent and reliable reference system could be applied. The main issue was that the characteristics of a sandy seabed limited the ability to securely and permanently fix control points as these would shift with water movement. Initial use of poles fixed to the ground with targets proved unsuccessful, as
they would not remain in place. In 2012, 25 kg blocks with targets attached were used, but these were only reliable for one excavation season and not necessarily permanent fixtures for years of research at the site (Demesticha et al. 2014:147). Consequently, control points were only reliable for one season and were not expected to be in the same spot for a long time. Nonetheless, a reference system could be attained by photogrammetric modelling of the photomosaic from 2007, which included amphorae that remained on site for the 2012 fieldwork. The archaeological materials, mainly amphorae with plastic tags, were used as a secondary control to georeference the overlaying I3DMs. Although not ideal, this did provide a comparison of the site overtime.

Two different camera set-ups were used for slightly differing purposes to record the site. First, a Canon 550D DSLR in an Ikelite housing, using 10-22 m zoom and without a flash was employed to record the site from a height of approximately 1.5-2 m to 4 m above the wreck (Demesticha et al. 2014:143). Secondly, a Nikon D200 with a 20 mm standard lens in an Ikelite housing with two strobe lights was used to record at a higher level of detail at 1.5-2 m above the wreck (Demesticha et al. 2014:142). This ensured that an overall site coverage was completed with the Canon, as well as close-ups of each trench with the Nikon. After each photographic dive, images were loaded straight onto PhotoScan to begin processing. For Mazotos, it is only essential to discuss the refined methods they employed to streamline a process, or acquire certain results.

To align the control points (referencing system) for each point cloud, they were manually measured and placed onto a single image. After placing the control point onto approximately four images the software then automatically identified the same point visible in all possible remaining images (Demesticha et al. 2014:142). What is particularly important to note here is the description of employing the ‘low’ settings in PhotoScan (see Chapter 4) to align the images and acquire a quick point cloud, determining the extent of coverage in the recording (Demesticha et al. 2014). This is significant to note for in-field use where the availability of high-end processing computers is minimal. With this technique, processing the highest detail can be left for later but an essential point cloud can be created and used as a draft site plan while excavation continues. The detailed description of each of these processes will be discussed in the Chapter 4.

Understanding the turn-around time for processing images after a dive requires knowledge of the computer capabilities employed throughout the project. For Mazotos, an example is provided of 100 high-resolution images (actual size and format not supplied)
processed with a 64 bit Intel Core™ Duo with 4GB RAM and NVIDIA Quadro® FX 3600M with 512MB dedicated memory took a total of 4-5 hours (Demesticha et al. 2014:144). Consequently, the resulting dense point cloud of a 5 x 5 m site area contained over 1 million points (Demesticha et al. 2014:144). These are particularly appropriate results considering the limited dive times (e.g. 20 minute bottom time at 44 m). The digital I3DMs allowed researchers to formulate hypotheses and recover artefacts with the knowledge that the level of recording was adequate for future interpretations and understandings.

The last recording stage described by the Mazotos team was creating a complete and dynamic digital 3D site plan of the excavation for all seasons. The site plan was based on smaller sections of the 3D point cloud or mesh created by PhotoScan. For example, a 3D mesh of a single amphora was created and uploaded separately to Rhino (Demesticha et al. 2014:144). From here the exact position and orientation of each artefact could be determined. Once the position and context were known, excavation proceeded and, when an artefact was recovered properly, it was manually measured on the surface and a digital 3D model was created in Rhino before being added to the digital 3D site plan (Demesticha et al. 2014:145). The recording results for Mazotos not only included an I3DM of the entire site, as well as individual, daily versions for each excavation area and orthophotos, but also created an accurate, digital 3D site plan (Figure 36).

Figure 36. Example of a) the 3D point cloud and b) final 3D site plan from Mazotos, indicating enhanced investigation of an anchor (Demesticha et al. 2014:145).
Overall, Demesticha et al. (Demesticha et al. 2014:146) refer to the ability to generally record the site with PhotoScan, instead of focusing on what are considered significant features or artefacts. This recording method does not rely on the archaeologist’s predetermined choice of significant aspects to record, as opposed to conventional tape trilateration and other manual methods. Rather, the resulting dense point cloud recorded much more information, which included aspects that are not considered important at the time of excavation. For example, the ‘…most significant advantage of this method for an excavator is the fact that it is based on the creation of a dense point cloud and surface, not specific points (or finds) that were predetermined as important’ (2014:141). The seemingly objective and complete recording of a site resonates with ethical values for recording archaeological sites to the best possible standard. This is also significant as it allows for future revisiting of the legacy photogrammetric data to study previously undervalued artefacts.

As work is ongoing at Mazotos, the majority of the findings and results are yet to be published. The long-running application of photogrammetry and digital 3D modelling at Mazotos is a pivotal investigation for photographic based visualisation as it represents the transition from PhotoModeler to PhotoScan software within underwater archaeological research. It is essential to note from these preliminary results, that the continual refinement of photogrammetry and computer vision techniques on this site indicate a focus of identifying the best-fit archaeological techniques. This is partially because a core aim from the beginning was to document the spatial positioning of artefacts to analyse the site formation processes, in order to interpret significant information, such as hull capacity and stowage forms (Demesticha et al. 2014:141). Overall, the work at Mazotos indicates a transition to semi-automated software, which also removes the need for photogrammetric specialists while still providing highly accurate, detailed results. An additional benefit from the photogrammetric recording at Mazotos is the proven ability to record non-standard shaped objects that may not have been identified as significant at the time of excavation. Although ongoing, this project already represents a key stage in underwater archaeological photogrammetry and digital 3D modelling.

### 3.3.4. PhotoScan as the core tool: Gnalić (Gagliana grossa) shipwreck

Another important site in the history of underwater archaeological photogrammetric recording is the 16th-century Venetian merchantman, Gagliana grossa. Recreational divers discovered the Gnalić shipwreck located in 27 m of water off the Croatian coast in the 1960s. The site was test excavated soon after the discovery, and once more in 1996 before
being revisited and excavated throughout 2013 to 2015 by lead archaeologists Irena Radić Rossi and Felipe Castro (Demesticha 2011; Demesticha et al. 2014; Demetriou 2012; Vlachaki 2010). Their aim was to study the hull structure and construction through P3DM given that the remains were well preserved having been buried beneath up to 1.5 m of sediment (Rossi and Castro 2013; Rossi and Nicolardi 2014). From the 2013 season of excavation, the team experimented with PhotoScan and developed a methodology that specifically tailored that software to this particular site (Rossi and Castro 2013; Rossi and Nicolardi 2014; Yamafune et al. 2016:5).

Over the complete excavations of 2013 to 2015, the team involved in the photogrammetric recording were Jose Louis Casabán, Kotaro Yamafune, Rodrigo Torres and Filipe Castro. PhotoScan was experimented with in the first season under the guidance of Casabán and the following two years saw an indepth approach to developing a methodology to record the site with PhotoScan that was acceptable to the requirements of the archaeological research project. In 2013, the P3DM resulted in exportation of orthophotos into AutoCAD that were digitally traced to create a 2D black and white line-drawn site plan to scale (Rossi and Castro 2013; Yamafune et al. 2016). This method was further developed and refined over the following two years and through the detailed doctorate research of Kotaro Yamafune.

From 2014 to 2015, the aim was to create accurate 3D visualisations of the site and extract, integrate and share archaeological information from the tridimensional visualisations (Yamafune et al. 2016:6). The photogrammetric methodology was based on Rodrigo Torres’ doctorate research that successfully integrated photogrammetry into the excavation process of some Brazilian shipwrecks, resulting in scaled I3DMs for precise measurement and study of the hull structure (Casabán et al. 2014). On the Gnalić Project, they reiterated that the primary requirement was to acquire high-quality images for data processing. Furthermore, the imaging team for the Gnalić project noted that use of wide-angle lenses for the P3DM allowed closer site detail captured within each image without losing overall site coverage (Yamafune et al. 2016:4). The methods applied throughout the Gnalić excavation were refined and ultimately represent a successful integration of photogrammetric recording during an underwater shipwreck excavation (Figure 37).
Significantly, the team relied upon a control network with permanent control points to record the site continually over the seasons. As they stated, a key to recording is including a control network as this gives correct scale and allows for correction of the overall distortion (Torres 2016). They noted that to set-up this control network, the conventional Direct Survey Measurement (DSM) trilateration technique was used with fibreglass measuring tapes to determine the exact position for each control point, providing each point to within centimetre accuracy across an area of approximately 20 x 25 m (Yamafune et al. 2016). The control points were made out of tagged metal pipes driven into the seabed and secured with sandbags. An additional six coded targets were securely fastened to archaeological structures within the site that would not be removed throughout the entire project. All of the control points acted as reference points not only for the photogrammetry surveys but also for the complete excavation (Yamafune et al. 2016:9). I return to the method refined for the Gnalić Shipwreck in the following chapter, as it formed the basis for the method proposed in this research. Notably, as argued by Yamafune et al. (Yamafune et al. 2016), this is the first example of a proposed workflow for underwater photogrammetric recording and 3D visualisation.

Reviewing the application of photogrammetric software to underwater archaeological site recording demonstrates an increased ability to record spatial accuracy with a relatively
fast methodology and provide insightful 3D information. However, a significant point to raise at this time is the lack of any acknowledgement of the freedom taken by advanced software, like PhotoScan, to fill gaps and create aspects of a I3DM that may not reflect reality. As described in detail in Chapter 2, the ideal of a completely objective and accurate recording and replication of a site is not yet possible. While the review of visualisation within archaeology in Chapter 2 highlighted some key research into visualisation and theoretical approaches to archaeological recording, application of P3DM to underwater archaeological research still lacks recognition of the subjective aspects of the archaeological process. For example, Yamafune et al. (2016:9) state that ‘Once accurate 1:1 scale tridimensional models are created, archaeologists can extract data from the models without having to revisit the actual sites.’ While they are correct to note the increased spatial accuracy of P3DM over conventional recording techniques, they are incorrect to suggest that archaeologists can use these I3DMs as exact copies of the real site. Like hand drawn site plans, I3DMs are a subjective interpretation of a site and should be considered as such. What they are stating here is that in the case of an archaeologist not being able to return to the site, the I3DMs provide a suitable pseudo-site with highly detailed spatial information that can be relied upon, not a complete replica. This is evidence of a lack of visualisation and theoretical discourse between underwater archaeologists about these ‘new’ photogrammetric technologies, an issue that this thesis aims to rectify.

3.4. Summary
This review of archaeological research into photographic recording methods and the various approaches to the visualisation of underwater archaeological sites shows that underwater archaeologists rely heavily on photography as a recording technique, particularly since the 1960s from when photographic methods have been tested as viable alternatives to forms of manual survey and plan making. From the earliest archaeological excavations of shipwrecks to current projects, photography continues to be a constant tool for data collection, interpretation and communication of ideas and theories. More recent application of digital technologies and algorithms that allow the use of P3DM to underwater sites by archaeologists signifies a step towards more accurate spatial recording.

Photography provided a medium for both recording and site visualisation from the earliest underwater archaeological excavations. As technology advanced so too have the tools and techniques employed by underwater archaeologists for photographic recording
and visualisation. As we have continued to apply them, we have also learnt valuable lessons on how these tools influence archaeological practice. For example, the recognition that a dynamic, turbulent site like *Batavia* could only be recorded in entirety by photographic surveys (Baker and Green 1976) and the revelation that increasingly better resolution in photogrammetric surveys at Pavlopetri identified archaeological features and artefacts that had gone unnoticed during numerous dives over the past 50 years (Henderson et al. 2013:251). From these lessons it can be inferred that underwater archaeologists are increasingly able to use photographic tools for more than just a comparison to conventional site recording techniques. Instead, we increasingly use them as a primary method for accurate, spatial recording of underwater sites. Using photographic visualisations (such as I3DMs) positively changes the way we interpret a site. The immediate recognition of features or artefacts that are viewed through I3DMs enables archaeologists to identify items more readily, to communicate the specific details and site formation of an area to colleagues and to plan the best approach for certain environments. This does not mean that this was not completed before I3DMs became readily accessible, just that we have improved how we visualised sites and reduced the time frame for site recording. As such, our interpretations can be more detailed, more informed and reliable. However, we are at a crucial stage where the next step must involve a theoretically informed approach to I3DMs and underwater archaeological visualisation to continue to improve the way that we record, communicate and interpret underwater archaeological sites.

Most evident from the preceding review is the fact that techniques for photogrammetric recording vary with each site, as marine environments contrast vastly between geographic locations. These variables are important to take into account when applying any of the recommended methods and techniques from the above literature for the method described in the next chapter. Testing is a significant and valid phase of refining any method for working in a unique environment such as the WA coast. As the focus of this thesis is on the shipwrecks in WA waters, the application of techniques for highly turbulent shallow water, and the review of previous archaeological projects such as *Batavia* are an important point for discussion in the following chapters. Advances in technology are often quickly applied to archaeological projects with varying results, and an evolution of methods, due to the physical implications of working underwater. One implication of this review is that, particularly in comparison to terrestrial archaeology, underwater archaeologists focus on the ‘how’ of a project. This is significant to note as it may indicate the groundings for a lack of theoretical awareness that underwater archaeologists have for the application of certain
techniques. Although it is essential for underwater archaeologists to first test a technique and determine if it can be successfully applied underwater, the focus on ‘how’ may be a draw-back for further advances in our understandings of shipwreck sites due to only a minimal focus on why we are applying certain techniques.
4. An archaeological approach for underwater shipwreck P3DM

To address my aim of researching and critically analysing the use of imagery within archaeological interpretation, particularly on underwater I3DMs, I needed to acquire a deeper and applied understanding of the P3DM process. This chapter describes how I refined a method for P3DM of underwater shipwreck sites in WA marine environments by application to two underwater sites incorporating both legacy and new visual data. To do this, I gained experience by applying a PhotoScan P3DM methodology to selected underwater shipwreck sites in WA. The previous chapter outlined the history of underwater photographic recording and described the background of digital 3D modelling of underwater shipwrecks over the last 20 years. This chapter combines recommended techniques gathered from the review in Chapter 3 with the applied use of PhotoScan to outline an approach best suited to perform P3DM processing on Western Australian underwater shipwreck sites. Critiquing the recent practices enables a deeper understanding of the overall method, which promotes further discussion on what improvements would provide the basis for more reliable P3DM techniques in the future.

The origin of the technical language employed here reflects the fact that archaeologists adopted photogrammetry practices, then adapted and refined them to suit the needs and context of terrestrial and underwater sites. However, where possible, the technical discussion in this chapter is primarily gathered from literature that focuses on the application of photography and P3DM for archaeological standards. Further, the method presented here is intended to primarily suit the needs of underwater archaeologists and may not necessarily be suited to the wider discipline of photogrammetric research. Additionally, as PhotoScan is the chosen software, the devised method specifically relates to intricacies of that commercial software, although an effort is made to describe each stage with general photogrammetric practices.

The P3DM process is divided into three distinct phases: 1) data acquisition, 2) data processing and, 3) post processing (Demesticha et al. 2014; Diamanti and Vlachaki 2015; McCarthy and Benjamin 2014; Skarlatos et al. 2012; Yamafune 2016). Data acquisition covers aspects such as the planning, preparation, equipment and techniques for recording a site. In archaeological research, the terms related to data acquisition includes ‘reality-based documentation,’ ‘multi-image photogrammetry,’ ‘image based survey,’ ‘underwater
photogrammetry,’ ‘underwater imaging,’ ‘data recording,’ ‘data acquisition’ and the ‘mapping methodology’ (Balletti et al. 2015; Barceló et al. 2003; Bernardes et al. 2014; Bianco et al. 2011; Callieri et al. 2011; Casabán et al. 2014; Demesticha et al. 2014). While it is easy to understand why different projects embrace different terms, for simplicity this study employs the term ‘data acquisition’.

The data processing phase is also referred to by a range of terms: ‘3D reconstruction stage,’ ‘photogrammetric processing’ and ‘underwater camera calibration’ (Balletti et al. 2015; Diamanti et al. 2011). Overall data processing involves all the aspects of creating an I3DM with P3DM software. In this research, data processing refers specifically to the settings, stages and processing within PhotoScan, however other software exists and will be developed in future. Importantly, the stages referred to here are well known within the wider discipline of photogrammetry, yet I have chosen to adopt terms from the PhotoScan manual for consistency while using the software (e.g. camera alignment instead of image alignment).

The final stage of post-processing is also described in different terms. Some standard nomenclature includes: ‘data representation,’ ‘visualisation,’ ‘post-processing’ or ‘exporting a digital 3D model.’ This research prefers the term ‘post-processing’ as it covers a variety of optional steps to export different types of 3D models and 2D images for use within other programs. It is important to note that the aim of this research was not to delve into the broad range of technical discussions regarding, for example, possible decisions about camera types, lenses, image sensors and other technical equipment used in the creation of digital 3D models (Capra et al. 2015; Menna et al. 2016; Yamafune 2016).

4.1. Data acquisition

Although P3DM can be considered the most recent development in the evolution of photographic recording of underwater sites, conventional site photography requirements (such as focus, composition and including scales on the site) still play an essential role and should be understood. There are four main decisions to make regarding the data acquisition phase: 1) selection of camera equipment, 2) the type of reference system to employ, 3) the method for acquiring quality imagery from the field and, 4) ensuring that the camera settings are selected with the intention of creating a reliable I3DM. As McCarthy and Benjamin (2014:5) state, a thorough understanding of the camera and photographic principles is essential in acquiring the highest quality images. Comprehending the technical abilities of cameras improves the success of photographing
underwater (e.g. low light conditions, water column movement and image coverage). Some cameras are better suited than others due to the variance between camera sensor size and the availability of necessary exposure settings. It is significant to stress that choosing the right tools and equipment for each site is the most critical for creating a final reliable I3DM (Demesticha et al. 2014:136).

4.1.1. Camera equipment
Currently, there are numerous types digital cameras on the market that cater to a range of uses. For example: personal smartphones generally have quality compact cameras included, small and durable action cameras (e.g. GoPros), compact digital cameras (that cater to automated ‘point and shoot’ use), digital single lens reflex (DSLR) cameras and mirrorless interchangeable lens cameras for more experienced users. To capture quality images for the P3DM of underwater shipwreck sites, McCarthy and Benjamin (2014:8) note that there are modern compact cameras that enable both low-light capabilities as well as fast shutter speeds. They suggest that an ideal compact digital camera for photogrammetry would have a 1-inch backlit sensor and be capable of f-stop 1.8, as well as high range ISO (1600-3200) (McCarthy and Benjamin 2014:8). Appropriate digital cameras were researched before purchasing one suitable for recording within the budget for this project. The camera employed for recording both James Matthews and Batavia was a Sony Alpha-7 II in a Nauticam NA-A7ii housing with a Nikonos Lens Adaptor and Nikonos UW Nikkor 15 mm f:2.8 lens (Figure 38). The Sony Alpha-7 has a 24.3 megapixel, 35 mm full-frame Exmor CMOS sensor that provides low noise and a wide dynamic range, and for these reasons is an excellent camera choice for photographing underwater environments. Recording on both sites required a 64GB memory card. Practice runs were completed first on land around the University of Western Australia (UWA) to become familiar with the camera and techniques for proper P3DM. Then test features (purpose-built small stainless steel mesh platform with attached wooden pieces) were recorded in local swimming pools allowing for further refinement of techniques. An overall familiarity of how the camera worked best improved the quality of the data sets captured on both sites for P3DM (see the reports on these pilot tests, see Appendix A).
4.1.2. Reference system

There is a critical element to orient a 3D point cloud in space, a reference system (De Reu et al. 2014; Demesticha et al. 2014; McCarthy 2014; Plets et al. 2012a; Yamafune 2016). A recent study by McCarthy (2014:177) reiterated the significance of designing coded targets and determining the layout of ground control points (GCPs) before beginning the photographic recording. It is suggested that at least three GCPs should be included to allow for adequate georeferencing of the model (De Reu et al. 2013:1110; Plets et al. 2012a:888). Further, Yamafune (2016:25) recommends that, in general, the diameter of the outer circle of a coded target should be between 80 and 300 pixels, but always checked in comparison to the particular camera and focal length.

Although GCPs are essential for georeferencing a model, they can be modified depending on individual site requirements. In this research, fixed GCPs (with known coordinates) were not used. Instead, the coded targets were employed as reference points for PhotoScan to improve photo alignment. Due to limited dive time, the use of non-fixed coded targets on Batavia allowed for modification on site as conditions changed. PhotoScan coded targets were printed onto A4 sheets of paper, laminated and attached to aluminium metal plates to ensure they were both waterproof and weighted to sit on the seafloor (Figure 39). The intention was to capture photographs with Yamafune’s pixel range (80 to 300) in mind. However, it was accepted that there would be variance throughout the dive on each site. One-metre long black and white scale bars were included during data acquisition recording to ensure there was a scale across the main
site. The inclusion of a scale guaranteed alignment of the final P3DMs within a 3D space and greater reliability for future interpretation of the images.

![Figure 39. Example of coded targets, laminated and attached to the aluminium plates.](image)

**4.1.3. Acquisition method**

Conventional guidelines for creating photomosaics of underwater shipwrecks consist primarily of transect line runs covering the entirety of a site, with overlap to line up images (Agisoft 2016:46). For P3DM, image overlap is crucial in ensuring that the algorithms within PhotoScan can calculate the required level of points to recreate the 3D information. The minimal vertical (top to bottom) overlap should be sixty percent and, vertical (side to side) eighty percent (Agisoft 2016:5). Previous applications to underwater archaeological sites also recognise that the approximate vertical overlap for images should be between seventy percent and fifty percent horizontal (Green 2004:169; Yamafune 2016:27). They also observe that each feature should be recorded in at least three images to ensure adequate site cover, but more is always better (Diamanti et al. 2011; McCarthy and Benjamin 2014; Skarlatos et al. 2012).

Planning the ‘swimming track’ or ‘flight path’ is essential to achieve the level of overlap noted above and cover all features on the site adequately. The site should first briefly be inspected to observe characteristics such as high relief vertical features. Primarily, the environmental conditions should be noted as extra information for any future attempts to recreate the same recording method on the same site. Depth readings of coded targets and
potential control points should also be taken around the site to ensure later rectification of the processed model into a 3D space (Green 2004:178). As Demesticha et al. (2014:143) recommend, depth measurements can be completed with a diver’s depth gauge or dive computer, as the accuracy is adequate for large-scale site surveys. Control grids and lines are no longer essential regarding general photographic site recording. Additionally, the recommended acquisition process for PhotoScan does not require the rectification and control scales in each photograph for manual ‘laying up’ as past photomosaics have (Green 2004:165).

The swimming tracks across both James Matthews and Batavia were based on a technique proposed by Yamafune (2014:143), who recommends that the coded targets be placed around the outside of the site, completing a track encircling the site to ‘lock’ it in. The majority of the site is then recorded using perpendicular images captured while finishing both transversal and longitudinal paths across the site (Figure 40) (Yamafune 2016:27). To ensure that an appropriate level of data for 3D is recorded, the swim tracks should circle high relief structures last (see camera positions from a test in Figure 41) (Yamafune 2016:27). This is reiterated by De Reu et al. (2013:1110), who suggest recording the large-scale features first, then those of smaller scale to capture the oblique details.

![Figure 40. Recommended swimming path for recording with coded targets (Yamafune, 2016:28).](image-url)
The last essential aspect of image acquisition is the diver’s height above the site when conducting the swim tracks across the site. Object-camera distance will vary as a diver’s height above the site changes depending on the level of detail required and the physical conditions (e.g. water depth and swell). When required, multiple sets of images can be recorded at varying dive heights. This allows archaeologists to record both large-scale sites, and complete small-scale recording with higher levels of detail for significant features or daily trench recording (De Reu et al. 2013:1110). The decision to use either large or small-scale recording depends on the aims of each project. For example, for this study, the objective is to record as much as possible of each site in one dive. Consequently, the diver height will be higher to capture more sea floor in each photograph and complete large-scale I3DMs.

4.1.4. Camera settings
4.1.4.1. File format

A greater number of images ensures a higher level of recording and overlap, although this can create an issue with both storage capabilities and budget (Agisoft 2016:5). This leads to large numbers of images, for example Yamafune (2016:19) notes that batches of at least 1000 photos per dive (depending on site size) should be expected, and that battery life and memory card should be carefully planned. Camera storage capacity is also affected by the
format that images are recorded in and should be considered when looking at the software and camera, as well as overall storage and processing capabilities of the computers used in the next phases. PhotoScan (2016:4) recommends recording images in RAW format, then converting them to TIFF files for processing. Although JPEG files save space and allow more images to be recorded in one dive, the compression of this format causes unwanted noise in each image (Agisoft 2016:4). Throughout this project, each image was recorded in RAW format, ensuring the highest level of detail captured for long-term storage of the original photographic data.

4.1.4.2. Exposure settings
Camera settings are essential aspects of photographic recording and can affect the quality of images captured. In particular, three exposure settings should be understood and established for underwater photography. PhotoScan recommends the following settings for adequate image capture. The level of light sensitivity is called the ISO setting, and it should be set as low as possible to reduce image noise. Sensor Aperture controls how much light is allowed to enter the image sensor and is best set relatively high to ensure that sufficient focal depth is covered in each image. Lastly, shutter speed manages how quickly an image is taken. This setting should be fast so that blur does not occur in each image (Agisoft 2016:4). While these settings may be satisfactory for recording features on land, underwater conditions often require slightly different camera settings. For example, McCarthy and Benjamin (2014:4) recommend using a shutter speed of 1/100th and a high-level ISO (e.g. 1600). A combination of PhotoScan and McCarthy and Benjamin’s suggested settings were used to start all recording of sites in this study and were adapted to fit the different conditions when required.

4.2. Data processing
PhotoScan was selected as the software to use for this study for multiple reasons. Primarily, the semi-automation and practical user interface allow a non-specialist to use the program. Further reasons include (1) affordability (student version is very affordable, at only AUD $160 [as of January 2015]), (2) its wide application by other archaeologists, (3) results that have been published and presented to date, and (4) supervisors’ knowledge of the program. This section describes each step of the processing, beginning with downloading images from the camera to exporting the final I3DM.
4.2.1. Pre-processing and storage of data

Downloading, labelling and archiving of images are essential parts of the archaeological process and should be completed in the field. Guidelines should be in place to ensure that all field data (descriptions, labels and observations etc.) are inherently linked to the images stored to safeguard context. For this study, images were downloaded to an external hard drive and then backed up copies were stored with the WA Museum and Pawsey’s (UWA) temporary storage and another external hard drive. The final storage of data and the resultant models are held at the WA Museum for future use and access.

After the original images were downloaded and stored, the files to be used in modelling were copied and exported in a TIFF format with Lempel-Zilch-Welch (LZW) lossless compression. Each image was assessed for quality, focus and exposure, which is a step that can be completed on any image viewer such as PhotoScan itself or a standard image viewer like Apple’s iPhoto or Window’s Photo Gallery. Digital pre-processing of the images occurred here (e.g. masking of moving objects and colour balancing, masking shiny features etc.). Basic editing was completed in Adobe Photoshop for one James Matthews dive. The editing involved batch colour correction, and one sharpen layer filter applied. However, the results were not ideal and, in general, colour correction was deemed unnecessary due to the shallow depth of both sites.

4.2.2. Generating an I3DM in PhotoScan

As discussed in previous chapters, PhotoScan uses algorithms to create geometrically accurate dense point clouds from the pixel information in multiple images. The necessary semi-automated steps taken to create the resulting I3DMs of sites are collated from the Agisoft PhotoScan Professional User Manual 1.2, Yamafune’s (2016) ‘Using Computer Vision Photogrammetry to record and analyse [sic] underwater shipwreck sites’ and Paul Bourke’s ‘Workflow for reconstruction using PhotoScan: a beginner’s guide’ (2013). Other sources are also included but were less significant (Bruno et al. 2015; Capra et al. 2015; De Reu et al. 2014; De Reu et al. 2013; Demesticha et al. 2014; Diamanti and Vlachaki 2015; Henderson et al. 2013; McCarthy 2014; McCarthy and Benjamin 2014).

4.2.2.1. Alignment of images

The first step when processing data is the alignment phase. The camera position and orientation for each image is determined, while a sparse point cloud is created (Yamafune 2016). PhotoScan uses the principles of Structure from Motion (SfM) to assess the internal camera orientations such as principal distance, point location, skew and distortion.
coefficients (Agisoft 2016:11; Plets et al. 2012a:887). The recommended settings for aligning images are displayed in Figure 42 (note: for each setting in the results chapter this could be adapted dependent on requirements for individual site recording and output).

Figure 42. PhotoScan window for alignment settings.

‘Accuracy’ in the camera alignment phase relates to the accuracy to which each camera position is established. Selecting the highest setting will increase processing time exponentially, whereas the lowest setting is relatively quicker and gives approximate positions for the camera (Agisoft 2014:8; De Reu et al. 2013:1111; Plets et al. 2012a:887). The implications of selecting high, medium or low throughout the stages in PhotoScan are essential to highlight. As stated above, selecting the highest setting for the accuracy of the camera alignment phase will result in a longer processing time. This is due to the program taking more time to process and ensure that the highest level of accuracy is achieved for each camera that it aligns. While this is ideal, in terms of the level of detailed recording and spatial accuracy that we are attempting to achieve, it also implies that the final model itself will be a larger file altogether. For final I3DMs to be used and opened by others, it is essential that the files can be opened on other standard computers. Consequently, although the best outcome is the highest level of accuracy and detail represented in an I3DM, there are choices to be made about the level of settings selected throughout each phase of P3DM. In this case, Bourke (2013) recommends starting with medium accuracy for all camera alignments. The next setting, ‘pair pre-selection’, relates to PhotoScan performing a low-resolution feature match across the whole image chunk as an initial attempt to identify images that match each other before performing a high-resolution feature match. As this adds extensive processing time, and does not particularly perform well, ‘pair pre-selection’ was always disabled for this research.
‘Key point limit’ is an essential setting to understand as it can significantly affect the output of a point cloud. The ‘Key point limit’ refers to the limit of matching points for every image (e.g. 0 allows PhotoScan to find as many points as possible but can result in many unreliable points (Agisoft 2016)). Initial alignments used a ‘Key point limit’ of 200,000 and adapted as needed (Bourke 2013). The ‘Tie point limit’ also affects the number of matching points for the camera alignment phase. It represents the upper limit of matching points for every image, having a ‘tie point limit’ of zero means that there is no limit for matching points in any image. The recommended setting for ‘tie point limit’ is 4000 (Agisoft 2016; Bourke 2013). Lastly, selecting ‘constrain features by mask’ allows areas that have been manually masked to be excluded from the feature detection procedure (Agisoft 2016:13) (note: for both Batavia and James Matthews masking was only used with legacy data).

The image alignment phase calculates the image (‘camera’) positions and produces a sparse point cloud for use in the subsequent processing steps to create new, more detailed data. The sparse cloud is not directly used in the next PhotoScan processing stages. It merely represents the image alignment, but the sparse point cloud can be used to visually determine the success of the image alignment and quickly identify major errors. The core aim of this phase is to accurately align the cameras, which is the basis for construction of the dense cloud and the mesh (Agisoft 2016:v).

4.2.2.2. Building a dense point cloud

Creation of a dense point cloud is the second step in the modelling process. The dense point cloud is based on the estimated camera positions and created using depth information that forms the basis of the geometric information in a 3D reconstruction (Agisoft 2016:13). In the case of building the dense point cloud, the ‘quality’ setting is nonlinear, consequently increasing the processing time massively when set on high and ultra high (Agisoft 2016:14). Although, the higher the ‘quality’ setting the more detailed and accurate the geometry in the resulting dense point cloud becomes. There are similar processing time implications using different ‘quality’ settings as there was with ‘accuracy’ settings in the camera alignment step. It is important to remember that the ultrahigh setting processes the original images, anything lower than this reduces each image size by a factor of 4 (e.g. for downscaling by a factor of 4, an image is minimized 2 times on each side) (Agisoft 2016:13). A ‘medium quality’ dense point cloud was selected for all models
in this research, as this enabled adequate detail and geometry while also maintaining a reasonable processing time and size of the final model (Figure 43).

![PhotoScan window for dense cloud settings.](image)

**Figure 43.** PhotoScan window for dense cloud settings.

The ‘depth filtering’ setting relates to the calculation of depth maps for every image and can be set to mild, moderate or aggressive. If the reconstruction contains small-scale detail that needs to be distinguished, then this should be set to mild. On the other hand, large-scale (i.e. approximately 10 metres or more, where small details are not necessarily required) areas should have aggressive selected here to reduce processing time (Agisoft 2016:14). Due to some poor quality images (poorly focused, noisy etc.), there can be many outlying points in the dense cloud. A further recommendation is to use the cropping tools at this stage to remove unwanted, unreliable points from the cloud before moving onto building the mesh (Agisoft 2016:15).

### 4.2.2.3. Building the mesh cloud

Building the mesh is an intensive stage for computer processing time. The outcome is dependent on image quality and resolution as well as the amount of the images. For this step, PhotoScan uses the dense multi-view stereo-matching algorithm (DMVS) (Koutsoudis et al. 2014:73-4). The geometric mesh output looks like a polygonal mesh visualised as a wire frame model, and the more polygonal structures in the wire-frame mesh, the better the recorded geometry and the more accurate the mesh representation (Koutsoudis et al. 2014:73). To build the mesh there are two options, either the sparse point cloud or the dense point cloud. Sparse cloud is only selected when a quick, preliminary model is needed (e.g. in the field). On the other hand, choosing the dense cloud ensures a higher quality mesh, but also incurs longer processing time. In this research, the dense point cloud was always selected to create the mesh in order to produce the most geometric information.
Choosing an appropriate surface type for the area modelled depends upon the kind of site, object or structure and affects the final mesh creation. ‘Arbitrary’ should be selected for statues, buildings and other closed objects, as it means the program does not make any assumptions on the digital model but, it does result in higher memory consumption (De Reu et al. 2013:1111). The opposite applies for ‘height field’, used for large terrain or base reliefs and aerial photography, as it reduces the amount of memory consumption and allows processing of larger data sets. ‘Arbitrary’ was selected for this study so that the final result has the highest accuracy in representing the real site.

Two specific settings influence the final appearance of the mesh: ‘the polygon count’ and ‘interpolation’. The number of polygons in the final model affect the detail and accuracy of the geometry presented in the model. For example, too few polygons and the resulting mesh will be rough and unreliable, too many and the file will be overly large, potentially creating viewing issues in other software at a later date (Agisoft 2016:16). Medium or high is selected for most of the models produced in this study. The second setting, ‘interpolation’ allows PhotoScan to infer data in the form of a circle around each point, smoothing out any potential holes and allows a full final mesh (Agisoft 2016:16). Enabling ‘interpolation’ means that the final model is not correctly represented by the dense point cloud data but a complete mesh is more likely.

This is taken to the next stage with ‘extrapolation’, which means there are no holes in the final mesh. For archaeological representation, this should be set to ‘disabled’, as when possible we do not want to create false data. Conversely, there may be times when the I3DMs are not complete enough to use for research without potentially selecting ‘interpolation’ or ‘extrapolation’ (e.g. noisy images, lack of overlap etc.). The settings generally applied in this study are shown in Figure 44. Lastly, the settings for point classes refer to the optional creation of a Digital Terrain Model (DTM), Digital Surface Model (DSM), or other variants of a Digital Elevation Model (DEM).
4.2.2.4. Decimating the mesh

One essential aspect to complete in between the mesh and texture building phases is reducing the size and complexity of the mesh. This step is called decimating the mesh and should be completed on a copy of the original model. It is performed to ensure that the model can be used and viewed on multiple platforms. For example, PhotoScan (2016:61) notes that the decimation tool is ‘…used to decrease the geometric resolution of the model by replacing high-resolution mesh with a lower resolution one, which is still capable of representing the object geometry with high accuracy’. Essentially, this means that the large size of the original mesh often created by PhotoScan can be reduced in size to produce a model that can be handled/displayed more easily. This step is performed before building the texture map on I3DMs for decimation of information.

Although it is desirable to retain as much of the original geometry as possible, the size of the final models (both Batavia and James Matthews) proved to be too large to work with in PhotoScan, let alone in other programs (although this can be a factor of poor computer processing power). PhotoScan (2016:61) specifically recommends that for general use the models should be reduced to 100,000 – 200,000 polygons (this is sufficient for exporting as PDFs and more than needed for use in programs such as Google Earth). In this case, the decision was made to use 200,000 – 600,000 for the polygon count (often reducing from polygons in the millions). A high polygon count could also allow higher accuracy measurements to be performed from the I3DMs if needed. Despite simplifying the geometry of the final mesh to export the I3DM to other software and view quickly, the early stages of processing should still be completed at a higher level. Firstly, recording images with the best possible level of detail ensures that a user in the future will have access to high-quality legacy data. Secondly, higher detail in the camera alignment, dense
cloud and initial mesh provides insight into the level of detail attained from the images. This pre-decimated model should always be saved for detailed reference and future modeling uses.

4.2.2.5. Building the model texture
This stage of the process relates to the aesthetic visual quality of the final P3DM. Unlike the mesh stage, the texture mapping stage creates a 2D surface from the images and wraps it over the 3D model. As PhotoScan (2016:16) notes this stage is really to enable a ‘nicer’ final result and can be deceiving as more geometry seems to be apparent). Ultimately, this is what give the final model a realistic appearance and ‘finishes’ the modelling process. A description of the settings selected and context are shown in Figure 45.

![Figure 45. Settings used for texture building.](image)

The ‘mapping mode’ allows the final texture to be mapped in different ways. ‘Generic’ was selected here as PhotoScan creates the texture map as uniform as possible without any predetermined assumptions (Bourke 2013). Regarding the flat and oblique surfaces, the mapping mode can also be set to ‘Adaptive orthophoto’, which splits them into different texture maps for the final output. Another option, ‘orthophoto’, creates a high-quality texture for an orthographic projection, but limits the vertical surface data in the 3D model (Agisoft 2016:17). The second setting is ‘Texture size/count’; this determines the size of the texture pixels and the higher this is set, the better the resolution for the final texture map. For an archive quality ‘texture, size/count’ should be set to 4 x 4092 (Agisoft 2016:17). Lastly, there is an option to complete ‘colour correction’ at this texture mapping stage. For this study it is unnecessary as any correction was completed at the image uploading stage.
In addition, selecting ‘colour correction’ within the texture mapping of the PhotoScan process also drastically increases the processing time.

4.2.3. Legacy data P3DM
The significance of using legacy data for P3DM was introduced in Chapter 1 and explored throughout Chapter 2. The following section outlines the recommended method for applying PhotoScan to legacy photographic data, in the form of black and white photographic negatives. The legacy data for *James Matthews* includes a collection of black and white negative film, colour negative slides and digital photography stored on the WA Museum server (see Chapter 5 for details). Addressing the *James Mathews* legacy data aimed to determine if a P3DM approach could be successful in providing an enhanced medium for viewing legacy data. The primary focus of this study was to use the black and white negatives from the 1976 photomosaic of the complete uncovered hull remains during large-scale excavation. The process involved scanning the original negatives to digital TIFF image files and testing the success of P3DM using PhotoScan.

As these images were not originally made with the aim of P3DM, there is the potential for limited overlap between images and capture of vertical data. A further possible limitation is the characteristic of negative filmstrips employed at the time: images were limited to between 20-36 per roll of film. The means that there may not be the required amount of image overlap that is recommended for adequate reconstruction with PhotoScan for the amount of images covering a site of 25 m x 8 m.

Despite these factors, creating a P3DM from legacy data provided an insight of what the excavated hull looked like in three-dimensions, a benefit that cannot be overlooked. The overall processing stages within PhotoScan did not differ from the above laid out steps unless certain aspects fail. One different process was the masking out of structures, features and aspects within each photograph that were moved, or could hinder the camera alignment process.

4.2.3.1. Masking legacy images
Unwanted data in each image can be masked so that it is not included in the following stages of 3D reconstruction: image alignment, building dense point cloud, building the texture map and creating orthophotos. In this study, the rigid grid frame used to excavate *James Matthews* was manually masked out of a set of images as a test to determine if this would help or hinder the camera alignment stage (note: the results are discussed in
Chapter 5). Masking at this level ensures that the detected camera positions and sparse point cloud ignore the repeated grid frame in each image (Bourke 2013). The settings selected for masking out the features at different stages are given in Table 5.

**Table 5. PhotoScan settings to mask features from image alignment.**

<table>
<thead>
<tr>
<th>PhotoScan setting</th>
<th>Description for use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>Medium</td>
</tr>
<tr>
<td>Pair pre-selection</td>
<td>NA</td>
</tr>
<tr>
<td>Key point limit</td>
<td>200 000</td>
</tr>
<tr>
<td>Tie point limit</td>
<td>4000</td>
</tr>
<tr>
<td>Constrain features by mask</td>
<td>YES</td>
</tr>
</tbody>
</table>

4.3. Data post-processing

The final stage of working with the data covers all aspects of visualisation involving the model created within PhotoScan. This encompasses decimating mesh, exporting the P3DMs and orthophotos, and the creation of DEM’s for further use within archaeological research.

4.3.1. Creating a DEM

Creating a DEM allows the height profiles of vertical structures to be determined from the dense point cloud data. When deciding on the input source data for creating a DEM, it is important to select the dense point cloud. This ensures that the most geometric information is converted into the DEM. If necessary, a test DEM can be created from the spare point cloud as a preliminary check for the level of coverage in the likely output of the final DEM. In terms of the settings for this stage, interpolation is related to the level of accuracy in reconstruction. When disabled this means that the results are as close to reality as possible. However, PhotoScan recommends enabling interpolation to create the DEM from all areas of the structure visible in at least one image (Agisoft 2016:53).

4.3.2. Creating orthophotos

Orthophotos are possible as a 2D representation for publication and use in other non-3D formats (e.g. slide presentations, magazines, newspapers, poster etc.) [See Chapter 1 for a detailed description of orthophotos]. This is similar to the conventional photomosaics used in archaeological work and described in detail in Chapter 3. However, Yamafune (2016:20) notes that orthophotos are more accurate than conventional photomosaics as there is no perspective distortion from single images and the overall image is to scale. An orthophoto can also be geo-referenced within a GIS program if the known coordinates are entered in...
the dimension parameters. This type of image is still generally preferred for archaeological reports and provides a valuable site reference. The settings used are described in Figure 46.

The surface selected to create the DEM from can easily be based on the DEM or the dense point cloud. Selecting the dense point cloud can further reduce processing times, as the mesh does not have to be created. However, if the coordinates to reference the DEM are not known then select mesh for this step. The **Blending mode** refers to the overall blending of pixels across the orthophoto and is generally set to the recommended Mosaic (default). This setting separates several frequency domains, which are then blended independently to reduce overall model blending. Once again **colour correction** is an option when creating the orthophoto. If selected, this setting can be useful in varying exposures between images; however, it adds exponential time to the processing phase. **Colour correction** was disabled for this study, as images were either pre-processed for colour correction or, did not need colour correction due to the amount of sunlight and shallow depth of water. The pixel size was left as default; in this case, it refers to the ground sampling resolution. Lastly, the **Maximum Dimension (pixel) parameters** relate to the maximum size of pixels for the final raster and were also left on default. Different forms of the orthophotos were
exported for use in this study. The large, highly detailed TIFF format was complemented by a compressed JPEG version and a GeoTIFF with the coordinates added for potential use within GIS software.

4.3.3. Exporting the models
Exporting the final I3DMs from PhotoScan into a format that can be used within other software ensures that the model can be opened, viewed and investigated by others who do not have a licence for PhotoScan. Meshlab™ is an open-source software for processing and editing 3D triangular meshes and was selected as the external software to view the models for this research (Yamafune 2016:93). Meshlab™ is applied within numerous archaeological and cultural heritage projects for viewing, colouring and editing point clouds and meshes (Cignoni et al. 2008). Further, the fact that it is free and available for both Mac and PCs increases the application and use for others to view the eventual models. Exporting the final model to be used within Meshlab™ is completed through the following stages in PhotoScan.

The export option is in the main File Menu in the program window, select export model into the form of ‘OBJ/FBX/KMZ’. This enables the OBJ format for Meshlab™. The following options in export parameters are generally acceptable for the P3DMs for both Batavia and James Matthews. Vertex Normals are a replacement projection of the original geometry, allowing for a smaller file size. For this study, Vertex Normals were selected when exporting the OBJ format model. The export texture should be chosen with JPEG as the output – although portable networks graphics (PNG) and TIFF formats are also available – and at least a precision of 8. It is essential to keep the files created through exporting an OBJ together. The following files are created: Example.obj, Example.mtl, Example.jpeg, Example1.jpeg, Example2.jpeg, Example3.jpeg etc. An OBJ is a plain text file that consists of a list of vertices, normal texture coordinates and a description of the triangular faces. The MTL file describes the material properties of the triangles, the MTL file is linked to the JPEG files that contain the texture (Dell’Unto et al. 2015; Diamanti and Vlachaki 2015; Koutsoudis et al. 2014; McCarthy and Benjamin 2014; Skarlatos et al. 2012; Van Damme 2015). These files can easily be compressed into a zipped folder for dissemination.

Lastly, there is the problem of including details about the processing of I3DMs within documents and publications. Further detailed discussion about the issue of how to communicate these details will occur in Chapter 6. For this thesis, the following caption,
‘Output’, is included with all figures to provide information about the processing stages and resulting detail and quality of the I3DMs, for example “[Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)]”. Each aspect of this caption refers to a part of the P3DM process and resulting output. The term ‘Cameras’ refers to the amount of images that aligned. ‘Markers’ indicates the amount of point markers included. Tie points are identified by ‘TP’ and describe the amount of points identified in the sparse point cloud, subsequently, ‘DC’ refers to the amounts of points identified in the dense point cloud. The final aspect, ‘Pol.’, describes the amount of polygons created in the I3DM mesh. A higher number for ‘TP, ‘DC’ and ‘Pol.’, indicates more detail and higher quality the model but, also the larger the model file.

4.4. Summary
This chapter outlined a method for P3DM of underwater shipwreck sites in Western Australia based on the review of previous archaeological applications. It presented the consideration of a range of studies that employed PhotoScan and results created previously by other archaeologists dealing with P3DM. PhotoScan was selected as the software program to use throughout the processing stages primarily because it is user-friendly, semi-automated and produces reliable results. The technical settings and specific terminology associated with P3DM were discussed about both PhotoScan and use within this project. In summary, there are four main aspects that should be addressed when applying P3DM to an underwater site: camera equipment, reference system, acquisition method and camera settings. Likewise, the second stage, data processing, can be broken into three core stages: pre-processing images, creating an I3DM and exporting/post-processing. The following chapter describes the results of applying the method outlined here to the two case study sites.
5. Applying P3DM to underwater archaeological sites

Two shipwreck sites were recorded using P3DM: *James Matthews* (1841) — located in shallow sandy seabed near the Perth metropolitan area; and *Batavia* (1629) — located on a dynamic reef in the Midwest of WA. Both present different challenges for archaeological recording, while also enabling a comparison of the reliability and applicability of P3DM to varying site conditions.

Initially, I present the historical and archaeological background to the *James Matthews* shipwreck, including the current physical status of the site. Next, I explain the legacy photographic recording approach during the 1970s excavation before detailing the method related to the use of the legacy photographic data for P3DM and the results. I finish described the results of the *James Matthews* case study by describing the outcomes of my own P3DM recording and processing. The last half of this chapter covers the result of the *Batavia* case study. Similarly to *James Matthews*, I begin by outlining the historical and archaeological background of the site. Then I describe the results of the two dives completed on the site and the P3DM processing into final I3DMs.

Throughout this chapter, I present the results of refining a method to P3DM underwater shipwreck sites in WA marine environments. This includes highlighting the issues and limitations encountered when incorporating legacy data (*James Matthews*) and exporting the I3DMs, orthophotos and DEMs for both sites. Where relevant, Appendices C and D contain other extensive results and are referred to throughout this chapter.

5.1. *James Matthews* (1841)

The first case study site, *James Matthews*, was selected due to it being located close to Perth and its accessibility. Additionally, the WA Museum has a long history of recording the site and it is subject to ongoing research. Although all of these factors initially appealed to this study, a challenge arose in the proximity of the shipwreck site to a sand dredging facility. Consequently, the 2-3 m water column was regularly cloudy and the reduced visibility was unsuitable for photographic recording. Accordingly, diving worked around a schedule with both the operations of the sand dredge and reasonable weather.
James Mathews also represents an excellent case study site regarding maritime cultural heritage. It has an interesting history, combined with an extensive archive of excavated material culture and documentation along with ongoing testing of site preservation methods. This site is a subject to ongoing archaeological and conservation research by the WA Museum, enabling the potential to visit it in the future to complete additional P3DM.

5.1.1. Historical background

James Matthews was built in 1800 in France as Le Voltigeur (Henderson 2007:245). Historical sources describe it as a 107 ton, brig-rigged vessel with two masts, one deck, a square stern and a standing bowsprit (Table 6 and Figure 47) (Henderson 2008a:230). In the early 1800s, it was owned by the infamous Portuguese slaver, Don Francisco, and renamed Don Francisco. At that time the vessel operated in the illegal slave trade out of Africa and the West Indies. In 1837 it was captured by the 10-gun British sloop, HM Griffon, off the coast of Dominica in the Caribbean (Henderson 2007:242-3), and subsequently sold at auction. The vessel was renamed James Matthews after one of the new owners (McCarthy 2012:96). From 1837 to 1841 James Matthews was employed in the Atlantic trade.

Table 6. Data collated from (Henderson 2008a).

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>James Matthews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonnage</td>
<td>107 tons (UK ‘long ton’)</td>
</tr>
<tr>
<td>Length</td>
<td>80.2 feet [24.5 m]</td>
</tr>
<tr>
<td>Beam</td>
<td>21 feet [6.4 m]</td>
</tr>
<tr>
<td>Depth</td>
<td>11.5 feet [3.5 m]</td>
</tr>
<tr>
<td>Decks</td>
<td>One</td>
</tr>
<tr>
<td>Masts</td>
<td>Two</td>
</tr>
<tr>
<td>Carvel/Lapstrake</td>
<td>Carvel</td>
</tr>
<tr>
<td>Galleries</td>
<td>None</td>
</tr>
<tr>
<td>Stern configuration</td>
<td>Square</td>
</tr>
</tbody>
</table>
In 1841, Irish brothers Henry and Robert de Burgh purchased *James Matthews* at auction. On 24 March 1841, under the command of Captain Edwards Roberts, *James Matthews* set sail from London to Fremantle with four passengers (including the de Burgh brothers), a crew of 15 and a cargo of 7000 slate tiles and general farming equipment (Henderson 2008a:231). By the 18th of July they sighted Garden Island, just off the coast of the Swan River Colony. On the 19th of July, *James Matthews* was manoeuvred inside Cockburn Sound at Owen Anchorage where, three days later, an intense storm hit the coast at approximately 12:30 am (Henderson 2008a:244). The vessel began to drag its anchors and hit the shore heavily, quickly sinking (McCarthy 2012:102; Richards 2012:171).

5.1.2. The site

*James Matthews* is located in 2-3 m of water, approximately 100 m north of Woodman Point in Owen Anchorage, approximately 12 km south of Fremantle (Henderson 1975; Richards 2012). The marine environment consists of a sandy, flat seabed with gradually changing colonies of sea grass (*Posidonia australis*) and other marine flora. The site is protected from south-easterly winds but is sometimes subjected to the north-westerly winter swell. Visibility varies during both winter and summer depending on the wind direction and operation of the nearby dredge (Figure 48).
The shipwreck is lying on a north-south axis with the bow pointing towards the shore (Figure 49). The preserved wooden structure consists of almost the entire port side of the vessel, including the keelson, parts of the rudder, sternpost, stem, and mast steps (Baker and Henderson 1979:236). Notable features currently visible on the site include: the remains of the windlass, iron deck supports on the western side and a large mound of slate tiles situated towards the stern (Kenderdine 1995).
5.1.3. Archaeological background

The Underwater Explorers Club (UCEC) of WA located the shipwreck site on 22 July 1973 (Henderson 2008a:39). Over the summers of 1973–74 and 1974–75, WA Museum staff and UEC volunteers conducted two short excavation seasons (Baker and Henderson 1979). The first season involved a triangulation survey conducted by UEC, and the second included a brief initial excavation by the WA Museum to remove 4000 slate tiles from the surface and determine the extent of the preserved structure underneath (Henderson 1975:42).

There were two subsequent excavation seasons, 1975–76 and 1976–77. In 1975, extensive excavations removed the remaining cargo and thoroughly recorded the hull remains with both photogrammetry and manual measurements. Poor visibility ensured that the majority of recording had to be completed manually, as photography was often unsuccessful (Henderson 1975:43). A rigid grid — based on those employed at Yassi Ada (Chapter 3) — was constructed from square, hollow steel pipes and laid out to cover 6 x 30 m over the entire site. Additionally, the archaeologists built a mobile 6 x 1 m grid square used for recording sections across the site (Henderson 1976:3). The grid was moved metre by metre to gradually record the entire 30 x 6 m site (Baker and Henderson 1979:233).
Despite the occasionally limited visibility, photography formed an integral part of the hull recording (Henderson 1976:5). The 1970s excavations of *James Matthews* present a valuable legacy of photography and stereo-photographic archives. A range of varied photographic techniques were applied during the excavation seasons to record: the overall site, daily photographic record of work, close-up recording of objects in situ and above water, and, horizontal and vertical stereo-photography (Baker and Henderson 1979:238). All photography employed Nikonos underwater cameras with 15 mm water correcting lenses throughout the excavation seasons (Baker and Henderson 1979:239).

Several reasons contributed to the employment of multiple photographic approaches on *James Matthews*. The already highlighted limited visibility was a primary challenge. Additionally, the combination of shallow water and high relief hull structure posed potential limitations for photographic recording as the camera to object distance could change rapidly across the site. Consequently, variation in scale between image sets prevented photographic runs from successfully joining as a whole site photomosaic (Baker and Henderson 1979:241). Stereo-photography was employed for recording the site photomosaics for each 6 x 1 m grid (Baker and Henderson 1979; Henderson 1976). The team constructed a steel photo-tower in the style of a pyramid with a base area of 2 x 2 m and a height of 1.4 m (Baker and Henderson 1979:239). At the apex of the photo-tower, two Nikonos cameras were attached 25 cm apart to a horizontal bar. The bar also had a circular bubble level to ensure that the bar was horizontal when recording images (Baker and Henderson 1979:239). The photo-tower was moved across the site taking overlapping images at 0.5 m intervals, resulting in coverage of 60% overlap between image pairs and minimal 50% coverage with the adjoining image sets (Figure 50) (Baker and Henderson 1979:239).
Figure 50. Diver operating the stereo-photogrammetry tower (WA Museum).

Unfortunately, it was not possible to create a single photomosaic of the whole site due to the different scale of an image between high and low relief areas (Baker and Henderson 1979:241). Attempts were made to change the magnification of a photographic negative when printed that did provide a more constant scale of a photomosaic, but the overall site still could not be compiled into one single image (Baker and Henderson 1979:241). To alleviate this problem, Baker and Henderson (1979:239-40) state that the stereo-pairs were used to create photomosaics of each single run across the 6 x 1 m grid. These photomosaic strips formed an additional integral set of information for the site plan and were used to double-check the manual measurements and help with complex features when compiling the final site plan (Baker and Henderson 1979).

Stereo-photogrammetry was also employed to ‘…explore the feasibility of gaining accurate measurements by using photogrammetric three-dimensional mapping techniques on shallow water high relief wrecksites, in water of poor or moderate visibility.’ (Baker and Henderson 1979:237). Although nothing further was published on photogrammetric measurements from the stereo-photographic pairs, a preliminary museum report noted that stereo-photography was ultimately only an interpretive guide and could not give the mapping accuracy necessary for the final site plan (Baker and Henderson 1979:238).
Nevertheless, it did prove valuable in aiding the overall interpretation and as a reference when drawing up the final plan (Figure 51) (Henderson 1976:5).

![Image](image.jpg)

**Figure 51.** Mapping out the site plan from scale measurements and photomosaic strips (Henderson & Baker 1976:235).

Notably, stereo-photography was also used to record artefacts *in situ*. Apart from the single camera photographs of artefacts, oblique and horizontal stereo-pair images also recorded complex artefacts and structural remains (Henderson 1976, 2008b). Due to limited visibility, understanding the dimensions of an object was completed by viewing image pairs with a mirror stereoscope (Baker and Henderson 1979:240). Also, seeing the stereo-pairs in 3D provided archaeologists with an enhanced view of the relief and perception of lay out, and a better understanding of the intricate nature of any particular artefact or part of the hull (Henderson 1976). Baker and Henderson (1979:240) gave the example of viewing the bulwarks in stereo, which was often easier to interpret than from the measured site plan. Both a single camera and the stereo-pair attached to the horizontal bar were employed for the detailed stereo-photography of individual site elements (Baker and Henderson 1979). The stereo-pair cameras were still placed at the 25 cm interval from the photomosaic recording but did not require extra careful orientation and positioning (Baker and Henderson 1979). Only one viewpoint of an object was recorded and in the case of using a single camera, two or three photographs were taken by first taking one image and then moving laterally 15 to 20 cm and recording another image (Baker and Henderson 1979). The ability to revisit an image of the artefact *in situ* and in 3D enabled a deeper understanding when memory faltered. The legacy photographic data collected
during this time is revisited later in this chapter to explore and demonstrate the possible research that can be conducted into the use of legacy data in contemporary underwater P3DM.

Numerous small finds were located throughout these excavations giving significant insight into the items imported at that time and items that migrants brought with them to live in the Swan River Colony. Artefacts included personal items such as a walking stick, umbrella, clay pipes, glassware, ceramics and an ivory chess set (Baker and Henderson 1979). As well as items indicative of the needs of the Swan River colonists, such as tools and items not produced locally at that time (i.e. awls, saws and carpenter’s planes) (Kenderdine 1995:105). Furthermore, this site is well-preserved and represents a unique resource for understanding early 19th-century slave ships. The excellent preservation of the entire starboard side of the vessel is uncommon and further indicates the archaeological value of the site (Figure 52).

![Figure 52. James Matthews site plan with the excavation grid numbers (WA Museum).](image)

At the end of the final season, the excavated site was reburied to preserve the remaining hull structure. From 1977 to the 1990s, the site remained adequately covered by sediments, however, the slate mound and iron frames were never buried quite as deeply as the hull structure due to oscillating exposure and had as a result suffered greater deterioration (Henderson 2008a:43). In 2000, a site inspection revealed that the timbers at the stern and bow were exposed and severely degraded by teredo worm (Richards 2012). To combat the degradation of the site, the Material Conservation Department at the WA Museum worked over the subsequent years to test methods of reburial and preservation. This included temporary reburial using cotton and polymeric sand bags, fake sea grass mats and shade clothes to catch sediment (Richards 2012:172).
In November 2013, a large-scale operation took place to surround the remaining structural site with ‘road crash’ barriers to create a cofferdam that would allow for further catchment of sediment — part of the Australian Historic Shipwreck Protection Project (Richards 2011, 2012). As necessary, selected objects previously fixed to the site to aid in preservation were removed, such as loose sandbags and geotextiles, before placing 36 road crash barriers around the site. Each barrier was weighted down with approximately 120 kg of blue metal stone and set 0.5–1.0 m away from the site in an elliptical formation, Figures 53 and 54 (Veth et al. 2016). The team dumped 20 cubic metres of clean sand into the middle of the site to begin the reburial process. An ultra violet (UV) resistant shade cloth was later stretched and secured over the top with the aim of catching sediment from the water column inside. Unfortunately, in 2014 a storm tore off the shade cloth and damaged the northern barriers. New barriers were inserted, with a greater amount of blue metal content added. In the future it is the Museum’s intention to cover the entire site with shade cloth at a level closer to the seafloor. The cofferdam reburial of James Matthews is an ongoing project that requires regular visiting and monitoring but also enables periodic visits to the site for photographic recording.

Figure 53. Surface view of the road crash barriers encircling James Matthews (WA Museum).
5.1.4. Results of James Matthews legacy data P3DM

Incorporating legacy images in this research presents the opportunity to explore a wealth of archaeological information from the 1970s to the present day. In this case, the main legacy data used in my research are the black and white digital copies of negative slides from the excavation of James Matthews (1976/1977). The collection of James Matthews excavation legacy images (both original negatives and digitised versions) is housed in the Maritime Archaeology Department at the WA Museum. Table 7 outlines the general black and white images relating to the underwater work on James Matthews and their description as per the Museum image catalogue. Research into the history of archaeological excavation and recording of James Matthews indicated that photographs for the photomosaic recording of the site were taken in transect strips cutting the site in an east-west direction that correlated to the moveable grid frame. In order to have the greatest possibility of success with processing image sets through PhotoScan, this study selected the film numbers associated with overall site recording, such as photomosaics and stereophotogrammetry. A total of 38 negative folders included the photomosaic images that recorded grids 3–27 (Table 7).
After consulting the catalogue, a search of the Maritime Archaeology image server and the B&W negative scans digital storage folder, revealed that many of the negatives were previously scanned, however only as a JPEG format. Furthermore, many contextual details were not described in the catalogue as part of the scanning process. Although PhotoScan has the capability to use JPEG format for processing, the recommended image format is either TIFF or PNG to provide the most detail without compression of images.

To test this, a selection of image strips was first processed as JPEGS to test the validity of rescanning a large portion of the images in a new format. The JPEG images would either not align at all or, if they did, the overall spatial dimensions of the resulting point cloud...
seemed to be incorrect or unidentifiable. Given this result it was decided that the original negatives were rescanned to investigate the alignment issues, saving them as TIFFs rather than JPEGS. Once again these were processed and the results demonstrated that some of the image sets were aligning and giving a comprehensible 3D representation of the site as it was during the excavation in the 1970s.

Due to the analogue camera equipment employed in the 1970s a much smaller set of images existed, when compared to the larger numbers of images typically generated with digital photography. As a consequence only a small amount of legacy images existed and this fact unfortunately decreased the potential likelihood of overlap between image sets. In comparison with a large number of digital images available through current photographic equipment, successful P3DM was not expected from the sets of 15-40 images per excavation grid. Consequently, the generation of any P3DM results from the legacy data was itself considered a good result. Visual inspection of the images indicated that there was enough overlap in some areas, particularly in the middle of the site, to warrant testing within PhotoScan.

After investigating the digital and negative archives, the negative sets chosen for this research were all rescanned (see Appendix C For the list of re-scanned images). The descriptions provided on the negative envelopes in storage indicated that not all of the grids across the site were recorded. For example, grid numbers 1, 2, and 3 are not in any of the image files. This is most likely because the grids 1, 2 and 3 cover one end of the site with a minimal, or no amount of structure remaining. Fortunately, when each image folder was scanned and compared to site plan, the areas covered by grids 1-3 were visible throughout the overall image sets.

5.1.4.1. Pre-processing: masking the legacy images

Some pre-processing issues were addressed before beginning the P3DM. The first was that in every image the moveable grid was present to aid manual recording and excavation throughout the entire project. Potentially, this could interfere with the overall processing if all images were processed as a complete chunk. The same grid frame could appear in different areas of the site. An initial test processing the full set of images together was unsuccessful. This failure indicates a complete site model of James Matthews is only possible by separately aligning and processing image sets before merging. Despite this, image set 489 was used to mask out the grid frame present in each image and test the effect on the final I3DM (Figure 55).
The first step was to complete image alignment without masking at the recommended settings from Chapter 4. Although 19 of 20 images aligned, which seemed successful, only 6,884 points were determined, and the overall appearance of resulting sparse point cloud did not resemble any coherent form. A further alignment stage was completed this time raising the accuracy to high instead of medium. The results at a higher accuracy were much better, and a visual inspection identified features such as the grid itself, and the curve of the hull, as well as outlines for the wreck structure (Figure 56) (Table 8 is of the subsequent processing stages of the unmasked images from set 489).

**Table 8.** Results from the high settings for camera alignment.

<table>
<thead>
<tr>
<th>Agisoft PhotoScan data</th>
<th>Unmasked - high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameras (Cameras aligned)</td>
<td>19/20</td>
</tr>
<tr>
<td>Tie points (points)</td>
<td>15,636</td>
</tr>
<tr>
<td>Dense cloud (points)</td>
<td>4,303,484</td>
</tr>
<tr>
<td>3D model (faces)</td>
<td>286,897</td>
</tr>
</tbody>
</table>
Figure 56. Image set 489 unmasked high - showing more success in aligning the images [Output: Cameras (19/20), TP (15,636), DC (4,303,484), Pol. (286,897)].

For comparison, the grids were masked out of each image and the initial medium settings were applied once again. As before 19 of 20 images aligned and a slightly higher amount of points were reconstructed (7,836) but, once again, the resulting sparse 3D point cloud had no comprehensible visual form and failed to present a logical model (Figure 57). This was repeated at the high setting to determine if a higher amount of points was also possible with the grids masked. The results at a high setting were also disappointing. A total of 19 of 20 images aligned with the final sparse point cloud reaching 12,744 points. Despite the increase in sparse points, the resulting 3D structure was also unrecognisable (Figure 58). Consequently, masking in legacy images employed to improve image alignment was also unsuccessful. Thus it seemed that the presence of features like the grid in the image aided in aligning the separate image sets.
Consequently the grids were included in all processing stages as they provided a structure for PhotoScan to recognise, as well as a reference for visual confirmation of the accuracy of the final I3DM. For example, a warped grid indicated that the I3DM had not adequately
reconstructed the hull shape. Including the grid within the images often provided a guide to determine the accuracy of the hull shape. A straight grid bar in the I3DM indicates that the reconstructed hull form is visually accurate (Figure 59), although this only suggests at the point cloud reconstruction accuracy. The only masking that did occur throughout the remainder of the processing was to eliminate errors that took place when scanning the negatives, such as white space at the edges that was scanned but does not belong to the actual image (Figure 60).

Figure 59. Indication of a successful reconstruction due to the horizontal accuracy of the grid bar.
Throughout this study, multiple settings and techniques were used to determine the best method for processing the negative strips into I3DMs. For example, this study tested both TIFF and JPEG formats, as well as masking out the excavation grid frames and additional objects (such as divers or floating measuring tapes). The final result was a combination of different file formats and settings. Due to the lack of overlap between images and image sets, only a few negative strips aligned with enough detail to be a reliable and interesting I3DM. The resulting successful merged combinations of image sets are 480, 490 & 495 and, 492, 493 & 494 (Table 9 and Figures 61-67).

The variation regarding file format and success in alignment, are unexplained. It may be a combination of factors such as lack of overlap and noise in each image, JPEG formats may help with alignment in some ways due to the compression of the image, and potential smoothing effect this has on the pixels. On the other hand, the image sets 492, 493 and 494 TIFF formats were more successful. For the remainder of this study, the image sets were scanned at 4500 dpi in a TIFF format without compression for processing and images were processed without additional filtering.
Table 9. Showing the resulting successful image sets and corresponding data results.

<table>
<thead>
<tr>
<th>Details</th>
<th>480</th>
<th>490 and 495</th>
<th>492, 493 and 494</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameras (Cameras aligned)</td>
<td>6/11</td>
<td>32/36</td>
<td>26/83</td>
</tr>
<tr>
<td>Tie points (points)</td>
<td>3,209</td>
<td>12,430</td>
<td>2,504</td>
</tr>
<tr>
<td>Dense Cloud (points)</td>
<td>1,452,530</td>
<td>4,590,926</td>
<td>3,756,402</td>
</tr>
<tr>
<td>3D model (faces)</td>
<td>97,094</td>
<td>306524</td>
<td>231,877</td>
</tr>
<tr>
<td>Image format</td>
<td>JPEG</td>
<td>JPEG</td>
<td>TIFF</td>
</tr>
</tbody>
</table>

Figure 61. Image set 480 final P3DM with texture [Output: Cameras (6/6), TP (6,659), DC (1,059,821)].

Figure 62. Image sets 490 & 495 P3DM (mesh only). [Output: Cameras 35/35, TP (12, 4380), DC (4,536,395)].
Figure 63. Image sets 490 & 495 P3DM (texture) [Output: Cameras 35/35, TP (12, 4380), DC (4,536,395)], Pol. 1,366,193].

Figure 64. Image sets 490 & 495 P3DM texture profile view [Output: Cameras 35/35, TP (12, 4380), DC (4,536,395)], Pol. 1,366,193].
Figure 65. Image sets 492, 493 & 494 P3DM (mesh only) [Output: Cameras (81/83), TP (6,593), DC (11, 266,395), Pol. (2,253,276)].

Figure 66. Image sets 492, 493 & 494 P3DM texture [Output: Cameras (81/83), TP (6,593), DC (11, 266,395), Pol. (2,253,276)].
Ultimately, a small number of the legacy image sets could not be aligned through PhotoScan (see Appendix D). Lack of overlap between images, particularly taking into account the high relief aspects of the hull on the north-eastern side is the likely reason for this failure. This is the same issue that hindered the creation of a complete photomosaic of the site in 1977. Photographs varied from high quality, clear and focused negatives to less focused and with limited overlap per grid. Due to the lack of a complete model, an orthophotograph of the site from 1977 was unable to be exported from PhotoScan.

On the other hand, some image sets successfully processed within PhotoScan. Image sets 488 and 489 aligned as one single chunk at a medium setting. Without any pre-processing, the results from 488/489 indicate that legacy photographic data can be processed within PhotoScan to create accurate I3DMs. The final I3DM of these images represents Grid #10 (includes the edges of 9 and 11) (Table 10 and Figure 68). The grid frame is reconstructed, as a horizontal bar, indicating that the reconstructed hull form is an accurate depiction of the original shape during the excavation.
Table 10. Output data for the Grid #10 I3DM.

<table>
<thead>
<tr>
<th>Details</th>
<th>488/489</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameras (Cameras aligned)</td>
<td>45/45</td>
</tr>
<tr>
<td>Tie points (points)</td>
<td>28,802</td>
</tr>
<tr>
<td>Dense Cloud (points)</td>
<td>4,630,769</td>
</tr>
<tr>
<td>3D model (faces)</td>
<td>926,149</td>
</tr>
<tr>
<td>Image format</td>
<td>TIFF</td>
</tr>
</tbody>
</table>

Figure 68. Grid #10 I3DM [Output: Cameras (45/45), TP (28,802), DC (4,630,769), Pol. (926,149)].

Not all of the legacy photographic data could successfully be processed using P3DM techniques. The results from P3DM the 1970s James Matthews legacy data indicate that the initial processing problems with minimal photographs and potential lack of overlap are not an issue for all of the data. The implications of this success are revisited in Chapter 6 to analyse the effect on the interpretation of the legacy data. It is sufficient just to state here that the success of even one strip accurately aligning enhances the overall understanding of the site, this will be discussed in detail in Chapter 6.

5.1.5. Results of James Matthews P3DM

The contemporary photographic recording of James Matthews occurred over six dives in 2015 and 2016. Different techniques and styles for recording were involved in refining the process for the final P3DM. Ultimately, there were several limiting factors to the methodology and equipment employed but a final I3DM was successfully generated. James Matthews was recorded with the method outlined in Chapter 4. The first five dives
were completed with the Sony RX100 II in an Ikelite housing without an additional wide-angle lens. After reviewing these initial results, a decision was made to change to the WA Museum camera configuration involving a Sony A7 in a Nauticam housing with a Nikonos IV wide-angle lens, (Chapter 4). Table 11 shows the dive dates, camera equipment employed, tasks conducted and number of images captured.

### Table 11. Dives and number of images collected per dive.

<table>
<thead>
<tr>
<th>Dive No.</th>
<th>Site coverage</th>
<th>Technique/equipment</th>
<th>No. Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 3 September 2015</td>
<td>Slate pile and barriers</td>
<td>SONY RX100II manual</td>
<td>382</td>
</tr>
<tr>
<td>2. 12 November 2015</td>
<td>Barriers at bow</td>
<td>SONY RX100II manual</td>
<td>358</td>
</tr>
<tr>
<td>3. 11 January 2016</td>
<td>Bow section – Windlass &amp; barriers, iron frames</td>
<td>SONY RX100II automatic</td>
<td>1509</td>
</tr>
<tr>
<td>4. 25 January 2016</td>
<td>Bow section – Windlass &amp; barriers, iron frames</td>
<td>SONY RX100II automatic + coded targets</td>
<td>1367</td>
</tr>
<tr>
<td>5. 4 July 2016</td>
<td>Stern area, slate pile, wooden structure east side</td>
<td>SONY RX100II automatic + coded targets</td>
<td>1132</td>
</tr>
<tr>
<td>6. 5 December 2016</td>
<td>Complete site</td>
<td>SONY A7 + Nikonos lens, 10 coded targets, scale square.</td>
<td>1326</td>
</tr>
</tbody>
</table>

Numerous issues arose when acquiring quality photographs for a P3DM. Primarily, James Matthews is close to the operations of the Cockburn Cement dredge and the constant dumping and suctioning of sediment in the water, combined with the natural movement of sediment within the bay, results in poor visibility most of the time. Cockburn Cement Company advised that they stop dredging at 1700 on a Sunday and would not recommence until 0900 the next day (Stewart Cramer pers. comm. 2016) providing the best window for diving with acceptable visibility. Consequently, most dives were completed between 0730 and 0900 on a Monday morning to attain the best visibility. The general techniques, equipment and results from each dive are discussed in the following sections.

#### 5.1.5.1. Dive No. 1: 3 September 2015

A primary test run for data acquisition during optimal conditions was completed during this dive. Multiple images were captured on the southern end of the site (for this dive, the slate mound was selected as a targeted test location as it is the most recognisable feature of the site). Data captured included 382 images covering the slate pile and nearby eastern side of the barrier wall. The results revealed that a high level of detail was captured on a smaller scale (i.e. the slate pile in comparison to the entire site) (Figures 69 - 71).
Figure 69. Dense cloud of the slate mound [Output: Cameras (147/147), TP (218,086), DC (19,885,092), Pol. (1,331,184)].

Figure 70. Profile view of the slate mound indicating texture [Output: Cameras (147/147), TP (218,086), DC (19,885,092), Pol. (1,331,184)].
5.1.5.2. **Dive No. 2: 12 November 2015**

The second dive aimed to record the southern end of the site, focusing on recording the bow and windlass, as well as some of the iron deck frames. Visibility was approximately 4 m, which is just suitable for image-based recording of the entire site. However, as the dive progressed, visibility began to deteriorate to the point that diving stopped and photographic recording only captured 25% of the site. A total of 357 images were recorded and uploaded, which is successful given the gradual reduction of visibility. Colour correction was not completed at any stage, as the lighting throughout the dive was good enough to provide consistent colour representation.

Initially, all of the images were processed as one single chunk. Although, the lack of overlap and deteriorating visibility in the images proved to significantly reduce the success of image alignment. The first round of alignment (at the suggested settings) only aligned 33 of 357 images and portrayed a small part area of the site (Figure 72). Subsequent stages were also minimally successful regarding alignment, with the second
attempt only aligning 3 of 325 images (Figure 73). The first attempt at aligning the remaining 321 images at the medium setting only aligned two images. The same chunk was aligned again at a low setting to determine if there was any improvement, this time 33 of 321 images aligned. However, PhotoScan only identified 529 tie points, and the dense point cloud reflected this with a blurred coverage of unidentifiable features (Figure 74). Textures were not created for any of these chunks due to overall unsuccessful image alignment.

**Figure 72.** Chunk 1 [Output: Cameras (33/33), TP (9,651), DC (3,864,129), Pol. (257,603)].

**Figure 73.** Chunk 2 [Output: Cameras (3/3), TP (496), DC (456,272)].
Results from this data capture indicated that although capturing some decent images with four metres of visibility, the reduced visibility proved unsuccessful for processing. The lack of clarity and detail on most features, due to the degrading visibility, and a likely lack of overlap between images resulted in minimal image alignment. Multiple attempts of trial and error to try to get a better alignment outcome resulted in a long post-processing time for this batch of images. The effect of reduced visibility after the second dive meant that all subsequent dives were to be conducted when site conditions were deemed suitable for appropriate image capture.

5.1.5.3. Dive No. 3: 11 January 2016

The next two dives were completed in the middle of summer to utilise weather conditions with a low swell, lighter winds and early, bright sunlight. The third dive employed a 64 GB memory card to increase the minimum limit of images available for capture. The dive took approximately 35 minutes and began at 0800 to ensure that the first incoming dredge load of sand did not affect the visibility of the site (which stayed at 5-7 m for the duration of the dive).

During this dive, the plan was to begin by recording the southern half of the site. As the reduced visibility and lack of overlap from photographic recording during Dive No. 2 resulted in unsuccessful alignment of images, this dive overcompensated by completing...
closer transect swim lines across the site on an east-to-west bearing. A total of 752 images were recorded, saved as original RAW files and converted to TIFF for processing within PhotoScan. The results revealed that narrower transect swim lines provided excellent coverage of the archaeological structures on the southern end of the site. Once again, the images aligned only as separate chunks, with multiple images not aligning at all (Figures 75 - 79).

Figure 75. Mesh for chunk 1 [Output: Cameras (66/66), TP (33,917), DC (7,079,619), Pol. (471,971)].
Figure 76. Texture for chunk 1 [Output: Cameras (66/66), TP (33,917), DC (7,079,619), Pol. (471,971)].

Figure 77. Chunk 2 mesh model [Output: Cameras (548/548), TP (381,850), DC (91,529,641), Pol. (6,129,234) Decimated (599,999)].
Regardless of the increased coverage with this dive, continued attempts to align and merge the separate chunks were unsuccessful. This was the result of a large amount of sparse sandy sea floor from which PhotoScan could not identify tie points. Chunks 2 and 3 are best viewed as the mesh models (Figures 77 and 78). Although texture was created for
Chunks 2 and 3, the clarity was much better in the mesh and dense cloud forms. This result is most likely due to the visibility deteriorating during the dive and the final quality of the original images taken with the Sony camera set-up.

5.1.5.4. Dive No. 4: 25 January 2016

Despite the changes made after the first two dives, further unsuccessful results of the third dive required a reassessment of the recording equipment employed. As visibility and overlap were no longer an issue in the quality of images something else needed to be attempted to improve image alignment. Consultation with the PhotoScan manual indicated that the next suitable phase was to make and employ coded targets based on the PhotoScan manual’s recommendation (although not stated as an essential requirement) (Agisoft 2016:46). As discussed in Chapter 4, the use of coded targets aids PhotoScan in aligning the images. Coded targets were not included in the first three recording exercises in an attempt to determine if the site could be adequately P3DM without the need to place extra reference equipment around the site. This in turn would mean increased dive time.

For the fourth dive, a total of 30 coded targets were printed onto A4 sheets of paper and laminated. The laminated sheets were attached to aluminium plates with heavy-duty electrical tape. Securing the coded targets to the aluminium plates was intended to ensure that they sat on the seafloor without lifting and moving around.

For the dive, a total of ten coded targets were placed around the outside of the barriers on the southern end of the site to test the success of the coded targets on *James Matthews*. Five more were placed on the inside — mostly located over bare, sandy patches. The aim was to start at the bow end of the shipwreck (southern) and work towards the stern in east to west transits (Figure 80). On the dive, swimming was completed slowly and methodically, with the camera set to continuous shooting mode and autofocus. Despite incorporating the coded targets, it was difficult to know if the images contained enough overlap (50-60% vertical and 70-80% horizontal) as the large sparse areas proved challenging to keep track of transit swim lines. Consequently, during the first few minutes of the dive, I decided to re-do certain swim tracks across the sparse sea floor before continuing. Subsequently, a total of 1360 images recorded the entire southern end of *James Matthews* with sufficient overlap. The visibility was excellent for photographic recording (6-7 m) although the sunlight was bright enough to create some reflectance off the coded targets. When this occurred, an image was immediately retaken attempting to reduce the flare of light off the white target with ranging success.
Unfortunately, the flare from the white coded targets resulted in some images having very dark backgrounds due to the automatic white balance setting on the camera. This led to overcompensation of white balance correction and flares of bright light from the coded targets (Figure 81). Unlike the previous dives, these images were run through a colour correcting process using Adobe Photoshop. Due to the high levels of sunlight reflectance off the white coded targets, there were a few images with the darker background. Initially, all of the images were run as a single batch through Photoshop, although some remaining images required individual correction and contrast grading.
Once the images were corrected, they were uploaded to PhotoScan and processed as a single chunk. This time, the success of the first phase was significantly improved in comparison to the previous dives. A total of 1359/1360 images aligned as a single chunk. The following stages of creating a dense cloud and mesh were also successful. The resulting 3D model indicated that the majority of the southern half of James Matthews was successfully processed. Despite the challenges with sun reflectance, incorporating the coded targets proved to be beneficial to align the images. This is best visually assessed through the final orthophotograph (Figure 82) that contains complete coverage of the sparse sandy areas with coded targets, and the areas without are not reconstructed at all. A further dive was required to capture the remaining northern end of the site with coded targets; however, due to availability of the WA Museum vessel and weather conditions, this did not occur until July 2016.
Figure 82. Orthophoto of the bow end with coded targets [Output: Cameras (1359/1360), TP (864,618), DC (140,746,033), Pol. (9,432,131) Decimated (599,999)].

5.1.5.5. Dive No. 5: 5 July 2016

For the fifth dive, the aim was to record of the stern of the site (northern half), including the remaining barriers. Five coded targets were placed inside the barriers to aid with alignment of images during the processing phase. The dive took approximately 35 minutes with a total of 1043 images recording the majority of the northern end of the site. Like the previous dive, the images were uploaded to PhotoScan as TIFFs, and the images aligned as a whole chunk. A total of 907 images aligned successfully in the first attempt (Figures 83-88). Although there was a significant amount of the northern end covered and reconstructed correctly, there were still visible gaps.

The next stage was to see if the remaining 136 unaligned images could be successfully aligned separately. Although, the second round was not as successful as the first, with only small sections of the road crash barriers aligned with minimal discernable 3D
geometry. Dividing the 136 images into smaller chunks improved overall alignment (Figures 77-79). Despite having some low level of success in aligning the remaining images, the smaller chunks could not be aligned to the original chunk of images, designated as ‘Chunk 1’ to avoid confusion. Despite the inclusion of coded targets, there was not sufficient overlap between the all of the chunks to ensure satisfactory image alignment and merging of aligned chunks (Figure 89).

**Figure 83.** Chunk 1 Dense Cloud [Output: Cameras (907/907), TP (368,113), DC (24,944,985)].
Figure 84. Chunk 1 Mesh model HIGH (not decimated) [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (1,668,480)].

Figure 85. Chunk 1 Mesh HIGH perspective view [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (1,668,480)].
Figure 86. Chunk 2 [Output: Cameras (11/11), TP (2,868), DC (180,423)].

Figure 87. Chunk 3 [Output: Cameras (14/14), TP (2,110), DC (295,665)].

Figure 88. Chunk 4 [Output: Cameras (6/111), TP (1,249), DC (82,169)].
Figure 89. July 5 P3DM Orthophoto [Output: Cameras (907/907), TP (368,113), DC (24,944,985), Pol. (1,668,480) Decimated (600,000).]
At this stage, reviewing the images created from all of the previous dives revealed that although the coded targets increased the likelihood of image alignment the number of images required to capture enough overlapping detail was excessive and led to overcompensation, and created difficult to use models within PhotoScan itself. Although the fifth dive was successful and recorded the entire stern section, the combination of shallow water depth and high relief features were too difficult to record completely with the camera set up employed. The coverage between images of both the January and July dives was insufficient, the two chunks could not be merged, and a final complete site I3DM was not possible.

Consequently, it was decided to swap the camera equipment from the Sony DX100II to another available Museum camera configuration. The new set-up was a Sony A7 with the Nikonos UW Nikkor 15 mm lens (see Chapter 4 for specifications). The incorporation of a water-correcting wide-angle lens was intended to ensure that more features were captured in one photograph. Consequently, the ability to capture detail in a shallow water column as well as the high relief barriers, windlass and slate mound improved.

5.1.5.6. **Dive No. 6: 5 December 2016**

The new camera set-up was employed for the sixth dive on *James Matthews*. Once again, the availability of the WA Museum vessel and unpredictable weather conditions postponed the final dive. Attempts were made to dive on the site throughout November by visiting *James Matthews* every Monday morning when weather allowed. Unfortunately, despite the dredging facility not operating, current and tidal conditions proved to reduce visibility to less than 0.5 m. However, on 5 December 2016, the conditions and visibility were adequate to allow a 45-minute dive to record the site.

For the sixth dive, a total of 15 coded targets were placed throughout the main site this time only within the barriers. They were individually placed in the sparse sandy patches across the site as the results from the previous dives revealed that they are essential for image alignment and reconstruction of the seabed. The 1 m scale square was placed just to the north of the windlass in a central position within the site. Recording began with transect swim lines starting at the northern end of the site and methodically worked on an east west bearing towards the southern end. After completing the first pass, another set of transect swim lines was completed, working back towards the northern end. Following this, a perimeter swim was completed around the site. The final task was close-up photography to record the oblique detail of the windlass and slate mound.
The images were downloaded and saved as both the original RAW image format and as PNG for use within PhotoScan. A total of 874 selected images (out of the complete image set of 1326) were deemed to be unfocused, partially obscured or working shots for later use — these images were removed from the model generation process. As the light conditions and the auto-colour correction on the Sony A7 were enabled, the images did not need to be colour corrected through Adobe Photoshop (see Figure 90 for example).

The first step was to align all of the images as one large chunk. This was not successful and the reason is likely related to overlap between images and the intricacies of the software processing algorithms. Consequently images were separated into two smaller chunks focusing on either the north or south end of the site, with enough overlap to allow the chunks to merge. Even though the images were not altered in anyway and the settings for processing were not changes, this was successful in P3DM the two chunks separately. The settings used to align these chunks are displayed in Table 12.

![Image](example.png)

**Figure 90.** Example showing the colour quality of the images, no colour correction was necessary before processing.

<table>
<thead>
<tr>
<th>Alignment</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair preselection</td>
<td>Disabled</td>
</tr>
<tr>
<td>Key point limit</td>
<td>9,000,000</td>
</tr>
<tr>
<td>Tie point limit</td>
<td>6,000</td>
</tr>
</tbody>
</table>

**Table 12.** Settings for alignment phase of processing the *James Matthews* images.
Some image sets aligned well and others not at all. The images that did not align were moved into new chunks to be run once more and, so on, until six chunks remained. One of these chunks (‘unaligned from bow’) contained images that did not align at any stage despite changing settings, and were consequently unable to be included in the final P3DM. The remaining five chunks covered a range of areas of the site, (see Figure 91 for the chunks in the PhotoScan workspace window for the James Matthews I3DM) with enough detail and overlap to be merged. Note that the chunks were renamed for ease of identification and to reduce confusion of alignment, and further processing steps did not work (e.g. ‘obliques’ means images capturing oblique views around the site). The chunks merged in two areas: (1) the bow end and obliques first; and (2) the resulting chunk with the stern part, which created the final complete site model. The time taken to process each of these steps was between 12–28 hours (Figures 92 and 93).

Figure 91. Workspace menu showing various chunks and merged sets from James Matthews model.
The original file was saved separately and a working copy created to complete the subsequent stages. Within this working copy, all of the previous smaller chunks were removed, and only the final merged chunk from dive 6 remained. The mesh was created at the highest level using the standard settings. Results showed adequate coverage and geometry with the final mesh being a total of 24,391,366 polygons (Figures 94 and 95). As
discussed in Chapter 4, the sizes of models created within PhotoScan are often too large for use within other programs. Accordingly, a copy of the original was made for decimating the mesh into a smaller size while retaining the structure required. The working model was reduced to 600,000 polygons to create the texture and for export to other programs. The last stage for processing the model was creating the texture. As with all of the previous models, the settings suggested in Chapter 4 were used to create the final texture at 4096 x 4 in JPEG format.

Figure 94. *James Matthews* dense cloud [Output: Cameras (1298/1298), Markers (11), TP (1,250,378), DC (365,870,498), Pol. (24,391,366)].
The process of generating the final I3DM of James Matthews reveals the challenges, as well as workable model. Ultimately, it shows that a complete I3DM of a shallow water site with high relief features is possible. Testing of both equipment and techniques for recording the site evolved over the study and resulted in employing a suitable camera and strategy for recording the site. The final I3DM required the 936 images from the last dive (Figure 96). Table 13 shows the data results for the geometry and processing of the P3DM. Overall, the dive, which lasted approximately 45 minutes, along with the many hours of processing, enabled the creation of an accurate I3DM of James Matthews.
Figure 96. Orthophoto of the final James Matthews I3DM.
The windlass, however, did not reconstruct as well from the final dive as it had from previous dives, and although the outline and most of the crash barriers encircling the site are apparent, holes and structure are missing. It is likely that this was the result of a significant amount of weed growth on the barriers (and windlass), which occurred over the spring and summer months when water temperature increases. PhotoScan could not identify single points of structure on the items covered in seaweed. There are two options for improving future recording; to complete a dive beforehand and clear away most of the obstructing seaweed or, return in the months during autumn or at the beginning of winter. Images from the other dives were not an option for filling the gaps for two reasons 1): that different camera equipment was used for most of the dives and, 2): the growth of seaweed across the site would affect the overall appearance of the model and may create issues for alignment (e.g. points visible in some images were covered in seaweed in others. Throughout this time there are clear days and the weed growth is minimal on the site, particularly during the dives in July (see Figures 83 and 90 for comparison of seaweed growth from July to December).

In the next chapter I discuss the results of the James Matthews P3DM in relation to the seven themes outlined in Chapter 2. For the rest of this chapter, the results of the other site used in this research are outlined. Batavia presented different challenges in terms of recording and processing images into an I3DM and refining an overall methodology.

5.2. Batavia (1629)

Batavia, WA’s most famous shipwreck was first archaeologically excavated by the WA Museum in 1971 (Figure 97). This shipwreck is a focus of this study for numerous reasons. It is well documented, researched and published with a large amount of photographic legacy data; it was accessible during the Roaring Forties fieldwork (2014-2018), and the conditions provided a very different case study to James Matthews. Two separate dives occurred on Batavia, one in February 2015 and another in November 2016. The first dive happened in the early stages of this study, and for that reason, essential aspects like coded...
targets and scales were not included as they were not yet part of the methodology. The resulting data and I3DM are described in the first part of this section as a matter of conscientiousness and for comparison with the results from November 2016.

Figure 97. Wallabi Group, Abrolhos Islands (ArcGIS, Landgate).

5.2.1. Historical background
The wrecking of Batavia and consequent events inspired research, novels, movies, songs and dramatic performances. A story of mutiny and murder on a desolate group of coral islands survived and was communicated throughout the years based on a 1647 publication of Francisco Pelsaert’s (the Commander) journal of the event by Ongeluckige Voyagie, van’t schip Batavia, nae de Oost-Indien (The unlucky voyage of the Batavia). The newly built Dutch United East India Company (Verenigde Oostindische Compagnie or VOC) vessel, Batavia set sail from Amsterdam to ‘Batavia’ (now Jakarta), Indonesia on 27 October 1628 (Richards et al. 2014:7). Batavia, a 600-ton ship, carried approximately 341 crew, soldiers and passengers along with a general trade cargo of cloth, lead, wines and cheese and about 250,000 silver guilders (approximately AUD$30 million today) (van Duivenvoorde 2008:1). Jeronimus Cornelisz, the undermerchant, convinced Adriaan Jacobsz, the skipper, to mutiny and take the ship with its cargo and bullion. Jakobsz slowly distanced Batavia
from the two other vessels in their squadron (Dordrecht and Assendelft) (Gibbs 1996; Henderson 2007; van Duivenvoorde 2008). Before they could complete their plan, Batavia struck a reef in the early hours of 4 June 1629 (Henderson 2007:22). Out of the 341 people on-board, more than 40 people drowned attempting to swim to the shores of small coral outcropping islands, including Beacon Island (Drake-Brockman 1963:20; Henderson 2007:22).

After the wrecking, Pelsaert and Jacobsz took one of the remaining ship’s boats and some crew to search for water, and then onto ‘Batavia’ to get help (Gibbs 1996; Paterson and Franklin 2004). This left Cornelisz in charge (as the highest remaining VOC officer) who aimed to continue the mutiny, only this time by taking the rescue ship that would inevitably arrive. With a select group of followers, Cornelisz systematically separated the survivors from the soldiers on different islands and began to murder anybody who objected or was a burden on supplies (Paterson and Franklin 2004). After three and half months Pelseart returned on Sardam and luckily made the first contact with soldiers — marooned on West Wallabi Island — who informed them of the massacres on Beacon Island (Drake-Brockman 1963; Paterson and Franklin 2004; van Duivenvoorde 2008). The mutineers murdered a total of 125 people and were consequently put on trial and executed on Long Island, their bodies left on the gallows as a warning to others (van Duivenvoorde 2008:4). The story of the Batavia murders was often retold and never failed to capture the imagination of those who heard it; what remained a mystery for centuries was the location of the wreck site and Batavia’s graveyard.

The site was discovered in 1963 by Dave Johnson, Max and Graham Cramer and Greg Allen, and was eventually protected under the Maritime Archaeology Act 1963 and later under the Historic Shipwrecks Act of 1976 (Green 1975). In 1973 archaeologists from the Maritime Archaeology Department of the WA Museum completed the first season of survey and excavation of the site. They discovered that the port stern side of the shipwreck had preserved under the ships cargo and concreted material. Between 1973 and 1975 the entire site was carefully recorded and the hull remains were excavated and recovered for conservation (van Duivenvoorde 2008). Chapter 3 outlines the details of recording the site and issues encountered. Nevertheless, the conditions the archaeologists faced are significant enough to reiterate: the high-energy; turbulent environment of the reef; and potentially 10 m swells (Baker and Green 1976:143). Consequently, applying modern image-based techniques to this site is a significant case study as a typical remote, challenging reef environment site for the WA coastline.
5.2.2. The site

*Batavia* is located in the Wallabi Group of islands in the Houtman Abrolhos off Australia’s Midwest (Figure 98). *Batavia’s* wrecksite is located to the south of Mermaid Reef, which surrounds Beacon Island, known as Batavia’s Graveyard — where the majority of survivors stayed. The Houtman Abrolhos is a group of islands located approximately 35 km west of the WA coast (Baker and Green 1976; Green 1975). The site itself ranges from 2-8 m depth and stretches across 50 m from the edge of the deeper water, upwards as the reef gradually rises (Green 1975) (Figures 99 and 100). After the excavations in the 1970s, the remaining indicative feature of the site is a 2-3 m depression where the hull ground its way down into the limestone reef, a collection of anchors and cannon from the wreck are left as important heritage and markers on the site (Ingelman-Sundberg 1975:46). The marine environment is difficult for archaeological work, and the site is only accessible one in four days as large swells make it impossible to get close enough on a boat, let alone stay on the site in the water (Chapter 3).

![Figure 98. Site plan showing only the recorded remaining cannon and anchors – (Green 1975:44), modified by K. Kasi (2016).](image-url)
Figure 99. Mermaid Reef and the Batavia shipwreck site on the southeast of the reef (ArcGIS, Landgate).

Figure 100. Close-up view of the Batavia shipwreck site (note: the sandy white patch) (ArcGIS, Landgate).
5.2.3. Dive No. 1: 3 February 2015

Although not a great outcome in comparison to both James Matthews and the subsequent Batavia I3DM, the early application during fieldwork in 2015 is valuable for multiple reasons. Mainly, the early recording proved that a) minimal images could produce an adequate I3DM and orthophoto of a large site, b) the recording technique needed refining and, c) movement of fish and untethered seaweed within the site did not prove to be a detriment for point identification.

During the first dive, the number of fish swimming around the site increased dramatically. The images recorded during this dive showed that fish covered a large area of any one image and any attempt to get closer to a structure for more detailed recording the view was completely swarmed by the fish (Figures 101 and 102). Initially, I proposed that this would be too much movement and change within an image cover and that the final model would be unsuccessful when aligning images. However, as this was the only chance to get onto Batavia during that field trip, the best possible coverage was aimed for. In total, 142 images were captured on this dive using the Sony RX100 II in an Ikelite housing.

![Figures 101. and 102. A) example of image from the 2015 set showing the amount of fish and, b) example of close-up images swamped by fish.](image)

The whole processing phase was completed without altering the images in any way, except to convert from RAW to PNG format. The first attempt at image alignment was unsuccessful and may have been due to the large fish presence in almost every image, along with the lack of photographic coverage of some areas. However, smaller image chunks were created and successfully aligned (Figures 103 and 104). This showed that the fish in the images did not in any way affect the alignment, nor the creation of a dense cloud and building the mesh (Figure 105). After aligning the chunks and then merging them, the P3DM partially recreated the southern end of the site. Unfortunately, despite
coverage with images, there are some gaps between the chunks in the final merged model (Figure 106). It is likely that the gaps represent areas where image overlap was not quite sufficient enough to adequately reconstruct the data. The holes were kept and not smoothed over in any way, as this represents the most accurate recording of the site. Table 14 details the data from PhotoScan for each stage of the processing.

**Figure 103.** Chunk 1 example dense [Output: Cameras (65/67), TP (13,623), DC (13,449,847)].
Figure 104. Chunk 5 example [Output: Cameras (14/33), TP (3,301), DC (3,804,276)].

Table 14. Data results for final model of Batavia 2015.

<table>
<thead>
<tr>
<th>PhotoScan data</th>
<th>Batavia - February 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameras (Cameras aligned)</td>
<td>134/142</td>
</tr>
<tr>
<td>Tie points (points)</td>
<td>31,816 points</td>
</tr>
<tr>
<td>Dense Cloud (points)</td>
<td>31,541,232 points</td>
</tr>
<tr>
<td>3D model (faces)</td>
<td>2,102,748 faces</td>
</tr>
</tbody>
</table>
Figure 105. Screen shot of the PhotoScan working window during processing (note separate and merged chunks).

Although visually interesting, the initial P3DM from 2015 is missing crucial information, such as gaps and the remaining section of the site. Only the southern area of the site is represented, and there is at least another half that was not adequately recorded on this dive. One further drawback is that there is no scale included for future interpretation. Although some sense of scale can be gained from the presence of cannon and anchors that have known lengths. Not having a known, reliable scale reduces the spatial accuracy of any measurements made from the I3DM. However, the results show that large amounts of fish are not an issue for the camera alignment stage of processing within PhotoScan. Furthermore, it represents the aligning and point determining power of PhotoScan to create over 31 million dense points for a large-scale site (approximately 20 m long and 10-15 m wide) with only a limited amount of images (142). Lastly, the experience gained through this initial recording of Batavia, particularly photographic recording in high swell, dynamic waters, was useful for the subsequent stages of technique refinement and preparation to return to capture the whole site.
Figure 106. Orthophoto of the final I3DM [Output: Cameras (134/142), TP (31,816), DC (31,541,232), Pol. (2,102,748) Decimated (600,000)].
5.2.4. Dive No. 2: 14 November 2016

The second, and final, dive on Batavia was completed on 14 November 2016. The aim was to improve the data set captured during the preliminary dive, incorporating scales and coded targets for the processing stages. This dive used the WA Museum’s Sony A7 and associated equipment. As noted above, Batavia is particularly difficult to access. On this day, there was 15-20 m visibility with swell low enough to access the site. Although the swell was relatively small, surge was still present and manoeuvring across the site was difficult. Completing the shortest transects across the site (approximately east to west), that would have enhanced the coverage of the site, was not viable in this instance. Instead, swimming transects were completed (on roughly north to south bearings) to move back and forth with the swell and reduce likelihood of missing sections of the site.

Due to time constraints and increasing swell, the northernmost end of the site was not recorded. A total of 967 images recorded the remainder of the site, which included additional equipment such as 15 coded targets and a 1 x 1 m cross scale bar placed in the middle. The coded targets were positioned from the southern end to the cannon at the northern end. Like James Matthews, these targets were selectively placed on sand or bare limestone reef areas in between the archaeological features on the site. Regrettably, the majority of the coded targets failed to remain in their original location on the seafloor (Figure 107). Although successful in the calm, protected location of James Matthews, when used on Batavia, they were too light to remain in place in the swell. Future recording on this site is recommended to include coded targets that can be fixed into a position, potentially on top of small iron stakes or weighted down sufficiently.
The images had minimal pre-processing before application within PhotoScan as sunlight filtration across the site was good enough to represent accurate colour, and the amount of noise or backscatter was minimal. The images were downloaded and stored in a RAW format. Further, from this, an initial copy of JPEG’s was made in the field to determine the coverage acquired across the site and after fieldwork converted to TIFF for processing within PhotoScan.

The complete set of images (967) was imported to PhotoScan for processing. Initially, the full set was used as one chunk during the alignment phase although this resulted in extensive processing time and had minimal success. From here the images that did not align were selected and moved to another chunk for alignment and so on until only a minimal amount of images that would not align at any setting were left over (e.g. Figure 108). The next stage was to complete the dense cloud processing for each of the chunks and attempt to align the chunks together. This step was unsuccessful; the chunks would not align due to minimal overlap between each chunk in areas that did not have a lot of structure. This stage was retested multiple times with different settings in the chunk alignment stage (medium, low and high) to determine if this would help. However, the alignment still failed.
In between aligning and merging chunks, each chunk was ‘cleaned’ up to reduce the amount of both error and processing time in the next steps of processing. For example, after a sparse cloud or a dense point cloud was created, there was often a range of inaccurate data points due to minor alignment errors, these data points sat outside the accurately reconstructed points. Cleaning up the chunks essentially involved manually masking and cropping out the points that were obviously incorrect or based on minimal data. These were identified as stretched points that were ‘floating’ without being attached to the primary model (Figure 109). Anything identified as possibly right or wrong was ultimately left in the model to ensure that data did not disappear during this process.

Figure 108. Example of a chunk (southern end of the site) before merging.

Figure 109. The red encircled areas show the dense points to be cropped from the model for further processing.
The coded targets became essential aspects for locating point markers in at least two chunks and aided chunk alignment and merging. The point markers were manually added to the model, initially using the centre of the coded targets as the points to help chunk alignment. If there were not enough coded targets (minimum of three), then a significant point of a structure (such as the end of an anchor stock or the top point of a cannon) were also used to create a point marker for manual alignment. Identifying point markers was the most time-consuming step, as the points were individually positioned within every single image. The closer and more accurate each marker point was, the more accurate the chunk alignment and merging would be (Figures 110–112).

**Figure 110.** Showing placements of point markers (#8) and the end of a cannon.

**Figure 111.** Close-up of manual placement of a point marker in the centre of a coded target.
Although placing the points accurately at the centre of the coded targets was achieved easily, the same level of accuracy for features (such as the end of anchors or cannon) is hard to achieve. The points were less easily identified the more that an image is magnified due to pixilation (breaking up of pixels when the image is zoomed right in), and this often resulted in cross checking and revisiting point markers already placed within an image. Despite the time taken at this stage, adding the marker points to the chunks enabled alignment and merging for the final model and was a valuable step in processing.

Another benefit of manually adding points and going through each image (all 967) separately, was the familiarity and knowledge gained for the site. This further acted as another crosschecking method for accuracy and authenticity of each chunk as points and features were identified first in images and then in the chunks. Any significant errors within the model became apparent through the placement of markers. While establishing each marker, images were zoomed as much as possible to select the correct point and to be as accurate and as careful as possible. Overall, aligning chunks required at least three markers per chunk, and they only had to have one that was the same in both chunks to be aligned, however, more made the accuracy of the alignment and merging improve.

The group of cannon and anchor at the northern end of the site (cannon 14-19 and anchors 5 and 6; see Figure 113) were especially difficult to align, even as separate chunks. In this case, a new chunk was created with these images, and the camera calibration was imported to aid in camera alignment. Camera calibration was not initially used in this study in order to determine the success of PhotoScan without it. This was more successful as the chunk could be aligned and merged with the others chunks. The final complete chunk included both sparse and dense point clouds (Figures 114 and 115).
Figure 113. Partial site plan of Batavia showing merged chunks (red outline) and areas where merging was an issue (grey) (K. Kasi – modified by M. McAllister).

Figure 114. Complete Batavia model showing the sparse point cloud [Output: Cameras (1204/1217), Markers (29), TP (828,578)].

Figure 115. Batavia complete model as dense cloud [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403)].
In the next stage, creation of the mesh and applying texture, some errors and potential limits to working on Batavia with P3DM became apparent. Namely, the mesh stage of processing contained many inaccuracies and holes in the site. This is most likely related to the lack of actual point data for the areas of sandy patches or areas with little structure. The mesh was created with the following settings (Figure 116).

![Figure 116. Mesh settings for initial Batavia mesh.](image)

Figures 117 to 122 highlight the missing geometry created from the available data. Figure 117 is a close-up of the sparse point cloud, Figures 118 and 120 show the dense point cloud and coverage and Figures 121 and 122 highlight the mesh created, based on the dense point cloud — indicating the missing geometry (holes) in the model. As noted in Chapter 4, the use of arbitrary settings at this stage to create the model mesh ensures that the software does not extrapolate from any of the points and the resulting mesh is based solely on the data in the dense point cloud.

![Figure 117. Sparse point cloud of Batavia.](image)
Figure 118. Example of the dense point cloud.

Figure 119. Close-up of dense point cloud.

Figure 120. Initial mesh created with arbitrary settings.
To retain the representation of the geometry created so far within the model, another attempt was made to create the mesh at a higher standard while maintaining the data authenticity. The mesh processing stage was completed again with a higher-level polygon count selected (i.e. high instead of medium in Figure 123). The resulting model had over 23 million faces, but overall it still had the holes and gaps from the medium level. Furthermore, the model is hard to manoeuvre and use, even within PhotoScan itself, as the large file size created delays. A complete mesh was processed at the high polygon setting to determine if this would help to close the gaps in geometric data shown above at the medium setting. Although it did successfully process, the result was a large and un-
manoeuvrable model with the gaps still present within the mesh. As this was not a benefit, the mesh created at the medium setting was selected as the best option to move forward.
Figure 123. Orthophoto of the complete mesh for original 3D model – note the holes/gaps [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730.293)].
Altering the *surface type* setting can also enhance the completion of a *full* mesh model. Instead of selecting *arbitrary* during the mesh creation step, *extrapolated* can be chosen. As a result, PhotoScan creates a complete mesh without any holes by extrapolating from each data point in the dense cloud (as described in Chapter 4). For this study, the *Batavia* I3DM was copied and an extrapolated mesh created to see what level the results would be. The outcome showed a complete mesh that covered the site well, although the boundary was largely extrapolated (Figures 124 and 125). Without a doubt, this mesh is far more aesthetically appealing and provides a robust 3D digital model for use within the next stages. However, it can be argued that the accuracy to the original data is not as close as it appears to be. The extrapolated (filled in) holes are data created by PhotoScan.

**Figure 124.** *Batavia* extrapolated mesh showing the markers as well as extent of extrapolation [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)].
Figure 125. Batavia profile mesh showing the extent of extrapolation outwards from the dense point cloud [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)].

Following this, the mesh was cropped and close-up examination of the results showed that the extrapolated data was visibly smoothed over — i.e. the perimeter walls with no defined geometry (Figure 125). The central area (circled in red) of Figure 126 also indicates that the gaps filled during the extrapolated mesh step are represented by blurred or slightly smoothed over areas. The only issue from here is whether there are potentially indiscernible areas extrapolated from the remaining accurate point cloud data.

Figure 126. Batavia extrapolated mesh showing the same area as the original mesh.
After creating the mesh using the *medium* setting, this final extrapolated mesh for the complete *Batavia* model has a total of 7,730,293 polygons. Although this is much smaller than the original mesh (at *high* setting) of approximately 24 million polygons, it was still important to decimate the mesh for use in other software programs and to create an appropriate texture. Like the *James Matthews* model, the mesh was reduced to 600,000 polygons enabling the creation of the texture layer at 4092 x 4. Subsequently, a user-friendly model was created from the original mesh, which is stored to retain the highest level of geometric accuracy (Figure 127).
Figure 127. Orthophoto of extrapolated mesh for 3D model [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)].
5.3 Summary

The final I3DM for Batavia indicates that a large scale, dynamic reef wreck site can be recorded and digitally reconstructed in 3D using affordable digital cameras with the aid of referencing equipment and techniques. Although the entire site could not be recorded during either of the two dives, these I3DMs represent a successful application of the approach put forward in Chapter 4.

In the following Chapter, I address the results given here in relation to the seven themes outlines in Chapter 2. That discussion identifies where P3DM and I3DM fit regarding the overall archaeological process that relates directly to the results presented here and insights from the review of imagery and archaeology.
6. Towards a future of P3DM in underwater archaeology

Throughout Chapter 5, I outlined the successes and limitations of applying P3DM techniques to the two case study underwater shipwreck sites in WA. Moreover, my research decision to address the thesis aims through the application of P3DM enabled me to profile provoking visualisation and interpretation issues for underwater archaeology. Photogrammetric digital 3D modelling is a powerful recording technique and the resulting I3DMs provide an engaging medium for communicating information.

From my own experience when applying P3DM to underwater shipwreck sites, I found that by completing both the recording and processing stages combined with viewing the final I3DM enhanced my understanding of the sites. Primarily, P3DM provided me with a way to quickly, record understand and visualise two different sites. As indicated through the review of previous excavations and surveys of underwater shipwrecks around the world (Chapter 2), shipwrecks are often complicated and extensive. Detailed visualisation improves how we understand the processes that may influence excavation and survey, while also providing the viewer with a general grasp of the site. Through my experience in this study, viewing an I3DM enabled a quick and easy comprehension of an underwater shipwreck. In particular, the spatial layout of features, overall dimension and height of features was easier to determine when viewing an I3DM then conventional 2D representations (e.g. site plans).

Complicated and intricate data are made more easily comprehensible through I3DMs. I3DMs also provide an easier and faster way to understand the overall site geometry. I found that they also could be used to capture a high level of detail and coverage in a short amount of time. For example, the second dive on Batavia only required two divers and 40 minutes. Although not possible in this study, this ease of recording and processing lower level I3DMS provides a quicker turn around in site recording and visualisation during excavations. Enhancing the overall archaeological process of a project and saving time at depth. Lastly, the combination of speed, level of detail recorded and ease of comprehension enable those working on only small sections of a site to understand the whole. For example, previous work that I have been a part of on the James Matthews site often required that we worked towards the stern, where degradation is an ongoing issue. Consequently, I knew the stern area of the site very well before completing photographic
recording for P3DM. Even though I completed photographic recording of the whole site, it was not until I was analysing the final I3DM that I comprehended the layout of features and noticed areas I had not studied in detail at the bow. As archaeologists often work in small grid squares and excavate vertically down. This can impede each individual’s overall understanding of the site, particularly the spatial correlation of their square to others and a general impression of how certain artefacts might lie in relation to others and the overall site formation. Employing I3DMs within the archaeological process provides enhanced understanding of the site. However, P3DM in archaeology is currently lacking distinct standards for steadfast archaeological use.

To determine the various limits and conditions required to appropriately and reliably apply P3DM as an archaeological tool on underwater sites, this chapter will use seven themes (outlined in Chapter 1 and Chapter 2) as a focus point for analysis and critical discussion (Table 15). Following that, two underlying issues — ocularcentrism and objectivity — are considered in detail. Finally, this chapter relates the significance of these findings to the wider archaeological discipline and discusses the implications of this study to the future of P3DM in underwater archaeology.

Table 15. Description of the themes for analysing P3DM and I3DMs.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Purpose</td>
<td>The reason for applying a tool/technique – the ‘why.’</td>
</tr>
<tr>
<td>2. Methodological rigour &amp;</td>
<td>Maintaining a standard for recording the processes, steps and settings used at all times. Being rigorous in applying a method and transparent at every stage.</td>
</tr>
<tr>
<td>transparency</td>
<td></td>
</tr>
<tr>
<td>3. Authenticity &amp; accuracy</td>
<td>Authenticity refers to how reliable the I3DM is to the original data and the site. Accuracy covers aspects of geometry, colour and reconstruction.</td>
</tr>
<tr>
<td>4. Complementarity</td>
<td>This theme focuses on a discussion on whether or not I3DMs should stand alone, or be applied in conjunction with other tools as a form of comparison and balance.</td>
</tr>
<tr>
<td>5. Legacy data</td>
<td>Specifically, addresses issues of time and revisiting archival data for the creation of I3DMs — allowing for new visualisations.</td>
</tr>
<tr>
<td>6. Sustainability &amp; Access</td>
<td>Describes the necessity of ensuring that all P3DM data and models are sustainable and accessible.</td>
</tr>
<tr>
<td>7. Paradata</td>
<td>This term encompasses the motives, choices and bias behind the entire process of creating I3DMs.</td>
</tr>
</tbody>
</table>

The primary research question of this thesis required evaluating how P3DM can provide new insights by enhancing the cognitive understanding of archaeological photographic data. This study applied P3DM to assess the benefits and potential implications I3DMs have on interpreting archaeological data. Both case studies, which vary considerably in physical conditions, illustrate the successes and limitations of P3DM on underwater shipwreck sites in WA. The final I3DMs for each site represent engaging visualisation
tools for communicating results to peers and the public. Moreover, I3DMs proved to be a gateway for enhanced archaeological interpretation, particularly through the recreated 3D point clouds and mesh that improved cognition of site geometry.

6.1. P3DM and underwater archaeological recording

Using P3DM allows for fast, spatially accurate recording across varying sites. In comparison to conventional techniques, such as trilateration and baseline/offset, P3DM requires only minimal dive time to set-up control points, coded targets and complete photography (Chapter 3). For example, James Matthews P3DM recording was completed in a single 45-minute dive, which included laying down 15 coded targets, a 1 m-scale grid and photographing the site. Batavia’s environmental conditions have always hampered conventional measuring and mapping of the site. Instead, during the original excavation archaeologists relied on photomosaics of the final site to locate and measure all of the artefacts and structures onto a plan. Manual recording of the site would have taken numerous dives and lacked accuracy, whereas the two P3DM dives were only 24 and 45 minutes. After processing, the final I3DMs for both sites indicate that recording large underwater sites can be completed with speed and ease.

The James Matthews I3DM demonstrates that high quality I3DMs can be generated in relatively shallow sites with high relief structures. The initial decision not to use a wide-angle lens (with the aim of obtaining greater accuracy across images) resulted in minimal overlap of features between images and, subsequently, hindered image alignment (Figure 89). After changing to the Sony A7 camera and water-correcting Nikonos lens, image overlap improved and consequently the overall recording of James Matthews for P3DM also improved. The ability to record James Matthews with this camera set-up and create a I3DM significantly improved the original 1977 attempts to create a 2D photomosaic. As described in Chapter 2, photomosaics are often a compromise on accuracy due to perspective distortion.

Multiple dives were undertaken on James Matthews at varying intervals from September 2015 to December 2016. As a result, the changes associated with different seasons caused some limiting effects on this study. For example, the data collection in December 2016 was problematic due to seasonal growth and continuous movement of seaweed on the high relief structures across the site. Consequently, PhotoScan could not identify tie points in those areas of the structures for the December 2016 dataset, although, the clearer sides of the barriers were captured and reconstructed successfully. On the contrary, earlier dives
on the site (e.g. September 2015 and July 2016) showed an excellent level of coverage of these features, as there was minimal presence of seaweed on the site features. In the future, the winter months to early spring — when seaweed growth is reduced — should be considered ideal for P3DM recording of James Matthews [note: this was not selected as the first option due to generally reduced visibility in winter months]. Alternatively, the seaweed can be removed to allow for better recording of overall structures, however; this is destructive to the environment and adds a significant amount of pre-recording dive time to the overall process.

Another minor issue with the photogrammetric recording of James Matthews was the use of white coded targets in a shallow water environment. Although the recording took place relatively early in the morning (07:30–09:00), sunlight coming through the water reflected off the coded targets placed across the site. The reflectance resulted in some blurring around the targets themselves and overexposure in those images (Figure 128). With some post-processing, the effect of the white blur in the final I3DMs was reduced, allowing the images to align and resulting in an adequate final texture (Figure 82). Future recording incorporating the coded targets on James Matthews should involve adapted versions printed on grey or yellow paper to reduce the amount of reflectance and aid in an appropriate white balance.

![Figure 128. Reflectance of sunlight on a coded target on James Matthews.](image-url)
James Matthews is a well-protected, generally calm site that can be dived year round (visibility permitting). However, the site’s proximity to the Cockburn Cement dredge and water current movement means that water visibility is often less than 1 m. As P3DM requires quality photographs, minimal visibility is not conducive to accurate recording. In comparison, conventional techniques (like baseline and offset) can be completed even with reduced visibility. Choosing which recording technique is the most accurate and reliable should take into account the characteristics and conditions of a site.

Unlike James Matthews, the majority of WA shipwrecks are located in dynamic environments with limiting dive conditions. The Batavia wrecksite is an excellent example, situated on a breaking limestone reef in the remote Abrolhos islands. Unlike the approach taken with James Matthews, the recording and processing stages of the Batavia case study needed a different recording plan. The environmental conditions and remote location of Batavia required a detailed dive plan and preparation for working within the swell and dynamic water column movement. The initial dive, completed in 2014, highlighted the need for coded targets, scales and detailed swim path planning for adequate recording. As the 2014 dive was only preliminary, it focused on the sand pit where the hull originally sat, and the resulting I3DM only covered approximately 50% of the site (Figure 116). Consequently, for the next dive in November 2016, it was essential to ensure that as much of the site surrounding the sand pit could be recorded as possible.

The second dive had a higher level of coverage. Both the sand pit and the northern group of anchors and cannon were recorded. Moreover, previous knowledge of the site ensured an appropriate swim path could be planned and executed. As shown in the results (Section 5.2.4), overlap per image for the second dive was much higher (Figure 114). Excellent visibility (approximately 20 m) enabled extra photographic coverage during the dive. Despite the presence of swell and potentially not recording some areas adequately, the overall results indicated a sufficient amount of captured geometric data to allow for an overall understanding of the 3D depth and geometry. Pre-planning and thoroughly assessing the site regarding requirements for adequate photogrammetric coverage improved the overall process.

Despite some minor issues (increasing swell) during the dive, the majority of the Batavia site was successfully recorded. Although the swell was relatively calm for the site, the surging water was enough to move some of the coded targets placed on the bare, sandy areas. This disruption occurred mostly towards the south of the site where sand
movement buried and shuffled the targets around (Figure 107). This dive proved that these targets were not appropriate for a dynamic site like Batavia. Although archaeologists previously used coded targets attached to spikes across an underwater site (see Chapter 4), the hard limestone rock reef at Batavia would make this method laborious and increase the overall dive time. In future, slightly smaller targets with a smaller surface area and heavy weights would be more suitable.

The data collection phase of this study raised issues that relate to the following three (out of the seven) themes for discussion: methodological rigour & transparency, purpose and paradata. Although this study suggests the ease with which archaeologists can now record often-difficult underwater sites, it also exposed the essential need to be rigorous in recording all of the methods, techniques and approaches to recording a site for P3DM. Not only could this information potentially influence choices and settings during the processing stage, but it also ensures that someone else could repeat the identical P3DM technique on the same site. Methodological rigour is of particular importance in these early years of applying new P3DM techniques and tools within underwater archaeology. Currently, there is limited information about the best practices for P3DM and this is only remedied by rigorous testing of appropriate methods and techniques. Another factor of being methodologically rigorous and transparent involves recording the motive for applying P3DM and the underlying choices and biases that may have influenced decisions throughout the recording phase. The importance of trialling equipment in varying environmental and physical conditions was also demonstrated over the numerous dives in this project.

Issues of authenticity and realism are also possibly solved by addressing the methodological rigour and transparency in recording the settings selected throughout the processing stages of an I3DM. For example, Figure 124 has the following caption “Batavia extrapolated mesh showing the markers as well as the extent of extrapolation [Output: Cameras (1204/1217), Markers (29), TP (828,578), DC (115,954,403), Pol. (7,730,293)].” The number of polygons (7,730,293) indicates that the final mesh was created at a medium setting, as a higher setting would have an output of approximately 20 million and more. Furthermore, this indicates that the mesh is not decimated for viewing, as the polygon count would be closer to 600,000, instead of over 7 million (using the computer power available in an average consumer PC of 2016 to 2017). Including this information allows a trained viewer to automatically identify the I3DM as a model that was not decimated for ease of viewing but was extrapolated during the processing stages. Being transparent by adding this type
of information enhances interpretation of those who are viewing the model (in this case a 2D screenshot) and encourages more reliable interpretations and conclusions.

The themes purpose and paradata best describe the bias and agency of human recording. Although the purpose of applying P3DM to James Matthews and Batavia aimed to determine if it was possible to get adequate results, I3DMs are already a reliable tool within archaeology and produced across numerous projects (Chapter 3). For future use, recording the reasoning for creating an I3DM of an individual site is an important step. It confirms the usefulness of the method and what is actually learnt from applying P3DM to a site.

Paradata seeks to record as much of the personal choices and reasoning behind the selection of equipment and recording techniques employed. For most of the dives, paradata was entered into a template document that contained some of the themes constructed as open-ended questions, which essentially acts as a combination of a field day book and journal (see Appendix B). As noted in Chapter 4, although it is impossible to completely record all of the bias throughout the archaeological process, recording at least some fundamental aspects encourages self-critique and reflexive thinking (Andrews et al. 2000; Hodder 1997b; Hodder 2003; Johnson 1989). For instance, why did the photographer decide to use a certain camera over another one? Was it simply because that is what they have access to or own, or did they select a specific one for this work over another option? Did some issue occur during the dive, which caused the original swim track to be changed? These are all factors that could affect the quality of the final I3DM. Embracing paradata as an essential aspect of rigorous recording highlights the subjective influences that I3DM may have on viewers. In contrast, some of the elements recorded included seemingly innocent data such as site conditions, camera equipment, scales to be used, swim path and overall site coverage. However, recording the decisions made about aspects like these highlights the reasoning behind any potential bias. These factors were included in the results for future reference ensuring that a rigorous method was available for future work.

Creating a template document to record the decisions and bias that I had throughout each dive was an invaluable reference for both later processing and to analyse the impact of P3DM on these sites (see Appendix B for the completed set of paradata templates). The last dive on James Matthews indicates the level of pre-planning included and the impact of my own decisions on the final collected data and I3DM. For example, under the heading
‘Purpose’ the following statement indicates the reasoning behind returning to the site and the focus of my recording throughout the dive:

“…this dive aimed at completing a full site recording. I knew that I had captured some high-quality data for the two most important visible structures – the slate mound and the windlass – as well as the iron deck frames, so the primary focus was on capturing adequate overlap of the site from a ‘site plan’ perspective.”

On the one hand, this indicates that the general aim was to capture the entire site in one dive. However, as the main site features were previously recorded, this dive was ultimately biased towards a high level of overlap of the areas in-between the structures and the barriers encircling the wreck. Due to this focus, the final I3DM is lacking high-quality reconstructed data on the slate mound and the road crash barriers, which was caused by the minimal level of photographic overlap. Without this written statement, it is likely that interpretations made by others in the future may be incorrect or misinformed. This information can aid future dives aiming to P3DM James Matthews as it reports that a lack of extensive overlap (particularly on high relief features) affects the final I3DM.

On the other hand, the paradata template encouraged my own self-reflexive critique of the data collection. Physically sitting down post-dive and debriefing myself by filling out the template ensured that a lot of my choices and small decisions at the time were highlighted and recorded. Without this, some essential aspects may have been overlooked for the subsequent dives. Even though it only took 15-20 minutes, the benefits of assessing my work included enabling better planning for the next dive, and analysis of the particular techniques I used influenced the use of equipment for future recording. This small step ensured that the overall P3DM of this study involved a reflexive and transparent approach.

Although the use of the paradata template provided a valuable reference for planning and self-critiquing the results of every dive, the format and layout needs refining to be a useful resource for other archaeological projects. Ideally, this template (or similar versions) would be employed in all applications of P3DM for archaeological research so that the raw data contains additional information for future generations to incorporate. In fact, advanced versions of reflexive documentation are well integrated into large-scale projects such as Çatalhöyük (Berggren et al. 2015). However, like the problem of publications and I3DMs (discussed in detail in Section 6.1.2) storing this information alongside both the raw
photographic data and making these details obvious in the final I3DMs is a challenging task. Successfully integrating paradata into published data and results is a challenge that may only be overcome with advances in the interactive viewing capabilities of I3DM software.

The data acquisition stages for recording on both James Matthews and Batavia indicate that surveying an underwater archaeological site can be completed with minimal dive time and equipment. The comparison of two sites located in vastly different environments further reinforces the application of P3DM to the sites that are difficult to record with conventional techniques. This study highlighted an overall improvement to underwater archaeological recording through the application of P3DM to two challenging case studies on the WA coast.

6.1.1. Processing I3DMs

Data processing proved to be both time consuming and more challenging to efficiently complete than initially thought. The alignment of images (and subsequently the alignment of separate chunks) proved to take up the most time. The resulting images from multiple dives on James Matthews allowed for improvement of image alignment when overlap between images was adequate and, during the later dives, when applying the Nikonos lens. The initial attempts at aligning images from the first dives demonstrated that the areas of sparse, sandy floor and the high relief of the road crash barriers were unable to be accurately reconstructed by PhotoScan (Figures 74 and 79). The use of coded targets across the site enhanced PhotoScan’s ability to identify points and provided a feature to aid alignment of the sparse sandy areas. Additionally, the use of a Nikonos lens increased the success of reconstruction of the road crash barriers. Based on the results, it would appear that more targets should be utilised across an underwater site during recording, so that at least three coded targets, and/or identifiable feature points, are visible in each image for automatic recognition within the software.

Despite these improvements in the data acquisition phase, successfully aligning the images in the final James Matthews I3DM (from Dive No. 6 in July 2016) required that the images to be separated into two chunks representing the northern and southern ends of the site. If processed as one large chunk, PhotoScan could not successfully align all of the images. The reason for this is likely that there was sufficient overlap to cover the majority of the site, but there was minimal overlap in the areas between the chunks. As PhotoScan uses the SfM algorithm to identify the camera pose and geometry of a site, the images are
aligned by tracking features from image to image (Westoby et al. 2012). It is possible that there was inadequate overlap in some minor areas that hindered the overall alignment of chunks. Regardless of this minor set back, the two chunks automatically merged within PhotoScan, and the final I3DM provided a reliable tool for visualising the site. Although it is should be highlighted here that PhotoScan is a ‘black box’ — meaning that we don’t really know what it is doing — and as a result it isn’t possible for us to make any firm conclusions about how PhotoScan can or cannot process a dataset (elaborated further in Section 6.2).

In comparison to James Matthews, the Batavia images were more time-consuming to process. The manual placement of ‘point markers’ for chunk alignment (described in Chapter 5) required that each of the 1217 images were inspected before images could be aligned and accurately merge the chunks into the final I3DM. Although PhotoScan has an automatic marker detection option, most images only had one or two coded targets visible and could not automatically be recognised (the minimum number required is 3). While this manual inspection and point marker placement onto coded targets or scene points (points you can identify between images) extended processing time, it also had an added benefit of a careful examination of each image. Through this stage the user became familiar with the main features present on the site. Interestingly, this can be seen as a change from conventional methods. To record the site, surveyors spent a long time interpreting the site, which in turn influenced what they recorded. Now, it is the person processing the images who spends more time interpreting the site – although through a virtual form.

One drawback of this technique is a reliance on the manual placement of each point marker as accurately as possible across multiple images (Figures 111 and 112). More than once the points had to be re-done, as manually identifying points was not accurate enough to successfully merge chunks to the point markers target were repositioned closer to the centre of coded targets. Although this increased processing time, higher accuracy during point identification ensured better alignment and overall final model representation.

The most revealing stage of data processing occurred in the final steps of creating an I3DM, building the mesh and creating a texture layer. As described in Chapter 4, the mesh stage creates the 3D geometry of the I3DM by making polygons from the dense point cloud. Creation of the mesh was completed after the chunks merged into a final model. Due to repetition of some images within chunks, the final image sets contained above 1000
images for each model and were consequently large file sizes (Batavia: 1217 images; James Matthews: 1298 images). Even at a medium setting for creating the dense point cloud, the point counts for the final models were large, sometimes over 300 million points. Subsequently, when the mesh was created at a medium or high setting, the file sizes were large and became unmanageable. Copies were made of each model, and the meshes were decimated to a smaller polygon count of 600,000 (described in Chapter 5). This ensured that the P3DMs were usable, could be opened and viewed in other software programs and, allowed the creation of an aesthetic texture layer for the final visualisation of the site.

The last two stages of creating a P3DM (e.g. mesh and texture) can be broken down into two outcomes with different purposes: 1) a highly detailed, accurate I3DM with a large file size and, 2) an aesthetically pleasing I3DM that is easily viewed on multiple software programs. Although it is possible to use the original mesh to create a texture map, in reality, most consumer level computers and software programs are currently not able to open and use an I3DM of such size and detail (e.g. upwards of 2–5GB per file). Consequently, even though the original mesh I3DM was saved, another copy was made and the mesh reduced for texture mapping and exporting to other software programs. The result is a compacted model that retains the overall geometric accuracy and representation of the site while also allowing for ease of communication and digital transfer of the I3DMs. Although decimating the mesh ensured a wider application and accessibility of the final models, it also, ultimately, reduces the amount of original data and detail portrayed in the final model. It is essential to understand here that there is a point in which decimation reduces the geometric detail — and consequently the authenticity, accuracy and reliability — of an I3DM. Currently, there is no answer as to where that point is, although future algorithms may solve this.

The increased super-realism of the final models can easily lead viewers to think that they are looking at an exact digital representation of the original site. As technology and software advance so too will the realism of digital models. This study argues that the gaps and spaces, which can occur due to lack of photographic data, should be left in the final model. The gaps remind those viewing and interpreting the final models that they are indeed interpretations and creations themselves, instead of portraying the most aesthetically complete model. In the same way, it is vital that the true mesh resolution of the mesh is available to viewers, along with the quality (high, medium, low etc.) of the models. This information is most valuable when creating I3DMs although, the decision to fill in the holes in photographic overlap, or not, depends on the audience and purpose for
creating the I3DM. For example, there are instances where a simple visual site representation is required (e.g. public lectures) where filling in the gaps for a more final model is a valid option.

More so, the fact that the software did not automatically process and align certain images may be significant to learn from. Such as the inability to process all of the Batavia images as one chunk. Batavia is a good example of the overlap issues with the original model and the ability to ‘fix’ the mesh (through extrapolation) so that it appears without any holes and is aesthetically pleasing (Figure 124). It is evident from the results of this research, and the brief discussion above, that authenticity is also about being transparent in the content represented in I3DMs. Although PhotoScan states that the decimation process reduces the overall file size while retaining the model geometry, it still alters the outcome in a manner that can potentially deceive viewers. Additionally, decimation reduces the intricate detail of a site, altering the original modelled data and may affect any virtual measurements made from the model as well as overall interpretations of the site.

Another aspect to address when collecting paradata is documenting the steps taken for each stage of processing. Like the data acquisition phase, recording these settings enables future archaeologists to attempt the same steps and recreate an I3DM with different software, or apply different settings to get a varied result. For instance, the same settings used to process the James Matthews images in this study could be completed with the same data set in the future. In addition, they would provide a valuable resource for any future attempts at P3DM of underwater archaeological sites, as there are currently no general guidelines for underwater archaeological P3DM. From my own experience within this study, any information about the best practices for underwater P3DM has to be gathered through an extensive search of related literature and testing varying techniques. As a result, I believe that it is essential we now work towards creating a detailed paradata approach with all assumptions and approaches expressed to achieve reliable P3DM of underwater sites. Guidelines for P3DM of underwater shipwreck sites cannot be based off a singular study, such as this one — a further discipline wide discussion is needed to understand what archaeologists want from the tool. To begin this discipline wide dialogue, I discuss the P3DM results in comparison to the seven themes (described in Chapters 1 and 2) from Section 6.1.2.

The results of this research demonstrate the overlooked levels of manipulation and adaptation that are a part of P3DM processing. From selection of an appropriate file
format to use within PhotoScan, to colour correction, extrapolating mesh, decimating mesh, manual alignment of image chunks and more; there are multiple steps that can change the outcome from importing the original images to exporting the final I3DM. Just as the importance of recording all methodological stages was discussed above, so too is it significant to record the paradata for the entire processing stage. Having access to the reasoning behind applying certain settings over others, and excluding or including information, allows viewers to have a wider understanding of exactly what sort of I3DM they are interpreting. The use of a simple word document as a form of field journal worked well as a tool for recording this information and encouraging a heightened level of self-criticism, while also reflexively addressing choices made over other potential beneficial settings. It is clear that recording all aspects of paradata is a mammoth and potentially unattainable task, however, this study suggests that recording even the basic paradata (i.e. why were medium settings used over high for a P3DM of James Matthews) allows a better, enhanced understanding of not only the final P3DM but insights into the project aim, equipment capabilities and use for the final model. The reflexive approach taken in this study is only minimal in comparison to the project-wide detailed approaches tested and applied at other sites. In this study, recording paradata successfully highlighted the use of paradata for further stages of recording and processing. It also indicated the range of choices and decisions made throughout the recording and processing phases that changed the final I3DM output. Even this attempt at identifying decisions and bias is significant for further investigation involving P3DM.

6.1.2. Post-processing and implications on the final I3DMs
As noted throughout this study, there are no guidelines or standards for the P3DM of archaeological sites. The London Charter and the Principles of Seville provide a general basis for heritage and computer visualisation but are arguably documents set in place to begin a process of refining the techniques into well-respected tools for archaeological research. Is it necessary to outline the exact steps needed to document all aspects of the process to ensure the results are reliable? Or, is it better to stick with general encompassing principles such as the Charter and Principles? Potentially, a combination of both is the key.

It is an ethical responsibility of archaeologists to communicate their findings to the public, and not just to colleagues and related disciplines. Advances in computer vision and processing capabilities, combined with the ever-increasing ubiquity of the Internet and personal devices, ensure that the ability to promote archaeological research and findings through eye-catching digital 3D models is easy and beneficial. Ever advancing technology
means that visualisation of digital 3D models is most likely the way of the future for museums — creating online, accessible 3D databases. Nonetheless, the benefit of rapid advances also threatens the longevity of digital material.

Technologies that were at one time cutting-edge are now mostly obsolete (e.g. floppy disks, cassette tapes, videocassette recorders (VCRs), compact discs (CDs) and compact disc, read-only-memory (CD-ROMs)). PhotoScan, which has mostly replaced PhotoModeler for underwater archaeological purposes, has only been the go-to software for a few years. In the near future, it is likely that another software program will supersede it. As software programs advance and new versions are released, the increasing capabilities of computer vision and algorithms will come with potential differences in formatting, processing and exporting models. What is acceptable now may not be in the next few years — let alone for future generations. Moreover, further developments usually make a program more user-friendly, therefore the next P3DM software may reduce the stages that a user completes (or eliminate them completely) and, consequently, also decrease their understanding of the overall process. As a result, I3DMs created now may not be digitally sustainable and accessible in the future due to continual advances in digital technology.

In addition, future computer vision capabilities may exceed current expectations. What we currently accept as the highest quality and detail may no longer be considered adequate by future archaeologists. It is probable that the original images will be reinvestigated and reprocessed with new software to create visualisations that may have higher quality and higher detail (in a similar way that legacy data has been reused in this study). The issue then becomes one of ensuring that the original images are recorded in the highest detail, with the highest quality possible (e.g. loss-less compressed TIFF or PNG). Additionally, that the images are archived in an institute or accessible place for future archaeologists and public alike. While the ability to archive I3DMs is a current problem, the most important aspect of ensuring the models will continue to be accessible to future generations is preserving the original images, unaltered and in an accessible format and place.

Storage issues hint at potential problems for publication of I3DMs in conventional academic journals. Incorporating I3DMs within publications is difficult and not recommended due to a lack of current longevity of storage and applicability within current document formats (e.g. PDFs containing 3D models). Instead, I3DMs are very
often replaced with 2D images (i.e. orthophotos or screenshots). Modern platforms for dissemination often include web-based mediums (e.g. Sketchfab™), publication in Adobe 3D pdf’s or creating a video of an I3DM (e.g. using program such as Blender™). Accessing models through websites such as Sketchfab™, institute or university blogs, websites and social media platforms are the primary pathway to get I3DMs out into the public.

There are currently no standards or recommended ways to disseminate I3DMs for archaeological purposes and the inclusion of I3DMs as viewable models within conventional publications. Without any globally accepted guidelines for the post-processing stages of a P3DM methodology, I3DMs are generally distributed only as a final model that lacks any accompanying metadata or paradata. Consequently, the super realistic final models are currently being used as tools to disseminate information about sites to the public and other heritage practitioners. Viewers without an understanding of the details and settings used to create these models can make misinformed interpretations about the I3DMs and subsequently about the actual site. This issue brings our discussion back to the challenges of authenticity, transparency and reliability of the I3DMs. This discussion highlights the many issues we are facing to refine I3DMs into reliable tools for visualising sites successfully. The next phase of archaeological visualisation, a digital 3D based visualisation of sites, cannot be widely accepted as a reliable tool until a stable, digital technique to publish these models within journals is achieved.

An interesting point for discussion is the comparison of I3DMs (and resulting orthophotos) to conventional site plans. The primary benefit of I3DMs is their ability to convey the same information as expected from a conventional site plan, while also conveying the complex geometry of a site. In addition, orthophotos can be created from I3DMs that can be used as conventional site plans. There are two techniques that can also turn orthophotos into black and white site plans. One is the process of tracing predetermined site features in a software program (e.g. GIS software like ArcGIS), which requires manual identification and digital tracing in these software programs. The second was devised by Yamafune (2016:102) and involves erasing. The orthophoto is converted into a black and white copy and then the irrelevant data is erased to leave only the outline of features. As a conventional site plan can also be created from an I3DM, the key point to note here is that I3DMs are created by a blanket capture of points through the P3DM process, whereas conventional site plans are created from predetermined points or features that are measured. Consequently, I3DMs could be seen to be more useful as they
initially capture more data and detail that may not have been included in a conventional site plan. Significantly, both are still interpretations of a site.

6.1.3. A change of focus: reflexively critiquing this study

Despite beginning this study with the primary research question focusing on the ‘how’ (e.g. how could an accurate P3DM be created from photographs of underwater shipwreck sites? How can an archaeologist embrace and successfully use new photogrammetric modelling software?), the emphasis eventually changed to ‘why’. For example, why should I use P3DM over another well-known and reliable technique? It became apparent that the application of P3DM to underwater archaeological sites was well and truly focused on the ‘how’ (Demesticha et al. 2014; Henderson et al. 2013; Mahon et al. 2011; McCarthy and Benjamin 2014; Yamafune 2016). Regardless of the necessary steps of testing and adapting tools and techniques for use underwater, we should come back to the motive and reasoning behind applying such technology within the archaeological process. Although current research is evidence of the success in testing equipment and methods to record sites and successfully create I3DMs, there is a need to return to the ‘why’ to determine if we are applying these techniques for the right reasons, with a thorough understanding of what we are creating.

Once the purpose of this study changed from ‘how’ to ‘why’, creating I3DMs evolved into an assessment of how these tools are currently applied within archaeology. From then, the purpose of creating I3DMs of Batavia and James Matthews became two-fold: (1) to test P3DM on sites where it has not been applied as part of an assessment of the method and, (2) as a way to experiment how to link I3DM to legacy data and I3DMs. Addressing why P3DM was employed (i.e. the purpose) enabled the evaluation of why certain techniques are used over others to record and visualise sites. Questions to be asked can include: is P3DM the best technique to record specific aspects of a site, such as hull shape, or is there another tool that can convey these elements in a better way? Does it capture and accurately convey the necessary information? If so, then it forces the user to critically review why the technique is the best possible tool to enhance our understanding of the archaeological data.

As pointed out in the Principles of Seville, the overall aim of employing any computer-based visualisation should always be to improve aspects of archaeological heritage, such as the research, conservation and dissemination of data. Critically assessing whether the application of P3DM enhances our knowledge, or not, is a valuable tool to re-centre a
research project focus. As a result, defining the purpose of employing I3DMs for archaeological interpretation engages archaeologists in a reflexive process of reviewing the aims and overall approach. Analysing the purpose of recording the *Batavia* and *James Matthews* sites to create I3DMs indicates the changing priorities that often occur throughout the archaeological process.

My investigation into the application of P3DM to underwater shipwreck sites further highlighted the significance of this statement by Mudge et al. (2007:1), ‘The tools and standards of best practice adopted by cultural heritage (CH) professionals will determine the digital future of cultural heritage work’. The future application of I3DMs of underwater shipwreck sites and both the success and archaeologists capabilities to utilise them appropriately depends on a well-defined set of standards for best practice. While this thesis certainly cannot argue for a final set of standards, it does allow the suggestion of potential inclusions into a future set of guidelines for P3DM of underwater shipwreck sites.

To adopt the use of I3DMs within archaeological research, in adopting any new digital visualisation tool, it is essential that cultural heritage professionals can rely on the data they represent as reliable. To do this they must be accurate, authentic and fulfil our requirements of rigour and transparency. While archaeologists should understand that I3DMs are an interpretation of a site, and do not represent an exact copy, there is still a gap in how we communicate the extent to which the I3DMs represent spatial reality and to what extent they have been added to, improved or altered to get to the final stage that they are viewed and interpreted at. The answer to this lies in the creation of standards for best practice in disseminating I3DMs, and perhaps Mudge et al. (2007) best summarise this as ‘empirical providence’ of digital tools. Mudge et al. describe empirical providence as recording the journey of the original, unaltered, empirical evidence from the way it was captured/recorded through to the final digital representation (2007:3). While I previously discussed objective observations and the limits we know exist with photographic capture and objectivity, the description provided by Mudge et al. suggests a way forward for cultural heritage professionals to ensure that they models they create, and use, are reliable, authentic, accurate and transparent.

So why apply image-based modelling to an underwater shipwreck site? Throughout Chapter 3, I discussed the background to photographic applications in underwater archaeology, finishing with the most recent uses of photogrammetric digital 3D modelling.
While criticising the processes used to apply these new tools, I also highlighted the widespread benefit of P3DM for archaeological purposes. Not only do these tools allow us to quickly and accurately record underwater sites, they also provide an invaluable medium for dissemination of data, ideas and arguments to our colleagues and the general public. However, I think there should always be a carefully thought out reason or argument for applying P3DM to a site – it should not simply be done because we can or because the final I3DM ‘looks cool’. Of course valid reasons will vary from site to site but, I believe that considerations into the site environment and conditions are essential reason for applying P3DM. For example, it proved to be a reliable and valuable method for surveying Batavia, a dynamic site that has previously proven too difficult to record with conventional means. Additionally, issues such as limited time at a site, available funding and skill should always be taken into account. What I am arguing for here is a solid purpose for employing these techniques that should be discussed and understood by the project team.

Another vital aspect of the application of I3DMs is their use for public dissemination and communication. Potentially the strongest use for I3DMs of underwater shipwreck sites will be to enlighten and engage the public on UCH. As highlighted at the start of this thesis, the 2001 UNESCO Convention for the Protection of Underwater Cultural Heritage (UN Educational 2001), places a high priority on public engagement mainly due to the inaccessibility and consequent lack of understanding of the finite UCH resources that we have across the world. For sites as remote, dynamic and hard to get to as Batavia, yet with such an infamous story, engaging I3DMs of the underwater shipwreck site can bring the site to the public. While this certainly does not give the public the feeling of actually diving on the site, it does provide them with a means of understanding the details such as the formation of the limestone reef and the sandy hole where the wooden hull once lay, it shows the coral growth and position of the remaining archaeological features. In its simplest form, viewing an I3DM allows the public to know what the Batavia shipwreck site looks like. For example, Mudge et al. state that digital representations can communicate empirical features of real world cultural heritage sites. In particular, they are a strong tool for communicating an idea through a visual context – though not necessarily in a highly accurate manner. Examples of these are the 3D shipwreck models created by 3deep Media. The models they create visualise the sites, as they currently are, with some additional interpretation through ‘info points’ at key locations (3deep 2018). While the models are far more creative and artistic then would be required to convey archaeological information. However, for the purposes of public dissemination and understanding, it does an
exceptional job. Through even a basic understanding of the site, the public can further engage with information and grow a deeper appreciation of the significance of protecting the UCH resources we have.

6.1.4. Enhanced perception through I3DMs of underwater archaeological sites

The level of spatial perception and cognition gained through viewing a site in 3D immediately enhances interpretation. A prime example is Batavia, located on a remote, dangerous reef; the site is inaccessible to the majority of the public. Despite the fame of the shipwreck — due to the tales of murder and well-known hull remains in the WA Shipwreck Museum — there is little public understanding of the site itself. The public may not understand how the marine conditions affect site visitation, what it is like to dive there or even comprehend how large the site is unless they have visited the actual site. The I3DM allows viewers to experience Batavia in an efficient and cognitive way by seeing where the wooden hull once lay (in the sandy pit) and understanding the dispersal of large anchors and cannon across the site. The benefits for communicating underwater archaeology to the public through the use of I3DMs are growing and expanding with each refinement of the technique. An immersive digital 3D model is only the beginning; online digital 3D site-based museums are soon becoming a possibility. For example, research into 3D immersive spaces and virtual reality exhibits within museums includes the work on the world heritage site Vijayanagara (Hampi) in South India by Kenderdine et al. (2009) and the recent work by Kuchelmeister et al. (in press) on an immersive virtual reality exhibit of the Parramatta Girls School in Australia. Significantly, recent work on a virtual reality experience of the Mazotos site (see Chapter 3) (Liarokapis et al. 2017), indicates the wonderful potential of digital immersive experiences, but is not yet at the level required for digital 3D wrecksite-based museums for each shipwreck site.

For archaeologists, the potential to disseminate research results such as surveys, excavations, site conservation and management is complemented by the incorporations of I3DMs. The Swedish Pompeii Project’s use of 3D recording and modelling within an innovative framework highlights the enhanced visual exploration of a large site (Chapter 2). Through the incorporation of laser-scanned and image-based digital 3D models, the Swedish Pompeii team highlighted the potential of having a 3D system for recording, viewing and interpreting data. The I3DMs created within this thesis can be employed similarly. Like the research in the Swedish Pompeii Project and Çatalhöyük (Chapter 3), applying digital 3D models with a GIS interface allows archaeologists to have both an onsite method for continual visualisation and documentation, as well as a highly detailed,
easily understandable tool for interpretation at a later stage. The results of this research were trialled in a GIS environment to provide an indication of how underwater archaeological investigations could also benefit from image-based digital 3D databases throughout excavations. For example, the James Matthews I3DMs were integrated within ArcGIS for enhanced visualisation and cognition (Figure 129). Although this wasn’t a core focus of this study, it indicates that the future for archaeological investigation and reflexive, fluid, digital databases is a promising reality.

However, issues of publication of final I3DMs in standard academic formats, such as academic journals and publications, is proving to be an ongoing battle for cultural heritage professionals engaging with digital 3D technologies. Early incorporation of Adobe 3D PDF’s to academic journals allowed authors to include 3D models, however, this soon proved to have numerous errors across platforms. The recent growth in digital online journals, such as the Journal of Computer Applications in Archaeology (JCAA) and Digital Applications for Archaeology and Cultural Heritage (DAACH) are leading the way for publication of 3D material.
Although there are still issues with how to publish the metadata of 3D models that allows readers to interpret them accurately, and as my research suggests taking this one step further and incorporating paradata. Groups like Force 11 are tackling these problems. Force 11 is a group of publishers, scholars, librarians and archivists who are working towards the improved use of knowledge creation and sharing through information technology (Force11 2017). Force11 aim to transition academic publishing away from traditional print forms and into ways that can embrace digital content (Force11 2017). In addition, the Archaeological Data Service (UK) produced a guide to 3D models in Archaeology that focuses on the preservation and documentation of 3D model datasets for archaeological use (Trognitz et al. 2016). While this guide provides a solid basis for issues such as storage or 3D models and associated metadata that should be recorded, it also highlights the current difficulty of publishing 3D models in academic publications. Until we find a way to reliably publish digital 3D data we will struggle to use them to the highest potential.

It is clear that I3DMs of underwater archaeological sites improves data knowledge and provides new dimensions for interpretation as highly cognitive forms for communicating information. My own experiences throughout this thesis revealed that there are innovative and powerful benefits of viewing, interpreting and understanding an archaeological site in a digital 3D form. For example, my own comprehension of the changes in depth across the Batavia site differed greatly from diving the wreck to then viewing the entire site virtually as an I3DM. What appeared to be large changes to me when in the water were comparatively gradual to the remainder of the site. Additionally, the ability to virtually revisit an underwater shipwreck site at any time (after a single dive to capture photographs) provides the opportunity for further interpretation and understanding of the spatial context of the site. Essentially, the site is preserved as a snapshot, a digital reconstruction, of what it was like at a particular time. Ethically, I3DMs may provide a tool that suits the requirements of archaeologists recording sites to the utmost degree — they preserve information that may be the only remaining record for future work. Above all, they allow archaeologist to perceive the spatial layout and formation of a shipwreck site through a digital medium.

On the other hand, the current lack of a way to also communicate the bias (paradata) behind the creation of these I3DMs is essential to note. For example, currently most I3DMs are uploaded to Sketchfab™ as an easy and widespread way to share moveable models. As
a user of the platform Sketchfab™, I can easily access and view numerous I3DMs of underwater archaeological sites. While some of the basic information about the models is available (e.g. mesh vertices, format and file size), there is a wealth of information not included. Such as the type of camera used, the quality of alignment, how extensively were holes in the mesh ‘filled’ and was this captured over one or multiple dives? The way that I interpret these I3DMs would change and become more informed if I could have both the metadata and the paradata while viewing them.

6.1.5. Legacy data I3DMs
Imagine a future where all data, past and present is integrated and available in a seamless, contextually reliable and spatially correct medium. The innovations and recent advances in P3DM are increasingly bringing us closer to this future. However, before we can achieve this, the management, incorporation and prospect of legacy photographic data need to be determined. My case study in this research involved the James Matthews legacy photos from the 1976-77 excavations. The success of reprocessing legacy data using P3DM depends on the questions to be answered and the overall aim of creating a legacy data I3DM. In this case my aim was to determine if black and white negative photographs — specifically taken for creating photomosaics — could successfully be used within PhotoScan to create a legacy I3DM of the site.

Incorporating the processing of legacy photographic data within this thesis determined that black and white negative film could successfully be digitised and P3DM. Images captured for the purpose of generating a 2D photomosaic of the James Matthews excavated hull in 1976-77 were carefully scanned and processed through PhotoScan with varying results. Unfortunately, the overlap between images was not sufficient to accurately align the majority of images. However, a variety of image sets were successfully reconstructed in small area I3DMs due to higher levels of overlap between selected images (see Figures 62 to 67). In addition, overlaying legacy I3DMs and orthophotos within ArcGIS provided further interpretive benefits. While the use of the 1976-77 site photomosaics of James Matthews was not entirely successful, it proved that there is potential for future modelling of legacy images that will provide significant enhanced interpretation value.

It is pertinent to understand why the majority of photographs did not align in PhotoScan before discussing the successes. As noted in Chapter 5, tests were run to determine if masking out certain sites features enhanced alignment as well as clarifying whether the file format changed the final results. The same settings were used for each image set first
as JPEGs, and then as TIFFs. Sometimes the images aligned in one file format but not in the other (see Appendix D). PhotoScan recommends the either PNG or TIFF file formats are used to create I3DMs so that there is no loss of data through compression that does occur with JPEGs. However, JPEGs were also tested as the majority of Museum’s Department of Maritime Archaeology image files are saved in this format. It is interesting that there was some success with JPEG over the other higher quality formats. What is perhaps more frustrating than significant is that there was no seeming reason for the success or failure with different formats. Although, it is likely that the successful use of the JPEG format for individual image sets acted as a smoothing filter for the high level of ‘noise’ that can occur with underwater images. As a consequence, the only suggestion from this study is that a set of legacy images should be tested as a range of formats in addition to various image-processing schemes (i.e. sharpening, blurring, de-noise etc.) to determine the best processing option. Although, this will add time to the overall process of creating legacy site I3DMs.

Ultimately, incorporating legacy data into I3DMs is a challenging process and this study indicated that varying results could occur. Despite the minimal success in reconstructing the complete James Matthews site through legacy images, the I3DMs do provide a solid partial understanding of the 3D geometry of the site during the 1970s excavations. Foremost, the I3DMs enabled a viewer to comprehend the high relief of the excavated hull structure that may still remain buried today. In addition, there is a known scale within the legacy images and new measurements could be taken from the I3DMs providing a guideline for investigating the buried hull without re-excavating. Although the successfully modelled strips provide some indication the overall geometry and shape of the hull as it was, some also proved to be slightly distorted (see Figure 56). The distortion indicates that there are errors in modelling the hull curvature from the legacy images. Consequently, accuracy of the legacy I3DMs should not be relied upon unless there are known features to georeference to.

This study of the James Matthews site showed that P3DM of legacy data from a site excavated 40 years ago is both a challenging and revealing experience. Despite processing difficulties, the legacy data I3DMs are an example of what good results can be achieved from image-based archival data. There are benefits in creating legacy data I3DMs, as long as it is understood that they may not be spatially accurate. The incorporation of legacy data I3DMs within archaeological research gives the viewer a chance to understand how a
site looked in 3D. Currently, others hoping to incorporate legacy image data into I3DMs could take the following recommendations from this research:

1. Ensure that there is sufficient overlap between legacy images to determine the necessary points
2. Images should be of a high quality (e.g. contrast, pixel resolution etc.) – as with any for P3DM.
3. Trial run some image strips as various formats e.g. JPEG, TIFF or PNG, as some formats may align better then others.
4. Compare the final I3DM to a conventional site plan, if available as a way of determining the reconstruction accuracy of the legacy I3DM.

It is hoped that future P3DM software programs will have better capabilities for accurately modelling legacy visual data. Although archaeologists recorded the hull shape of James Matthews during the excavation, it is currently only viewed as 2D reconstructed ship lines or a table of measurements. On the contrary, despite only minimal success generating the legacy data I3DMs, viewing at least small sections of the site in 3D allow for enhanced cognitive understanding of the hull shape at the time of excavation (Figure 59). Furthermore, interpretations about the site formation processes and potential cargo layouts are easily made from viewing the I3DM, which enables questions about site degradation and artefact location to be answered 40 years after the excavation. Utilising legacy data for P3DM gives us the chance to ask new questions of the site that were unable to be answered when the photographs were taken.

Interestingly, my own understanding of James Matthews increased following the completion of the legacy I3DMs. By viewing the available images and site plan, the geometry of the site and height profile of the remaining structures appears to be very flat, even to an archaeologist. After diving on the site as it is today, the remaining slate pile and windlass indicate that the other buried remains are likely to be horizontal. After processing the legacy data and seeing the reconstructed hull shape of Grid 10, I was sure that there was an error in the final I3DM. However, the grid bar itself was accurate and, when compared to other profile images of the site, I understood that there was far more variation in the overall site geometry when uncovered than is first perceived through the 2D material. The legacy data I3DM certainly enhanced my understanding of the site today, and is a valuable tool to bring the discussion back to issues of perception gained through visual media.
Another way of using the legacy data I3DMs is to export an orthophoto. Overlaying the legacy data I3DM orthophotos and site plans within ArcGIS enabled a higher-level understanding of the site, particularly in terms of site management and monitoring of degradation. Although this is already discussed here regarding the I3DM results from this study, the incorporation of legacy data adds a unique aspect — time. As noted in Chapter 5, perspective distortion from the height of the features on James Matthews eliminated the likelihood of creating a photomosaic. The success, if currently only partial, of the legacy I3DM indicates that comparison with future excavation I3DMs could provide vital comparisons. Comparison of the legacy data orthophotos to the site plan further provides archaeologists with the chance to investigate the accuracy of the manual measurements completed during the excavation, with the reconstructed data in the I3DMs (Figures 130 and 131). For example, if further site excavations are ever completed, the ability to compare the 1970s data to the remaining material will provide a wealth of information about the degradation of the site and overall preservation management.

Figure 130. GIS images of the varying stages of overlap of the 2D orthophotos (ArcGIS).
Hopefully, as digital 3D modelling software advances, more details points and structures will be identified from images and P3DM processing will become more accurate. For example, there is currently substantial research on P3DM of the legacy images from the *Batavia* excavations in the 1970s (Woods et al. 2016 (in press)). In the reference study, the authors rescanned the original legacy black-and-white 1970s photography of the *Batavia* site and applied a range of P3DM techniques to generate I3DMs. What this research found is that there will be varied success with processing legacy image datasets were not captured with P3DM in mind. However, there is a current benefit of adding legacy data I3DMs into a GIS interface — even for areas of partial coverage. The ultimate aim is to successfully recreate a complete legacy site in 3D, enabling a multi-layered I3DM, from the earliest surveys to the most recent and place these in GIS or VR. Using legacy data within this research emphasises the future potential for reprocessing the wealth of photographic data stored in museums and archives. Consequently, the application of new technology, such as P3DM, enables archives to be readdressed and reinvestigated.

6.2. How does P3DM of underwater shipwreck sites fit within a review of the history of archaeological recording?

This thesis highlighted the reliance archaeologists have on visual media to document and communicate data. Stemming from the earliest antiquarians and their fascination of cabinets of curiosity to early imagery within texts such as *Britannia* (Chapter 2). Visualisation of archaeological sites became a centrepiece to the suite of antiquarian and, eventually, archaeological tool sets. Further refinement in the late nineteenth and early twentieth centuries by the likes of Pitt-Rivers and Wheeler brought incited reverence of technical drawings, scientific methodology and routinely following conventions and guidelines for accurately recording archaeological sites. The invention of photography enabled a greater level of detail to be captured by archaeologists and further enforced the ideals of visualisations of sites achieving such high levels of detail they were relied upon.
immensely. The digital era of computers, GIS and digital photography removed the need for highly skilled specialists. Archaeologists can now be of the surveyor, photographer, computer scientist and photogrammetric specialist, all with the help of advanced algorithms and user-friendly software programs. Photogrammetric digital 3D modelling is the current state-of-the-art regarding digital tools and techniques for archaeological recording and visualisation.

Research into both literature and historical sources highlighted one continual trend in underwater archaeology; minimal acknowledgement of larger theoretical issues affecting research and interpretation. I am not arguing that there is a complete lack of research in archaeology and visualisation, as there are multiple, excellent examples that indicate otherwise (reviewed in Chapter 2) (Bateman 2000, 2005; Molyneaux 2013; Moser 1992; Moser 2012, 2014; Moser 2015; Shanks 2013). What is argued throughout this research is the sudden embrace and application of P3DM within underwater archaeology lacks the necessary theoretical acknowledgement of wider visual theories such as ocularcentrism and the rhetoric of imagery. In general, the application of P3DM to underwater sites focuses on the ‘how’. Such as, how can these techniques be applied accurately and, what results are possible. There is no apparent recognition of the ways in which these tools are influencing our interpretations, ideas and conclusions.

A compelling aspect to discuss here is the influence that vision has on our everyday lives. I have investigated this argument throughout this thesis with a specific focus on the subjective influence of photography. In particular, the reliance we have on vision to immediately understand something relates to the rhetoric of imagery and ocularcentrism. Our reliance on visual media leads us to trust images to convey meaning and data in an understandable form, we believe that which we see with our own eyes. When photography is brought into the discussion, the technical manner of photographic equipment and the idea of a photograph capturing reality enhance the belief that photography is a tool for mechanical objectivity. This issue is often overlooked in Western society due to our ocularcentric values, and simply that we believe what we see to be true.

The underlying argument I took throughout this thesis is that the mechanical objectivity of photography and the ocularcentric values of Western society are greatly enhanced with the application of I3DMs. Image-based digital 3D models represent the culmination of an ocularcentric discipline combined with advances in photography, computer vision and software. They are the latest and most advanced equipment for recording and visualising
an archaeological site. However, I3DMs are far more than just a recording tool, they influence the interpretations and cognition of archaeological information. The ease of recording even dynamic, difficult sites is further enhanced by the highly realistic results of the final models. An I3DM is not an exact copy of a site, but the choices and decisions involved in data acquisition and processing stages are hidden behind the realistic qualities of the final product. The ability to easily perceive the information portrayed in I3DMs relates to the ocularcentric values of archaeology; vision is a simultaneous mode to understanding something. Throughout this study it is argued that I3DMs are more than just a tool, they are an illustrative gateway enhanced contextualisation of archaeological information in a manner that is far more usable and easily understandable than traditional databases.

This study indicates that recording the choices and bias behind I3DMs provided an essential technique to look past the impressive and persuasive realistic digital representations. To do this I adopted reflexivity as an underlying theme throughout this study, particularly when addressing the purpose in applying certain techniques. By employing a reflexive approach not just in regards to recording techniques, I encouraged myself to question the influences that human bias has on archaeological research (Chapter 2). For instance, I questioned why I was selecting certain techniques over others to record or communicate information. This included small aspects such as choosing which way to swim across a site to record it, to larger issues like why I was using P3DM at all. Being reflexive highlighted how I made choices that were biased and eventually refined the core aims and purpose of this study. The results of this study suggest that a reflexive process reveals the fluid, evolving nature of archaeological research.

Essentially, because we see photography as a highly technical, mechanical piece of equipment, we automatically accept the created results as the truth. In a small sense, this is true; a camera will capture all of the detail presented to its lens in a photograph. What is overlooked is the power that the camera operator has in choosing what to photograph and what to ignore — the motives behind the work. Whether there is always a motive behind the shot or not is irrelevant. The photographer could be ignorant, limited in knowledge and trained judgement or, they could lack understanding of a camera’s abilities. Regardless, there are conscious and subconscious actions that affect the objectivity of photography. This study argues that the persuasive influence of photography, combined with our reliance on vision to understand meaning and truth, further increases the silent power that I3DMs have on the creation of archaeological data. Even more so, the silent
power of imagery combined with the super realism presented in I3DMs only encourages us to believe exactly what we are seeing. It is easy to forget that they are interpretations and illustrations of a site, and instead we value them as accurate, realistic and reliable copies of a site.

In the light of the overall application of P3DM and I3DMs, the analysis of the epistemology of archaeological visualisation introduced in Chapter 2 is now revisited. In Chapter 2, I proposed that Daston and Galison’s (2007) perception of visualisation and objectivity within science could be refined to suit archaeology and be expanded upon to encompass the current digital era (Figure 132). The experience I gained by applying P3DM enabled a critique of the method and refinement of Daston and Galison’s ideals. In particular, I focus on the effect that employing the final I3DMs has on archaeological interpretation. Firstly, that underwater archaeology is currently engaged in a phase of ‘digital realism’ that is hindering archaeologists’ abilities to engage with archaeological data.

![Figure 132. Refined epistemology of archaeological visualisation based on Daston and Galison’s (2007) Objectivity (modified by M. McAllister).](image)

The current use of P3DM within archaeological research represents a way of embracing the capabilities of digital technologies to ‘capture’ and ‘recreate’ archaeological sites in a realistic, digital form. Advances in digital equipment and computer vision algorithms now enable the transformation of photographs into realistic 3D representations of an archaeological site or artefact. I argue that currently, the application of these techniques has been so fast (due to the user-friendly interfaces) that true understanding of the inner workings of these processes is not entirely understood by archaeologists. Particularly, for maritime archaeologists, recording underwater sites of varying conditions simply with a camera, a scale and a selection of coded targets allow recording with proven accuracy to the centimetre (Henderson et al. 2013; Yamafune et al. 2016). Manually recording sites with such a high level of accuracy was previously only possible in clear, calm underwater conditions. In this way, I3DMs are enhancing our capabilities of recording underwater archaeological sites.
Despite the ability to record and model sites with P3DM, there is still much about the inner workings of programs such as PhotoScan that we do not know. PhotoScan is a closed commercial package. We cannot see its inner workings — how it performs the processing, see intermediate results, or completely understand why things fail when they do fail to process. There is also a lack of clarity about the meaning and impact of various user controlled settings throughout the various processing stages. A variation of levels and quality in the settings can sometimes have major effects on the quality of the final model, and sometimes in subtle ways. Images can be pre-processed to alter colour, pre-filtered masked or cropped to exclude information in the P3DM process with varying results. For instance, every stage has at least three options for reconstructing accuracy or quality (e.g. low, medium or high) and these varying levels can be adapted to suit the purpose of the archaeologist, project or theoretical view. While the highly realistic portrayal of the sites is aesthetically pleasing, it hides the steps and settings chosen by the user to create an I3DM that conveys certain information. The deception is further masked by the current dissemination of I3DMs to both archaeological and non-archaeological audiences. While this study showed that models could have various outcomes concerning the resolution, point cloud and polygon count, final models are currently included in publications and presentations without accompanying information. Another way of looking at this is that there is little scope for representing the uncertainty or potential errors in the resulting I3DMs. Consequently, viewers do not understand exactly what they are seeing in an I3DM.

The lack of acknowledgement by underwater archaeologists of the impact that choices, bias and ocularcentrism have on interpretation indicates that we are indeed currently in a phase of ‘digital realism’ (see Figure 132). This is most evident with the advances in technology and super-realistic results of I3DMs that are swaying the mindset, particularly of maritime archaeologists, to relying on the ‘truth’ and ‘objectivity’ they seemingly portray. It appears that archaeology has made a step sideways by almost re-embracing the ideal of ‘mechanical objectivity’ through digital technologies.

6.3. Summary
This chapter delved into more detailed discussions on archaeological recording, visualisation and theoretical discourse about the results from the photogrammetric recording and 3D modelling of Batavia and James Matthews. It linked reviews of theoretical positioning of archaeological visualisation to the historical background of archaeological reliance on visual media to convey meaning. The underlying issue argued for here is that
users with minimal knowledge of a P3DM program can create highly realistic I3DMs due to the ever-evolving abilities of computer-vision and processing algorithms. This creates a further enhanced use of visual media in a form that hides the fact that all I3DMs are, essentially, archaeological illustrations. Currently, archaeology is embracing digital realism and this chapter argues for continued debate and discussion on how to move forward and turn these recent, eye-catching tools into reliable methods within the archaeological discipline.

If we are to move beyond this phase, we need to begin wider discussions about the implication of so readily applying P3DM within archaeology and the consequences on enhanced or limited interpretations of archaeological data. This new phase could be likened to an advanced stage of trained judgment specifically for computer visualisation and the use of I3DMs. As I3DMs are essentially interpretations of the real site (not exact copies) users need to be armed with sufficient understanding of the biases in creating them. Once this is achieved, the impact and benefits of employing I3DMs will be more reliable. Potentially the answer lies with Moser’s (2012:296) argument that archaeological visualisations are, and have always been, critical gateways for enhanced exploration ideas and concepts. In order to successfully use these ‘critical gateways’ we need to be aware of the specific ways that semi-automated programs are hiding the detailed process from the user. We need to understand how to communicate the underlying bias within the final results and how to address the issues that most greatly affect the final I3DMs through a set of guidelines or standards. Until we embrace the themes investigated here, I3DMs will not be the reliable powerful gateways to enhanced interpretation that they could represent. Consequently, the ocularcentric notions of archaeology will only be strengthened.
7. Conclusions and Future Research

This study showed that photogrammetric digital 3D modelling is possible across varying environmental conditions on underwater archaeological sites. Both James Matthews and Batavia were successfully P3DM with the technique devised from literature reviews and experience. Using a simplified set of equipment, one diver recorded each of the sites across numerous visits and created accurate, engaging and reliable I3DMs. By applying the P3DM method described in this thesis, I was able to engage with the technique as a complete process and understand the implications of employing I3DMs as interpretative illustration tools within archaeological research. A thorough review of the literature surrounding imagery and meaning in archaeology indicated the strengths and weaknesses of P3DM within the overall archaeological process. In particular, I argue that underwater archaeology is currently in a phase of digital realism. We rely on digital tools to provide accurate and realistic ways to record sites without challenging the subjective influences that employing them creates. The only way to move forward as a discipline is to critically assess the use of these illustrative tools and ensure they are employed in reliable and transparent ways.

Reviewing the history of archaeology and imagery over time highlighted a long-term trend of changing perspectives on visualisation and the implications of objectivity within photography. Along with the natural sciences, archaeologists began by attempting to record everything as close to reality as possible until the invention of photography seemed to provide the answer of mechanical objectivity. As the discipline developed, so too did our perspectives on the abilities of human recording and the implications of the perceived capabilities of cameras. By the 1980s, human agency, bias and subjective understanding were well-accepted theoretical positions regarding archaeological recording and interpretation. The application of computers and associated software sparked debate about the potential loss of individuality by the mass processing of archaeological data. From the 1990s, the focus on investigating objectivity through imagery has waned. The influence of digital cameras and computer vision capabilities on ideas of objective recording seemingly went unnoticed in archaeology except for a noteworthy few. Perhaps it is simply that the subjectivity of photography is an accepted fact within archaeological recording. This statement may have proven true, had the recent use of P3DM and I3DMs not been so readily applied and utilised throughout the underwater archaeological community without criticism. Consequently, digital realism defines an almost regressive
stage of archaeologists returning to a reliance on the technological and mechanical capabilities of digital tools. While this may relate to the history of maritime archaeology as a practical pursuit with much emphasis on technical pursuits instead of that on a theoretical discourse that questions results. I argue that it is time to turn away from digital realism and strive for the next level of trained judgement and awareness of the capabilities of computers and digital creations, particularly realistic I3DMs.

Beneficial aspects of P3DM, such as accuracy, speed, enhanced cognitive understanding and spatial representation, promise a bright future for archaeological site recording. Additionally, the evidence that P3DM software programs, such as PhotoScan, are easily used, taught and affordable ensures that these techniques continue to be supported throughout archaeological projects. Higher accuracy with such a small amount of dive time is slowly overtaking conventional methods as a primary recording tool, and the increase in digital 3D modelling may potentially become the main way of communicating results. The ability to communicate ideas, theories and findings to other academics as well as the general public is significantly enriched with the application of I3DMs.

When first attempting to use P3DM techniques it appears that a high level of expertise is not essential for success. In contrast, it is vital to have skill in underwater photography and to have an understanding of the conditions faced on each site and a thorough dive plan before entering the water. Attempting to record a site for P3DM without awareness of the issues encountered when photographing underwater and of photogrammetric requirements such as limited overlap can negatively affects the final I3DM. Nevertheless, having a basic grasp of the expected marine conditions and essential requirements for P3DM ensure that the final I3DM is likely to succeed in spatial coverage and accuracy. While this research shows that good quality photographs, a basic knowledge of the site and a thorough dive plan enhance the P3DM results, the processing stages are a different matter.

Although the interface for PhotoScan is user-friendly and semi-automated, the overall modelling process and the resources available (including the PhotoScan manual) do not fully convey the details needed to understand the inner workings and best options for all stages. I found that throughout all processing stages, a user should have both experience in using the program and comprehensive knowledge of exactly what each setting means for the resulting I3DM. A lack of user experience is potentially mediated with training and guidelines on P3DM using PhotoScan for archaeological and cultural heritage purposes.
As discussed throughout this study, the recent advances in computer vision, combined with algorithms for processing, ensure that the results are super-realistic portrayals of archaeological sites. Uninformed viewers may immediately believe that the I3DM they are interpreting is an accurate digital replica of the site given the realistic portrayal. Using P3DM software, like PhotoScan, to create realistic I3DMs that mimic real sites, is a deceptively powerful tool. The super-realism combined with a high level of textural and spatial accuracy hide the fact that an I3DM is essentially a highly subjective archaeological illustration. Instead archaeologists are currently relying on I3DMs as tools for completely accurate site recording. The general acceptance of complete capture and truth by P3DM encourages their misuse and misunderstanding. Instead, we should think of them as advanced forms of illustrations, reinforcing the creative, subjective aspects of their production.

Often, new techniques are applied within archaeological projects because they are accessible and provide seemingly accurate results. For example, this study suggests that P3DM is currently being rapidly applied to underwater archaeological sites as a tool for recording and measuring instead of simple visualisation alone. By reviewing relevant literature, I identified a common thread of P3DM, particularly with PhotoScan, as an overall lack of deeper understanding and critical evaluation that archaeologists have for the P3DM method and final I3DMs. Consequently, when outlining a potential method for my own P3DM it became increasingly obvious that the semi-automated aspects of PhotoScan and the complex varying stages of processing enable a high level of creative choice, adaptation and bias that are hidden in the final I3DM. As a result, I devised seven themes for discussion to strengthen the application of this technique to underwater archaeology. They are: purpose, methodological rigour and transparency, authenticity and accuracy, complementarity, legacy data, sustainability and access and paradata. All of which proved to be critical points for discussion.

Chapter 6 discussed the results of applying a P3DM methodology to two different shipwrecks sites (*James Matthews* and *Batavia*) with two of the above seven themes continuously proving to be aspects that need more acknowledgement: purpose and paradata. As practitioners of underwater archaeology are quickly reaching a point of familiarity and confidence in the application of P3DM within the archaeological tool kit, it is time that we embrace the necessary theoretical debates to gauge what these tools actually can accomplish. To achieve this, we need to now move away from the ‘how’ and critically look at ‘why’ we are using this technique. Why do we need to apply image-based digital 3D modelling to a site? What is the purpose of applying this illustrative tool? This
thesis addressed these questions by reviewing the use of visualisation within archaeology to better understand the motives and influences of imagery for archaeological interpretation. Ultimately, it is evident that P3DM is often applied without the level of criticism that ensures it is being employed for the right reasons. I think that the best way to determine this is simply questioning whether or not another recording tool could capture certain data more appropriately. The extensive review of the previous application of P3DM to underwater sites, combined with the P3DM of *Batavia* and *James Matthews*, indicate that this tool is best applied on sites that only have small windows of opportunity for recording (i.e. dynamic environments or deep sites). In addition, the complexity of a site’s geometry and spatial layout could lend itself towards benefiting from recording and visualisation through P3DM. From this study, it is clear that P3DM of shallow sites (less than 2m) and those with poor visibility may not provide enhanced forms for interpreting layout or even be successful as a recording tool.

In terms of *paradata*, a reflexive process was adapted specifically for the P3DM method. For this study the reflexive process involved a post-dive write-up (paradata template) of the associated decisions that occurred during a dive. This also required that I analyse the overall dive, the environmental conditions or sudden changes, along with any changes to the recording technique that I made on the spot. Recording this paradata ensured that I critiqued my own choices regarding equipment, recording techniques, focus area, problems and changes on the day. In addition, the template proved to be an excellent tool to easily determine how to improve the next dive or the overall data acquisition technique. Applying this simple, but useful, phase to the recording process guaranteed that the next dive would be well planned and would cater to any previous issues encountered. To encourage a reflexive process in applying P3DM, regularly returning to the ‘why’ of any research is essential.

A reflexive approach is also relevant in terms of the ocularcentric tendencies of western archaeology. Ocularcentrism and the rhetoric of imagery are core theoretical topics in this field – our dependence on imagery to communicate details is enhanced through the use of P3DM to record and visualise archaeological sites. Understanding and acceptance of ocularcentrism and the rhetoric of imagery are growing within archaeological discourse. Unfortunately, although underwater archaeology is a sub-discipline, there is little acknowledgement of these theoretical positions within underwater archaeological research. Photographs and imagery are accepted as methods of capturing accurate site representations primarily due to the difficulties of working in marine environments. I am not arguing that all underwater archaeologists consciously ignore the subjective influences
that imagery. Rather the issue is that it is not revisited in a manner to remind us all of the dangers in relying on visual media as a form of data communication.

Photogrammetric digital 3D modelling is the next step towards innovative 3D research. From surveying, planning excavation methods, recording excavation, visualising a site, testing hypotheses and theories to interpreting data – the future of archaeological research through P3DM will enable immersive digital 3D frameworks for all levels of archaeological investigation. There is future potential to mould a fascinating and engaging discipline that can communicate archaeological principles on a global level. Overall, the rapid application and success of P3DM represents a turning point for underwater archaeologists. It serves as a timely reminder to always maintain our critical edge and there is much more work needed to integrate P3DM into the suite of reliable and accurate techniques for underwater archaeological recording.

The analysis and discussion within this study show that the use of P3DM has powerful implications regarding the rhetoric of imagery and the super realistic portrayals that the models create. As archaeologists viewing an I3DM it is easy to overlook the fact that it is based on photographs taken by someone with a purpose in mind. However, as highlighted extensively throughout this study, this can be mediated through a self-reflexive and critical process. The results of this research indicate that there is success in recording the motives and choices behind a final I3DM.

Along with other digital 3D modelling technologies, P3DM represents the next stage in underwater archaeological recording. It combines speed, accuracy and enhances visualisation techniques. Using this technique on underwater sites, particularly those with dynamic conditions, provides more accurate data and an ability to interpret detailed site representations than conventional techniques. Furthermore, the integration of I3DMs within programs like ArcGIS allows for updated, 3D perspectives of a site. If used appropriately, P3DM can offer a higher cognitive understanding of aspects of an underwater archaeological site. Not only do archaeologists benefit from this enhanced understanding, but it also enriches our ability to engage with the public and train the next generation of diving archaeologists. Overall, it can be used to provide a new way of viewing and interpreting archaeological data.

James Matthews (1841) and Batavia (1629), two WA shipwreck sites, were successfully recorded with digital photography. The resulting images were used within the semi-automated photogrammetric 3D modelling software to create spatially reliable digital 3D
models. From this application it became clear that we are now capable of employing these tools to record dynamic sites in a relatively short amount of time. Not only is the acquisition of data during a dive faster and more spatially accurate, but also the resulting I3DMs allow for enhanced data knowledge through the representation of a highly spatially accurate complete site in combination with the realistic representation of texture and colour of features for virtual measurement and interpretation.

This study also showed that these recent advances in technology, algorithms and computer vision allow archaeologists to complete site recording in a quick and easy manner. This research indicated that, as a discipline, archaeology relies heavily on visual media for communication of both data and understandings. I argue that the application of P3DM is only going to increase the reliance we have on visual media. Unaware and ignorant use of I3DMs threatens to hide subjective influences behind super realistic digital representations. The application to both James Matthews and Batavia indicated that recording paradata throughout the P3DM is essential in creating reliable, repeatable results. Further, the application of seven themes for discussion ultimately indicated that the rhetoric of imagery is reduced when employing a reflexive and self-critiquing approach. Above all, this study point out the lack of standards for best practice and provides a starting point for increased awareness of visualisation and archaeology, aiming to incite further discussions, debates and, ultimately, to enhance the theoretical ideals of underwater archaeology.

The application of P3DM to archaeology is a successful catalyst for raising and actively engaging in debates that enhance our understanding of interpretation and agency issues. The super realistic appearance of I3DMs is likely to improve in the future and, if not reviewed adequately, poses a threat of further hiding the level of ocularcentrism in archaeology. To combat this, we need to seek reliable methods for reflexively assessing P3DM and recording our motives and choices, so that others know the potential limits and strengths of what we created.

This study hopes to reignite the discussions on visualisation and archaeology, which peaked in the 1990s, now with a particular focus on the application of P3DM to underwater archaeological site interpretation. The creation of seven themes for discussion began a deeper analysis of the influences that an I3DM has on interpretation, but mainly sought to be a technique for analysing how this technique can become more reliable. It is hoped that the seven themes will become a basis for the creation and application of a set of standards and guidelines for reliable incorporation of P3DM within archaeological
research. Overall, more testing and training, conferences and workshops are needed to refine the methods and spark debates and discussions on the best way to move forward with digital 3D technologies and archaeological interpretation.

Although a solid recommendation for the best standard of practice for P3DM of underwater shipwreck sites cannot be determined from this study alone, the research compiled here does allow the suggestions of some key points to consider. First, as I have highlighted throughout this thesis, employing a reflexive approach to P3DM is essential to capture the choices, personal bias and hidden influence of imagery. To do this, I suggest employing a simple form of personal debriefing to P3DM, such as the paradata template I devised for this research. This template should include the basics from camera equipment, camera settings, processing settings, software used through to the choices of ‘swim-path’ areas not recorded, environmental conditions and the objective of the survey. I think it is vital to have a section that asks for critical evaluation of the process, including the purpose and arguing for the use of this tool. To further encourage a reflexive process for P3DM on larger projects I think that the whole team should be briefed on the application of P3DM and why it is being employed. The theoretical underpinnings of ocularcentrism and how it can influence us to rely on photorealistic detail should be clearly conveyed to the team – even to those who are already aware – this would encourage all team members to interpret the final I3DMs with a critical ‘eye’.

Second, I argue for the use of P3DM in conjunction with other conventional recording methods (when possible). Such conventional tools as a simple manual recording of some structures for known dimensions to reference the final I3DM ‘s to, or other 3D digital recording technologies, for example Reflective Transformation Imaging (RTI) or laser scanning. This would provide a reliable comparison of the spatial accuracy of the final I3DM and both tools may complement each other in recording aspects that the other cannot represent. In addition, comparison to other recording techniques would also continue to encourage critical viewing if I3DMs.

Lastly, I would suggest the following inclusions into a set of guidelines for best practice to reliably P3DM of underwater archaeological sites. That dissemination of both the metadata and paradata are as vital for informed interpretation of the final I3DM and should include the following:

1. Data acquisition
   a. Camera equipment
   b. Camera settings
c. Scales/coded targets
d. Site conditions and encountered issues

2. Processing
   a. Computer equipment
   b. Software utilised
   c. General settings selected (i.e. quality of alignment)

3. Post-processing
   a. Mesh visibility along with texture and point cloud
      i. For example: polygon count, quality, cameras aligned, standard error etc.

4. Dissemination of the I3DM
   a. Purpose of the I3DM
   b. Any errors, gaps or issues encountered with processing

The above suggestions are intended to stimulate discussion and are the basis of a movement towards a way of validation P3DM as a reliable tool for both archaeological recording, and as a powerful medium for public engagement and education of underwater cultural heritage resources.

The future application of digital 3D tools for both archaeological research and public dissemination of information is promising. Increasingly methods for engaging with digital visualisations are becoming more affordable and pushing the boundaries of both computer vision and technological capabilities. Immersive virtual reality environments now allow archaeologists to virtually wander through a complete site excavation stage-by-stage. Where once this was only available in specially constructed visual labs, now affordable equipment such as the ‘Oculus Rift’ headset manufactured by Oculus VR, and even Google’s ‘Cardboard’ VR headset allow us to explore these virtual worlds in our own homes – at low cost. In terms of P3DM, it is likely that this tool will continue to develop as a primary source of data for both I3DMs and virtual realities of UCH. So, a theoretically aware approach to recording for P3DM and how it influences the interpretations we make of sites is invaluable. It paves the way for all future interpretations based on this image data.

The culmination of both a thorough literature review into photography, visualisation and photogrammetric digital 3D modelling, combined with the results of applying P3DM to underwater shipwreck sites in WA revealed a lack of debate, discussion and acknowledgement in the literature of the influences and silent power that P3DMs have on
archaeological interpretation. What is needed for P3DM techniques to move forward within underwater archaeology is an extended and continued debate to validate what we do. This debate may ensure that there are standards for the creation of digital 3D models (not just image-based) for use within archaeological research. Much like the London Charter and the Principles of Seville succeeded in starting, underwater archaeology needs to push for a set of guidelines, standards or themes that relate specifically to the advancing field of P3DM. As technology evolves, computer visualisation will become more and more realistic. Therefore, the discussions that should begin now will only continue to be essential to our discipline. It is hoped that this research provides a stimulus for rumination and further discussion on visualisation, photography and interpretation within archaeology.
References


Anon. 1923 Deep sea thrillers in natural hues for the movies: Bonnier Corporation. 102.


Beacham, R., H. Denard and F. Niccolucci 2006 *An Introduction to the London Charter*.
Berry, D. and M. Dieter 2015 *Postdigital aesthetics: art, computation and design*: Springer.
Berry, D.M. 2015 *Critical theory and the digital*: Bloomsbury Publishing USA.
Bourke, P. 2013 *Workflow for reconstruction using PhotoScan: a beginners guide*.
Bruno, F., A. Gallo, F. De Filippo, M. Muzzupappa, B. Davide Petriaggi and P. Caputo 2013 3D documentation and monitoring of the experimental cleaning operations in the underwater archaeological site of Baia (Italy).


Capper, J.E. 1907 XXIII.—Photographs of Stonehenge, as seen from a War Balloon. *Archaeologia* 60(2):571-571.


Deetz, J.J.F. 1965 *The Dynamics of Stylistic Change in Arikara Ceramics*: University of Illinois Press.


Harp, E. 1975 *Photography in archaeological research*: University of New Mexico Press.
Henderson, G. 2007 *Unfinished Voyages: Western Australian Shipwrecks 1622-1850*. Crawley, Western Australia: University of Western Australia Press.


Hodder, I. 2006 *Çatalhöyük, The leopard’s tale: revealing the mysteries of Turkey’s ancient ‘town’*. London: Thames & Hudson Ltd.


Holt, P. 2017 *Site Recorder 4 Software*. Retrieved August 26 from 
http://www.3hconsulting.com/ProductsRecorderMain.html.


Kuchelmeister, V., L. Hiberd and A. Davies in press Affect and place representation in immersive media: Parragirls past, present project.1-8.


Lercari, N. 2017 3D visualization and reflexive archaeology: A virtual reconstruction of Çatalhöyük history houses. *Digital Applications in Archaeology and Cultural Heritage*.


Manley, J. 2014 Archaeology.


Paterson, A. and D. Franklin 2004 The 1629 mass grave for Batavia victims, Beacon Island, Houtman Abrolhos Islands, Western Australia. *Australasian Historical Archaeology* 22:71-78.


Richards, J.D. and N.S. Ryan 1985 *Data processing in archaeology*. CUP Archive.


Richards, V.L., I. MacLeod and P. Veth 2014 *The Australian Historic Shipwreck Preservation Project: In-situ preservation and long-term monitoring of the Clarence (1850) and James Matthews (1841) shipwreck sites*. Proceedings of the 2nd Asia-Pacific Regional Conference on Underwater Cultural Heritage.


Roghi, G. 1959 La seconda campagna di scavo sotto marina sulla nave romana di Sparghi (Sardegna). *Rivista di Studi Liguri* 25.


Scollan, I. 1982 Thirty Years of Computer Archaeology and the Future, or Looking Backwards and Forwards at the Same Time While Trying Not to Twist One's Neck. Computer Applications in Archaeology 1982, Centre for Computing and Computer Science, University of Birmingham, Birmingham.


Skarlatos, D. and M. Rova 2010 Photogrammetric approaches for the archaeological mapping of the Mazotos shipwreck. 7th International Conference on Science and Technology In Archaeology and Conservation, Petra.


Torres, R.O. 2015 The archaeology of shore stranded shipwrecks of Southern Brazil, Texas A&M University,


Yamafune, K. 2016 Using Computer Vision Photogrammetry (Agisoft PhotoScan) to record and analyze underwater shipwreck sites, Anthropology, Texas A&M University.
Introduction

Regularly utilised software programs for 3D modelling and rendering, such as PhotoModeler, often require complex camera calibration before recording images of a site to Past software programs that are associated with image-based recording for 3D digital visualisation often recommend or require cameras to be calibrated before being able to capture images of a site. This ensures that the camera dimensions and specifications are pre-known to the program. Advances in computer algorithms and the evolution of programs such as Agisoft’s Photoscan have the ability to calibrate a camera but potentially do not need it. The following pilot project was conducted to determine if this was a requirement for highly detailed visualisations.

Aims

To calibrate selected cameras as recommended by Agisoft software programs Lens and Photoscan for image-based recording and processing of 3D digital visualisations.

To discuss the effect on the digital visualisation with calibrated vs. non-calibrated and determine if it is necessary in order to achieve more spatially accurate models.

Conditions

Time: 9:00 am
Weather: Windy, overcast.
Temperature: 19°C

Location
University of WA – Unipool
Medium sized outside (chlorinated) pool – maximum water depth – 2 metres

Equipment
Cameras: (add in specifications of each camera)
- Canon G1X in (Ikelite) housing
- Sony RX100 II in Ikelite Housing (both with and without Wide Angle lens)

Calibration Sheet:
In order to calibrate the cameras, an A1 sized grid made using Adobe Illustrator by Paul Bourke at iVEC@UWA. This grid was based on the recommended calibration sheet from Agisoft Lens so that the program could use it. Simple black and white check board style [matte laminate (to reduce reflection) from Uniprint campus ($40.50)]. The calibration sheet was then attached to a stainless steel sheet (dimensions + thickness) using standard masking tape so that it remains completely flat. Attached to a steel sheet so that it stays both flat and on the floor of the pool Using brown masking tape.

Test features:
One piece of 2 inch x 4 inches pine approximately a metre in length. The other part of the test feature is one red/brown brick with a shallow depression on the topside. The weigh down the pine a small 3 pound dive weight to hold down the other end of the pine.

Computers
Valium
Dell Inc. Precision T7610
2.70 gigahertz Intel Xeon E5-2697 v2 (2 installed)
262090 Megabytes Usable Installed Memory
NVIDIA Quadro K5000 [Display adapter]
NVIDIA Tesla K20c [Display adapter]

Xanax
Dell Inc. Precision WorkStation T7500
2.67 gigahertz Intel Xeon (2 installed)
131070 Megabytes Usable Installed Memory
NVIDIA Quadro 6000 [Display adapter]

Method
The entire recording of images for calibration was taken by one snorkeler diving down to an appropriate depth to record 2-3 images and then surface for air. [note: snorkelling is tiring and not the best for calibration, next time plan to complete the calibration using SCUBA]

The calibration board was placed in the southwest corner of the pool, in the last lane at the deepest end. The pool lanes are marked with dark blue tiles in the form of a line and a ‘T’ at each end. For scaling purposes and as a future reference, the pool floor tiles were measured (width of one tile is 117 mm per tile and 242 mm across both tiles that make up the dark blue line on the pool floor).

Recording:
1. Canon G1X was used initially followed by the Sony RX100II (both with and without the wide angle lens) The aim was to have the screen completely filled with as much of the grid as possible, as per the instruction from the Agisoft Standard Lens calibration program.

2. **Canon G1X:**
   - Five images were recorded for calibration, ensuring that the entire image was filled with the calibration board, images taken from different angles (See figure 2).

3. **Sony RX 100 II:**
   - Only 3 images were captured with the Sony RX100 II (see figure 2)

4. **Sony RX100 II + wide-angle lens:**
   - Six images were recorded with the wide-angle lens added.
   - A far greater field of view meant that much more of the calibration board was visible. (see figure 2)
5. The same process was then repeated, this time to record the test feature for 3D digital visualisation. The process for recording the test feature was based on the recommended practices of Agisoft Photoscan. This includes recording each structural aspect in at least 3 images, ensuring a high amount of overlap. Also a set of images was recorded at floor-level, moving around in a circle, then moving the angle of the camera up and repeating this process.
   a. G1X – 19 images recorded
   b. Sony RX100 II – 24 images recorded
   c. Sony RX 100 I + wide-angle – 29 images
NOTE: misread the Agisoft Lens manual — more than 3-4 images should be taken and from each of the different angles. Instead I recorded approximately 8-10 for the entire calibration.

NOTE: The depth of the pool (approximately 2 metres) and undertaking the calibration and testing on snorkel proved to be an issue. Working hard to dive down, line up an image, stay still and take a focused shot was tiring. On average 2-3 images were taken on each ‘dive’. This depth was acceptable, as it is more likely to provide similar conditions to the shipwrecks sites (illumination, depth etc).

Calibration and processing

The processing on both the XANAX (PC) and VALIUM (PC) computers at iVEC@UWA. High-end processing computers with both Agisoft Photoscan Professional and CloudCompare licenses.

Calibration method:
1. Images for each camera were loaded into Agisoft Lens for calibration.
2. The setting for calibration were selected as follows:
   a. Fit aspect
   b. Fit k1, k2, k3, p1 and p2 – radial distortion following the Brown’s model
   c. Fit CX – x coordinate of the principal point
   d. Fit CY – Y coordinate of the principal point
3. Calibrations were then saved as .xml files to be employed by Agisoft Photoscan.
Processing method:

1. Images were imported as jpeg files (this was the practice that the author is familiar with, since this this testing it is apparent all images should be imported as RAW/PNG image files to ensure the highest resolution and minimal compression of images.
2. The calibration was imported from the saved .xml files.
3. The following settings for aligning the images were selected:
   a. Accuracy: Medium,
   b. Pair pre-selection: Disabled,
   c. Point limit: 200000.
   d. Only one image for the G1X did not align.
4. In order to build a dense point cloud of the test structures the following settings were selected:
   a. Quality: Medium
   b. Depth Filtering: Moderate
5. For the third phase of processing, building a mesh the following settings were selected:
   a. Surface type: Arbitrary
   b. Source data: dense cloud
   c. Polygon count: high
   d. Interpolation: enabled (default)
6. Texture building settings:
   a. Mapping mode: Generic
   b. Blending Mode: Mosaic (default)
   c. Texture size/count: 4096 x 4
   d. Colour correction NOT selected
7. The entire process was then repeated for each camera and then once more minus the calibration imported from lens.

The processing time proved to be minimal as approximately 25 images were taken for each camera. Some issues that occurred when processing the images included the shadow from overhang of having the brick sit diagonally across the pine. The author is aware that reconstruction of features dealing with height and multiple aspects needs at least 3 image of each ‘feature’ to be taken at the same degree of altitude before moving on.

Results

The following results were recorded for each model:

**G1X - calibrated**
- Cameras: 18/19 aligned
- Tie Points: 2,955 points
- Dense Cloud: 650,259 points
- 3D model: 179,999 faces

**G1X – uncalibrated**
- Cameras: 19/19 aligned
- Tie points: 2,825
- Dense Cloud: 668,127 points
- 3D model: 179,999 faces

**Sony RX100 II calibrated**
Cameras: 22/24 aligned
Tie Points: 3,604
Dense cloud: 904,687 points
3D Model: 180,916 faces

Sony RX100 II uncalibrated
Cameras: 22/24 aligned
Tie Points: 3,584
Dense Cloud: 753,225 points
3D Model: 179,999 faces

[Note: the smaller numbers given in the above two models are due to the author reducing the size of the box surrounding the models so less was needed to process the models.]

Sony RX100 II + wide-angle calibrated
Cameras: 29/30 aligned
Tie Points: 4,535
Dense Cloud: 1,424,425 points
3D Model: 284,878 faces

Sony RX100II + wide-angle uncalibrated
Cameras: 29/30 aligned
Tie Points: 4,457
Dense Cloud: 1,402,627
3D Model: 280,518 faces
Appendix B – Paradata examples

2.1 Paradata for Dive 1, September 2015

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>to complete a preliminary test dive to gain experience recording part of an underwater shipwreck site for 3D digital visualisation. To use and test new photographic equipment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodological rigour and transparency:</td>
<td>I chose to follow the recommended practices from the Agisoft Photoscan manual. Mainly this involved circling the slate mound at the lowest level, middle and then the highest to ensure complete coverage. No targets or scales were included which is not ideal but, as this was simply a test run it was not a priority. Looking back at this now, it was not ideal and as part of good archaeological methodology, a scale should always be included for reference and any future use of images.</td>
</tr>
<tr>
<td>Accuracy and authenticity:</td>
<td>the images were not pre-processed in terms of colour correction or any sharpening filters. They were captured in a RAW format, converted to PNG for processing in Agisoft. From there all stages of the modelling were completed, from aligning of images through to texture. All settings were kept in the mid-range. However, the notes from processing these were lost and the exact point limits (amongst other factors) are not known.</td>
</tr>
<tr>
<td>Complementarity:</td>
<td>no other methods were completed as part of this test run as it was not necessary to gauge scale etc, merely to gain experience in the recording and processing stages.</td>
</tr>
<tr>
<td>Sustainability and access:</td>
<td>all images are stored with the WA Museum so that they can be used for future research at any stage.</td>
</tr>
<tr>
<td>Reflexivity through paradata:</td>
<td>I chose to record just the slate pile as it is an easily recognisable feature of this site, it also proved to be an ‘easy’ first test run in the water to record both oblique and horizontal structure. I chose not to use a scale or targets at the time because I aimed to gain experience with the techniques and methods recommended with Photoscan and become familiar with the camera equipment.</td>
</tr>
</tbody>
</table>

2.2 Paradata for Dive 2 on Batavia, November 2016

| Purpose: | The purpose of this dive was to improve on the previous photographic recording of the site from 2014. Overall, the aim is to acquire a set of photographs that can be used to create a digital 3D model of the site for future archaeological interpretation and enhanced understanding of the site. The purpose was to ensure that as much of the site was photographed for 3D digital modelling as possible. It is part of this PhD research and forms part of a wider attempt at refining the method for recording sites with this technique that have particularly dynamic conditions. |
| Methodological rigour & transparency: | The method for photographing the site was based on the recommended practice devised in the previous chapter. However, adaptations were made to deal with the environmental conditions. (1) visibility was excellent at 20m + this therefore enabled the option to take photographs higher above the site (2) swell, this provided some hindrance in both taking the photographs at a steady rate with consistent overlap, secondly the coded targets were potentially moved and flipped over at points. I made the decision to leave them as they were for the duration of the survey as they were not going to stay even if I ‘fixed’ them once again. Unfortunately, this may mean that there are some irregularities with processing but this is the best case for the results. This provides a recommendation for future attempts in recording this site – or others like it – to change the style of the coded targets as the surface is either turbulent sand or hard limestone reef so pinning something down is illogical. My aim was to cover in great detail the white sand hole and the close surrounding cannon and anchors. Anything more then that was a bonus and added when I felt that the first part was completely recorded. |
| Authenticity & accuracy: | A 1 x 1m cross bar scale was securely placed on the site as a form of measure and scale. The cross bar could be folded into a single bar which was essential to safety and traversing the site in swell. Coded targets were placed around the site to enhance the accuracy of the processing and photo alignment. TO be added to when processing complete. |
Paradata:
I chose to use the Museum’s camera set up for this dive – previously I have used my own Sony RX100 2. The Museum camera is a Sony NEX7 in a Nauticam housing with a Nikonos lens. The wider angle is specifically designed for underwater photography and allows me to capture more detail per image. I knew that my time on the site could be limited due to rising swell conditions so I set certain priorities of the site to capture first. I knew from the dive in 2014 that the sand hole was successfully modelled because of the sand ridges – they proved to be a useful feature and easily recognised by Photoscan. I set the coded targets on surfaces close to the anchor and cannon that were away from the sand patch to ensure that aspects of this were close to necessary targets that would be needed for processing later to help with alignment. I chose to go along the site in north-south transects as this was going with the swell flow (from deep to shallow) and going across the site would have resulted in much less continual coverage as I swam. I then went closer to the sea floor and took photographs looking at the side of the site to cover the oblique angles and vertical faces of the site and structures etc.

What would I have done differently? Only changed the coded targets to be heavier and smaller to sit on the sea floor in the swell. I expected the direction of the swell and understood what the site comprised of so I was prepared in the method for photographing.

Biases? Focusing on one part of the site – this could be a future bias that means that research on the most shallow aspects is missing? Why was the priority on the deeper part of the site? More interesting – to whom? Me because it will provide the most dynamic uses for 3D digital modelling and future incorporation of legacy data.

2.3 Dive No. 6: December 5 2016

Documenting Paradata of photographic recording – James Matthews

Dive: #6
Date: December 5 2016

Purpose:
The aim for this dive on James Matthews was to use a different camera to all previous dives – the Sony A7 in a Nauticam housing with a Nikon UW-Nikkor lens.

Due to previous dives resulting in difficulties in processing a complete model – despite a good and adequate coverage of the site, it was determined that the narrow lens of the Sony RX1002 was the limiting factor. Therefore, this dive aimed at completing a full site recording. I knew that I had captured some high quality data for the two main visible structures – the slate mound and the windlass – as well as the iron deck frames, so the main focus was on capturing adequate overlap of the site from a ‘site plan’ perspective.

Methodological rigour & transparency:
The same swim path as recommended by Kotaro Yamafune (see chapter 4) was enlisted in this dive, with a few minor changes. Because the focus of the site is inside the barrier area, coded targets (total of 10) were placed inside the barrier area – instead of adding an encircling set of targets as well. Secondly, I began recording at the stern end (NW) of the site and immediately began transect lines across the site, once completed I then completed longer transects at 90 degrees. Following this I submerged further and captured obliques of the two main features and then recorded the obliques of the barriers encircling the site.

The shallow water is a real issue in recording, a much better overlap and view could have been captured if the site was another metre deeper – instead of 2 metres. Also I noticed a large increase in the weed growth on the site particularly on the barriers, but also on the windlass. This may affect processing and aligning of those features covered in weed – although this also wasn’t a problem for the first Batavia dive so it should not matter too much for this one.

Authenticity & accuracy:
I included a large 1 x 1 m scale square for this dive in order to provide a scale for the entire site. When I tried to place it on the site it would not sink and sit on the bottom – however, it did stand upright. At the time I thought this would provide an indication of depth and scale on a three-dimensional level as well as having the one metre bar (one side of the square) sitting on the sea floor.

The images were recorded in RAW format to later be converted to PNG for use in Photoscan.

Paradata:
My choices for using the camera relate mainly to the recommendations by the extremely experienced team within the maritime archaeology department – the use of the Nikkon adaptor lens is also based on their experience and noted the best data capture photographically underwater. Further to this the Sony A7 has brilliant capabilities of photographing continuously (approximately 1 image per second) that allowed me to focus on the dive and ensure that I was completing each run with adequate overlap to the previous run.

Because my focus was on the visible shipwreck features on the inside of the barriers I chose to start recording with the transects (west to east) instead of the capturing circle as Yamafune recommends – to ‘lock’ the site in. I did however complete this at the end as I had enough time and memory to complete this as the second priority.

I chose to only use 10 coded targets that adequately covered the ‘bare’ sandy patch between easily identifiable structures. This coverage seemed to work well.
Appendix C – Results tables

3.1 List of *James Matthews* excavation related B&W negative film from WA Museum catalogue

<table>
<thead>
<tr>
<th>Film number</th>
<th>Description</th>
<th>Date</th>
<th>File format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1094</td>
<td>Above Water, Underwater 1975-6, Mark Staniforth</td>
<td>1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>1095</td>
<td>Underwater 1975-6 Mark Staniforth</td>
<td>1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>1097</td>
<td>Timber plans</td>
<td>nd</td>
<td>jpeg</td>
</tr>
<tr>
<td>1671</td>
<td>Underwater 1975-6</td>
<td>1975, 1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>3842</td>
<td>Aerial photographs</td>
<td>19751106</td>
<td>jpeg</td>
</tr>
<tr>
<td>222</td>
<td>Underwater, first inspection</td>
<td>19730823</td>
<td>jpeg</td>
</tr>
<tr>
<td>236</td>
<td>Inspection, probing, underwater</td>
<td>19731125</td>
<td>jpeg</td>
</tr>
<tr>
<td>299</td>
<td>Underwater wrecks miscellaneous excavation</td>
<td>19740605</td>
<td>jpeg</td>
</tr>
<tr>
<td>449</td>
<td>Underwater</td>
<td>1975</td>
<td>jpeg</td>
</tr>
<tr>
<td>450</td>
<td>Underwater</td>
<td>19750400</td>
<td>jpeg</td>
</tr>
<tr>
<td>451</td>
<td>Rope and Rigging, underwater</td>
<td>19750200</td>
<td>jpeg</td>
</tr>
<tr>
<td>452</td>
<td>Underwater, Photomoasic</td>
<td>19750306</td>
<td>jpeg</td>
</tr>
<tr>
<td>474</td>
<td>1975-6 excavation, airlifting</td>
<td>19751204</td>
<td>jpeg</td>
</tr>
<tr>
<td>475</td>
<td>1975-6 Excavation</td>
<td>197512</td>
<td>jpeg</td>
</tr>
<tr>
<td>478</td>
<td>Excavation Airlifting</td>
<td>19751211</td>
<td>jpeg</td>
</tr>
<tr>
<td>479-481</td>
<td>1975-6 excavation, survey, grid frame</td>
<td>1975-1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>482-3</td>
<td>1975 Excavation</td>
<td>19760108-12</td>
<td>jpeg</td>
</tr>
<tr>
<td>484-487</td>
<td>1975-6 Excavation, right and left stereo</td>
<td>1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>488</td>
<td>1975-6 Excavation</td>
<td>19760121</td>
<td>jpeg</td>
</tr>
<tr>
<td>490</td>
<td>1975-6 Excavation</td>
<td>19760127</td>
<td>jpeg</td>
</tr>
<tr>
<td>492</td>
<td>1975-6 Excavation, stereo left &amp; right, birch broom</td>
<td>19760201</td>
<td>jpeg</td>
</tr>
<tr>
<td>493</td>
<td>1975-6 Excavation, birch broom, bottles</td>
<td>19760206</td>
<td>jpeg</td>
</tr>
<tr>
<td>494</td>
<td>1975-6 Excavation</td>
<td>19760206</td>
<td>jpeg</td>
</tr>
<tr>
<td>495</td>
<td>1975-6 Excavation, stereo left &amp; right, iron pots</td>
<td>19760210</td>
<td>jpeg</td>
</tr>
<tr>
<td>496</td>
<td>1975-6 Excavation, double pulley block, leather shoes</td>
<td>19760210</td>
<td>jpeg</td>
</tr>
<tr>
<td>497</td>
<td>1975-6 Excavation, shoes, rope, chessman</td>
<td>19760213</td>
<td>jpeg</td>
</tr>
<tr>
<td>498</td>
<td>1975-6 Excavation, chain leg</td>
<td>19760216</td>
<td>jpeg</td>
</tr>
<tr>
<td>499</td>
<td>1975-6 Excavation</td>
<td>19760216</td>
<td>jpeg</td>
</tr>
<tr>
<td>500</td>
<td>1975-6 Excavation, rope and rigging</td>
<td>19760218</td>
<td>jpeg</td>
</tr>
<tr>
<td>502</td>
<td>1975-6 Excavation, Photomoasic</td>
<td>19760219</td>
<td>jpeg</td>
</tr>
<tr>
<td>503-505</td>
<td>1975-6 Excavation</td>
<td>19760220-21</td>
<td>jpeg</td>
</tr>
<tr>
<td>507-515</td>
<td>1975-6 Excavation</td>
<td>19760224-29</td>
<td>jpeg</td>
</tr>
<tr>
<td>597-603</td>
<td>Underwater</td>
<td>19770211-20</td>
<td>jpeg</td>
</tr>
<tr>
<td>606-609</td>
<td>Underwater</td>
<td>19770220-0302</td>
<td>jpeg</td>
</tr>
<tr>
<td>611</td>
<td>Photogrammetry, Underwater tests</td>
<td>19770301</td>
<td>jpeg</td>
</tr>
</tbody>
</table>

3.2 Markers and accuracy of each chunk.

<table>
<thead>
<tr>
<th>Point number (shows some overlaps)</th>
<th>Projections</th>
<th>Error (pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52</td>
<td>128.063</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>2.937</td>
</tr>
<tr>
<td>2</td>
<td>108</td>
<td>152.749</td>
</tr>
<tr>
<td>3</td>
<td>29</td>
<td>60.807</td>
</tr>
</tbody>
</table>
### 3.3 List of film numbers that were rescanned for processing.

<table>
<thead>
<tr>
<th>Film Number</th>
<th>No. Images</th>
<th>Need to be rescanned?</th>
</tr>
</thead>
<tbody>
<tr>
<td>481</td>
<td>27</td>
<td>Yes - jpegs</td>
</tr>
<tr>
<td>482</td>
<td>24</td>
<td>Yes - jpegs</td>
</tr>
<tr>
<td>483</td>
<td>37</td>
<td>Yes - jpegs</td>
</tr>
<tr>
<td>486</td>
<td>20</td>
<td>Yes - jpegs</td>
</tr>
<tr>
<td>487</td>
<td>20</td>
<td>Yes - jpegs</td>
</tr>
<tr>
<td>488</td>
<td>37</td>
<td>Half done (20-37 already tiffs)</td>
</tr>
<tr>
<td>489</td>
<td>24</td>
<td>Yes - jpegs</td>
</tr>
<tr>
<td>490</td>
<td>27</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>492</td>
<td>15</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>493</td>
<td>33</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>494</td>
<td>?</td>
<td>Yes – unscanned</td>
</tr>
<tr>
<td>495</td>
<td>?</td>
<td>Yes – unscanned</td>
</tr>
<tr>
<td>497</td>
<td>19-27</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>498</td>
<td>30</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>499</td>
<td>28-42</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>500</td>
<td>?</td>
<td>Yes – jpegs</td>
</tr>
<tr>
<td>502</td>
<td>?</td>
<td>Yes – unscanned</td>
</tr>
<tr>
<td>503</td>
<td>?</td>
<td>Yes – unscanned</td>
</tr>
</tbody>
</table>

### 3.4 Legacy image sets for James Matthews described in the Museum image catalogue.

<table>
<thead>
<tr>
<th>Film Number</th>
<th>Description</th>
<th>Date</th>
<th>File format</th>
</tr>
</thead>
</table>

281
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Date</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>479-481</td>
<td>1975-6 excavation, survey, grid frame</td>
<td>1975-1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>484-487</td>
<td>1975-6 Excavation, right and left stereo</td>
<td>1976</td>
<td>jpeg</td>
</tr>
<tr>
<td>488</td>
<td>1975-6 Excavation</td>
<td>19760121</td>
<td>jpeg</td>
</tr>
<tr>
<td>490</td>
<td>1975-6 Excavation</td>
<td>19760127</td>
<td>jpeg</td>
</tr>
<tr>
<td>502</td>
<td>1975-6 Excavation, Photomosaic</td>
<td>19760219</td>
<td>jpeg</td>
</tr>
</tbody>
</table>
Appendix D – Legcy Data I3DM results and output

<table>
<thead>
<tr>
<th>MA #</th>
<th>Grid #</th>
<th>Figure</th>
<th>Details</th>
</tr>
</thead>
</table>
| 481 482 | part 1 | 6      | Cameras: 32/32  
Tie Points: 10,659  
Dense Cloud: 2,556,665, medium quality  
Polygons: 511,323 faces  
Texture: 1 x 4096 |
| Part 2 | 4  | Cameras: 27/27  
|        |    | Tie Points: 22,929  
|        |    | Dense Cloud: 2,366,843, medium quality  
|        |    | Polygons: 473,368  
|        |    | Texture: 1 x 4096  
|        |    | Tie Points: 10,479  
|        |    | Dense cloud: 1,022,944, medium quality  
|        |    | No mesh. |
Cameras: 4/4
Tie Points: 6,963
No further processing

Cameras: 45/45
Tie Points: 28,802
Dense Cloud: 4,630,769 Medium quality
Polygons: 926, 149 faces
Texture: 1 x 4096
Cameras: 26/26
Tie Points: 3,552
Dense Cloud: 4,037,925, Medium quality
Polygons: 807,583
Texture: 1 x 4096
| 492-493 | 14,15 | Cameras: 43/68  
Tie Points: 7,419  
Dense cloud: 3,762,012, medium quality  
Polygons: 752,388 faces  
Texture: 1 x 4096 |
| Cameras: 30/30 | Tie Points: 8,557  
| Dense Cloud: 2,344,592, medium quality  
| Polygons: 468,913 faces |
| 513-490 part 2 | ? | Cameras: 30/38  
Tie Points: 8,747 |
| 494 | 5 | Cameras: 33/35  
Tie Points: 11,892  
Dense Cloud: 4,565,956, medium quality  
Polygons: 913,188 faces  
Texture: 1 x 4096 |
Cameras: 3/3
Tie Points: 5,584
Dense Cloud: 1,338,767, medium quality
Cameras: 13/13
Tie Points: 4,681
Dense Cloud: 4,432,620, medium quality
Polygons: 886,522 faces
Texture: 1 x 4096
<table>
<thead>
<tr>
<th>Image</th>
<th>Description</th>
</tr>
</thead>
</table>
| 503   | Cameras: 13/14  
Tie Points: 1,029  
Dense Cloud: 1,142,152, medium quality  
Polygons: 228,429 faces |
| 504-507-508 | Cameras: 15/15  
Tie Points: 11,775  
Dense Cloud: 4,435,443, medium quality  
Polygon: 887,073 faces  
Texture: 1 x 4096 |
Cameras: 35/36
Tie Points: 18,390
Dense Cloud: 4,985,646, medium quality
Polygons: 997,110 faces
Texture: 1 x 4096
Cameras: 14/15
Tie Points: 2,665
<table>
<thead>
<tr>
<th>Part 2</th>
<th>Cameras</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>Polygons</th>
</tr>
</thead>
<tbody>
<tr>
<td>499-500 part 2</td>
<td>40/45</td>
<td>32,737</td>
<td>5,069,265, medium quality</td>
<td>1,013,850, faces</td>
</tr>
<tr>
<td>498 part 2</td>
<td>21/29</td>
<td>7,079</td>
<td></td>
<td>1,013,850, faces</td>
</tr>
<tr>
<td>Partial</td>
<td>Camera Data</td>
<td>3D Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 497     | Cameras: 3/9
          Tie Points: 1,892 |
| 502     | Cameras: 3/13
          Tie Points: 1,182
          Dense Cloud: 718,525, medium quality |
| 488 | Cameras: 56/56  
Tie Points: 38,793 | Cameras: 56/56  
Tie Points: 38,793 |
|------|------------------|------------------|
| 488 part 3 | Cameras: 29/29  
Tie Points: 34,911  
Dense Cloud: 2,943,643, medium quality  
Polygons: 196,241 faces | Cameras: 29/29  
Tie Points: 34,911  
Dense Cloud: 2,943,643, medium quality  
Polygons: 196,241 faces |