

Authenticity in Digital Surrogates

Workflow Development for Generating an Authentic Digital Surrogate for Heritage Conservation

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

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Abstract

This practice-based study is concerned with the creation of authentic 3D digital surrogates of large-scale heritage artefacts. The research develops and demonstrates an effective workflow using a multi-method approach with LIDAR laser scanning and photogrammetry. The workflow includes optimisation for online and Virtual Reality (VR) use. The thesis examines the notion of authenticity and current research around it. It considers predominant views and proposes an idea of *hybrid authenticity*, which can be used as a guideline for digitalising heritage artefacts for further multi-purpose uses. An introduction to museum philosophy and the general requirements for digital heritage preservation are part of the theoretical contextualisation of this thesis. The resulting artefact of the research project, a digital 3D model of a large-scale shipwreck, has also been evaluated with regard to its successful representation of authenticity. While the evaluation is only preliminary in nature due to the infancy of the overall research trajectory that this project is part of, the study presents the responses of a number of museum professionals. The results of this evaluation show a positive tendency regarding the general success and acceptance of the digital model as an authentic representation.

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Technical Terms

Asset – in this research, a reference to the digital polygonal model.

Decimation (Decimated) – in ZBrush, a process applied to a model, which allows a greatly reduced polygonal count in the model while preserving high-resolution details.

DynaMesh (Dynameshed) – in ZBrush, a mode which restores a uniform geometry distribution, creating a workable topology on the surface of the asset for further manipulation.

Mesh (Polygonal Mesh) – a configuration of polygons or triangles that defines the shape of a digital asset.

Mesh Polycount – number of polygons or triangles that define a polygonal shape.

Point Cloud – in this research, the number of points with data in a three-dimensional space which are defined by X, Y and Z coordinates and form a surface of an object.

Polycount – number of polygons or triangles.

Polygon – in a digital space, a closed plane with three or more sides. A polygonal mesh is formed by polygons.

Retopology – in this research, a process of reorganising the flow of polygons for easier UV unwrapping.

Topology – in this research, the organization and flow of the edges of polygons on a mesh.

Up-resing – in this research, generating a higher resolution of a texture or geometry.

UVs – U and V are the coordinates in 2D space assigned for texturing a 3D model. Each model that has texture map has a UVs layout as well.

VR – virtual reality.

1. Introduction

The Bamiyan valley, Afghanistan, located on the ancient Silk Route, was once a meeting point of West and East, blending elements of Greek, Turkish, Persian, Chinese and Indian cultures. For centuries, it was a site for the expansion of Buddhism, with numerous depictions of Buddha carved in the cliffs of the mountain, including three colossal statues, one of them being the world's tallest (53m). Carved into sandstone by the Greeks around 1700 years ago, these statues were among Asia's great archaeological treasures and were a major tourist attraction, surviving the military campaigns of Genghis Khan, Tamerlane and almost 20 years of civil war until March 2001 when the statues, despite a massive international protest, fell under the Taliban's dynamite.¹ Such a sudden loss of the world's significant archaeological treasures is not an exception to the rule: others include the destruction of cultural heritage by ISIS in the Mosul museum;² the devastating earthquake in Mirandola, Italy, which caused extensive damage to heritage buildings, including some that now are considered to be beyond repair;³ and the vandalism in Egypt's Malawi National Museum of Antiquities in 2013, when numerous artefacts were damaged or stolen⁴. While the list can be continued, the saddest fact in these examples is that there is no detailed documentation left, which could make up, at least to some extent, for the loss of unique works of art and culture.

The destruction of the Bamiyan statues of Buddha ignited interest in numerous projects in the field of digital heritage conservation and restoration. One of the first attempts after the event was by Jason Yu and Liyan Hu, who recreated the Buddhas using 3D laser holographic projections.⁵ Another group of researchers from ETH Zurich completed a 3D reconstruction from available photographs of one of the Buddha statues and used it to create a 1:200 physical model.⁶ The *Mosul Project*, or as it is now called, *Rekrei*, initiated by Mathew Vincent and Chance Coughenour⁷, continues to this day and focuses on the digital preservation of artefacts and monuments destroyed in Mosul Museum using 3D modelling based on crowd-sourced photographs, which can be reproduced with 3D printers in the future.

¹ Ahmed Rashid, "After 1,700 Years, Buddhas Fall to Taliban Dynamite," *Telegraph*, March 12, 2001, accessed May 9, 2017, <http://www.telegraph.co.uk/news/worldnews/asia/afghanistan/1326063/After-1700-years-Buddhas-fall-to-Taliban-dynamite.html>

² CBS/AP, "ISIS Leaves Mosul Museum in Ruins as Iraq Forces Advance," *CBS News*, March 8, 2017, accessed December 21, 2017, <https://www.cbsnews.com/news/isis-mosul-museum-ruins-iraq-forces-advance/>

³ Elisabetta Povoledo, "Quakes Deal Irreparable Blow to Italian Region's Cultural Heritage," *New York Times*, June 2, 2012, accessed May 8, 2017, <http://www.nytimes.com/2012/06/03/world/europe/italy-assesses-damage-to-cultural-heritage.html>

⁴ Jill Reilly, "Looters ransack Egyptian antiques museum and snatch priceless artefacts as armed police move inside stormed Cairo mosque," *Daily Mail*, August 18, 2013, accessed May 8, 2017, <http://www.dailymail.co.uk/news/article-2396100/Egypt-Looters-ransack-Egyptian-antiques-museum-s snatch-priceless-artefacts.html>

⁵ Mary-Ann Russon, "Afghanistan: Buddhas of Bamiyan resurrected as laser projections," *International Business Times*, June 12, 2015, accessed May 8, <http://www.ibtimes.co.uk/buddha-statues-destroyed-by-taliban-resurrected-laser-projections-1505794>

⁶ Katsushi Ikeuchi et al., "The Great Buddha Project: Digitally Archiving, Restoring, and Analyzing Cultural Heritage Objects," *International Journal of Computer Vision* 75, no. 1 (October 1, 2007): 197, <https://doi.org/10.1007/s11263-007-0039-y>

⁷ "Home | Rekrei," accessed December 21, 2017, <https://projectmosul.org/>

The discussed examples highlight the vulnerability of heritage sites and are just a few among many cultural examples that are increasingly being destroyed every year by military conflicts, natural disasters, vandals, erosion or natural deterioration. Though numerous workflows focus on bringing back digitally what was lost, the final outcome inevitably will be unlikely to resemble the original in full accurate detail. It is not simply the physical detail that may be lost, but also what is perceived as authenticity and often as originality. Therefore, the focus of heritage preservation today should be not only on the maintenance of the materiality of an artefact as a physical substance present in the real world, but also on developing workflows for providing a 'digital materiality'⁸ for that artefact; in other words, creating an authentic digital copy before the original is lost forever.

Computer technologies are often used for historic reconstructions and visualization. However, due to the complexity and scale of some sites or artefacts, traditional manual 3D modelling techniques are often too time-consuming and difficult to apply for creating a digital copy, as each digital point has to be placed manually, resulting in a high chance of producing errors and inconsistencies in the shape of the artefact.^{9 10} Manual modelling also requires detailed video or photographs of the artefact to be taken so that these materials can be used as a reference for the modelling workflow. This requirement is achievable for small, simply built artefacts; however, it is unlikely that a practitioner will be able to manually capture photo references of every detail of buildings, ships, monuments, machinery, archaeological sites and other large-scale complex structures. The continuous development of new sensors, data capture methodologies and the improvement of existing ones contribute significantly to the 3D documentation, conservation, and digital presentation of heritage and to the growth of the research in this field.¹¹ The innovations and improvements in digital 3D scanning devices as well as increasing computational powers have provided new means for generating a high-quality digital copy of a heritage site or an artefact, which can be further used in photorealistic reconstructions, simulations or immersive VR experiences for educational and scholarly purposes.

There are numerous research projects dedicated to 3D scanning in the field of heritage preservation^{12 13 14 15 16 17}, but their approach either provides a general overview of the techniques

⁸ Paul M. Leonardi, "Digital Materiality? How Artifacts without Matter, Matter," *First Monday* 15, no. 6 (2010), <http://journals.uic.edu/ojs/index.php/fm/article/view/3036>

⁹ Peter K. Allen et al., "The Beauvais Cathedral Project," 2003 Conference on *Computer Vision and Pattern Recognition Workshop*, (June, 2003): 1, doi: 10.1109/CVPRW.2003.10004

¹⁰ Raffaella Fontana et al., "Three-Dimensional Modelling of Statues: The Minerva of Arezzo," *Journal of Cultural Heritage* 3, no. 4 (October, 2002): 325, [https://doi.org/10.1016/S1296-2074\(02\)01242-6](https://doi.org/10.1016/S1296-2074(02)01242-6)

¹¹ Fabio Remondino and Alessandro Rizzi, "Reality-Based 3D Documentation of Natural and Cultural Heritage Sites—Techniques, Problems, and Examples," *Applied Geomatics* 2, no. 3 (September, 2010): 85–86, <https://doi.org/10.1007/s12518-010-0025-x>

¹² David Svânå, "Environment Re-Creation Methods for Virtual Heritage Using a Game Engine with Discernment of Visual Learning Cues," Master's thesis, Norwegian University of Science and Technology, 2010, <https://brage.bibsys.no/xmlui/handle/11250/252408>

¹³ Marc Levoy et al., "The Digital Michelangelo Project: 3D Scanning of Large Statues," in *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '00 (New York, NY, USA: ACM Press/Addison-Wesley Publishing Co., 2000), 131–144, <https://doi.org/10.1145/344779.344849>

¹⁴ Fontana et al., "Three-Dimensional Modelling of Statues."

¹⁵ Armin Gruen, Fabio Remondino, and Li Zhang, "Photogrammetric Reconstruction of the Great Buddha of Bamiyan, Afghanistan," *The Photogrammetric Record* 19 (September, 2004): 177–199, <https://doi.org/10.1111/j.0031-868X.2004.00278.x>

¹⁶ Ikeuchi et al., "The Great Buddha Project."

used, or focuses on one issue, commonly the 3D laser scanning itself, while failing to demonstrate methods for handling raw laser scan data, converting it into standard digital formats, cleaning, restoring, and optimising it for public use. While learning about the processes behind 3D laser scanning and the techniques that can be used with it is important, this knowledge alone does not provide a full understanding of the pipeline (methodology) that is used by digital specialists during field work and post-production. Mudge and Ashley write:

There is a desperate need for methodologies for digital heritage conservation that are manageable and reasonable, and most importantly, can be enacted by cultural heritage professionals as essential elements of their daily work. The collaboration between cultural heritage professionals and digital specialists should lead to the democratization of technology through widespread adoption, not the continued mystification of technology...¹⁸

Production of an effective pipeline for digital heritage conservation that can be used not only by digital specialists, but also by cultural heritage professionals who might not necessarily have the formal training and skills to produce digital artefacts, is the main focus of this thesis.

The testbed for the pipeline development is the Edwin Fox, a 164-year-old merchant ship, partially preserved and displayed at Marlborough's Edwin Fox Museum, in Picton. There are several reasons behind this choice. First of all, the Edwin Fox is a large-scale heritage object with a complex structure, which makes it extremely challenging, but at the same time an ideal candidate for developing a workflow that is most likely to cover a wide range of major issues that might occur in similar or less demanding projects. Secondly, and most importantly, is the possibility of losing the Edwin Fox to an earthquake, which almost happened in November 2016 when the devastating Kaikoura earthquake hit the top of New Zealand's South Island. The Edwin Fox suffered minor damage, but there is no assurance of her surviving another hit if it happens near her resting place.

The final deliverable in this thesis is a complete workflow that includes a demonstration of the laser scanning technique, mesh cleaning, restoration and texturing methods tested and refined using the *Edwin Fox Project*, resulting in the production of a three-dimensional high-resolution model of the ship in its current state. In addition to that, optimisation techniques for displaying the final 3D model online are included in the pipeline to showcase a complete pathway from acquiring data to the final product delivery to the end user. Furthermore, the required model optimization is developed with the aim that the final model will be integrated into an immersive Virtual Reality experience, which is planned for in later stages of collaboration with the Edwin Fox Museum.

While production of an effective pipeline is the focus of this research, maintaining the authentic appearance of the final 3D model is the main factor determining the development of this workflow. When working with museums and heritage sites, authenticity is the concept that plays a central role in production of any types of copies, and its definition is often debated. This thesis discusses and summarises available understandings about this concept in order to determine how it can be applied in the field of digitalisation for heritage preservation purposes.

¹⁷ Yunsu Bok et al., "Capturing Village-Level Heritages with a Hand-Held Camera-Laser Fusion Sensor," *International Journal of Computer Vision* 94, no. 1 (August, 2011): 36–53, <https://doi.org/10.1007/s11263-010-0397-8>

¹⁸ Mark Mudge and Michael Ashley, "A Digital Future for Cultural Heritage," in *Proceedings of the 21st CIPA Symposium*, Volume XXXVI-5/C53 of ISPRS Archives (October 2007): 4, https://www.researchgate.net/publication/239531698_A_DIGITAL_FUTURE_FOR_CULTURAL_HERITAGE

The effectiveness of the developed workflow for museum workers and other digital specialists has to be tested upon completion of this thesis because creating a digital surrogate is a lengthy process in itself, which may take weeks or months depending on the complexity of the artefact. In saying that, collaboration with museum workers on various projects will allow a gradual tweaking and adjustments to the developed workflow to make sure that it is understandable and easy to use. While a thorough testing of the technical side of the workflow requires significant amounts of time, the first insights concerning the effectiveness of the workflow to maintain an authentic appearance of a digital copy of the artefact can be seen in the results of an interview conducted with museum professionals and discussed in detail in **Section 6**.

This thesis is divided into the following sections:

Section 1 – Introduction

Section 2 – Establishing the theoretical background. Introduction to the Edwin Fox. Museum Philosophy and Digitalisation of Cultural Heritage

Section 3 – Establishing the theoretical background. The concept of Authenticity

Section 4 – Methodological approach

Section 5 – Workflow development

Section 6 – Interview discussion

Section 7 – Discussion

Section 8 – Conclusion & Future Work

2. Introduction to the Edwin Fox. Museum Philosophy and Digitalisation of Cultural Heritage

2.1 Brief History of the Edwin Fox

Built at Sulkeali on the Ganges Delta, India in 1853 for the Anglo-Indian trade, the Edwin Fox is said to be one of the last East Indiamen. She is an emblem of a time when sea-going trade with India seemed intrinsically alluring and exotic. In contrast to our globalised world, an air of romanticism and glamour now surrounds her history.¹⁹ Similar to vessels built for the East India Company, she was constructed of teak and saul timber in just 9 months and prior to her launching was sold to Sir George Hodgkinson who named her the Edwin Fox.²⁰ There is no tangible evidence of who she was named after, but the most likely explanation is that Edwin Fox was a trusted friend of the Hodgkinson family.²¹

On her maiden voyage to London the Edwin Fox carried 10 passengers and a general cargo. Almost a year later she was sold to Duncan Dunbar and served as a troop ship, *Transport 109*, for the British Government in the Crimean War. There is written evidence that the Edwin Fox transported Florence Nightingale, who was taking care of wounded soldiers.²² After the war, the Edwin Fox was again refitted to carry cargo and passengers and spent her days trading between various Eastern ports. In 1873 the Edwin Fox was chartered by the Shaw Savill Company to carry immigrants to New Zealand from England, making four voyages and transporting a total of 751 passengers to the new colony. By the 1880s the Edwin Fox remained on New Zealand shores and was redesigned to serve as a floating freezer hulk storing numerous sheep and cattle carcasses. In 1897 the Edwin Fox was towed to Picton, where she continued to serve as a freezer hulk, later as a coal hulk, and finally now she has come to rest in a specially designed dry dock as a prominent tourist attraction.²³

Among the ships of her kind, there is no competition in terms of long-term durability and best state of preservation. Two notable examples still surviving are the *Jhelum* and the *Batavia*, with the former having been shipwrecked and gradually being destroyed by natural elements, and the latter being submerged near the shores of Western Australia.²⁴ In terms of value, the Edwin Fox is precious not only to New Zealand's, but to the world's heritage as the oldest surviving, best preserved merchant ship of her kind (**Fig. 01** and **Fig. 02**).

¹⁹ Nigel Costley, *Teak and Tide* (Nikau Press, Nelson, 2014), 9.

²⁰ "History of the Edwin Fox," *Edwin Fox Society* (blog), accessed December 21, 2017, <http://www.edwinfoxsociety.com/history/>

²¹ Costley, *Teak and Tide*, 31.

²² Karen McCleod, the Edwin Fox Museum curator, "Edwin Fox," email, 2018.

²³ "History of the Edwin Fox."

²⁴ Costley, *Teak and Tide*, 9.



Figure 01. Top - the Edwin Fox Museum; bottom - the dry dock, where the Edwin Fox is located.

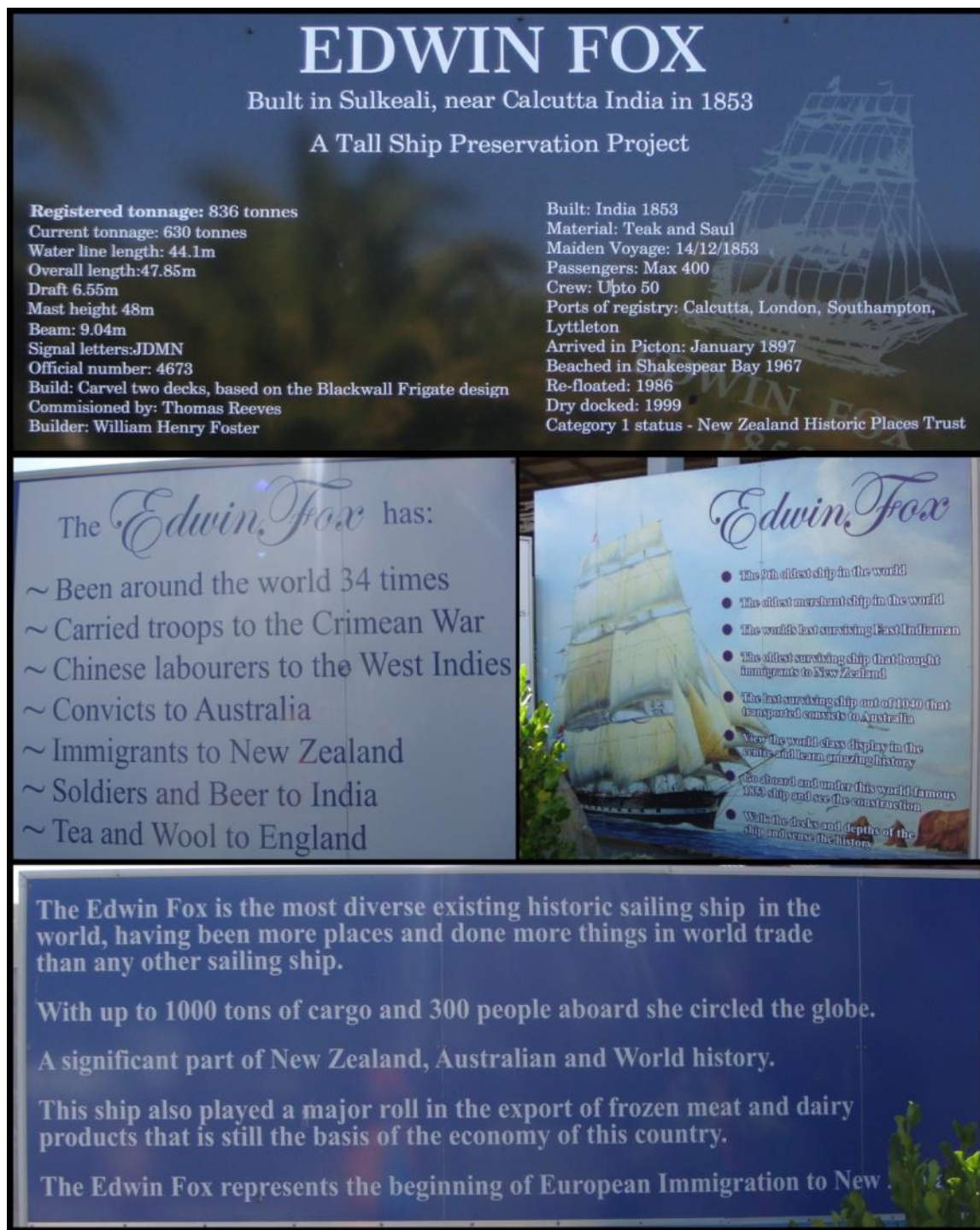


Figure 02. Additional information about the Edwin Fox and her voyages.

2.2 Museum Philosophy and Democratisation of Museums

Museums, an invention of the Enlightenment, were created as repositories of valuable or rare things in order to ensure their preservation.²⁵ Shifting the focus from acting as cabinets of

²⁵ Philippos Mazarakis-Ainian, "Archaeological Copies: A scientific Aid, a Visual Reminder or a Contradiction in Terms?" in 22nd ICOM General Conference (Shanghai, China, November 2010), 118, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

shown a significant change towards the democratization of exhibits.²⁶ Until the 1970s, collection, care and preservation were the foundation of the core museum principles, but today museums exist as “cultural capital-driven development complexes”²⁷ to not only curate public education, but also to facilitate authentic experiences in various forms of leisure activities. Consumerist and capitalist ideology has become an accepted standard in museum operations, as the scarcity of public funds requires supplementing public money with other sources of income, such as tourism, to sustain museum collections.

Experiencing heritage sites or artefacts has become one of several priorities in the cultural motivation for tourism.²⁸ The demand for heritage-based tourism can be explained by an increasing awareness of heritage value and its ability to express individuality through the recognition of national identity, which helps to create a sense of place and belonging; it is the desire to maintain one’s identity and fulfil psychological needs for continuity through an appreciation of personal history.²⁹ Rispal summarises this idea by saying that heritage objects:

...take individuals and groups back to another time that places them face to face with their roots... They are the crucibles of life, for they contain everything that nourishes our spirit, knowledge, experiences, thoughts, suffering and what men and women have created, thanks to which we are alive today, which forms invisible links between us and them, dead or alive, here or elsewhere. These objects are thus the mediators between us and that invisible human immensity whose origin escapes us.³⁰

McDonald, as cited in *Visitor’s Engagement and Authenticity*, notes that such strong emotional links between a population and its heritage are established and strengthened through heritage-related behaviours such as watching a TV show or reading a book about the heritage site.³¹ The power of secondary sources in general forges expectations and bolsters the urge to travel to see the original precisely because tourists have already seen an image or reproduction of it.³²

With the increase in consumerism and the edutainment culture required for the heritage field to flourish, the main question for the survival of heritage museums in the 21st century is whether curators can recognise and integrate other forms of representation to fit the object into the minds of present-day multi-perspective audiences. As museums are not isolated from the rest of the world, they have to reflect the current culture of the digital age in order not only to preserve, but also to promote their artefacts.

²⁶ Deepak Chhabra, “Positioning Museums on an Authenticity Continuum,” *Annals of Tourism Research* 35 (April, 2008): 429, <https://doi.org/10.1016/j.annals.2007.12.001>

²⁷ Ibid.

²⁸ Gordon Waitt, “Consuming Heritage: Perceived Historical Authenticity,” *Annals of Tourism Research* 27, no. 4 (October, 2000): 838, [https://doi.org/10.1016/S0160-7383\(99\)00115-2](https://doi.org/10.1016/S0160-7383(99)00115-2)

²⁹ Yi-Ju Lee, “Creating Memorable Experiences in a Reuse Heritage Site,” *Annals of Tourism Research* 55, no. Supplement C (November, 2015): 157, <https://doi.org/10.1016/j.annals.2015.09.009>

³⁰ Adeline Rispal, “The Object in History Museums, Mediator for the Invisible”, in 22nd ICOM General Conference (Shanghai, China, November 2010), 106, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

³¹ Derek Bryce et al., “Visitors’ Engagement and Authenticity: Japanese Heritage Consumption,” *Tourism Management* 46, no. Supplement C (February, 2015): 574, <https://doi.org/10.1016/j.tourman.2014.08.012>

³² Rosmarie Beier-de Haan, “You Can Always Get What You Want. History, the Original, and the Endless Opportunities of the Copy,” in 22nd ICOM General Conference (Shanghai, China, November 2010), 4, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

2.3 Digital Heritage and Digitalisation

For centuries, archaeologists and museum workers meticulously drafted maps, made illustrations and impressions, and later took photographs of artefacts for documentation purposes.³³ Despite being highly detailed and precise, images often are not able to serve as the embodiment of the artefact, especially in terms of spatio-volumetric relationships to the viewer, because of their two-dimensional nature. Nowadays, individuals, organisations, and communities are able to use digital technologies to document and express what they value and what they want to pass on to future generations. Unlimited by time, geography, culture and format, digital heritage is potentially accessible to every person in the world, enabling minorities to speak to majorities, and the individual to address a global audience.³⁴ Bianchi defines Digital Cultural Heritage as follows:

...the entire series of productions that aspire to enhance, complement or substitute the experience of a site or object of historical and or cultural significance, by making active use of digital computer technologies. The range of applications is very broad and includes (from simple to complex): digital cataloguing for online or offline accession; website and CD-ROMS, including images and descriptions of sites and objects; three-dimensional reconstructions of remote or destroyed objects, delivered via a number of different platforms; augmented reality systems, in which real images and movies are combined with synthetic data in order to put computer simulation into a natural context.³⁵

Growing collections of digital surrogates generated from non-digital sources provide numerous examples of objects that are the only surviving versions of originals that have since been damaged or lost.³⁶ The goal of such surrogates is to reliably represent 'real world' content in a digital form. Their purpose is to enable scientific study and personal enjoyment without the need for direct physical experience of the object or place. Their essential scientific nature distinguishes them from speculative digital representations.³⁷ In order to function as intended, digital surrogates must be consistently faithful and authentic to the original, having captured details in ways that lend confidence to those who would employ the surrogate as they would an original.³⁸ The digital capture process must be undistorted and reliable. In the words of Grycz: "The users must be comfortable using the 'product' of digitisation as surrogates, as subjects of research, and as sources of pleasure"³⁹.

Numerous researchers emphasise the obvious advantages of having a digital surrogate created for a heritage artefact. First of all, a digital surrogate can serve as a 'communicative

³³ Suzanne Keene, "Visualising Heritage," in *Electronic Visualisation in Arts and Culture*, Jonathan P. Bowen et al., eds., (London: Springer-Verlag, 2013), 241.

³⁴ Guidelines for the Preservation of Digital Heritage. United Nations Educational, Scientific and Cultural Organization (National Library of Australia, March, 2003): 15 – 16, accessed May 13, 2017, <http://unesdoc.unesco.org/images/0013/001300/130071e.pdf>

³⁵ Cristiano Bianchi, "Making Online Monuments More Accessible through Interface Design," in *Digital Heritage: Applying Digital Imaging to Cultural Heritage*, Lindsay MacDonald, ed. (Amsterdam: Elsevier, 2006), 449.

³⁶ Guidelines for the Preservation of Digital Heritage, 31.

³⁷ Mudge and Ashley, "A Digital Future for Cultural Heritage," 1.

³⁸ Czeslaw Jan Grycz, "Digitising Rare Books and Manuscripts," in *Digital Heritage: Applying Digital Imaging to Cultural Heritage*, Lindsay MacDonald, ed. (Amsterdam; London: Elsevier, 2006), 35.

³⁹ Ibid., 59-60.

projection⁴⁰ of the physical artefact and perform an educational and promotional function via its online presence. A digital surrogate can be distributed online and accessed by the scholarly community, thus expanding knowledge about the artefact and helping to establish shared interpretations and common reconstructions of the past.⁴¹ A digital copy suffers no degradation through the duplication process, providing the ability to distribute inexhaustible copies to any personal computer or mobile device.⁴² A digital copy can be accessed from remote locations, breaking language barriers due to its visual nature and allowing for collaborations of various kinds.⁴³ The online presence of a digital copy allows people who are elderly or disabled to enjoy explorations of tourist sites that often are not physically accessible to them. Tourists who did not have time to see an object or site can continue their virtual exploration at home, or if they are planning a journey, a digital copy can give a sense of what to expect when they are at the real-world location.⁴⁴

Alongside online access and distribution, a digital copy can provide a high level of familiarity with the artefact, exact measurements, and empirical data of various kinds that previously were hard to gain in museum settings.⁴⁵ Since the whole artefact is digitalised into a 3D model, there are no hidden parts as in photographs or drawings, or inability to view artefacts from angles and positions that cannot be set while exploring the physical artefact.⁴⁶ A digital surrogate provides real-time interactivity and visual feedback, which may help to reinforce learning and lengthen the attention span.⁴⁷ The ability to repurpose a digital surrogate for different contexts, such as rendering, real-time exploration, and accurate documentation allows it to be an effective tool in experimental archaeology, where various hypotheses can be tested through virtual reality simulations.^{48 49}

Another important advantage of a digital surrogate is the insurance that information about the shape and appearance of an object is not lost in the event of damage to the physical artefact from natural or accidental causes.⁵⁰ If the physical artefact is lost, or in a condition that makes it unavailable to general public, an authentic digital copy can serve as a replacement for educational

⁴⁰ Filippo Stanco, "Experiencing the Past: Computer Graphics in Archaeology," in *Digital Imaging for Cultural Heritage Preservation: Analysis, Restoration, and Reconstruction of Ancient Artworks*, Filippo Stanco et al., eds. (New York: CRC Press, 2011), 4.

⁴¹ Ibid.

⁴² Grycz, "Digitising Rare Books and Manuscripts," 34-35.

⁴³ Bianchi, "Making Online Monuments More Accessible through Interface Design," 450.

⁴⁴ Ibid.

⁴⁵ Mudge and Ashley, "A Digital Future for Cultural Heritage," 1.

⁴⁶ Hrvoje Stancic, "Digital Heritage Preservation," (Zagreb: Croatian Information Technology Association – GIS Forum, University of Silesia, 2010), 282-283, accessed March 28, 2017, <http://bib.irb.hr/prikazi-rad?rad=480004>

⁴⁷ Svânå, "Environment Re-Creation Methods for Virtual Heritage Using a Game Engine with Discernment of Visual Learning Cues," 1.

⁴⁸ Stefan Boeykens, "Using 3D Design Software, BIM and Game Engines for Architectural Historical Reconstruction," (2011), in *Proceedings of the 14th International Conference in Computer Aided Architectural Design Futures*, 2011, 2, <https://lirias.kuleuven.be/bitstream/123456789/306891/1/P043-3d-dsgn-bim-game-engine-hist-reconstr-high.pdf>

⁴⁹ Stanco, "Experiencing the Past: Computer Graphics in Archaeology," 4.

⁵⁰ Leonardo Gomes, Luciano Silva, and Olga Bellon, "3D Reconstruction Methods for Digital Preservation of Cultural Heritage: A Survey," *Pattern Recognition Letters* 50 (April, 2014): 3, <https://doi.org/10.1016/j.patrec.2014.03.023>

and research purposes.⁵¹ Such digital copies can be printed on a 3D printer at full scale and used instead of the original artefact.

In order to build an authentic digital copy (surrogate), the developed workflow has to provide a complete documented empirical provenance so that the final outcome can be repeated as well as being subject to a qualitative evaluation. Also, the importance of technology accessibility and automation in a workflow development, which offers enhanced reliability and greatly reduces the computer technology expertise necessary to manage a digital workflow, is highlighted by Mudge and Ashley in *A Digital Future for Cultural Heritage*.⁵² While an exact copy of a 'real-world' artefact is a requirement for a digital surrogate, in *Guidelines for the Preservation of Digital Heritage* it is argued that "it may not be practical to expect an entirely objective guarantee of authenticity – there may always be an element of trust or subjective judgement in deciding that authenticity has been sufficiently proven"⁵³. It is also emphasised that the relationships on which the required level of authenticity rests must be thoroughly documented. Authenticity of a digital copy derives from being able to trust both the *identity* of an object - that it is what it says it is, and the *integrity* of the object - that it has not been changed in ways that change its meaning. Maintenance of both *identity* and *integrity* also implies thorough documentation of the development process.⁵⁴

It is understood that a documented development process that is able to provide empirical provenance is crucial for delivering an authentic digital surrogate. But what is authentic and how much authenticity is needed for a digital surrogate to be considered a valid digital record? A detailed study of the concept of authenticity and how it is understood in the context of this thesis is presented in the next section.

⁵¹ Grycz, "Digitising Rare Books and Manuscripts," 34.

⁵² Mudge and Ashley, "A Digital Future for Cultural Heritage," 5–6.

⁵³ *Guidelines for the Preservation of Digital Heritage*, 114.

⁵⁴ *Ibid.*, 113.

3. Authenticity

3.1 History is fluid

Oliver Grau writes in his book *Virtual Art* that “it is not possible for any art to reproduce reality in its entirety, and we must remain aware that there is no objective appropriation of reality”⁵⁵. Recent findings in neurobiology propose that what we call reality is in fact merely a statement about what we are actually able to observe. Any observation is dependent on our individual physical and mental constraints.⁵⁶ In addition to that, human sensory perspective is not only biological, it is also historical. The way people perceive adjusts to social and political changes.⁵⁷

Over the centuries, philosophers have discussed the notions of reality, truth, identity, continuity and change, which are all relevant for understanding the concept of authenticity. The attempts to clearly explain this extremely complex multi-faceted concept can be illustrated using *Theseus’s paradox*.⁵⁸ First mentioned by Plutarch, this paradox presented the case of Theseus’s ship, which was kept by the Athenians as a memorial for a long time. Due to the gradual replacement of rotten planks, the ship retained its original form but its material was entirely renewed. The question was then raised: was it still Theseus’s ship? In modern times, the issue has been posed as two alternative problems. In the example just given, we can think that the gradual renovation over time still provided a spatio-temporal continuity for the ship, thus retaining a certain identity. On the other hand, one could suggest that the materials that were removed could have been reassembled elsewhere in another ship. What would then be the original ship?

This paradox demonstrates the fact that whatever is labelled today as an original artefact is very subjective and open to interpretation. Waitt underlines this by stating that “‘history’ is just one version of the truth, often bearing only a faint and extremely partial resemblance to past events as documented in various alternative sources...Unquestionably, all representations of the past are selective”⁵⁹. Chhabra reinforces Waitt’s statement by claiming that “the past is often distanced from the personal or collective memory of individuals who inherit it and is reshaped by professionals such as historians and curators”⁶⁰. In turn, historians call for facts, which are selected and put in a particular order and context to reflect the most vocal power-based view of reality, thus making the past not factual, but rather “an intellectual concept”⁶¹. Therefore, it must be emphasized that

⁵⁵ Oliver Grau, *Virtual Art: From Illusion to Immersion* (Cambridge, Mass. : MIT Press, 2003), 17.

⁵⁶ Ibid.

⁵⁷ Andrew Robinson, “Walter Benjamin: Art, Aura and Authenticity,” *Ceasefire Magazine* (blog), June 14, 2013, accessed June 8, 2017, <https://ceasefiremagazine.co.uk/walter-benjamin-art-aura-authenticity/>

⁵⁸ “Ship of Theseus - Oxford Reference,” accessed January 3, 2018, <http://www.oxfordreference.com/view/10.1093/oi/authority.20110803100502431>

⁵⁹ Gordon Waitt, “Consuming Heritage: Perceived Historical Authenticity,” *Annals of Tourism Research* 27, no. 4 (October, 2000): 836, [https://doi.org/10.1016/S0160-7383\(99\)00115-2](https://doi.org/10.1016/S0160-7383(99)00115-2)

⁶⁰ Chhabra, “Positioning Museums on an Authenticity Continuum,” 433.

⁶¹ Alison J McIntosh and Richard C. Prentice, “Affirming Authenticity: Consuming Cultural Heritage,” *Annals of Tourism Research* 26, no. 3 (July, 1999): 592, [https://doi.org/10.1016/S0160-7383\(99\)00010-9](https://doi.org/10.1016/S0160-7383(99)00010-9)

absolute historical integrity is very elusive and the best that can be hoped for is a high degree of authenticity.⁶²

An intricate concept of authenticity remains as a benchmark against which the quality of culture, experience, and life itself are measured.⁶³ Authenticity discourse is often subject to multiple perspectives (Objectivism, Constructivism and Postmodernism are discussed in detail in following subsections), because it is always in a state of transmutation⁶⁴ and it has to be recognised in all its complexity. Therefore, the purpose of this thesis is not to present a conclusive definition of authenticity, but to clearly communicate the understanding of this concept within the context of this study as an analytical tool for an effective workflow development with respect to the positions taken by earlier researchers.

Authenticity is a multi-disciplinary term, which has been conceptualised in many ways to suit the goals of a particular research field. As the Edwin Fox Museum is a touristic heritage site, the understanding of authenticity within tourism studies is the most relevant to this study. The concept of authenticity is presented further from the perspective of museum curators, theory scholars and tourists.

3.2 Museum-linked Authenticity

Distinguishing features such as authenticity, selectivity, and ownership have become the marketing emblems of museum repositories. Of those, authenticity occupies a central place and is a fundamental measure of museum exclusivity, serving as an important criterion for allocating a museum's always insufficient resources.⁶⁵

Among scholars in tourism studies, museum-linked authenticity is often associated with an objectivist approach or essentialism, which implies that authenticity is a real property of genuineness of objects, which can be measured against absolute and objective criteria by experts. Objectivism also suggests that no copy could ever be authentic and that an inauthentic object yields an inauthentic experience. Such an approach has features of realism, which is based on the idea that there is an objectively real world to which one can refer as a standard or for confirmation when making judgements about what is true, genuine, accurate, and authentic.⁶⁶ However, viewing the concept of authenticity from such a perspective is too simplistic and as Zhu argues, does not "capture its true complexity"⁶⁷. Chhabra also notes that pure essentialism does not exist, as nature itself "is a result of historical and social construction"⁶⁸. The rise of relativism, postmodernism,

⁶² Bai Yan, "Significance of Originals and Replicas in Archaeological Site Museums with a Case Study of the Han Dynasty Site Museums in China," in 22nd ICOM General Conference (Shanghai, China, November 2010), 7-15, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

⁶³ Robert J. Shepherd, "Why Heidegger Did Not Travel: Existential Angst, Authenticity, and Tourist Experiences," *Annals of Tourism Research* 52, no. Supplement C (May, 2015): 60, <https://doi.org/10.1016/j.annals.2015.02.018>

⁶⁴ Chhabra, "Positioning Museums on an Authenticity Continuum," 428.

⁶⁵ Ibid., 430.

⁶⁶ Yvette Reisinger and Carol J. Steiner, "Reconceptualizing Object Authenticity," *Annals of Tourism Research* 33, no. 1 (January, 2006): 67-74, <https://doi.org/10.1016/j.annals.2005.04.003>

⁶⁷ Yujie Zhu, "Performing Heritage: Rethinking Authenticity in Tourism," *Annals of Tourism Research* 39, no. 3 (July, 2012): 1497, <https://doi.org/10.1016/j.annals.2012.04.003>

⁶⁸ Chhabra, "Positioning Museums on an Authenticity Continuum," 431-433.

poststructuralism and constructivism has convinced many that there is no actual, true, genuine, objective reality that can be a standard against which to evaluate authenticity. Authenticity is objective only so long as no one disagrees with or challenges it.⁶⁹ Although Reisinger and Steiner argue that the idea of objectivism is no longer accepted, Chhabra, in her survey conducted among museum curators, found that “representation of the past, documented history, and ‘from the actual period’ were deemed to be the most important criteria of what constitutes the authentic for museum curators... Overall the curators attach highest significance to the authentic essentialist ideologies while delivering messages in constructivist settings”⁷⁰.

3.3 Constructivist Authenticity

There is a general acceptance that age and rarity add value to museum artefacts.⁷¹ While some claim that value is based on object authenticity, others state that there is no objective value, only an increased sense of value provoked by our bodily experiences. Rispal expands this idea by stating that:

Value is no longer intrinsic to things, but always comes from outside, a social exterior that is essentially emotional. Value stems from the same process of harnessing a collective emotion, and is thus totally subjective...A museum is an institution that crystallizes shared, pre-formed affects, constituting a symbolic capital.⁷²

Emotional experience is one of the basic tenets of the constructed nature of authenticity⁷³ and even the notion of authenticity is itself a social construct.⁷⁴

From a constructivist point of view, things appear authentic not because they are inherently authentic, but because they are constructed as such in terms of points of view, beliefs, perspectives, or powers. The ontological assumption of constructivism relates to the idea that there is no unique ‘real world’ that pre-exists and is independent of human mental activity and human symbolic language. Reality is best seen as the result of the versions of our interpretations and constructions. The validity of knowledge is not to be found in the relationship of correspondence to an independently existing world: what we take to be objective knowledge and truth is the result of perspective. Knowledge and truth are created, not discovered, by the mind. Multiple and plural meanings about the same things can be constructed from different perspectives, and people may adopt different constructed meanings dependent on the particular contextual situation or intersubjective setting. For constructivists, authenticity is no longer a property inherent in an object forever fixed in time; it is seen as a struggle, a social progress in which competing interests argue for their own interpretation of history.⁷⁵

⁶⁹ Reisinger and Steiner, “Reconceptualizing Object Authenticity,” 67-74.

⁷⁰ Chhabra, “Positioning Museums on an Authenticity Continuum,” 441-442.

⁷¹ Philippos Mazarakis-Ainian, “Archaeological Copies: A Scientific Aid, a Visual Reminder or a Contradiction in Terms?” in 22nd ICOM General Conference (Shanghai, China, November 2010), 118, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

⁷² Rispal, “The Object in History Museums, Mediator for the Invisible,” 106.

⁷³ Chhabra, “Positioning Museums on an Authenticity Continuum,” 428.

⁷⁴ Bryce et al., “Visitors’ Engagement and Authenticity,” 572.

⁷⁵ Ning Wang, “Rethinking Authenticity in Tourism Experience,” *Annals of Tourism Research* 26, no. 2 (April, 1999): 351-359, [https://doi.org/10.1016/S0160-7383\(98\)00103-0](https://doi.org/10.1016/S0160-7383(98)00103-0)

The idea of constructivist authenticity can be summarised by the rhetorical question that was asked by one of the tourists during the survey conducted by Kuon at Siem Reap-Angkor: “Maybe authenticity in tourism is difficult to find. I don’t know what authenticity is. Authenticity is reality, but what is reality?”⁷⁶

3.4 Postmodernist Authenticity

In postmodernist interpretations of authenticity, favour is given to the illusion of authenticity rather than a definitive reality, with fragmentation, imperfection, and blurred boundaries that allow for various types of authenticity and its experiences. Some critics question usefulness and validity of the concept of authenticity because many tourist motivations or experiences cannot be explained in terms of its conventional definition. A typical postmodernist position in regard to the issue of authenticity in tourism can be seen in the works of Umberto Eco, who totally deconstructs the concept by destroying the boundaries between signs and reality. Eco introduces the term *hyperreality* – a condition in which what is real and what is fiction are seamlessly blended together so that there is no clear distinction between where one ends and the other begins. Eco demonstrates the idea using the example of the *Oval Office*:

Absolute unreality is offered as a real presence. The aim of the reconstructed *Oval Office* is to supply a ‘sign’ that will then be forgotten as such: the sign aims to be the thing, to abolish the distinction of the reference, the mechanism of replacement. Not the image of the thing, but its plaster cast. Its double, in other words.⁷⁷

Since there is no concept of an original, for postmodernists it is irrelevant whether something is real or false, original or copy, reality or symbol – representational techniques and convincing presentations can make anything look and sound authentic. Another postmodernist writer, Jean Baudrillard, reintroduces Plato’s concept of *simulacra*, which is the increasing representation of the hyperreal with signs. In his book *Simulacra and Simulation* Baudrillard argues that the question of authenticity is no longer lies in the fields of imitation or duplication, but rather in “substituting the sign of the real for the real...detering every real process via its operational double, a programmatic, metastable, perfectly descriptive machine that offers all the signs of the real...”⁷⁸. For Baudrillard, the contradictory process of true and false, real and imaginary, is abolished: today’s world is a simulation which admits no originals, no origins, no ‘real’ referent but the ‘metaphysic of the code’.⁷⁹

Postmodernists claim that tourists are not concerned with authenticity and the origins of attractions as long as they enjoy them. If the products transformed by the commoditization process maintain characteristics that satisfy tourists, they will remain authentic in their eyes.⁸⁰ Postmodern society is thus characterized by fragmentation, confusion, emptiness, alienation and by a crisis of morality and identity. Hence, people have become more concerned with identity, meaning and values, but also with nostalgia and history. Postmodernism suggests that tourists do not judge

⁷⁶ Vannsy Kuon, “The Pursuit of Authenticity in Tourist Experiences: The Case of Siem Reap-Angkor, Cambodia” (Lincoln University, 2011), 51, <https://researcharchive.lincoln.ac.nz/handle/10182/4306>

⁷⁷ Umberto Eco, *Faith in Fakes: Essays* (London: Secker and Warburg, 1986), 6.

⁷⁸ Jean Baudrillard, *Simulacra and Simulation, The Body, in Theory* (Ann Arbor: University of Michigan Press, 1994), 2.

⁷⁹ Wang, “Rethinking Authenticity in Tourism Experience,” 351 – 359.

⁸⁰ Reisinger and Steiner, “Reconceptualizing Object Authenticity,” 67-74.

authenticity from an intellectual distance but through emotional experiences. The postmodern tourist is an affect-driven, experience-seeking hedonist⁸¹, who is well aware of the fact that cultures, traditions and lifestyles are no longer authentic.⁸² Reisinger and Steiner argue that if the concept of authenticity is so vague and can have a variety of contradictory definitions then it is truly meaningless and cannot be the basis of social discourse. They continue by stating that if the postmodernist approach claims that “no one, including the tourist, cares about it anymore”⁸³, then the concept has to be abolished.

While Reisinger and Steiner note that modern tourists do not care whether the toured object is authentic or not, a survey conducted in *Siem Reap-Angkor* showed that the concept of authenticity was important to tourists and overall their understanding of it was associated with “something real/true/original/genuine/honest, old/traditional, and rural/local/non-touristy”⁸⁴. One of the tourists commented on the reproduction of the heads of some of the figures, which in his opinion not only eroded the physical authenticity but also diverted from original history: “That was good, I think, but if you put a new head on the statue...that is not authentic to me...because the destruction of the heads of the statues is as important as the history of the original”⁸⁵.

The survey results showed that authenticity is still acknowledged as a universal value and an essential force that motivates tourists to travel to distant places. Tourists still go to the Louvre in order to see the *Mona Lisa*, and many of them would be disappointed if they were instead presented with a reproduction. Many Christian pilgrims are still interested in archaeological evidence from the era of Jesus. All the examples show that object authenticity is still relevant to tourists, and as long as this is the case, it must be relevant to scholars as well.⁸⁶ Belhassen, in his paper *Authenticity Matters*, comments on Reisinger and Steiner’s proposition to abandon the concept of object authenticity:

Of immediate concern in this commentary is an epistemological issue, one that affects the very nature of research, how knowledge should progress within that domain, and what its purpose should be. Consequently, scholars cannot simply abandon a term/concept that continues to play such a significant role in as it functions in reality.⁸⁷

A postmodernist deconstruction of authenticity of the original implicitly paves the way to defining existential authenticity as an alternative experience in tourism.

3.5 Existential Authenticity

Existential authenticity relates to perceptions, emotions and a feeling of connectedness to human history, which is important for experiencing the authenticity of a heritage site.⁸⁸ Tourists

⁸¹ Tomaz Kolar and Vesna Zabkar, “A Consumer-Based Model of Authenticity: An Oxymoron or the Foundation of Cultural Heritage Marketing?” *Tourism Management* 31, no. 5 (October, 2010): 654, <https://doi.org/10.1016/j.tourman.2009.07.010>

⁸² Kuon, “The Pursuit of Authenticity in Tourist Experiences,” 23-24.

⁸³ Reisinger and Steiner, “Reconceptualizing Object Authenticity,” 73-81.

⁸⁴ Kuon, “The Pursuit of Authenticity in Tourist Experiences,” 47-48.

⁸⁵ *Ibid.*, 55-56.

⁸⁶ Kellee Caton and Yaniv Belhassen, “Authenticity Matters,” accessed January 3, 2018, 855, https://www.academia.edu/13818877/Authenticity_Matters

⁸⁷ *Ibid.*, 853.

⁸⁸ Kolar and Zabkar, “A Consumer-Based Model of Authenticity,” 655.

obtain a self-reinforcing or self-reaffirming experience in that they achieve a better appreciation of their own existence. Such perceptions are individually constructed and depend on individual social and cultural experiences.⁸⁹ Existential authenticity was introduced as an alternative concept by Ning Wang, who writes that “...differentiation of ‘the authenticity of experiences’ from ‘the authenticity of toured objects’ is crucial for introducing ‘existential authenticity’ as an alternative source of authentic experiences”⁹⁰. Wang argues that both objectivism and constructivism have focused their attention on the toured object rather than the touring self. To illustrate the concept, Wang gives an example of rumba, where if it is treated as a toured object (spectacle), then it involves object authenticity, but once it is turned into a tourist activity, it constitutes existential authenticity, which has nothing to do with the issues of whether this dance is the exact re-enactment of a traditional dance.⁹¹ He also notes that because tourists engage in an existential form of authenticity-seeking of the self, the authenticity of a site or a tourist object is secondary.⁹² A tourist experience can be authentic even if the site or object toured is staged. This is because tourists are preoccupied with an existential state of being in response to the daily alienation they face in modern society and the routinization that gives rise to the ‘feeling of loss’. If individuals cannot remove this feeling in everyday life, they use tourism to fulfil their authentic selves.⁹³

Although postmodernists support Wang’s view, Shepherd argues that the concept of existential authenticity is rather strange, as it presupposes a “certain inadequacy in everyday life ‘at home’”⁹⁴. Shepherd continues further by questioning the premise that one’s self at home is not one’s genuine self, and that this illusive genuine self can be found, paradoxically, outside home among strangers.⁹⁵ Shepherd finalises his argument by stating that:

...authenticity-seeking tourists are far more bothersome as they insist on a right to intrude in the lives of others in their desire to reach...backstage of communities to which they do not belong. This illustrates the key problem with a quest for touristic existential authenticity. This model is not only Eurocentric but class-centric. An unacknowledged archetype...who believe they are beyond culture. Culture is, for them, something others have, which they paradoxically demand a right to experience...If leaving home and the familiar is a pathway towards finding one’s self, then the most authentic travellers should arguably be the millions of migrants who each year leave their home.⁹⁶

While numerous scholars debate existential authenticity and its application in tourism studies, in his study Wang established an important understanding within the notion of authenticity, which is the necessity to differentiate between “that of tourist experiences and that of toured objects”⁹⁷.

3.6 Authenticity of Object vs Experiential Authenticity

Authenticity is considered both a consequence of the tourist experience and an important precursor due to its ability to motivate, interest and drive tourist visitations, which is why the

⁸⁹ Kuon, “The Pursuit of Authenticity in Tourist Experiences,” 87-93.

⁹⁰ Wang, “Rethinking Authenticity in Tourism Experience,” 351.

⁹¹ Ibid., 359.

⁹² Shepherd, “Why Heidegger Did Not Travel,” 61.

⁹³ Wang, “Rethinking Authenticity in Tourism Experience,” 363.

⁹⁴ Shepherd, “Why Heidegger Did Not Travel,” 62.

⁹⁵ Ibid.

⁹⁶ Ibid., 68.

⁹⁷ Wang, “Rethinking Authenticity in Tourism Experience,” 351.

concept was divided into object-based and existential authenticity, allowing tourist experiences to be explained in the absence of an authentic object.⁹⁸

While Wang emphasizes that these authenticity types have to be viewed from different perspectives, Rickly-Boyd states that “it is rare when the authenticity of experience is examined without an analysis of the object toured”⁹⁹. There is a strong interaction between object, site, and experience; they are not mutually exclusive. Reisinger and Steiner conceive object authenticity as how people see themselves in relation to objects. This is confirmed by Waitt, who found that historical authentication relies mainly on physical artefacts.¹⁰⁰ In his study devoted to this issue, Kolar concluded that object-based authenticity has an effect on existential authenticity, because tourist “management namely seeks to positively influence tourist existential experience...primarily by offering them authentic artefacts”¹⁰¹.

While acknowledging the link between those two types of authenticity, it is not necessarily the case that one determines the other. The authenticity of an artefact can be judged objectively, but that may have no merit in the preconceptions and touristic perceptions of that artefact. Likewise, the authenticity of experience may be separated from the authenticity of the site and objects toured, as it is action- and emotion-based. That is why various potentially interesting elements of exhibited objects must be presented in a way that inspires and pleases tourists. This means that objects must be presented not only in an objective expert way, but also in an enjoyable, engaging and understandable manner. Cultural artefacts must be seen from the consumer standpoint and consequently offered in a way that satisfies their needs and expectations.

This dynamic interplay between two concepts of authenticity, as noted by Rickly-Boyd, suggests that “conceptually functioning simultaneously as a measurement, representation, experience, and feeling it must be a register for something more”¹⁰². Rickly-Boyd argues that the concept of aura, introduced by Walter Benjamin, is that ‘something more’, offering an understanding that can bridge the gap between object and experience in tourism studies because it is a concept developed around the idea of an interaction, an engagement, an experience between person and object or site.¹⁰³ The next subsection describes the concept of aura as it is understood in this study, followed by a brief look at how this concept is linked to digital media. In particular, it focuses on evidence that highlights how aura, as an important component of perceived authenticity, can be experienced through interaction with a digital artefact.

3.7 The Concept of Aura

The concept of aura has numerous meanings across various disciplines. The Oxford Dictionary gives three widely used definitions of aura:

1. The distinctive atmosphere or quality that seems to surround and be generated by a person, thing, or place.

⁹⁸ Bryce et al., “Visitors’ Engagement and Authenticity,” 573.

⁹⁹ Jillian M. Rickly-Boyd, “Authenticity & Aura: A Benjaminian Approach to Tourism,” *Annals of Tourism Research* 39, no. 1 (January, 2012): 274, <https://doi.org/10.1016/j.annals.2011.05.003>

¹⁰⁰ Kolar and Zabkar, “A Consumer-Based Model of Authenticity,” 655.

¹⁰¹ Ibid., 653.

¹⁰² Rickly-Boyd, “Authenticity & Aura,” 274.

¹⁰³ Ibid., 271-277.

2. (In spiritualism and some forms of alternative medicine) a supposed emanation surrounding the body of a living creature and regarded as an essential part of the individual.
3. A warning sensation experienced before an attack of epilepsy or migraine.¹⁰⁴

In terms of interaction between person and object or site, the first definition is more likely to explain the notion of aura in museum settings. However, this definition is extremely shallow and does not explain the nature of the concept. Although the concept of aura is one of the most commonly invoked in tourism and media theory, there is no specific definition of it. In his earlier writings, Walter Benjamin, who first introduced this concept, focuses primarily on works of art and suggests that aura is that feeling of reverence that arises from their uniqueness.¹⁰⁵ The concept of aura includes a sensory experience of distance between the reader and the work of art, which presupposes that no matter how physically close the object is to the viewer, he or she cannot touch or affect its unique history.¹⁰⁶ In *The Works of Art in the Age of Mechanical Reproduction*, Benjamin defines this idea as the “unique phenomenon of a distance, however close it might be”¹⁰⁷. He also argues in his work that though the concept of aura, characterised by the desire to be in touch with uniqueness, inspired mechanical reproduction, it has deteriorated because of it.¹⁰⁸ Along with loss of aura, copied objects lose their authenticity and authority. Disagreeing with Benjamin, MacCannell, who introduced the concept of aura to tourism studies, argues that “he [Benjamin] should have reversed his terms. The work becomes ‘authentic’ only after the first copy of it is produced. The reproductions are the aura...”¹⁰⁹ Likewise, Gable and Handler affirm that museums have become the repositories of cultural artefacts, ‘the physical remains, the auras of the really real’.¹¹⁰

Throughout his life Benjamin’s theories of aura grew more complex. While many scholars focus on Benjamin’s earlier writings, his latest elaboration of the concept expands it from being an inherent quality of an object to a definition of a range of human experiences that stem from the intersubjective nature of aura: “to perceive the aura of an object we look at means to invest it with the ability to look at us in return”¹¹¹. This reciprocity of gaze, the ability of an object to exist outside its time and place, and to be reinterpreted, facilitates the resurgence of experience. Such an understanding of the concept leads to the conclusion that the aura of an object can be experienced in relation to the person who used it. Aura is not a given property of the real; we create the experience of aura so that we might enjoy the sense of reciprocal experience.¹¹² In simple terms, what is called aura can be understood as a psychological state, an attitude or feeling that the viewer experiences when contemplating the work of art, object or site.¹¹³

¹⁰⁴ “Aura | Definition of Aura in English by Oxford Dictionaries,” Oxford Dictionaries | English, accessed January 3, 2018, <https://en.oxforddictionaries.com/definition/aura>

¹⁰⁵ Robinson, “Walter Benjamin: Art, Aura and Authenticity.”

¹⁰⁶ Jay David Bolter et al., “New Media and the Permanent Crisis of Aura,” *Convergence* 12, no. 1 (February, 2006): 25, <https://doi.org/10.1177/1354856506061550>

¹⁰⁷ Walter Benjamin, *The Work of Art in the Age of Mechanical Reproduction*, Hannah Arendt, ed. (UCLA School of Theatre, Film and Television: Schocken/Random House: 2005), <https://www.marxists.org/reference/subject/philosophy/works/ge/benjamin.htm>

¹⁰⁸ Robinson, “Walter Benjamin: Art, Aura and Authenticity.”

¹⁰⁹ Rickly-Boyd, “Authenticity & Aura,” 278.

¹¹⁰ Ibid., 279.

¹¹¹ Ibid., 275.

¹¹² Ibid.

¹¹³ Jay David Bolter et al., “New Media and the Permanent Crisis of Aura,” 26.

A survey conducted by Hampp, Bauer and Schwan indicated that the auratic effect of an object depends not only on authenticity but also on many other factors, including prior knowledge and interest in the object.¹¹⁴ These researchers presume that the appearance of a museum object can be quite simple, but it can, nevertheless, have a strong effect provided that the visitor knows or is told the history of the object.¹¹⁵ They mention as an example the original worktable of Otto Hahn. What constitutes the aura in this example is the meaning and the consequences of the experiments executed on the table. Exploring the table, visitors see the origin of nuclear science and visualise how the Nobel laureates stood in front of the table, changing the arrangement and testing different adjustments until they were successful. It would be very easy to replace the table, but in this case, referring to Walter Benjamin's earlier theories, a reproduction would not have the aura of the original.

Psychological state that provide auratic experiences by interacting with an object's history can be explained by the *law of contagion*, first formulated by the anthropologists Frazer and Mauss in their concept of 'sympathetic magic'. Frazer explained that "the 'law of contagion' holds that people, objects, and so forth, that come into contact with each other may influence each other through the transfer of some or all of their properties. The influence continues after the physical contact has ended and may be permanent"¹¹⁶. It can be assumed that certain original museum objects have strong effects on visitors because they were in contact with famous people or distant locations or times. While they were in contact, according to the *law of contagion*, a contamination in a positive sense took place and the knowledge of these contacts endows the objects with aura. According to this assumption, visitors should dedicate more attention to the exhibit when they believe it to be an original rather than a copy. Furthermore, originals should provoke a more vivid reaction in visitors, compared to copies. The law of contagion, and the desire to touch the exhibit, should be stronger if visitors think they have an original in front of them.¹¹⁷

Even though Walter Benjamin emphasised that only original objects can provide the experience of aura, artefactual fiction proves that objects can have a simulated aura as well. Artefactual fiction is defined as the allusion to any conceivable culture through the fabrication of artefacts which reflect the values of such culture.¹¹⁸ A common approach in artefactual fiction is the requirement that works be presented, or documented, as factual. This presents a potential contradiction regarding the 'aura of the real'. Walter Benjamin clearly states that "even the most perfect reproduction of a work of art is lacking one element: its presence in time and space, its unique existence at the place where it happens to be"¹¹⁹. The underlying principle of artefactual fiction is the fabrication of a provenance and history of the artefact. Without this, artists working in the genre cannot create the experience they wish to provide. For Benjamin, the provenance and history of the object supply a significant portion of the object's aura. This can be visually illustrated

¹¹⁴ Constanze Hampp, Daniela Bauer and Stephan Schwan, "The Role of Authentic Objects in Science Museums," in 22nd ICOM General Conference (Shanghai, China, November 2010), 84, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

¹¹⁵ Ibid., 77.

¹¹⁶ Ibid., 79.

¹¹⁷ Ibid., 80.

¹¹⁸ Jennifer Restauri, "The Potential of Museum Artifacts: Meta-historical Art in the Museum World," in 22nd ICOM General Conference (Shanghai, China, November 2010), 90, http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf

¹¹⁹ Benjamin, *The Work of Art in the Age of Mechanical Reproduction*.

in the works of Donald Evans and Norman Daly. Daly aspired not only to create a fictional culture, but to provide the physical evidence and narrative to verify its existence. As a result, those who encountered his work were convinced that the civilization of *Llhuros* had actually existed.¹²⁰

3.8 Aura & Digital Media

Oliver Grau, in his book *Virtual Art*, states that in the digital world there is no concept of original or copy. For an artwork in virtual reality, which knows no original, connotations of the cult of uniqueness, in the sense used by Walter Benjamin, do not apply. In digital art, aura originates through artificial inaccessibility or deep, immersive contact with the work.¹²¹

While numerous scholars maintain a traditional view and argue that a digital copy will never be able to match an experience of the original because of its mediated and biased representation¹²², today's digital world introduces new considerations on authenticity and aura. In fact, some suggest that new media designers must exploit our culture's ambiguous attitude towards these concepts.¹²³ How auratic experiences are gained through digital media can be seen in the example of photography.

Rickly-Boyd suggests that postmodernist tourists' self-reflexivity during production of photographs and their accumulation facilitates intersubjective relationships in the form of a reciprocity of gaze that is a characteristic of aura.¹²⁴ Photographs are the result of the desire to capture the aura of the toured place. While Benjamin's basic argument that photographs are non-auratic because they are an outcome of mechanical production, one finds that today the images are personified and therefore are auratic.¹²⁵ A photograph is not simply a pictorial form but an object that connects us to other times and spaces by its material presence; it returns our gaze. Andrew Benjamin suggests that a key to the experience of the aura of an object is the idea of an afterlife:

...the potential to exist beyond the restriction of any instant...When we look at photograph we reopen a particular space of experience, there is a relation existing through both time and space to the moment encapsulated...this moment is at once eternal, and at the same time ephemeral, it has passed and yet it continues to exist in the present.¹²⁶

While souvenirs and photographs are obtained at sites of socially constructed importance, it is the embodiment of experiences that gives them the ability to return our gaze – aura and authenticity. Because these objects continue to build meaning in our lives, they have an afterlife, which further builds their aura and therefore authenticity.¹²⁷ It is important to note that an auratic experience can be invoked not only in the case where a person has previously physically interacted with an object or site, but also through previously gained knowledge of history of that object or site in particular. This idea can be clearly understood through the example of old photographs, postcards or postage stamps, where an individual may have not created them, but still has an auratic

¹²⁰ Restauri, "The Potential of Museum Artifacts: Meta-historical Art in the Museum World," 93.

¹²¹ Grau, *Virtual Art*, 11.

¹²² Bianchi, "Making Online Monuments More Accessible through Interface Design," 450.

¹²³ Jay David Bolter et al., "New Media and the Permanent Crisis of Aura," 28.

¹²⁴ Rickly-Boyd, "Authenticity & Aura," 281.

¹²⁵ Ibid., 283.

¹²⁶ Ibid., 282.

¹²⁷ Ibid., 285.

experience through the feeling of establishing connection through previously gained knowledge or a story that is linked with that object.

If photography can deliver auratic experiences, it may be hypothesised in this thesis that a digital surrogate based on accurate measurements and detailed topological and texture representations is able to deliver an experience similar to that offered by photography. The immediate nature of transparent photography, be it analog or digital, where light establishes an indexical relationship between the object and the photograph, is in a way similar to heritage digitalisation techniques such as 3D scanning and photogrammetry, where an indexical relationship is also established in the form of coordinates in a digital space. Digital surrogates imply transparency during their production workflow. Bolter et al. suggest that transparency in the digital world evokes aura and can enhance it by providing a sense of distance-through-proximity.¹²⁸ In the case of historical or cultural sites, this enhancement can be achieved by supplying detailed information about the place or object, which establishes a connection with the viewer's previous knowledge.¹²⁹

3.9 Authenticity: Summary

An extensive discussion on the multi-faceted concept of authenticity has been presented in this section. It has shown that authenticity as a concept has come to be used simultaneously as measurement, representation, experience, and feeling, which has been the cause of rigorous debate over its meaning and utility. As the multiple perspectives used to address the concept in tourism studies (Objectivism, Constructivism, Postmodernism, Existentialism) have shown, authenticity is relational. It is measured, perceived, experienced, and felt in relation to the context it is used in as well as to other phenomena, such as aura. Some scholars have suggested abandoning the concept of authenticity due to its complex and often vague nature, but in this section, it has been demonstrated that it is still recognised and has to be further studied to expand existing understandings about its complexity.

As a result of the democratization of technology and museum policies for presenting their artefacts in the form of edutainment, in today's postmodern society each individual sets himself or herself a standard for what to consider authentic and what not to, based on preconceived ideas about the toured object formed by watching TV, reading a book, watching videos or browsing through articles on the Internet. Scholars have noted that tourists' insightfulness and knowledge help greatly in the production of their own experiences of authenticity. Therefore, an online digital surrogate can have not only preservation but also promotional purposes, generating awareness about the heritage object, which in turn can lead to a desire to visit the original site.

In terms of heritage preservation, digitalisation of physical objects requires transparency in the workflow and thorough documentation in order to claim a high level of authenticity. Transparency in a digital workflow is characterised by representing a 'real' world in a digital space as it is seen by the human eye, which implies a photorealistic approach through mimesis of details, textures, colours, lighting, perspective and everything that the human eye can capture in the real world. Though it may seem that such an approach is based on objectivist understandings, the final digital surrogate, at least in this project, does not aim to replicate 'real' in any metaphysical sense.

¹²⁸ Jay David Bolter et al., "New Media and the Permanent Crisis of Aura," 29.

¹²⁹ Ibid.

Instead, the real is defined in terms of the viewer's experience; it is that which would evoke an immediate (and therefore authentic) emotional response. The goal of the digital surrogate is to provide an authentic experience, not only with the direct historical provenance of a physical artefact, but to underline and integrate the invisible properties of the artefacts in terms of elements of auratic experiences, which are associated with cultural significance, its stories and the impact it made on New Zealand's history.

The theoretical understanding of the concept of authenticity presented in this section is applied to the workflow development and explained further in **Section 4**.

4. Methodological Approach

4.1 Multi-method Design Outline

This study employs a multi-method design based on the principles of practice-based and practice-led research. The two main goals of this study are to create an authentic artefact and to develop and deliver an effective practical workflow that can be used not only by specialists in the digital field, but also by museum workers for digitalisation of heritage artefacts. The dominant methodological approach in this thesis is practice-led because “practice-led research is concerned with advancing knowledge within practice and it is often described in text form without the need to produce a creative artefact”¹³⁰. While the delivery of the workflow is the ultimate goal of the project, its effectiveness is measured by assessing the level of authenticity of the resulting artefact, which is an optimised model of the Edwin Fox ship. The necessity of delivering an artefact as a final research product is an element of practice-based research, in which new knowledge is gained and demonstrated through the development of creative work, such as designs, digital media, exhibitions or performances.¹³¹ The effectiveness of the workflow is verified by the level of authenticity the resulting artefact has. In this case, this is evaluated via responses obtained from experts in the field of heritage preservation and museum curation.

This multi-method approach improves the workflow development through its capacity to answer the research question thoroughly and to establish linkages between two methods that help with the advancement of new knowledge. McMurray notes that by incorporating multiple techniques in a research design, a more accurate perception of reality, knowledge and truth can be gained.¹³²

While developing an effective workflow that can be applied in real-world practice, it is extremely important to constantly refine and reflect on the methods used. Practice is an integral part of this practice-based and practice-led research, which falls into the general area of Action Research¹³³, integrated into this study as its core methodology.

4.2 Principles of Action Research

As a term, Action Research was first introduced in 1946 by Kurt Lewis and was described as a reflective process involving recurring cycles relating to planning, action, and review.¹³⁴ Today, Action Research is defined by its goal of generating new understandings in a certain professional field through a cyclical process of exploration, knowledge construction, and action at different moments throughout the research process, which leads to improvement of understanding and experience for

¹³⁰ Linda Candy, “Practice Based Research Guide,” *Scribd*, accessed May 18, 2016, <https://www.scribd.com/doc/14811777/La-investigacion-basada-en-la-practica>

¹³¹ *Ibid.*

¹³² Adela McMurray, R. Wayne Pace, and Don Scott, *Research: A Commonsense Approach* (Southbank, Vic.: Thomson/Social Science Press, 2004), 262.

¹³³ Candy, “Practice Based Research Guide.”

¹³⁴ McMurray, Pace, and Scott, *Research*, 277.

social benefit.¹³⁵ Advancement and development of professional practice, expanding and bringing together new understandings is the major principle of Action Research.¹³⁶ While numerous critics question Action Research as a valid methodology by arguing that it is rather a particular style of research where learning is achieved by doing, Action Research has gained many supporters.^{137 138} Robin Ewing notes that Action Research “can be regarded as both ‘an orientation to inquiry with an obligation to action’ and a methodological approach for advancing professional knowledge”¹³⁹.

The idea of self-reflection throughout the research development is central to Action Research. In traditional forms of research researchers do research on other people. However, in Action Research, researchers do research on themselves. Such self-reflection, in the words of McIntyre, “does not give a licence for ‘anything goes’”¹⁴⁰. It means honestly evaluating one’s own practice, recognising what is good and building on strengths, as well as understanding what needs improvement and further development. It involves commitment to the idea that the research process will transform into purposeful personal action for social benefit.¹⁴¹ To support this view, McMurray quotes Cunningham, who explains that “an action researcher is a person with a scientific attitude, an understanding of qualitative research principles, an understanding of the dynamics of change, and a commitment to studying problems that are relevant in real settings”¹⁴². The requirement for practitioner excellence and accountability goes without saying, along with the need to produce empirical evidence to support claims that one knows what one is doing and takes responsibility for the ongoing improvement of practice.¹⁴³ An honest, self-reflexive attitude generates a constant cyclical process of questioning, reflecting, investigating, planning, implementing, refining, and questioning again. In saying that, however, such research methodology generally does not aim for closure of the cyclical process, but rather for reflection and evaluation of whether what the researcher is doing is the best it can be in a project’s context and within a particular inquiry area. Such an approach contributes to gaining new knowledge that is judged not against objective truth, but against the idea of practicality and efficacy in a particular professional field.¹⁴⁴ **(Fig. 03)**

¹³⁵ Jean McNiff and Jack Whitehead, *Action Research: Principles and Practice* (London: Routledge Falmer, 2002), 17.

¹³⁶ Lina Markauskaite, Peter Freebody, and Jude Irwin, *Methodological Choice and Design: Scholarship, Policy and Practice in Social and Educational Research*, Methodos Series: V. 9 (London: Springer, 2011), 76.

¹³⁷ Ibid., 57-67.

¹³⁸ McMurray, Pace, and Scott, *Research*, 277.

¹³⁹ Markauskaite, Freebody, and Irwin, *Methodological Choice and Design*, 71.

¹⁴⁰ Alice McIntyre, *Participatory Action Research*, Qualitative Research Methods: 52 (Los Angeles: Sage Publications, 2008), 61.

¹⁴¹ McNiff and Whitehead, *Action Research*, 17.

¹⁴² McMurray, Pace, and Scott, *Research*, 280.

¹⁴³ McNiff and Whitehead, *Action Research*, 60.

¹⁴⁴ Candy, “Practice Based Research Guide.”

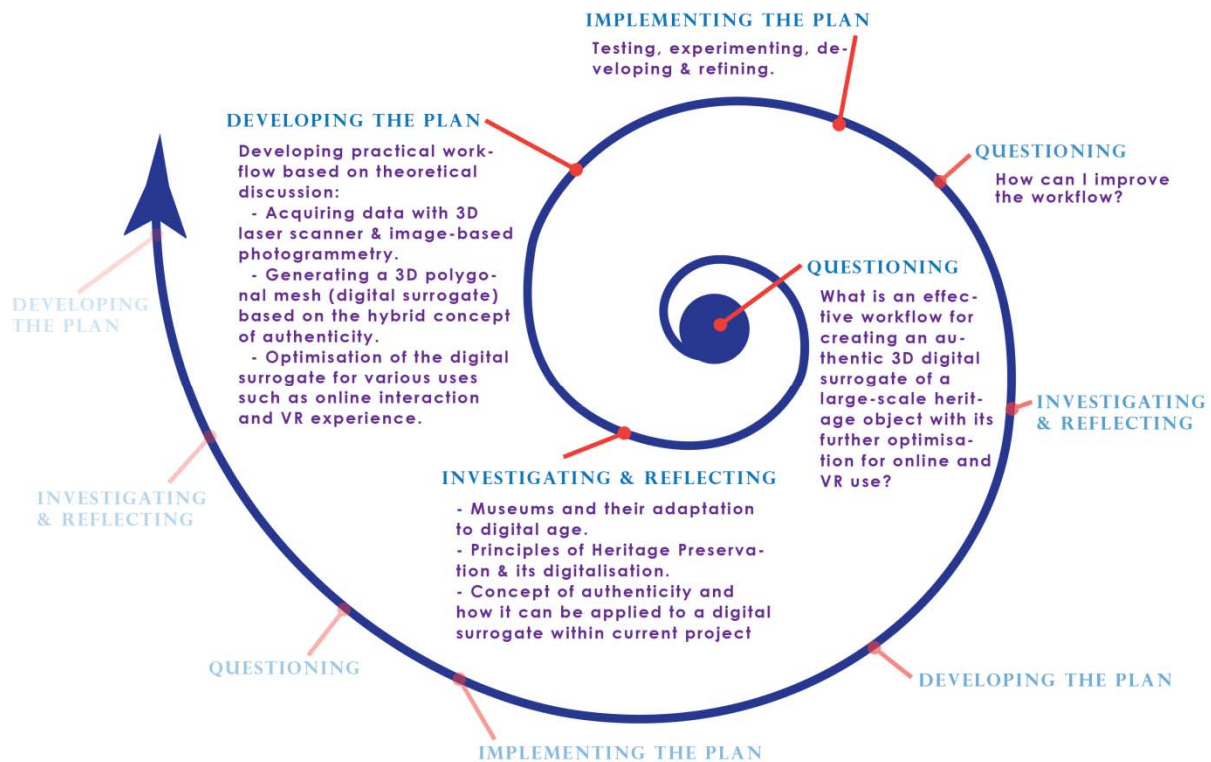


Figure 03. The Action Research principles applied in the current thesis. A transcript of the illustration is available in Appendix A.

Figure 03 demonstrates the implementation of Action Research principles in the research design of the current thesis. The idea of self-reflection throughout the research development is illustrated in the spiral, with the research question at the beginning and the arrow at the end, which means a constant questioning and improvement cycle that may continue outside the timeframe of this thesis. The final outcome in a form of a workflow still will be an answer to the proposed question in the current time and field of professional practice, but the workflow will undergo constant improvement through further experiments on various practical projects and the development of new technologies.

The research design is divided into four sections that follow one another along the spiral:

4.2.1 Questioning:

What is an effective workflow for creating an authentic 3D digital surrogate of a large-scale heritage object with its further optimisation for online and Virtual Reality (VR) use?

As mentioned earlier in the introduction, there is a need for a clear and manageable workflow for digital heritage conservation that can be used by museum workers as well as digital specialists. The proposed question allows setting out the basic understanding of the methods and techniques developed throughout the workflow, which can be used as a foundation or a starting point for development of an individual approach in settings particular to the practitioner. The developed workflow can be used as a guide for museum workers interested in generating digital copies of artefacts, and as an illustration of various experiments with the techniques that can be integrated into the workflow of experts in the field of digital preservation. Due to its immense complexity, the *Edwin Fox Project* allows for a workflow development with a wide range of

possibilities for technical experiments and tests covering a large number of problems that might occur in other similar or less demanding heritage digitalisation projects.

4.2.2 Investigating & Reflecting

There are theoretical concepts within the proposed research that should be addressed before developing a plan for a practical workflow. **Section 2** and **Section 3** gave a detailed overview of those concepts. How those concepts are integrated in the *Edwin Fox Project* is discussed below.

Museum philosophy and adaptation to digital age

With the increase in consumerism and the edutainment culture required for heritage operations to flourish, the main question for the survival of heritage museums in the 21st century is whether the curators can adapt to other forms of representation to fit the object into the minds of today's audiences. Museums have to reflect the current culture of digital age in order not only to preserve, but also to promote their artefacts. The ability of an optimised digital surrogate to be repurposed for a variety of uses including online representations, depiction on a digital screen, virtual reality exploration, and game experience development allows museums to foster knowledge about their artefacts and promote themselves as technologically advanced institutions, which in return fulfils today's demands by an increasingly sophisticated public for education in the form of entertainment. For a small heritage preservation institution, such as the Edwin Fox Museum, the online presence of its artefacts is essential for reaching scholars and history enthusiasts worldwide in order to attract more attention and funding for further study and preservation of the physical artefact. The Edwin Fox Museum regularly provides tours for schoolchildren, educating them about the immigration history of New Zealand and the history of the Edwin Fox in particular. A digital surrogate allows children to interact with the model and to view it from any angle, which is impossible in real life. Such interaction lengthens the attention span and may improve learning and help in understanding the structure of the ship.

Principles of heritage preservation and its digitalisation

Because of the numerous techniques (ranging from tape measurement and image-based modelling to GPS measurement, aerial surveys, photogrammetry and 3D laser scanning) used for digitalisation of heritage objects, there is no specific, widespread, established methodology to be applied in the field of heritage preservation. However, a few important principles that must be incorporated into mainstream digitalisation methodology are outlined by Mudge and Ashley in *A Digital Future for Cultural Heritage*.¹⁴⁵ The most important principle for heritage digitalisation is the reliability of the preservation team and its ability to maintain the authenticity of the final deliverable through the process of digitalisation. In the current project, the motivation for excellence is the clear understanding of the vulnerability of the Edwin Fox, which could be lost any day as the consequence of an earthquake. Such a concept goes hand in hand with the principles of Action Research, where the claims of the researcher must be valid and supported by empirical provenance. Mudge and Ashley state that only practices that are able to provide a complete empirical provenance can be used to construct a reliable digital surrogate.¹⁴⁶ The importance of automation is also highlighted as

¹⁴⁵ Mudge and Ashley, "A Digital Future for Cultural Heritage," 1.

¹⁴⁶ Ibid., 2.

a crucial factor, as it allows the workflow to be faster while capturing data and reduces the chance of inaccuracies in measurements, as well as being repeatable and consistent, which is important in maintaining a scientific approach to produce a workflow that can be empirically tested. Automation helps lessen the feeling of “mystification of technology”¹⁴⁷, which implies that the ease of access to software and equipment used in a digital workflow also reduces the computer technology expertise necessary to manage production of a surrogate.

Combined with these principles, the Action Research approach is able to produce a detailed self-reflective record of workflow development as empirical provenance, using accessible equipment and software available in the market while delivering a high-quality, authentic digital surrogate as an end product of the workflow.

The concept of authenticity and how it can be applied to a digital surrogate produced in this project

As mentioned before, the high-resolution 3D model produced as a final artefact in this project has two applications. One is to serve as an online projection of the real artefact for educational and promotional purposes, which may attract more visitors to the original site. Digital cultural heritage can augment and enhance our lives by offering the chance to connect our busy selves with our overlooked past. Online representation, which does not claim to replace the real thing, but rather to augment its perception, allows viewers to create new connections and extends the meaning of the objects beyond the physical boundaries of museums. Such representations may also help to create a “sensory mediation”¹⁴⁸ (rarely achieved in a physical museum because of limited time), which allows for the complex processes of moving from emotion to cognition, to the innate pleasure of acquiring knowledge. The second application for the final artefact is to serve as a digital archival record, not only for preservation purposes in case of an earthquake, but also for allowing worldwide access by the scholarly community to study and discuss the heritage object. While the first application does not necessarily imply an exact digital representation, the second means that the final digital artefact is of diminished value if there is any information in the original that is not completely and satisfactorily recorded by the digitalisation process. Where digital materials have value as records that offer evidence of some kind, object authenticity is extremely important so that researchers can confidently use it for their studies. Digital surrogates must provide the highest level of authenticity as the term suggests that they are a digital copies of ‘real world’ objects.

While deciding that authenticity has been sufficiently demonstrated by empirical provenance in terms of generating digital surrogates is quite a subjective criterion, the concept of authenticity is even more subjective and open to interpretation. **Section 3** discussed in detail the complexity of the concept and its socially constructed nature. When working with the concept of authenticity, researchers are required to clearly state their views on this concept and how it is applied in the context of their research. In the digital world, researchers are encouraged to explore the meaning of authenticity and establish new understandings since there are no defined principles of what to consider authentic. Therefore, in this study it is proposed to understand authenticity in

¹⁴⁷ Mudge and Ashley, “A Digital Future for Cultural Heritage,” 4.

¹⁴⁸ Rispoli, “The Object in History Museums, Mediator for the Invisible,” 106.

the context of a digital surrogate as a *hybrid* form, which combines some elements of existing perspectives on this concept. A detailed explanation of the proposed idea is provided in **Figure 04**.

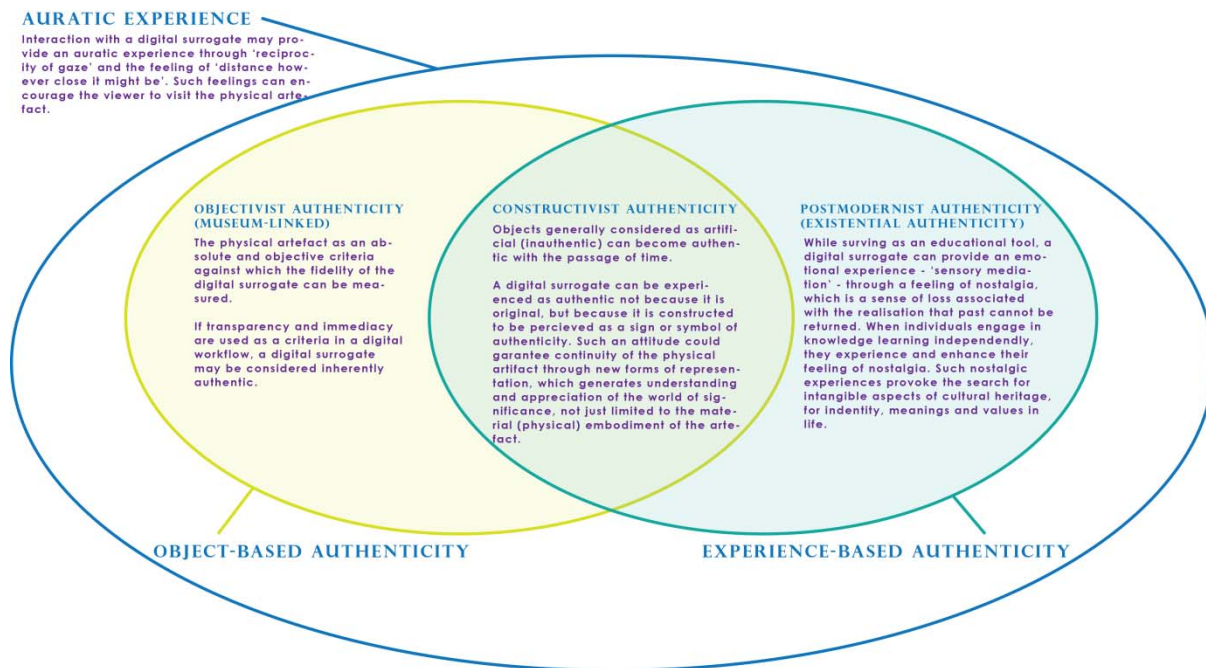


Figure 04. Proposed concept of *hybrid authenticity*, which combines elements from existing perspectives. A transcription of the text can be seen in **Appendix B**.

In literature, generally, it is argued that the aura of an artefact cannot be experienced in the digital world. **Figure 04**, however, demonstrates that, if understanding of the theory presented in **Section 3** is correct, auratic experiences can hypothetically be achieved while engaging with digital copies. **Figure 04** also shows that while postmodernist elements of authenticity rely fully on the viewer's previous experiences and worldview with constructivist elements partly relying on object-based (though constructed) authenticity, the elements of objectivist authenticity imply that transparency and immediacy must be used during the workflow development of a digital surrogate. Although transparency and immediacy are the ultimate goal in this project, as stated earlier, it is unrealistic to expect a complete digitalisation of the 'real world' as it is. There are numerous reasons for this in the current project. First of all, the large scale and complexity of the artefact is extremely labour-intensive in terms of capturing data. The ship, due to its old age, is always in need of small repairs, which means small timbers continue to change their location and some areas are physically inaccessible or dangerous to be around. The second reason is the state of technology today, which does not allow handling the enormous amount of data involved if each square millimetre of the ship is to be captured and presented to the target audience in any meaningful way. For smaller museum artefacts it is possible to achieve full transparency; however, the current project requires some digital restoration techniques based on photographic references, as demonstrated in **Section 5**, to remove unnecessary objects and to correct possible errors in the photogrammetric capture. Despite any errors that may occur in the mesh or colour information of the digital copy during the capturing process, the highest possible level of objectivist authenticity, established through transparency and immediacy, is a priority for a digital surrogate produced as an outcome of the developed workflow.

4.2.3 Developing the Plan

The planning of the workflow development is based on the previously discussed theoretical conclusions.

Achieving transparency and immediacy in digitalisation process

Not long ago a photographic medium was considered the apogee of mimesis – an accurate representation of the real world. Gaining its status mainly due to the concept of immediacy, or what some scholars call indexicality, the photographic medium was used to document heritage objects and sites. Such reliance on photographic medium supposed that when light touches an object and reflects back to the camera sensor, a physical continuity with reality is established. The knowledge that at some point there was a physical contact with the real-life object forms trust and the experience of presence.¹⁴⁹ In this sense a strong parallel can be seen between the photographic medium and the 3D laser scanning techniques used for digitalisation by numerous practitioners, and in the current project.

Technologies for 3D laser scanning have been available since the 1980s. The National Research Council of Canada (NRCC) was among the first to apply laser scanning technology to heritage recording. Despite being among the common practices used in the digitalisation of heritage objects, only recently have 3D scanning devices started to provide sufficiently high resolution and accuracy while becoming more accessible and affordable.¹⁵⁰

The technology behind 3D scanning and calculation of an object's parameters is quite complex and a detailed discussion of its principles is outside of the scope of this study. In simple terms, a laser scanner passes a laser beam over the object's surface and the reflectance of this is sensed by a camera device on the laser. The position of the laser emitter and the sensor are fixed and known. Therefore, it is possible to calculate the changes in surface shape from the varying angles of reflectance. Positional information about the laser emission reflectance is optically recorded and these values are used to determine depth by a trigonometric triangulation calculation. To build 3D data from a continuous surface it is necessary to take measurements from many location points. This is achieved rapidly when the laser beam is passed through a lens to create a strip of light, which is then swept back and forward at high speed by an internal tilting mechanism. In this way, many coordinates are recorded simultaneously, resulting in a dense set of points known as a 'point cloud'.¹⁵¹ The scanning device itself is manually moved (allowing an overlap between areas) after each scanning session, to capture the next area of the object's surface.

In the current workflow, in addition to 3D laser scanning, image-based photogrammetry is used to enhance the fidelity of laser scanner calculations. Photogrammetry is the science of obtaining reliable measurements from photographs, which can be used to generate point cloud

¹⁴⁹ Tom Schofield, Marian Dörk and Martyn Dade-Robertson "Indexicality and Visualization: Exploring Analogies with Art, Cinema and Photography," in *Proceedings of the 9th ACM Conference on Creativity & Cognition* (June, 2013), 2, <http://mariandoerk.de/papers/cc2013.pdf>

¹⁵⁰ Angela Geary, "3D Virtual Restoration of Polychrome Sculpture: Techniques and Applications," in *Digital Heritage - Applying Digital Imaging to Cultural Heritage*, Lindsay MacDonald, ed. (Elsevier, Oxford, 2006), 490.

¹⁵¹ *Ibid.*, 492.

data. A sequence of high quality photographs is required in order to provide the highest level of transparency in the final point cloud data.

To ensure the reliability of the final point cloud data, specifically designed software for handling point clouds is used for automatic calculation and merging of 3D laser scanner data and image-based photogrammetry. Numerous softwares are commercially available, with Agisoft PhotoScan, RealityCapture and Autodesk ReCap being most commonly used by professionals. The current research uses RealityCapture software due to its faster processing algorithm calculations and automation in almost every step for generating a point cloud.¹⁵²

Managing a high-resolution 3D model

The raw 3D model generated from the point cloud data can be handled only in specialised 3D modelling software due to the large amount of data that has to be displayed on the screen. The raw scans can have varying levels of cleanness of their polygonal meshes. While maintaining as much as possible of the transparency and automation in the workflow, the polygonal mesh has to be cleaned of unnecessary objects and artefacts, and have all the hidden areas on the mesh restored. The process of cleaning and restoration may take from an hour to months of work per artefact depending on the scale of the object, the quality of the scans and the complexity of the textures. The Edwin Fox is an extreme case of a laborious and time-consuming cleaning and restoration process, as this ship is a very large-scale artefact with a complex interior and exterior structure and intricate small details in the variety of textures it possesses. A complete and detailed cleaning and restoration process is discussed in **Section 5**.

Optimisation process for meaningful presentation

A restored high-resolution model is generally characterised by having a dense polygonal mesh that replicates all the details that can be visually seen in the physical artefact. This means that a high-resolution model might have a polygonal count in the millions, which can only be displayed and interacted with in a specially designed 3D modelling software. For the high-resolution model to be viewed online, used in real-time in a gaming engine, or incorporated into a Virtual Reality experience, it has to go through an optimisation process, which allows a reduction in the model's polygonal count while maintaining all high-resolution details. Preserving the scanned details while reducing the size of the model poses a major issue in developing an optimisation workflow demonstrated in detail in **Section 5**.

A complete workflow proposal for digitalisation and optimisation of the final digital surrogate can be seen in **Figure 05**.

¹⁵² Graham Hinchliffe, Auckland University of Technology Science faculty, personal conversation, November 2016.

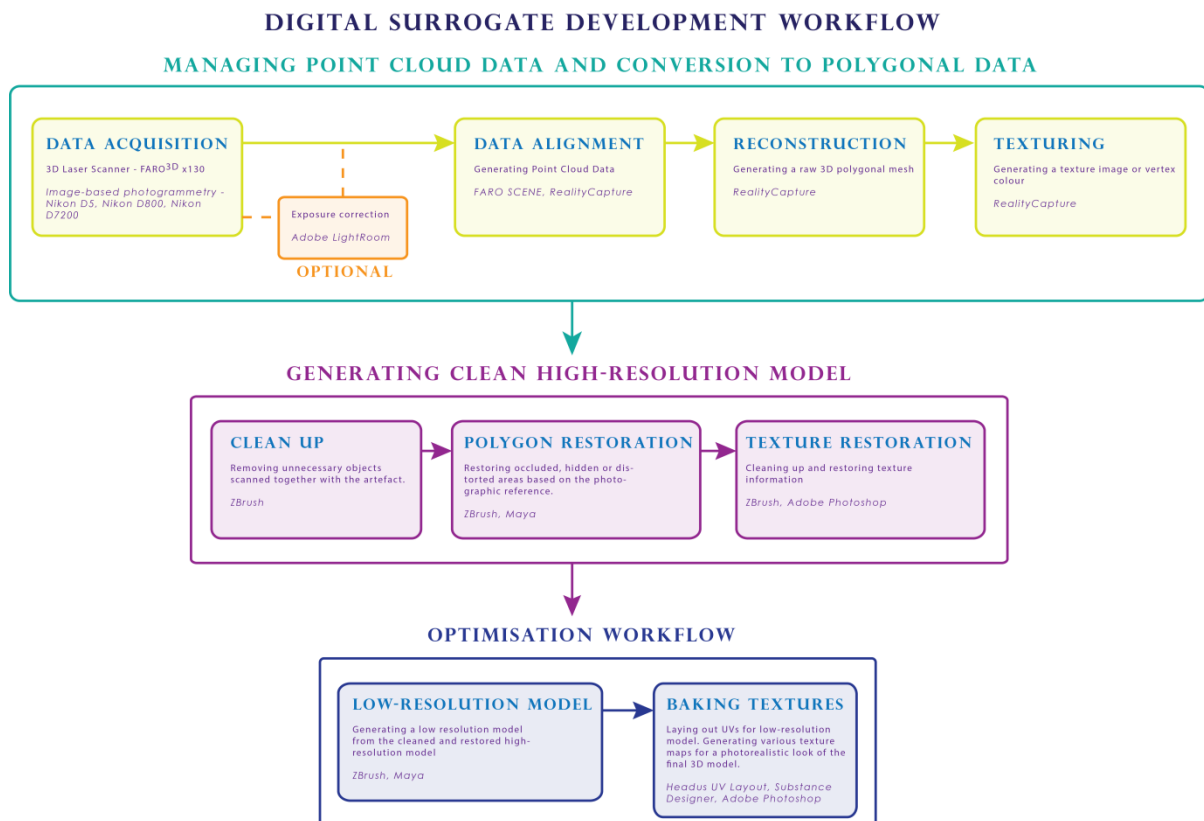


Figure 05. Digital surrogate development workflow. A text transcription is available in **Appendix C**.

4.2.4 Implementing the Plan

The final stage of the workflow development is the implementation of all the theoretical foundations discussed in this thesis into the development of the practical workflow. This process requires numerous tests, experiments, further developments and refinements to deliver a socially beneficial outcome that is useful in the heritage preservation and digital fields. During the development new questions will arise throughout the refinement stage and will be addressed and documented in order to illustrate a complete pathway of the workflow progression so that it can be repeated and can deliver an empirical provenance.

4.3 Advantages of the Proposed Methodology

Action Research presupposes that there is no final answer to a proposed question, but that there should be a constant desire for further improvement of the developed workflow. As indicated earlier, when using Action Research as a methodology, the researcher is not aiming to provide an ultimate solution within a research project, but to deliver the best possible answer to the question within the project's context and timeframe. MacNiff comments: "Knowledge is never static or complete; it is in a constant process of development as new understandings emerge...There are no fixed answers, because answers would immediately become obsolete in a constantly changing future"¹⁵³. Such an understanding seems to be relevant in the area of heritage preservation and its digitalisation, where rapid changes in technologies and techniques provide new considerations and opportunities for further workflow development or restructuring. The essential idea of the proposed

¹⁵³ MacNiff and Whitehead, *Action Research*, 18.

methodology is a learning cycle that generates an effective workflow, which can be practically used by field professionals before new technical solutions emerge. The proposed multi-method approach allows filling the gap between theory and practice in the field of heritage digitalisation to strengthen the validity, practicality and effectiveness of the final workflow and the digital surrogate as its outcome.

4.4 Concerns with the Proposed Methodology

McNiff notes that Action Research is a collaborative inquiry, where it is “always research with, not research on”¹⁵⁴. While it is ideal to maintain this notion of collaboration, it is often not possible or practical. However, this does not mean that the research undertaken is not valuable. Walter Adams suggests that personal professional inquiry may at times need to precede collaborative inquiry; practitioners may start with reflection and change in their own practices and then see the need for more collaboration with their colleagues.¹⁵⁵ Considering the time limit and the scope of this Master’s degree research, the ‘individual practitioner-researcher’ approach is likely to deliver faster and more focused results, which can serve as a foundation for more extensive analyses in future research involving a group of practitioners.

The proposed perspective on authenticity as a hybrid authenticity of a digital surrogate attempts to bring together theoretical and practical understandings to form an effective workflow. However, the arguments presented in this research are not conclusive but rather suggestive and require additional research once the final optimised surrogate is delivered.

¹⁵⁴ McNiff and Whitehead, *Action Research*, 87.

¹⁵⁵ Markauskaite, Freebody, and Irwin, *Methodological Choice and Design*, 73.

5. Workflow Development

5.1 Introduction

Data acquisition techniques used in the *Edwin Fox Project*

Large complex heritage objects and sites pose a variety of challenges at each stage of the workflow development. Among others, one of the main challenges in the first stage of a heritage object or site digitalisation is to choose an appropriate data acquisition technique to suit the goals of the particular project. The workflow developed for the current project requires the highest level of fidelity (accuracy) to the 'real world' to produce a valid digital surrogate that can be used not only for entertainment, but also for educational purposes. Whenever fidelity and realism are the requirement, the quality of the measurement and capture techniques should be a priority for the project.¹⁵⁶ Remondino and Rizzi identify five properties that are required for heritage digitalisation techniques:

- **Accuracy**, where precision and reliability of measurements are important;
- **Portability**, where equipment used is easy to transport due to accessibility problems, space constraints and absence of electricity on many heritage sites;
- **Fast acquisition**, where data has to be captured relatively fast due to limited time for site access or natural environmental lighting constraints;
- **Flexibility**, where the technique can be applied on heritage objects/sites of various shapes and scales in any possible condition.
- **Low cost**, where equipment and techniques used can be affordable for most museums and archaeological sites.¹⁵⁷

Large-scale heritage objects and sites require the integration of multiple reality-based techniques for producing the best results in terms of visual look and accuracy of surface details. The combination of multiple data acquisition techniques allows compensation for the individual weaknesses of each method, to achieve more accurate and complete data for generation of a digital copy.¹⁵⁸ Among the versatile non-contact, reality-based surveying devices, a 3D laser scanner is considered sufficiently fast and accurate to guarantee a high level of fidelity for the gathered surface data.^{159 160} However, most of the generally available 3D laser scanners do not provide the highest quality of colour texture information. For that reason, photogrammetry (an image reality-based surveying technique) is usually used together with a laser scanner to generate high-quality colour texture information from high-resolution photographs. Typically, this combination of multiple data

¹⁵⁶ Grycz, "Digitising Rare Books and Manuscripts," 66.

¹⁵⁷ Remondino and Rizzi, "Reality-Based 3D Documentation of Natural and Cultural Heritage Sites - Techniques, Problems, and Examples," 87–88.

¹⁵⁸ Ibid., 91.

¹⁵⁹ Fontana et al., "Three-Dimensional Modelling of Statues: The Minerva of Arezzo," 325.

¹⁶⁰ Paul Bryan, "User Requirements for Metric Survey," in *Digital Heritage: Applying Digital Imaging to Cultural Heritage*, Lindsay MacDonald, ed. (Amsterdam: Elsevier, 2006), 171.

acquisition techniques is justified only for large-scale objects and sites. For smaller heritage artefacts, photogrammetry is the most versatile, fast and cost-effective method for producing high-quality geometric and colour texture data.

Introduction to the principle of the workflow development in this study

The standard workflow for creating a digital copy for an artefact of any size consists of three main stages (a detailed description for the *Edwin Fox Project* is presented in **Section 4, Figure 05**):

- **Data acquisition and point cloud generation**, where all the surface and colour texture information are gathered through surveying techniques, and then processed in specifically designed software to generate point cloud data. The workload of the subsequent stages largely depends on the scale of the artefact and the quality of the data acquisition process;
- **High-resolution polygonal mesh generation**, where a high-resolution polygonal mesh is produced from the previously obtained point cloud data. If there are any holes or unnecessary artefacts, the model undergoes a cleaning and restoration process;
- **Optimisation process**, where a high-resolution model is converted into a low-resolution model while keeping all the details of the high-resolution model visually present on the low-resolution model.

Those stages engage with different technologies and require a particular set and level of skills, which is why the current workflow development introduces two sections in each stage. The first section, named **Basic Workflow**, demonstrates the workflow that presents the basic set of skills required for people such as museum workers, who would want to produce digital copies of their collections but have no professional experience in the digital field. For clear and easier understanding, this section features examples of smaller objects, which were used to ‘test the ground’ before proceeding with the *Edwin Fox Project*. The other section, named **Advanced Workflow**, demonstrates more advanced techniques of digital copy generation that might be useful for experts in the digital field to integrate into their own workflows. The advanced workflow across the last two stages is demonstrated on a part of the Edwin Fox digital copy as its principles are applied to generate all the parts the digital Edwin Fox consists of.

5.2 Data Acquisition

5.2.1 The 3D laser scanning and point cloud data

Basic Workflow

Data acquisition

As mentioned earlier in the introduction to this section, the photogrammetry technique alone, described further, is sufficient to provide accurate, high-quality data acquisition for medium- and small-sized artefacts. If a large-scale artefact needs preservation, it is recommended that museum workers collaborate with digital specialists who can use the advanced workflow, because

large-scale artefacts require a wide range of skills in the digital field to deliver the final high-quality outcome.

Advanced Workflow

Data acquisition

There are two types of laser scanners commercially available, based on either optical triangulation or on Light Detection and Ranging (LiDAR) principles that use a laser to transmit a light pulse. In the *Edwin Fox Project* a FARO Focus^{3D} x 130 laser scanner (**Fig. 06**) was used for its known high-quality performance outdoors in changing light conditions. This laser scanner uses a time-of-flight technology to measure the distance to points on the scanned object. Data from the scanner generates a point cloud, where each point has coordinates in the space (x, y, z) and a value representing the amplitude of the laser light reflected back to the scanner. The amplitude depends on the reflectance of the material and the surface orientation.¹⁶¹

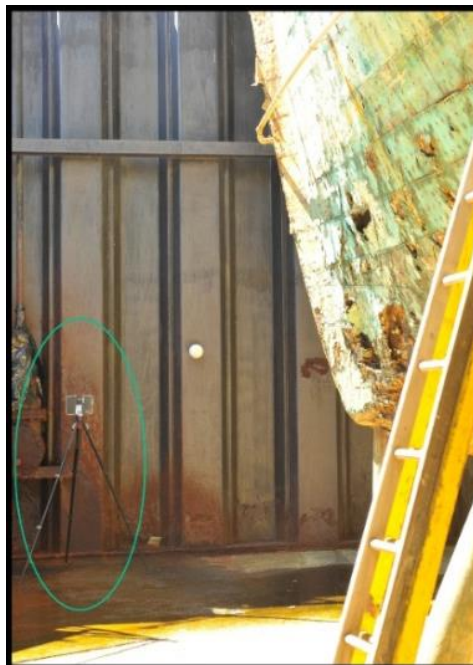


Figure 06. FARO Focus^{3D} scanner (outlined in green) at the Edwin Fox site.

In order to gather the required data for a large-scale object such as the Edwin Fox, multiple scans must be taken from different locations and scanner orientation. It is recommended to use specially designed targets placed on a scanned object, to speed up and ease the registration ('stitching') process, which matches all the scans and resolves them as a continuous surface of the scanned object. There are two types of targets that can be used with the FARO Focus^{3D} scanner (**Fig. 07**¹⁶²):

¹⁶¹ Allen et al., "The Beauvais Cathedral Project," 10.

¹⁶² FARO Focus x 130 and x 330 Laser Scanners SCENE 5.3 Training Manual, September 2014, 87, <https://www.faro.com/download-center/08m13e19%20-%20SCENE%20v5.3%20-%20FARO%20Focus3D%20Laser%20Scanner%20Training%20Manual%20-%20September%202014.pdf>

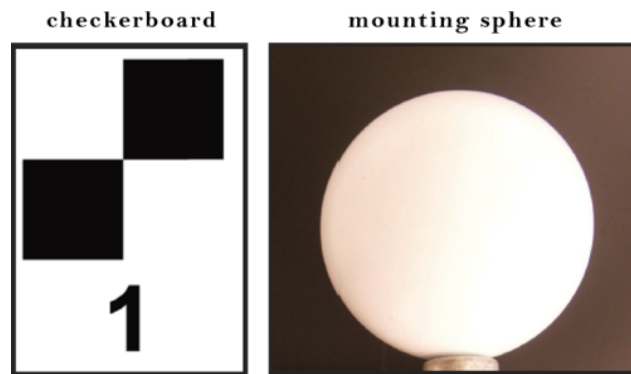


Figure 07. A checkerboard template can be downloaded at the FARO website. A spherical mounting target can be hired with the laser scanner. *Images are taken from the Faro Training manual.*

When using targets, their position relative to one another and to the scanner is critical for the correct registration process. At least three targets must be seen in one scan session in order to be registered with the next one. The checkerboard target is a flat paper print that must always be securely attached to a flat surface and be seen at a straight angle to the scanner. Checkerboard targets that are tilted away from the scanner by less than 45 degrees might not be seen as targets. Checkerboard targets can also be numbered for easier identification. A mounting target is a three-dimensional white sphere that can be seen at any angle to the scanner. When placing the mounting targets there should be a clear line of sight from the scanner to the targets. Targets should form a polygon around the scanner and be placed at varying heights, distances and planes. More detailed and project-specific instructions can be found in the FARO SCENE training manual¹⁶³ and the FARO Focus^{3D} manual¹⁶⁴.

When scanning the Edwin Fox, both target types were used to ensure the correct registration process for all the scans. The checkerboards were evenly attached with sticky tape within reach from a small ladder available at the site. Some areas of the ship were so damaged that there was no opportunity to tape down the markers (**Fig. 08**).

¹⁶³ FARO Focus x 130 and x 330 Laser Scanners SCENE 5.3 Training Manual, 99 – 112.

¹⁶⁴ FARO Laser Scanner Focus^{3D} x 130 Manual, February 2015, 49 – 52, <https://faro.app.box.com/s/r45cyjqengcts8vnh5kawemgsvdfxt81>



Figure 08. The checkerboard targets placed on the Edwin Fox close to the pipe that horizontally encircles the ship.

There were also four spherical targets with magnets at their ends, which were attached at varying heights on the metal walls of the dry dock and other metal supporting structures, and placed on the floor during scanning of the exterior (**Fig. 09**). Target placement was guided firstly by the fact that the targets could not be attached to the ship's exterior surface, and, secondly because the targets might occlude surface information, which adds to the cleaning and restoration process. In the interior, the targets were attached to the metal 'knees' of the ship, also varying their height level where possible. With each subsequent scanning session there were at least three spheres visible to the laser scanner. If there were less than three targets visually aligned with the device, one of the hidden ones was moved forward to the overlapping area of the next scan. Point cloud data is a large data that can be viewed only using a specifically designed software on a powerful computer. The widespread problem of such data is to find a way of converting point cloud data into polygonal data, which can be cleaned, restored and optimised for a public access.



Figure 09. The spherical targets placed for the laser scanning workflow.

Before proceeding with the scanning, it is important to set a resolution determining the distance between the points of the scanner's beam. The smaller the distance between those points, the higher the resolution of the point cloud recorded by the scanner (**Fig. 10**). The highest resolution is one to one, which might be considered the best choice for the workflow but is not always the

case, as the higher the resolution is set, the more time per scan is needed to capture the required data. Also, highest resolution scans are often extremely large in size, making them hard to manage in the subsequent steps of the workflow. The resolution setting also depends on the distance the scanning device is from the target object – the greater the distance, the higher the resolution setting needs to be in order to produce a high-quality scan (**Fig. 11**).

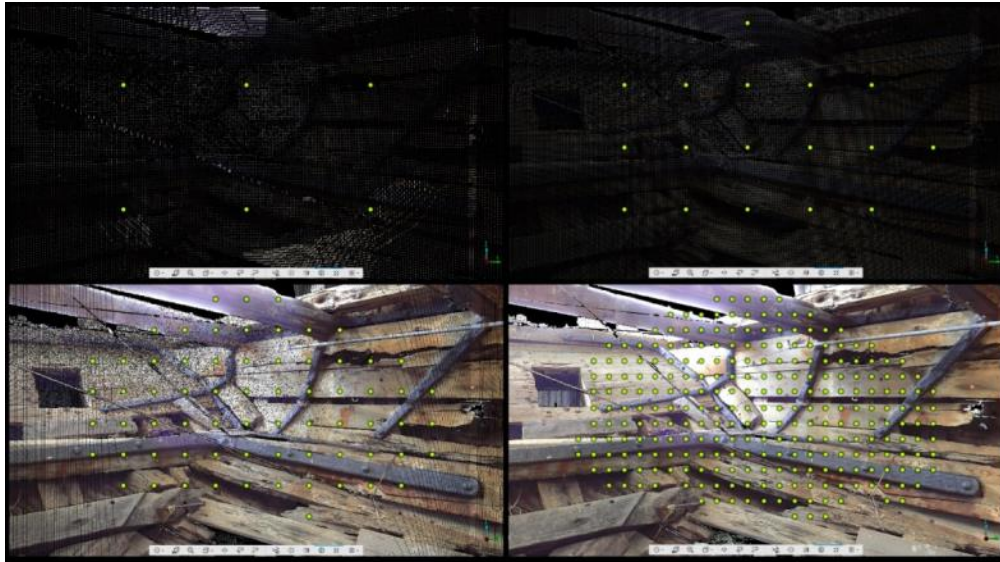


Figure 10. An example of various values for resolution setting. The green dots are a symbolic visual representation of the spot where the scanning beam touches the surface of the object. The larger the distance between those dots, the lower is the resolution of the point cloud generated. For the Edwin Fox scanning, the $\frac{1}{2}$ resolution (half of the highest resolution 1:1) was set to balance between the quality of the data and its size. However, to obtain this level of detail, each scanning session took approximately 30 minutes. This should be taken into consideration when time restriction is a priority while capturing data.

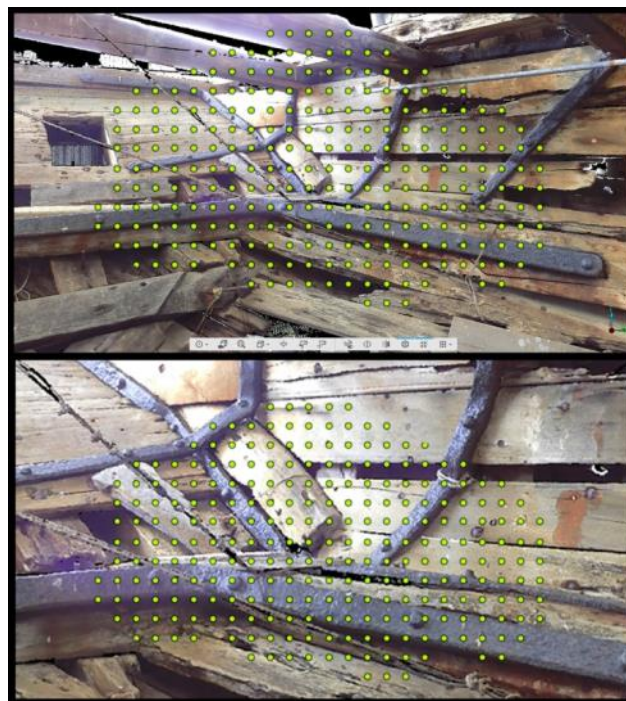


Figure 11. An example of distance and resolution dependence. The resolution symbolically represented by the green dots is hypothetically set to the same value of $\frac{1}{2}$ on both images. In the **top image** the scanner is further away, while in the **bottom image** it is closer to the object. The comparison shows how the choice of resolution quality depends on the

particular project demands and distances available for capturing the target object. The distance between two points on the object increases with the distance of the scanner from the target object. In the *Edwin Fox Project*, the maximum capturing distance was set to no more than 20 m and the location of the scanner was always within 1- 4 m from the ship, which made a chosen resolution of ½ optimal for generating a high-quality point cloud.

Together with resolution, a quality value has to be set before the scanning process. The quality value regulates the quality of the scanned data in terms of noise reduction. The bigger the value, the better the quality of the scan, which results in an increase in the time invested in each scan. Quality setting allows changing the time per scan while maintaining the same resolution during the scanning session. For the correlation between various values of resolution, quality and time required for scanning, refer to the Scanning Parameters Table in the FARO Laser Scanner Focus^{3D} x 130 Manual.¹⁶⁵ For the Edwin Fox scanning session, a constant resolution of ½ was set for each scan with the quality value pre-set to 4x, which is recommended for outdoor environments where distances from the scanner to the target object are less than 20 m.¹⁶⁶

When scanning a large-scale artefact, a number of potential issues that pose threats to successful data acquisition can occur, including limited access to the site, object or parts of it, changing weather conditions for exterior objects, lighting that is too dark or too bright for interior objects, and the presence of objects occluding the target artefact. In case of the Edwin Fox, all of these factors influenced the scanning process at the site.

First of all, the very narrow metallic structure of the dry dock where the ship is located did not allow placement of the scanner further from the object to capture a wide range of exterior information. Instead, the scanner was placed in the accessible areas along the perimeter of the ship, very close to its surface. This restriction in space resulted in a high number of scans being taken to allow an acceptable overlap between them, where at least three targets per scan could be observed (**Fig. 12**).

¹⁶⁵ FARO Laser Scanner Focus^{3D} x 130 Manual, 48 – 49.

¹⁶⁶ Ibid., 72.



Figure 12. Photographs showing the limited distance between the dock and the ship. The orange circle shows the people on the site as a scale reference.

The second issue on the site arose when the soft ambience of morning sunlight changed to a very sunny day in the middle of the scanning process, overexposing the front part of the ship. In addition to that, the metallic material of the dock captured the bright light and added even more ambient lighting (**Fig. 13**). The only solution to this problem was to continue scanning the rest of the exterior and aim to capture the front part again the next day, provided the weather was stable and cloudy, which did occur.



Figure 13. Photographs showing the difference in the lighting conditions during the laser scanning of the Edwin Fox.

The second day, dedicated to interior scanning, posed even more challenges in terms of accessing some areas because of safety issues, which prevented the scanner being positioned evenly around the ship's perimeter. While the weather provided stable ambient lighting on most parts of the ship, the front part remained very dark due to the installation of the new top deck for visitors, which prevented light from coming in (**Fig. 14**). The potential solution to this problem could have

been an artificial lighting set up, which was not available in the case of the Edwin Fox due to budget limitations.



Figure 14. **Top left** – photograph showing the area on the top deck that is not accessible due to safety reasons; **top right** and **bottom right** – photographs showing modern-day reconstructions that occluded the original timber of the ship; **bottom left** – the dark conditions prevailing in the interior front part of the ship.

The most drastic problem for the interior of the ship, especially the front part, was the modern-day installations, such as historical cabin recreations, newly built stairs connecting the top and bottom decks, and new timbers supporting the structure of the ship (**Fig. 14**). All of that contributed to obscuring the original timber of the ship and did not allow the equipment to get close to the structure due to space limitations. Such elements, which are unnecessary for the final outcome, can only be removed during the cleaning and restoration stage presented later in this thesis.

The challenging two-day scanning process resulted in 26 highly-detailed laser scans (**Fig. 15**) for the exterior of the ship and 21 scans for the interior of the ship (**Fig. 16**).

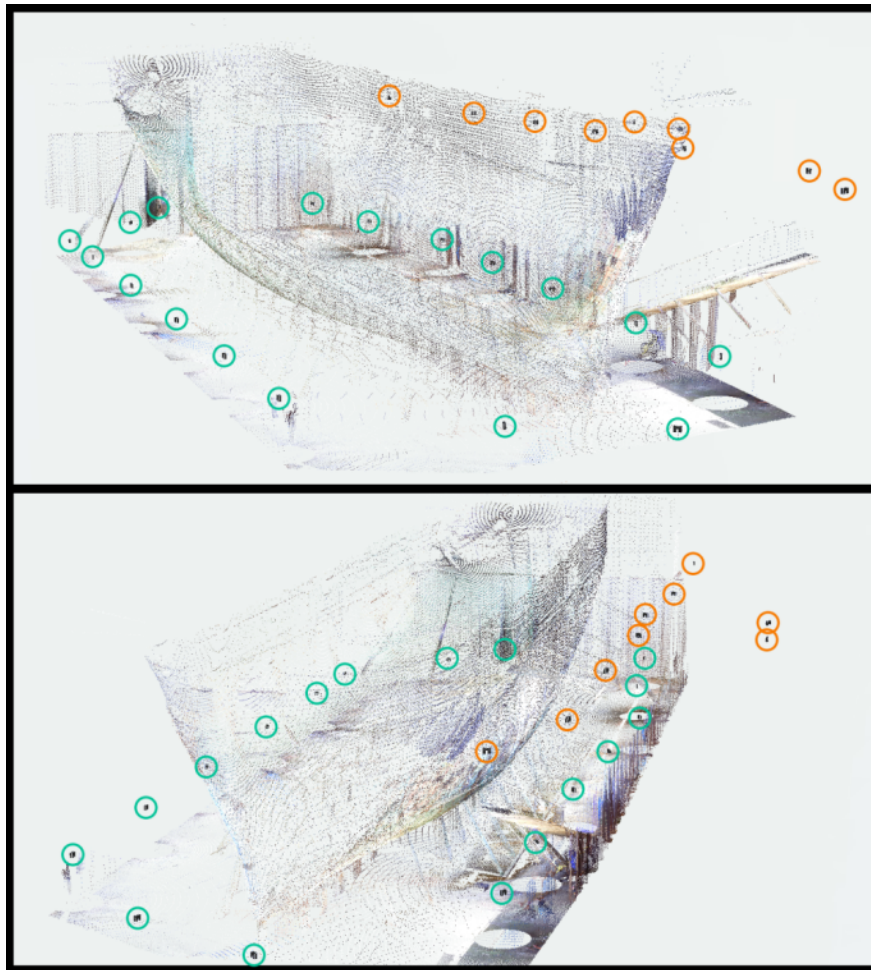


Figure 15. *SCENE*. A 3D view showing the 26 positions of the scanner during the data capturing process for the exterior of the Edwin Fox. **Top** – front right view; **bottom** – front left view.

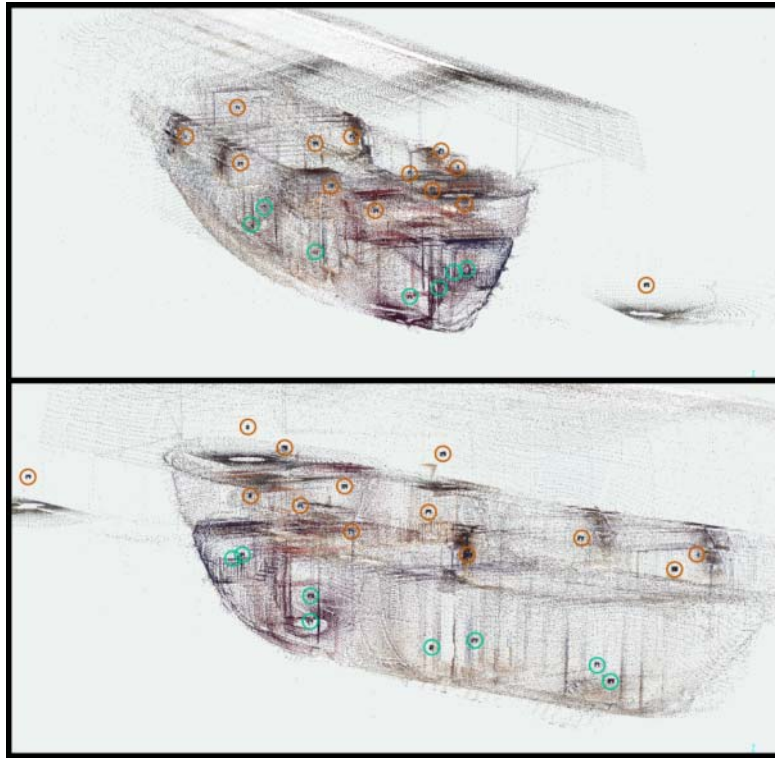


Figure 16. SCENE. A 3D view showing the 21 positions of the scanner during the data capturing process for the interior of the Edwin Fox. **Top** – front right view; **bottom** – rear left view.

‘Stitching’ the laser scans and generating point cloud data

Registration, or in simple terms ‘stitching’ of the scanned data, is a process of aligning all the data in the same coordinate system, where a complete digital ‘real-world’ record of an object is assembled in one scene in the form of a point cloud. Access to the software for managing point cloud data is provided with the laser scanner and depends on the brand of the scanning device. SCENE 7.1 was used in the current workflow for registering and managing all the scanned data from the *Edwin Fox Project*. The basic workflow is the same across the various brands; the difference is in the availability of various functions that may ease the navigation and manipulation of the aligned point cloud. Before scanning and using the software it is recommended to become familiar with the user manual for formats of the scanned data compatible with the available software. The exterior and the interior of the Edwin Fox scans were registered separately to avoid registration errors, and provide easier management of the final outputs due to their large sizes. For each scan the laser device creates a folder with an .fls extension that can be automatically imported into SCENE software (**Fig. 17**).

The point clouds for each scanning position can be seen in **Figure 18** and **Figure 20** (interior and exterior respectively) and the final merged point cloud is demonstrated in **Figure 19** and **Figure 21** (interior and exterior respectively).

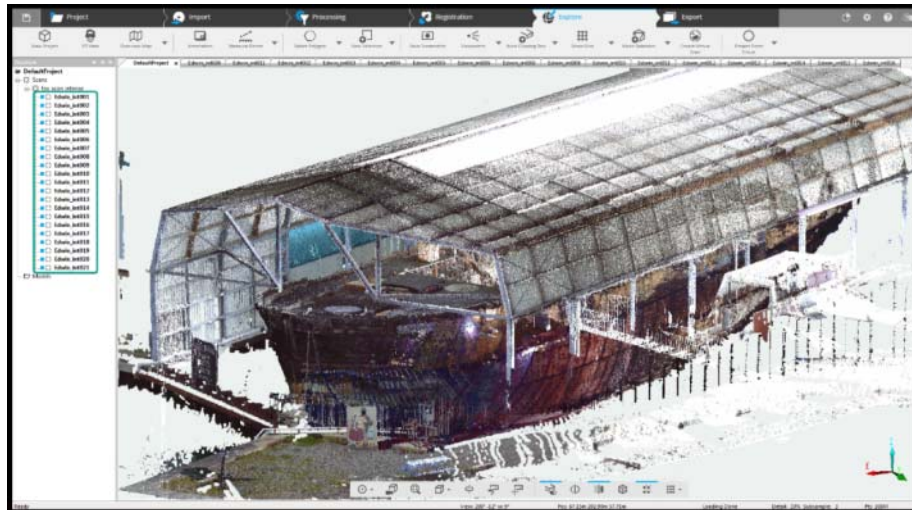


Figure 17. *SCENE* viewport with registered point cloud of interior. *Structure Window* on the left shows all the 21 scans imported into the software.

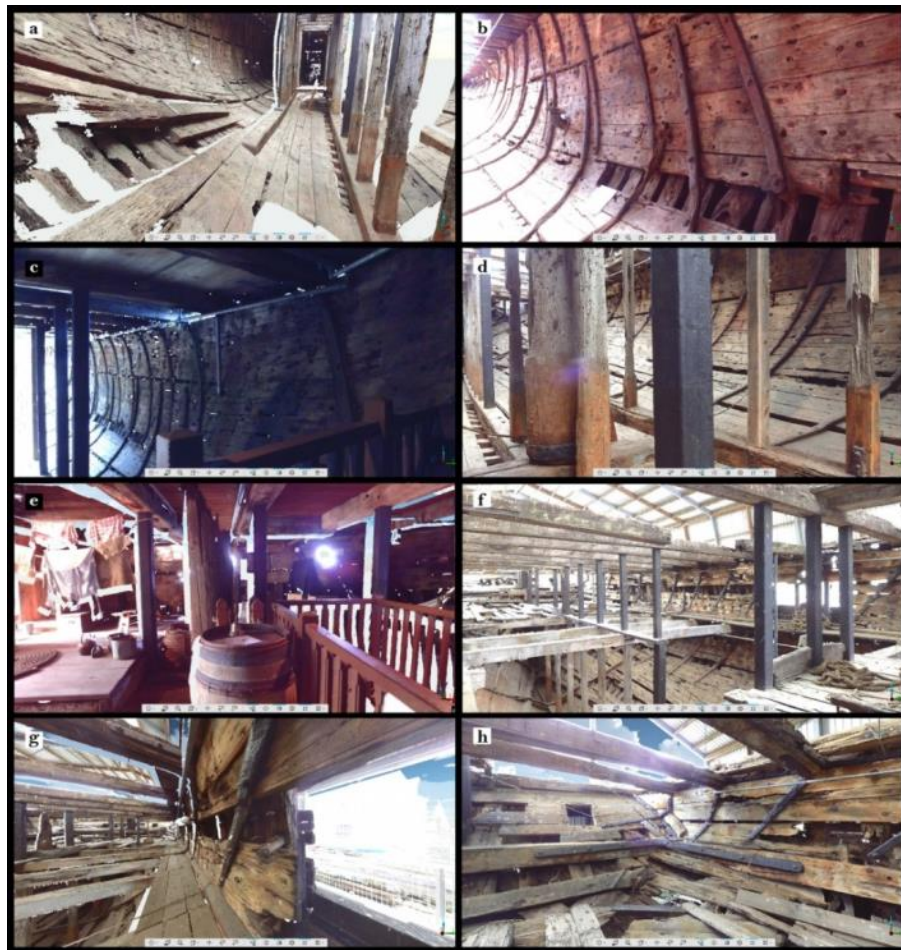


Figure 18. *SCENE*. Interior of the ship. Example of the point cloud view seen from a single scanner position. Each scanning session is combined into a complete point cloud digital copy of a physical object. **a** – scan 001; **b** – scan 005; **c** – scan 008; **d** – scan 004; **e** – scan 009; **f** – scan 016; **g** – scan 013; **h** – scan 014.

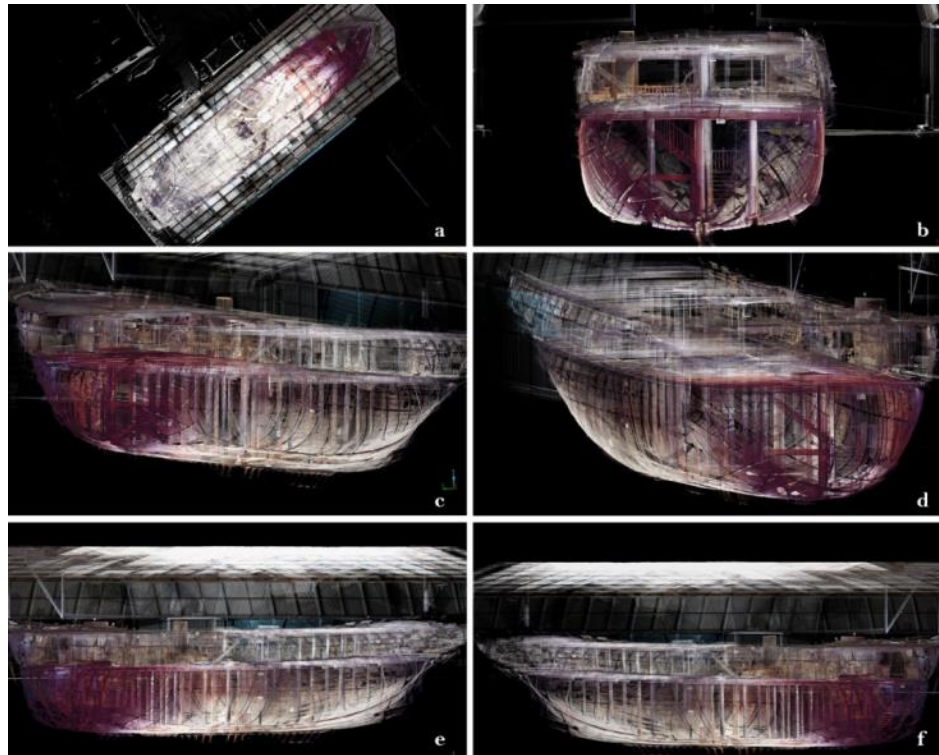


Figure 19. *SCENE*. Exterior of the ship. 21 registered scans of the interior. **a** – orthographic top view; **b** – orthographic section view from the rear; **c** – 3D view from the back; **d** – 3D view from the front; **e** – 3D view from the left; **f** – 3D view from the right.

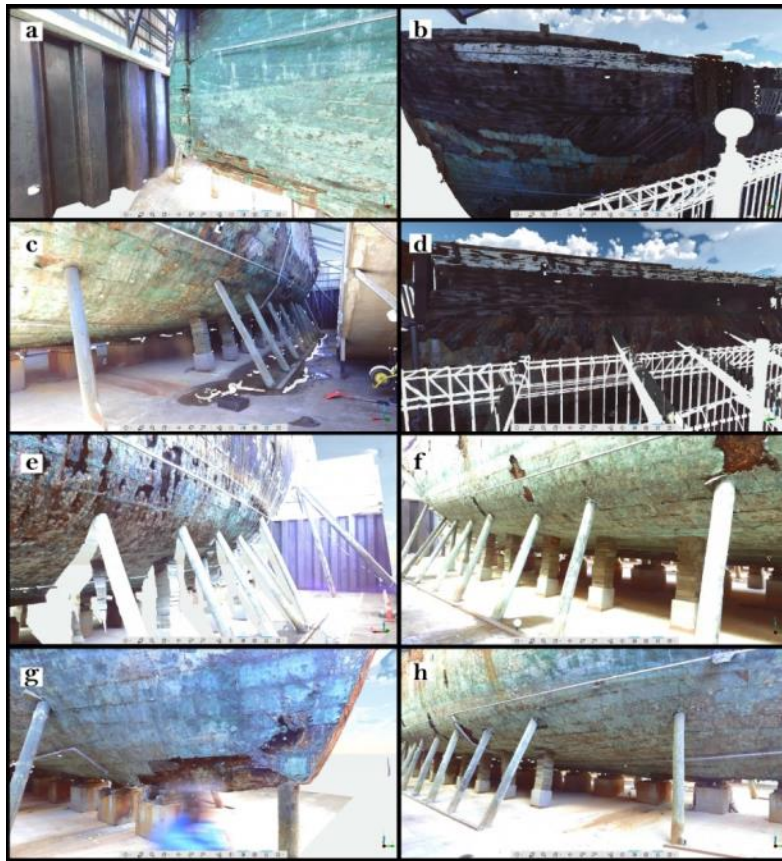


Figure 20. SCENE. Example of the point cloud view seen from a single scanner position. Each scanning session is combined into a complete point cloud digital copy of a physical object. **a** – scan 011; **b** – scan 020; **c** – scan 003; **d** – scan 022; **e** – scan 006; **f** – scan 015; **g** – scan 018; **h** – scan 017.

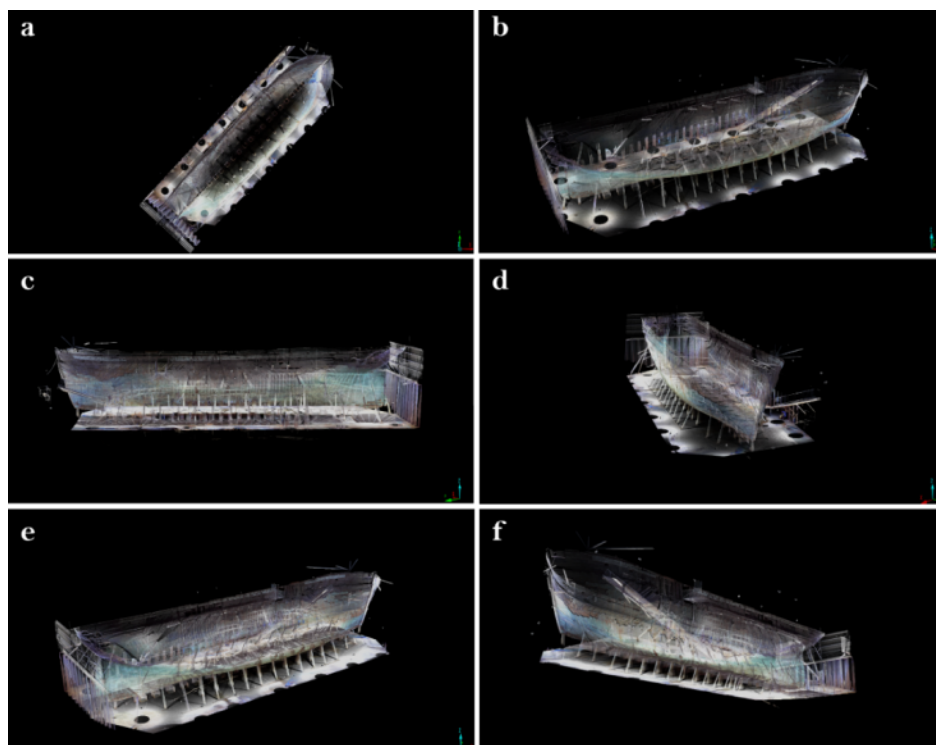


Figure 21. SCENE. 26 registered scans of the exterior. **a** – orthographic top view; **b** – top left 3D view; **c** – 3D view from the right; **d** – front right 3D view; **e** – back left 3D view; **f** – bottom left 3D view.

Reflections & Considerations

Bearing in mind the amount of difficulty experienced with lighting, restricted access and the short time assigned for the laser scanning process, the FARO Focus^{3D} laser scanner produced high-quality data of the geometric shape and surface details of the Edwin Fox when registered and inspected in the viewport of the FARO SCENE software. However, during the further workflow development, issues emerged in the cleaning and restoration stage that could not be easily seen when viewing the point cloud data on the site. For future projects involving 3D laser scanning techniques, the points mentioned below must be addressed and taken into consideration.

Planning. If budget and time allow for preliminary preparations, careful planning for scanner positions and scanning tests for optimal distance, resolution and quality should be done before the final laser scanning session is conducted. Planning is extremely important, so that the final point cloud data is of the highest quality possible, because it provides the foundation for successful outcomes in the further steps of the workflow.

For the *Edwin Fox Project*, with a very limited budget, it was possible to hire the equipment only for four days, two of which were spent travelling to the location and the other two for data acquisition. Such time and budget constraints only allowed for planning at the location and examining the ship just before the actual final scanning session took place. Having had a first experience in laser scanning such an enormous heritage object and testing it within the workflow development, for future projects with assets of such size and shape, a slightly different approach to scanning should be considered. First, a quick scanning session with low resolution settings using the same positions of the scanner as indicated earlier in the workflow should be done in order to generate a point cloud that can be used as a reference for the general shape of the object and the positions of its component parts. As a second step, the target object should be visually separated into a few main parts. Using the example of the Edwin Fox, the ship could be divided into front, middle and back sections (same for exterior and interior), which could be treated as separate objects during the scanning sessions. Such an approach would allow the generation of even higher quality point clouds while maintaining a manageable file size per point cloud. Then, each section could be treated as a separate object further down the pipeline and be merged during the restoration workflow (**Fig. 22**).

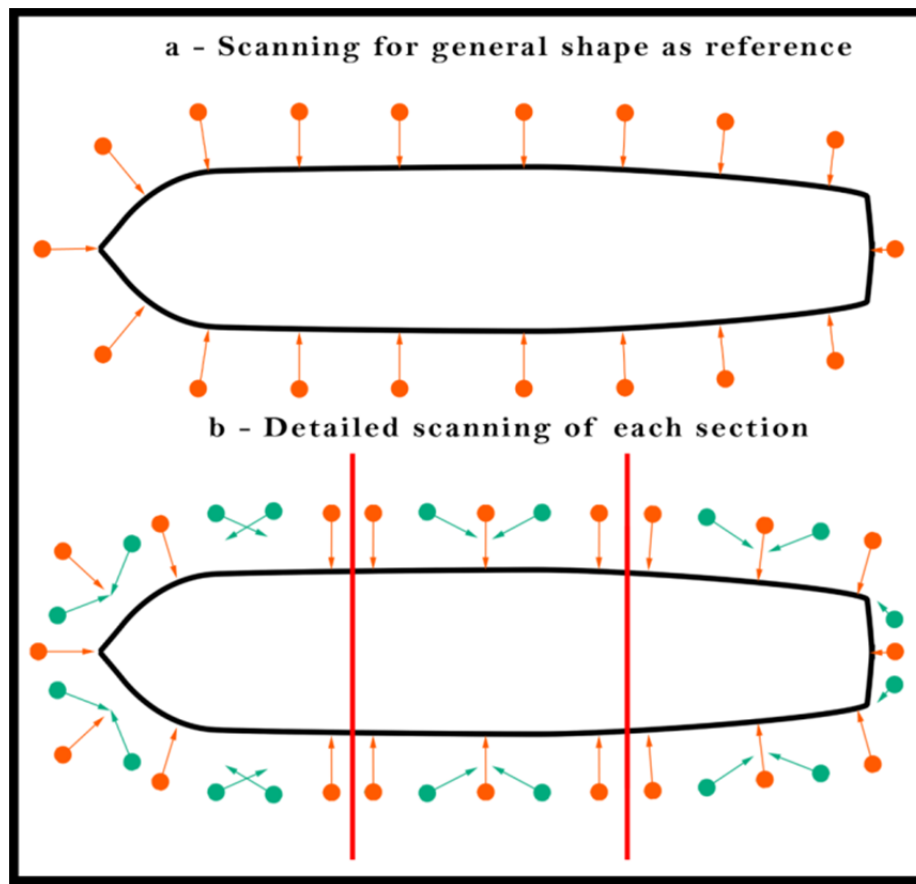


Figure 22. **a** – scanning for general shape as reference. The scanning resolutions can be set to $\frac{1}{4}$ with quality of 2x with no colour information. **b** – showing the positions of the scanner for the proposed three-section detailed scanning. The orange camera position faces perpendicular to the object and the green ones are positioned under the angle to the surface of the object, which allows the gathering of more data that might be occluded in the perpendicular position of the scanner.

Scanning technique. During the restoration process it was discovered that additional scanning sessions should be done due to the occlusion of various parts of the ship by itself or other objects. An additional scan was required under the bottom of the ship to avoid ‘smudging’ effects and to remove the noise that was introduced by the supporting timber. The bottom part of the hull of the ship curls in almost 90 degrees, which makes it parallel to the rays of the laser beam. Such positions of surfaces to the scanner cause a ‘smudge’ effect on the details of the surface and may even prevent recording of the required data (**Fig. 23**).

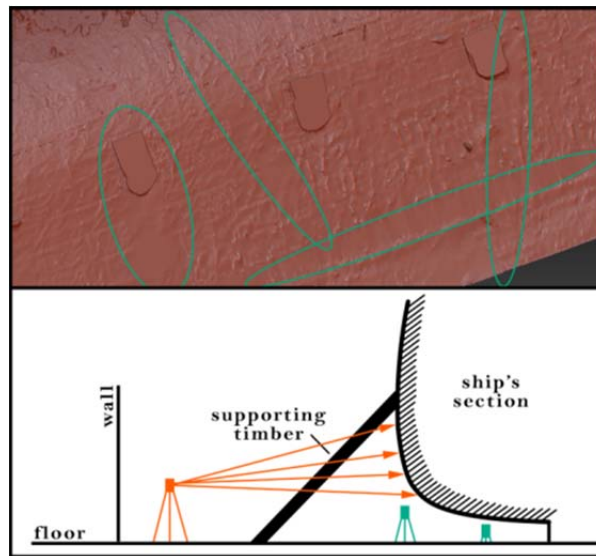


Figure 23. Top image – a ‘smudging’ effect that was discovered during the restoration workflow development. A part of the digital model demonstrates ‘smudged’ details on the bottom surface of the ship. The green outlines show the area of occlusion by supporting timbers, which could be avoided if the scanner was placed behind it, closer to the ship. **Bottom image** demonstrates the proposed idea – green elements of the graphic represent additional positions for acquiring data to avoid detail smudging and occlusion by supporting timbers. The orange element of the graphic represents the scanner position that was used and how its data acquisition was affected by the supporting timbers as well as perpendicular surfaces.

Similar problems of occlusion occurred in the interior scanning data, mostly around protruding elements such as beams and iron knees (**Fig. 24**).

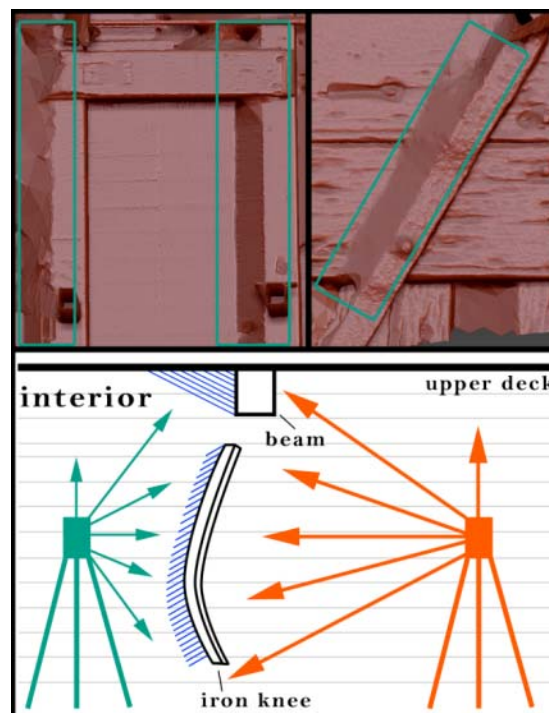


Figure 24. Top image – a ‘smudging’ effect that was discovered during the restoration workflow development around some of the beams and iron knees in the interior of the ship. The green outlines show the area of self-occlusion by beams (**top left image**) and an iron knee (**top right image**). **Bottom image** demonstrates the proposed idea – green elements of the graphic represent additional positions for acquiring data to avoid self-occlusion. The orange element of the graphic represents the scanner position that was used and the areas marked with blue show how its data acquisition was affected by self-occlusion.

A simple rule to avoid self-occlusion artefacts is to make sure that all the details of the target object have been inspected visually first and then scanned. This means that the scanning device only captures data that is visible to human eyes at the scanning position. All areas that are self-occluded or hidden by other objects, and horizontal and vertical planes parallel to the scanner beam surfaces cannot be successfully recorded with the scanning device. That is why the occluded areas have to be remembered and scanned during the next scanning session. This principle is demonstrated in **Figure 25**.

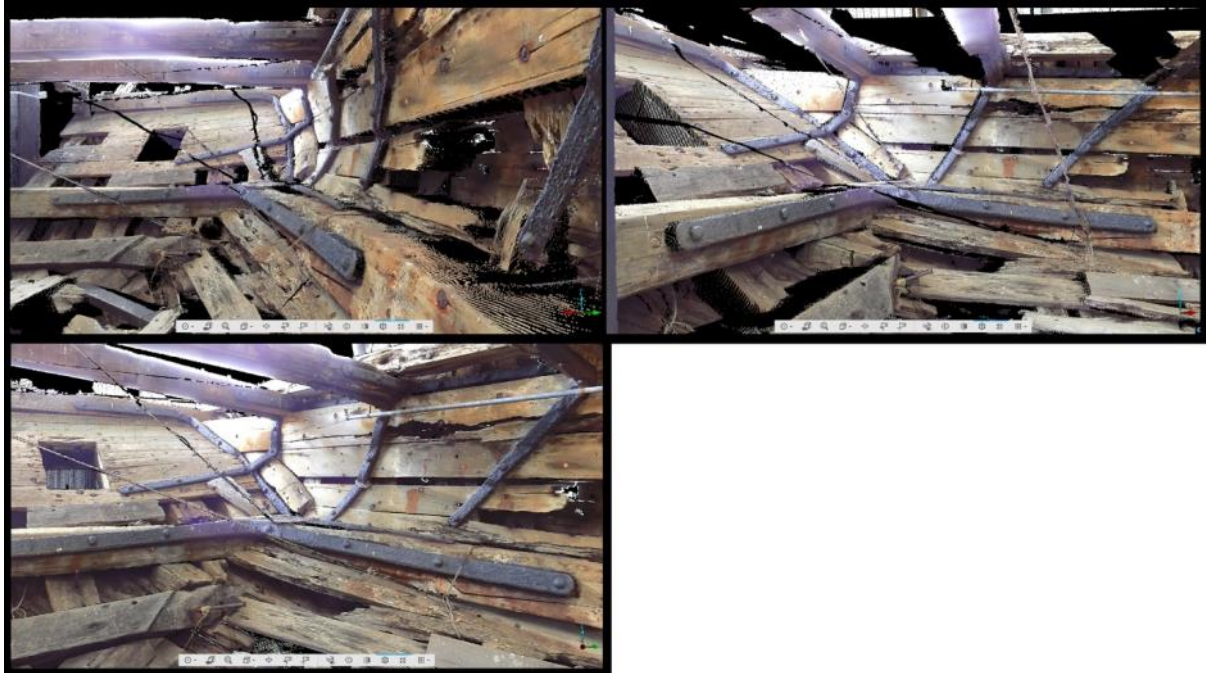


Figure 25. The images of the point cloud data demonstrate a scanner view during the capture of an area in the interior of the ship. The **bottom image** is the original scanner position from where the data was gathered. It can be seen that there are many areas parallel to the scanner surfaces, as well as self-occlusion. **Top images** reveal black (occlusion) areas, as well as dotted (parallel to the beam) areas by changing the position of the viewport's camera from the original view of the laser scanner at that site.

Lighting. The first experience with laser scanning a large-scale artefact in natural lighting conditions proved (as discussed in more detail in **Texturing Workflow**) that additional lighting is extremely important in dark conditions. If the final point cloud requires the capturing of colour information and photogrammetry will not be used as additional technique, a shadowless lighting set-up must be provided for the scanning session. While the issue of dark areas on the artefact can be resolved with an artificial lighting set-up, overexposed areas due to intense sunlight (like the front part of the Edwin Fox) represent a problem for capturing colour information. An ideal variant to address the issue would be to wait for a cloudy windless day to conduct a scanning session. But with tight budgets and timeframes, as is often the case in the majority of projects of this nature, it would be best to wait till the sun changes its position so that the previously overexposed area can be captured.

'Stitching' point cloud data. It is important that a portable device (a laptop) with the installed software required for managing point cloud data is available at the site. This allows the operator to ensure that there is no corrupt data, all scans are registering properly and the final point cloud represents what is required for a project. An appropriate laptop was available at the site,

which gave an opportunity for the digital specialist to identify problematic areas that could be immediately addressed at the site.

5.2.2 Photogrammetry

Basic Workflow

Photogrammetry is a reality-based, non-contact technique that uses a mathematical formulation to transform photographs into 3D data. Nowadays, digital photography skills are widespread and do not require long, in-depth training to produce sufficient 2D information for generating highly detailed digital surrogates. The accessibility of digital cameras lowers the barriers to adoption of this technique and for general acceptance of 3D copies in museum archives and online display.

For the current project, photogrammetry was used as an additional technique to the 3D scanning workflow, which allowed the capture of a better quality of colour information and added more accuracy to the geometric calculations, as well as being used as a separate technique to capture reality-based photographic data for smaller objects located at the museum. In this subsection, **Basic Workflow** using this technique is demonstrated on various small and medium-sized objects captured at the museum site and in other locations.

Photogrammetry is an example of transparency in capturing data from the object as it uses unedited photographs taken at the site for calculating the object's digital representation in the form of a point cloud. With this capturing technique not only is a digital copy of the artefact produced, but also a wealth of images that make up the sequence required for the software to calculate the object's shape. Such images are often extremely detailed, making them a valuable resource in their own right in the preservation process.

Equipment

Camera. The minimum equipment required for photogrammetry is a camera. Good results can be produced by any digital camera ranging from the built-in cameras in the latest cell phones (**Fig. 26**) to high-end full frame DSLR cameras (**Fig. 27**). The best option for creating digital surrogates is a high-end camera as it allows the capture of tiny details in high resolution with high-quality images. For the *Edwin Fox Project* three cameras were used – a Nikon D5 and Nikon D800 for the ship and a Nikon D7200 for smaller objects in the museum. These cameras were chosen as professional DSLR cameras that are able to capture high-quality photographs. The first two cameras used for the ship are full-frame cameras with a wide range of ISO to capture as much detail as possible in a low-light environment. The third available camera is not a full-frame DSLR, but it performed extremely well in low-light conditions.



Figure 26. A 3D model of a tree trunk generated from a sequence of 284 photographs taken with a Samsung Note 5 in manual photography mode. The images captured with a cell phone produced great results, but in close-up views of the model some geometry and texture noise can be seen. Also, in some areas the texture looks overexposed.



Figure 27. Same model of a tree trunk as in **Figure 26** but generated from a DSLR Cannon Mark II. There is no surface noise in close-up views and the texture is correctly exposed.

Lens. Built-in or mounted lenses are suitable for photogrammetry. However, it is important to note that zoom lenses must be always locked while capturing data to maintain constant camera settings for the shooting session. Previous experience in photogrammetry capture has shown that 35 mm and 50 mm fixed lenses have less distortion and are closer to the ‘real-world’ data representation. Nikkor 24.0-70.0 mm and Nikkor 18.0-55.0 mm lenses set with variation between 45 – 50 mm of focal length were used for capturing data in the *Edwin Fox Project*.

Tripod. Using a tripod is essential while capturing images, especially in dimmed lighting conditions, which often occur in museums. Sharpness of each image is one of the keys to avoid producing noise in the geometry and smudging colour information. As an additional feature, a remote that controls the camera’s shutter can be used to activate the shutter without touching the camera, thus avoiding unnecessary vibrations that might influence the sharpness of the image. A tripod also prevents camera rotation, which is not recommended in photogrammetry. If handheld, the camera position should be fixed either horizontally or vertically for optimal results.

Lighting. If the object is located outdoors, a cloudy windless day is the best scenario for photogrammetry (**Fig. 28**).

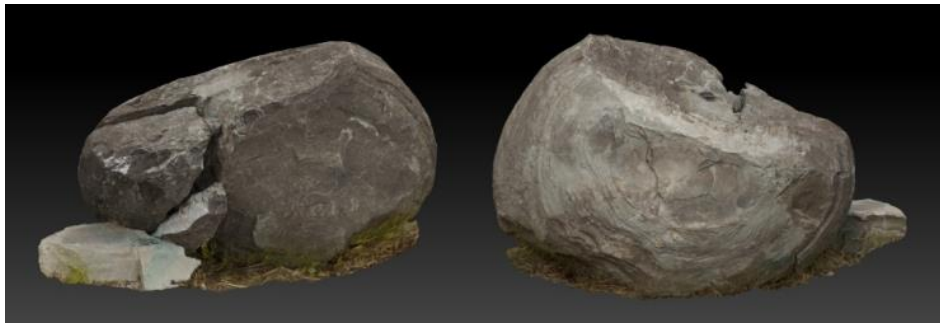


Figure 28. An example of a 3D rock model obtained with ideal outdoor lighting conditions for photogrammetry – a cloudy, windless day with soft sky ambience casting no dark or sharp shadows.

For indoor objects, a shadowless lighting set-up is recommended. Such a set-up allows the creation of a soft ambient light, thus removing sharp shadows that otherwise would have to be cleaned out during the texture de-lighting process. A studio strobe, diffused flash, and softboxes can be used as lighting solution for photogrammetry. The lighting equipment can be set up in various combinations, depending on the size and shape of the object. The important principle is to avoid sharp shadows and achieve even lighting of the target object. There is not always an opportunity to use lighting set-ups due to budget, time or site restrictions, as in the case of the Edwin Fox. In such situations using a tripod and long exposures can help in capturing high-quality images.

The lighting issue of overexposure that occurred in the front part of the Edwin Fox, mentioned in the 3D scanning subsection, was fixed using photogrammetry (**Fig. 29**). The second day of scanning was a cloudy day, which allowed a sequence of images of the part that had been overexposed before to be obtained, followed by the creation of a 3D model that could be used as a patch to replace the distorted texture during the texture restoration described later in the workflow development.

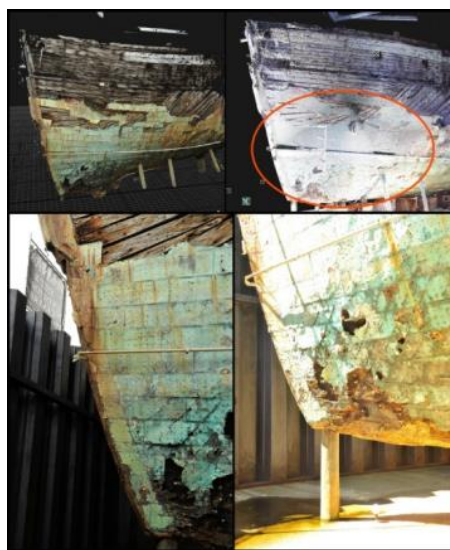


Figure 29. A 'patch' that was made using photogrammetry to replace the overexposed front section that had been scanned on the first day of the data acquisition. **Bottom right** – photograph of the overexposed area in the front area of the ship; **top right** – point cloud data shows the missing colour information due to overexposure; **bottom left** – one of the

photographs from the image sequence that was used to generate a 'patch'; **top left** – a point cloud that was generated from the image sequence taken for the 'patch'.

Rotating platform. If there is a need to capture small artefacts, a rotating platform is an optimal solution for fast and easy data acquisition. A rotating platform should be motorised to smoothly rotate every 10 degrees, allowing 36 images to be captured per full rotation circle. A motorised platform speeds up the capturing process and reduces the vibration that may occur during manual rotation of the platform. Exact 10-degree measurements on the platform help to maintain sufficient overlap in the image sequence for software calculations.

Data acquisition

Camera Settings. Manual control of the focus should be used with photogrammetry. Deep depth of field is recommended in each image of the captured sequence so that the processing software is able to see all the details in order to properly calculate and align all the images of the photogrammetry sequence. This means that high aperture values of f/11 onwards are optimal for capturing information. The higher the f-stop value is, the smaller the size of the aperture, which limits the amount of light that comes into the sensor. Here, long exposure or, if available, appropriate lighting as mentioned earlier, becomes essential for the image capturing process.

It may be appealing to compensate for high f-stop values by boosting an ISO value, which is acceptable in situations where extra lighting is not available. However, it should be noted that higher ISO values may introduce noise in the image, which can confuse the aligning process when generating a 3D mesh, as well as produce low-quality colour information.

Although a high aperture value is desirable, it is usually used in ideal lighting situations such as a studio set-up. For outdoor field work, a compromise between aperture and ISO has to be found for the desired quality of the final outcome. Often, long exposures cannot be afforded due to time limits, especially in large-scale projects where more than a thousand photos are taken per target object. There are no default values that should be used, as each object and location has its own specific environment that has to be analysed before proceeding with capturing images. Generally, values between f/8 and f/11 with pre-set ISO settings were used in all the experiments done in preparation for the *Edwin Fox Project* (demonstrated further in **Capturing Patterns and General Principles**). During the Edwin Fox capture, values around f/6 with a range of ISO 200 in the overexposed areas and ISO 3000 in the underexposed areas were used, which are far from ideal, due to the extreme lighting conditions. However, if such ranges of ISO are used in a project, a professional camera that is capable of using such ranges without substantial noise introduction must be used by a skilful photographer. Each photograph has to be checked for the level of noise and reshot with different values if the quality of the image is excessively compromised. Overall, the fundamental rule is to achieve a constant sharp focus on the target object, constant exposure and no harsh shadows.

Image Format. Two image formats are used in photogrammetry. Shooting in .RAW format allows the capture of much more lighting information, which helps in manipulating exposure values in post-processing. However, .RAW files are often very large, allowing the fitting of relatively few images on a memory card. Dealing with .RAW files requires additional knowledge of editing software in order to manipulate lighting in the images to achieve the desired results. Shooting in .JPEG format

is faster and allows many more images to be stored on a memory card than .RAW format. While .RAW format can be manipulated significantly in the editing software, images in .JPEG format can undergo only slight manipulation in post-processing.

The choice of the format depends on the skills of the photographer, both in terms of taking pictures and their knowledge of and access to editing software. Non-professional photographers should experiment with both formats in order to understand what format suits their skills. In the *Edwin Fox Project*, there were two professional photographers shooting in .JPEG format to save memory space as there were numerous photographs taken at the site. In total, more than 7,700 digital photographs were captured at the location during the two-day data acquisition period. Adobe Lightroom software was used to manage and edit the exposure in all the photographs in the project.

Capturing Patterns and General Principles. Careful planning should be done before capturing a target object. An object's shape and its surrounding environment play an important part in deciding what capturing pattern should be applied in order to get the correct alignment of the image sequence. There are no specific patterns as such, as there are vast varieties of objects with different structures and volumes. However, there are certain rules behind pattern creation that can be applied and modified to the needs of a particular project. First of all, everything that is within the frame of the image has to be stationary. This means that the objects must be in the same position in every image of the sequence so that the software can calculate the matching points between all the images in the sequence and generate a 3D mesh from it. Secondly, an overlap between images of approximately 30-50% should be allowed for the software to find the matching points. Thirdly, there should be enough space around the object to move freely and thus be able to take a photo of the object from any angle that is necessary for the image sequence. There are a few generic patterns that have been found to be of particular value (**Fig. 30**):

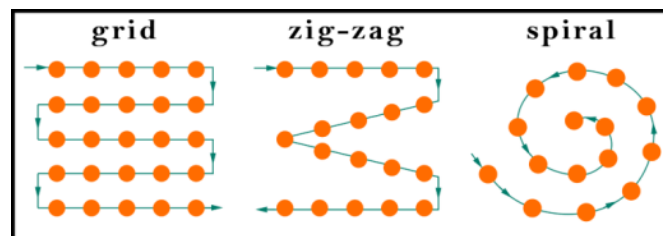


Figure 30. Generic patterns of movement when capturing a target object. The decision about which capturing approach to choose depends on the object's scale and shape. These patterns can be combined to achieve the best results in capturing data.

While planning the pattern for shooting, a 'full-frame-detail shot' principle should also be considered. When taking photographs of the object, it is important to capture the entire target within an image frame as well as close-up details. The order of capture is not crucial: an entire object can be captured first within the image sequence and the details can be captured for the remaining part of the sequence and vice versa. This principle is demonstrated in **Figure 31** using the grid pattern.

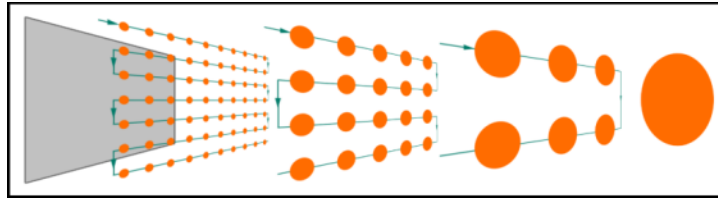


Figure 31. A 'full-frame-detail shot' principle is demonstrated using the grid pattern. The orange circles represent camera positions for each image facing a target object, which is represented in grey colour. The stage close to the object should capture all the details and the stage further from the object should capture the whole object in the image frame.

Adding to the 'full-frame-detail shot' principle, a principle of 'perpendicular planes' should be considered. This principle is similar to the idea of capturing what can be seen directly with the eyes, as described in the 3D laser scanning workflow. When the target object's shape is visually broken down to simple planes, every plane that is facing the camera at less than a 45-degree angle will most probably be distorted or not captured at all. That is why it is important to capture many images to cover every angle, where the object's surfaces are facing perpendicular to the camera to produce the best possible outcome. This principle is demonstrated in **Figure 32**.

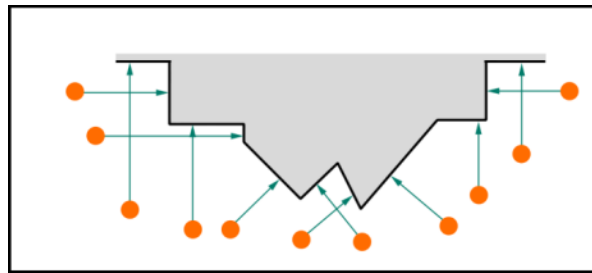


Figure 32. An orthographic top view of a hypothetical target object represented symbolically in light grey outlined with black. The orange dots represent a camera position for a single shot that must be present within the image sequence in order to capture all the data from the target object. If the object has a complex shape, then it has to be visually broken down into simpler forms that can serve as a reference for a 'perpendicular plane' principle.

When capturing an image sequence, it is important to take numerous images of full-frame and detailed shots. An important lesson that was learned during the *Edwin Fox Project* is to never pan a camera when taking photographs. Images that are taken when a camera is panned on the tripod will not add additional information to the software calculations and may slow down the alignment. The best recommendation is to always move around the object and never shoot from the exact same place. This is done to provide as many reference points as possible for the software to calculate and generate an accurate mesh. With regard to reference points, if there are any objects with large repeating patterns, such as fabric or architectural elements, colourful reference points should be added so the software is not confused by the repeating patterns. Colourful small pieces of paper or pins can be attached to the object and edited out during the clean-up and restoration process. Some examples of applying all the principles described above and integrating them into general patterns are illustrated further.

All objects can be divided into planar or volumetric types. Planar objects can use any generic pattern from the three described earlier. For vertical planar objects it is best to use grid and zig-zag patterns (**Fig. 33**). For horizontal ones, any pattern will be adequate to produce high-quality results (**Fig. 34**).

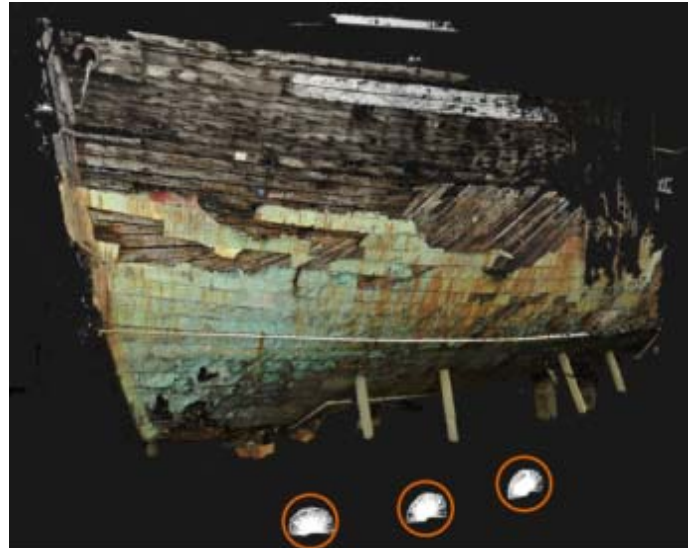


Figure 33. The front section of the ship, mentioned earlier in the Lighting subsection, was captured using a one-row variation of a grid pattern. The orange circles indicate the camera positions. A high-quality result was achieved using this pattern, but much better quality could be gained in the upper part of the ship if there was access to capture images from that height as well. Also, there should be no panoramic images (shooting from one place while panning the camera on a tripod), as those images add little to the final mesh calculation.

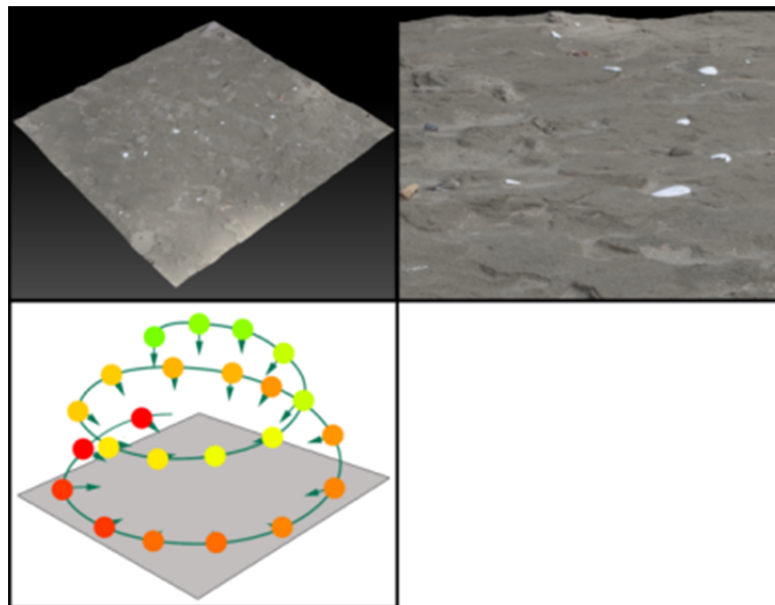


Figure 34. 3D model of sand. This used a spiral pattern that started from ground level and continued upwards. With surfaces like sand, it is better to start from the outer part of the spiral and move in so as not to disturb the configuration of the shape with footprints. Grid and zig-zag patterns would be commonly used to capture objects of a similar nature. This experiment proves that spiral pattern can be used as well.

Planar objects with protruding features may use the same spiral pattern described in **Figure 34** together with ‘full-frame-detail shot’ principle to capture all the details of the target object (**Fig. 35**).

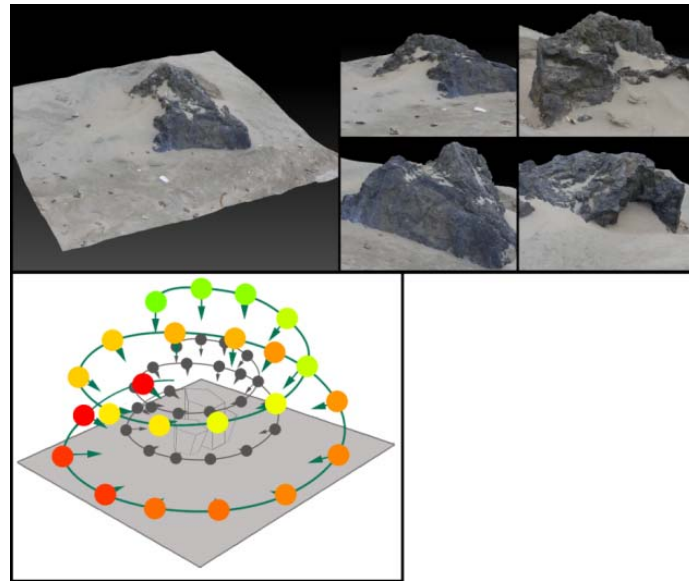


Figure 35. 3D model of ground with sand and rock. An outer spiral pattern, represented in colour, was used to capture the target object fitting in a frame and the inner spiral, represented in dark grey, was used as a pattern to capture only the details of the rock.

Encircled grid patterns (**Fig. 37** and **Fig. 38**) or variations of a spiral pattern in combination with ‘full-frame-detail shot’ and ‘perpendicular planes’ principles are commonly used for volumetric object types (**Fig. 36**).

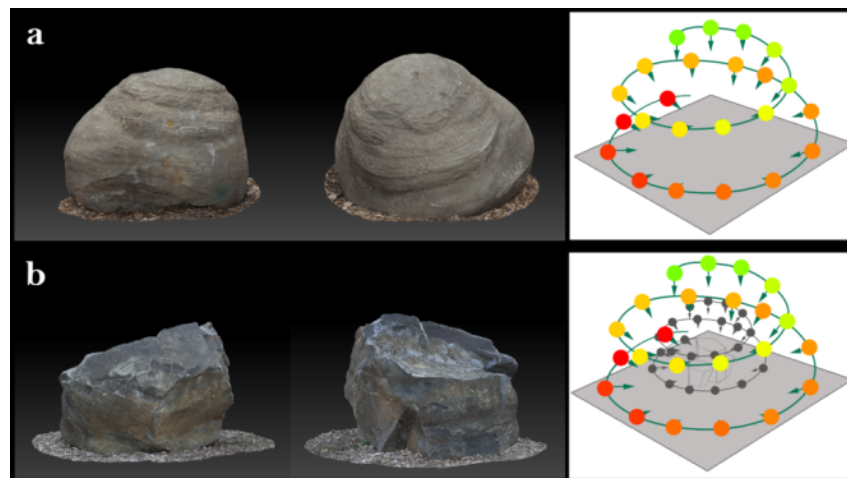


Figure 36. Image illustrates two types of rock of relatively the same scale, but with different shapes. **a** – a very smooth rock can use a simple spiral pattern that is sufficient to capture all of the details. **b** – a rock that has a complex shape and has to incorporate the spiral pattern already presented in image **a**, but this time the inner spiral is added to use the principle of ‘perpendicular’ planes to capture all the surfaces of the rock.

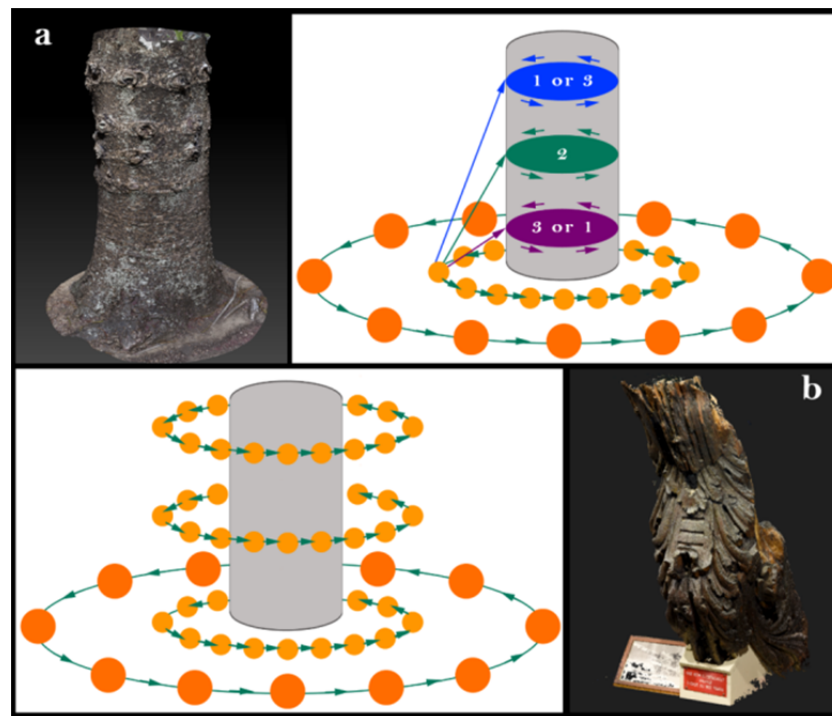


Figure 37. **a** - left image illustrates a 3D model of tree bark generated using the pattern on the right. The pattern represents a variation of the one-row grid pattern. The outer circle with dark orange dots represents camera positions, where 'full-frame' images of the target are taken. The inner circle with light orange dots represents camera positions for taking detailed shots. Since there was no ideal situation for capturing the target as it is illustrated in **b** left and right images, all the shots were made from the ground. First, the bottom circle of image sequences was captured (purple), then the middle (green) and top (blue); however, it could also be done in reverse order. **b** – a wooden decoration from the front part of the Edwin Fox captured using the pattern on the bottom left. A spiral pattern can also be applied to capture objects shaped like this.



Figure 38. A 3D model of a small rock. The grid pattern demonstrated in **Figure 37 b** was tested with a self-made rotating platform seen in the **bottom left image**. The platform was quickly improvised from household materials to test patterns and camera settings. The platform was manually rotated clockwise approximately every 10 degrees. For such installations it is important to prepare a backdrop with solid neutral colours and to have only the object and the platform in sharp focus. If the backdrop is in focus as well and has any wrinkles or specks, they may be interpreted by the photogrammetry software as reference points, which can create a conflict in calculation between the stationary backdrop and moving platform.

All the patterns demonstrated serve as examples to illustrate the main principles behind capturing image sequences to generate a high-quality outcome. Numerous pattern combinations using the principles mentioned earlier in this thesis can be combined, and their design depends on the object and the photographer who is capturing it. However, in stating that, it has to be emphasised that even though the pattern depends on the photographer, all the calculations are done by the specifically designed software. Different patterns of equally high standards will produce the same outcome, which is not influenced by the photographer's bias. In this workflow, a photographer is used as a transfer mechanism that captures the images through a digital camera and passes the data to the software to do all the work. The completeness of the final 3D model relies only on the amount and quality of data provided to calculate the mesh, which lies in the skills of the photographer and his or her understanding of the general principles behind data acquisition.

Material. Almost anything physical in our world can be transferred into digital space through photogrammetry. However, there are objects made of materials that are extremely hard to obtain data from using this capture technique. Such materials include transparent substances as water, glass and clear plastic; very reflective materials, such as various types of polished metals and mirrors; and one-colour materials, especially pure black and pure white. The complexity of capturing such objects mainly lies in the fact that they are made of materials that do not contain solid reference points that can be used by software to calculate a volumetric 3D shape. A solution for this may be a mattifying spray, together with sprinkles of contrast colour paint on top of it to serve as reference points. However, in the heritage preservation environment such methods are not applicable. Very thin objects, such as hair, wire and objects of a similar nature, have to be mentioned as well, as they are not ideal candidates for photogrammetry due to their delicate and repeating structure. Numerous practitioners continue to develop techniques for capturing objects of this nature.

Advanced Workflow

The **Advanced Workflow** discussed below is wholly based on the principles described in the **Basic Workflow**. The difference between two workflows is that in this subsection some additional techniques will be illustrated that require knowledge in the digital area and may seem too advanced for those who just have started to gain understanding in the digital heritage preservation field.

Equipment

Colour checker. When capturing objects outdoors and indoors, different types of lighting can add various hues to an object's native texture. In addition to that, different cameras see colours differently. To counteract such influences, a colour checker can be used. A colour checker usually comes in a plastic pack that opens like a book, with an array of colours on both sides for calibration. To fix the colour, a photo of the colour checker is taken together with the target object. This photograph is used in specific software, commonly Adobe Lightroom, as a template to calibrate all the images to true colours. A colour checker was not used in the *Edwin Fox Project* due to its scale and the drastic fluctuations in lighting conditions.

Chrome ball. A chrome ball is used to capture all the lighting information in the environment in which the capture of the object takes place. This can be helpful to digitally provide exactly the same lighting for the final optimised model as that which was during the capture process. Images

with different exposures of the chrome ball are taken and then combined in specific software to create a high dynamic range (HDR) map, which can be imported together with the final model into an online 3D viewer. A chrome ball was not used in the *Edwin Fox Project*, as the final model will be placed in the natural environment, not in the dock, where it is located at the moment.

Data acquisition

All the principles of data acquisition described in the **Basic Workflow** serve as a foundation for the **Advanced Workflow**. However, large-scale complex heritage sites, such as the Edwin Fox, require an experienced photogrammetry professional and photographer to capture all the necessary information in the correct way.

On the first day of the work in the museum, photogrammetry of the exterior was done at the same time as 3D laser scanning to enhance the accuracy of the geometry and improve texture quality. The same workflow was applied to the interior during the second day in the museum. The initial capturing set-up for both exterior and interior work used a variation of the circular grid pattern described in detail in the **Basic Workflow**. As mentioned earlier, lighting conditions were the major issue while capturing data. On the first day, while the front exterior section of the ship was overexposed, the front interior area was underexposed. The bright sun blew out the details on the ship, which prevented the image sequence from being properly calculated into one mesh (**Fig. 39** and **Fig. 40** for the exterior and the interior respectively). However, as mentioned earlier, the next day the patch for the front section was produced during cloudy weather, which gave high-quality results that could be used to replace the overexposed texture in the texturing workflow development.

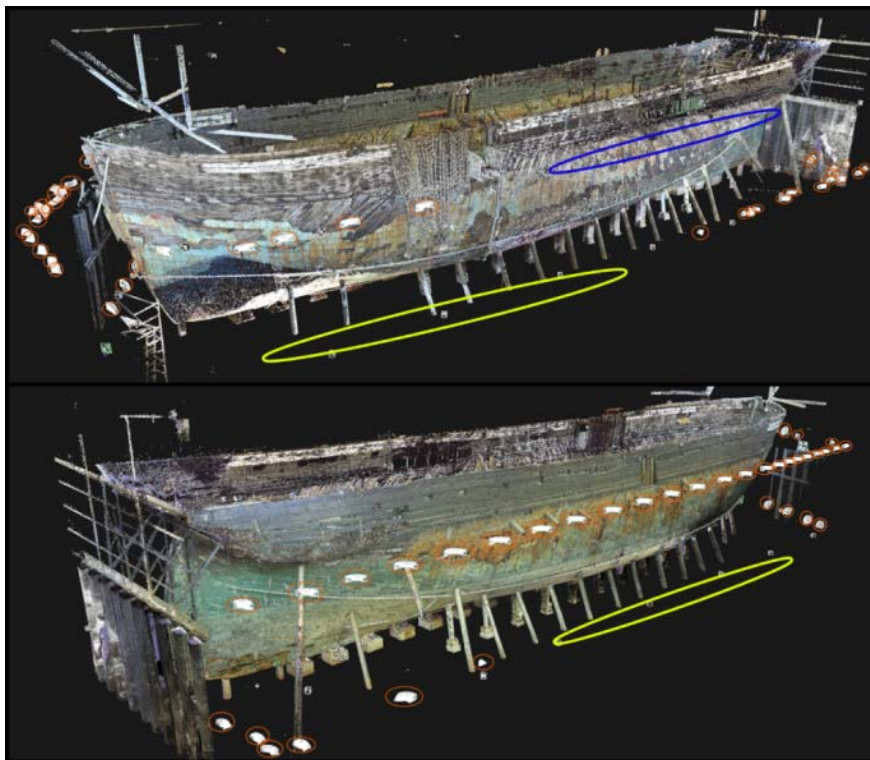


Figure 39. A point cloud of the exterior of the ship. The yellow outlines indicate positions of the camera, which captured the overexposed area of the ship. This area was calculated in several components because of the software failing to connect all the sequence images into one geometry reconstruction. If there was no laser scanning information, those areas

would probably be hollow. The orange circles indicate camera positions that aligned with the scanner data. The blue outlines represent areas that were inaccessible from closer positions, and therefore were not captured as they would not add significant improvements.

Combining photogrammetry with the scanning workflow gave a surprisingly good final result considering all the complications and restrictions during the intensive two-day work period. Data from the captured images added significantly to the improvement of textures recorded with the laser scanning device (**Fig. 41, Fig. 42 and Fig. 43**). An exterior image sequence from the left top row also added geometry details to the area, where the laser scanner gathered little data due to accessibility issues. A photographer was able to climb a small indentation on the wall (this can be seen in bottom right image in **Figure 12**) to capture the missing details.

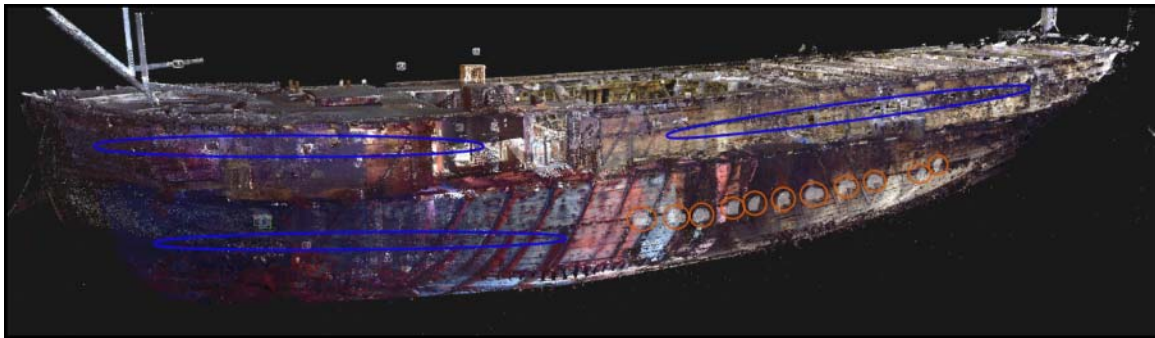


Figure 40. A point cloud of the interior of the ship. The orange circles indicate the camera positions and the **blue outlines** indicate inaccessible areas. The **bottom left blue outline** marks the areas where stairs are integrated, covering the original timber in the front bottom part of the ship. The **top left blue outline** indicates the area of the top deck, where all the modern historical representations are installed, occluding the major part of the original timber. Far into the front section of the ship, some of the original timber is seen, but it was too dark to capture any additional texture information. The **top right blue outline** represents the top deck, which is not accessible from the top. However, some of the top deck timber texture information was captured from the bottom deck, as there is a large opening in that area of the deck.

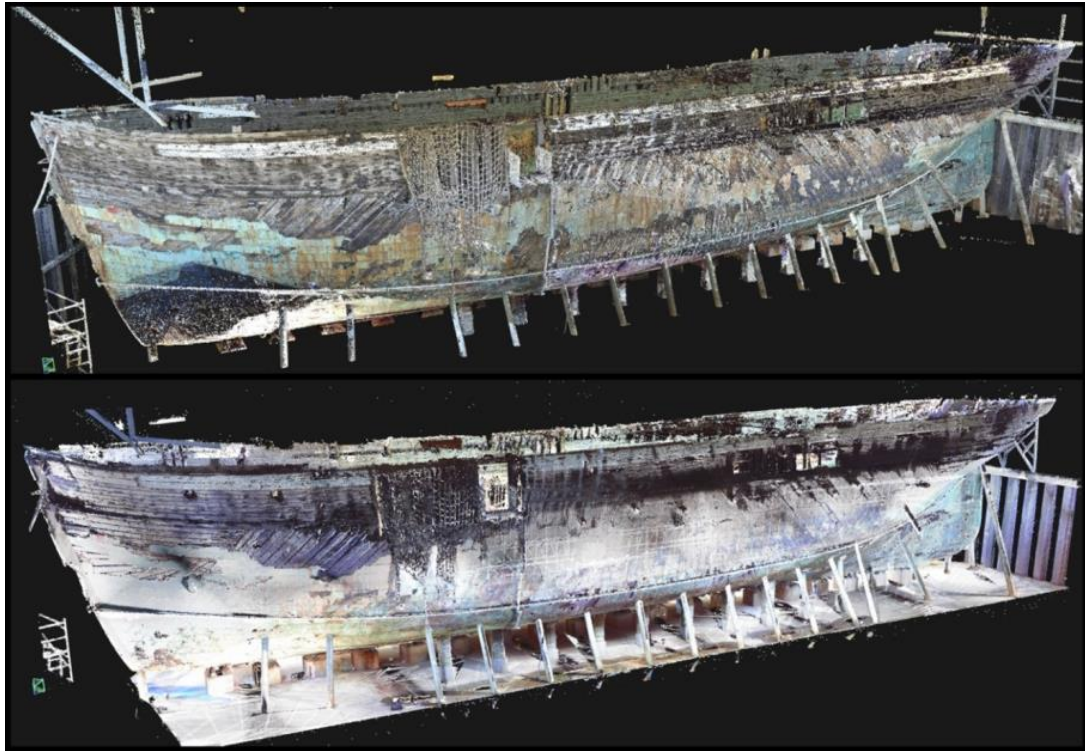


Figure 41. Exterior left side of the ship. **Top image** – a point cloud combining the results of 3D laser scanning and photogrammetry. **Bottom image** – point cloud data with 3D laser scanning information only.

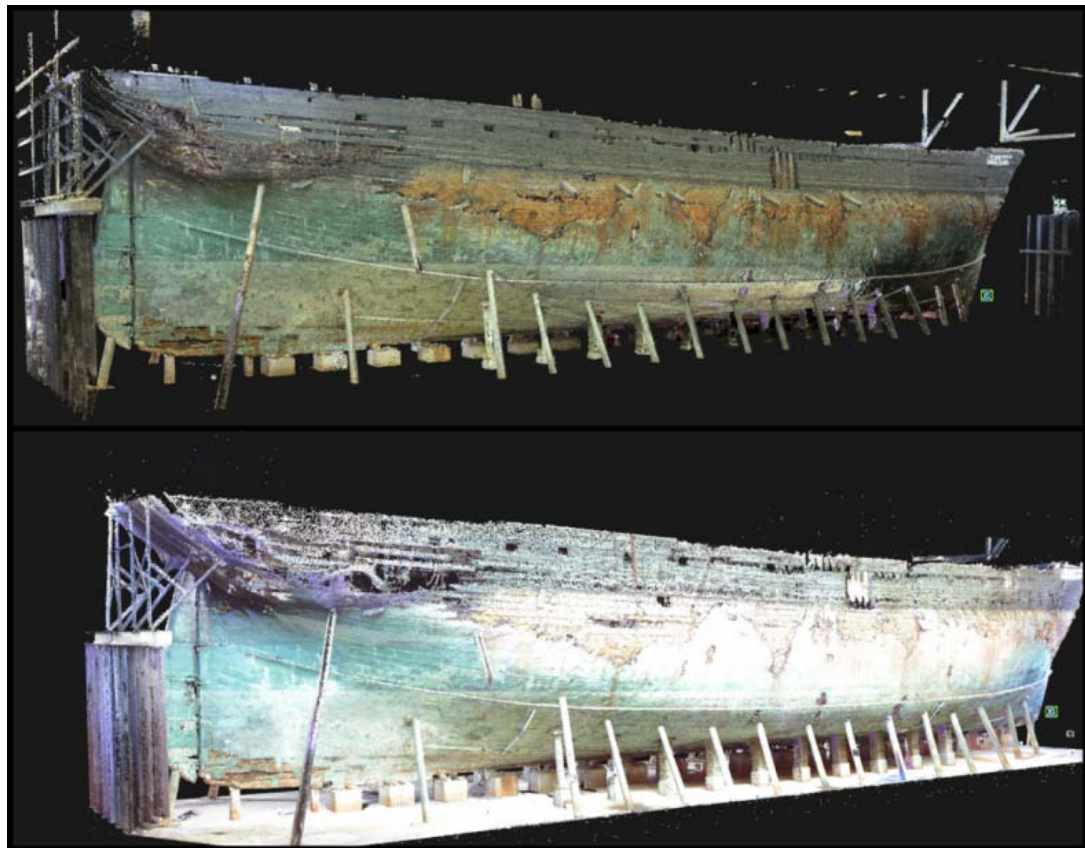


Figure 42. Exterior right side of the ship. **Top image** – a point cloud combining the results of 3D laser scanning and photogrammetry. **Bottom image** – point cloud data with 3D laser scanning information only.

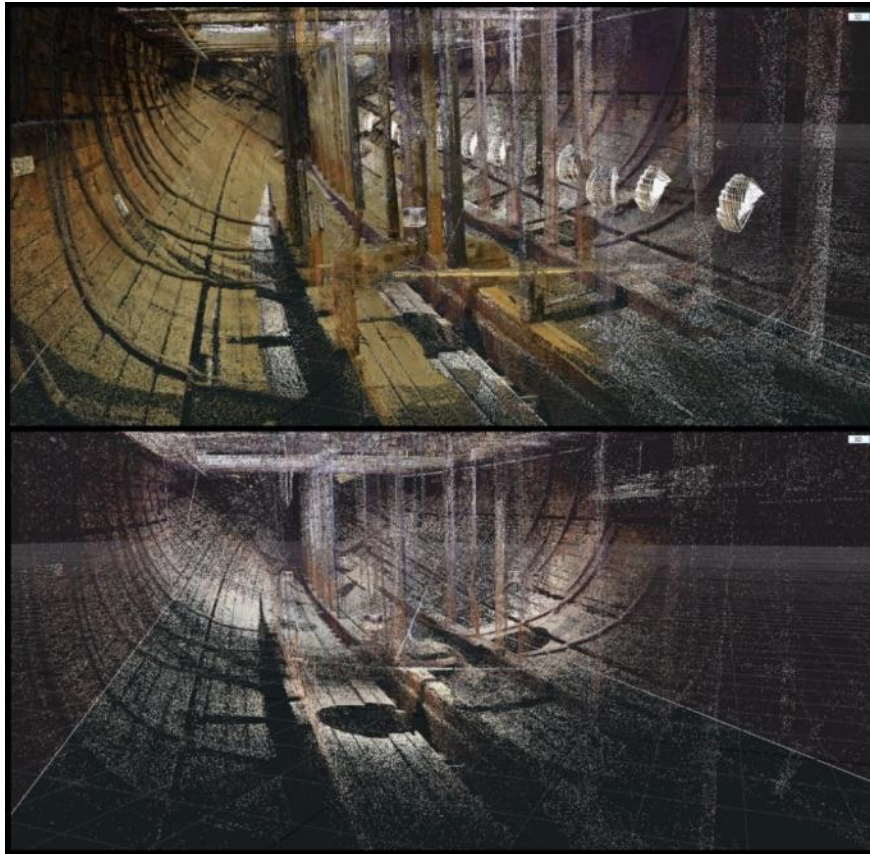


Figure 43. Interior of the ship. **Top image** – a point cloud combining the results of 3D laser scanning and photogrammetry. **Bottom image** – point cloud data with 3D laser scanning information only.

Reflections & Considerations

While a combination of 3D laser scanning and photogrammetry provided a descent result, there were a range of artefacts in the surface and colour information that needed to be addressed during the cleaning and restoration process described further in the workflow. This is mainly due to accessibility issues encountered on the site and extremely unstable lighting conditions. Since the Edwin Fox is the first large-scale project that has been used as a testbed to develop a workflow, there are some suggestions for improvement that can be tested in the next project. First of all, following the proposed example of laser scanning workflow for future projects, the ship has to be visually divided in a similar fashion as proposed earlier for easier photogrammetry management. Secondly, the principles of ‘full-frame-detail shot’ and ‘perpendicular planes’ have to be more actively integrated into the workflow if there is enough space around the object. Thirdly, no panning shots on the same spot should be done; instead numerous detailed shots, varying the placement of the camera, should be made to provide the parallax that is needed for proper image sequence alignment (**Fig. 44**). The final point lies in the fact that artificial lighting must be present at sites with dark indoor areas in order to capture all the colour details necessary for a final satisfactory result. All these points can be demonstrated on the example of another large-scale object that was captured during workflow development (**Fig. 45**).

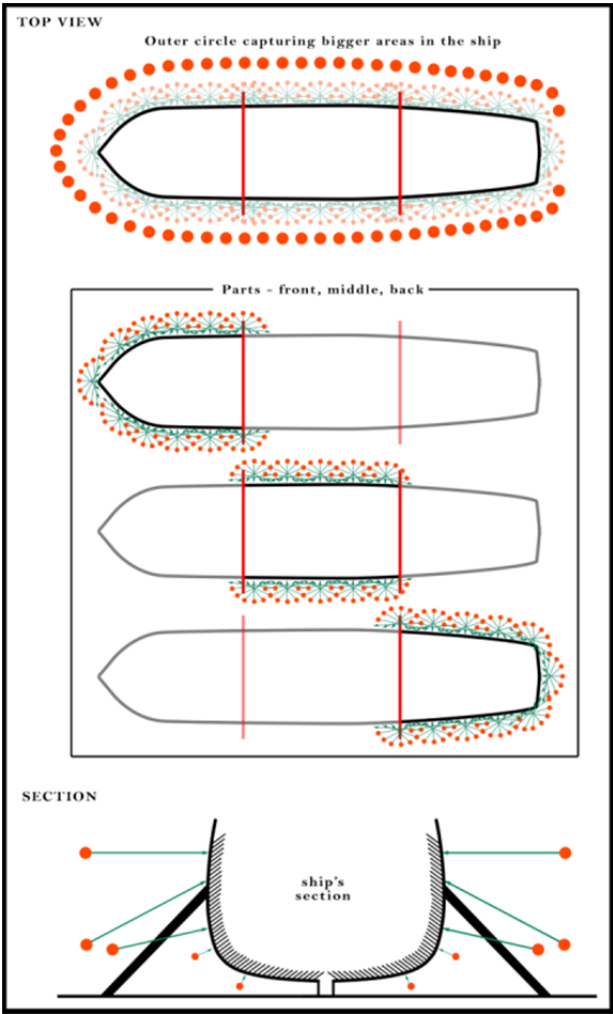


Figure 44. A proposed plan for photogrammetry workflow improvement. The orange dots represent a camera position per image.

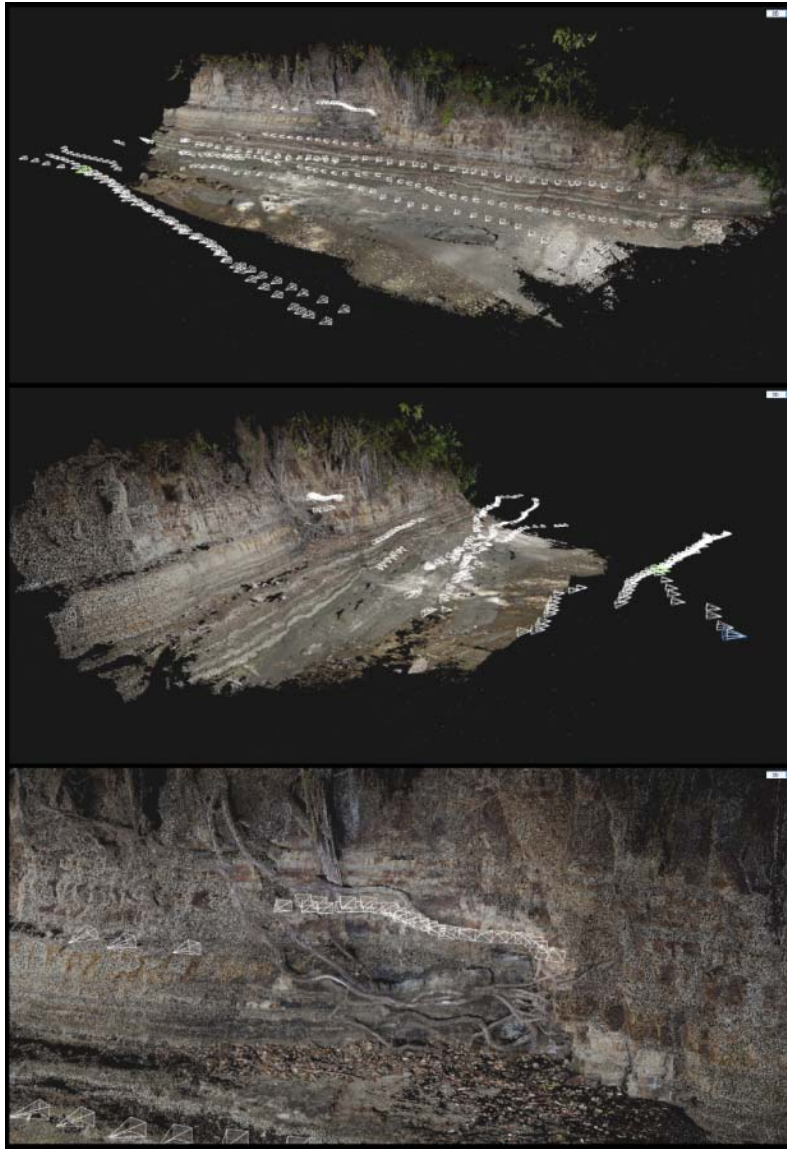


Figure 45. *RealityCapture*. A 3D reconstruction of a cliff. This experiment with a large-scale object shows the principles that should have been applied in the Edwin Fox data acquisition. **Top and middle images** vividly demonstrate the ‘full-frame-detail shot’ principle. The bottom image shows how the detailed shots influence the density of the point cloud. The close-up area, which has cameras represented in white graphics in front of it, is filled with more data than the surrounding areas. The lighting in the object is an example of ideal outdoor lighting that does not contain any sharp shadows.

5.2.3 Generating a Polygonal Mesh from a Point Cloud

Numerous software packages exist that focus on producing a 3D polygonal mesh from an image sequence, ranging from free apps to fully developed professional software. Some of the high-end professional software used in the digital field includes Agisoft PhotoScan, RealityCapture, and Autodesk ReCap. These packages use similar general principles in their workflow. However, there are some differences in the way each type of software processes image sequences. For example, when importing an image sequence, RealityCapture automatically removes all blurry images that are not suitable for calculations. Agisoft PhotoScan imports all the images from the sequence and tries to solve them, which may slow down the calculation process. While there are differences in software calculation algorithms, available tools and interfaces, the general workflow consists of the following stages:

- Importing image sequence (and laser scans for **Advanced Workflow**);
- Alignment;
- Reconstruction of the polygonal model;
- Simplification (if necessary);
- Texturing;
- Exporting the final model.

As mentioned earlier, RealityCapture was used in all the tests demonstrated in this thesis due to its fast and precise calculation algorithms. For a detailed workflow demonstration specific to RealityCapture refer to **Appendix D** for the **Basic Workflow** and **Appendix E** for the **Advanced Workflow**.

5.2.4 Data Acquisition: Summary

The reality-based techniques of 3D laser scanning in combination with photogrammetry were used to record and transfer ‘real-world’ information into digital space. As a fundamental step determining the further workflow development, the process of data acquisition was explained and thoroughly documented to provide the entire empirical provenance so it can be used to repeat the process from scratch if needed.

The final results, based on the data acquired during the two days of work on the Edwin Fox location, turned out to be better than expected, despite all the challenges in capturing such a large-scale complex heritage object. However, there are numerous considerations of what should be improved in the data acquisition workflow.

First of all, if there is possibility for a prior visit to the site, this should be done in order to explore the target object and the space around it for careful planning of the data capturing patterns. The best approach would be to take a rough sequence of photographs and run it through the alignment process in the photogrammetry software. This would help estimate problematic areas that need to be carefully addressed during the final data acquisition process. A prior visit to the site can also help to determine whether there is any additional equipment (ladders, long poles) needed that may help in capturing otherwise inaccessible areas.

Secondly, lighting, as an important factor that determines the general quality of the alignment and in particular the quality of texture, has to be addressed. As seen in many examples illustrated earlier, for an outdoor environment, a cloudy, windless day is perfect for capturing data as it gives soft ambience and does not create harsh black shadows. If there is an opportunity to gather data in such conditions, it will give perfect results, especially for the colour data. However, if there is a very limited timeline, as in the case of the Edwin Fox, overexposed areas and shadows have to be fixed in the texture restoration workflow described later in this thesis. For indoor environments an artificial lighting set-up must be provided to achieve high-quality results.

5.3 Generating a Clean High-resolution Polygonal Model

Accuracy and high-quality details are the main objectives in the digital heritage preservation field. For that reason, reality-based techniques like photogrammetry and laser scanning are used. While these techniques fulfil the requirements, they produce enormous amount of data that can be viewed only using specifically designed software on a powerful computer. The widespread problem with such data is finding a way of converting point cloud data into polygonal data, which is manageable for cleaning and restoration purposes. A possible solution to this problem is demonstrated below.

5.3.1 Exporting mesh from photogrammetry software

The exporting workflow that is specific to RealityCapture in the *Basic* and the *Advanced Workflows* is illustrated in **Appendix F** and **Appendix G** respectively.

5.3.2 Cleaning and Restoration

Basic Workflow

The mesh output can be viewed in MeshLab, an open source software for processing and editing polygonal meshes. MeshLab has a number of tools that allow cleaning and closing holes in the imported model if necessary. The example model of a tree trunk, shown earlier in this thesis, does not have visible artefacts due to the high quality reconstruction (**Fig. 46**). A basic cleaning and hole-closing process can be found on www.meshlab.net, a MeshLab website, where detailed instructions for using the relevant tools are available.

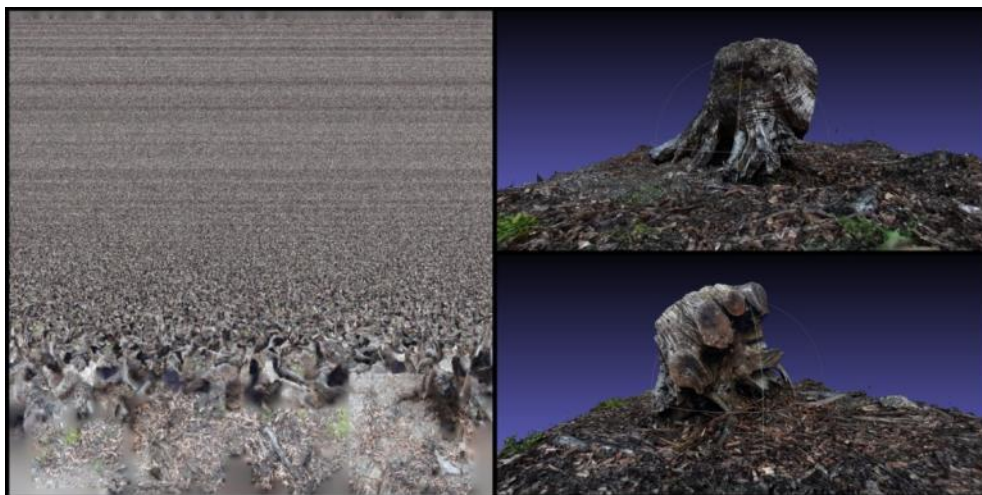


Figure 46. *MeshLab*. **Left image** – the final texture of a tree trunk. It can be seen that the texture space is almost fully filled and there are no visible artefacts in the texture. **Right image** – tree trunk model in the MeshLab viewport.

Advanced Workflow

The *Advanced Workflow* is divided into two parts – a process for managing small and medium size objects, and one for large-scale objects like the Edwin Fox – to demonstrate the

different workflow approaches for meshes that vary in size and, therefore, require different approaches to preservation of details for maintaining high levels of authenticity.

Small and Medium objects

A workflow for a small or medium object is presented using the example of a small rock that was captured using a rotating platform. A sequence of photographs was taken of the rock, but the bottom part of the rock was occluded. Therefore, one more image sequence was produced to capture the bottom of the rock. As an outcome, two models were exported from RealityCapture and imported to Pixologic ZBrush, software designed for creating and editing meshes with high polygonal counts (**Fig. 47**). The final workflow uses ZBrush as an editing tool; however, the same results can be achieved using the principles in the developed workflow and equivalent tools in other 3D editing packages. The final results of the developed cleaning and restoration workflow are described in detail in **Appendix H** for the rock example, which can be viewed in **Figure 48**.

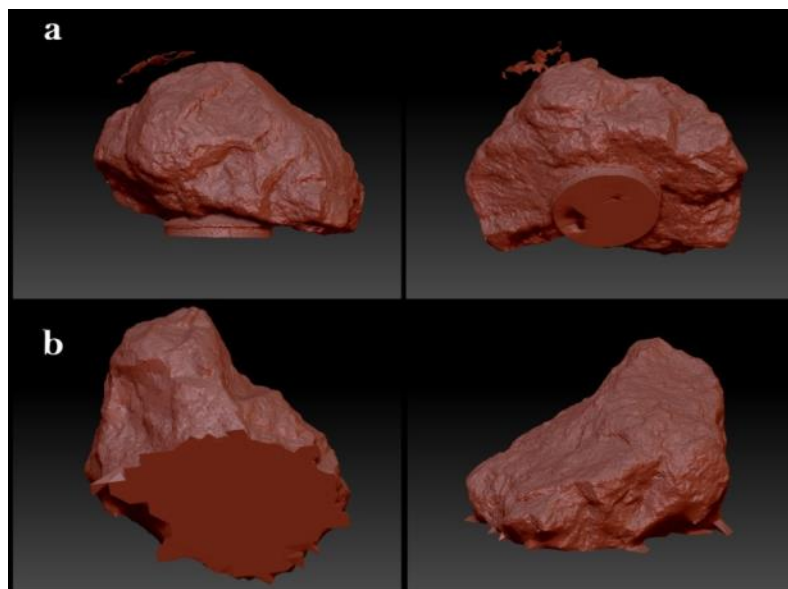


Figure 47. ZBrush. **a** – raw 3D model of top of the rock captured on a rotating platform; **b** – bottom of the rock.

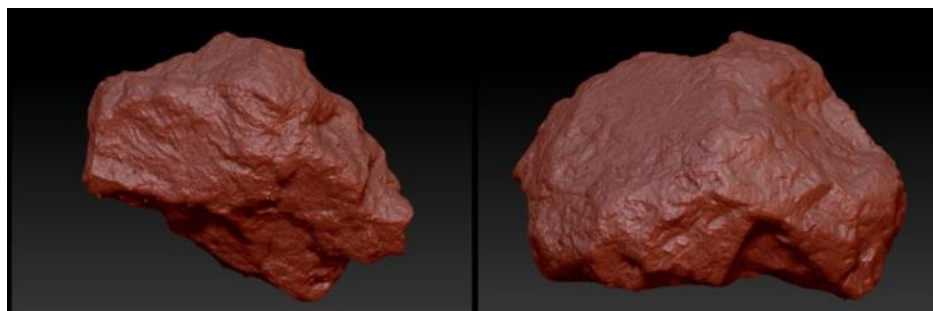


Figure 48. ZBrush. Final cleaned and restored high-resolution rock model.

Large-scale objects

The cleaning and restoration process for a large-scale artefact is illustrated using the example of the Edwin Fox. While some aspects of the presented workflow are specific to the Edwin

Fox, the general approach demonstrated in this subsection is applicable to other large-scale heritage artefacts and can be executed in any 3D editing software that is able to manage a high polygonal count. The main objective behind the workflow development was to preserve as much detail as possible in the high-quality capture areas and restore those details where the information was missing or smudged, based on photographic references.

The parts exported from RealityCapture were imported separately for the exterior and interior into one ZBrush project, where they were roughly cleaned of unnecessary elements (**Fig. 49, Fig. 50**).

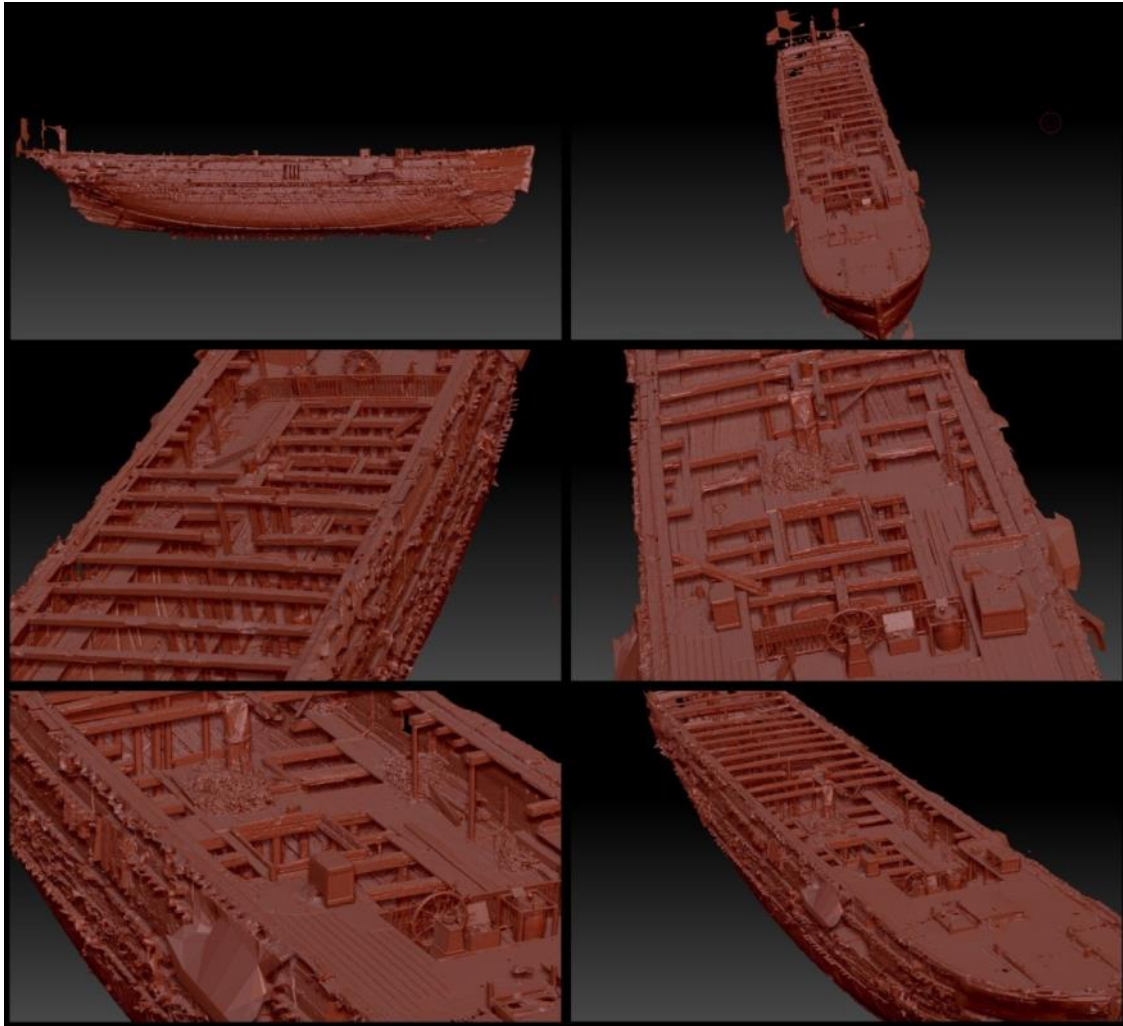


Figure 49. ZBrush. All 154 of the interior parts were put together into one ZBrush project. Unnecessary objects were roughly cleaned out using *Mask Tool*. The model is not textured using the default material for easier editing of the polygons.

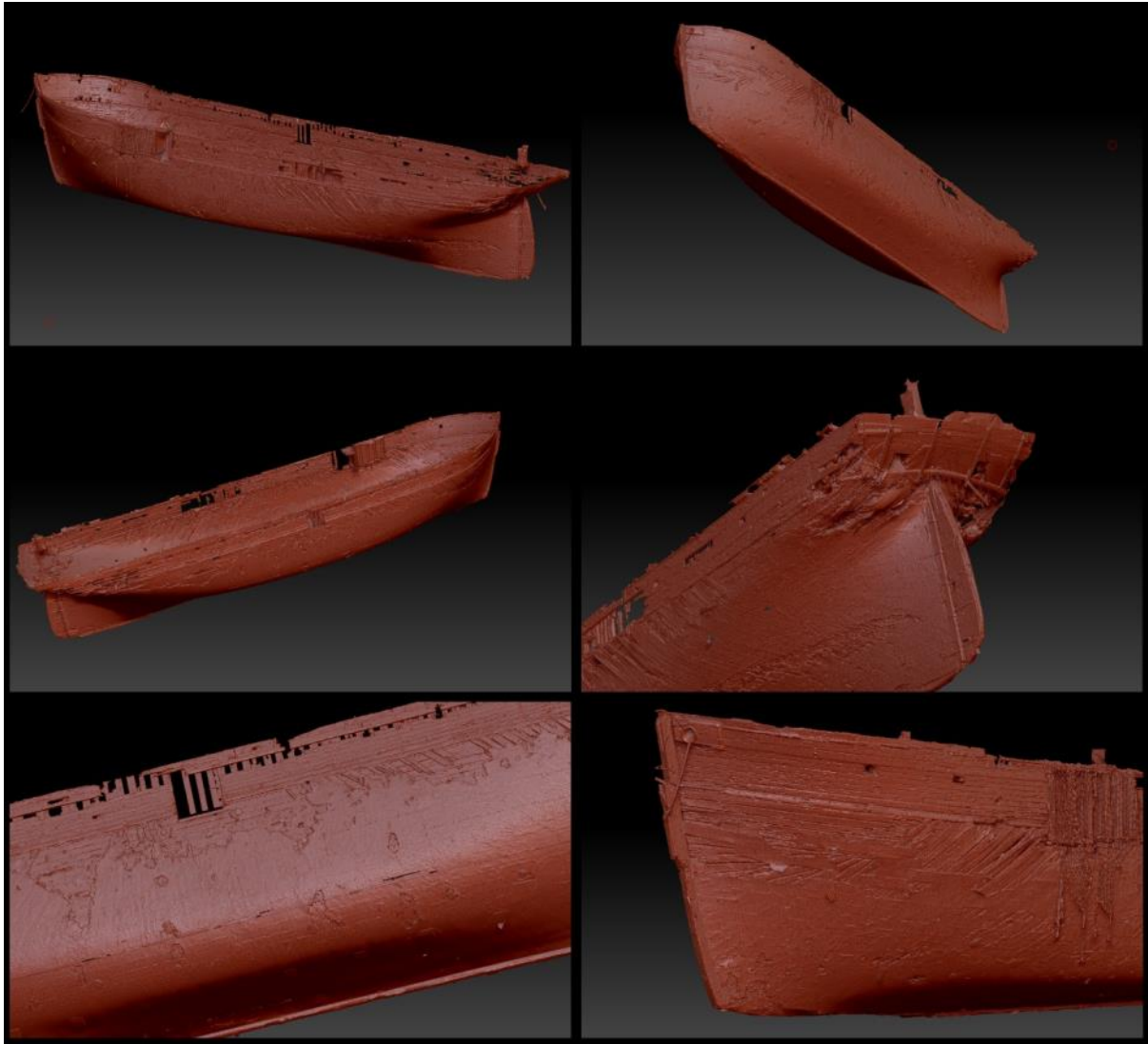


Figure 50. ZBrush. All 280 of the exterior parts were put together into one ZBrush project. The supporting timber and other unnecessary objects were roughly cleaned out using *Mask Tool*. The model is not textured using the default material for easier editing of the polygons.

The number of polygons in each part of the ship did not allow for an effective and fast workflow, so each model was divided into slices to develop a cleaning and restoration workflow in separate ZBrush files (**Fig. 51**). The interior model was further divided into basic shapes – hull, masts and beams, iron knees and modern installations, for removal of what was not needed and easier management of the rest (**Fig. 52**). All the small parts outlined in orange in **Figure 52** are historical visualisations of living conditions on the ship. These parts, as well as all the supporting new timber, were removed during the cleaning and restoration workflow, so that only the original timber of the ship as it was found in Shakespeare Bay was digitalised. This brings to mind the previous example of the ship of Theseus, where all the original timber was gradually removed. The Greeks were able to preserve the ship's shape, but not its timbers. Today, digitalisation not only gives the opportunity to provide a better view and appreciation of the ship's construction, but also, at least visually, to preserve its timbers for future generations to see.

While slicing helped with management of large polycounts, the process of dismantling the ship into basic shapes not only eased the cleaning and restoration workflow, but also laid down the foundation for the optimisation workflow so that the final model can have multipurpose applications. This modular approach of breaking down the slices into singular basic structural elements was applied across the entire cleaning and restoration workflow. The logic behind this approach is demonstrated further.



Figure 51. *ZBrush*. Exterior mesh divided into slices.

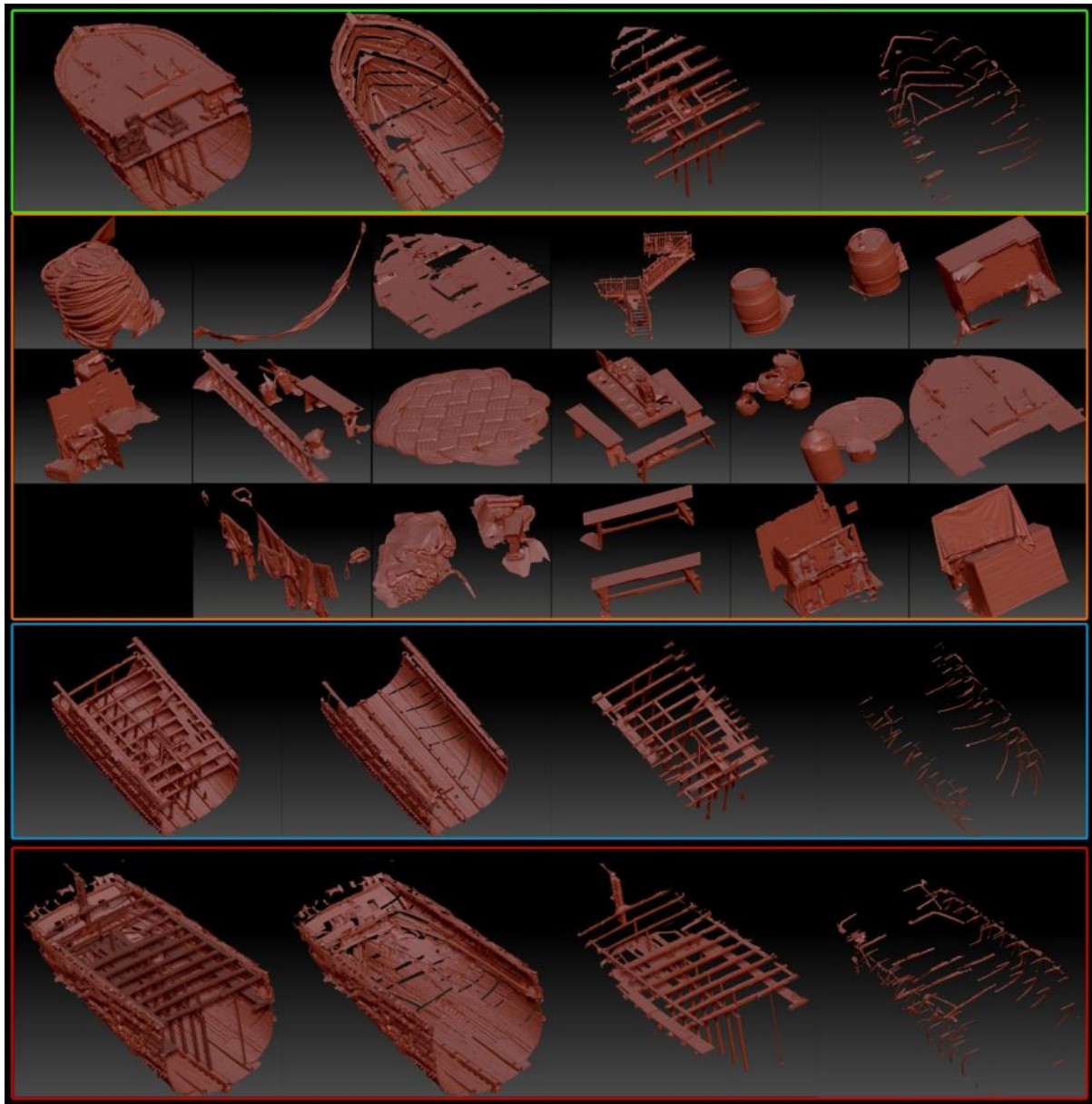


Figure 52. ZBrush. Using *Masking* and *Split* tools. The interior model is divided not only into slices, but also into basic shapes - hull, beams and masts, iron knees, ropes and modern installations (outlined in orange).

The cleaning and restoration process was gradually refined across the project. However, the basic approach was established during the experiments with the first modular parts in the frontal slice of the ship. Preliminary tests were done using those parts, as it was important to define a fast and easy workflow before starting the very long and laborious process of fixing all the artefacts on the entire digital model. The final cleaning and restoration workflow is demonstrated using an example of one part as the developed techniques were repeated across every part of the ship, differing only in amount of time spent on the process due to shape complexity or large numbers of artefacts.

The first step of the workflow was to analyse the shape of the artefact. The front slice of the ship was divided into parts of three basic shapes, which differ either in structure or material. The hull, the masts and the beams have different structures, where the former involves planar shapes and the latter have volumetric shapes. The iron knees could have stayed within the planar hull part;

however, because of their metallic material they had to be separated from the timber hull for an easier optimisation and texturing workflow (**Fig. 52 green outline**). Being a base for the other parts, the process of restoration started with the hull, which can be further taken apart based on the continuity of the timber structure (**Fig. 53**).

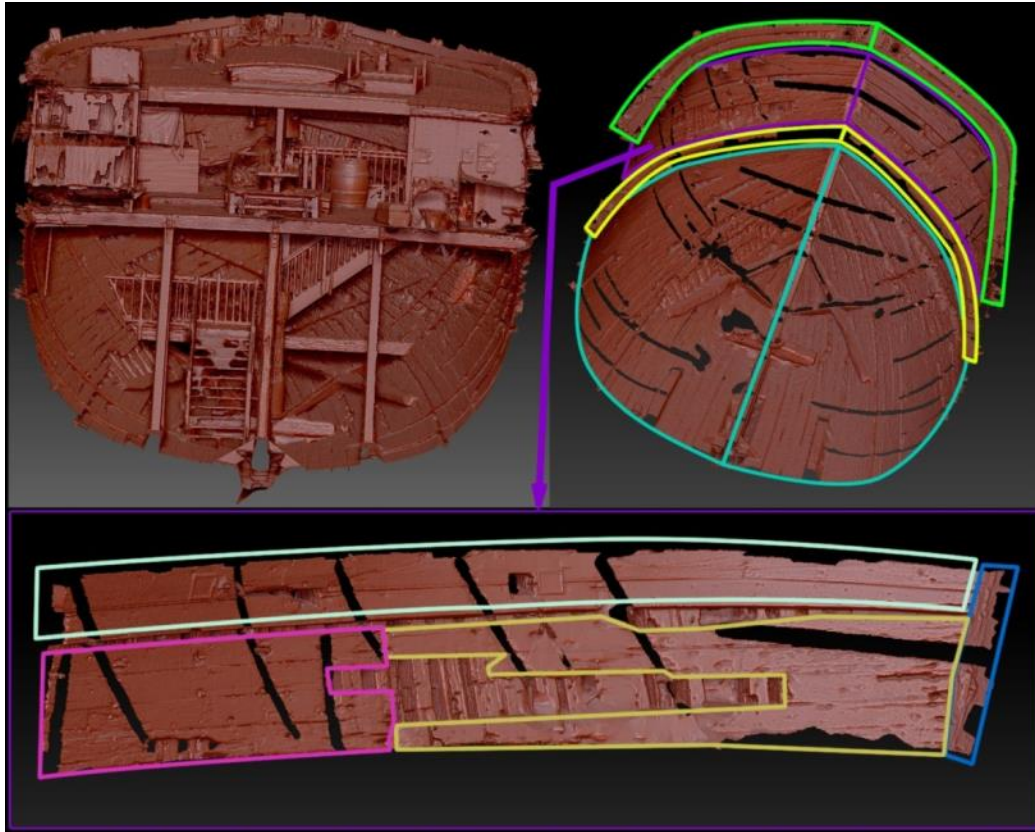


Figure 53. Top left – raw frontal slice; top right and bottom - the coloured outline graphically shows the timber planks that can be cut out from the hull based on continuity of shape. This division into parts allows focusing on one part at a time in a separate ZBrush project, which makes the restoration workflow much easier.

While experimenting with the parts in the front slice, many useful tools were discovered. Some of the successful experiments using those tools (see **Appendix I**) laid the foundation for the final cleaning and restoration workflow development illustrated in detail in **Appendix J**. The cleaned and restored parts of the model were assembled in a ZBrush scene, and some of the parts were merged back again for easier management. A number of work-in-progress screenshots of restoration of the hull from the exterior and interior can be seen in **Figure 54 – Figure 61**. All the final parts from the exterior and interior ZBrush scene were brought together as per the initial slices for the final adjustments and preparation for the optimisation workflow (**Fig. 62 – Fig. 65**).

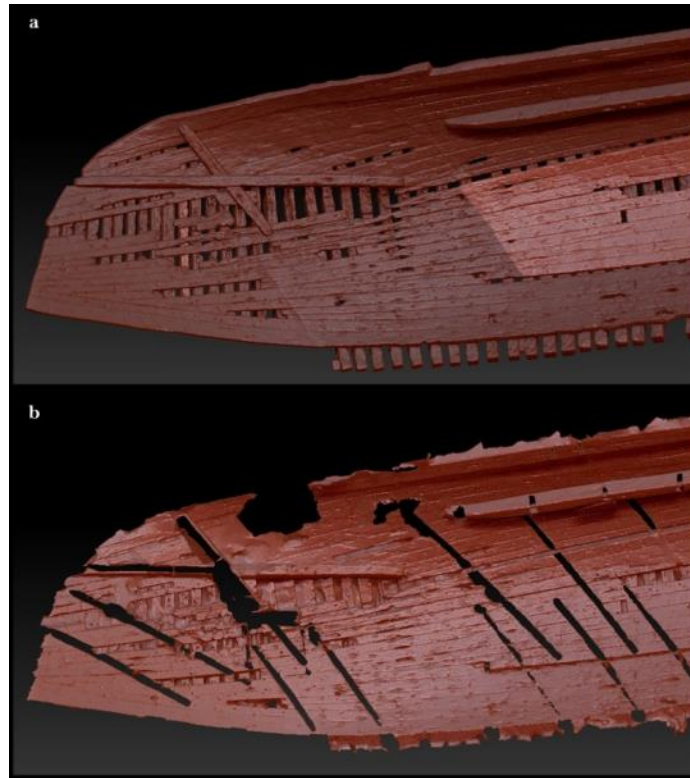


Figure 54. *ZBrush*. Close-up of the interior of the right bottom deck of the hull. **a** – restored parts in one viewport; **b** – raw mesh.

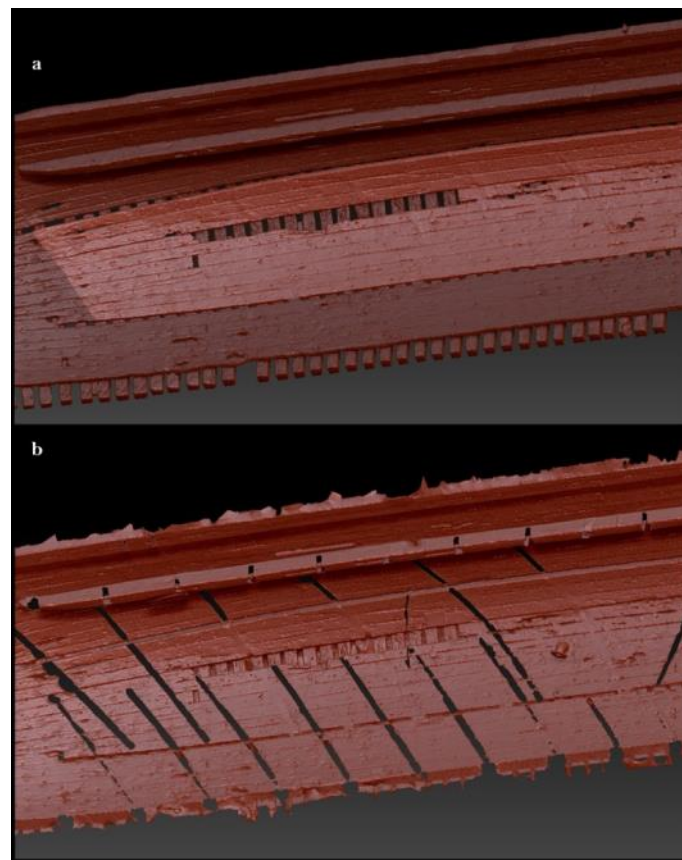


Figure 55. *ZBrush*. Close-up of the interior of the right bottom deck of the hull. **a** – restored parts in one viewport; **b** – raw mesh.

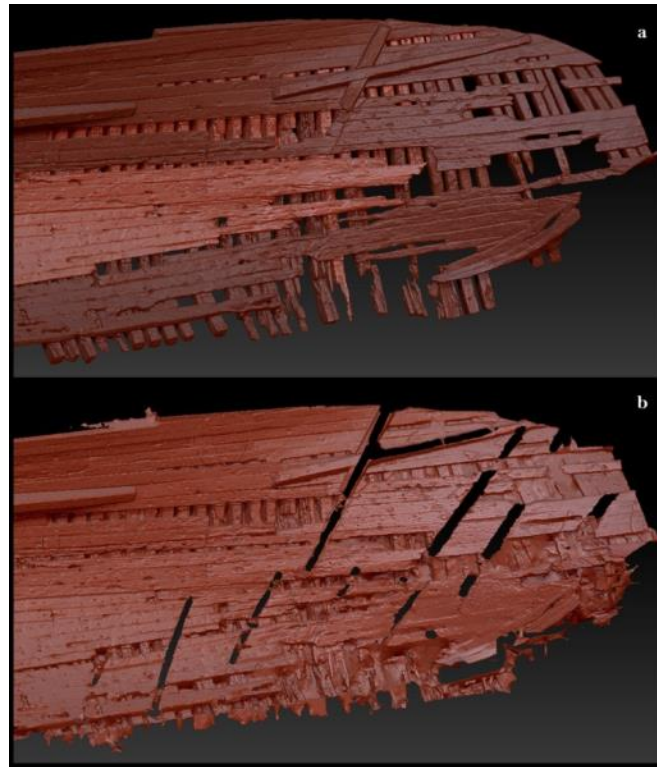


Figure 56. ZBrush. Close-up of the interior of the right bottom deck of the hull. **a** – restored parts in one viewport; **b** – raw mesh.

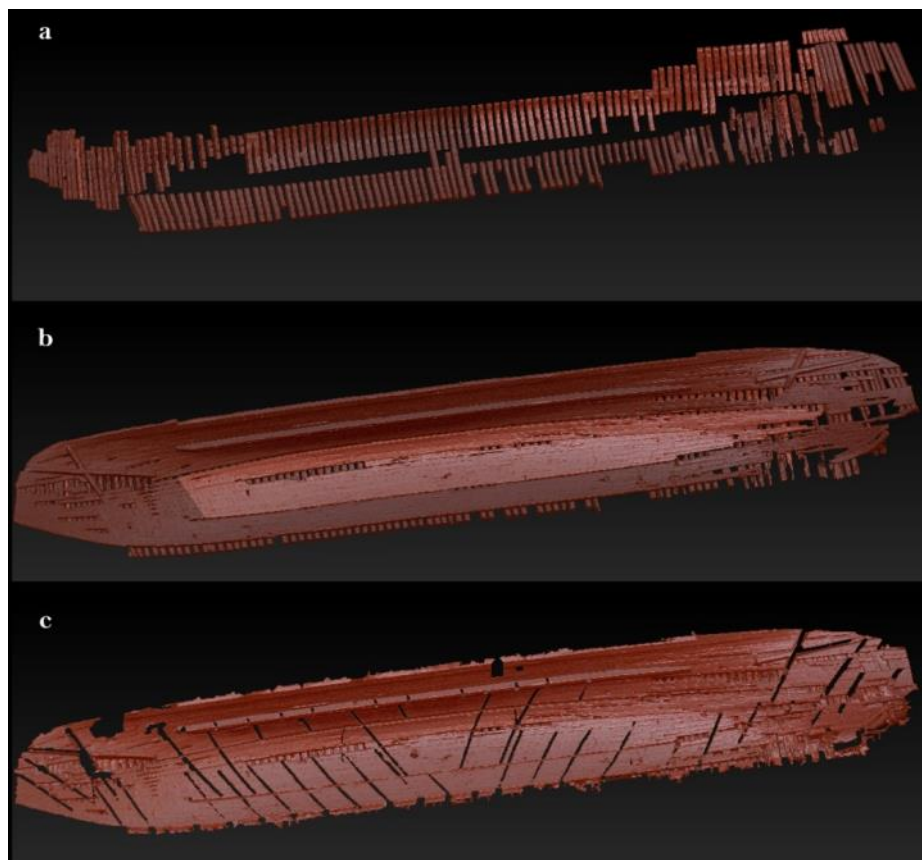


Figure 57. ZBrush. Interior of the right bottom deck of the hull. **a** – restored 'ribs' of the ship; **b** – completely restored right bottom deck of the hull; **c** – raw mesh.

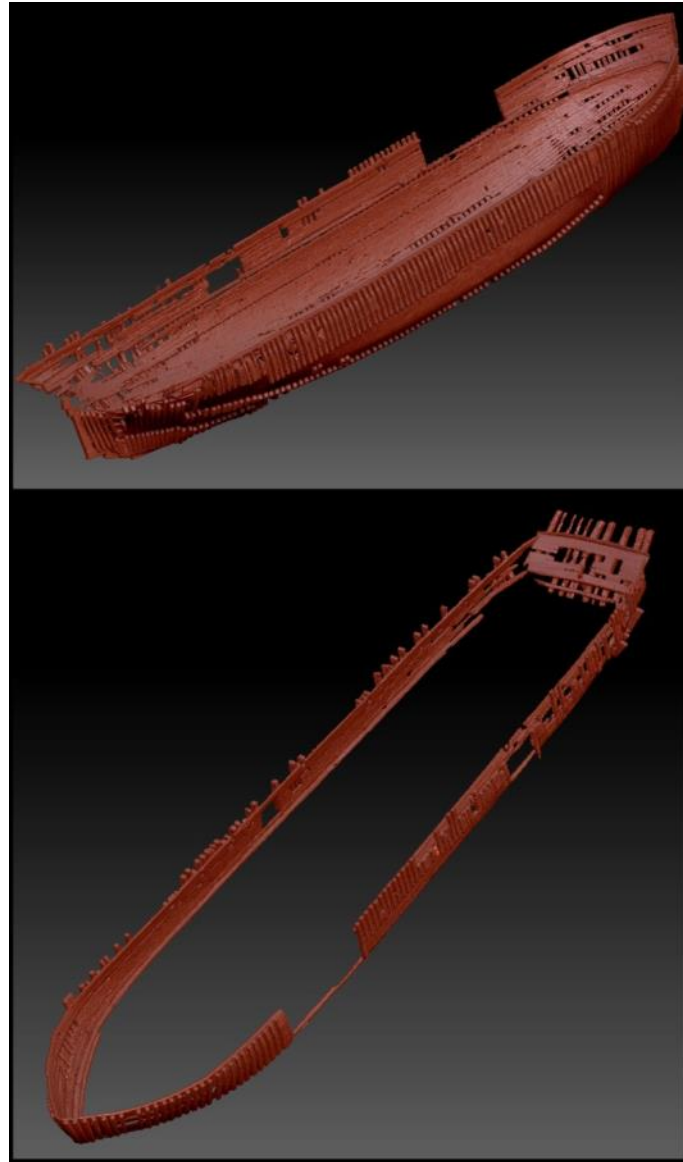


Figure 58. ZBrush. Interior of the ship. The **top image** almost completely shows the fully restored hull of the ship; however, the left side of the top deck could not be imported due to the extremely large polygonal count of meshes that were already in the project. That is why the complete top deck was assembled in a separate ZBrush document (**bottom image**).

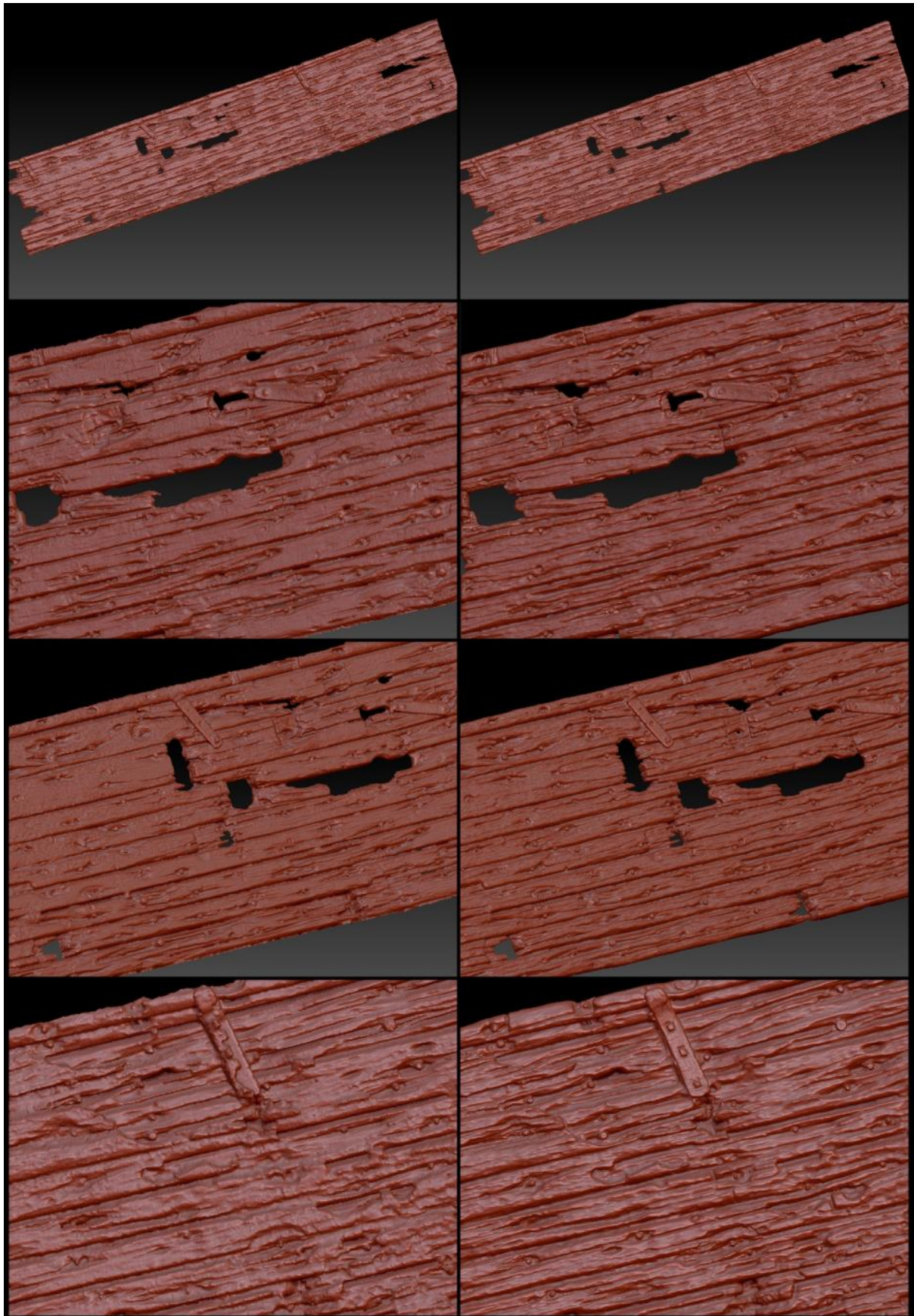


Figure 59. *ZBrush*. Exterior of the ship, close-up of the right side of the top deck. **Left** images – raw model; **right** – restored.

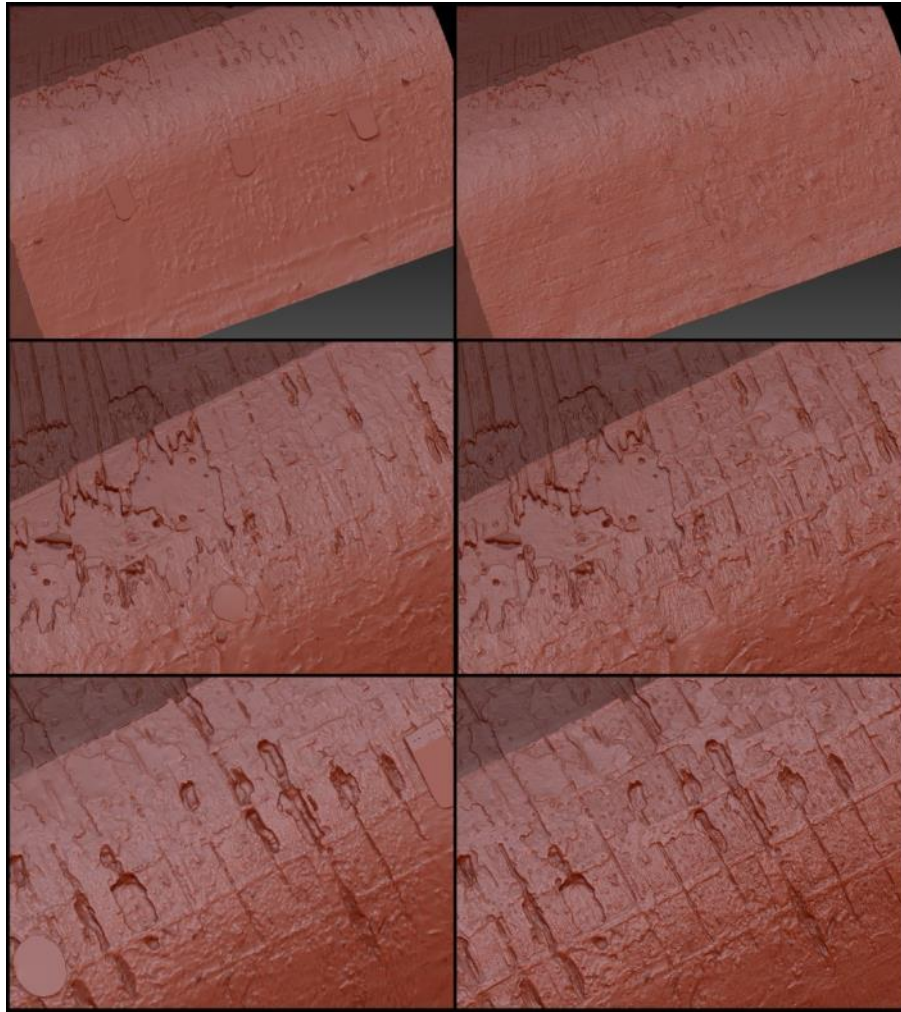


Figure 60. *Zbrush*. Exterior of the ship, close-up of the right side of the bottom deck. **Left images** – raw model; **right** – restored.

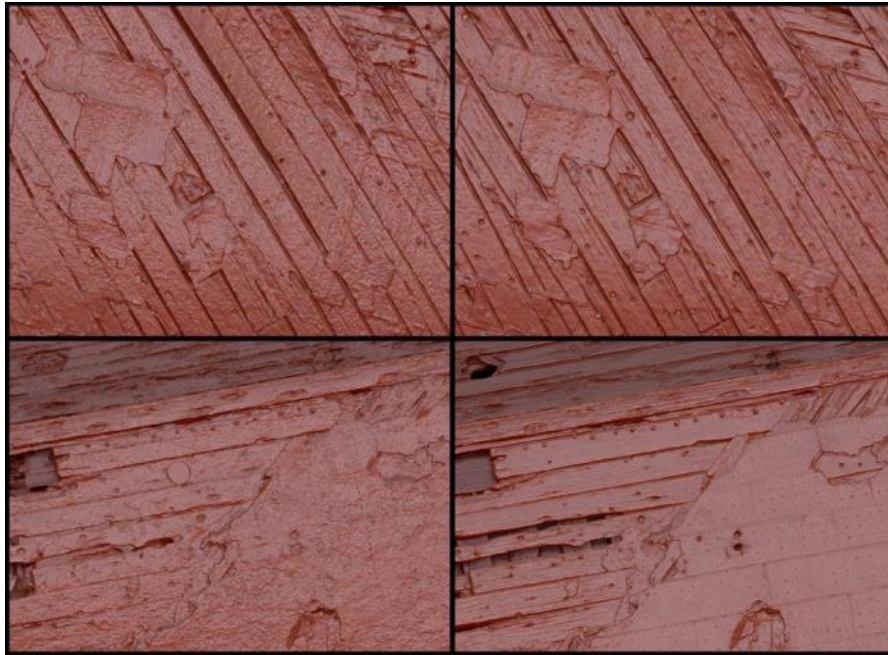


Figure 61. *ZBrush*. Exterior of the ship, close-up of the right side of the middle of the hull. **Left images** – raw model; **right** – restored.

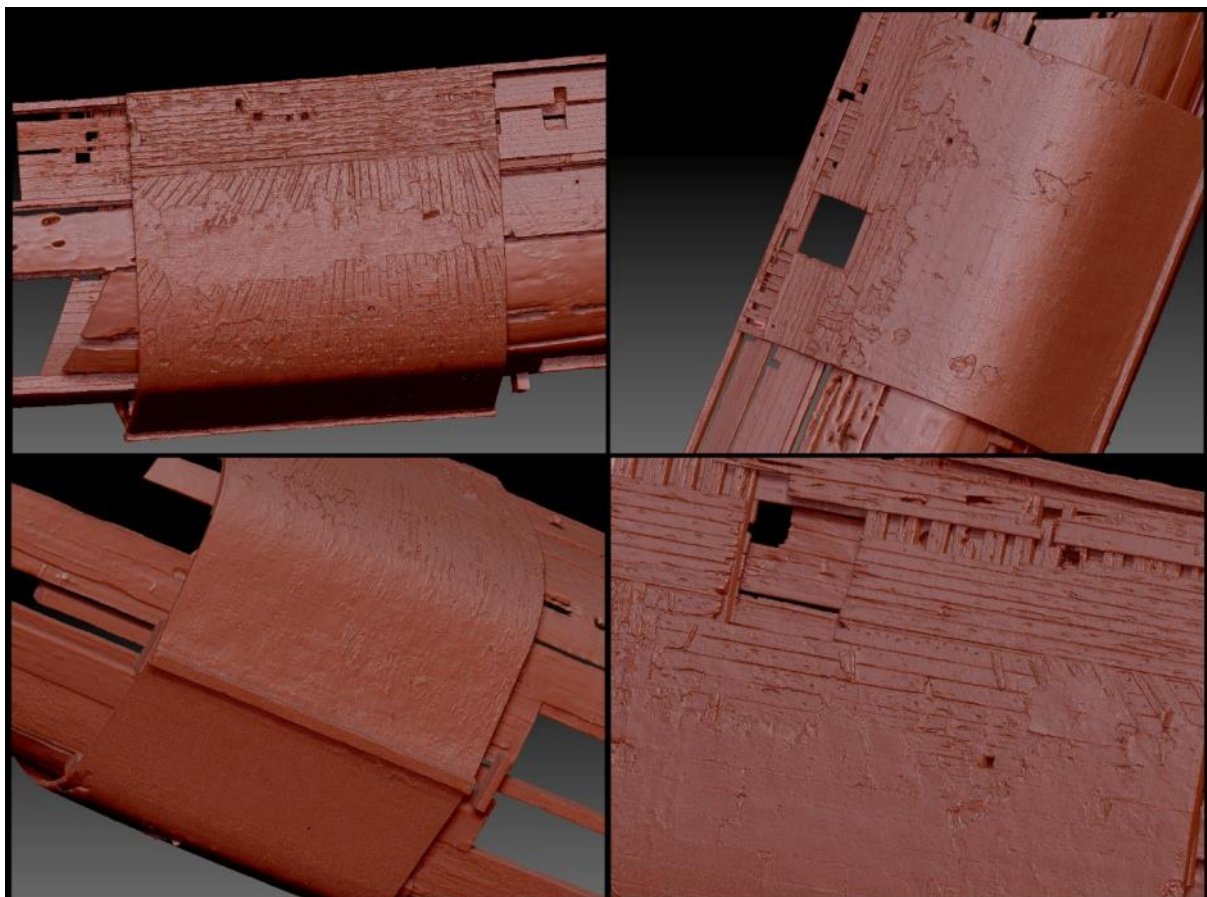


Figure 62. *ZBrush*. Exterior of the ship. Restored middle slice.

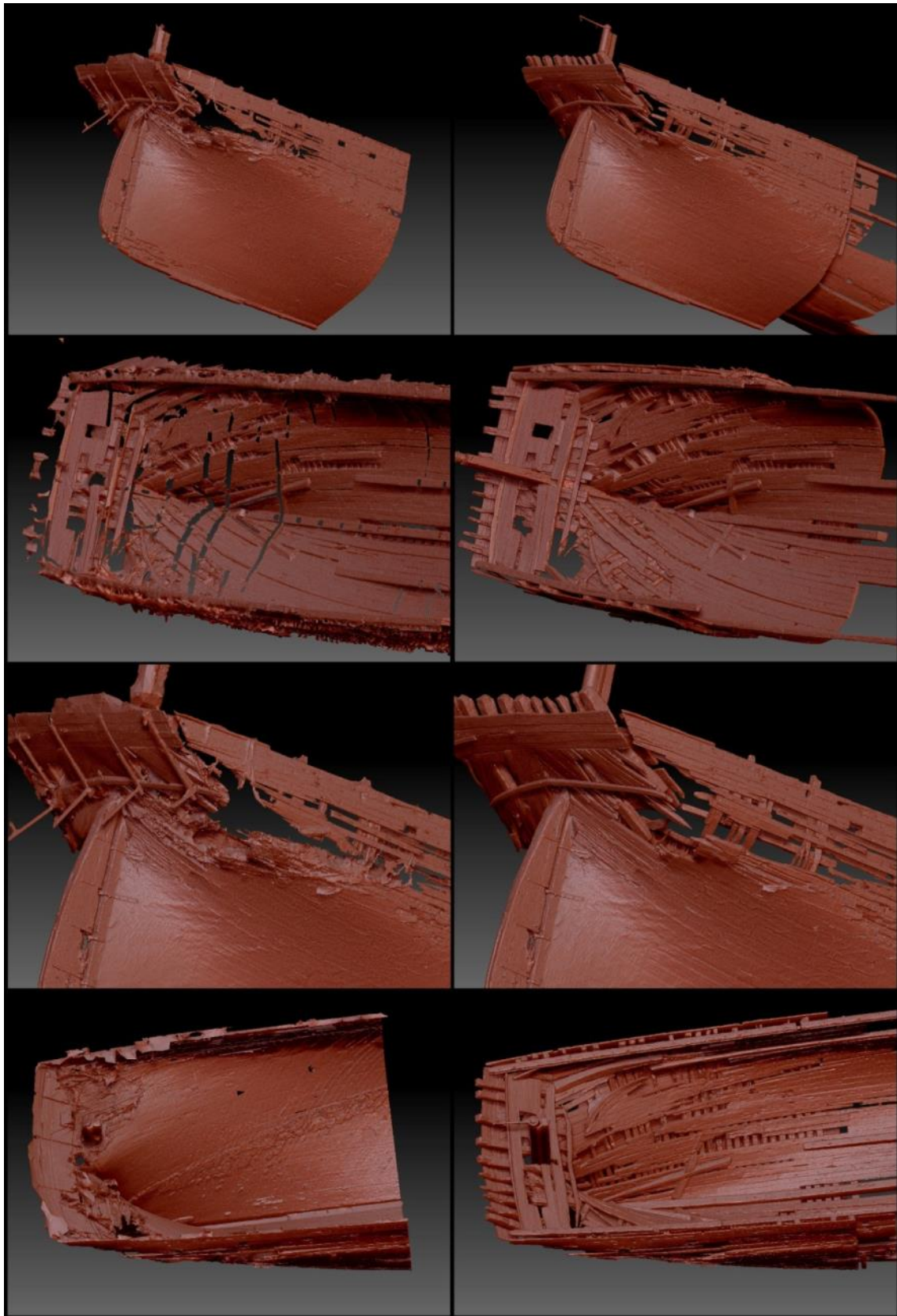


Figure 63. ZBrush. Exterior of the ship, back slice. **Left images** – raw cleaned; **right** – final restored.

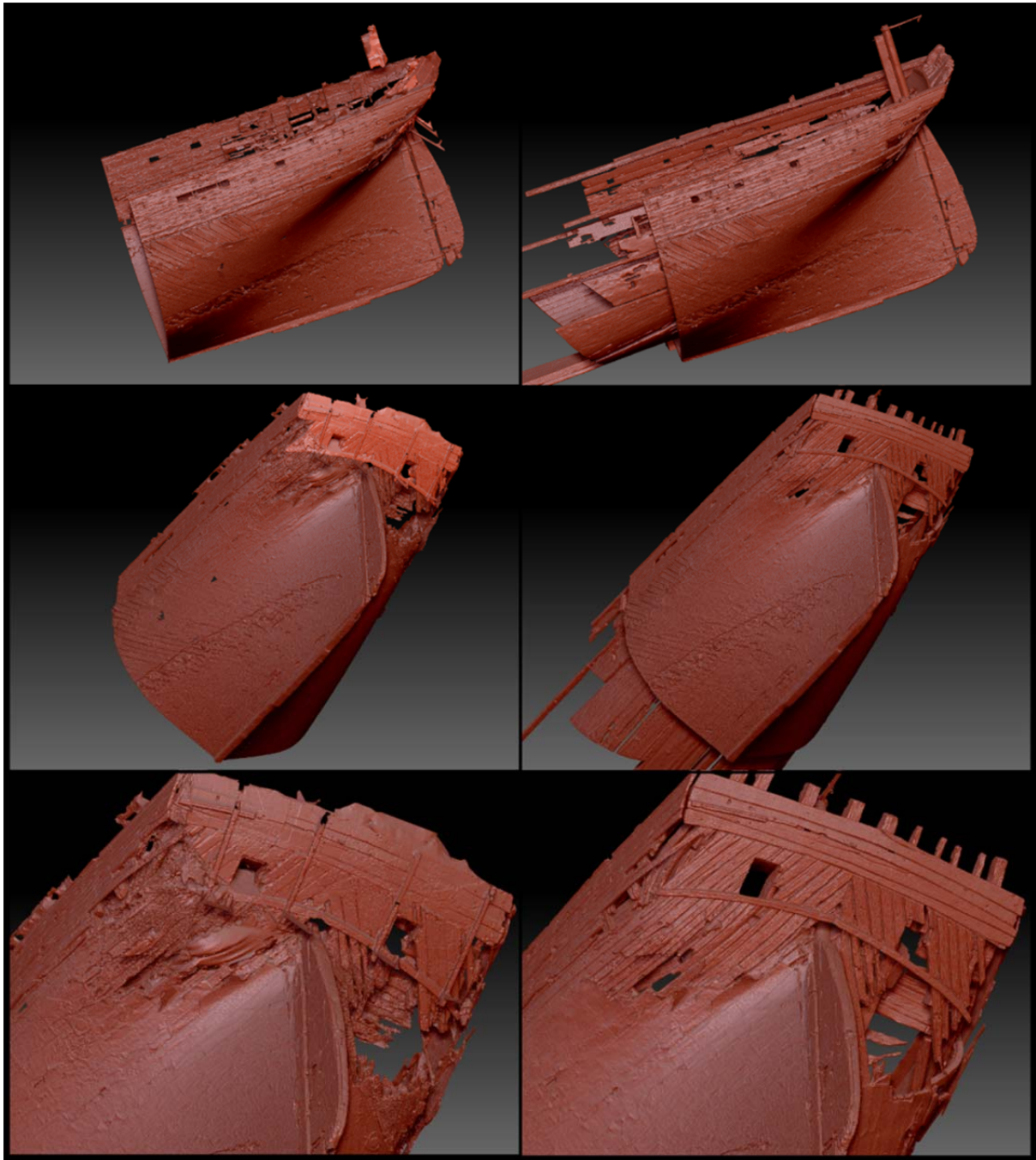


Figure 64. *ZBrush*. Exterior of the ship, back slice. **Left images** – raw cleaned; **right** – final restored.

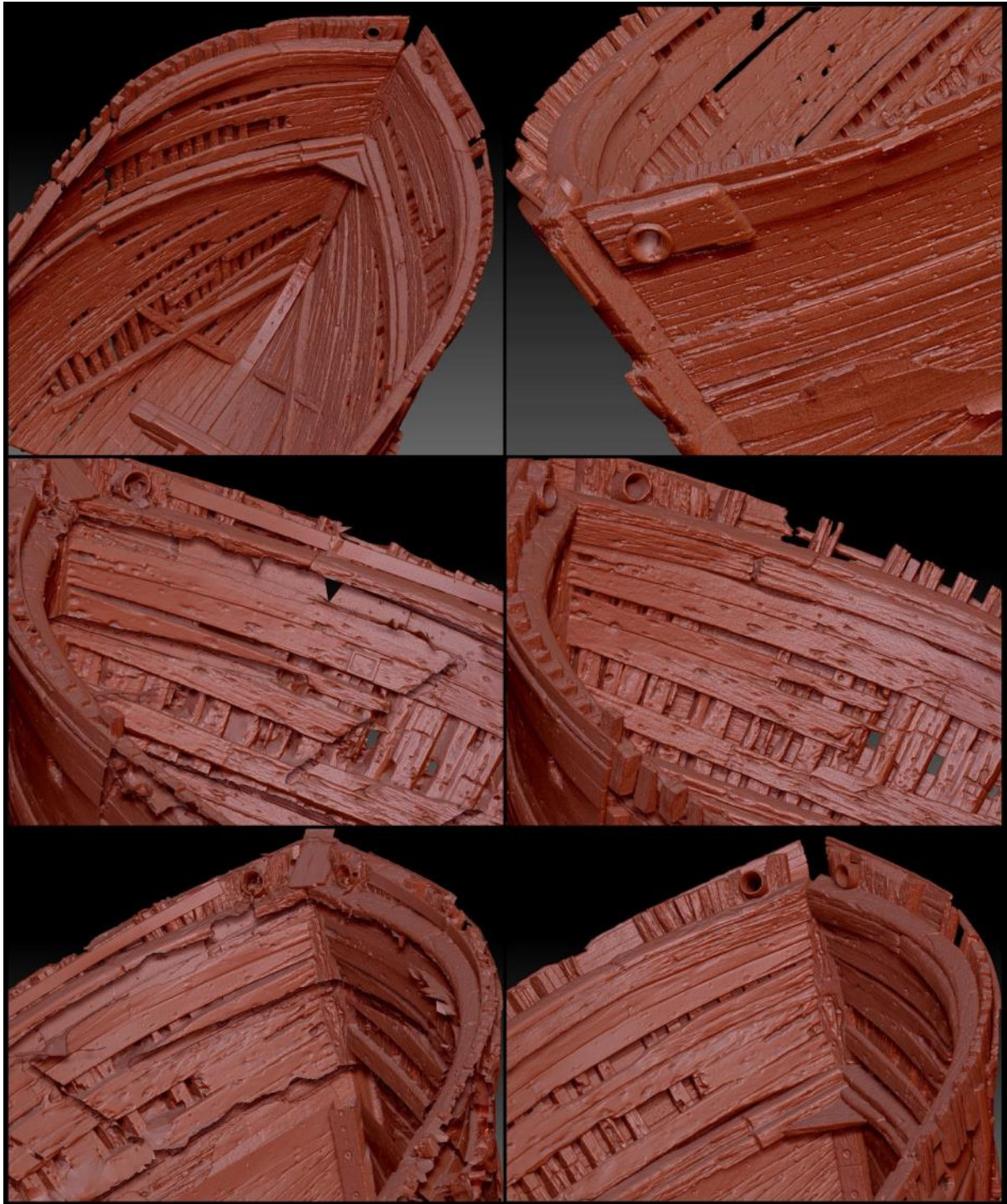


Figure 65. *ZBrush*. Front slice of the ship. **Top two images** – exterior and interior parts combined into one viewport; **bottom images: left** – raw cleaned model; **right** – restored.

5.3.3 Generating a Clean High-resolution Polygonal Model: Summary

The creation of a high-resolution clean model from a point cloud can be a matter of half an hour, as demonstrated in the examples of a tree stump and small rock, or many months of laborious restoration processes and large data management, as in the case of the Edwin Fox. This subsection has demonstrated the importance of the quality of the data initially captured on the site, as it determines the rest of the workflow direction and the amount of work involved during the cleaning

and restoration stage. For smaller and medium objects, if captured appropriately, the restoration stage might not be needed. In the case of large objects, the number of artefacts inevitably increases with complexity of the shape, scale and accessibility to the site. For the Edwin Fox, laser scanning in combination with photogrammetry produced extremely detailed polygonal models of the exterior and interior of the ship; however, they still left much to be desired in terms of surface details. This was due to the initial capturing technique, which should have been replaced with that proposed described earlier in order to capture the maximum level of detail and create manageable data sets. Such a technique would have meant much less time spent in the cleaning and restoration process, which was aimed at preserving as much detail as possible to maintain an accurate digital representation of the physical model. That is why photographs of the available areas were used at all times as references during the detail restoration process (some examples can be seen in **Fig. 66 – Fig. 69**).

The **Basic** and **Advanced** cleaning and restoration workflows illustrated in this subsection show a number of work-in-progress images that demonstrate the results of the developed workflow on examples involving objects of different size and complexity. While the specificity of each workflow will depend on its target object, the presented restoration workflow attempted to show the main principles behind generating a clean high-resolution model from point cloud data. For a heritage object like the Edwin Fox, a non-destructive workflow that maintains the details of the physical artefact throughout the restoration workflow is required. That is why automation and simplicity of the tools are a priority. In the **Basic Workflow** all the processes shown are completely automatic so that a non-digital specialist is able to produce a high-resolution model without former training in the digital field. This is in line with the requirement of qualitative capture of data and alignment of a high-quality point cloud. In the **Advanced Workflow**, through the work-in-progress images, the final presented workflow demonstrated its ability to not only preserve captured data through automated functions in ZBrush, but also to manually restore lost details with a few simple brushes and alphas in a non-destructive manner based on photographic references. It may be argued that manual sculpting does not belong in reality-based modelling techniques as it is often biased by artist interpretations. However, as stated in the **Methodological Approach**, in Action Research the requirement for practitioner excellence and accountability goes without saying, along with the need to produce empirical evidence to support claims that one knows what one is doing and takes responsibility for the ongoing improvement of practice.¹⁶⁷ Such empirical evidence was produced in the form of side-by-side comparison images due to the visual nature of the project itself. These images were presented in abundance in this subsection so that the effectiveness of the restoration workflow can be evaluated in detail.

While accuracy in details is a requirement for every heritage preservation project that aims for a high level of authenticity, another important principle behind a cleaning and restoration workflow is modularity or in other words, breaking the model into basic shapes. The principles of a modular approach allow working with each part of the object individually, making sure all the details are inspected and assigned the required polygonal count to maintain a high level of authenticity. This approach will not be useful in every heritage preservation project; however, the majority of large-scale complex projects, like the *Edwin Fox Project*, will find this technique very helpful in terms of managing large data and restoration processes, where each modular part can be given the

¹⁶⁷ McNiff and Whitehead, *Action Research*, 60.

required attention. All the general principles of the proposed capturing technique as well as the modular approach presented earlier in the cleaning and restoration workflow can find useful applications in any heritage preservation projects of similar size.

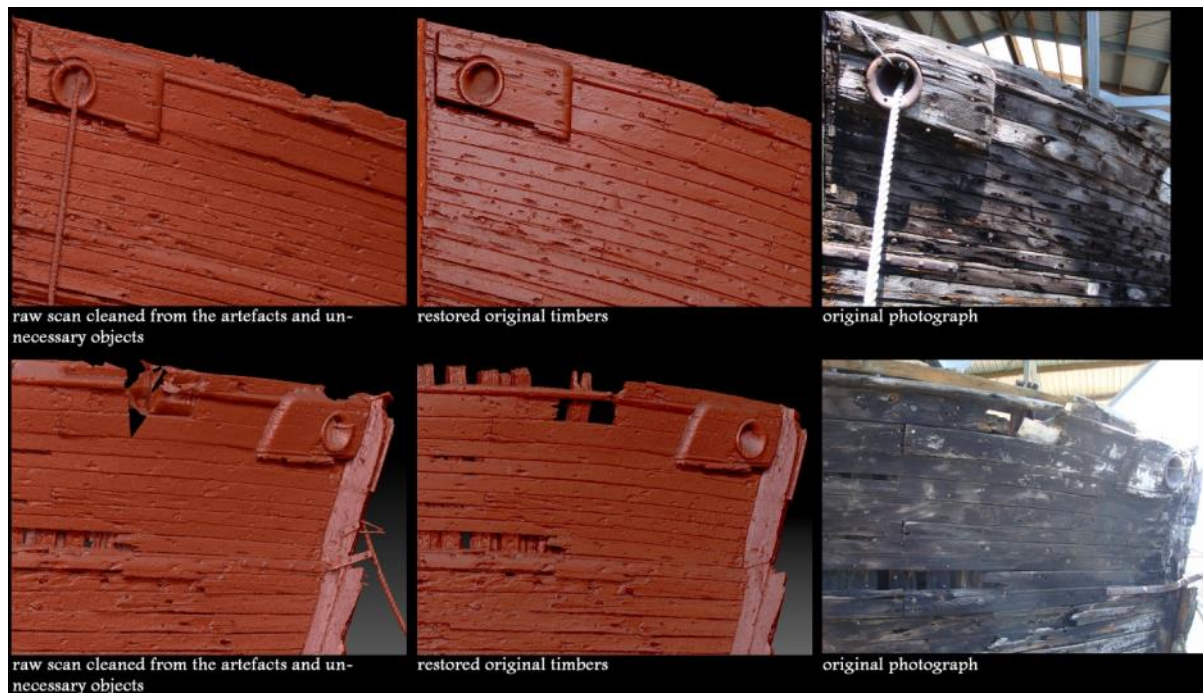


Figure 66. Left column – cleaned raw model; middle column – restored original timbers. All the smudged small details are re-sculpted and the surface noise is completely removed. Note that major metal parts (iron knees and protruding large nails) are yet to be restored and added to the hull. Right column – photograph from the site.

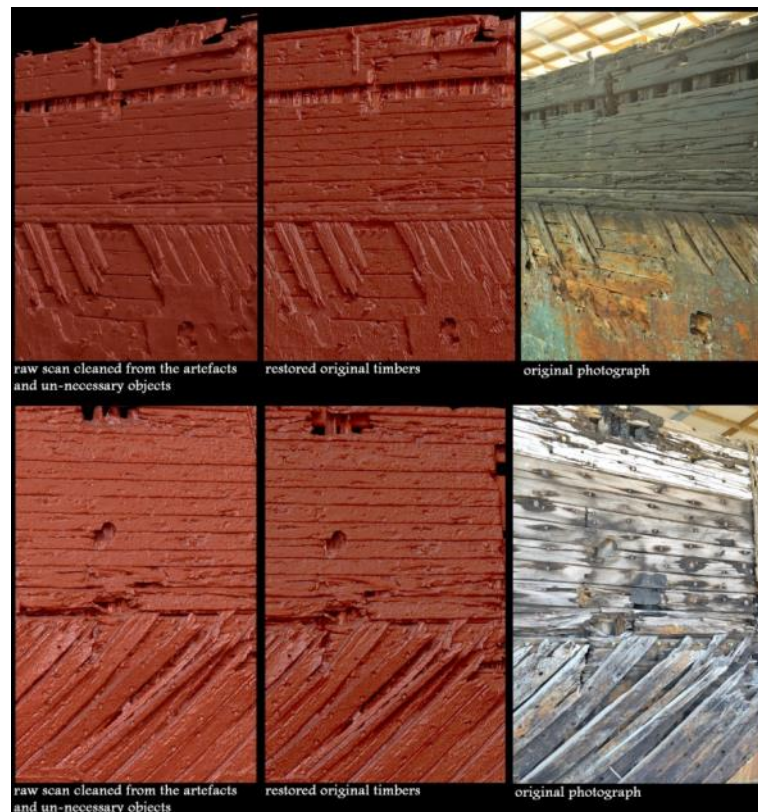


Figure 67. Left column – cleaned raw model; middle column – restored original timbers. All the smudged small details are sculpted in and the surface noise is completely removed. Note that major metal parts (iron knees and protruding large nails) are yet to be restored and added to the hull. **Right column** – photograph from the site.

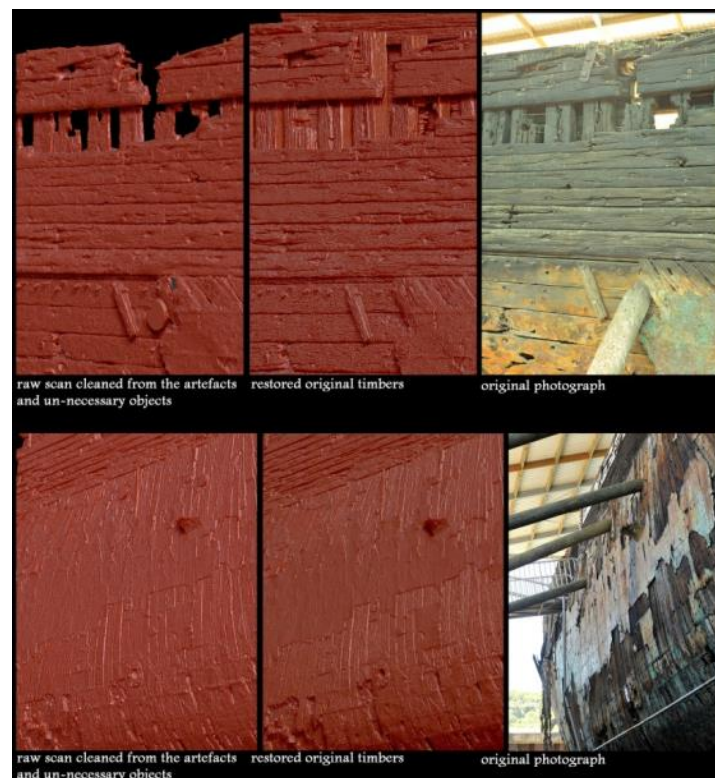


Figure 68. Left column – cleaned raw model; middle column – restored original timbers. All the smudged small details are re-sculpted and the surface noise is completely removed. Note that major metal parts (iron knees and protruding large nails) are yet to be restored and added to the hull. **Right column** – photograph from the site.

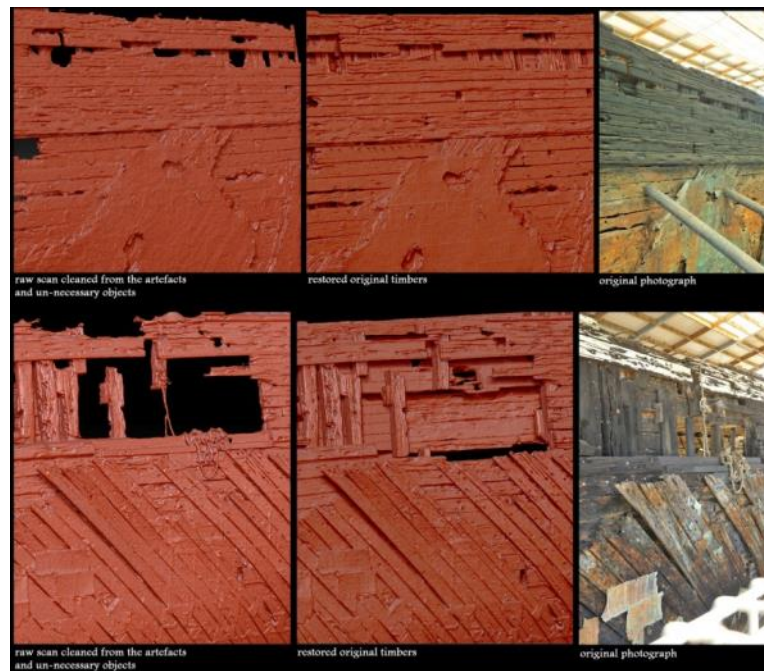


Figure 69. **Left column** – cleaned raw model; **middle column** – restored original timbers. All the smudged small details are re-sculpted and the surface noise is completely removed. Note that major metal parts (iron knees and protruding large nails) are yet to be restored and added to the hull. **Right column** – photograph from the site.

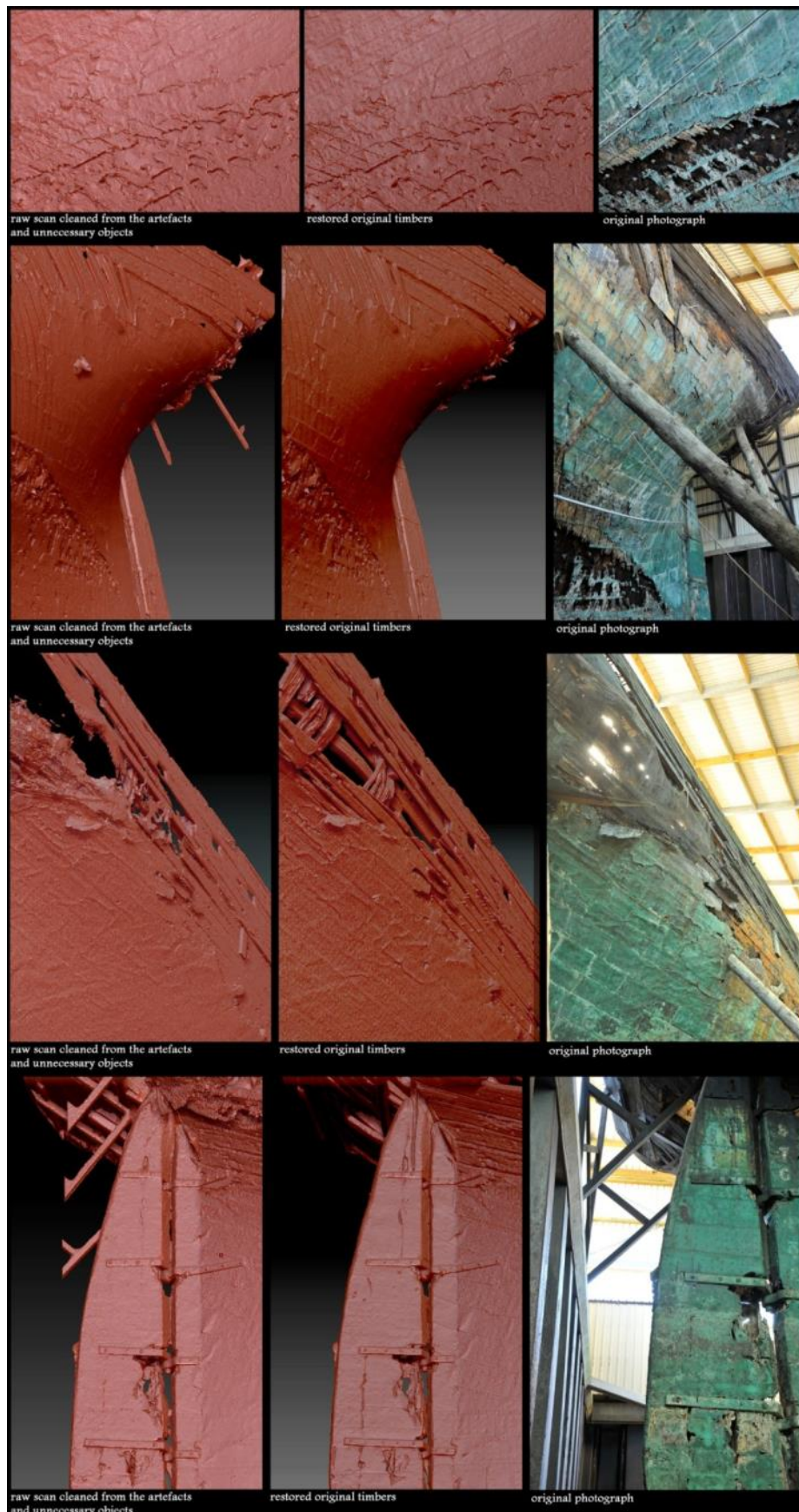


Figure 70. Left column – cleaned raw model; middle column – restored original timbers. All the smudged small details are re-sculpted and the surface noise is completely removed. Note that major metal parts (iron knees and protruding large nails) are yet to be restored and added to the hull. Right column – photograph from the site.

5.4 Optimisation for Multi-Purpose Use

Many non-digital specialists may think that the creation of a high-resolution digital model of an object is a prime goal for a heritage preservation workflow. While this is true in a certain sense, such high-resolution models can be viewed only on computers with high specifications, in a specially designed 3D package. In the case of the Edwin Fox, the high-resolution model of the restored hull cannot be viewed fully in any software as the five restored slices add up to approximately 710 M polygons. Such detailed models are extremely important for documentation and preservation in case of natural disaster, where the item can be damaged or lost. However, for general public use the model must go through a process of optimisation.

Optimisation is defined by Oxford Dictionaries as “the action of making the best or most effective use of a situation or resource”¹⁶⁸. This definition reflects the idea of optimisation in digital modelling, where a high-resolution model undergoes a process of simplification while maintaining its details, so that it can be used for various purposes such as online presentation in 3D view plugins, image renders, real-time interactions and immersive VR experiences. Through optimisation techniques, a digital copy of a heritage artefact is made available to a large number of audiences around the world, which adds to the promotion of the artefact, education and touristic interest.

Optimisation process generally consists of three stages, which include:

- Access to a high-resolution model;
- Manual or automatic generation of a low-resolution model (smaller polycount) based on the high-resolution model;
- Baking polygonal details of the high-resolution model into texture maps that can be applied to the low-resolution model to imitate a high-resolution model.

There are different levels of optimisation, which depend on the future use of the final model. To be used online, the optimisation requirements are not as demanding as, for example, use in VR, in terms of polygonal count and texture utilisation. In this thesis, both variants are illustrated below.

5.4.1 Generating a low-resolution model

Basic Workflow

For the **Basic Workflow** demonstration, an example of a 3D shell model is used. Generally, a proper low-resolution mesh with a clean topology is created manually; however, this requires specific skills in the digital field. For that reason, an automatic generation of a low-resolution model is illustrated in this **Basic Workflow**.

¹⁶⁸ “Optimization | Definition of Optimization in English by Oxford Dictionaries,” Oxford Dictionaries | English, accessed January 18, 2018, <https://en.oxforddictionaries.com/definition/optimization>.

The process of creating a low-resolution model involves reducing the polygonal count on the high-resolution mesh. There is no exact equation linking the high-resolution model polycount and the low-resolution model polycount, as the reduction of polygons depends on the shape and complexity of the high-resolution model. There is, however, a general practice to create a low-resolution model in such a way that it retains all the basic shapes of the high-resolution model (**Fig. 71**).

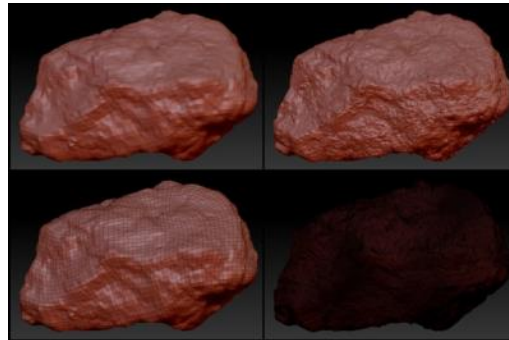


Figure 71. An example of low-resolution and high-resolution meshes. The **left column** is a low-resolution model of a rock. **Bottom image** shows topology and density of polygons, which is 4,493 polygons; **right column** – a high-resolution model of a rock. **Bottom image** shows topology and density of polygon, which is 4,5 M polygons.

Tools for automatic reduction of polygons are available in many 3D editing software packages. The best way for the **Basic Workflow** is to reduce the polycount with the *Simplify* function in RealityCapture (or any other photogrammetry software in which the initial mesh reconstruction was done). As soon as the high-polygonal model is exported, the *Simplify* tool can be used to assign the desired polygonal count to generate a low-resolution mesh. In addition to RealityCapture, meshes can be simplified in ZBrush with *Decimation Master*, Autodesk Maya with *Reduce* function and MeshLab with *Quadratic Edge Collapse Decimation*, which is illustrated in **Figure 72**.

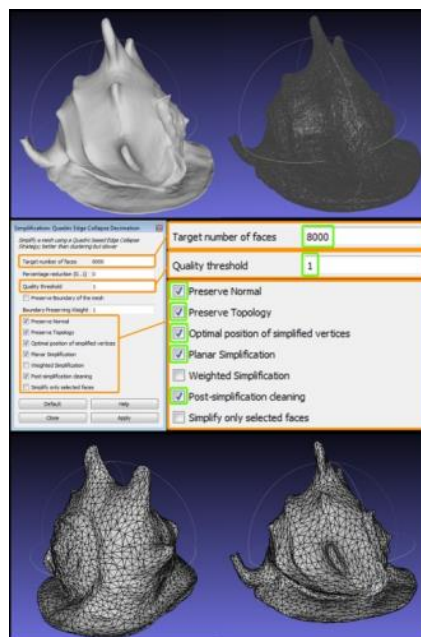


Figure 72. MeshLab. A 3D model of shell. **Top images** – a high-resolution model. **Top right image** shows the density of the mesh. Mesh polycount is approximately 1 M polygons. The **middle images** show the settings of *Quadratic Edge Collapse Decimation* applied to the high-polygonal shell mesh. **Bottom images** show the outcome of simplification. 8000 polygons are holding the shape of the low-resolution model.

After the polygonal reduction, if done in external software, the model can be imported back to the photogrammetry software for further workflow steps. It is important to note that it is safest to import the model into a copy of the original project, so that the high-resolution data is not lost.

Advanced Workflow

The manual workflow is usually applied to have full control over the polygonal count and distribution to make sure the highest level of optimisation is performed for a particular project. This is important when the final optimised model, first of all, is of large polygonal count and scale, and, secondly, when it is going to be used in a gaming engine or VR experience. Such a goal applies to the *Edwin Fox Project*, which is why manual optimisation will be demonstrated on one of the parts of the Edwin Fox high-resolution digital model (**Fig. 73**).

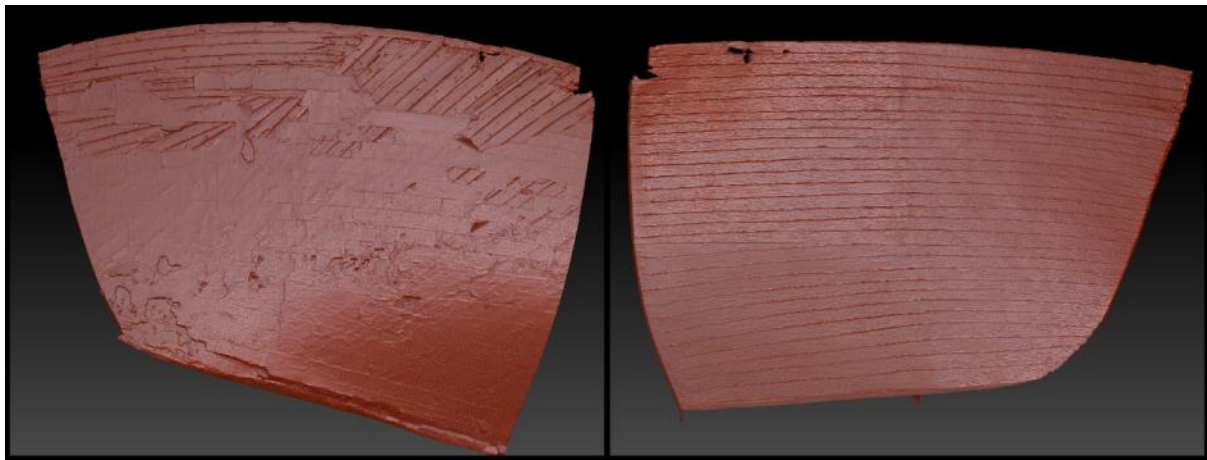


Figure 73. Front left part of the exterior of the Edwin Fox high-resolution model, approximately 17 M polygons. This part is used to demonstrate the optimisation workflow.

Unlike in the **Basic Workflow**, the creation of the low-resolution model in this workflow is manual so that the distribution of polygons can be controlled. The principle behind the distribution of the polygons is assigning more polygons to areas with finer details and fewer polygons to large planar areas. Any 3D modelling software can be used to manually create a low-resolution version of the high-polygonal model. In this workflow, standard modelling techniques are used within Autodesk Maya and demonstrated in detail in **Appendix K**.

5.4.2 Baking and Texturing

Basic Workflow

As the simplified model is imported into the photogrammetry software, the texturing process is run to project all the colour information from the image sequence to the new low-polygonal model. Then, this model is exported with the same settings as the high-resolution model to the directory where the high-resolution model was previously exported. Now, the models can go through the baking process, where details from the high-resolution mesh are baked to texture maps that can be applied to the low-resolution mesh to imitate all the details of the high-resolution model.

There is a wide range of software that has the function of baking textures. For the **Basic Workflow** xNormal was applied as a simple, freely available, but very effective tool used by many artists. Baking workflow in xNormal and its results are illustrated in **Appendix L**. With all the final baked maps the low-resolution model can be published online and imported into a gaming engine for further development or VR experiences.

Advanced Workflow

When exporting a model from the photogrammetry software, it has default UVs generated for it. Those UVs are, in simple terms, flattened surfaces of the model. Every textured polygonal model has UVs that are laid out correctly to display 2D texture on the 3D surface of the model. There is a term, 'clean UVs', which is widely used in the digital field, which means UVs that cover a large surface area of mesh, stitching without visual artefacts between patches of UVs (shells) and packed well within the UV space. An example of UVs can be seen in **Figure 74**.

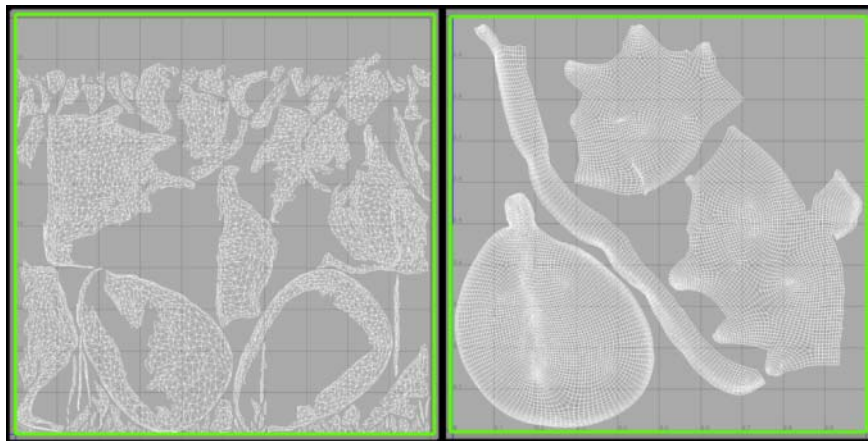


Figure 74. Example of UV layout on the earlier mentioned 3D shell model. The outline in green is 1x1 UV space, where all the UV shells must be laid out without crossing the border. **Left image** is an example of automatically unwrapped UVs. Texture projection on such UVs has a greater chance of showing artefacts and it cannot be easily used in a restoration and de-lighting workflow. **Right image** shows manually produced clean UVs, which are much easier to handle for texturing.

The function of unwrapping UVs exists in many professional 3D modelling software packages. For the **Advanced Workflow**, Headus UV Layout is recommended, as it is specifically designed for laying out UVs and has, arguably, one of the best unwrapping algorithms. The detailed workflow in Headus UV Layout, using the example of the shell model, is demonstrated in **Appendix M**.

The basic approach to texturing and baking in the *Edwin Fox Project* lies in the same fundamental steps of the workflow already described in the **Basic Workflow**. However, the number of artefacts in the colour information of the ship's model required the introduction of a restoration stage into the developed workflow. Substance Painter and Adobe Photoshop were used to manage this colour restoration process.

Substance Painter is a texturing program that has an inbuilt baking function similar to xNormal. Substance Painter works with low-resolution models and was initially created to help with texturing assets for games. As mentioned before, the baking process requires a high-resolution model, its colour texture map and a low-resolution model. The development of the workflow for a

high-resolution model preparation was dictated by the large number of polygons, which prevented the creation of any manageable topology or UVs without losing the restored details. The original UVs that were created in RealityCapture were lost through the restoration process while using *DynaMesh* in ZBrush. All meshes that are in *DynaMesh* mode do not have UVs as this function was not made to work with them, so the exported colour textures from RealityCapture cannot be mapped on the restored model. However, a manageable workaround, illustrated in **Appendix N**, can be delivered with combination of Zbrush and Substance Painter tools in order to bake a colour texture map to the previously modelled low-resolution mesh.

Before baking takes place, the low-resolution model is prepared by dividing it into sections so that each section has its own high-resolution map. This is done so that the overall quality of the final colour texture of that part allows for close-up views of all the details captured on the photographs used for photogrammetry. Such an approach allows for transparency in the workflow, thus continuing with the maintenance of a high level of authenticity. Each part is assigned 4K resolution maps, which is an appropriate value for a close inspection of each part on a 2K resolution monitor.

With already laid out UVs, all four sections are imported into Autodesk Maya, where UVs can be distributed and materials assigned for providing an ID to polygons, so that Substance Painter can separate each UV set for baking and texturing purposes (**Fig. 75**). All four sections are selected and exported as one model in .FBX format from Maya and imported into Substance Painter for baking and texturing workflow presented in detail in **Appendix O**.

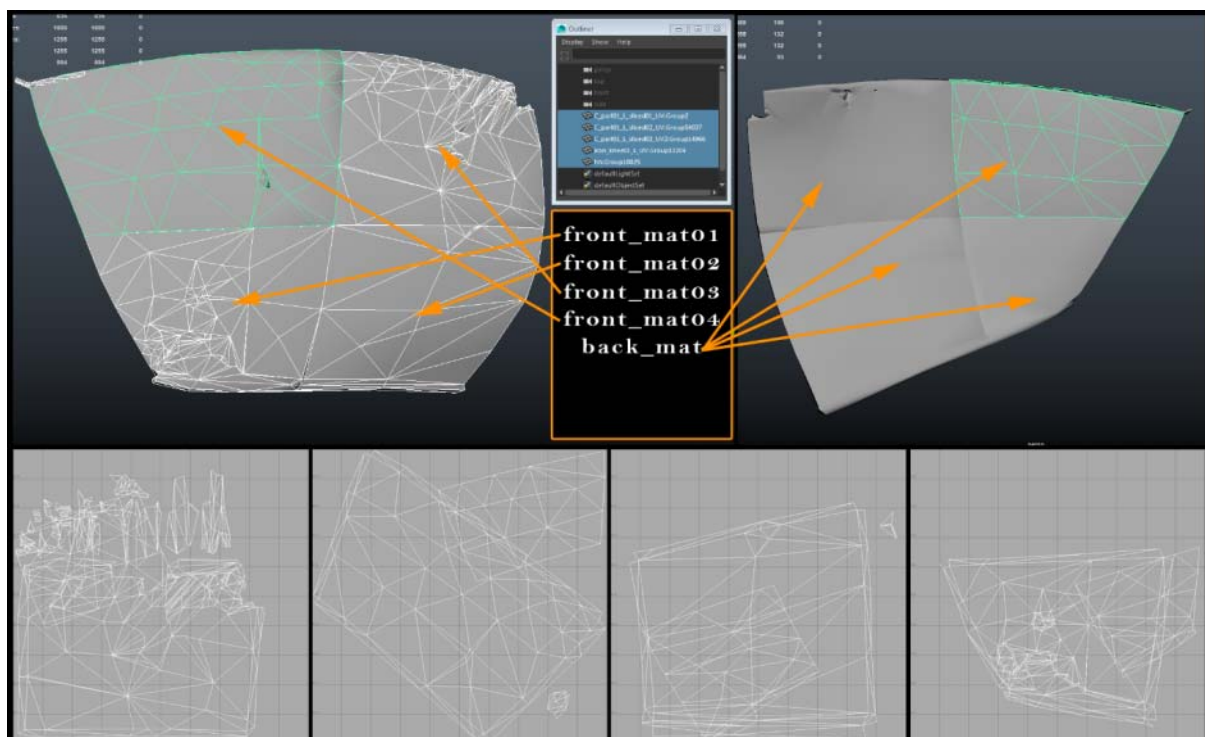


Figure 75. *Maya*. Each part is assigned its material. The back faces of each part, however, are assigned common material that will have an overall resolution of 4K because they do not need as much resolution as they are mostly covered by interior parts. **Bottom images** depict the UVs. The overlaying UVs of the back faces will be translated into different UV space as per assigned material. The empty UV space will be used for laying out the UVs of the iron knees as soon as they are restored.

When the restored colour texture was inspected in a gaming engine in extreme close up, subjectively, the texture quality was not satisfactory. The goal in this project was to preserve as much detail as possible in geometry and texture for an accurate digital representation of the physical ship so that an authentic representation of the original could be achieved. That is why original 4K resolution photogrammetry photographs were used to manually re-project all the details on top of the restored texture (**Fig. 76**). In addition to that, 8K photographs of the ship's texture that had been preliminarily taken on site were used for patching badly captured or missing colour data (**Fig. 77**).



Figure 76. An example of the original 4K photographs from the photogrammetry sequence that were used for projection on top of the restored map to up-res the final colour texture.

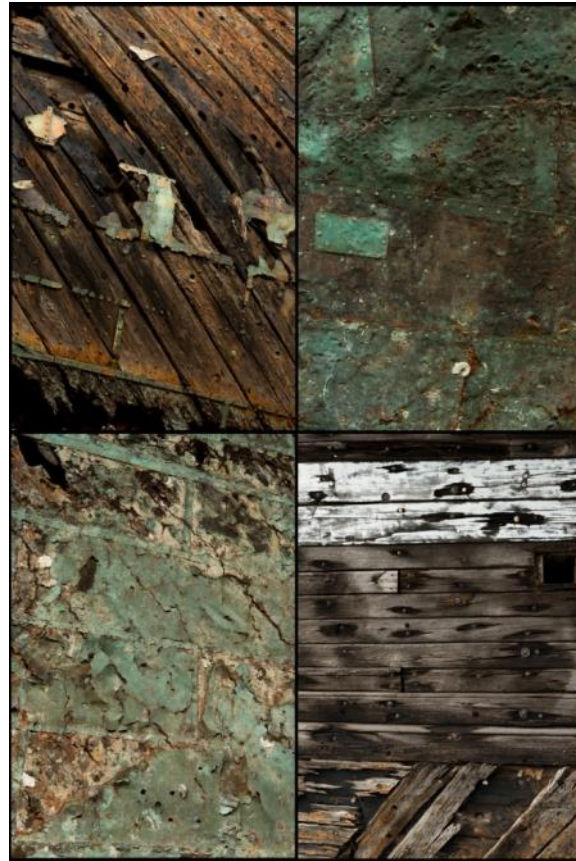


Figure 77. An example of the 'patch' images that were used during the up-resing workflow for the colour texture.

The process of improving (up-resing) colour maps was done in Adobe Photoshop using the *Warp Tool* for establishing the general position of a high-resolution texture and the *Liquefy Tool* for adjusting separate details. The previously restored texture was used as a reference for the photograph positioning. In some cases, the *Puppet Warp Tool* was used to pin down particular reference points while matching the textures (Fig. 78).



Figure 78. Adobe Photoshop. *Puppet Warp Tool* is used for manipulating a photograph to match it with the texture. The photograph is positioned on the top layer with *Opacity* set to 40%.

The final high-resolution texture went through a de-lighting process using *High Pass Filter*. The final results can be seen in Figure 79. A close view of the colour textures can be seen in Figure 80, where the resolution of the first restored texture is compared with the final one.

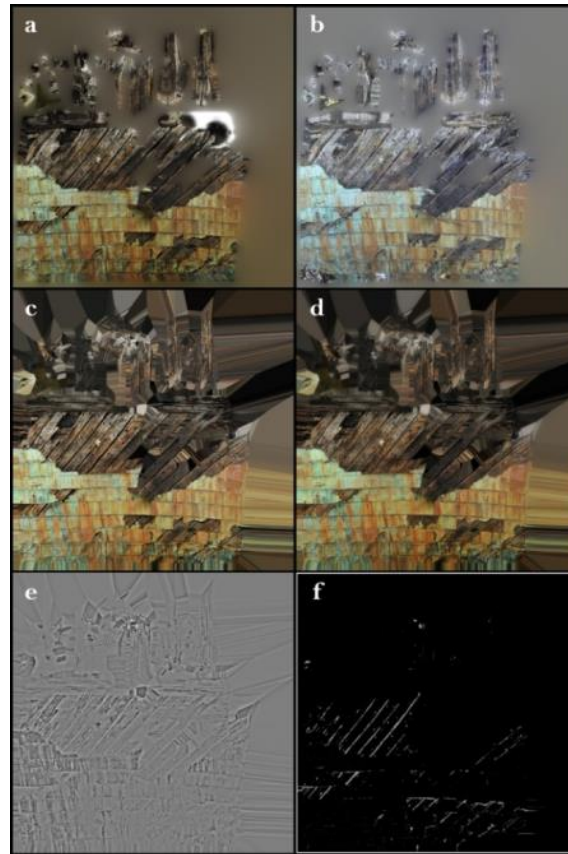


Figure 79. An example of one of the five colour textures applied to the exterior front section that went through the cleaning and restoration process. **a, b** – two colour maps – one from the original model and the other from the patch for the front part, which were used during the restoration process; **c** – high-resolution restored map; **d** – high-resolution restored map after the de-lighting process; **e** – high pass filter map for controlling highlights, **f** - high pass filter map with levels adjustments for controlling deep shadows. If there are many sharp visible shadows, it is best to use a de-lighting process, which is done using a chrome ball.

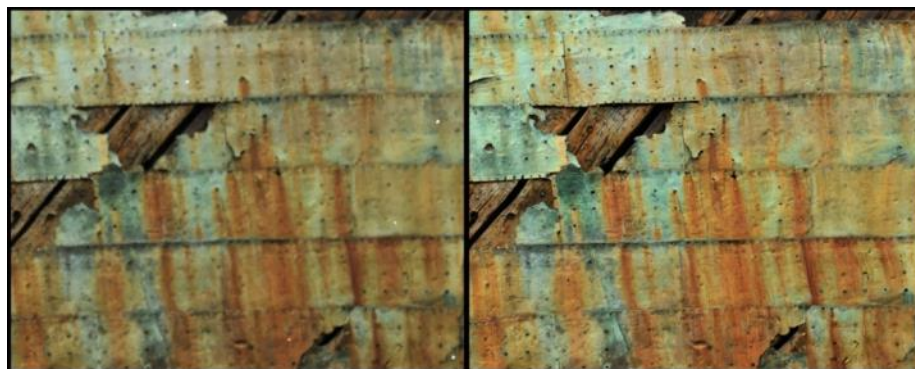


Figure 80. A close-up comparison between the first restored colour map texture and the final colour map that went through up-resing before the de-lighting process. **Left** – restored texture acquired from photogrammetry software; **right** – final colour map created through manual texture projection.

All five colour maps for the exterior front section went through the described texture restoration process. The interior part needed much more restoration work, as there was almost no colour information due to lighting issues described earlier in the thesis. Based on the final colour maps, Roughness maps were created in Adobe Photoshop in a same way as presented in the **Basic Workflow** (Fig. 81).



Figure 81. *Substance Painter*. Optimised exterior parts with the final high-resolution texture maps applied.

5.4.3 Optimisation for Multi-Purpose Use: Summary

While generating a point cloud and a clean high-resolution model could be satisfactory for the preservation purposes, today's demand for online presence requires an effective optimisation workflow to deliver a digital copy of a heritage artefact for public use. The developed and detailed optimisation workflow presented in this thesis uses some of the common and freely accessible tools available today for optimising a high-resolution model and texturing it for final integration into a gaming engine or online 3D viewer.

While the fidelity of the object's details is not influenced by the optimisation workflow when performing polycount reduction due to the texture baking process, which transfers all the high-resolution details through texture maps, the quality of the colour information that impacts on the perception of the object's authenticity is a prime focus here. The texturing workflow presented in this subsection has illustrated a variety of approaches, ranging from automatic texture projection in photogrammetry software, to cleaning and restoration processes and manual up-resing of the final colour maps. For the *Edwin Fox Project*, these techniques were used in combination to make sure that the final result delivers the highest level of authenticity possible for the optimised digital copy.

5.5 Online Presentation and Export for a Gaming Engine

There is a wide range of possibilities where an optimised model can be applied. In this thesis the commonly used tool for online presentation or further interactive development is illustrated.

Basic Workflow

In the **Basic Workflow** a publishing process in Sketchfab is demonstrated using the example of a shell. Sketchfab is a free service for uploading and previewing 3D content, and is widely used by digital artists. There is an extensive range of 3D content gathered on this online platform, including digitalised artefacts from museums around the world. To make the digital copy available online, an optimised low-resolution model of the artefact and all the baked maps must be uploaded onto the Sketchfab account. The detailed set-up in Sketchfab is demonstrated in **Appendix P**. As all the settings are set and saved, the model is online and can be viewed from anywhere in the world. If the model is used in other applications, it will not look identical, but will be very similar because the PBR (Physically Based Rendering) material system is used across different software and platforms. Small visual differences can occur due to the variety of settings and different logic behind the interpretation of the same material properties. The screenshots of the final optimised model uploaded on Sketchfab can be seen in **Figure 82** and can be compared with the screenshots of the same model imported into the gaming engine (**Fig. 83**). The online model can be accessed via <https://sketchfab.com/models/7d420234e7d141edbf2bc0bd2f162f8a>.



Figure 82. Sketchfab. Final shell model.



Figure 83. *Unreal Engine 4*. Final shell model.

Advanced Workflow

The advanced workflow development is determined by the further use of the final model. Currently, the restored parts of the hull of the Edwin Fox are going through the previously described optimisation process to be imported into a gaming engine for creating a VR experience. The basic approach for working with large-scale assets in a gaming engine is modular so that as many details as possible can be preserved during optimisation, and for easier management of the parts in the gaming engine itself (**Fig. 84**).

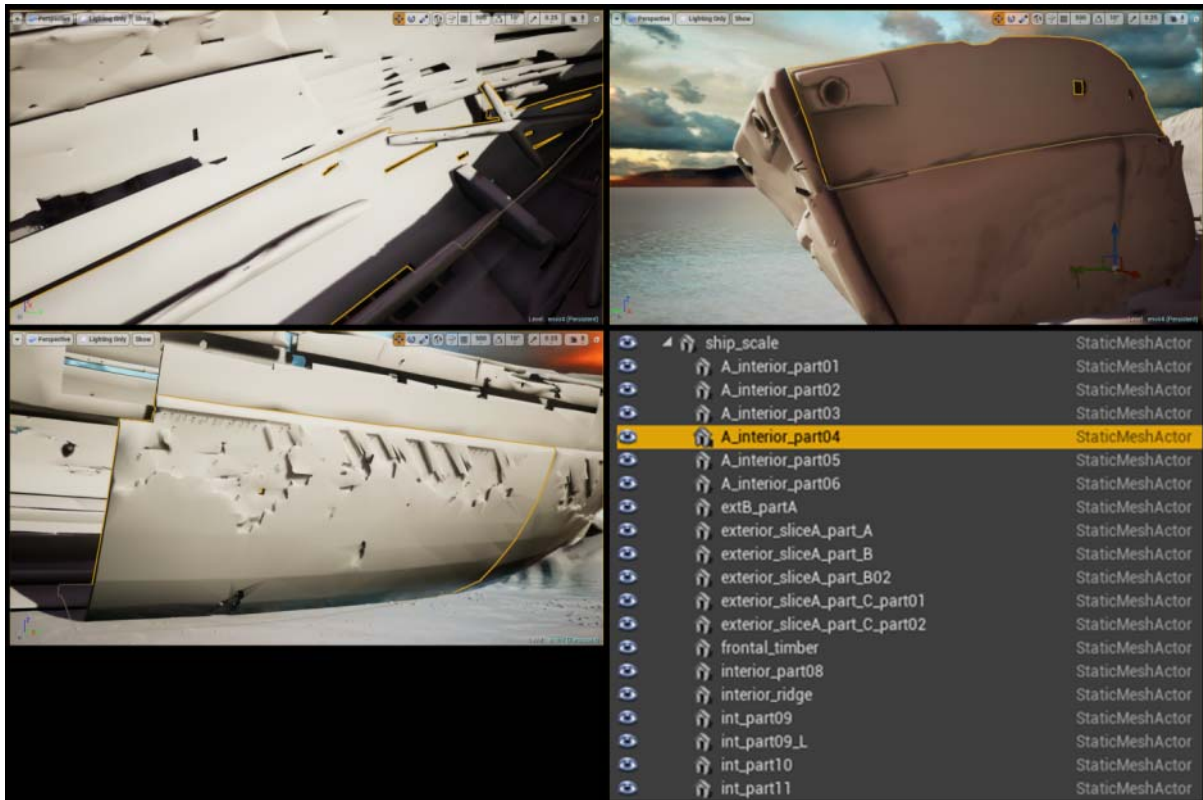


Figure 84. Unreal Engine 4. **Top and bottom left images** – optimised modular parts of the ship. **Bottom right** – 19 parts of the ship shown in the *World Outline*.

The idea behind the modular approach is to cut the final restored model of the hull in such a way that borders between parts are not seen when assembled in a gaming engine. In the Edwin Fox model, the timbers are cut behind the iron knees of the ship, so that when they are restored and put in place, the adjacent borders of the timber are hidden (**Fig. 85**).



Figure 85. A seam that can be seen on the hull model will be concealed by an 'iron knee' model when it is restored and optimised.

As the final optimised model for VR is completed, it will be optimised further to be published for online presentation on Sketchfab using the approach demonstrated in **Appendix P**. The current stage of model optimisation for VR can be seen in **Video 1**.

6. Interview Discussion

The **Workflow Development** section has demonstrated in detail all the processes behind the development of an effective workflow for creating an authentic digital surrogate that can be used in its entirety or in part by museum workers and digital professionals. This detailed approach to the demonstration of the workflow development was not only driven by the desire to provide guidelines for an authentic digitalisation of other heritage artefacts, but also to document empirical provenance of the Edwin Fox digitalisation, so that it can be repeated if necessary. It has been constantly underlined that the direction of the workflow development is imposed by the requirement for maintaining a high level of fidelity to the original artefact so that the final digital surrogate can be considered to be a valid, authentic representation of the physical object.

While the developed workflow requires prolonged user testing in several projects to be refined and adjusted to the specific needs of the scanned artefact, a venture that is beyond the scope of this thesis, the early practical outcomes of the current project were evaluated by conducting short interviews with museum professionals. The purpose of these interviews was to understand how a sample of museum professionals perceived the early outcomes of this project in the context of authentic representation and to confirm or to disprove the suggested hypothesis that transparency in reality-based capturing techniques can provide a similar level of authenticity in the digital copy as in a photograph.

Museums across the world were contacted to gain a variety of opinions from professionals of different levels of expertise and occupational fields, and included maritime historians, maritime archaeologists, museum curators, museum educational directors, shipwrights, and heritage officers. All of the interview participants were chosen randomly within their professional field of heritage preservation and were sent an email containing the three following questions and attached images (**Fig. 86**):

1. In your opinion, would you consider both representations being of a similar level of authenticity?
2. Do you think both a photograph and a digital model are an acceptable representation of the original artefact? If you value one of the two representations over the other, please indicate which one and why.
3. Do you think both a photograph and a digital model are equally suitable for educational purposes? If you prefer one over the other, please indicate which one and why.

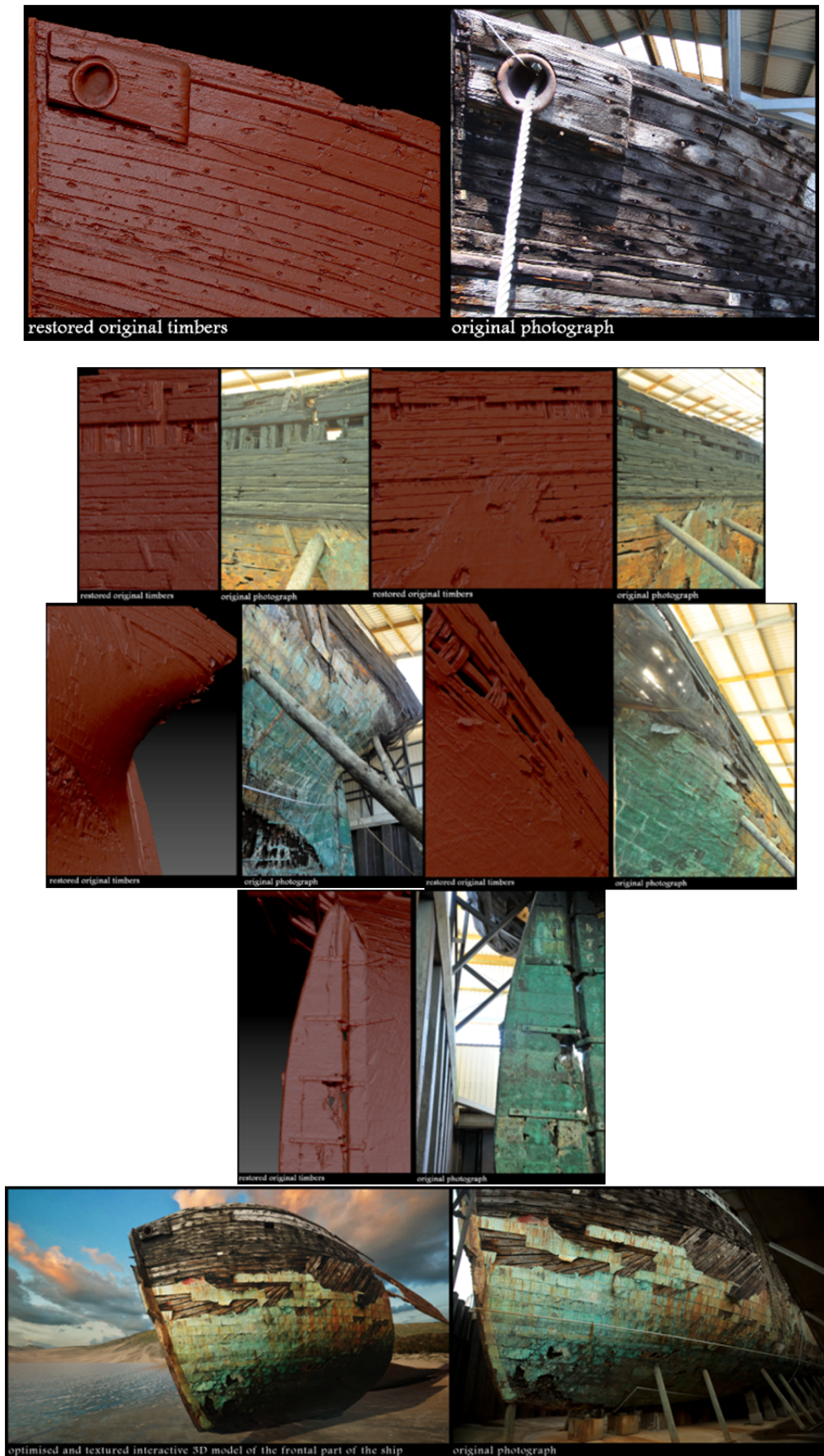


Figure 86. Images attached to the email with the interview questions.

Preceding the interview outcomes, the choice of the attached email representations must be explained. The digital model on the left and the photograph of the artefact on the right are different in their nature in terms of visual representation. The digital model is an interactive 3D representation and the photograph is a 2D capture of the artefact. However, the method of capturing the surface and texture data from the original artefact is, in a way, similar in both representations, as indicated in the **Aura and Digital Media** subsection. Both methods use transparency while handling data, which excludes human bias in interpretation, thus capturing the 'real world' as it is: when taking a photo the data from an original object is transferred via light and recorded to the camera sensor as combination of pixels; when laser scanning the data is transferred via laser beam to the sensor in a form of a point cloud, where each dot has its own coordinate in a 3D digital space.

About 100 requests were sent, and approximately a quarter of the museums responded, with 4 replies stating that the museum did not work with digital models, and therefore lacked the expertise to reply to the questions. The remaining 19 replies indicated that some participants did not fully understand the first two questions due to their limited knowledge of digital 3D scans and digital models. Therefore, a second, clarifying email was sent to explain the capture technology and the nature of the digital model, because creating a digital surrogate for a heritage artefact is a relatively new method of preservation, which employs technologies that might not have been used by most museums yet.

Replies to the first question indicated that twelve of the participants considered both representations to be of a similar level of authenticity, four participants did not consider the digital representation to be authentic because it "would really not be something that 'authenticity' could be ascribed to" and "has no aura/patina" (a reason which is often mentioned by museum professionals and addressed earlier in the thesis). In general, all the replies to the first question can be summarised by the reply of one participant, who stated that:

Of course, it depends on what you mean by authenticity. Both require a level of interpretation and expert knowledge to be able to understand as a representation of the original object. Depending on the viewer's skills, experience and prejudices there may be a preference one way of the other.

This reflects the ideas presented in detail in **Section 3**, and further in **Section 4**, where the concept of *hybrid authenticity* is introduced to be used in the context of digital surrogate creation. But it can also be assumed that a similar level of skill, experience and prejudices is required to conduct curatorial work with historical photographs, not just digital surrogates. Therefore, looking at just the level of perceived authenticity, a careful claim can be made that digital surrogates based on the workflow presented in this thesis can be assumed to be of similar quality to other artefacts traditionally considered "authentic". With this first, positive indicative result, it seems viable to pursue the issue further in future work and conduct a deeper and broader study into the authenticity of digital surrogates obtained from accurate data acquisition methods.

Replying to the second question, seven interviewees indicated that both representations must be used to deliver the best depiction of the physical artefact as "each has own benefits" and "the more the better". Some argued that while a digital copy is a great way to understand the shape and construction of the object, a photograph "may be more familiar to some viewers". Five interviewees stated that they would prefer a digital model over a photographic representation

because it gives “more accuracy depicting dimensions and spatial relationships” and “allows for more adaptability”. An interesting point added by one of the participants was that the un-textured digital model provided an “ease of seeing the timber with all the blemishes removed”. Two participants stated that a photograph is of more value, with one of them explaining that “that is certainly due to my having spent many years poring over photos to try to glean the smallest detail to aid in the restoration process.”

The third question united all the opinions of the participants and responses can be summarised as stating that both representations are very valuable for educational purposes and can be used in conjunction with each other. Some participants indicated that they would prefer using a digital model for education because it “clearly contains more data and can be manipulated in a way that a photograph can’t”, “will capture the imagination more than a flat photograph”, and “photographs don’t necessary fully depict the full scope of the artefact”. In addition to that, some indicate that the printed digital copy would allow students to touch and manipulate it, which cannot be done with a valuable artefact.

To summarise, it seems necessary in future studies to give a more detailed explanation of authenticity as a term, and that participants’ experience with the digital technologies used in the study needs to be considered in selecting the right experts to evaluate the technique. While the results indicate a positive tendency towards the use of new technologies and their perceived authenticity among experts, the outcome depends heavily on the respondent’s experience with contemporary technology. The general tendency shows that participants who have never used laser scanning or photogrammetry in their work or are not familiar with the term prefer using both methods of representation in conjunction. However, people who have used the technology seem to have a good understanding of the process and consider it valuable for preservation purposes. Some of the participants even believed the digital model to be superior to the photograph in terms of authenticity. Most participants, however, believed that a digital model is a valuable tool for educational purposes. The hope of the researcher is that the in-depth documentation of the workflow will encourage more experts to employ modern technology to support their work, which in turn will increase the ability of museum experts to understand the material better and educate them through practice using technology.

This interview was only meant to be a preliminary trial to understand whether it is worth pursuing this technology for digital preservation and further developing a workflow for it. Based on these initial results it is clear that more expert feedback is needed, but the preliminary outcomes show some promise in favour of digital surrogates to provide good educational tools with a high level of authenticity, assuming the process is well understood and explained to the prospective audience.

7. Discussion

7.1 *What has been done? Analysing research*

The recent devastating earthquake in New Zealand, which hit the top of the South Island, created an urge and stimulated the development of a practical workflow that can be used for digital preservation of vulnerable historical treasures around the world. While a wide range of research papers demonstrate a variety of approaches to the digitalisation of heritage sites, many of them either take too general approach to describing their workflow or aim at specialists in a particular digital field. This study presents current research that concentrates on the idea of development of a fast and easy-to-follow workflow for creating authentic digital surrogates so that it can be used by museum workers without prior skills in the digital field. While authenticity is central to the current workflow development, what authenticity is and how it is defined, especially in a digital realm, is extremely ambiguous. Considering the vastness of the notion of authenticity, **Section 3** in this thesis attempted to demonstrate its subjective nature from the most relevant perspectives in the research fields of museum and tourism studies. In this thesis the term 'hybrid authenticity' was proposed to define the approach to this notion and how its principles can be applied in the digital realm to deliver various authentic experiences during further development of the current project.

Constant self-reflection was applied during the advancement of **Section 5**, where the workflow development is presented, which allowed the refinement of techniques that are, subjectively, considered useful during the production of an authentic digital surrogate. To understand whether the developed workflow was successful and worth further development in other heritage preservation projects, a short interview was conducted with museum professionals regarding the level of authenticity of the early outcomes of the developed workflow. The interview results showed a general acceptance of the digital surrogate as an authentic representation of the physical object. However, the final opinions were gained after clarification of the nature of a digital surrogate and the technologies used to capture it, indicating that the majority of museum professionals are not familiar with new technologies and methods of preservation. Some of the opinions demonstrated opposing views on the same question based on personal experience, which underlines the subjective nature of the various meanings assigned to the concept of authenticity. The general outcome of the interview analysis showed that the early result of the developed workflow is a useful tool for education and it is worth pursuing further research on various aspects of authentic representation and its experience within the heritage preservation field.

7.2 *Implementations*

There are numerous implementations in the current research project. First of all, one of the main priorities, which was to de-mystify technology for museum professionals, was achieved by demonstrating a **Basic Workflow** development using various examples of real-life objects that were digitalised in very high resolution. The **Basic Workflow** demonstrated a number of freely accessible tools and easy-to-use techniques that may help museum professionals to digitalise and publish online artefacts in need of digital preservation. The transparency of the image-based capturing techniques, together with the automated processes for generating a model, its texturing and optimisation, presented in the **Basic Workflow**, guarantee a high level of authenticity of the final

outcome. The **Basic Workflow**, however, covers only small and medium-sized objects, because large-scale artefacts are likely to require the involvement of a digital specialist. Current technology does not allow perfect capturing of large-scale complex heritage objects without having artefacts in the shape or texture of a digitalised copy. For that reason, the **Advanced Workflow** using the example of the Edwin Fox was introduced to benefit digital specialists working in the heritage preservation field who might find useful techniques to include in their own workflow routines.

Secondly, there are numerous beneficial outcomes for the Edwin Fox Museum, which allow for documentation, promotion and education about the Edwin Fox around the world as New Zealand's first-class heritage artefact. The availability of more than seven thousand digital photographs and point cloud data ensures digital preservation of the Edwin Fox as a historical heritage artefact. The final high-resolution model of the ship can serve as a tool for scientific enquiries. When fully finished, the optimised model of the ship will be used for creating a VR experience for schoolchildren visiting the museum and for history enthusiasts who want to virtually explore the Edwin Fox. The final optimised model will be also published online for promotional and introductory purposes.

Being not widely known, but an extremely important part of New Zealand's history, the *Edwin Fox Project* and its ongoing promotion may influence Kiwis to learn more about their history and support the Edwin Fox physical restoration, as it requires significant funding to be maintained in its present good condition.

The creation of a high-resolution hull with 79 separate parts involved approximately 45 weeks of cleaning and restoration work, with 2 – 6 working days per part. This work, together with the rest of the cleaned and restored parts, will be donated to the Edwin Fox Museum by the 3D Scans team (all of whom are immigrants) as a sign of their appreciation of New Zealand as a country and its history.

8. Conclusion and Future Work

8.1 Conclusion

From the short interviews conducted with museum professionals, it can be concluded that the early practical outcomes of the developed workflow are able to deliver similar levels of authenticity as photographic representations. While more in-depth research must be conducted in the future, these preliminary results indicate that all the interviewees believed that the presented digital surrogate can serve as a valuable research and educational tool, which indicates that the final workflow developed in this Master's thesis is effective in delivering its objectives.

This thesis extensively illustrated all of the nuances of the workflow development based on the principles of Action Research for digitalising heritage artefacts of any size, guided by theoretical understandings of museum philosophy and the notion of authenticity. The experiments with various small and medium-scale objects that were done before undertaking a large-scale project were visually demonstrated in the **Basic Workflow**. The **Advanced Workflow** illustrated the principles of working with large-scale objects, using the example of the Edwin Fox ship, which was chosen due to its scale and extremely complex shape, allowing the development of a workflow that potentially offers solution for issues that may occur during work on other similar scale projects.

As empirical evidence was one of the requirements for producing a digital surrogate, a thorough documentation of the workflow development was presented in **Section 5** so it can be repeated if necessary. The requirements for authenticity and automation were also fulfilled by using reality-based-capturing techniques such as 3D laser scanning and photogrammetry in order to transfer 'real world' data into the digital realm without human bias. In addition to reality-based techniques, for the Edwin Fox asset a non-destructive manual modelling of surfaces was used during the restoration process. It can be argued that manual modelling techniques are biased; however, all the restoration done for 'smudged' surface details as well as occluded areas was based on photographic references. The results of the restoration are compared to photographs in **Section 5** for evaluation of the quality of the restoration.

The software packages used in the workflow ranged from free, simple tools to professional 3D software and can be chosen according to the level of experience in the digital field. Also, the presented workflow does not tie itself to the demonstrated software, so any other tool made for a required purpose can be used instead. The developed workflows aimed at showing the general principles behind delivering a final, optimised digital copy by using particular examples for easier understanding. It must be noted, however, that the illustrated principles are not set in stone and will be developed further in the spiral fashion characteristic of Action Research, with feedback from museum workers, improvement in computational power, and the emergence of new software.

While small and medium artefacts generally do not tend to be problematic, large-scale objects like the Edwin Fox present a wide range of issues that have to be considered before proceeding with data acquisition. First of all, the budget must be carefully planned for hiring a quite expensive 3D laser scanner device, having at least two experienced photographers on the site, and ensuring the availability of a suitable lighting set-up and personal computer, on which acquired data can go through preliminary testing during capture. Secondly, large complex sites must allow for time

during data acquisition to carefully capture all the areas, and for the cleaning and restoration process, which can take months to accomplish.

From the interview replies, the practical workflow outcomes demonstrated effectiveness in terms of generating visually authentic digital copies. Therefore, it will be further used to generate the rest of the digital copies of the parts of the Edwin Fox, which will be assembled in a gaming engine for a VR project development.

8.2 Future Work

While the main goal of the workflow development was achieved, the practical outcome of this workflow that was planned at the beginning of the project as an optimised digital copy of the Edwin Fox was not fully delivered. This was due to the amount of cleaning and restoration that took place in order to create an authentic high-resolution mesh. Initially, when inspected, the raw models from RealityCapture looked extremely detailed. However, upon closer inspection, small artefacts and noise could be seen in the surface texture. The desire to preserve all the fine details resulted in a laborious cleaning and restoration process, which took much more time and effort than was ever imagined. However, after the completion of this Master's thesis, the *Edwin Fox Project* will continue with the work on finalising the model for an immersive VR experience and online presentation. The future work will mainly be involved with the concept of immersion and the level of auratic experiences that can be achieved when combining elements of object-based and experience-based authenticity in a Virtual Reality environment.

The final vision for the *Edwin Fox Project* is to create a digital visualisation of the Edwin Fox as it looked when it was built. Such a model can also be integrated in VR so that the ship's initial beauty can be experienced and appreciated by today's generation. The availability of two models in VR will foster scientific research on the ship's gradual degradation, timber deformations and other areas of inquiry.

As for the established workflow, it will be refined on future large-scale projects and will be regularly changing, as data capture and visualisation technologies are continually in a dynamic state of development. Additional in-depth user testing by museum professionals will be conducted to further explore the concept of authenticity and its application in an immersive environment that is planned to be created in the future.

Bibliography

- Allen, Peter, Alejandro Troccoli, Benjamin Smith, Ioannis Stamos, and Stephen Murray. "The Beauvais Cathedral Project." In *2003 Conference on Computer Vision and Pattern Recognition Workshop*. Madison, Wisconsin, 16-22 June, 2003. Accessed October 18, 2017. <https://doi.org/10.1109/CVPRW.2003.10004>
- "Aura | Definition of Aura in English by Oxford Dictionaries." Oxford Dictionaries | English. Accessed January 3, 2018. <https://en.oxforddictionaries.com/definition/aura>
- Bai, Yan. "Significance of Originals and Replicas in Archaeological Site Museums with a Case Study of the Han Dynasty Site Museums in China." In *22nd ICOM General Conference*. Shanghai, China, 7-12 November 2010, 6-22. Accessed April 10, 2017. http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf
- Baudrillard, Jean. *Simulacra and Simulation. The Body, in Theory*. Ann Arbor: University of Michigan Press, 1994.
- Beier-de Haan, Rosmarie. "You Can Always Get What You Want. History, the Original, and the Endless Opportunities of the Copy." In *22nd ICOM General Conference*. Shanghai, China, 7-12 November 2010, 1-5. Accessed April 10, 2017. http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf
- Benjamin, Walter. *The Work of Art in the Age of Mechanical Reproduction*. Edited by Hannah Arendt. UCLA School of Theatre, Film and Television: Schocken/Random House, 2005. Accessed August 20, 2017. <https://www.marxists.org/reference/subject/philosophy/works/ge/benjamin.htm>
- Boeykens, Stefan. "Using 3D Design Software, BIM and Game Engines for Architectural Historical Reconstruction." In *Proceedings of the 14th International Conference in Computer Aided Architectural Design Futures*, 493-509, 2011. Accessed March 28, 2017. <https://lirias.kuleuven.be/bitstream/123456789/306891/1/P043-3d-dsgn-bim-game-engine-hist-reconstr-high.pdf>
- Bok, Yunsu, Yekeun Jeong, Dong-Geol Choi, and In So Kweon. "Capturing Village-Level Heritages with a Hand-Held Camera-Laser Fusion Sensor." *International Journal of Computer Vision* 94, no. 1 (August, 2011): 36-53. Accessed October 10, 2017. <https://doi.org/10.1007/s11263-010-0397-8>
- Bolter, Jay David, Blair MacIntyre, Maribeth Gandy, and Petra Schweitzer. "New Media and the Permanent Crisis of Aura." *Convergence* 12, no. 1 (February, 2006): 21-39. Accessed August 20, 2017. <https://doi.org/10.1177/1354856506061550>

- Bowen, Jonathan, Suzanne Keene, and Kia Ng, eds. *Electronic Visualisation in Arts and Culture*. London: Springer-Verlag, 2013.
- Bryce, Derek, Ross Curran, Kevin O’Gorman, and Babak Taheri. “Visitors’ Engagement and Authenticity: Japanese Heritage Consumption.” *Tourism Management* 46, Supplement C (February, 2015): 571–81. Accessed October 12, 2017. <https://doi.org/10.1016/j.tourman.2014.08.012>
- Candy, Linda. “Practice Based Research Guide.” *Scribd*. Accessed May 18, 2016. Accessed May 8, 2017. <https://www.scribd.com/doc/14811777/La-investigacion-basada-en-la-practica>
- Caton, Kellee, and Yaniv Belhassen. “Authenticity Matters.” *Annals of Tourism Research* 33, no 3: 853-856. Accessed January 3, 2018. https://www.academia.edu/13818877/Authenticity_Matters
- CBS/AP. “ISIS Leaves Mosul Museum in Ruins as Iraq Forces Advance.” *CBS News*, March 8, 2017. Accessed December 21, 2017. <https://www.cbsnews.com/news/isis-mosul-museum-ruins-iraq-forces-advance/>
- Chhabra, Deepak. “Positioning Museums on an Authenticity Continuum.” *Annals of Tourism Research* 35, no. 2 (April, 2008): 427–447. <https://doi.org/10.1016/j.annals.2007.12.001>
- Costley, Nigel. *Teak and Tide*. Nelson: Nikau Press, 2014.
- Eco, Umberto. *Faith in Fakes: Essays*. London: Secker and Warburg, 1986.
- FARO Focus x 130 and x 330 Laser Scanners SCENE 5.3 Training Manual. September 2014. Accessed August 5, 2017. <https://www.faro.com/download-center/08m13e19%20-%20SCENE%20v5.3%20-%20FARO%20Focus3D%20Laser%20Scanner%20Training%20Manual%20-%20September%202014.pdf>
- FARO Laser Scanner Focus^{3D} x 130 Manual. February 2015. Accessed August 5, 2017. <https://faro.app.box.com/s/r45cyigengcts8vnh5kawemgsvdft81>
- Fontana, Raffaella, Marinella Greco, Marzia Materazzi, Enrico Pampaloni, Luca Pezzati, Claudio Rocchini, and Roberto Scopigno. “Three-Dimensional Modelling of Statues: The Minerva of Arezzo.” *Journal of Cultural Heritage* 3, no. 4 (October-December 2002): 325–331. Accessed January 18, 2018. [https://doi.org/10.1016/S1296-2074\(02\)01242-6](https://doi.org/10.1016/S1296-2074(02)01242-6)

- Gomes, Leonardo, Olga Bellon, and Luciano Silva. "3D Reconstruction Methods for Digital Preservation of Cultural Heritage: A Survey." *Pattern Recognition Letters* 50 (December, 2014): 3–14. Accessed January 18, 2018.
<https://doi.org/10.1016/j.patrec.2014.03.023>
- Grau, Oliver. *Virtual Art: From Illusion to Immersion*. Leonardo. Cambridge: MIT Press, 2003.
- Gruen, Armin, Fabio Remondino, and Li Zhang. "Photogrammetric Reconstruction of the Great Buddha of Bamiyan, Afghanistan." *The Photogrammetric Record* 19, no. 107 (September, 2004): 177–99. Accessed January 17, 2018.
<https://doi.org/10.1111/j.0031-868X.2004.00278.x>
- "Guidelines for the Preservation of Digital Heritage." United Nations Educational, Scientific and Cultural Organization. National Library of Australia, March, 2003. Accessed May 13, 2017. <http://unesdoc.unesco.org/images/0013/001300/130071e.pdf>
- Hampp, Constanze, Daniela Bauer and Stephan Schwan. "The Role of Authentic Objects in Science Museums." In 22nd *ICOM General Conference*. Shanghai, China, 7-12 November 2010, 68–86. Accessed April 10, 2017.
http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf
- "History of the Edwin Fox." Edwin Fox Society (blog). Accessed December 21, 2017.
<http://www.edwinfoxsociety.com/history/>
- "Home | Rekrei." Accessed December 21, 2017. <https://projectmosul.org/>
- Ikeuchi, Katsushi, Takeshi Oishi, Jun Takamatsu, Ryusuke Sagawa, Atsushi Nakazawa, Ryo Kurazume, Ko Nishino, Mawo Kamakura, and Yasuhide Okamoto. "The Great Buddha Project: Digitally Archiving, Restoring, and Analyzing Cultural Heritage Objects." *International Journal of Computer Vision* 75, no. 1 (October, 2007): 189–208. Accessed October 20, 2017. <https://doi.org/10.1007/s11263-007-0039-y>
- Kolar, Tomaz, and Vesna Zabkar. "A Consumer-Based Model of Authenticity: An Oxymoron or the Foundation of Cultural Heritage Marketing?" *Tourism Management* 31, no. 5 (October, 2010): 652–664. <https://doi.org/10.1016/j.tourman.2009.07.010>
- Kuon, Vannsy. "The Pursuit of Authenticity in Tourist Experiences: The Case of Siem Reap-Angkor, Cambodia." Master's Thesis, Lincoln University, 2011. Accessed October 15, 2017. <https://researcharchive.lincoln.ac.nz/handle/10182/4306>
- Lee, Yi-Ju. "Creating Memorable Experiences in a Reuse Heritage Site." *Annals of Tourism Research* 55, Supplement C (November, 2015): 155–170. Accessed September 17, 2017. <https://doi.org/10.1016/j.annals.2015.09.009>

- Leonardi, Paul M. "Digital Materiality? How Artifacts without Matter, Matter." *First Monday* 15, no. 6 (June, 2010). Accessed February 8, 2018.
<http://journals.uic.edu/ojs/index.php/fm/article/view/3036>
- Levoy, Marc, Kari Pulli, Brian Curless, Szymon Rusinkiewicz, David Koller, Lucas Pereira, and Matt Ginzton. "The Digital Michelangelo Project: 3D Scanning of Large Statues." In *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques*, 131–144. SIGGRAPH '00. New York: ACM Press/Addison-Wesley: 2000. Accessed October 4, 2017. <https://doi.org/10.1145/344779.344849>
- Macdonald, Lindsay, ed. *Digital Heritage: Applying Digital Imaging to Cultural Heritage*. Amsterdam: Elsevier, 2006.
- Markauskaite, Lina, Peter Freebody, and Jude Irwin. *Methodological Choice and Design: Scholarship, Policy and Practice in Social and Educational Research*. Methodos Series: V. 9. London: Springer, 2011.
- Mazarakis-Ainian, Philippos. "Archaeological Copies: A scientific Aid, a Visual Reminder or a Contradiction in Terms?" In *22nd ICOM General Conference*. Shanghai, China, 7-12 November 2010, 118–123. Accessed April 10, 2017.
http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf
- McIntosh, Alison J, and Richard C. Prentice. "Affirming Authenticity: Consuming Cultural Heritage." *Annals of Tourism Research* 26, no. 3 (July, 1999): 589–612. Accessed September 2, 2017. [https://doi.org/10.1016/S0160-7383\(99\)00010-9](https://doi.org/10.1016/S0160-7383(99)00010-9)
- McIntyre, Alice. *Participatory Action Research*. Qualitative Research Methods: 52. Los Angeles: Sage Publications, 2008.
- McMurray, Adela, R. Wayne Pace, and Don Scott. *Research: A Commonsense Approach*. Southbank, VIC: Thomson/Social Science Press, 2004.
- McNiff, Jean, and Jack Whitehead. *Action Research: Principles and Practice*. London; New York: Routledge Falmer, 2002.
- Mudge, Mark and Michael Ashley. "A Digital Future for Cultural Heritage." In *Proceedings of the 21st CIPA Symposium*, Volume XXXVI-5/C53 of ISPRS Archives (October, 2007). Accessed April 15, 2017.
https://www.researchgate.net/publication/239531698_A_DIGITAL_FUTURE_FOR_CULTURAL_HERITAGE
- "Optimization | Definition of Optimization in English by Oxford Dictionaries." Oxford Dictionaries | English. Accessed January 18, 2018.
<https://en.oxforddictionaries.com/definition/optimization>

- Povoledo, Elisabetta. "Quakes Deal Irreparable Blow to Italian Region's Cultura Heritage." *New York Times*, June 2, 2012. Accessed May 8, 2017. <http://www.nytimes.com/2012/06/03/world/europe/italy-assesses-damage-to-cultural-heritage.html>
- Rashid, Ahmed. "After 1,700 Years, Buddhas Fall to Taliban Dynamite." *Telegraph*, March 12, 2001, sec. World. Accessed March 12, 2017. <http://www.telegraph.co.uk/news/worldnews/asia/afghanistan/1326063/After-1700-years-Buddhas-fall-to-Taliban-dynamite.html>
- Reilly, Jill. "Looters ransack Egyptian antiques museum and snatch priceless artefacts as armed police move inside stormed Cairo mosque." *Daily Mail*, August 18, 2013. Accessed May 8, 2017. <http://www.dailymail.co.uk/news/article-2396100/Egypt-Looters-ransack-Egyptian-antiques-museum-snatch-priceless-artefacts.html>
- Reisinger, Yvette, and Carol J. Steiner. "Reconceptualizing Object Authenticity." *Annals of Tourism Research* 33, no. 1 (January, 2006): 65–86. Accessed October 14, 2017. <https://doi.org/10.1016/j.annals.2005.04.003>
- Remondino, Fabio, and Alessandro Rizzi. "Reality-Based 3D Documentation of Natural and Cultural Heritage Sites—Techniques, Problems, and Examples." *Applied Geomatics* 2, no. 3 (September, 2010): 85–100. Accessed October 23, 2017. <https://doi.org/10.1007/s12518-010-0025-x>
- Restauri, Jennifer. "The Potential of Museum Artifacts: Meta-historical Art in the Museum World." In 22nd ICOM General Conference. Shanghai, China, 7-12 November 2010, 87–102. Accessed April 10, 2017. http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf
- Rickly-Boyd, Jillian M. "Authenticity & Aura: A Benjaminian Approach to Tourism." *Annals of Tourism Research* 39, no. 1 (January, 2012): 269–289. Accessed October 15, 2017. <https://doi.org/10.1016/j.annals.2011.05.003>
- Rispa, Adeline. "The Object in History Museums, Mediator for the Invisible." In 22nd ICOM General Conference. Shanghai, China, 7-12 November 2010, 103–117. Accessed April 10, 2017. http://icom.museum/uploads/tx_hpoindexbdd/Actes-Shanghai-complet2.pdf
- Robinson, Andrew. "Walter Benjamin: Art, Aura and Authenticity." *Ceasefire* (blog), June 14, 2013. Accessed June 8, 2017. <https://ceasefiremagazine.co.uk/walter-benjamin-art-aura-authenticity/>

- Russon, Mary-Ann. "Afghanistan: Buddhas of Bamiyan resurrected as laser projections." *International Business Times*, June 12, 2015. Accessed May 8.
<http://www.ibtimes.co.uk/buddha-statues-destroyed-by-taliban-resurrected-laser-projections-1505794>
- Schofield, Tom, Marian Dörk and Martyn Dade-Robertson. "Indexicality and Visualization: Exploring Analogies with Art, Cinema and Photography." In *Proceedings of the 9th ACM Conference on Creativity & Cognition*. 175–184. June, 2013. Accessed April 16, 2017.
<http://mariandoerk.de/papers/cc2013.pdf>
- Shepherd, Robert J. "Why Heidegger Did Not Travel: Existential Angst, Authenticity, and Tourist Experiences." *Annals of Tourism Research* 52, (May, 2015): 60–71. Accessed October 15, 2017. <https://doi.org/10.1016/j.annals.2015.02.018>
- "Ship of Theseus - Oxford Reference." Accessed January 3, 2018.
<http://www.oxfordreference.com/view/10.1093/oi/authority.20110803100502431>
- Stancic, Hrvoje. "Digital Heritage Preservation." Zagreb: Croatian Information Technology Association – GIS Forum, University of Silesia, 2010. Accessed March 28, 2017.
<http://bib.irb.hr/prikazi-rad?rad=480004>
- Stanco, Filippo, Sebastiano Battiato, and Giovanni Gallo. *Digital Imaging for Cultural Heritage Preservation: Analysis, Restoration, and Reconstruction of Ancient Artworks*. New York: CRC Press, 2011.
- Svånå, David. "Environment Re-Creation Methods for Virtual Heritage Using a Game Engine with Discernment of Visual Learning Cues." Master's thesis, Norwegian University of Science and Technology, 2010. Accessed May 23, 2017.
<https://brage.bibsys.no/xmlui/handle/11250/252408>
- Waitt, Gordon. "Consuming Heritage: Perceived Historical Authenticity." *Annals of Tourism Research* 27, no. 4 (October, 2000): 835–862. Accessed October 17, 2017.
[https://doi.org/10.1016/S0160-7383\(99\)00115-2](https://doi.org/10.1016/S0160-7383(99)00115-2)
- Wang, Ning. "Rethinking Authenticity in Tourism Experience." *Annals of Tourism Research* 26, no. 2 (April, 1999): 349–70. Accessed October 10, 2017.
[https://doi.org/10.1016/S0160-7383\(98\)00103-0](https://doi.org/10.1016/S0160-7383(98)00103-0)
- Zhu, Yujie. "Performing Heritage: Rethinking Authenticity in Tourism." *Annals of Tourism Research* 39, no. 3 (July, 2012): 1495–1513. Accessed October 23, 2017.
<https://doi.org/10.1016/j.annals.2012.04.003>

Appendix A

QUESTIONING: What is an effective workflow for creating an authentic 3D digital surrogate of a large-scale heritage object with its further optimisation for online and Virtual Reality (VR) use?

INVESTIGATING & REFLECTING: - Museums and their adaptation to digital age;

- Principles of Heritage Preservation & its digitalisation;
- Concept of authenticity and how it can be applied to a digital surrogate within current project.

DEVELOPING THE PLAN: developing practical workflow based on theoretical discussion:

- Acquiring data with 3D laser scanner & image-based photogrammetry;
- Generating a 3D polygonal mesh (digital surrogate) based on the hybrid concept of authenticity;
- Optimisation of the digital surrogate for various uses such as online interaction and VR experience.

IMPLEMENTING THE PLAN: Testing, experimenting, developing & refining.

QUESTIONING: How can I improve the workflow?

Appendix B

AURATIC EXPERIENCE: Interaction with a digital surrogate may provide an auratic experience through ‘reciprocity of gaze’ and the feeling of ‘distance however close it might be’. Such feelings can encourage the viewer to visit the physical artefact.

OBJECT-BASED AUTHENTICITY (OBJECTIVIST AUTHENTICITY (MUSEUM-LINKED)): The physical artefact as an absolute and objective criterion against which the fidelity of the digital surrogate can be measured. If transparency and immediacy are used as criteria in a digital workflow, a digital surrogate may be considered inherently authentic.

CONSTRUCTIVIST AUTHENTICITY: Objects generally considered as artificial (inauthentic) can become authentic with the passage of time. A digital surrogate can be experienced as authentic not because it is original, but because it is constructed to be perceived as a sign or symbol of authenticity. Such an attitude could guarantee continuity of the physical artefact through new forms of representation, which generate understanding and appreciation of the world of significance, not just limited to the material (physical) embodiment of the artefact.

EXPERIENCE-BASED AUTHENTICITY (POSTMODERNIST AUTHENTICITY (EXISTENTIAL AUTHENTICITY)): While serving as an educational tool, a digital surrogate can provide an emotional experience – a ‘sensory mediation’ – through a feeling of nostalgia, which is a sense of loss associated with the realisation that past cannot be returned. When individuals engage in knowledge learning independently, they experience and enhance their feeling of nostalgia. Such nostalgic experiences provoke the search for intangible aspects of cultural heritage, for identity, meanings and values in life.

Appendix C

DIGITAL SURROGATE DEVELOPEMNT WORKFLOW

DATA AQUISITION: 3D Laser Scanner – FARO^{3D} x 130; Image-based photogrammetry - Nikon D5, Nikon D800, Nikon D7200;

Exposure correction – *Adobe LightRoom*;

DATA ALIGNMENT: Generating Point Cloud Data - *FARO SCENE, RealityCapture*;

RECONSTRUCTION: Generating a raw 3D polygonal mesh – *RealityCapture*;

TEXTURING: Generating a texture image or vertex colour – *RealityCapture*.

GENERATING CLEAN HIGH-RESOLUTION MODEL

CLEAN UP: Removing unnecessary objects scanned together with the artefact – *ZBrush*;

POLYGONAL RESTORATION: Restoring occluded, hidden or distorted areas based on the photographic reference - *ZBrush, Maya*;

TEXTURE RESTORATION: Cleaning up and restoring texture information - *ZBrush, Adobe Photoshop*;

OPTIMISATION WORKFLOW

LOW-RESOLUTION MODEL: Generating a low-resolution model from the cleaned and restored high-resolution model - *ZBrush, Maya*;

BAKING TEXTURES: Laying out UVs for low-resolution model. Generating various texture maps for a photorealistic look of the final 3D model - *Headus UV Layout, Substance Designer, Adobe Photoshop*;

Appendix D. Generating a Polygonal Mesh from a Point Cloud

Basic Workflow

When captured, all the data, in the form of an image sequence, can be imported directly into RealityCapture if it is in .JPEG format (**Fig. D_1**). If the image sequence was acquired in .RAW, it has to be converted into readable form for the software format, which can be done using Adobe Lightroom.

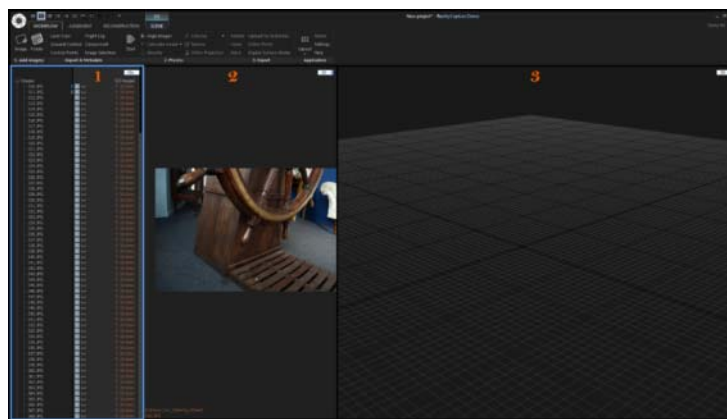


Figure D_1. RealityCapture. Viewport showing three windows: **1** – 1D view, where the imported images of the sequence through the *Folder* icon on top can be seen; **2** – 2D view shows the image when it is selected in the 1D view; **3** – 3D view shows the 3D output after the alignment process.

The process of alignment takes place as soon as images are imported. Alignment helps create a preview of the point cloud allowing the operator to understand whether the mesh of the final output will be calculated properly (**Fig. D_2**). When the point cloud is of satisfactory quality, a polygonal reconstruction can be conducted. If the object is large, first, a *Preview* reconstruction can be done to make sure that the final outcome is of the desired quality. For the final outcome it is recommended to use *High Detail* reconstruction (**Fig. D_3**).

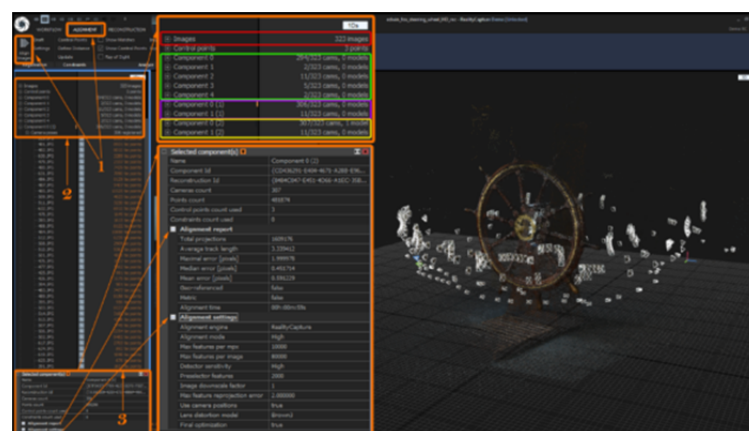


Figure D_2. RealityCapture. **1** – Alignment tab and Alignment button that starts the process; **2** – when alignment is finished a point cloud can be previewed in the 3D window. A tab called *Component* appears after the process in the 1D viewport. After running the first alignment, five components were generated (**outline in light green**). Each component contains a

group of images that were connected together and generated a separate point cloud. It is recommended to delete components with the least number of images and run one more alignment process after the first process to connect all the components in one, which is an ideal outcome. When the second alignment is finished, two components are produced. While the total number of images is 323 (**red outline**), the first component has 306 images and the second component 11 (**purple outline**), resulting in 6 photographs being dismissed by the software. If running alignment more than twice (**yellow outline**) doesn't merge the components into one, they can be combined using control points or deleted if the number of images is insignificant; **3** – the success of the alignment can also be seen in the alignment report and the alignment settings by comparing with the standard values that can be found in the *Help* window of RealityCapture.

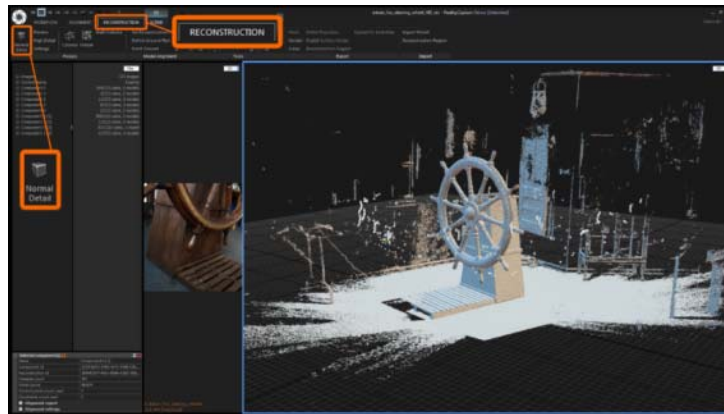


Figure D_3. RealityCapture. A 3D model of a steering wheel after reconstruction process in *High Detail*.

The reconstruction of polygons is a time-consuming process as the software calculates and solves the point cloud data by connecting each point with another one to form a polygonal model. Smaller objects can take up to few hours to be reconstructed, and bigger objects, such as the Edwin Fox, may take more than 24 hours. The speed of the process also depends on the technical specifications of the machine that runs the software. **Figure D_3** shows the reconstruction of the complete point cloud. However, the time for calculating the reconstructed mesh can be reduced by removing unnecessary objects prior to the reconstruction process via the *Set Reconstruction Region* function (**Fig. D_4**).

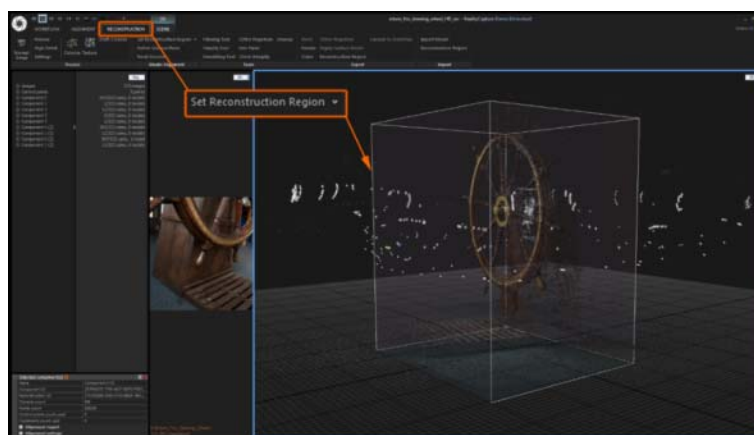


Figure D_4. RealityCapture. A reconstruction region has to be set prior the reconstruction process to remove unnecessary objects.

After the reconstruction, the model can be too large in terms of polycount, which determines the number of triangles that form the surface of the object. On the example of the steering wheel it can be seen that after the reconstruction the model had approximately 131 million triangles, which is a large amount for an average-sized asset. A simplification of the mesh with such

large polygonal counts is recommended for easier management of further work with the digital object (**Fig. D_5**).

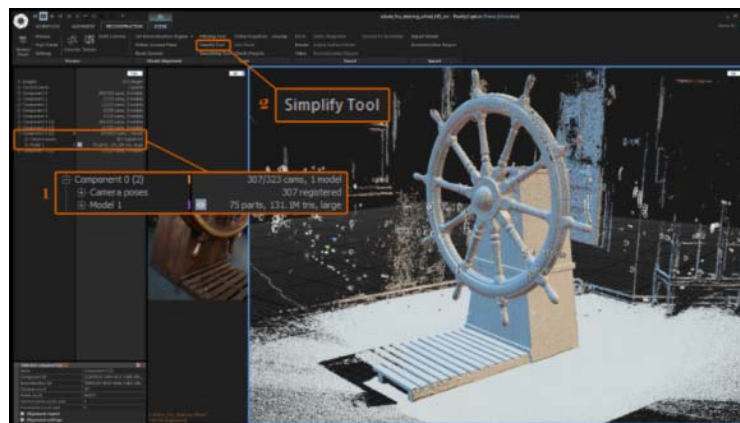


Figure D_5. RealityCapture. **1** – under *Component* can be found a list of images with camera poses that were used for the reconstruction as well as a model that was generated after the reconstruction process; **2** – *Simplify Tool* helps in reducing the triangle count. The desired value can be entered to start the simplification. Generally, the polygonal count depends on the complexity of the target object, but it is recommended to keep it under 10 million triangles for an object of a medium size.

As the desired polygonal count is established, the model can be given its colour using the *Colorize* or *Texture* command. The *Colorize* command assigns a colour to each triangle that makes up the model's surface; therefore, the higher the polycount of the model is, the better the quality of the colour. The *Texture* command does not depend on polygonal count and creates a separate texture file upon export; thus it can be used for cleaning, restoration and delighting if necessary. The *Texture* command is used across all the examples in this thesis (**Fig. D_6**).

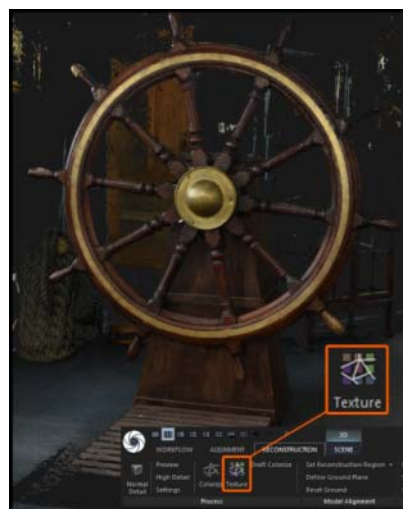


Figure D_6. RealityCapture. A textured 3D model of a steering wheel.

Appendix E. Generating a Polygonal Mesh from a Point Cloud

Advanced Workflow

The **Advanced Workflow** demonstrates, using the example of the Edwin Fox, the integration of the laser scanning information into the **Basic Workflow** that was discussed earlier. Also, more detailed tests with texturing workflow are presented.

When working with laser scanning data in RealityCapture, a specific format, .e57, which can be imported into the software, is used. The final registered point cloud data was generated using SCENE software for both interior and exterior and exported in the required format. When imported into RealityCapture through the *Laser Scan* button, the data is converted into native .lsp format, which can be seen in a form of images in the RealityCapture 2D viewpoint (**Fig. E_1**).

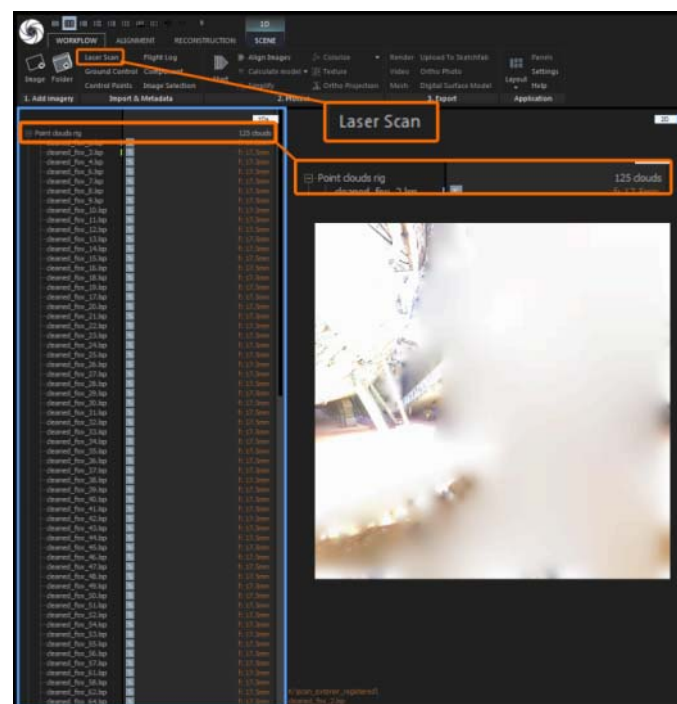


Figure E_1. RealityCapture. A point cloud rig is generated, which consists of .lsp files. The total number of files in one rig can be seen next to it.

As soon as the laser scan data is imported, it can be aligned to generate a point cloud preview. Folders with photogrammetry image sequences can be added to the 1D view. When all the desired data is assembled in the 1D view window, the alignment process is run again to combine laser scanner and photogrammetry data. After the desired result of the point cloud is achieved, the reconstruction and texturing process can be performed as described in the **Basic Workflow**. For a large-scale model like the Edwin Fox, it is suggested to reconstruct first in *Normal Detail*, as there might be not enough processing power to generate a mesh in *High Detail*, which may lead to the software not responding or even crashing.

The reconstruction process may seem long, but is quite simple in terms of its workflow. However, when it comes to fine-tuning textures, RealityCapture becomes rather ambiguous regarding its settings. There are few written instructions in the *Help Window* concerning the texturing workflow and clear definitions of terms. Therefore, some tests with different settings are introduced here to gain a clearer understanding of their functions. The experiments were conducted on the 3D model of a steering wheel due to the minimal number of artefacts on its texture, which makes it much easier to visually compare the results of changing the texture settings.

Texturing. To gain maximum benefit from the texturing process, it has to be understood how the asset will be used further in the workflow and what quality and number of textures are required for that purpose. In the case of heritage artefacts, the highest resolution of colour information available in the captured image sequence should be projected onto the reconstructed mesh, thus maintaining transparency in the production of an authentic digital surrogate. This, however, can result in a high number of colour texture maps, which will not be manageable during further workflow development. The quality of the final texture depends on the *Texel Size*; the smaller it is, the crisper is the colour information on the mesh. For effectiveness of the further workflow and maintenance of the highest level of authenticity in the acquired colour information available in the image sequence, a balance between *Texel Size* value and the texture maps count should be achieved.

Before beginning the texturing process the *Unwrap Tool* must be used to determine the layout of the texture based on UVs. The *Unwrap Tool* is located in the *Reconstruction* tab and has four main settings to experiment with in the texturing workflow:

- **Optimal texel size**, which is automatically calculated by the software. Texel size determines the resolution of the texture on a 3D mesh;
- **Maximal texture resolution**, which is the size of texture required to cover the object;
- **Style** with **Maximal textures count**, **Fixed texel size** and **Adaptive texel size** variants of UV unwrapping to choose from;
- **Texel size** that can be manually set up if there is a need for a fixed texel size in textures.

For best results, while experimenting with texture settings, the *Downscale images before texturing factor* in *Colouring/Texturing* tab was set to 1, which meant that software would not be reducing the resolution of images that were going to be used while performing texture projection. The *Texturing* tab and its values, influenced by the *Unwrap Tool*, have seven parameters of interest:

- **Unwrapping style**, which indicates what style in Unwrapping Tool is used;
- **Textures count** indicates how many textures are necessary to cover the model with current settings. This parameter largely depends on texture resolution;
- **Texture resolution**, which is the size of texture required to cover the object;
- **Texture utilization** shows how well UVs are packed into the UV space;
- **Optimal texel size**;
- **Texture quality**, a vague term that is relational rather than definite in terms of quality. If understood correctly, this value represents the relationship between values of **texel size** and optimal **texel size**, where the former is a current value and the latter the highest possible for this mesh;

- **Texel size.**

The texturing test presented below was conducted based on changing the *Style* parameter in the *Unwrap tool*, which pre-sets how the rest of the values are calculated.

Maximal textures count – default settings (Fig. E_2):

The *Maximal texture count* provides the highest number of textures required when Texel size and Texture resolution are assigned their values.

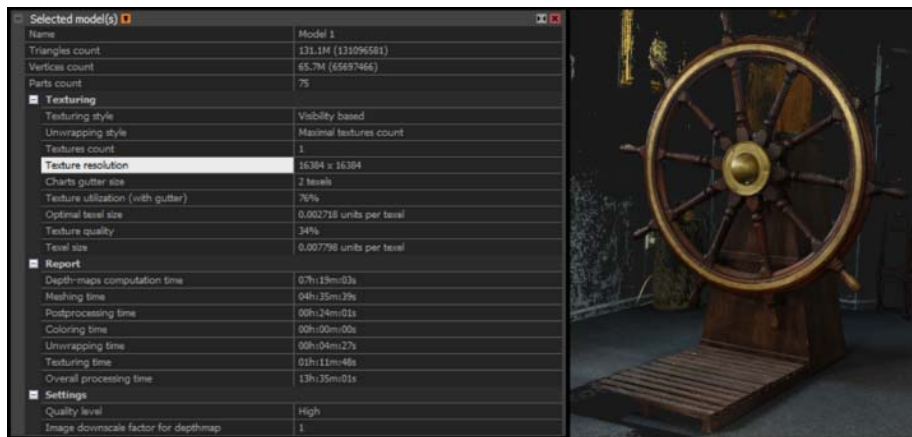


Figure E_2. RealityCapture. Texture before using the *Unwrap Tool* with original triangle count and the default texturing settings with highest texture resolution of 16384x16384.

Before using the *Unwrap Tool*, the *Texture utilization* shows 76% and the *Texture quality* shows 34%, which are good results. However, large resolution maps like 16K and 8K tend to leave large amounts of texture space without UVs, causing the Texture utilization percentage to drop (Fig. E_3).

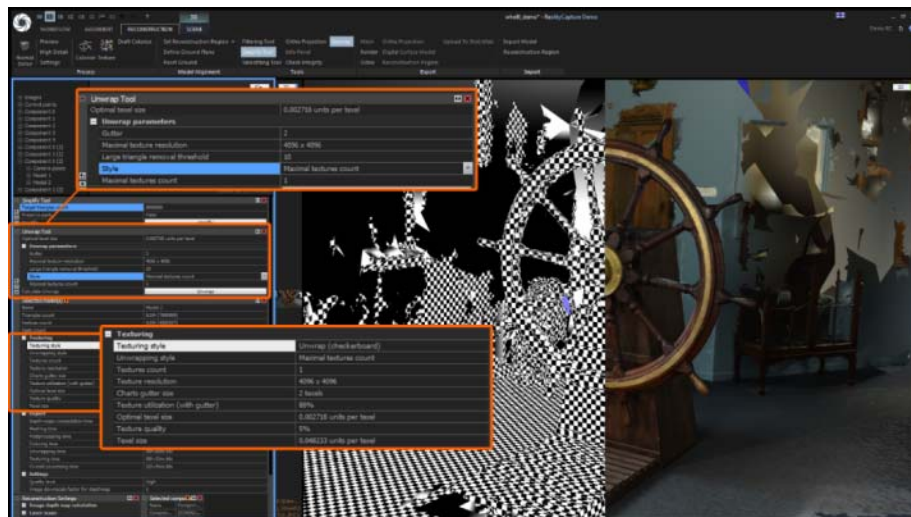


Figure E_3. RealityCapture. Changing the *Maximal texture resolution* in the *Unwrap Tool* gives better value for *Texture utilization*; however, the *Texture quality* percentage drops down to 5%, which still shows a very good result in the viewport. Note here that the *Texel size* value is further from the *Optimal texel size* when compared to the default settings in Figure E_2, which is why *Texture quality* in this example is lower than in the previous. The outcome of this texturing will be one 4K map with 88% *Texture utilization* and 0.048233 texel size.

Adaptive texel size:

If understood correctly, the *Adaptive texel* size helps define texel size based on camera positions from the image sequence. Using the example of the steering wheel, the *Minimal required texel size* parameter will receive those areas that are constructed from the close-up shots in the sequence as they are positioned closer to the target object. The *Maximal required texel size* will be assigned to areas further from the target object, such as walls and the floor. This could be useful when the final outcome will have its target object as a 'hero object' and the rest of the environment surrounding it will not be seen closely (**Fig. E_4**).

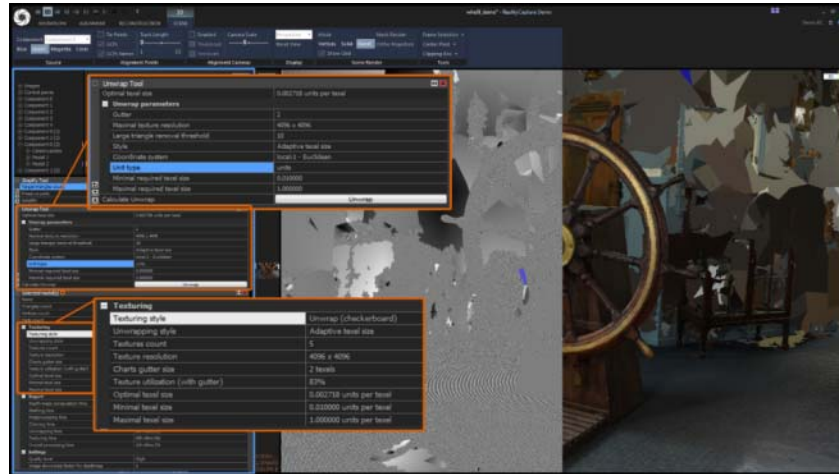


Figure E_4. RealityCapture. Adaptive texel size unwrapping style gave five 4K textures with 83% Texture utilization and 0.01 Minimal texel size and 1 Maximal.

When comparing the two unwrapping styles mentioned above, it seems unusual that while the second method generated maps with higher specifications, in the 3D viewport the texture looks too noisy in comparison with the *Maximal textures count* unwrapping style in **Figure E_3**.

Fixed texel size:

The third unwrapping style, *Fixed texel size*, should be used when a specific texel size must be assigned to textures (**Fig. E_5**).

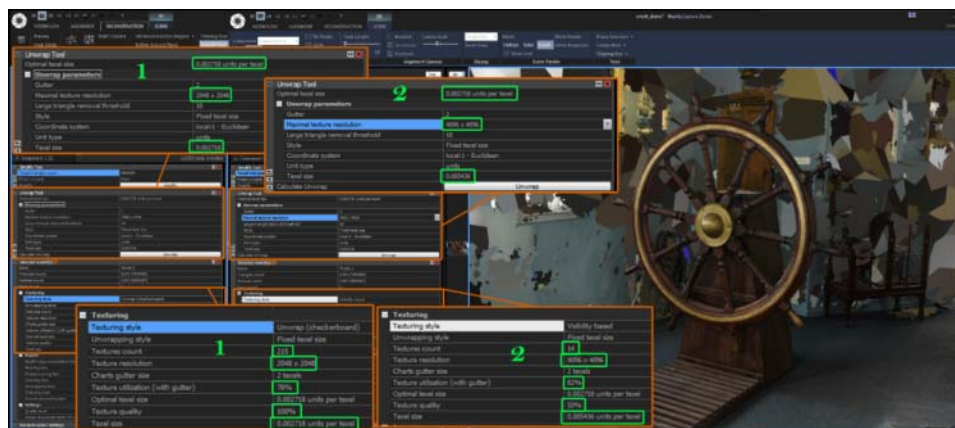


Figure E_5. RealityCapture. When using Fixed texel size, a particular value for the Texel size can be assigned. 1- if the same value of Optimal texel size is assigned to Texel size, the generated texture is theoretically of the highest quality, which can be seen under Texture quality as 100%. A 2K value of Maximal texture resolution was assigned, producing 215 textures in

Texture count, which is an extremely large number, not manageable in an every-day workflow. **2** – in this test a double value of *Optimal texel size* was assigned to *Texel size*, which resulted in a *Texture quality* of 50%. Also, *Maximal texture resolution* was increased to 4K map, generating 14 maps in the *Textures count*, which is much more manageable than the 215 textures produced during the first test.

When comparing all three results from the tests illustrated above, the *Maximal textures count style* of unwrapping seems to produce the best visual results. However, a comparison of numbers shows that the second test with the *Fixed texel size style* seems to produce a balanced compromise between *Texture resolution*, *Textures count*, *Texture utilization*, *Texture quality* and *Texel size* (Fig. E_6).

Values	Default (without using Unwrap Tool)	Maximal textures count	Adaptive texel size	Fixed texel size (test 1)	Fixed texel size (test 2)
Texture resolution	16Kx16K	4Kx4K	4Kx4K	2Kx2K	4Kx4K
Texture count	1	1	5	215	14
Texture utilization	76	88	83	78	82
Texture quality	34	5	n/a	100	50
Texel size	0.007798	0.048233	0.01-1	0.002718	0.005436

Figure E_6. From all the presented results, approximate averages are shown in red, which are values from the *Default texturing* and when using the *Unwrap Tool* with *Fixed texel size (test 2)*. When comparing all the values, the latter seems to be the most balanced in terms of quality and manageability. The two last values in the *Fixed texel size (test two)* are of higher quality than *Default texturing*, so the last test would have been used for producing the final textures.

While visually comparing the results of the *Maximal textures count style* and the second test of the *Fixed texel size style*, it must be noted that the difference in the texture of the target object was only slightly better in *Maximal textures count style* and could be noticed only in close up views. Considering such a small visual difference between the two and the numerical advantage, the *Fixed texel size (test 2)* method of texturing would be used as a foundation to generate final textures. It must be emphasised, however, that these tests were conducted to give an introduction to values and how they are related, so that they can be tweaked according to the needs of a particular project, because the best solution for the texturing of the steering wheel might not be acceptable for another object.

Concerning the *Edwin Fox Project*, *Default texturing* with 2 highest resolution maps of 16K was used. This is due to the fact that experiments with different styles in the *Unwrap Tool* could not be successfully conducted due to the enormous size of the model (376 M tris), which caused software to crash during the unwrapping process. Specifications for the final polygonal models of the exterior and interior that are ready to be exported can be seen in **Figure E_7** and **Figure E_8**.

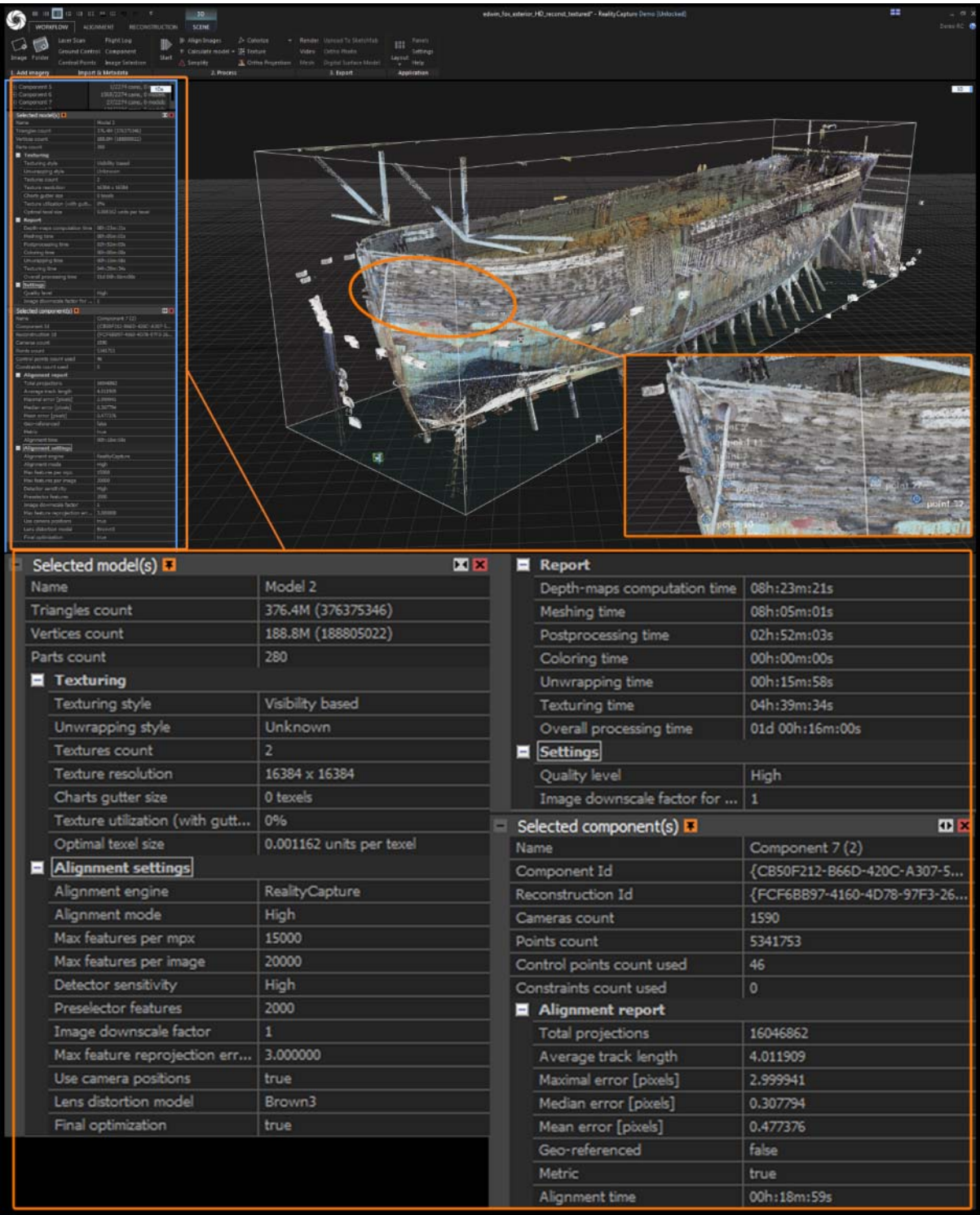


Figure E_7. RealityCapture. Final settings before exporting the exterior model of the ship. The majority of the mentioned techniques, illustrated in the *Basic Workflow*, were used during the production of the exterior polygonal model. Control points for connecting components of the front section to the main part of the ship and the *Reconstruction region box* were the ones among them.

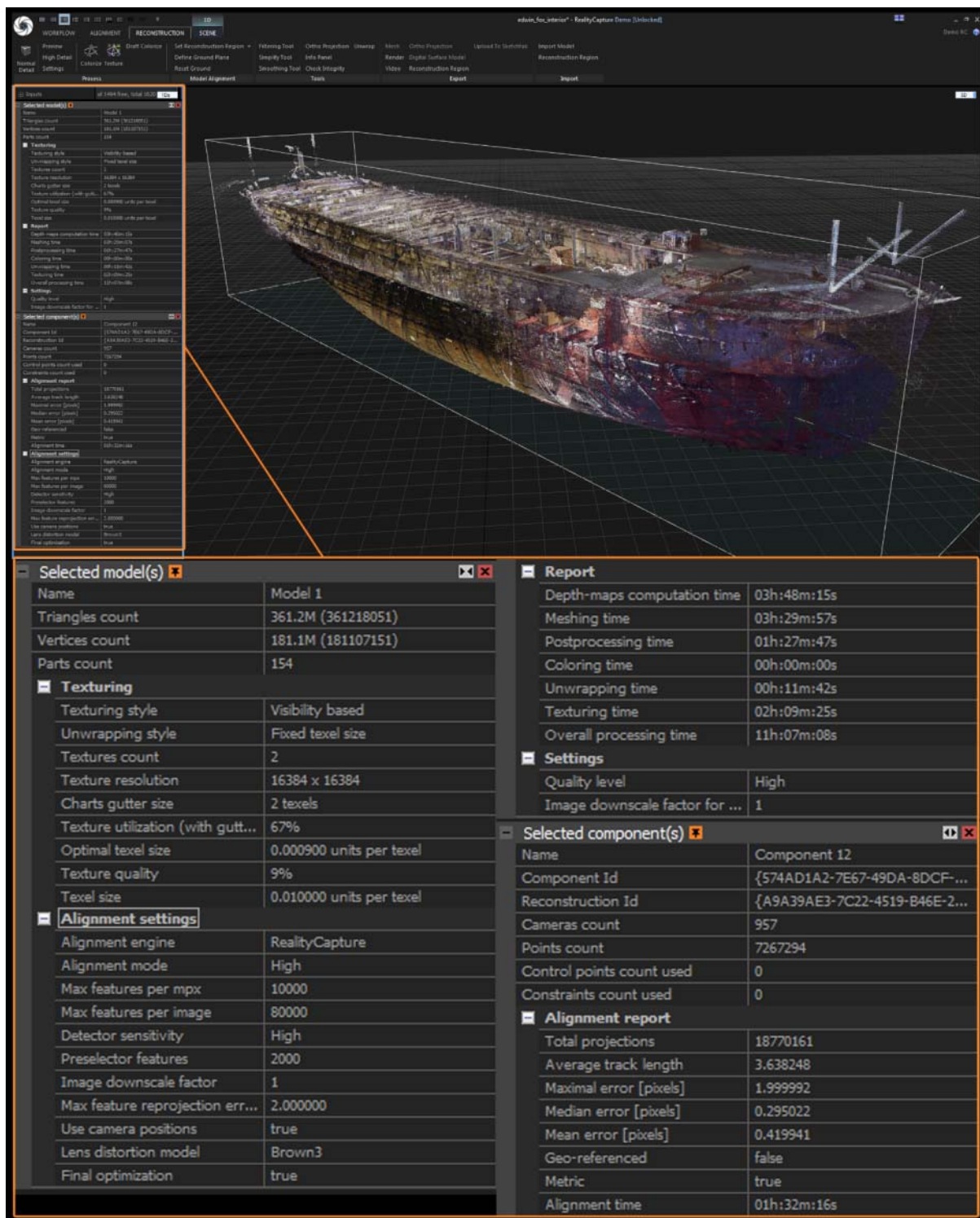


Figure E_8. RealityCapture. Final settings before exporting the interior model of the ship.

Appendix F. Exporting a Mesh from Photogrammetry Software

Basic Workflow

For the basic workflow demonstration, an example already illustrated in this thesis (a tree stump captured with a Samsung Note 5) will be used (**Fig. F_1**).

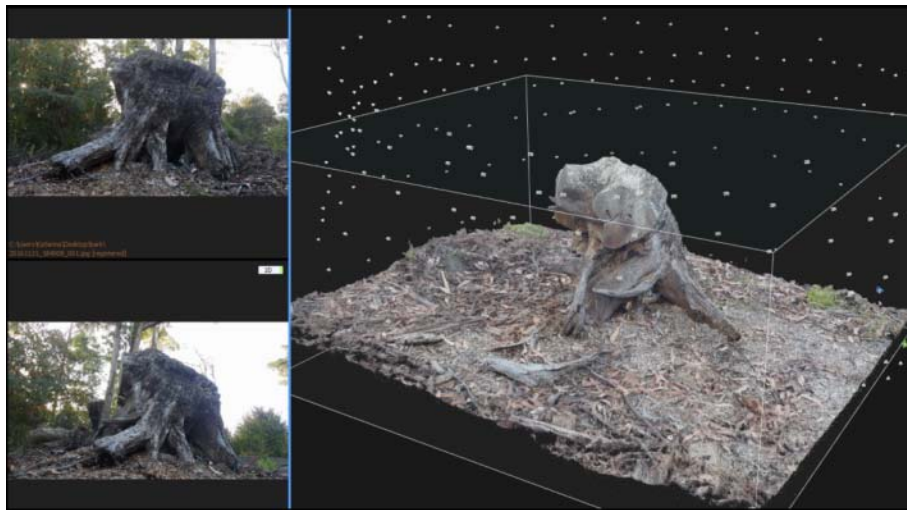


Figure F_1. *RealityCapture*. Reconstructed and textured 3D model of a tree stump. The white graphics around the model represent the camera positions, which used a cylindrical spiral pattern for capturing data. The texturing style used *Default settings* with one 16K resolution map. The original polycount, 57 million triangles, was simplified down to 15 million triangles, which maintained all the visible details in the mesh. There is no particular rule for the optimal value during the simplification process as it must be guided by the complexity of the object's shape. For the basic workflow it is recommended to maintain a limit of 10-15 million triangles.

The reconstructed model is exported through *Mesh* command in the *Export* tab (**Fig. F_2**).

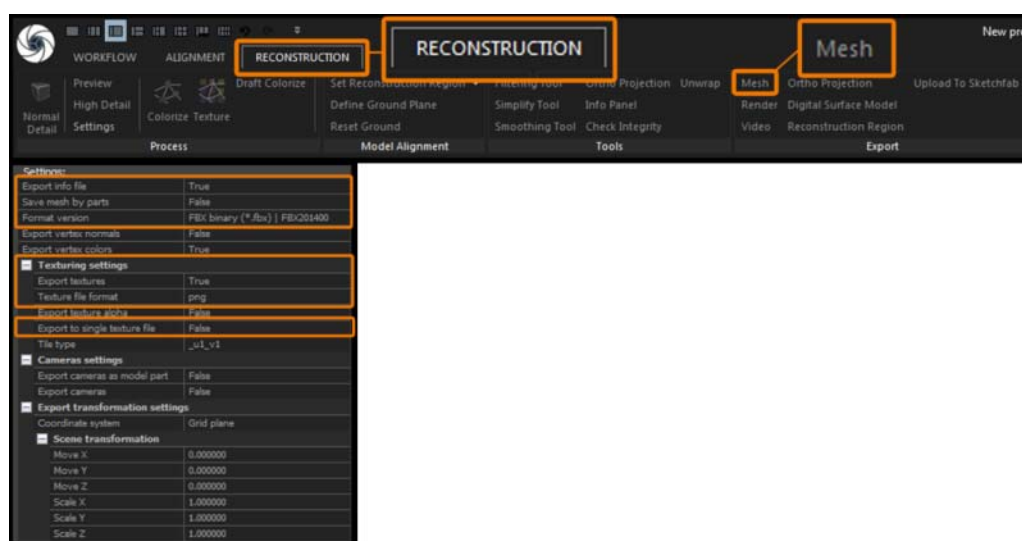


Figure F_2. *RealityCapture*. For the **Basic Workflow** a few values had to be changed in the export window: Export info file – **true**; Save mesh by parts – **false**; Format version – **OBJ** (also commonly used FBX and PLY formats); Export textures – **true**; Texture file format – **PNG** (also JPEG can be used); Export to single texture file – **true**.

Two outputs in the form of a file with the model's shape data and a file with its texture data were produced as an outcome of the export process with the settings presented in **Figure F_2**. The texture data must be inspected to determine whether it has a proper layout and the texture information covers all the available texture space. If the file is of not satisfactory quality, the reconstructed model in RealityCapture has to be re-textured with different settings until the necessary result is achieved (**Fig. F_3**).

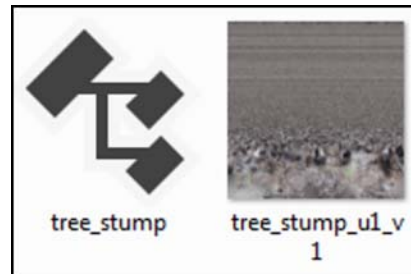


Figure F_3. Two files are the outcomes of the command with settings presented in **Figure F_2**.

Appendix G. Exporting a Mesh from Photogrammetry software

Advanced Workflow

When creating large-scale heritage artefacts, it is important to maintain all the captured information to preserve transparency in the workflow for delivering the highest level of authenticity while producing a digital copy. For this reason, simplification should be used only if it does not influence the visual properties of the object's geometry. For the *Edwin Fox Project*, preservation of 'real-world' details in the captured state was a prime goal for delivering an accurate and authentic digital surrogate, which is why simplification was not used.

The total polygonal count for the exterior and the interior of the ship was 736.6 M triangles with 361.2 M for the interior and 375.4 M for the exterior. There is no known software that is able to manage such polycounts easily outside RealityCapture. For example, the exported mesh of the exterior of the ship resulted in 43.7 GB of data in a single file, which cannot be imported into 3D editing software without crashing it. Fortunately, RealityCapture has the ability to export the final mesh in parts. This feature, mentioned in **Figure F_2**, can be activated by setting the value to 'true'. While this function breaks down the object into parts, there is no opportunity to control this process. For this reason, when the object is exported, those parts have to be viewed in a 3D package in order to be identified. With regard to the texturing, the *Export to single texture file* function should be set to 'false' to export all the texture maps available during the texturing workflow. The final outcome was 280 .OBJ files with mesh information and two 16K texture maps for the exterior and 154 .OBJ files with mesh information and two 16K texture maps for the interior of the ship.

Appendix H. Cleaning and Restoration Workflow

Advanced Workflow

Small and Medium objects (ZBrush Workflow)

Using *Polygroups*, *Masking Tool* and *Decimation Master*, the top mesh of the rock model was cleaned of unnecessary geometry. First, large areas that had to be cleaned out were selected with the *Masking Tool*, *Split* from the main mesh and deleted. The original mesh of the top part had approximately 8 M triangles, which is a large amount for fast workflow management, so *Decimation Master* was used to simplify the mesh down to approximately 2 M triangles. Before decimation, the original mesh was duplicated for later use.

When reconstructing a mesh in a RealityCapture project, small artefacts can appear next to the main mesh. For that reason, *Polygroups* are used to automatically remove those artefacts. First, the *GroupVisible* function should be used to unify all the geometry in one group, then the *AutoGroup* function, which groups mesh triangles into groups as per mesh continuity. With the *SelectRect* brush the main body of the target is selected, making the small artefacts invisible. The invisible geometry can be deleted by *Del Hidden* function in *Modify Topology* tap. Here all the holes in the mesh can be closed using the *Close Holes* function (Fig. H_1).

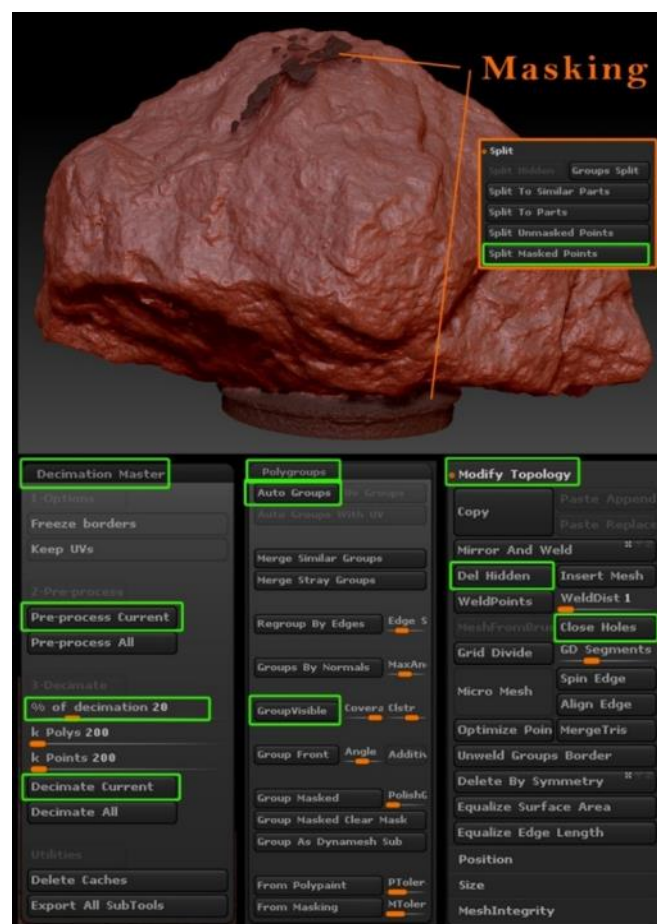


Figure H_1. ZBrush. A cleaning workflow demonstrated on the example of a rock model.

As soon as the mesh is cleaned, all the details that were lost during decimation process can be re-projected onto the fixed mesh from the original. To make sure that the mesh doesn't have any hidden internal geometry, *DynaMesh* is used at a resolution that gives approximately the same polygonal count as the clean mesh. In the example of the rock, a resolution of 995 was the required value. The mesh is subdivided once to get approximately the same polygonal count as the original mesh. Once the cleaned mesh is prepared, the details from the original mesh are projected using *Project All*. The *Dist* value is commonly used to adjust the re-projection distance (**Fig. H_2**).

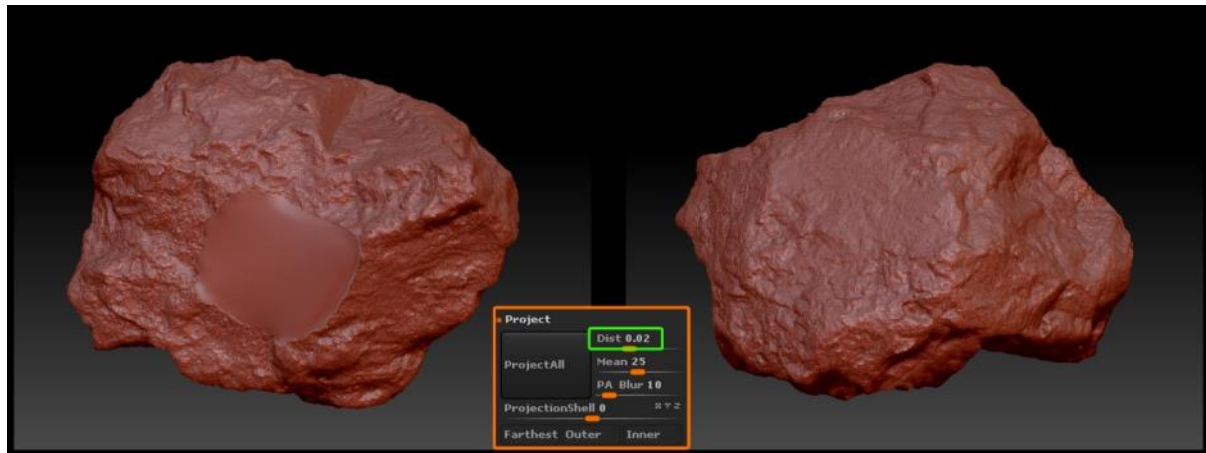


Figure H_2. ZBrush. The results of re-projecting the details from the original to the cleaned mesh.

As soon as the same workflow was applied to the bottom part of the rock, it was imported for restoration into the same project where the cleaned top part was located. The bottom part was transformed to match the top part so that the details of the bottom part could be re-projected onto the top part (**Fig. H_3**). When re-projection was done the remaining artefacts were removed with the restoration process. To achieve accurate results for maintaining a high level of authenticity, the native texture of the rock was used to create an alpha texture for patching the small artefacts (**Fig. H_4, Fig. H_5**).

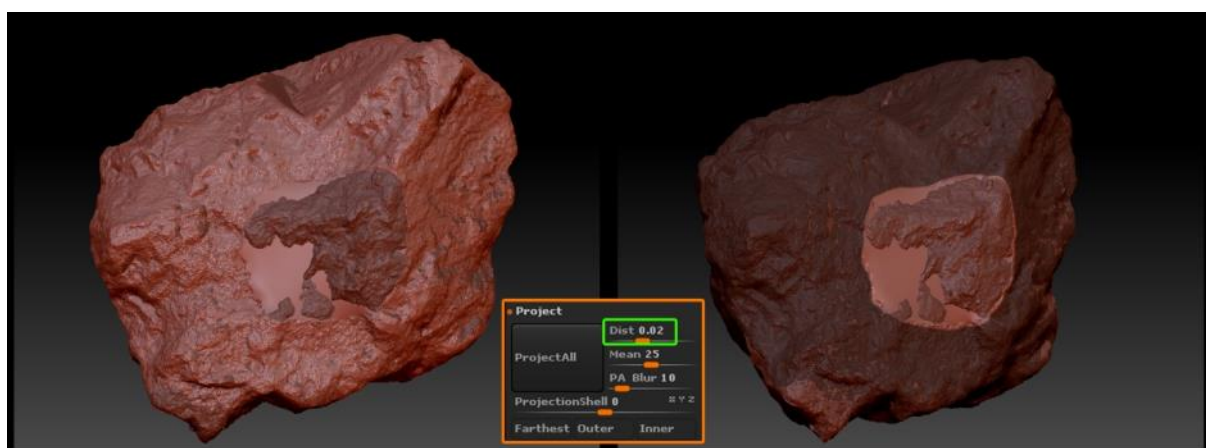


Figure H_3. ZBrush. The bottom part is matched to the top. The top part is masked where the details from the bottom needed to be projected, then inverted to preserve the top details from projection. *ProjectAll* is used to project the details.



Figure H_4. ZBrush. 1 – the model in the viewport is positioned facing the area that will be used to create an alpha with *GrabDoc* function for patching the areas that need restoration; 2 – modifying the grabbed texture in the *Alpha* tab; 3 – the *DragRect* style of stroke is chosen for the restoration workflow.



Figure H_5. ZBrush. Left image – green circles indicate the areas that need to be restored; right image – the final result of restoration.

Appendix I. Restoration Experiment in ZBrush

While experimenting with the front slice of the Edwin Fox to establish the cleaning and restoration workflow, many useful tools were discovered that found their way into the final workflow, including *DynaMesh*. *DynaMesh* is a tool that allows mesh editing with no restriction to topology, which is perfect for a cleaning and restoration workflow. However, during experiments it was found that *DynaMesh* works only on volumetric meshes, so one of the goals of the final workflow included the transformation of the mesh from planar to volumetric. One of the experiments using *DynaMesh* that delivered a successful outcome is demonstrated in **Figure I_1**.

When applying the developed workflow to the next part, it became apparent that the process of creation of the back walls of the planks was too cumbersome and not as fast as it may seem when used on a large number of parts. Therefore, more experiments with various tools were done to find a way of producing a volumetric model from a planar one. In the end, relatively fast results were achieved based on experiments with the *Extract tool*, which became essential in the final workflow.

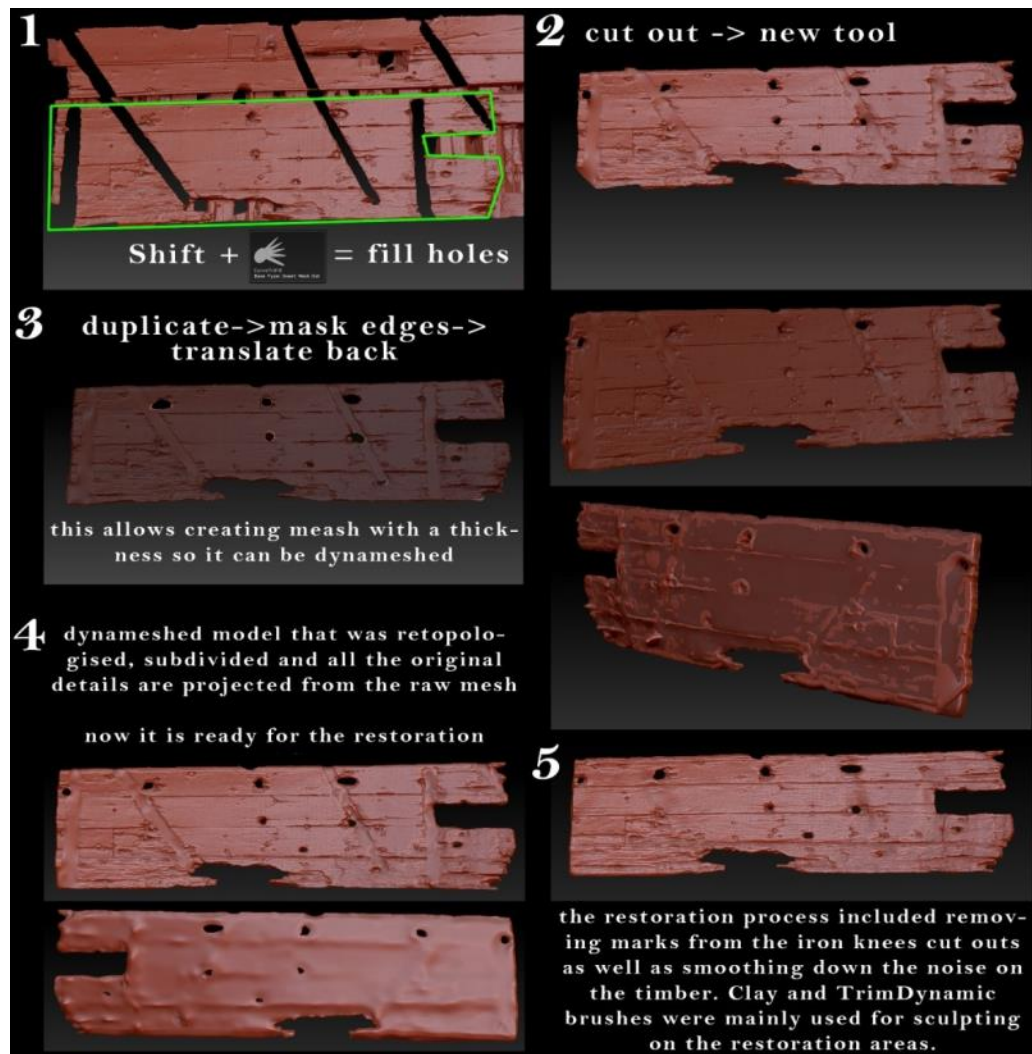


Figure I_1. ZBrush. One of the preliminary experiments in cleaning and restoration workflow that delivered good results and produced basic understandings of what had to be achieved in the final workflow.

Appendix J. Final Cleaning & Restoration Workflow

Advanced Workflow

Large-scale objects (ZBrush Workflow)

Preparation. The final workflow is demonstrated in this thesis via one of the last parts in the back slice of the ship that was restored. This part was cut out from the hull in ZBrush and a new *Tool* was created in the ZBrush project to focus on the cleaning and restoration of this part (**Fig. J_01**).

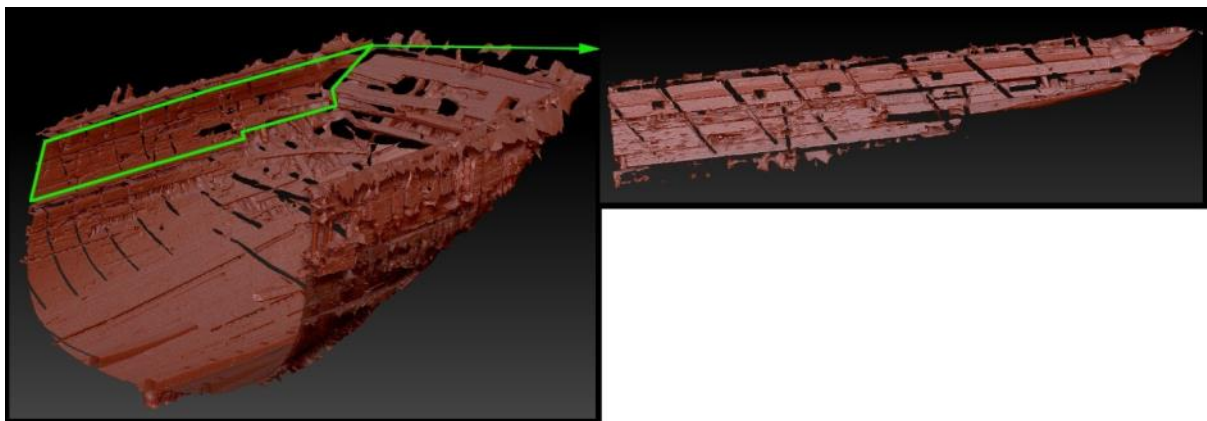


Figure J_01. *ZBrush*. The part is separated from the hull, prepared and saved as a separate *Tool* in ZBrush.

Masking and Separation (Video_2). Using *MaskLasso* in combination with the *MaskPen* brush the planks were masked out from the rest of geometry (**Fig. J_02**). This was done to isolate unnecessary elements and artefacts that were automatically generated where there was no point cloud data available.

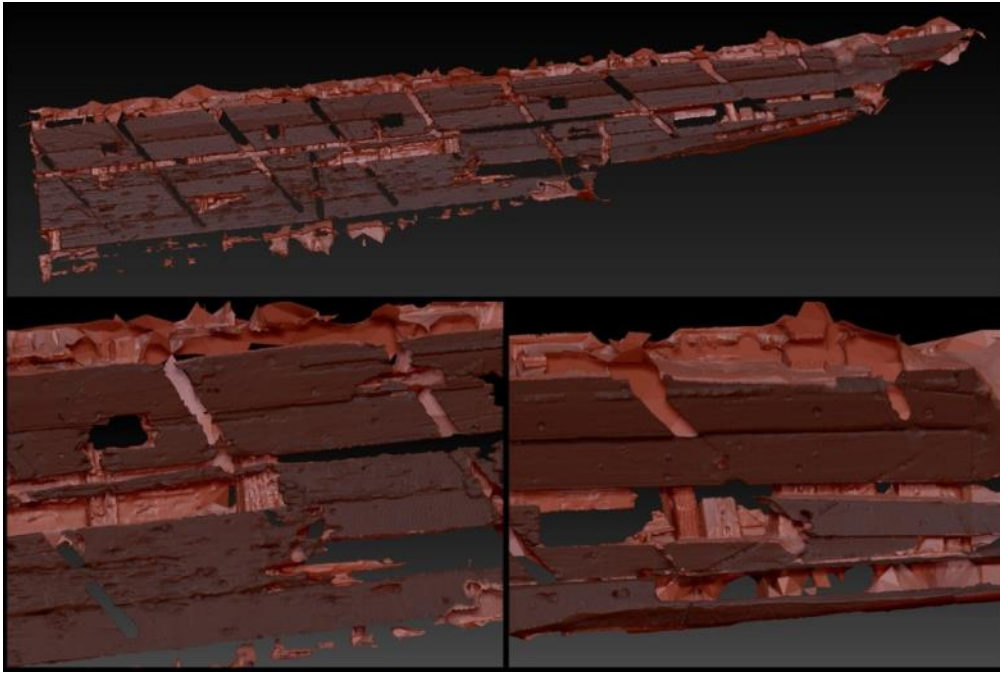


Figure J_02. ZBrush. Top – masked planks; bottom images – close-up of the mask.

Careful masking may take some time; this part required an hour and a half. When the masking process is finished, the parts can be separated via the *Split* function (Fig. J_03). Two *Subtools* were generated after performing a *Split* function – the timber planks and the rest of the geometry. The planks were duplicated to preserve one copy for further use and allow work to continue with the other one. The duplicated planks went through the masking process again to remove all the side planes and leave only the frontal planes of the planks. After performing the *Split* function again, only the flat frontal geometry of the planks remained, which could be used for creating a volumetric mesh via the *Extract Tool* (Fig. J_04). However, before that the holes left by the iron knees removal had to be closed. To close holes and apply the *Extract Tool*, it is recommended to simplify the mesh via *Decimation Master* so that previously mentioned operations can be performed much faster. The decimation percentage depends on the size of the model. For example, the current model of the planks had a 1.35 M polycount, which can be decimated to 200 or 300 thousand polygons for faster performance of functions. The *CurveTriFill* brush in combination with *Shift* was used to close all the holes (Fig. J_05). Before that, though, some holes had to be closed off using the *ZModeler Bridge* function, otherwise the *CurveTriFill* brush could not work (Fig. J_06). When the work with *ZModeler* was finished, all the *Polygroups* had to be grouped via *GroupVisible* function in the *Polygroups Tab* for the *CurveTriFill* brush to be used (Fig. J_07). When filling holes with *CurveTriFill* the *Double geometry* view must be switched off in the *Display Properties Tab* because the brush can flip the geometry around. If that happens, the flipped geometry must be isolated with *SelectRect* brush and conformed with the rest of the geometry by using the *Flip* function in the *Display Properties* (Fig. J_05). If the geometry is not conformed, the extraction process will not give the desired results. Finally, all the *Polygroups* must be grouped via the *GroupVisible* and *WeldPoints* functions in *Modify Topology Tab* to ensure mesh continuity (Fig. J_07).

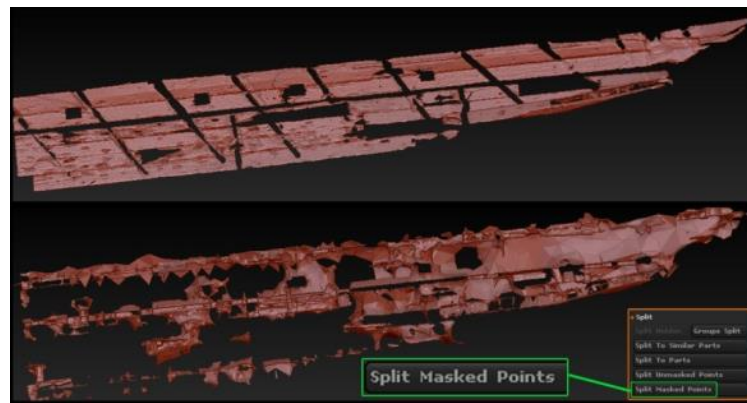


Figure J_03. ZBrush. Top image – masked surface that was split from the surface shown in the bottom image.

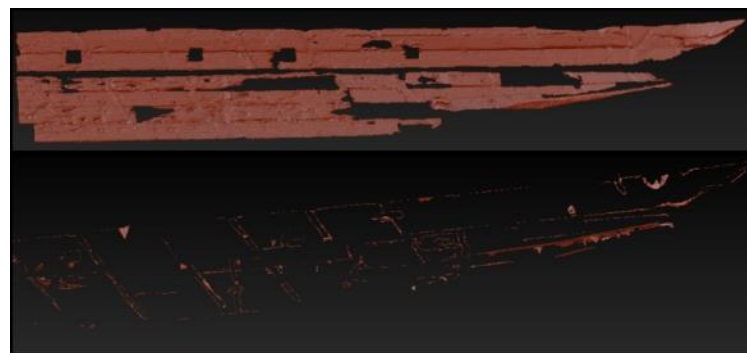


Figure J_04. ZBrush. Preparing a mesh for extrusion. Only the frontal faces of the planks were masked and *Split* from the rest of the mesh.

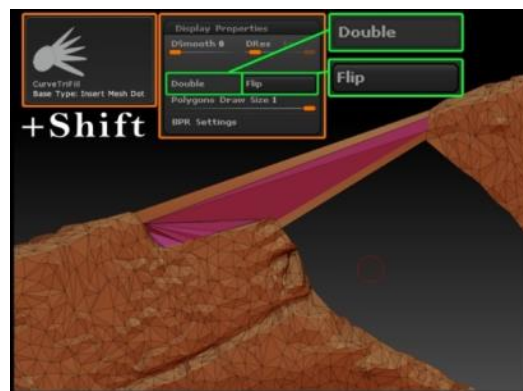


Figure J_05. ZBrush. CurveTriFill brush is used to close a hole, where the pink colour tris are generated by the brush.

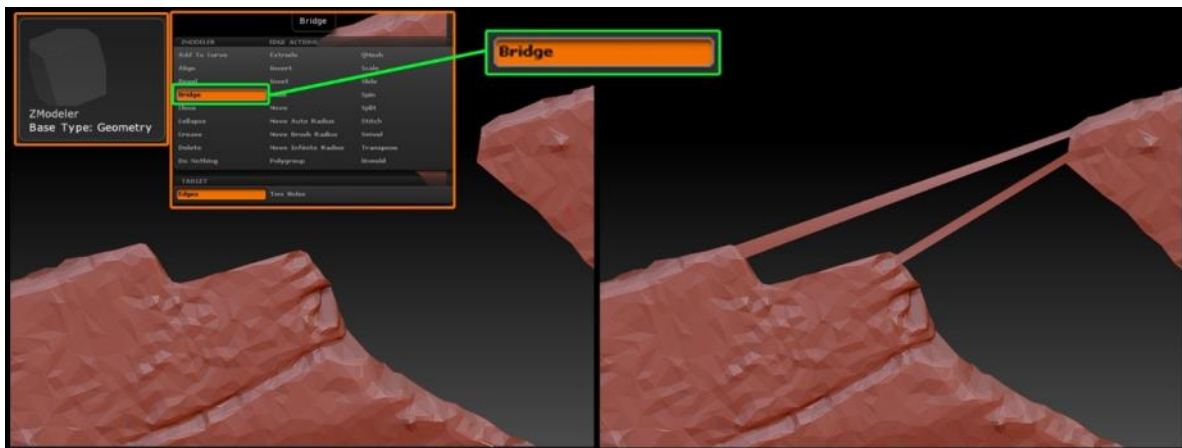


Figure J_06. ZBrush. ZModeler Tool closing off the open holes.

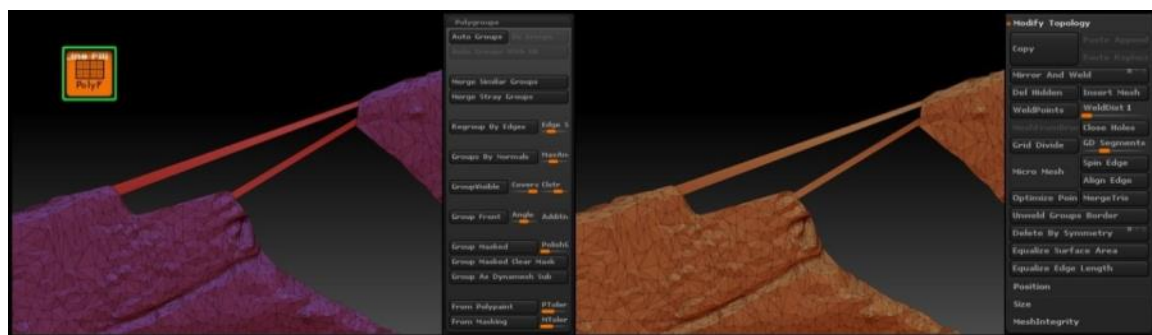


Figure J_07. ZBrush. Grouping visible polygons and welding all the points.

Extraction (Video_3). The clean mesh is fully masked to apply the *Extract* function. Before extraction, the original non-edited *Subtool* is made visible to use as a reference for the depth of the extraction. The *Thickness* parameter was modified several times before the correct thickness of the planks was generated (Fig. J_08). After the extraction, artefacts can appear, which can be reduced with the *Polish* function in the *Deformation Tab*. Usually, a small value such as 1 or 2 is enough for smoothing, although this value can be applied several times if necessary. The final output is dynameshed to achieve even distribution of the polygons and prepare the mesh for the details projection (Fig. J_09).

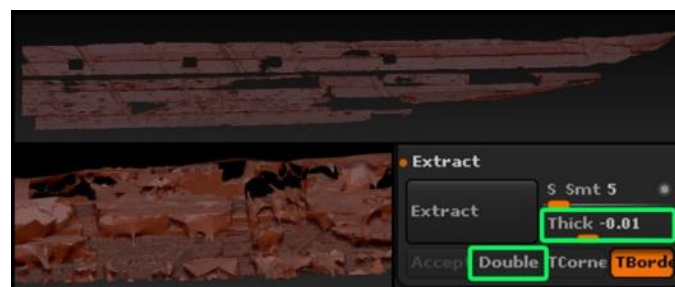


Figure J_08. ZBrush. Top image – the cleaned planks are selected with the *MaskLasso* brush; bottom left – the original raw mesh is visible to serve as a reference for thickness; bottom right – setting for this extraction, which can vary between projects.

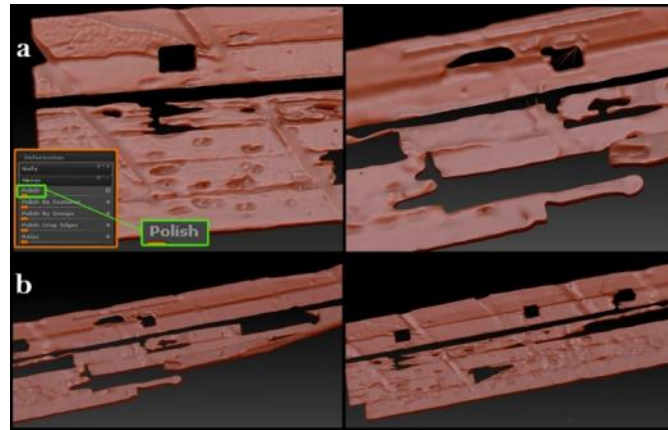


Figure J_09. ZBrush. **a left and right** – mesh after extraction, in which a few artefacts can be seen. The *Polish* function can be used to smooth down these artefacts; **b left and right** – dynameshed mesh ready for the restoration process.

Restoration (Video_4). The smoothed mesh and the original split mesh that was duplicated previously should be visible in the viewport for the projection of details. It is important that the detailed mesh is under the dynameshed mesh for the projection to work correctly. The *ProjectAll* function is used to transfer all the details to the new volumetric dynameshed model. The result of the projection depends on the resolution of the dynameshed model. With each projection the volumetric mesh should be cleaned of any artefacts if any appear after the projection, and dynameshed again. For the second projection, the volumetric model should be subdivided and the projection workflow should be repeated until the volumetric mesh has the same quality of details as the original mesh (**Fig. J_10**).

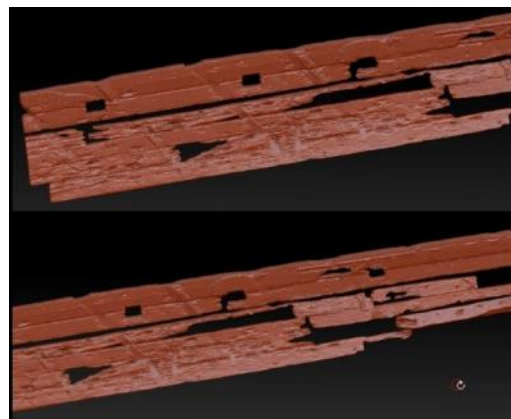


Figure J_10. ZBrush. Dynameshed volumetric model with projected details from the original mesh.

Upon projection of all the details, the model is closely inspected and major artefacts are removed. The model is dynameshed again while maintaining the same resolution. When all the major artefacts are removed and the shape of the mesh is restored, the mesh is subdivided enough to maintain all the fine details. The minimum amount of sculpting brushes was used for restoration purposes to maintain all the original details as far as possible. The main issues to be addressed during the restoration process were the lack of higher resolution in the mesh and surface noise that had to be smoothed so that new subtle wood texture details could be sculpted with alphas (**Fig. J_11**). During the restoration process all the details were manually sculpted using photographic

references from the site to ensure an accurate representation of the physical model. The final restored model can be seen in **Figure J_12**.

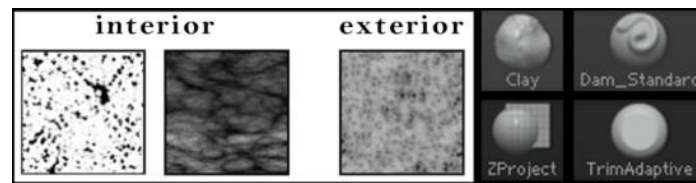


Figure J_11. Interior alphas on the left – right was used for imitating timber and the combination of both was used at the back of the planks to give them surface details. On the right of the image are the brushes used during the restoration process.

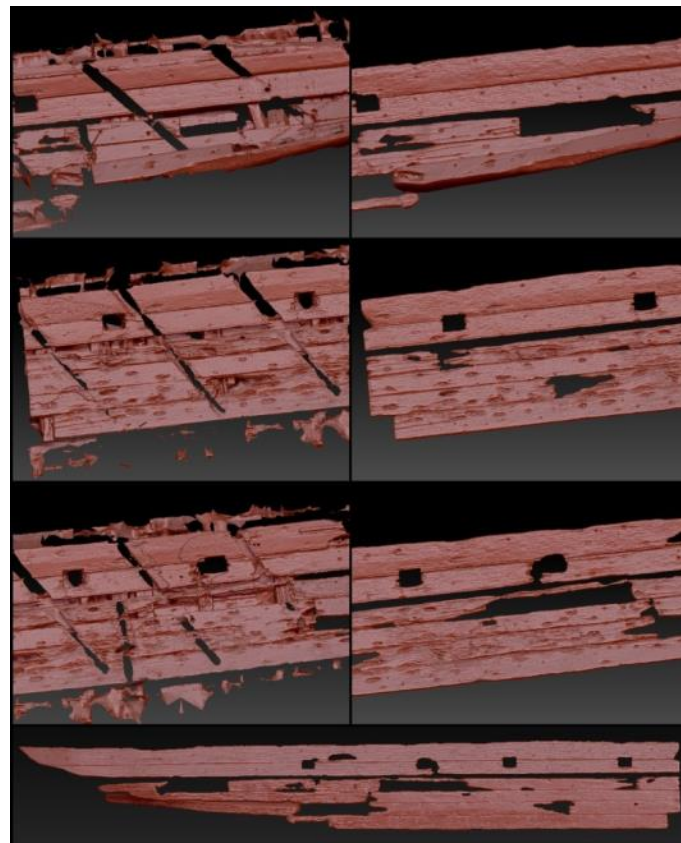


Figure J_12. On the left – raw model; on the right – final restored model; bottom image – back side of the planks that were given details with alphas.

All the parts of the ship's hull were restored in DynaMesh mode without creating a proper topology. This was done on purpose so that when a new part is restored, the one next to it can be tweaked without disturbing the topology. Only when the complete hull has undergone the full cleaning and restoration process and all the details are set in place, can it be given a proper topology during the optimisation process.

Appendix K. Manual Modelling of a Low-resolution Model in Maya

Advanced Workflow

Using the example of the left front part of the exterior of the Edwin Fox, the first step was to simplify the high-resolution cleaned and restored mesh down to approximately 200,000 triangles using *Decimation Master* in ZBrush to serve as a reference in the modelling software. The simplified model was exported from ZBrush to Autodesk Maya, where it was assigned to a layer and locked so it could not be edited. Using a *Modelling Toolkit* in Maya, a low-resolution model can be created within 3 – 6 hours depending on model complexity and amount of detail (**Video_5**). The example model was relatively simple so it took approximately 3 h to be completed. (**Fig. K_1**)

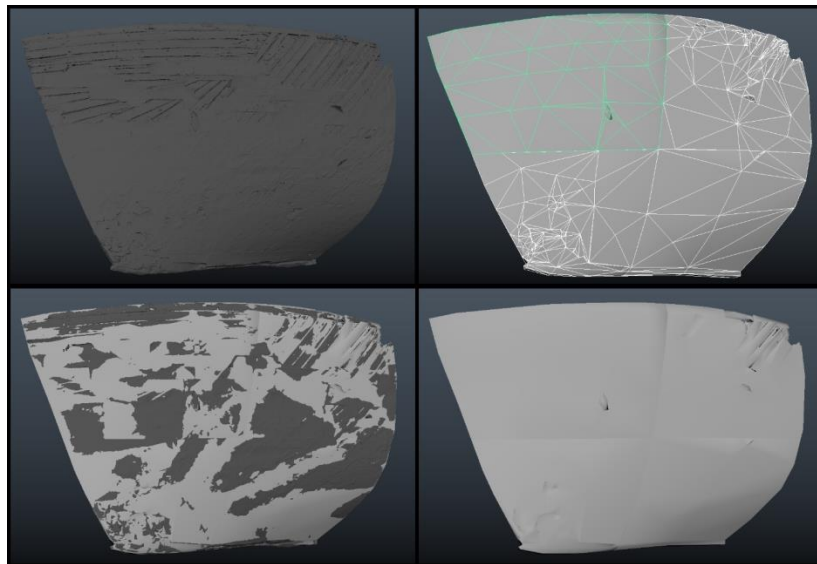


Figure K_1. Maya. **Top left** – a simplified version of a high-resolution model. The default material of the model is made darker for easier modelling workflow. **Top right** – final low-resolution model. The model was sliced into four parts for easier texturing workflow. **Bottom left** – the reference and the low-resolution model together. The low-resolution model has to match as closely as possible to the geometry of the high-resolution model for the best baking results. **Bottom right** – final low-resolution model with smoothed edges.

Appendix L. Baking using xNormal

Basic Workflow

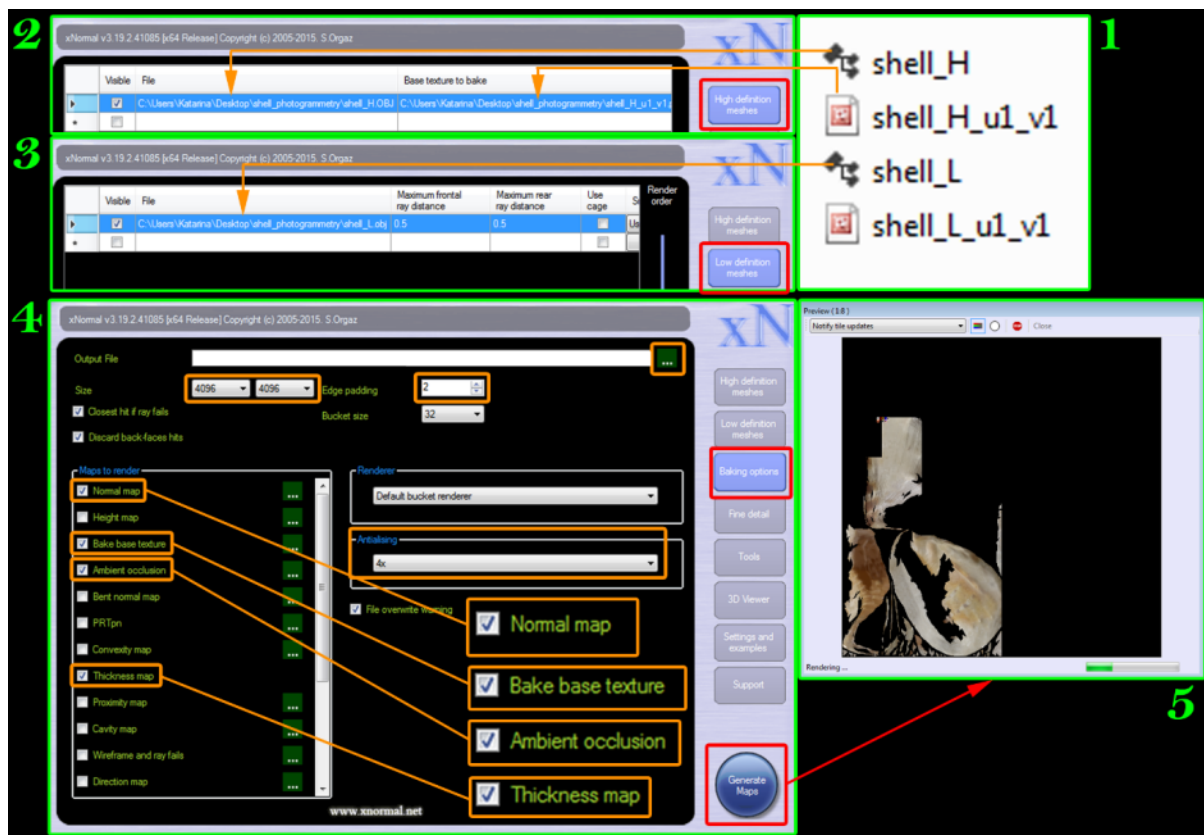


Figure L_1. xNormal. Red outlines show buttons for navigation through windows, which are outlined in green. **1** – folder view with the exported models from RealityCapture – one is an original high-resolution model with its map and the other one is a low-resolution model with its map. If there is no opportunity to bring the simplified model back to RealityCapture for texture projection, the texture can be baked in xNormal through *Bake Base Texture*, which is a map exported together with the high-resolution model. Through this bake all the colour information can be transferred to the low resolution model; **2** – *High Definition Meshes* window, where a high-resolution model and the texture of the high-resolution model are imported; **3** – *Low Definition Meshes* window, where a low-resolution model is imported; **4** – a window with baking options, where the required maps, their resolution and edge padding can be chosen. Also, antialiasing is chosen here, which determines the quality of baked maps. Usually, it is recommended to have a value of 4x, which gives the best quality. When all the values are set, a directory for saving baked maps and their names should be set. It is recommended to bake one map at a time. **5** – when the *Generate Maps* button is hit the process of baking starts. On the screenshot the process of baking the Base texture is seen.

The maps needed for baking depend on the model material. Generally, normal and ambient occlusion maps are selected in the *Maps to render* section. A normal map is a texture that contains all the details that were generated from the high-resolution model. An ambient occlusion map contains ambient lighting information. The software calculates how each part of the mesh is influenced by ambient light and records it into a map; protruding areas are coloured in white, and the areas that cave into the mesh will have a dark colour. This map allows the creation of realistic materials on the object. For the shell example, four maps were created – Normal map, Diffuse map (colour), Ambient occlusion map and Thickness map. A thickness map is needed if the material of the object has translucent properties, as in the case of the shell (**Fig. L_2**).

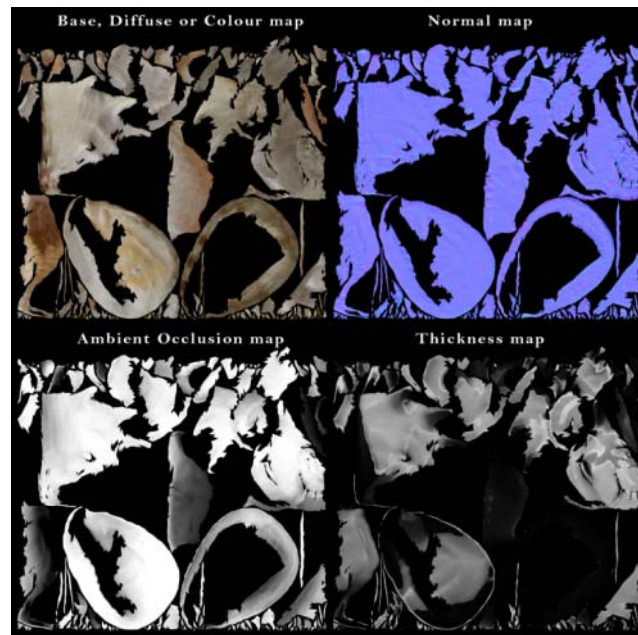


Figure L_2. Baked maps for the shell low-resolution model. The maps were projected according to the UV layout exported from a photogrammetry software.

An additional map is required to complete the optimisation workflow. A Roughness map that contains values of material roughness can be generated from the Colour map using any image editing software. The colour map is duplicated and desaturated. The white values indicate the roughness of the material and the dark values control the glossiness of the material. On the Colour map it was possible to identify the areas of the shell, which could serve as a reference for editing the bright and dark values for the roughness map (Fig. L_3).

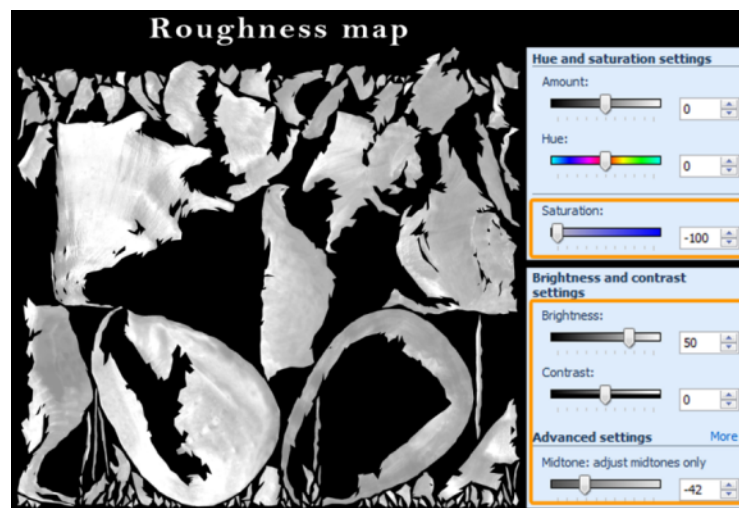


Figure L_3. A Roughness map is created with Microsoft Picture Manager.

Appendix M. Laying out UVs in Headus UV Layout

Advanced Workflow

Before unwrapping UVs, the shell model was given a proper topology using an automatic *ZRemesher* tool in ZBrush. *ZRemesher* is not vital within this workflow, as UVs can be laid out with the original topology on the low-resolution mesh. However, even topology produced with *ZRemesher* allows speeding up of the slicing of UVs.

As the model was imported in Headus UV Layout, it could be sliced into parts, which, when unwrapped, are called shells. The basic logic behind slicing the mesh into parts is to cut in the areas where it will not be noticed as much. Such areas may include bends, caved in zones of a mesh, and hidden areas. In the shell example, the cuts were put across pitching areas, where they most likely would not be as noticeable as if they were put across shell's body (**Fig. M_1**).

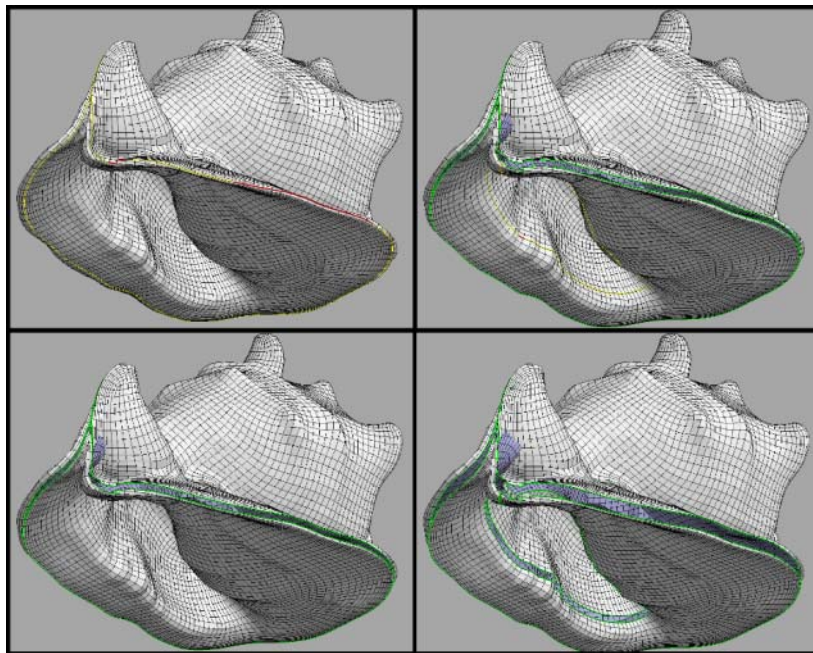


Figure M_1. *Headus UV Layout*. Shell mesh is sliced with *C* hotkey. The number of selected edges can be controlled with the *Untag Edges* function in the *Edit* tab. The *BackSpace* hotkey helps remove unnecessary selected edges. The cuts along the edges should be closed off, meaning that the cutting edge should complete a loop where the first cut is connected with the last cut. **Top left image** shows the first loop is selected. **Bottom left image** shows how the parts are separated by pressing the *Enter* hotkey. **Top right** and **bottom right images** show the same process repeated on another area of the mesh.

While slicing, the parts are dropped down to a 2D view to be flattened. When shells are flattened they can be also sliced or welded in 2D view to receive the desired UV shells layout. All the final shells must be packed within the UV space for the final export of the low-resolution model (**Fig. M_2**). The quality of the unwrapping can be seen in a 3D view window by pressing the *3* hotkey. All the brightly coloured areas show distortion of UVs, which is unavoidable in complex models. The bright red colour indicates squashing and bright blue indicates stretching of the UVs (**Fig. M_3**).

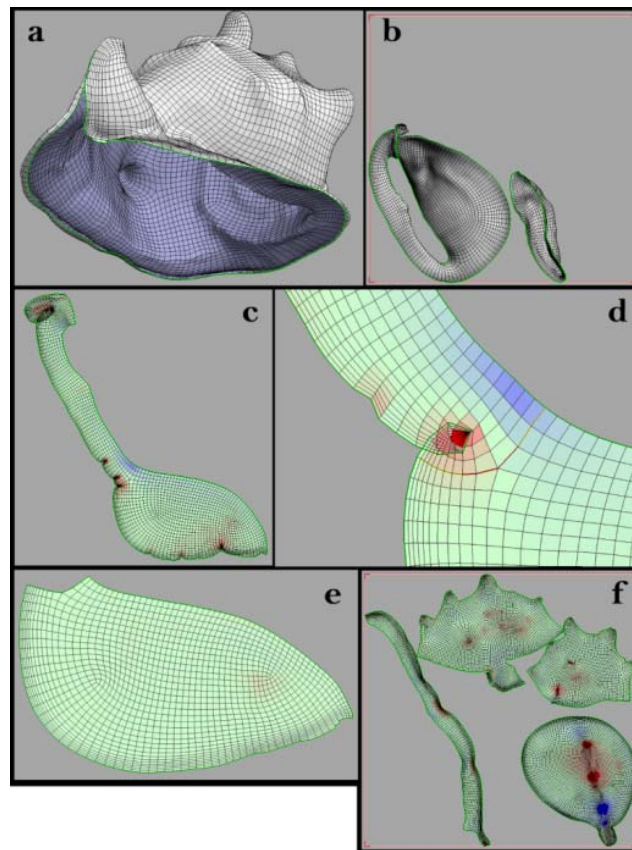


Figure M_2. *Headus* UV Layout. **a** – 3D view of the mesh, with the cut out parts dropped down into 2D view (**b**); **c** – by hovering with the mouse cursor over one of the parts in 2D view and pressing *Shift+F* hotkeys the unwrapping process starts, which can be stopped at any time using the *Space* hotkey; **d** – mesh can be sliced in 2D view as well and unwrapped again to achieve the best results, where a shell is predominantly of a light green colour as illustrated in image **e**; **f** – final UV shells packed into one UV space for export.

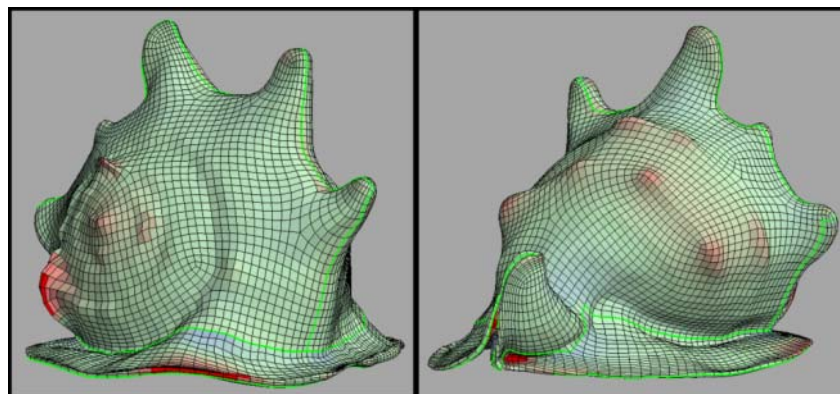


Figure M_3. *Headus* UV Layout. 3D view showing the quality of UV layout. The bright green lines indicate the edges of each shell along which the cut was done.

When packed, the low-resolution model has clean UVs. However, the automatic packing does not fully use the UV space. It is recommended to manually position all the shells into the UV space while maintaining an equal scale for each shell. Manually repacked shells can be seen in the right image of **Figure 74**. After a manual unwrapping workflow, the model can be imported into photogrammetry software to re-project colour texture on clean UVs or it can go straight through the baking process described in **Appendix L**, where the colour map can be baked from the texture of high-resolution model.

Appendix N. Workaround for Projecting Colour Information in ZBrush

First of all, an original raw mesh, which contains its UVs from RealityCapture, is imported into ZBrush. The exported textures from RealityCapture are applied on the required parts and projected as *Polypaint*. *Polypaint* is able to colour the surface of a model without the need for UVs. However, the model has to be of a very high resolution, as in the case of the Edwin Fox, to obtain a high-quality *Polypaint*. If there is not enough resolution in the model, it should first be subdivided and then the texture can be projected as a *Polypaint* (**Fig. N_1**).



Figure N_1. ZBrush. **Top left** – original raw model; **top right** – a photogrammetry model that was done on the second day of work on the site to use as a patch that could fix the overexposed texture information; **bottom right** – a cut out part after *Polypaint* projection.

After *Polypaint* projection, the required part of the mesh can be cut out and imported into same viewport as a restored high-resolution model. The restored high-resolution model is in *DynaMesh* mode, which is native to ZBrush and cannot be exported. *Decimation Master* can create new topology for the model and make it exportable to other software. The minimum decimation of 99% is set to preserve as much detail as possible. After the decimation, the *Morph Target* of the restored high-resolution model should be stored. Now all the colour information is ready to be projected from the raw high-resolution model to the restored high-resolution model through the *ProjectAll* function, introduced earlier in the workflow. After projection, all the geometry details from the raw model are projected onto the restored model; however, it can be reverted by switching the *Morph Target* that was stored earlier. If there are any small areas that did not receive colour information, this can be manually projected through the *ZProject* brush with only colour mode on. Now the restored model has an original texture without the need laying out UVs and can be exported as .FBX for baking process (**Fig. N_2**).

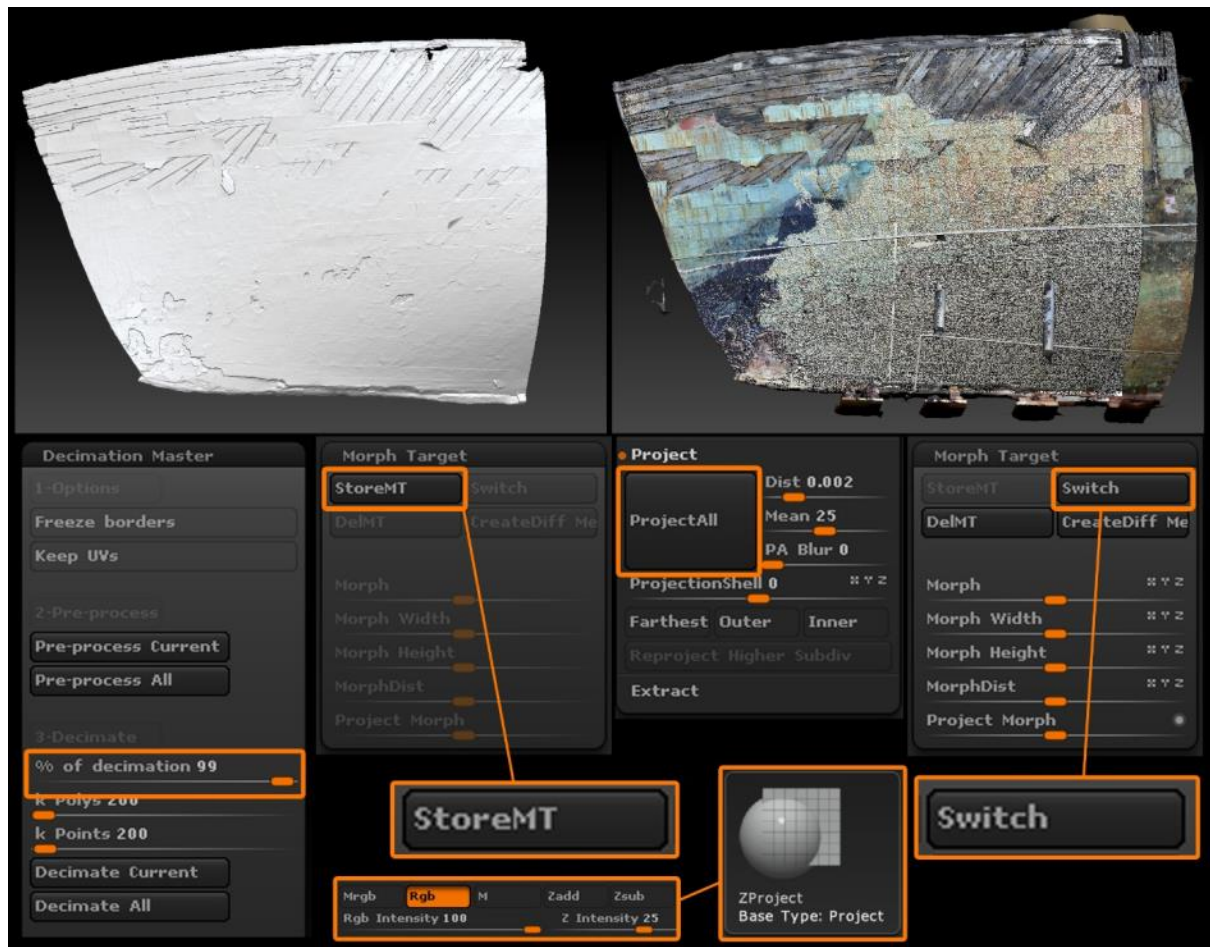


Figure N_2. ZBrush. Top left – restored high-resolution model; top right – restored and raw models visible in viewport ready for projection.

Two high-resolution models were exported: one with the original overexposed colour information and the other with the colour from the photogrammetry patch of the front part of the ship.

Appendix O. Baking & Texturing Workflow in Substance Painter

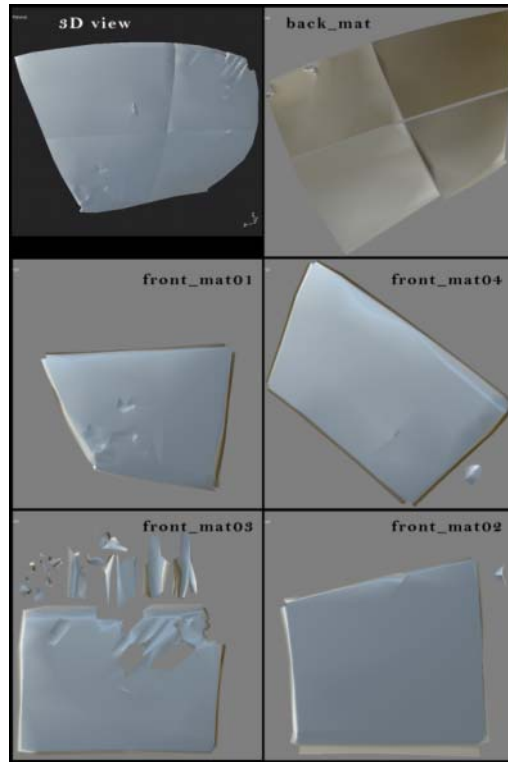


Figure O_1. Substance Painter. UVs are separated into their own UV space according to the materials assigned in Maya.

The baking workflow in Substance Painter is very similar to the xNormal baking workflow presented in **Appendix L**. All the set parameters that were used for baking textures of the front part of the Edwin Fox can be seen in **Figure O_2**.

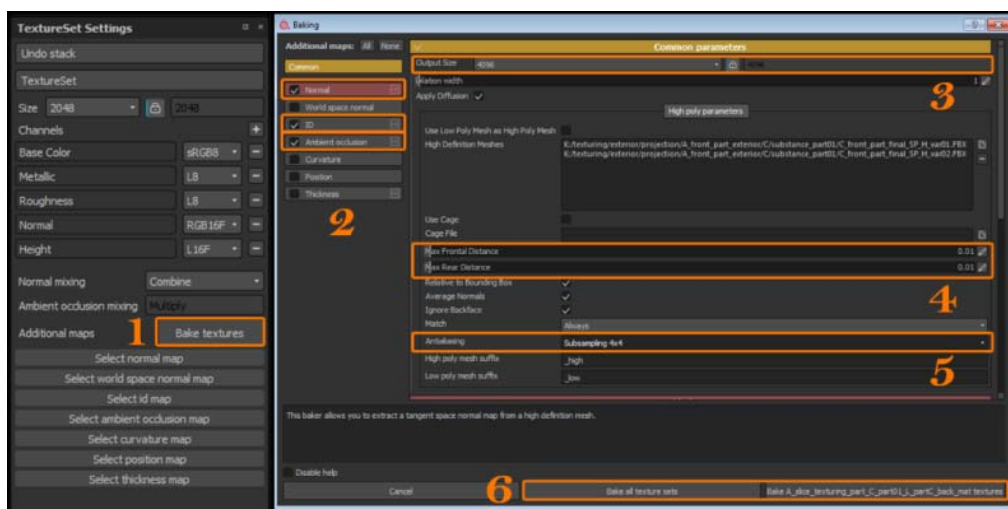


Figure O_2. Substance Painter. Baking parameters. 1 – TextureSet Settings Tab, Bake Textures function through which the baking window can be accessed. 2 – Normal, ID and Ambient Occlusion maps are baked; 3 – resolution of the final maps. Each map can be baked separately with its own resolution; 4 – baking distance. Usually the default parameter works well if the low-resolution mesh is made properly and closely repeats the high-resolution model; 5 – antialiasing parameter, which

determines the quality of the baked maps; **6** – baking function. *Bake all texture sets* creates maps for all the texture sets (5 in this case, **Figure O_1**). However, it is recommended to bake textures for one set at a time to make sure the baking parameters are set up correctly.

Baking in Substance Painter automatically assigns all the baked maps, except the ID map, for each set, which can be viewed in a 3D view window. An ID map can be used as a colour map and assigned to the *Fill Layer* in order to apply it to the model and view it in 3D view together with the other baked textures (**Fig. O_3**).

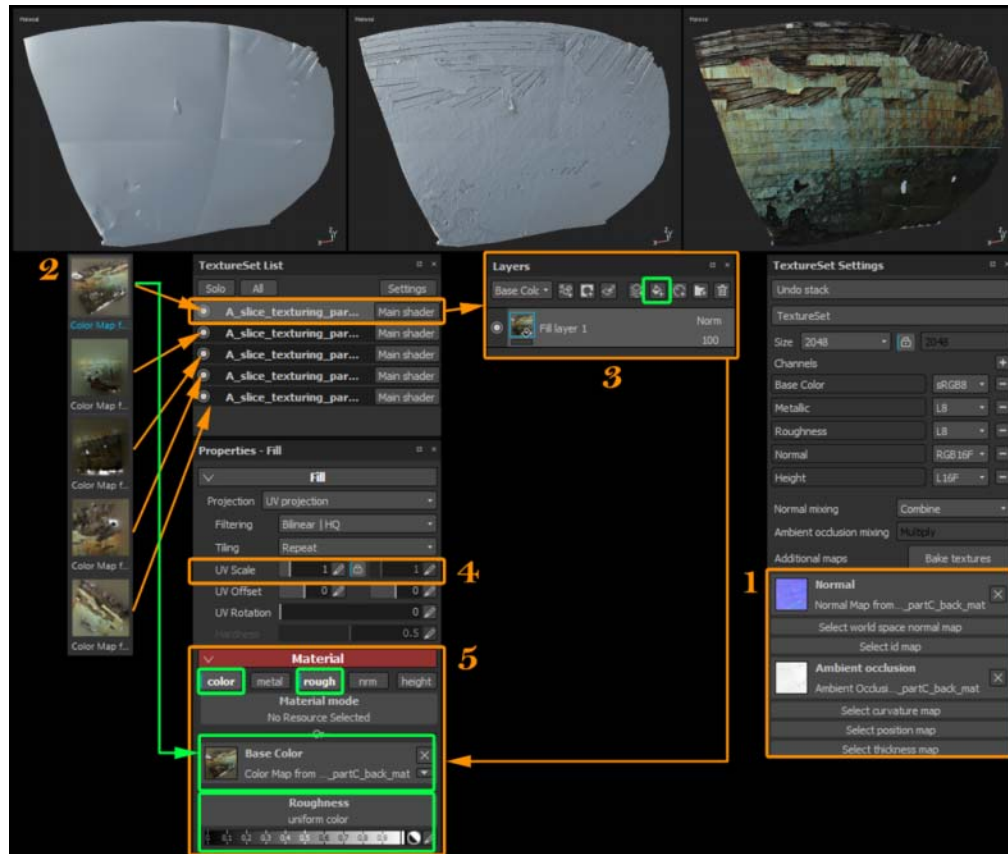


Figure O_3. Substance Painter. To images from left to right – low-resolution model just imported; baked maps applied (1); 2 – ID maps after baking are stored in Textures window; 3 – a *Fill Layer* is created with the settings of UV Scale 1x1 (4) and Material colour and roughness set to 1 (5). The corresponding texture is dragged to the colour slot in *Material* to texture the model and view it in a 3D window.

The applied colour information helps to inspect it in the 3D view for artefacts that need to be addressed. The restoration of the map can be done fully within Substance Painter. However, in this project, Adobe Photoshop was used as well. Major restoration work was done with *Clone Stamp Tool* in Photoshop and the seams between shells were fixed using Substance Painter as it allows the use of *Clone Tool* directly in the 3D viewport. For that a new *Layer* is created on top of the *Fill Layer* with *Passthrough* mode.

Appendix P. Uploading on Sketchfab

First of all, an account on Sketchfab should be made to upload and edit the settings of the model preview. When account is set up, a low-resolution model can be uploaded using an *Upload* button and managed using the *3D Settings* button (**Fig. P_1**).

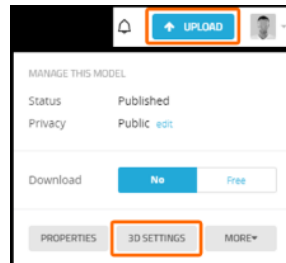


Figure P_1. Sketchfab. Uploading the model.

The majority of the values are specific and depend on the model. The settings for the shell model are illustrated in **Figure P_2**.

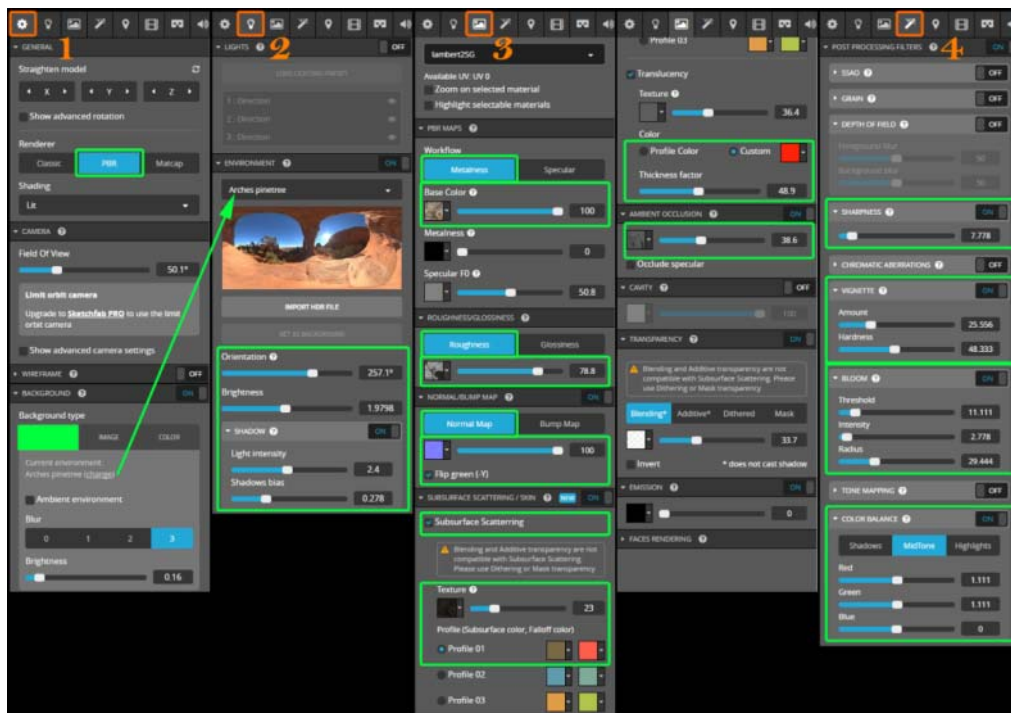


Figure P_2. Sketchfab. 3D Settings. **1** – General Settings. PBR (Physically Based Material) is recommended to be used for a realistic look in the final model. Here the background environment can be changed. **2** – Lights. Here the environment image can be changed and controlled in terms of brightness and orientation. **3** – Material set up. Metalness, Roughness, Normal Map and Ambient Occlusion sub-parameters have slots to drop in the texture maps that were previously made for the low-resolution model. **4** – Post Processing Filters, which are not necessary to use, but can give extra control in the final appearance of the asset.