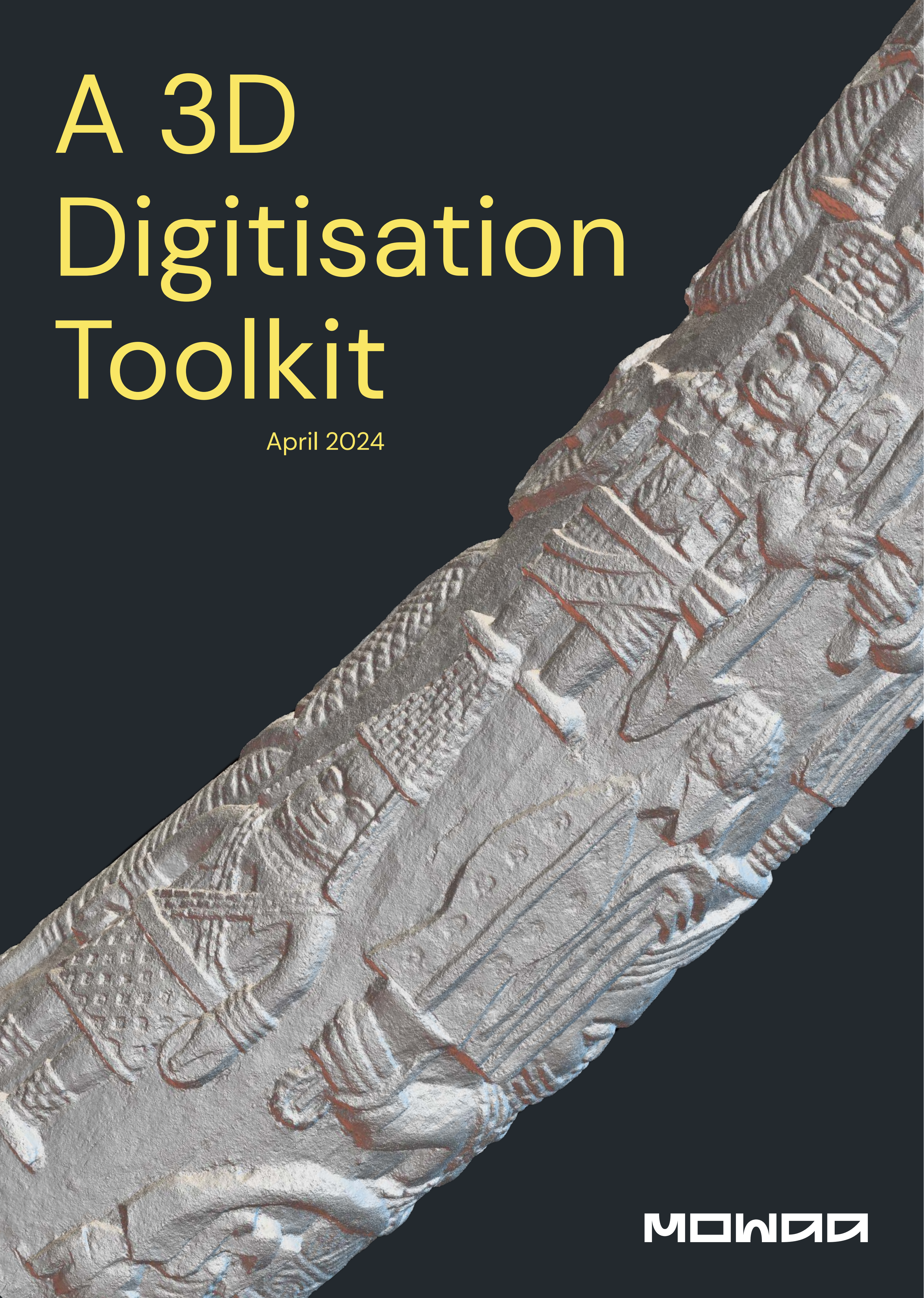
A 3D Digitisation Toolkit

April 2024



MOWAA

Contents

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Foreword

As digital technologies evolve in their capabilities and reach, the concept of "Digital Heritage" emerges as a dynamic integration of cultural heritage and digital technology, becoming a viable lens through which to expand and refresh museum practice – for practitioners, non-specialists, and communities alike. In this Toolkit, we focus on an innovative digitsation method referred to as 'photogrammetry' – exploring the practice, workflows, and theoretical underpinnings of the approach to better understand how we can take action as Heritage Practitioners in the Digital Age. Drawing on our experience of piloting this approach in-house, we consider its growing potential and adoption both on the continent and for African material heritage abroad.

This Toolkit was produced by the Museum of West African Art (MOWAA) with support from the Ford Foundation.

About MOWAA

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The Museum of West African Art (MOWAA) was formed in 2020 as an independent, non-profit organisation dedicated to the preservation of heritage, the expansion of knowledge, and the celebration of West African arts and culture. To fulfil its mission, MOWAA will provide exceptional infrastructure and programs for the preservation, exhibition, research, education, and exchange of the arts and culture at a campus in the historic district of Benin City, Nigeria.

MOWAA's upcoming 15-acre Campus will feature multiple buildings and public spaces - a series of complementary platforms for display, performance, interaction, and commerce. MOWAA Institute - the first building - is slated for completion in the fall of 2024. It will serve the continent and global exchanges as a world-class centre for archaeological research, conservation, and public programming.

Introduction

Heritage Digitisation at MOWAA

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In August 2022, the Museum of West African Art (MOWAA) initiated a multi-year programme:
Digitising African Heritage. This timely and ambitious initiative seeks to digitally preserve collections at home and reunite geographically dispersed ancient African artworks. In collaboration with Nigeria's National Commission for Museums and Monuments (NCMM), the project intends to:

- Preserve and improve accessibility to heritage assets with high-resolution digital recordings of West African antiquities
- Establish the foundation for digital infrastructure in Nigeria, with opensource and user-friendly capabilities designed to sustainably integrate other related digital heritage assets
- Build local facilities to create, manage and engage with digital collections in multifaceted ways
- Expand public learning surrounding significant cultural artefacts and the historic centres and civilisations they stem from

Digitising African Heritage operates within a broader framework encompassing training, knowledge exchanges, research, and public engagement. The resulting virtual collection will serve as a platform for disseminating more information about these intricate and historical works. Our hope is that, as a platform, it facilitates public discussions and engages both local and diaspora communities in the ideation and curation of the exhibitions.

Our first edition focuses on digitally preserving and uniting the Plaque Corpus of the Benin Empire, a two-year endeavour supported by the Ford Foundation. This Toolkit was produced as a direct result of the project, and serves as an in-depth guide, offering comprehensive insights into the photogrammetry digitisation process, using the Benin Bronze plaques as a practical case study.

Brief History of Benin Bronzes

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In the 19th century, trade disagreements strained the relationship between the sovereign empire of Benin and its primary trading ally, Great Britain. Tensions heightened with the European powers' push to carve Africa into colonial domains. The situation reached a peak in 1897 following the decision by Britain's acting Consul-General in the region, James Phillips, to journey to Benin City, ignoring Oba Ovonramwen's (enthroned c. 1888) decree to delay their visit.

On January 12, an ambush by Edo forces, reportedly without the Oba's consent, led to the near-total demise of the British delegation, Phillips included. Subsequently, a substantial British military contingent, dubbed the Punitive Expedition, was mobilised. By February 18, they had reached Benin City with explicit instructions to subdue and annex it in an act of retaliation. Eventually, they captured Oba Ovonramwen, exiling him to Calabar, east of Benin.

These occurrences disrupted the royal court's everyday life and disconnected the Edo people from their governance. The palace's royal emblems became war loot, with many sold to a variety of foreign buyers to offset the invasion costs, while others were distributed among the British expedition members. Thousands of art and cultural objects ranging from brass plaques and carved elephant tusks to ivory leopard statues and wooden heads – today collectively referred to as 'Benin Bronzes' – were displaced by the upheaval and steady looting that followed.

Upon reaching London, the royal arts of Benin became a subject of intense discussion and curiosity, garnering immediate interest from museums, especially in Britain and Germanspeaking countries, all of whom sought to acquire these objects for their collections.

Digitising the Benin Plaques

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Today over 800 plaques are dispersed across 47 collections across the world, with the majority in Germany, the United Kingdom and the United States. By creating a unified, accessible archive of the plaques, MOWAA aims to bring these works together, allowing scholars, researchers, and the public to explore and study the corpus as a whole.

Led by MOWAA's Digital Heritage team, this project seeks to safeguard, preserve and archive the cultural heritage embodied in these remarkable artefacts, by employing a cutting-edge digital preservation technique. The digital record will also serve as a safeguard against material deterioration, ensuring that the knowledge and beauty encapsulated in the plaques endure beyond physical constraints.

Through the process of digitally documenting the plaques, MOWAA aims to provide a platform to understand and engage with their historical, artistic and socio-cultural significance as a collective body of work. This approach further enables their application in public learning and engagement initiatives. Through digital representations and research, this project intends to revive their lost context and provide a comprehensive understanding of their meaning, offering points of connection for a wide audience.

This project is supported by the Ford Foundation and delivered in collaboration with NCMM under the framework of a five-year collaboration agreement effected 27 October 2022 with the leading national heritage management agency. This multi-year collaboration centres on skill and knowledge transfer in the areas of digital conservation and archive management.

Our 3D Digitisation Toolkit

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This Toolkit is designed as a free guide and reference tool for 3D modelling through the process of photogrammetry. Careful consideration has been given to how it can be applied to cultural heritage objects within museum and archive environments.

Our objectives are to:

1. Provide a reference tool for heritage and museum professionals, cultural practitioners, heritage enthusiasts, students and other interested parties
2. Provide an introduction, context and understanding of the fundamental techniques and best practice in photogrammetry
3. Support museums and heritage organisations in taking advantage of digital technological innovation in the field of 3D modelling

Through the development of this Toolkit and related programmes, MOWAA hopes to support the cultural ecosystem to achieve the following wider aims:

1. Foster interest and understanding in the realm of digital technology within the field of heritage and museum studies
2. Promote the adoption of photogrammetry as a method to document, record, reconstruct, display, interpret and preserve both tangible and intangible heritage before it is irreversibly damaged, fragmented, destroyed or lost
3. Promote the adoption of the photogrammetric technique for specific African and Black heritage digital humanities studies and knowledge creation
4. Promote the assemblage of fragmented and dispersed heritage

5. Provide a mechanism to increase public access to heritage knowledge resources and connect diverse audiences
6. Provide heritage organisations with a mechanism to increase their visitor traffic and virtual outreach, especially in hard-to-access locations
7. Provide insight into the rapidly changing digital heritage world

About this Toolkit

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While the Toolkit has been designed with reference to MOWAA's Heritage Digitisation Project, the approach can be applied to other artefact preservation initiatives. Moreover, the underlying concepts are applicable to larger-scale applications such as building and landscape recording.

The digital models produced through this process can be utilised for a wide array of purposes, including virtual exhibitions, interactive educational materials, and immersive, Extended Reality (XR) experiences that transport audiences back in time.

→ Chapter 1

Digitisation in Heritage Management

The Importance of Digitisation for Cultural Heritage

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The UNESCO Charter for the Preservation of Digital Heritage (2009) defines 'Digital Heritage' and Digital 'Preservation' as practices that involve the transformation of analogue entities, such as objects, images, or documents, into digital surrogates. This process facilitates computerised processing, bridging the gap between tangible artefacts and the digital realm.

The history of cultural heritage preservation is marked by significant technological advancements, with each breakthrough ushering in a better understanding of how we should conserve, interact with, and understand our historical treasures.

Digitisation is the latest, most effective form of preservation technology, spanning early preservation mechanisms such as folklore and oral history, through to the advent of writing, textual, and ideographic approaches. By the late 20th century, the use of the printing press and written forms to record descriptions and ideas became standardised practice. This occurred in parallel with the application of conservation and preservation science techniques to physical objects to maximise their lifespan.

However, many of these preservation approaches created interpretation issues, subjectivity, and bias. In the 19th and 20th centuries, as large-scale archives and libraries were created, more 'objective' approaches to preservation emerged. Technologies like photostats, microfilm, photocopying, and digitisation have since been instrumental in preserving information more accurately and in greater quantities.

[1] UNESCO, Concept of Digital Heritage, https://en.unesco.org/themes/information-preservation/digitalheritage/concept-digital-heritage

[2] UNESCO, Concept of Digital Preservation, https://en.unesco.org/themes/informationpreservation/digital-heritage/concept-digital-preservation

'Digital' Heritage Challenges

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For many industries, including heritage management and museology, the transformative potential and power of digital technology is enormous. In the process of applying digital technologies to preservation, exhibition and other functions, it therefore important to be aware of the wider implications and challenges embedded in this 'digital' paradigm shift.

1. Access to heritage, digital technology, internet, electricity, and other essential infrastructure is still not standardised or equal, leaving behind marginalised and economically disadvantaged communities.
2. Digital capabilities differ between demographics, regions, and countries. Younger generations are generally considered to be 'early adopters' of digital innovations and mobile technology.
3. The widespread availability of digital technology contributes to increasing global disparities, further exacerbated in terms of crises such as war and pandemics.
4. Digital technologies, whilst often replacing the need for physical items such as paper printing, have other large impacts on environmental resources-- particularly in terms of rare minerals extracted for devices and microchips, material supply and waste, and energy consumption (the latter partly remedied by the use of renewable power).
5. Rapid changes in technologies, format types, and typical file sizes require constant consideration and planning for the future. Digital files and legacy data require proper maintenance, management, and wider storage strategies. This effort to maintain a system, comes at a cost.

Guiding Principles for Undertaking Digital Preservation

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MOWAA promotes ethical, resource-efficient, and socially responsible heritage management practices. Before embarking on a digital preservation project, it is important to consider several factors that can impact the legal, cultural, and practical effectiveness of your project. The guiding principles outlined below draw from MOWAA's 3D Digital Policy (March 2024), as well as from discussions with leading cultural practitioners and institutions active in digital preservation efforts.

Permission: It is important to ascertain whose permission is required to record or digitise the relevant cultural asset. To avoid delays, their authorisation should be formally documented and secured well in advance of the proposed digital preservation initiative. This process may vary depending on whether you are dealing with public or private collections. It is important to clearly spell out your aims, justification, and proposed contribution, and to consider the collection owner's values and needs when preparing your proposal.

Legal Ownership: Intellectual property rights are typically spelled out at national levels, and draw on global conventions, for example, the Berne Convention.3 Whether drawing on pre-existing laws or determined on a case-by-case basis, copyright terms should explicitly specify terms of use (including rights to use, duplicate and modify) and publication. Creative Commons, an international non-profit, has developed practical solutions for better open sharing of knowledge and culture that serves the public interest. It offers a range of open access licenses which are recognised by institutions globally.

Cultural Sensitivity: There may be situations where it is not appropriate for certain records to be made publicly accessible due to ethical or cultural concerns. In these cases, it is possible to restrict access to the records in question for either a limited or indefinite period. Cultural owners and custodians are also important stakeholders to bear in mind, given their knowledge of how the objects were made and cared for.

Conservation Awareness: Digitsing an object involves more than just taking a photograph. Before starting the process, it is crucial to assess the object's condition and its storage. Additionally, certain materials may react negatively to prolonged exposure to light and penetrating beams used in some digitisation processes. Other objects may require specialised support structures for stabilisation during documentation, or they may be too fragile to handle. Consulting with professionals, like conservators, before any direct handling is always recommended. Where these professionals are not readily available, as in remote communities and underserved institutions, speak to the custodian directly and discuss caretaking options.

Recording Access: In most cases, access for the purpose of digital recording requires careful planning and coordination. Owners and custodians of heritage assets may not have up-to-date or easily understood ordering systems, requiring additional planning or guidance from subject matter specialists or curators. Furthermore, museums and archive managers typically require staff supervision around high-value objects necessitating scheduling to align with their often-limited availability. Physical access, imperfect lighting, and space restrictions also need to be factored in when planning.

Sharing Access: While not all digital preservation projects result in publicly accessible deliverables, there is increased interest and rationale for sharing digitised cultural material more widely. This is often mandated in government-funded projects and those supported by non-profit organisations with educational or social impact goals. It is crucial to plan for this from the outset, considering factors such as obtaining permissions from relevant authorities, addressing cultural sensitivities, and designing the final output. Early consideration of, data resolution, public dissemination formats and hosting costs all play a part in the successful implementation of digital preservation public outputs.

Sustainability: Data management and governance are important in ensuring the long-term security, availability and accessibility of digitally preserved heritage. Sustainability planning should, at minimum, consider well-resourced data hosting arrangements, clear data management responsibilities, and the development and adherence to protective policy.

More generally, a good starting place for any heritage management initiative – digital or physical – is to first determine the value and need of your intervention. This is typically based on carefully weighing its historical significance, urgency (for example with endangered or rapidly deteriorating cultural assets), and the evidence of prior documentation. Given limited resources, the surplus of under-researched collections, and the expanding needs of at-risk collections and other heritage materials, developing a well-informed justification prior to kickstarting new projects is both ethical and practical.

[3] American Society for Photogrammetry and Remote Sensing (ASPRS), 1980, https://www.asprs.org/organisation/what-is-asprs.html

Basics of Photogrammetry

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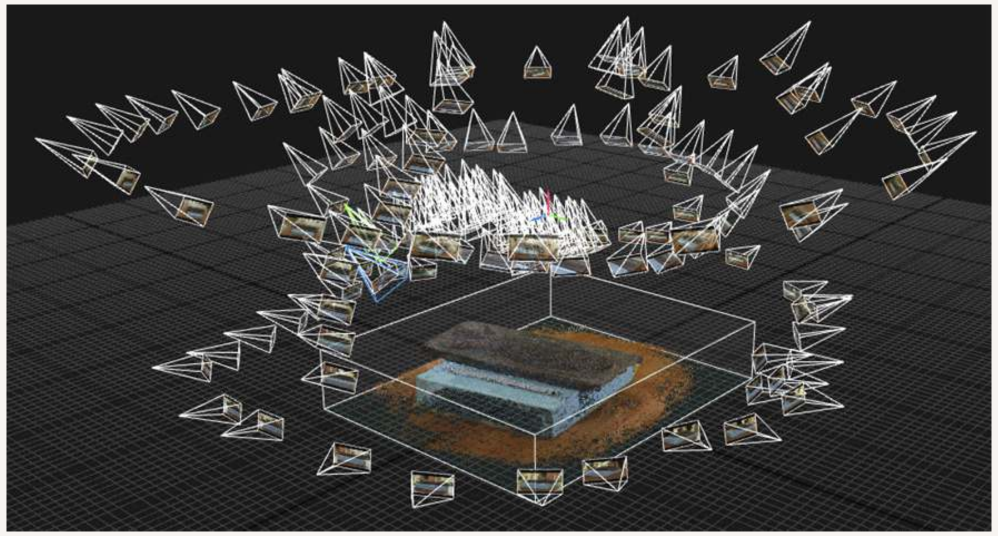
Photogrammetry is "the art, science, and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images and patterns"[3]. In other words, it is the systematic method of obtaining measurements by means of photographs.

Figure 1 - By taking a series of overlapping images from different angles, 'spatial' information can be calculated. Credit: MOWAA Digital Team



Photogrammetry relies on trigonometry - the branch of mathematics concerned with specific functions of angles and their application to calculations. The photogrammetry software identifies common patterns or features in many digital images - made up of often millions of pixels – and applies trigonometry to calculate the geometric properties of the visible patterns or objects shared across the set of images.

It builds up a dataset of 'cloud points' which then become the common nodes of a triangulated mesh (a digital web or surface) by interpolating the distance between the points with a straight line.

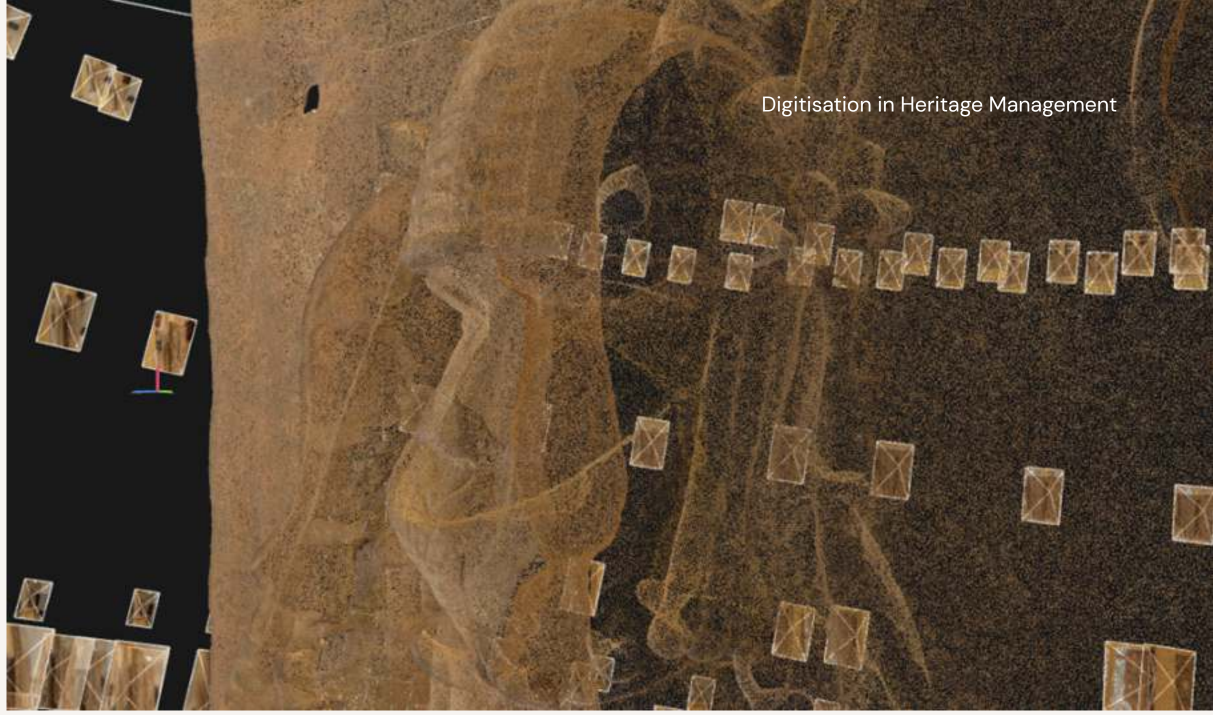


Figure 2 - A point cloud model of identified areas of commonality found between a number of images. Credit: MOWAA Digital Team

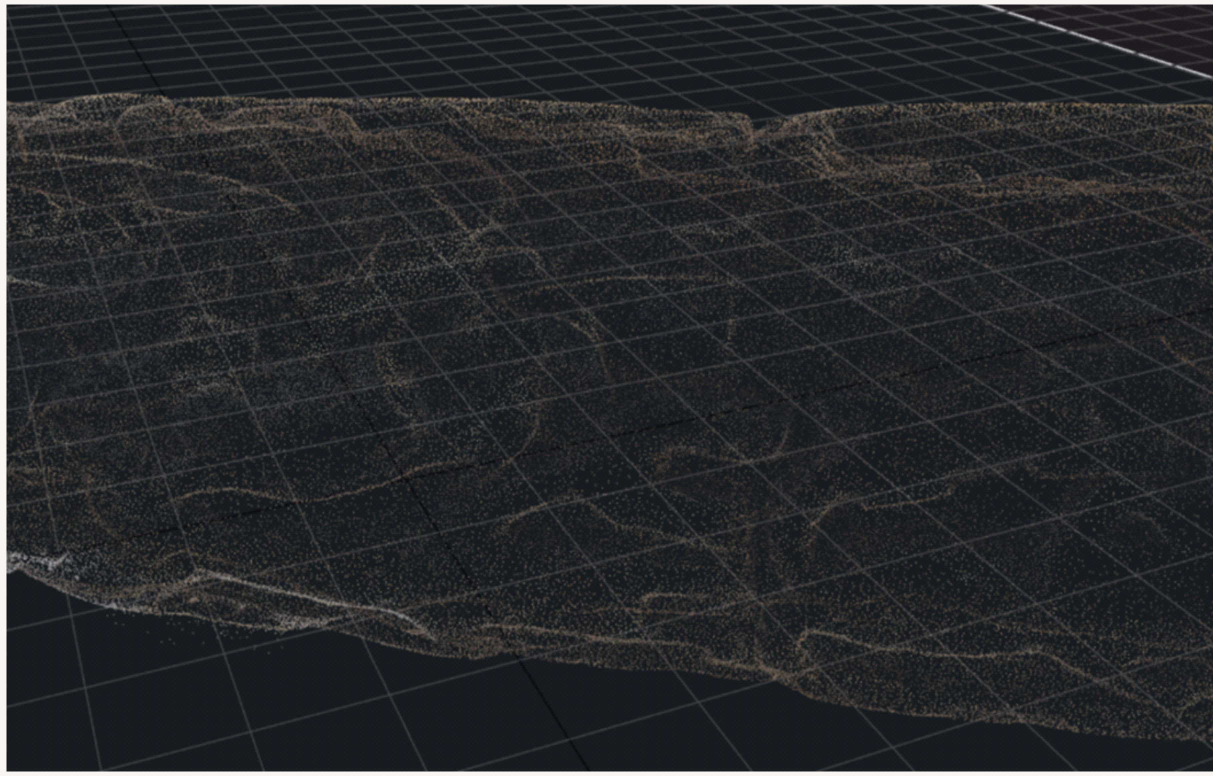


Figure 3 - A point cloud model of identified areas of commonality found between a number of images. Credit: MOWAA Digital Team

This builds up many triangles which in turn become a representation of the topology or surface of the form being capture. The more node points – smaller sizes and higher numbers of triangles – the more accurate and realistic the representation of that topology.

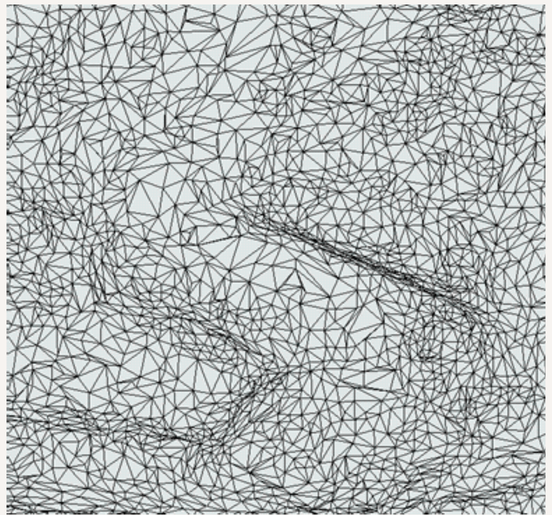


Figure 4 - A wire frame created by straight-line interpolation between node points. Credit: MOWAA Digital Team

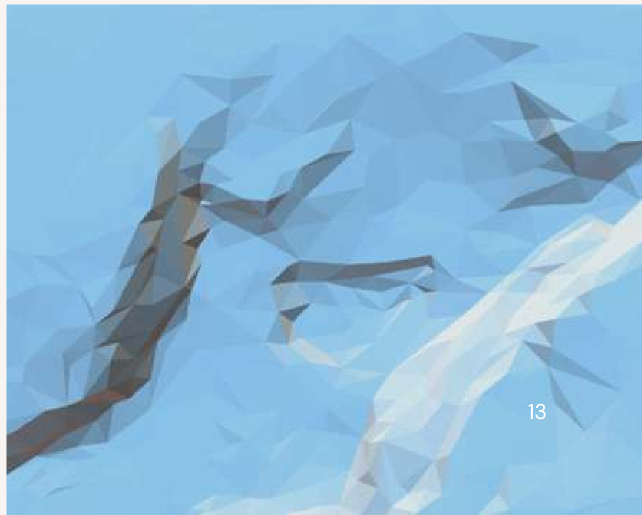


Figure 5 - The output mesh, based on the triangulated wireframe. Credit: MOWAA Digital Team

Figure 6 - Combined mesh and wireframe of an output model created through photogrammetry. Credit: MOWAA Digital Team

Photogrammetry applications span both aerial and terrestrial domains, with terrestrial photogrammetry categorised as 'close-range'.

The accuracy of photogrammetric measurements hinges on the optics quality, clarity of the image objects, and sensor resolution of the camera. Modern software solutions streamline tasks like camera calibration, geometry computations, and 3D mesh generation.

Utilising common digital images under suitable conditions can yield high-accuracy measurements. This renders photogrammetry to be an objective, reliable, cost-effective, and accessible technique, especially when combined with precise measurements from devices like total stations. This convergence of precision and simplicity propels photogrammetry as a powerful tool for generating highly accurate models at various scales.

Principles of the 3D Process

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Within heritage preservation, the process of 3D modelling has no physical size or scale limitations – ranging from landscapes, through archaeological monuments, down to individual artefacts. Whilst the size and nature of the objects require slightly different data collection techniques, the underlying concepts and information processing tactics are essentially the same.

Photogrammetry can be applied at different scales:

Sensor 'Types'

'Active' Methods: These systems deploy energy – usually in the form of light – onto the object being scanned. This energy interacts with the object and reflects back to the scanner. The reflected energy is then captured and analysed to create a digital representation. Examples include laser scanning and structured light scanning, where a laser or a pattern of light is projected onto the object. The way this light deforms upon hitting the object's surface is used to calculate its shape and texture.

'Passive' Methods: Passive systems, on the other hand, rely on ambient energy sources, typically light, available in the environment. They do not project any energy onto the object. Instead, they use sensors to detect and capture the energy that is naturally reflected or emitted by the object. A common example is photogrammetry, wherein multiple photographs taken from different angles are used to reconstruct a 3D model. This method relies on the ambient light present when the photographs are taken.

Both methods have their unique advantages. Active systems can be more precise, particularly in controlled environments. Passive methods are often more flexible and can be used in a wider range of settings, especially where deploying active energy sources is impractical or disruptive.

Examples of active systems:

- Laser scanning
- Structured light
- Range sensing
- Time of Flight (TOF) devices
- Phase Shift (PS) laser scanners
- Confocal microscopy
- X-Ray devices

Credits in order:
Creative Commons,
MOWAA Digital Team,
Michael Tomiak, MOWAA
Archaeological Services

Small museum objects | Large museum objects | Buildings | Landscapes or archaeological sites

Structure-from-Motion

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MOWAA adopts these methods mindfully, acknowledging the need for preservation while respecting the fragility of artefacts. The African experience within the digitisation realm thrives on the convergence of technological precision and cultural reverence.

In the realm of capturing three-dimensional wonders from the lens of two-dimensional snapshots, Structure from Motion (SfM) emerges as a transformative technique. Leveraging a series of 2D images, SfM reconstructs the 3D structure of scenes or objects, akin to LiDAR technology. What makes this technique groundbreaking is its accessibility. With consumer-grade digital cameras and advancements in computers and unmanned aerial systems (UAS), a diverse range of users can now delve into 3D modelling without the need for extensive expertise or expensive equipment.

SfM operates on the bedrock of stereoscopic photogrammetry principles. Traditionally, stereophotogrammetry required specialised and costly equipment. However, SfM simplifies the process, necessitating numerous images of an area or object, taken from varied angles with a high degree of overlap. Remarkably, standard consumer-grade cameras prove effective here. Whether images are captured by a moving sensor, such as UAVs, or by individuals from diverse locations, SfM affords the digitisation landscape with a margin of flexibility.

While a minimum of three visible features in images is generally required, it's recommended to capture as many overlapping images as possible for faster processing speed and higher model quality. SfM demonstrates its versatility by accommodating various sources, such as crowd-sourced images, to create 3D models of historical buildings and monuments. These models are generated with 3D point clouds, which are positioned within a relative 'image-space' system, finding their coordinates with the realworld using ground-control points (GCPs) and georeferenced imagery.

The technique whilst flexible in terms of its applications and simple in principle, requires careful consideration in terms of planning, access and management of the output data. The following chapters look at each of the specifics that are required to be understood at each stage to ensure efficient, effective application, as well as accurate resultant models. This, in turn, supports preservation efforts and ensures a better legacy for the future. The tips and approaches outlined draw from MOWAA's experience with its own projects as well as from exchanges with other cultural practitioners.

→ Chapter 2

Photography

Introduction

To ensure appropriate and good quality information capture, a foundational grasp of photography and adherence to specified capture techniques is vital.

This segment discusses the fundamental photography principles, essential equipment, and the planning stage for capture. The approach is based on use of digital Single-Lens Reflex (SLR) cameras where there is at least some control over the photography variables (see below) and the images are captured in a digital format from creation. This excludes smartphone or film-based devices where high-quality photogrammetry – presently – cannot take place.

Photography Variables

The 'Exposure Triangle' (see Figure 7) describes the relationship between three key image capture variables: ISO, Shutter speed and Aperture.

These technological functions are used to manage the camera's light intake and sensor sensitivity; they also influence depth of field, motion capture, and image noise. Understanding this triangle is crucial for achieving the desired photographic effects.

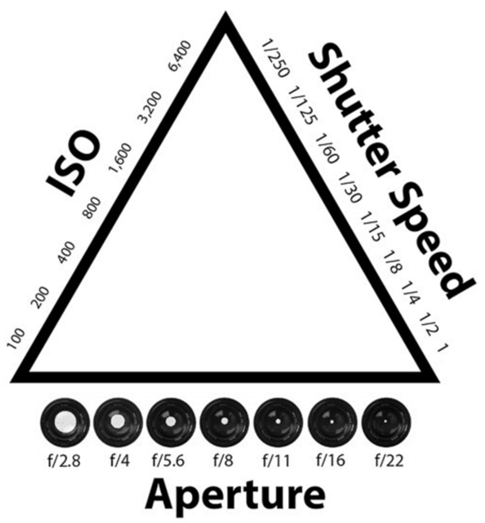

Figure 7 - The Photography 'Exposure Triangle'. Credit: Photography Life

It is the interaction of all three variables that determines the exposure of It is the interaction of all three variables that determines the exposure of an image.

- Aperture controls the amount of light entering through the lens
- Shutter speed dictates the duration of light hitting the sensor. A fast shutter freezes motion, while a slow one may introduce blur if the subject (or the camera) moves while the shutter is open
- ISO sets the camera sensor's sensitivity to light. A low ISO yields a cleaner image, while a high ISO may introduce noise but may be necessary for shooting in low-light conditions where the risk of blur means you can't simply use a very slow shutter speed

The three elements are a balance. A good photogrammetry specialist must be aware of their implications and know when and how to adjust them to achieve clear, useable data.

Shutter Speed

Shutter speed refers to the duration during which light impacts the sensor, usually expressed in seconds. Doubling the exposure time enhances light intake by a factor of two. For example, adjusting the shutter speed from 1/60 second to 1/30 second means the shutter stays open for twice as long.

Conversely, decreasing the shutter speed from 1 second to 1/8 second reduces exposure by a power of three. This reduction occurs in increments called stops. Going from 1 second to 1/2 second constitutes one stop, then from 1/2 second to 1/4 second is a second stop, and finally from 1/4 second to 1/8 second is the third stop. Each stop halves the duration the shutter is open, progressively reducing light intake.

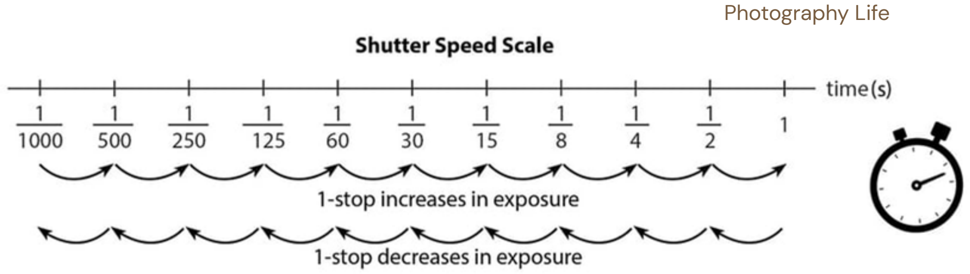

Figure 8 - Shutter Speed Scale. Credit: Photography Life

Aperture

As well as exposure, aperture also affects depth of field (B): large apertures (1) create a shallow depth of field, meaning only a small area of the scene is in sharp focus (3). As the aperture gets smaller (2), the depth of field grows, so that more of the scene is in focus.

Aperture, denoted by f-stops (A), is defined by the diameter of the lens's circular opening which controls the amount of light entering.

A larger aperture allows more light to reach the camera's sensor. Doubling the size of this aperture doubles the light,or increases the exposure. Conversely, reducing the aperture's size by half decreases the light reaching the sensor by half, reducing the exposure.

A larger aperture such as f/1.4, due to the inverse nature, means a wider opening than a narrow aperture such as f/16.

f-stop (A) = focal length (f)/diameter

Mathematically, adjusting the aperture size to either double or halve the light involves the square root of two (approximately 1.414). This calculation underpins the non-rounded values found in f-stop scales, enabling precise control over light exposure by adjusting the aperture size in relation to the f-stop value.

ISO

ISO, or ISO/ASA Speed, also known as 'Gain', controls the camera sensor's sensitivity to light and should generally be maintained at a low level to prevent noise in images. Noise manifests as graininess, diminishing the quality, which can adversely affect the precision of scans in both geometry and textures.

A lower ISO setting reduces an image's exposure by decreasing the sensor's light sensitivity.

Higher ISO values indicate that the sensor requires less light for proper exposure.

This adjustment allows photographers and scanners to balance the need for light with the desire to minimise noise, ensuring the highest quality images for detailed work such as photogrammetry, where the integrity of textures and geometry is paramount.

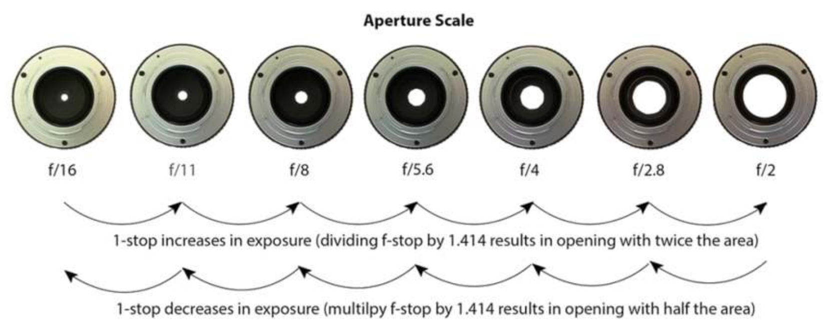

Figure 9 - Aperture Scale. Credit: Photography Life

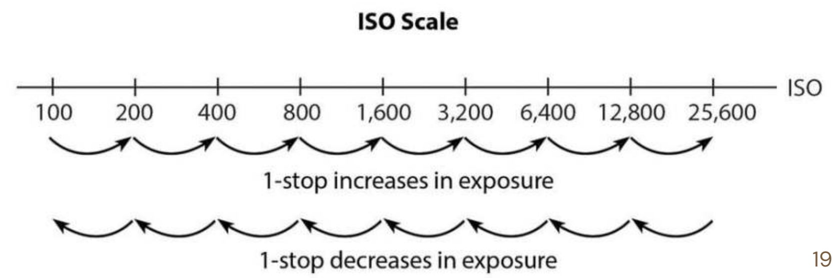

Figure 10 - ISO Scale. Credit: Photography Life

Equipment

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Hardware

The equipment used, including the digital camera type, significantly influences the quality of the final photogrammetric model.

Both the camera and lens capabilities are crucial as they can restrict each other's performance during the documentation process.

At MOWAA, mirrorless cameras are favored over DSLRs for several key reasons, including their superior dynamic range, absence of mirror-induced interference, enhanced performance in low light, and their compact, portable design.

The following photography equipment list is recommended as the baseline for any documentation project:

- A DSLR or mirrorless camera with at least 12 megapixels resolution.
- A standard 50mm lens.
- A tripod for stable shots, enabling longer exposures and lower ISO settings to minimise blur.
- A camera trigger to avoid camera shake when pressing the shutter.
- A flash unit (See Lighting below)
- Rulers or physical reference markers for accurate object scaling (multiple markers positioned around the subject are preferable).

Lighting

On bright sunny days, when light intensity may be too intense, shading the subject can be helpful. Soft illumination from light bouncing off surfaces is ideal, with the extent of diffusion depending largely on the object's surface texture and the size of the light source relative to the object. Ring lights are another option, especially for objects that reflect light. Ensuring uniform lighting and minimising shadows, although not strictly necessary, is beneficial for the photogrammetric process. This is because dark shadows can lead to loss of information.

Moreover, variations in lighting—such as changes in sunlight direction throughout the day and year—can pose challenges for processing algorithms. To address these issues, LED panels provide even quality and coverage of light, promoting more uniform lighting.

Do's and Don'ts

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1. **Prioritise RAW Capture Format:** Try to always shoot in RAW format. Unlike JPEGs, which might have embedded alterations, RAW format ensures control over image adjustments in white balance and recovery of shadow and highlight details.
2. **Select Cameras with Global Shutters:** Avoid cameras with rolling or electronic shutters to prevent image distortion during motion capture.
3. **Ensure Consistent, Diffused Lighting:** Aim for uniform lighting to avoid overexposed highlights and shadows.
4. **Invest in High-Quality Lenses:** A prime lens, preferably around 35mm for full-frame sensors, is essential for capturing detailed images.
5. **Maximise Resolution Within Limits:** Utilise the highest resolution camera available, mindful that higher resolutions demand steadier hands (or a tripod) and may introduce noise at lower ISO values. For terrestrial projects, 24mpx suffices, but aerial or distant captures benefit from resolutions upwards of 42mpx.
6. **Avoid AI Upscaling:** Artificially enhanced resolutions via computational techniques can distort the pixel matrix, rendering images unsuitable for photogrammetry.
7. **Understand Sensor Size Implications:** Broadly speaking, the higher the sensor size, the better quality the image. However, using different sensor sizes will also change the 'Angle of view', 'Field of view' and 'Depth of Field' (DOF) when using a consistent focal length.
8. **Maintain Low Noise with Appropriate ISO Settings:** To ensure clean data, ISO settings should be as low as possible, ideally ISO 100 or lower, to minimise noise.
9. **Achieve Sufficient Depth of Field:** For reconstruction software to effectively use the sharp information in your pictures, a deep depth of field is preferable, which means using a high f/stop value. However, be cautious not to stop down your aperture too much (e.g., f/16), as this can cause diffraction issues that blur the entire image. In general, aim to shoot between f/8 and f/13, adjusting based on your sensor size, focal length, and lens quality.
10. **Emphasise Sharpness with Fast Shutter Speeds:** To maintain focus and sharpness, short shutter speeds are advisable.
11. **Optimise Sensor Coverage:** Ensure the subject occupies at least 60% of the frame to maximise the sensor coverage to object ratio.
12. **Forego In-Camera Stabilisation for External Solutions:** In-camera stabilisation might misrepresent camera position due to micro-movements. Instead, rely on lens stabilisation and gimbals to counteract camera shake.
13. **Refrain from Video Capture for High-Quality Outputs:** Avoid using video capture in lieu of images due to inherent limitations in resolution, dynamic range, and potential for rolling shutter effects. Video footage typically does not use full sensor readout, resulting in data loss.

→ Chapter 3

Image Capture

Photogrammetry utilises 2D imagery to generate spatial information, allowing for the creation of 3D models. This process requires not only capturing images but capturing them in a way that optimises their usefulness for model creation.

For specific guidance, this Toolkit draws from MOWAA's experience with RealityCapture, a photogrammetry software owned by Epic Games. It analyses multiple detected features brining many images into a coherent three-dimensional format. However, there are several software available, both paid for and open-source, where many of the principles discussed here are applicable.

Producing a high-quality 3D model relies on adherence to three fundamental principles:

1. **Filling the Frame:** Ensuring the object occupies as much of the image frame as possible.
2. **Image Overlap:** Creating 60-80% image overlap to establish numerous points of commonality between images.
3. **Adequate Subject Coverage:** Capturing all areas of the object to be modeled, including undersides, nooks, and crevices.

Filling the Frame

In photogrammetry, the principle of "Filling the Frame" emphasises the need for the subject to dominate each photograph, utilising a majority of the image's pixels for capturing the subject detail and minimising irrelevant backgrounds. This method ensures that photogrammetry software, such as RealityCapture, can accurately and efficiently process images to create detailed 3D models.

Not every photo needs to encompass the entire subject for effective scanning. The aim is to ensure the subject substantially fills the frame to enhance detail capture.

This principle can be demonstrated when scanning more vertically oriented objects, such as a tree trunk. Taking photos in 'landscape' orientation might result in excessive background space on either side of the trunk, which doesn't contribute to the model. By switching to 'portrait' orientation, the frame becomes densely packed with the subject, significantly increasing the proportion of useful data captured in each image.

Image Overlap

For successful photogrammetry, ensuring sufficient overlap between photographs is essential; without it, alignment of images is poor and occasionally not possible, resulting in a poor or no 3D model output.

An optimal overlap of 70% to 80% is generally recommended, though more intricate subjects, such as paintings or flat objects, may require up to 90% to ensure 'high resolution'.

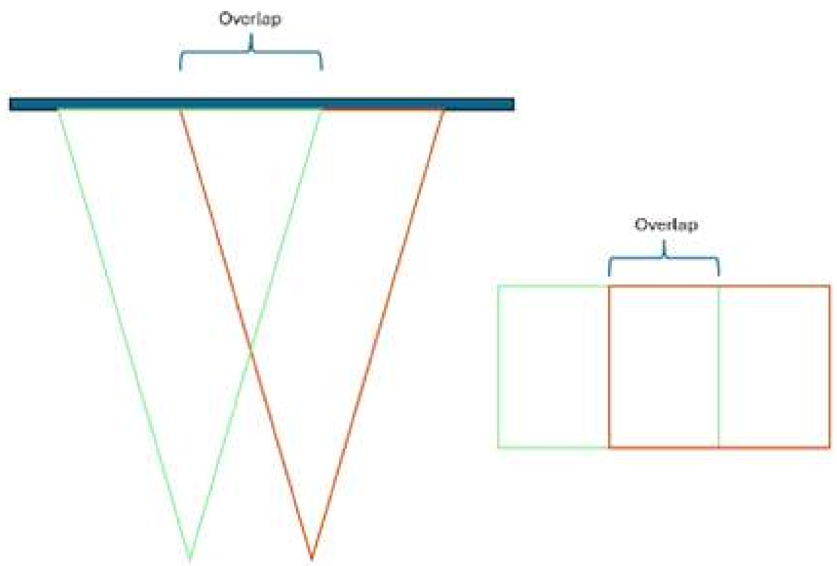

Figure 11 - Area of overlap required for photogrammetric measurements to occur. Credit: MOWAA Digital Team

Subject Coverage

Planning to guarantee complete coverage of the object is an important element of good photogrammetry practice. This involves systematically photographing around the object at consistent intervals and from various elevations, including overhead shots, to capture every angle, ensuring no area is left unscanned or underrepresented.

The reconstruction software needs to recognise every part of the subject to accurately reconstruct it, so taking pictures at every possible angle is also key to a successful scan and reconstruction. You shouldn't change the angle by more than 30˚ between each picture.

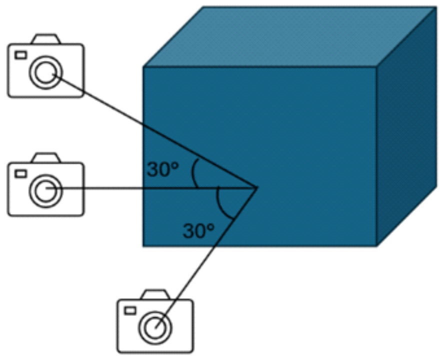

Figure 12 - 30 degrees is the upper angle limit between image capture. Credit: MOWAA Digital Team

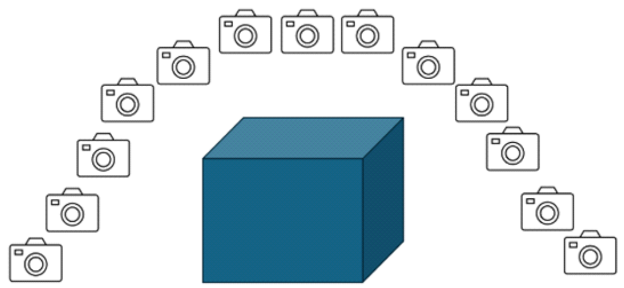

Figure 13 - An example single capture path to ensure adequate coverage. Credit: MOWAA Digital Team

Without multiple images capturing duplicate points, most software algorithms struggle with resolving points and will introduce errors.

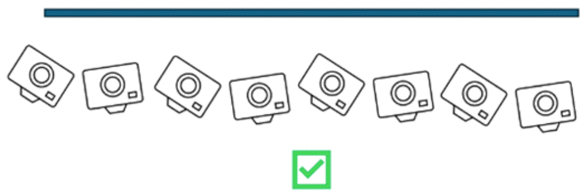

Figure 14 - Shift position and angle of camera to acquire good overlap. Credit: MOWAA Digital Team

Avoid shooting from the same camera position or creating panorama pictures; always move around the object. Panorama images contribute inaccurate 3D information to a model.

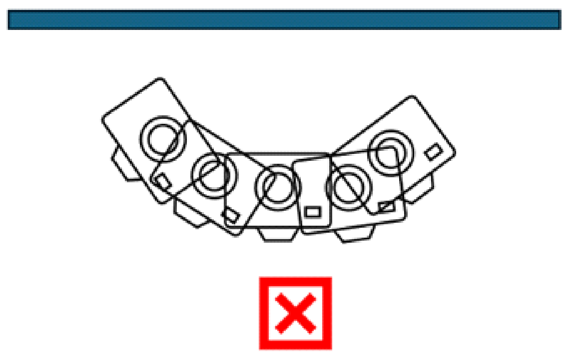

Figure 15 - Avoid changing angles without changing position. Credit: MOWAA Digital Team

Avoid "stacking" images at the same camera elevation; vary the height/elevation of the camera. RealityCapture cannot automatically filter panorama-style images, and including them in the dataset may produce inaccura-cies and registration misalignments.

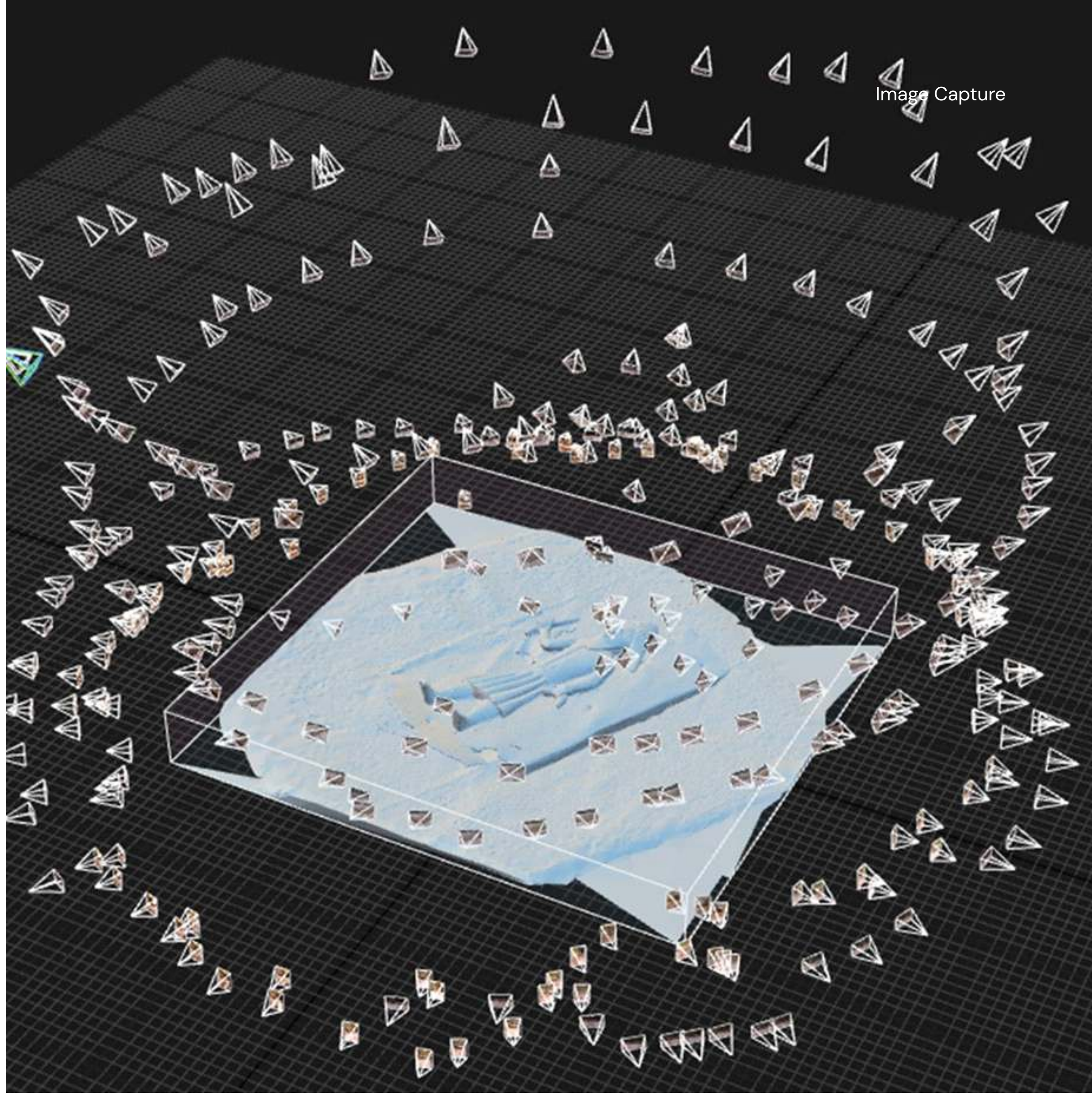

Figure 16 - A systematic capture of images ensuring adequate overlap. Moving in a circular fashion around the object at different heights ensures good coverage of the object. Credit: MOWAA Digital Team

Moreover, it is recommended that photographs are as sequential as possible to help RealityCapture identify relationships between them. Images should not be random. Maintain a planned path with as few interruptions as possible. This will aid RealityCapture's success in generating an accurate 3D model.

Other factors to consider include capture of scale, lighting, colour correction, and reflection.

Scale

Establishing a reliable reference within the images is crucial for accurate scaling in photogrammetry and is vital for the integrity of the 3D modeling process and the resultant output. Accurate scaling is important to ensure the images, and therefore output model, reflects the actual size of the digitised object in reality. This is important if the model is to be imported into other virtual environments; scale and size can also be important for specific research questions.

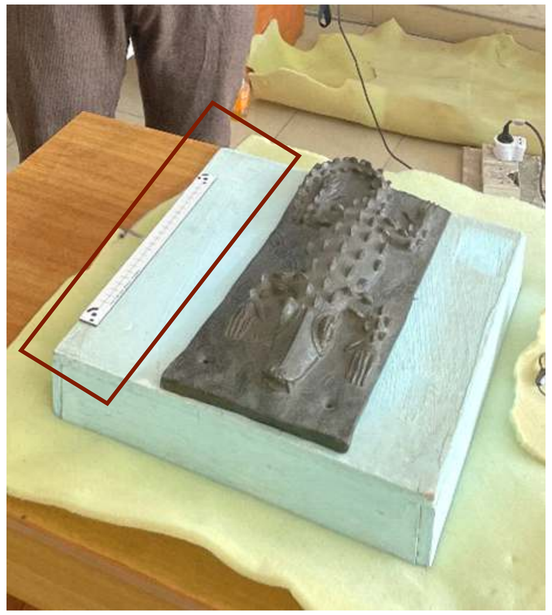

Figure 17 - Scale bars used to provide a reference scale of the object. Credit: MOWAA Digital Team

Reference or 'control' points allow scale adjustment during processing. To ensure 'scaling' is addressed in the data capture element, include a known scale - such as a ruler - with clear markings in a minimum of five of the images. Ensure these reference points are visible in the image and are 'sharp' (not blurry/out of focus).

Figure 18 - Scale bars used to provide a reference scale of the object. Credit: MOWAA Digital Team

Aim for perpendicular measurements to minimise perspective distortion, maximising pixel representation between reference points.
As the distance between these points is known, the image and the model can be scaled accordingly.

The same principle applies to modelling landscapes – however given that rulers are mostly under 1m, two or more 'ground control points' (GCPs) can be used instead. In landscape modelling, which typically covers a large area of the earth's surface, it is preferable to tie the images into a 'Co-ordinate Reference System' (CRS) – which takes into account not only distance, but the curvature and nuances of the earth's surface. While his may seem minor, but it does have small accuracy implications, which are crucial in fields like architecture and engineering. Establishing the models within a Coordinate Reference System (CRS) is vital for ensuring accuracy, not only within the model itself (relative accuracy) but also concerning other features beyond the model content (absolute accuracy).

The referencing of GCPs is undertaken within the software. To understand how to do this, and which CRS to use, requires further understanding of Datums and Projections which are not covered within the scope of this Toolkit.

Figure 19 - Various types of ground 'reference' or 'control' points. Credit: MOWAA Digital Team

Markers for all object or landscape scenarios should be special high-contrast patterns printed on flat surfaces that can be identified in the images captured. This principle applies whether data capture is carried out with a ground-based camera, or a drone-mounted camera. The shape and size of the marker should allow them to be easily identified in photographs – meaning larger markers for landscape models.

Lighting

Awareness of the role of lighting and surface types is important to effectively record features. When considered and addressed appropriately, high-quality results can be achieved in the face of 'difficult' scenarios. For optimal photogrammetry outcomes, images should strive to minimise shadows and avoid underexposed or overexposed sections. This helps to achieve even, diffused lighting across the subject.

When capturing indoors, this can be managed by utilising diffused flash to control ambient light. Especially during sunny days, light from windows can present issues; blinds, curtains or shutters help significantly if available.

Outdoor captures present more challenges due to variable natural lighting conditions, (shifting sunlight and cloud cover, etc.) To adapt, select recording times strategically by capturing images in as short a window as possible and employ shading techniques as needed. If at all possible, avoid outdoor sessions during wet weather, as rain, water, snow and ice cause issues in the algorithm and make it doubly difficult to identify features, hiding or altering important visual information.

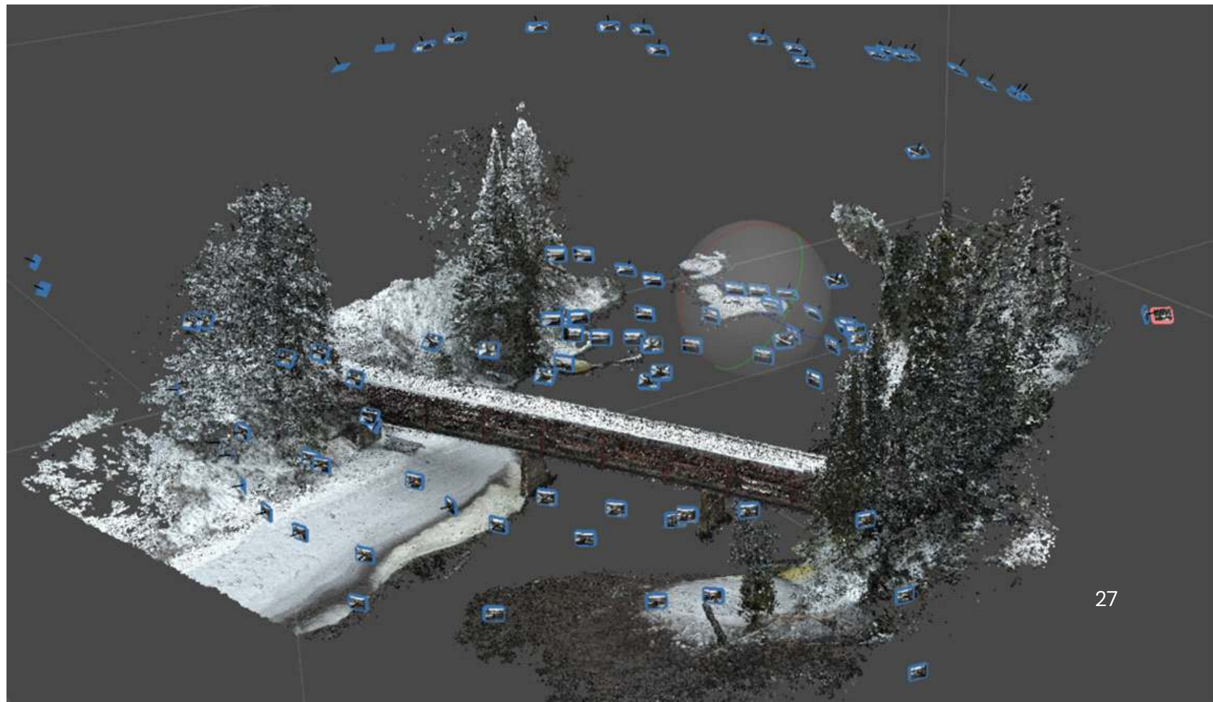

Figure 20 - Landscape model produced through photogrammetry when snow is present. Credit: Michael Tomiak

Colour Correction

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For precise colour representation in photogrammetry, incorporating a manual 'colourchecker' (See Figure 21 below) within your image frames is essential. A colour-checker device is typically equipped with twenty-four standardised colour tiles and serves as a reference for colour calibration. It facilitates the creation of an accurate colour profile during the development phase, ensuring consistency across images. This is crucial for the 'feature detection' element of the process which is easier if the software can refer to a pre-defined or known colour when comparing images and finding patterns.

The colour-checker needs to be in only a few images and is best applied to the first images taken so you don't forget. The image processing workflow (See Chapter 5 – Processing) includes this as a distinct step to help you build this into your photogrammetry practice.

Figure 21 - A colour-checker to help standardise photo colours in image processing. Credit: MOWAA Digital Team

Figure 22 - A white balance-checker to help standardise photo colours in image processing. Credit: MOWAA Digital Team

Reflection

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Minimising glare or specular reflections in your images is crucial for photogrammetry. Specular reflection occurs when light rays reflect off a surface and enter the camera at the same angle, often resulting in images with noise and insufficient detail.

To combat this, position light sources at a 45° angle to the object's surface. For highly reflective or shiny objects, the cross-polarisation technique, can significantly reduce glare. This involves placing polarised filters on both the flash units and the camera lens. It is important to note that while cross-polarisation can lessen the impact of reflections, it may not fully eliminate the potential loss of data in the captured images.

Preliminary Alignments

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Conducting a 'draft capture review' while on-site is a sensible step in ensuring the quality of your image capture. A preliminary alignment runs the data modelling process at a very low detail level, enabling you to verify the accuracy of your capture technique in a matter of minutes. This step is not about processing the final model but ensuring the foundational captures are correctly aligned.

Figure 23 - Preliminary 'draft' model checks to ensure adequate image capture. Credit: MOWAA Digital Team

Figure 24 - Preliminary 'draft' model checks to ensure adequate image capture. Credit: MOWAA Digital Team

To conduct a preliminary alignment, you will need to bring your laptop to the field and ensure that your preferred 3D modelling software is installed. After capturing comprehensive views of the object, transfer the JPEG files from the camera to the laptop and run an 'alignment check' in the photogrammetry software (See Chapter 5 – Processing).

JPEGs are less heavy than their RAW formats. They provide sufficient resolution for a check,but will not result in a high-detail 3D model. This quick process provides an immediate overview of the object's mesh geometry and highlights where detail or coverage is missing.

If you discover missing sections in the point cloud, this indicates areas needing additional image focus and/or coverage.

A failed alignment often points to insufficient overlap among images, signalling the need for adjustment in the capture strategy.

This on-site feedback allows for immediate corrections whilst with the object or site, increasing the quality of the image capture and minimising the potential need to return due to inadequate information capturing the first time.

Summary

- Select camera positions that will completely cover your object – taking note of complex or more ‘hidden’ areas
- Maintain a 60-90% overlap of the terrain of your subject so that you capture stereopairs of the entire object.
- Don’t change the angle of each image by more than 30° between each shot
- The aim is to create a ‘sphere’ of camera positions by copying the terrain of the subject from all possible angles.
- Scaling is vital for accurate models. Seek to include distance references within your images using either rules or larger ground control points to enable scaling and accurate models.
- If in doubt collect more photos. You can always remove poor images later.
- Use a colour-checker in a couple of photos so that you can make the images colour consistent – and support more common feature detections
- Shiny surfaces and reflections are difficult to deal with. Avoid if possible – but there are certain steps that can help reduce problems that it causes
- If possible, run a preliminary alignment on site to ensure you have adequate image capture.

Figure 25 - Onsite tasks not only include imagery capture but preliminary processing to ensure you capture adequate information. This saves you returning to site or the objects at sometimes considerable time and resource. Credit: MOWAA Digital Team

→ Chapter 4

Data Management & Archiving

Archiving cultural heritage is not just about preserving the past; it is about securing the legacy for future generations and ensuring organised and easy access to that information. Projects will vary in scope depending on the purpose, funding and technical capabilities of those involved. In research contexts, archive management typically involves logically and comprehensively collecting and documenting your work and the approaches or methods deployed.

In the context of scientific approaches or where practitioner learning is a project priority, being transparent about your methodology is just as important as your end results. It allows others to test your outcomes, reproduce them if necessary, and learn from or propose other approaches.

Whilst the digitisation of cultural heritage through photogrammetry presents a unique set of challenges and procedures, the digital transformation occurring presently provides a lot of new, more efficient ways of working and archiving.

There is a no 'correct' way to manage, store and structure your data; a logical, organsied and intuitive method is required, however. The goal is to allow someone in the future to access the data and, in a short time, understand the workflow and work with the data themselves.

File Management

A practical approach to organising data involves dividing folders by their content type. In this project example, a folder 'tree' structure is created – storing the original 'imported' data containing the RAW (larger file size) and JPEG (lower file size) images (splitting between those with the 'colour-checker' images and those without), a Photogrammetry software file that holds the process (RC), and 'exported' 3D model data (Export).

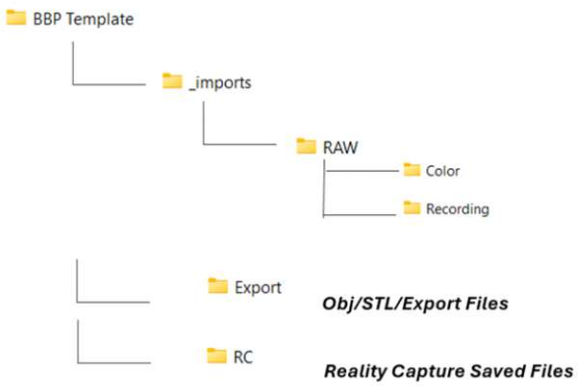


Figure 26 - An example folder tree to store organised datasets created in photogrammetry. Credit: MOWAA Digital Team

Within these primary categories, further subdivision by the object or area of interest enhances navigability.

Employing a consistent naming convention significantly aids in this process. This supports efficient file management and contributes to a more coherent and manageable project environment, particularly beneficial in projects with extensive datasets.

Naming Conventions

Structured Identification

For both archiving and post-processing, naming conventions are paramount. They aid in the alignment process by allowing specific photographs of the documented object or site to be easily identified.

For instance, a naming convention like 180mm_Room_J_Wall_E_001 gives location information that facilitates overlap identification, making it easier to navigate through vast amounts of data.

Data Backup

Redundancy is Key

Given the RAW file formats and the large volume of images collected, ample storage space is necessary, not just on the processing machine but also within a backup system. Data is vulnerable to being deleted, altered, or corrupted at various stages of the workflow. Hence, maintaining redundant file sets is essential for recovery in the event of data loss or drive failure.

Cloud Platforms

Cloud platforms are becoming increasingly more cost effective for safe, secure, large dataset backups. This avoids the need to address and invest in the latest supported storage types. Products such as Amazon Web Services 'Glacial' or 'Deep Archive' products allow you to store large quantities at a relatively affordable price. However, this is on the basis that you will not likely need regular access to them.

Long-Term Storage

Adapting to Technological Evolution

For long-term storage, updating file types to the most current format is important and an ongoing battle. As software and hardware evolve, older file types may become obsolete, making them difficult to access. Periodic updates help mitigate the risk of information decay, ensuring that cultural heritage remains accessible to future technologies.

Metadata

Comprehensive Documentation

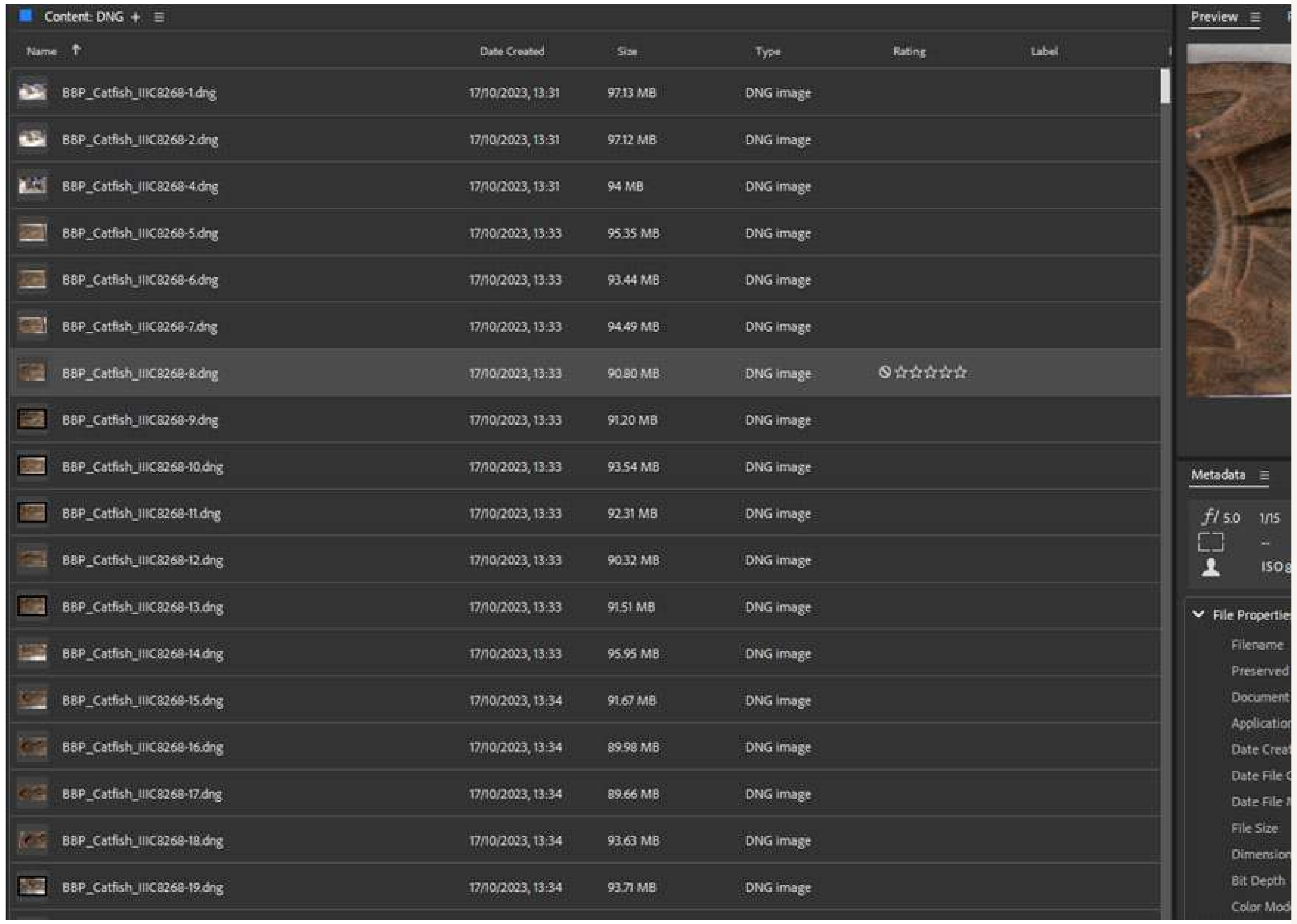
Metadata serves as a vital roadmap for processing, offering context and ensuring that the archived cultural heritage is not merely a collection of images, but a well-documented snapshot of the method and effort involved. Metadata attribution, ideally embedded within the image files or folders, can include details such as location, site/capture conditions, individuals involved, site/capture plans, collection areas, and naming conventions.

Collecting metadata about the image capture, as well as the individuals, conditions, and circumstances involved, is crucial for establishing the dataset's context. Generally, more metadata is better, but there's a trade-off in terms of time and resources.

Such data can be efficiently embedded in applications designed for 'metadata' attribution.

For MOWAA's project, Adobe's Bridge application (See Chapter 5 – Processing) was used to input metadata within each image file.

Figure 27 – Managing metadata for many images is made easier with applications like Adobe's Bridge. Credit: MOWAA Digtial Team



→ Chapter 5

Processing

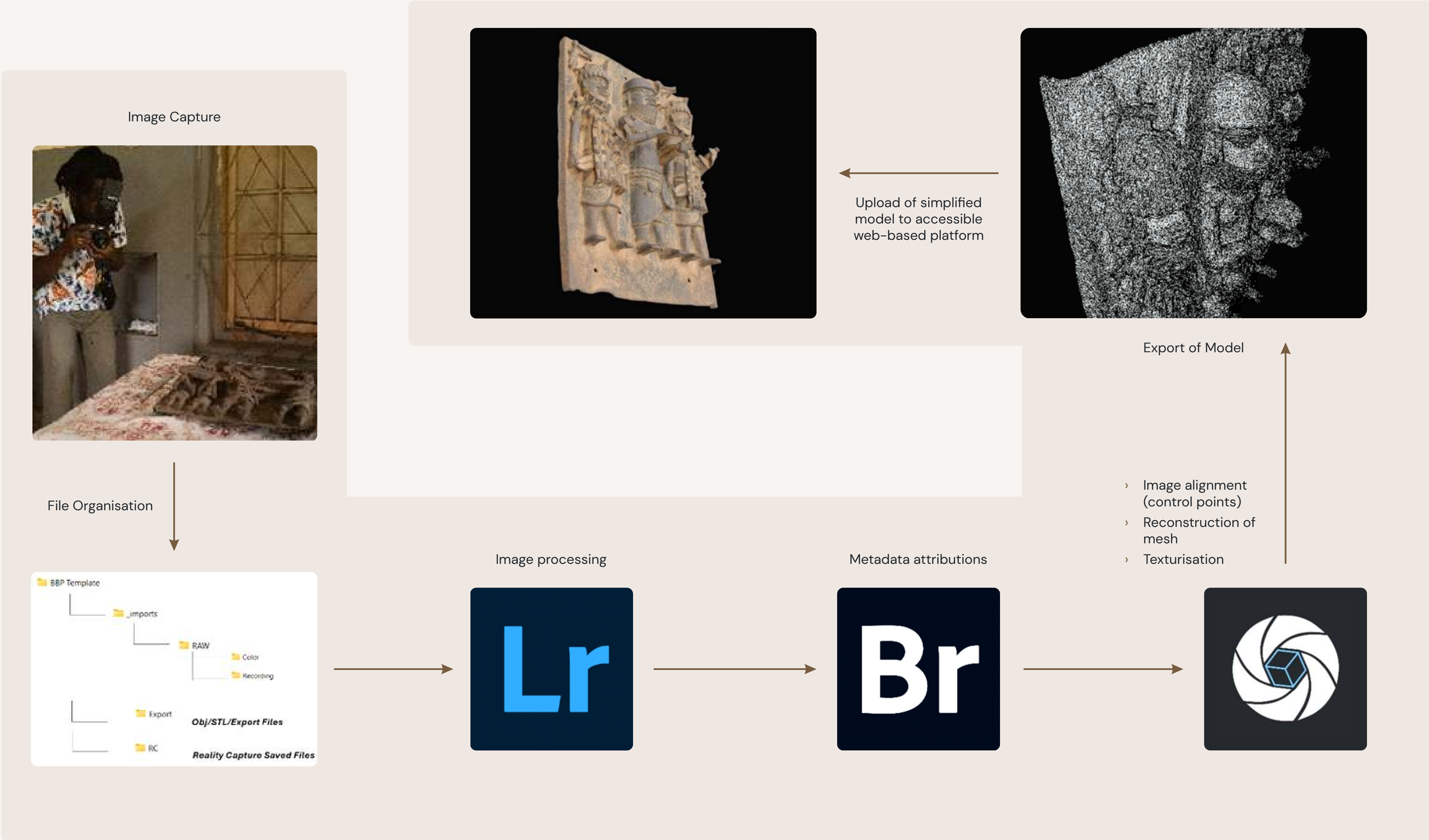
Processing Workflow

The 'Processing' Stage for 3D model creation through photogrammetry requires training in photogrammetry software. This software training element is not covered within this Toolkit. Photogrammetry softwares broadly follow the same basic steps, differing in Graphical User Interface (GUI) and efficiency of the underlying algorithms.

While a variety of software options are available, MOWAA's digital team used the following products in recent undertakings:

- Adobe's Light Room for image colour/quality standardisation
- Adobe's Bridge for metadata input
- Epic Games' Reality Capture for image alignment, mesh reconstruction and texturing

A typical processing workflow would comprise the following:



Outputs

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After processing, 3D digital models can be downloaded as outputs – final products that are compatible with various viewing platforms, including websites and offline databases. 'Output' or 'Export' formats of models broadly depend on the software. Whilst by far the most common is OBJ, this format may become fairly quickly outdated as changes in technology and format improvements occur.

For the Plaques Project, RealityCapture supported the following 3D output formats: OBJ, FBX, DXF, DAE.

When deciding on your output format, it is sensible to review the 'accepted' formats from any other platform you wish to house, display or visualise your models in. For this project, MOWAA has selected to host models on SketchFab, a 3D modelling platform website used to publish and share 3D, VR and AR content. SketchFab allows users to display 3D models on the web, to be viewed on any mobile browser, desktop browser or Virtual Reality headset. It supports FBX, OBJ, DAE, BLEND, STL formats.

A comprehensive comparison of the advantages and disadvantages of 3D formats and their integration with other 3D visualisation software platforms or tools is beyond the scope of this Toolkit. However, cultural practitioners and other readers are highly encouraged to keep up to date with developments in this area by watching or reading software reviews and speaking with other active practitioners.

Tips and Recommendations

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Here are some Key Tips and Recommendations in the processing steps:

- **Store the original RAW or DNG Format:** Ensure that you shoot in and store the 3D model in RAW (or DNG). This format provides non-destructive editing capabilities, higher bit depth, and better colour information. This ensures maximum quality retention for processing and flexibility to revert to original, highest quality image.
- **Quality Development:** Develop images at the highest quality possible, adjusting parameters such as exposure and white balance if necessary. Use software that offers comprehensive editing features to enhance image quality without compromising the original data.
- **Avoid Artificial Sharpening:** Be cautious with artificial sharpening. Excessive sharpening can introduce non-real pixels, potentially confusing the photogrammetry software. Aim for minimal to no artificial sharpening.
- **Image Masking:** 'Masking' can be used to eliminate unnecessary elements from images, speeding up processing by reducing the pixels analysed. However, this reduces the quantity of pixels or visual information available for better alignment; as such, balance is needed. Masking can be helpful for busy backgrounds (including clouds or skies) and preventing these elements from being processed as features in the final product, leading to better mesh and texture quality.
- **Maintain Aspect Ratios:** Use the camera sensor's native aspect ratio to avoid cropping distortion data. Altering aspect ratios post-shooting is not recommended as it can hinder the software's ability to calculate accurate camera poses.
- **Preserve EXIF Metadata:** EXIF data contains critical information for photogrammetry processing, including camera settings and GPS data. Do not delete or alter this information.
- **White Balance and Colour Calibration:** Utilise colour checkers for accurate colour calibration. Apply calibration consistently across images shot under similar lighting conditions. Software like Adobe Lightroom and Capture One can significantly aid in making colours consistent and improving image quality.

→ Chapter 6

Hardware & Software Requirements

To be able to undertake photogrammetry, there are a few specific hardware and software requirements to fulfil. These are required to perform the processing steps, including the alignment, reconstruction, UV wraps, texturing and projections.

Hardware

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Hardware includes the data capture device (e.g. a camera – see Chapter 2 – Photography) but also the computer for processing the images and creating the 3D Models. Broken down into their more basic parts, this comprises:

1. A central processing unit (CPU) - the logic circuitry that responds to and processes the basic instructions that drive a computer.
2. A graphics processing unit (GPU) - that performs mathematical calculations at high speed allows tasks like graphics rendering, machine learning (ML), and video editing.
3. Random Access Memory (RAM) – the computer's short-term memory. It's where the data is stored that your computer processor needs to run your applications and open your files.

The following specifications[4] for the computer element are required in terms of hardware processing capabilities:

› 64bit Microsoft Windows version 7 / 8 / 8.1 / 10 or Windows Server version 2008+

› 64bit PC with at least 8GB of RAM (16GB recommended)

› A machine with at least 4 CPU cores

› GPU: NVIDIA graphics card at least 1GB VRAM and CUDA 3.0+ capabilities (recommended 6.1+)

It's important to note the industry trend towards 'cloud processing'. This involves capturing data/images and uploading them to a cloud server for processing. However, this method tends to be more expensive due to storage space, processing costs, and the advantages of using modern, secure infrastructure. Cloud computing often requires a subscription (monthly or yearly). Additionally, it can be problematic if you discontinue the subscription and need to find storage for the backlog of input images used for all created models.

[4] Reality Capture Data Sheet, TARASQUE 1.2, https://www.capturingreality.com/assets/Documents/datasheet_TARASQUE_1.2.pdf

Software

While we used Reality Capture in this project, there are several other photogrammetry software currently on the market. See Additional Tools & Software for more details on approaches to software types.

For this project, Reality Capture was selected for several reasons including its focus and support of cultural heritage projects ventures.

Alternative options include:

- Pix4D
- ArcGIS Reality
- Meshroom

These range from $1000 through to $5,000 per year depending on features, supported output formats and integration with other software.[5]

Reality Capture also offers a Pay Per Input ('PPI') option as do some other photogrammetry software providers. This is a cost-effective, especially if you do not want to create models on a regular basis and therefore cannot justify a purchase of the software. This pay model option enables you to plan according to the resources you have available.

Once you are ready to export, the software application will check how many of your 'inputs' (i.e. images) will need licensing to export any product, and you pay just for that.

Reality Capture provide a PPI Cost Calculator here.

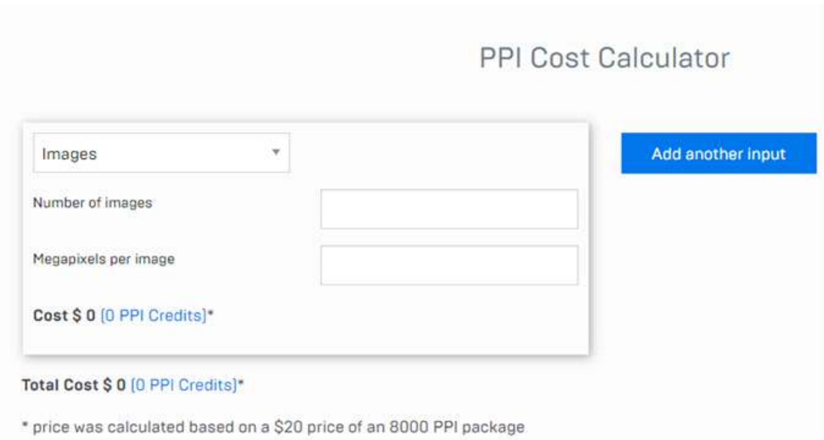

Figure 28 - Reality Capture's PPI cost can be calculated using their credit calculator.
Credit: RealityCapture PPI https://www.capturingreality.com/RealityCapture-PPI
(Accessed 01/02/2024)

However, if you plan to undertake photogrammetry on a regular basis and tend to create complex models that require many photos for a model – this ends up being reflected in the cost.

The software is free for anyone to download and is accessed via a purchased 'license' which provides user with unique credentials to 'login' within the software application.

[5] Note as of April 2024, Reality Capture will be freely available to "free to use for students, educators, and hobbyists, and companies earning under $1 million USD in yearly revenue.

→ Chapter 7

Getting Started

Careful planning and consultation are key to getting high-quality results, particularly when working with collections and sites beyond your control. Data capture scenarios are different in terms of location, time, equipment availability etc. As such, planning and collaboration are essential to ensure success when preparing for photogrammetry projects.

Pre-Scan Preparation
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Environment Assessment: Allocate time, ideally a day or two before the scan, to assess the environment for favourable scanning conditions. This includes evaluating the lighting to ensure it is even and determining if additional lighting is required.

Collaboration with object owners and caretakers: It is important that digital preservation initiatives do not result in further deterioration or damage to the work. Certain objects may respond negatively to light exposure or may simply be too fragile to work with. Engage with those responsible for the object and its care, such as conservators, to understand any special conditions needed to handle or work with the objects. It is encouraged to work closely with professionals where possible to determine how the artefacts can be positioned advantageously for photogrammetry and whether stands and supports may be needed. This collaboration can also uncover any specific considerations or other restrictions related to the objects to be scanned.

Project Planning
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Storage: Consider the likely data quantities and file sizes needed for the entire project. Even a few images can quickly build p – especially when stored in RAW (uncompressed) format. Ensure that there is more than ample data storage space and purchase all storage prior to commencing image capture. The project data sizes will vary depending on the camera type and resolution you use. A single raw-format 40 mega-pixel image can be up to 100MB per photo (a JPEG version of this would be reduced to about 30MB). A resultant model from 200 JPEG images simplified to 5 million triangles would result in around a 500MB 3d model.

When using the recommended camera types and megapixels, the images can easily accumulate up to 50GB per item and will only increase with time. When combined, the images (especially RAW format) are usually of greater size than the overall 3D model.

For example, an object with 300 RAW images captured using a 40 megapixel digital SLR camera results in approximately 30000MB (30GB). The JPEGS – compressed RAWs – which create the model, equate to around 9000MB (9GB).

The resultant model in its highest resolution would be around 2 GB. The simplified model used for online access would be around 500MB. This equates to 41.5GB.

That said, there is a balancing act and if there are a large number of items to digitise, but not the budget for adequate data storage, reduced file sizes might be required (sacrificing the model quality) or, if you do not back up your data, loss of the original data.

For processing, a Solid-State-Drive (SSD) - external or internal - is much preferred for efficient processing.

For long-term storage data can be stored on physical hard drive(s), or cloud-based storage. This also applies when the data requires higher security protocols and remote access is necessary amongst the team. For example, Amazon Web Service's

Figure 29 – Products like Amazon Web Services (AWS) provide a more cost-effective way to store large datasets which you are unlikely to require regular access to. Credit: rawpixel.com Creative Commons https://creativecommons.org/publicdomain/zero/1.0/

(AWS) 'Deep Archive' can be used as it has a relatively low cost, on the proviso that access is rarely needed, and when it is, immediate access isn't necessary.

Site and Capture Planning: Developing an object or site plan of approach (using existing drawings or documentation if available), helps in the efficient execution of imagery capture – and supports naming conventions used in post-processing (See Chapter 4 – Data Management & Archiving). This also helps plan the choice of lens and camera.

Figure 30 - Considering lighting and other factors prior to arriving on site. Talking to curators or object owners prior to commencement is key. Credit: MOWAA Digital Team

Mitigating External Factors

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Weather and Lighting: For outdoor objects, consider weather conditions and optimise capture times based on sun angles to minimise shadow effects and align images more effectively in post-processing.

For indoor lighting, if poor, arrangements for museum lighting can be made, and for tall objects, ladders acquired.

Traffic and Accessibility: Understand the site's traffic patterns and public accessibility hours to plan captures during less crowded times, ensuring a stable and consistent capture environment.

Learning with Us

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This project was supported by the Ford Foundation.

Please contact info@wearemowaa.org if you would like to get in touch with us.

Appendices

Glossary of Terms

- **Aperture:** Size of the opening behind the lens through which light travels. The larger the aperture, the shallower the depth of field; the smaller the aperture, the greater the depth of field.
- **Bracketing:** Taking several shots of the same subject at different exposure settings. This is useful for ensuring at least one photo is exposed correctly or for creating HDR images.
- **Chromatic Aberration:** A type of distortion where colours are fringed or blurred in an image, caused by the lens' inability to focus all colours to the same convergence point.
- **Colour Balance:** The global adjustment of the intensities of the colours. This process is used to acquire correct colour for rendering and printing. Also known as White Balance, a term used frequently in photography.
- **Colour Depth:** The number of bits used to represent each colour of a pixel. Higher bit depth allows for more colours and more detailed colour gradation in an image.
- **Colour Checker:** A colour calibration target with twenty-four known colour tiles that provides a baseline much like a scale for colouration.
- **Depth of Field:** Also known as the "focus range", depth of field is the distance within which everything is in focus.
- **Dynamic Range:** The range of luminance values that a camera can capture, from the darkest shadows to the brightest highlights. A higher dynamic range allows for more details in both areas.
- **Exposure:** The length of time in a single shutter cycle. Determines how bright or dark an image will be.
- **Focus:** The area of the image with the highest quality and clarity. Areas out of focus will appear blurry and cannot be used for photogrammetry.
- **Geotagging:** Adding geographical identification metadata to photographs, such as latitude and longitude coordinates, often for mapping or locating images on a map.
- **Global Shutter:** A type of camera shutter that exposes all pixels on the sensor simultaneously. It eliminates the distortion that can occur with rolling shutters in fast-moving subjects.
- **HDR (High Dynamic Range):** A technique used to increase an image's dynamic range by combining several images taken at different exposure levels.
- **ISO:** The sensitivity of the camera's sensor. Greater sensitivity absorbs light more quickly but produces a lower quality image.
- **Lens Distortion:** Deviations from rectilinear projection in photography, affecting the shape and features of the subject. Common types include barrel, pincushion, and mustache distortion.
- **Rolling Shutter:** A shutter mechanism where the sensor is exposed and read line by line. It can cause distortion in fast-moving subjects or when the camera moves rapidly.
- **Solid-State Drive:** An external or internal – preferred for efficient processing.

Additional Tools & Software

Software Approaches

There are a variety of mobile photogrammetry software on the market for both iOS and Android, with diverse pricing plans. However, for high-end professional projects – which cultural heritage projects should strive for in terms of recording maximum detail –photogrammetry software is found in two categories: Open Source and Paid license Applications.

Open-Source Photogrammetry Software

Open-source software is typically developed collaboratively, with its source code freely available to anyone who wants to use, study, modify, and distribute it.

The development community often contributes to its improvement and expansion.

Pros:

- Open source is typically free
- Drives a community – often of very proficient knowledge specialists.

Cons:

- Usually lags behind paid for software in capabilities, in that it is often more complex or less intuitive to use, and prone to errors and bugs.
- Not guaranteed to utilise the latest capabilities in technology (e.g. latest graphics cards.)
- Providers typically won't offer customer support (although research may be undertaken on community forums), and there will be less professional, dedicated training available.
- Cannot offer functionality like integrated storage and built in datasets.

Examples of open-source software include Linux operating system, Mozilla Firefox web browser, and Apache web server.

Paid Applications

Pros:

- Usually offers the latest techniques and technologies
- Features higher investment in design and customer usability
- Has customer support, dedicated training, and regular updates.
- More likely to have integrated functionality with other applications and/or storage.

Cons:

- Can be expensive to use (either one-time purchase or a subscription model)
- The source code and details of algorithms are typically not accessible to users/public

Examples of paid applications include Microsoft Office suite, Adobe Photoshop, and various mobile apps available on app stores.

Other photogrammetry software applications include:

	Software Name ↓	License ↓
Image Processing and Metadata Management	Adobe Bridge	Paid
	Adobe Lightroom	Paid
	Darktable	Open Source
	Capture One	Paid
Photogrammetry Applications	Reality Capture	Paid
	Meshroom	Open Source
	Visual SFM	Open Source
	PolyCam	Paid (Mobile App)
	Pix4D	Paid
	Agisoft Metashape	Paid
	Blender	Free

Canon EOS 5D Camera
(5 November 2019)
Credit: parth787
Creative Commons
https://commons.wikimedia.org/wiki/File:Black-canon-dslr-camera.jpg

Other Data Capture Tools for 3D Model Creation

As discussed in the , there are a variety of ways to capture information to create 3-dimensional models including active and passive sensors. These vary in cost, accessibility and flexibility. Photogrammetry itself, is a method of collecting geometric data from photos or two-dimensional images. It entails the analysis of digital information – collected by any means - with the objective of creating spatial measurements of environments and objects.

As 'heritage' can span from the small scale through to the very large, consider which of the following devices/sensor types may be best harnessed in your project to digitally preserve, in 3D, the subject matter in question. The 'best' capturing device for photogrammetry depends on several factors, including the specific application, the level of detail required, and the budget available – as well as the device you have on you at the time.

Digital Cameras

- High-quality DSLR or mirrorless cameras with interchangeable lenses are popular choices for photogrammetry.
- They offer excellent image quality, manual controls, and the ability to use different lenses for various shooting scenarios.
- Popular brands include Canon, Nikon, Sony, and Fujifilm.

Action Cameras

- Action cameras like GoPro are compact, lightweight, and rugged, making them suitable for capturing images in challenging environments.
- While they may not offer the same level of image quality as DSLRs or mirrorless cameras, they are often sufficient for many photogrammetry applications.

Smartphones

- Modern smartphones are equipped with increasingly capable cameras, with some models featuring multiple lenses for enhanced photography. The latest iPhones (2020 'Max options' onwards) have built-in 'depth-map' capability – which is described as 'quasi-lidar' results.
- Smartphone cameras can produce high-resolution images suitable for photogrammetry, especially when combined with dedicated photography apps or accessories like lens attachments.

Action Camera
Creative Commons
https://www.trustedreviews.com/best/best-gopro-3584702

Smart Phone
Creative Commons
https://www.trustedreviews.com/best/best-android-phones-3438996

Drones (Unmanned Aerial Vehicles – UAVs)

- Drones equipped with high-resolution cameras are commonly used for aerial photogrammetry, allowing for the efficient capture of large areas and inaccessible terrain.
- They offer unique perspectives and can capture images from different altitudes, enhancing the quality and coverage of photogrammetric data.
- Popular drone brands include DJI, Parrot, and Yuneec.

LiDAR Scanners

- While not strictly cameras, LiDAR scanners are often used alongside photogrammetry techniques to capture highly accurate 3D data.
- LiDAR scanners emit laser pulses and measure the time it takes for the light to return, allowing for precise measurements of distances and geometry. They are able to 'see through' vegetation to the ground through the small number of light pulses that are able to sieve through the gaps in the canopy/foliage.
- They can be ground or, to cover large areas UAV or airplane mounted. They are provide very organised, high-quality datasets. This isn't always preferable, if you need more data on specific detailed/hard to access areas.

Drone
Credit: rawpixel.com
Creative Commons
https://dronelife.com/2023/01/16/all-sim-cards-are-not-the-same-the-risks-of-using-consumer-sim-cards-for-drone-operations/

LiDAR Scanner. Credit: MOWAA Digital Team

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