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【研究論文】

Archaeological 3D Scanning in Context
- Multi-scalar 3D Capture and Visualization from the Final Jomon Period Sugisawa Site -

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要旨

本稿では、滋賀県米原市の杉沢遺跡における縄文時代の土器棺の 3D 画像化の方法とプロセスについて述べる。本プロジェクトでは、杉沢遺跡の 2023 年度の土器棺発掘において 3D 画像で土器棺の発掘過程を記録し、180 点以上に破砕していた土器棺の破片を、3D 画像で撮影し、地中に埋没した土器棺を土砂がない状態で観察することができる状態に復原した。ドローンによる空中スキャン、発掘現場のスキャン、180 点を超える個別の土器片のスキャンを統合して、出土した遺物を正確に記録し、周囲の土層を除いた状態で、遺物を三次元空間における位置関係の中で可視化することを可能にした。

Abstract

This article describes the 3D capture and visualization of Jomon period burial pottery from the Sugisawa site in Maibara City, Shiga Prefecture. The project took a multi-scalar approach to the 3D documentation of the excavation at Sugisawa, with a specific emphasis on a pottery burial that was excavated on site. Drone scans, excavation scans, and the scans of over 180 individual pottery sherds were combined in order to accurately record the artifacts excavated on site and to be able to visualize the artifacts in their positional contexts in 3D space, absent of the surrounding layers of soil.

1. Project Introduction

The Sugisawa site is a Final Jomon period site, dating back approximately 3000 to 2300 years ago, located in Maibara City in Shiga prefecture. The site has been excavated a number of times over the past hundred years, unearthing many stone tools, pottery, and of particular note, a number of pottery burials. Pottery burials are a form of mortuary practice in which the remains of the deceased are placed inside an earthenware pot or jar which is then buried as part of the funeral. While single pot burials date back to the Early Jomon period, the Sugisawa site was the first location in which a conjoined pottery burial, where two pots are buried together as a single container with the openings facing one another, was dated to the Jomon period. To date a total of 14 sets of burial pottery from the late Jomon period have been excavated at the site, and Kenichi Yano (Ritsumeikan University) who has been continuing excavation surveys at the Sugisawa site since 2011 has helped to excavate several of them[1,2,3,4].

In the most recent excavation in 2023, another pottery burial was uncovered. At this time, work was already underway by Yano and Corey Noxon (Ritsumeikan University) to incorporate photogrammetry scans into the survey work done that year[5]. When the pottery burial was identified, it was decided to direct the majority of the digital capture work towards the burial pottery. The excavation approach of the burial pottery was specifically tailored to facilitate the construction of a 3D model of the burial pottery in the position it was found while excavating. The burial pottery was cracked and somewhat deformed, with some upper sections likely lost due to modern cultivation work but was largely in the same state in which it was buried. These circumstances aligned well with an effort to follow up on a community art and archaeology project that had been started several years before.

In 2017, the first collaborative exhibition of artifacts excavated from the site was undertaken with artist Naho Yokotani, UMMM Co., Ltd., and Megumi Matsuo (VOICE GALLERY). Over the course of the 2017 field season, the locations of artifacts were meticulously recorded as they were collected, and once the excavation was complete, the pottery fragments were hung from the ceiling of the exhibition room, with their positional contexts from underground being recreated in mid-air. This allowed viewers to not only view materials from the site, but to better understand the complexity and spatial context of the artifacts within the site. When Sugisawa was again excavated in 2018, the locations of the pottery fragments were recorded as they were excavated, and another exhibition was held in 2019 in which the pottery fragments were supported by thin poles supported from the floor[4].

The excavation approach of the burial pottery in 2023 is intended to be a continuation of these previous exhibits, but with the goal of displaying the artifacts digitally. The excavation in 2023 wasn't the first to attempt a 3D visualization of the burial pottery at Sugiswa. In 2020 Noxon came to the site and took preliminary scans of one of the burial pots after it was uncovered, allowing for a 3D view of the pottery within the excavation context. The resulting 3D model only showed the upper exposed pottery sherds, but the 2023 project aimed to go much further. Could we once again raise these artifacts out of the ground to be viewed in the air, but digitally? By combining multiple scans of the excavation area as the burial pottery was being excavated and extensive scans of the individual sherds after they were gathered and processed, we were able to present the excavated sherds in the same spatial arrangement in which they were buried, but free from the surrounding soil, positioned in the digital air. This article provides further background on the Sugisawa site, discusses the steps that were taken to tackle this new project including a multi-scalar approach to digital recording, describes the difficulties encountered along the way, and includes a discussion on how this approach can be expanded upon and improved in the future.

2. The Sugisawa Archaeological Site

The Sugisawa Site is a site from the late Jomon period located in Sugisawa, Maibara City, Shiga Prefecture. While stone tools were known to have been discovered near the site since the Meiji period, local historian Nakagawa Senzo was the first to formally introduce the stone tools excavated at the site in 1924[6]. In 1936, two sets of earthenware burial pots were excavated at the site, and in 1938 an excavation survey conducted by Kyoto University's Kobayashi Yukio discovered a burial in which the burial pots were joined mouth-to-mouth which were dated to the latter half of the Final Jomon period[7]. While this style of burial had been identified during the Yayoi period, it was the first instance of this burial style being identified in the Jomon period. Another similar pair of burial pots were discovered at Sugisawa in 1954 during an investigation by Kyoto University of Arts and Sciences (now the Kyoto University of Education), with yet another conjoined pottery burial was discovered in 1995 which dated to the Final Jomon period[8]. In 2006, two more pottery burials from the Final Jomon period were unearthed, including a set of conjoined burial pots containing burnt Jomon-period human bones[9]. In 2011, Ritsumeikan University conducted an excavation survey to confirm the extent of the site, unearthing one grave and two storage pits from the Final Jomon period, and the following year unearthed a possible storage pit from the Final Jomon period[1,2,3].

In 2022 and 2023 however, another three pottery coffins from the late Jomon period were excavated. Of these, two were conjoined burial pots. To date, a total of 14 pottery burials from the Late Jomon period have been excavated at the Sugisawa site so far. In addition to these pottery burials, at least three pits that are presumed to be storage pits for buried nuts have been confirmed at the site. Although no remains of pit dwellings have been identified, multiple pillar holes have been confirmed, making it highly likely that a dwelling from the late Jomon period existed. Numerous sanukite flakes, which are traces of stone tool production, have been excavated, as well as numerous pottery fragments and stone tools such as stone arrowheads and grinding stones. This makes it highly likely that the settlement continued for approximately 300 years, from the middle to late portions of the Final Jomon period. This occupation period seems to be fairly discrete, as very few remains from before the Final Jomon period have been found at the site, and no artifacts dating to the subsequent Yayoi or early Kofun periods have been found.

3. A Multi-scalar Approach to Digital Archaeological Recording

Context is a key factor in the interpretation of archaeological sites and remains, and the context of artifacts, features, and related geographic topographies can be approached from a variety of different scales. On a broad scale researchers might look at the spatial relationships between archaeological sites in a geographic region as well as how those sites are situated in, and connected to, geographic features such as mountains, rivers, and lakes within that region. Within a single site an archaeologist may look at how different dwellings and structures were positioned at a site and how the position of dwellings, structures, and other archaeological features changed over time. At a smaller scale one could look within the dwellings themselves, and how different features are arranged within the dwellings and where artifacts within the dwellings were positioned or discarded, providing some insights into daily life within the dwelling or how it was dealt with when it was finally abandoned. Zooming further in, an archaeologist might be interested in focusing on a specific artifact within the site, looking for evidence as to how it might have been made or how it was used. Stylistic elements inherent in the artifact could also indicate connections to other sites and cultures, which once again shifts us out to a much broader scale, emphasizing the importance of the connections between these scales and the context that they provide.

Before any analysis can be completed, however, the data needs to be collected and placed within a cohesive context from which connections can begin to be made. The methods of gathering data, and for the purposes of this paper, 3D data, differs depending on the scale in which one is working at the time. Broad-scale 3D capture often places an emphasis on capture speed at the expense of extreme accuracy and precision, while those values might be reversed when dealing with the scanning of smaller objects. The approaches to scanning and integrating 3D data from these different scales are still in the process of development within the field and were an important aspect of this project.

4. Starting Wide

The 3D scanning and digitization of the Sugisawa burial pottery aimed to provide not only a positional context of the pottery sherds to one another, but also to provide a broader spatial context of the pottery to the surrounding excavation area and the neighboring environment. A multi-scalar approach was needed to accomplish this task. For the broadest scale, a DJI Air2S drone was used to make a wide spanning 3D scan of the excavation site and the surrounding area. This base scan was intended to help provide a georeferenced context for the later excavation area scans. Broad-scale scans using the drone were completed on two separate occasions but in both instances, areas of significant tree cover made it difficult to properly capture certain areas of the surrounding environment. Despite some gaps in the scans, these scans captured enough information to properly position later scans within the broader context of the site and surrounding areas as intended (Figure 1).

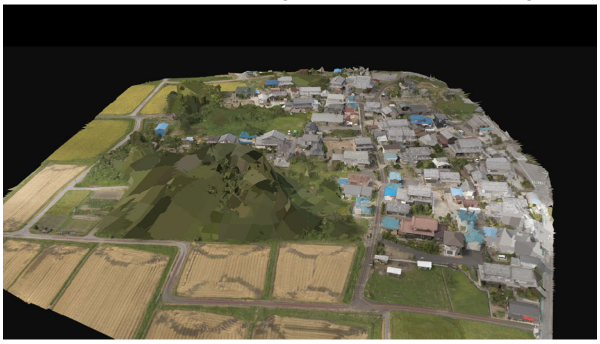

Fig. 1. Image of 3D scan of Sugisawa site and surrounding area. Excavation area visible in the lower right portion of the image by white shade tents.

These scans were conducted at fairly high altitudes in order to efficiently capture a broad area, but the scans also needed to be able to be connected to the more focused scans of the excavation area. To help align these different scans, semi-permanent 3D printed targets were designed to provide consistent control points to tie multiple scans together. The initial altitude in which the drone was capturing images for the photogrammetry scan was too high to be able to clearly identify these markers, however. To compensate, at the end of the flight the drone was positioned above the excavation area, the elevation was reduced, and additional image sets of the excavation area were captured. This process was repeated several times, reducing the elevation at each step in order to help align the higher altitude images with the excavation area.

5. Scanning the Trench

In total, there were fifteen scans that focused on the excavation area and the burial pottery. Scans initially focused on the entirety of the excavation area, but once the pottery burial was discovered, the focus shifted towards the burial and the immediately surrounding areas. The scans were made with several different cameras including a Sony α7R IV, a Nikon D5300, and an Olympus TG-3. The scans made by these different cameras were shot under a variety of different shooting conditions, which later led to some difficulties in aligning the resulting scans. The semi-permanent targets played an important role in these alignments, which would have been incredibly difficult without the shared reference points between the scans. The custom targets were designed to fit around the top of large metal camping stakes that would hold their position throughout the excavation period. The targets were 3D printed and had removable tops with machine readable 12-bit circular encoded targets printed on top to assist with automatic detection during the photogrammetric reconstruction process (Figure 2).

Fig. 2. 3D printed targets and bag containing the stakes and hammer needed for placement.

The targets were sturdy and could be easily washed off if they got dirty, which was important in an active excavation area. Because the targets could remain in place throughout the excavation, their position didn't need to be rerecorded each time a new scan was made, which bypassed a major drawback of temporary markers. The locations of the targets were recorded after an initial base scan and those recorded coordinates were input into the corresponding targets in subsequent scans to help with proper scaling and alignment.

5-1. Taking Notes

In order to match the location of the collected sherds with their location in the excavation scans, a relatively quick recording system was needed. To accomplish this task, at each excavation stage, a digital image of the sherds in an uncovered state was taken and printed out on a large A3 sheet of paper. The outline of the sherds being collected were notated and the corresponding artifact number was written down on the printout (Figure 3).

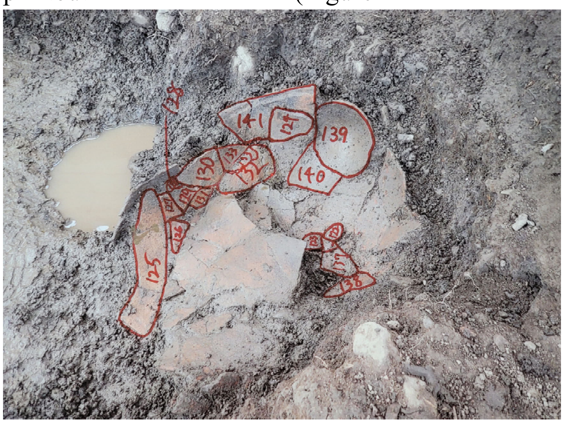

Fig. 3. Paper printout of excavation photo with artifact numbers notated.

The approach proved to be flexible and was mostly successful, however, there were a few instances in which the reference image didn't show a totally clear view of the sherds, causing later difficulties with sherd placement. The lag time between when the artifacts were ready to be collected and when the printout was ready also had a tendency to slow down the excavation process to some extent. Despite the difficulties, the approach still served its purpose without any major problems. With the artifacts collected and the trench scans completed, the next step was to begin processing and scanning the sherds.

5-2. Gathering the Pieces

During the excavation process, there were a number of times in which several clearly connected sherds were collected and recorded as a single piece due to them being obviously connected in their excavated contexts. It is not uncommon for pottery sherds to break to some extent during the excavation process or while being cleaned, so this didn't appear to be a serious issue at the time. The sherds were brought back to the university where they were cleaned and processed. Prior to scanning the sherds, we decided to first refit these separate pieces together and scan them all at once as a single piece. This reduced the overall number of images needed to be taken and avoided the extra work required to digitally position and orient multiple separate pieces, as they could instead be processed as a single combined piece. While this decision helped with the speed of the scanning process, we discovered that this would cause unexpected complications in the reconstruction process which will be described later.

6. Artifact Processing

6-1. Buried in Sherds

The artifact scanning process was a significant undertaking. With over 180 pottery sherds to scan, a replicable method was needed to try to keep results consistent between scans and ensure that the capture process was as efficient as possible. Building upon experience gained from earlier scanning of pottery from the Tsuzuraozaki Lakebed Site in Shiga prefecture, an automated turntable was used to speed up the scan process and help keep the spacing between images consistent[10]. Sherds were held using 3D printed clamps and placed on an automated Syrp Genie II turntable, which was mounted on a tripod. The turntable unit was controlled by Bluetooth using a smartphone app and was connected to the camera which could be triggered by the turntable. A Sony α7R IV mirrorless camera with either a 35mm or 55mm lens was used to photograph the sherds. The camera was mounted to a ring light adapter for a Godox AD1200 flash unit, which was mounted on a Toyo studio stand. Previous scanning projects had involved using a separate tripod for the camera instead of studio stand, but the smooth, quick, and repeatable position changes that the studio stand allowed was a welcome improvement. Once the equipment was configured and the sherd secured on the turntable, the camera settings were adjusted to ensure proper exposure and focus, and the scanning began.

In order to minimize scan time and limit required storage space, the overall number of images per sherd was reduced as much as was reasonably possible. Reducing the number of images too much can lead to misalignments, however. These misalignments take additional time to fix in the processing stage, and generally can negate the intended time-saving step of reducing the number of images taken in the first place. After some trial and error, most of the scans were reduced to 106 images each. An initial image was taken with an information card identifying the artifact, the site it was from, and the date that it was recovered. A second image was taken of the sherd and a ColorChecker Passport calibration target to help with color and exposure adjustments. A series of approximately four images were taken with a scale bar taken at slightly different rotation angles in order to properly scale the model in the photogrammetry software, and the remaining 100 images were of the sherd itself (Figure 4).

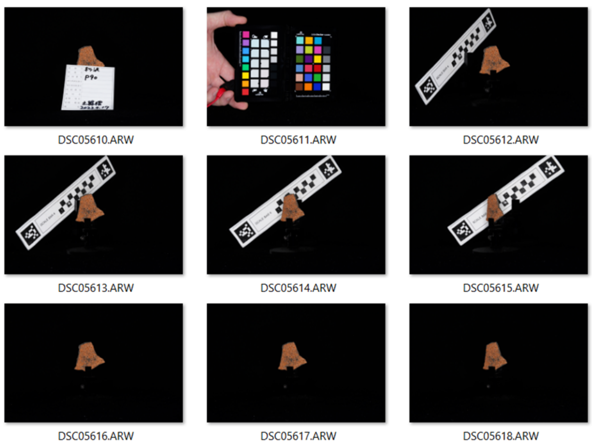

Fig. 4. Image series of pottery sherd scan.

To help further streamline the digitization process, this scanning approach intended to eliminate the need for any image masking. When a pottery sherd or other similar object is held for scanning, the clamp used to hold the object obscures part of that object. To compensate, the clamp needs to be repositioned at some point during the scan process so that the obscured portion of the object being scanned is clearly visible in subsequent images. Unfortunately, because the clamp position relative to the object is inconsistent during the scan, misalignments will occur, often showing the clamp connected to the object in two different locations.

A common method for dealing with this problem is to mask the images to remove any data that visualizes the clamp. This can be done in a photo editing program, or often within the photogrammetry program itself. The masking process can be labor-intensive, however, requiring multiple processing passes of the model in the photogrammetry program or individual masks needing to be created for each image using photo editing software. One possible way to avoid these extra steps is using the "void" method.

The void method uses cross-polarization in order to try to isolate the data being captured to just the scanning target itself. To accomplish this, the surrounding background of the scan is covered in black, non-reflective material. A linear polarizing sheet is applied to strobe lighting and a circular polarizing filter is attached to the camera lens. The orientation of the circular polarizing filter is adjusted to be perpendicular to the polarization angle on the lighting, resulting in a cross-polarized lighting environment. The camera settings are adjusted so that the image frame is completely black when the strobe is not applied, and the object being scanned is the only object visible when the strobe lighting is used. The resulting image should appear as if it is already masked, with everything other than the object being scanned showing up as black. While we have used this technique a number of times on other objects in previous project, the clamps holding the pottery sherds caused significant problems. Around the exterior of the area where the sherds were clamped there was often a distinct darker area on the model textures as a result of slight shadowing in the images (Figure 5).

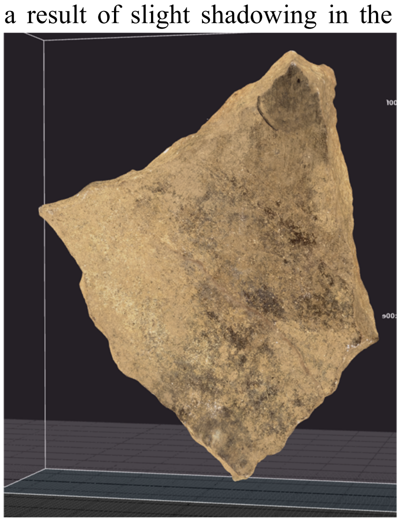

Fig. 5. Image of a sherd scan showing a circular shadow at the top and a squared shadow on the bottom caused by the clamps

holding the sherd.

Several image postprocessing adjustments were tested in an attempt to solve the issue, but in the end the only solution to the issue was to mask the clamps out in the photogrammetry software, which unfortunately removed any benefits of the void setup. Alternative mounting options such as using adhesive putty to affix the sherds to the turntable were considered but would likely have damaged the low fired pottery when the putty was removed. Supporting the sherds with pins was another option that was tested but was also unsuccessful in the end. It was difficult and time consuming to mount the sherds in an upright position using the pins and was unstable even when properly positioned. While scanning the objects lying flat would seem to be a reasonable alternative, the sherd edges lacked a significant amount of tie point features, making aligning the two sides together very difficult. Aligning the two sides together would often require feature points to be identified and matched manually, which is a time-consuming process. As such, reverting to a masking workflow and trying to quickly reposition the sherds between scans ended up being the most efficient approach at the time of the project.

6-2. Small Sherds, Big Problems

The scanning of small sherds proved to be another interesting endeavor. We wanted to try to digitize as many sherds from the excavation as possible, but as the size of the sherds got smaller, new challenges were introduced. One pressing issue was the degree of diminishing returns in terms of the time, effort, and digital storage requirements. Small sherds took just as long to scan, required just as many pictures, and took just as long to process as larger sherds, but the small sherds were overall less important in terms of understanding the overall deposition process of the burial pottery. To try to counteract these diminishing returns, we began scanning two sherds at once.

Theoretically, by scanning two sherds at once we would be reducing the average numbers of pictures per sherd by half, which would also cut our scanning time and required storage space per sherd in half as well. These improvements didn't come for free unfortunately. There are some unavoidable complications to scanning multiple objects at once in a turntable setting, and the solution to one problem often becomes the cause of yet another problem. The first difficulty in scanning multiple objects at once involves the camera's depth of field. When taking images for photogrammetry, you ideally want as much of the targeted object in focus. The depth of field of a camera is determined by the camera sensor size, the focal length of the lens, the aperture setting of the camera, and the distance between the camera sensor and the object being photographed. Reducing the aperture size by increasing the f stop value will increase the depth of field, but it will also reduce the amount of light getting to the camera sensor, which will in turn require increasing flash power, decreasing the shutter speed, and/or increasing the ISO. Additionally, increasing the f stop too much not only increases the difficulty of properly exposing the images, but can begin to degrade image quality, with significant blurriness introduced due to lens diffraction at the highest settings. An alternative solution to increasing the depth of field is to increase the distance between the camera and the object being photographed, but this will result in the object taking up a smaller portion of the image frame, meaning that less data from the object is being captured.

If multiple items are being scanned at once and there is a significant amount of distance between them, at some point in the image sequencing objects will likely start to go out of focus due to traveling beyond the normal bounds of the camera's depth of field. By positioning the objects being scanned close together and within the camera's calculated depth of field you can help to counteract this problem. This close positioning introduces a separate problem, however, in which the objects being scanned start to significantly obscure each other. While this problem is unavoidable to some extent, it's important to try to position the pieces in such a way that they obscure each other as little as possible as they move around on the turntable. Through trial and error, we found that having the sherds placed in a similar orientation but slightly offset ensured that both sides of the sherds could be captured on the turntable, but the degree of obstruction was minimal (Figure 6).

Fig. 6. Image showing offset positioning when two small sherds were scanned together

Using this setup, it was still common to have one or two images not align properly due to the sherds obscuring each other, but the effect was limited.

Another complication with scanning multiple sherds at once was that an extra layer of masking per photo set was required. After the images from one set of photos were aligned and the initial mesh was created, a masking set for each sherd needed to be created. This resulted in 4 sets of masks in total, two for each sherd, which was the same amount as was needed per sherd if scanned individually. Scanning two sherds at once did nothing to reduce the masking workload and actually added a minor file management complication as you had to make sure not to mix up the masking sets as they were saved or the models wouldn't align.

Related to the issue of failed alignments was the final problem with scanning small sherds. As the scans approached 1cm in size, the chances of alignment problems increased due to a lack of viable tie points. Even when the clamping area was minimized as much as possible, a significant portion of the sherd would be blocked from view making it more difficult to identify overlapping tie points necessary to be able to combine the two scanned orientations. While the use of a macro lens and focus stacking could help to provide clearer, more data rich images to help with this issue, the increase in images necessary would significantly raise the time per scan capture as well as the storage needs per scan. While this approach is a viable one for scanning a smaller number of important pieces, it would have created an undue burden in terms of time and resources for the Sugisawa project.

6-3. Large Image Files

Data management was a significant point of concern for this project. With over 180 scans consisting of over 100 high resolution images each, data storage requirements could have quickly gotten out of hand if not properly planned for. RAW images from the Sony camera used in this project were typically over 100MB each. Denoising of RAW files is a processing wtep which we have used in previous projects but avoided with Sugisawa. While the process can help improve image quality, using DxO PureRAW for this step results in another set of DNG images that are close to double the size of the RAW files[11]. While skipping the denoising step avoids creating an additional set of DNG files, the RAW images still need to be processed to ensure proper exposure and color representation. In earlier scanning projects with pottery from the Tsuzuraozaki lakebed site in Shiga prefecture we experimented with using uncompressed TIFF files for texturing purposes[10]. The TIFF files were often three times as large as the original RAW files and offered minimal improvement over using 100% quality JPEG files. As the Sugisawa project involved a large number of scans and with over 20,000 images taken through the process, we decided that the JPEG file format would suit the project's needs. In addition to the separate texturing image sets however, it is also not uncommon to create a separate image set is not focused on color accuracy, but is instead optimized towards geometric reconstruction, with the aim of emphasizing the clarity and increasing the number of contrast points used in the reconstruction process. Through basic testing we found that the JPEG texturing sets performed well enough that this additional step generally wasn't needed, which further helped to avoid an extra load on our data storage resources. Finally, for smaller sherds, the APSC crop mode on the camera was used which also helped to reduce storage demands. This mode uses a smaller portion of the camera sensor and significantly reduces the size of the RAW images, from approximately 100MB per image to around 20MB per image. Since the distance between the camera and sherds being scanned needed to be separated enough to ensure the depth of field fully encompassed the objects, the exterior portions of the frame typically consisted of only black backdrop, which wasn't contributing any useful information for the model. Using APSC mode therefore reduced file sizes without any drawback in terms of usable image resolution as the cropped sections would have been cropped later in the process anyways.

7. Putting Things in Context

7-1. Aligning Excavation Scans

Before artifact models could be positioned into their proper contexts within the digital excavation space, the excavation models themselves needed to be aligned. The initial hope was that the coded markers used on site would allow for clean alignments with very little additional manual input. An initial broad-scale base scan would be used to calculate the initial coordinates, and that marker position data would be applied to later scans. In practice, however, the process included a number of unforeseen complications.

The first problem was that three different camera systems were used for the excavation scans, and the scanning approach used by the camera operators was not standardized. The initial plan for scanning involved first setting the camera white balance to a fixed setting, matching the general lighting environment at the time, and taking an image of a neutral gray card for white balance reference. Once the reference image was taken, the operator would start by taking pictures of an exterior marker, and work along the exterior of the excavation, ensuring a good overlap between images and making sure that at least three markers were included in the scan. With the exterior markers captured, the operator could then move in towards the main targeted area, ensuring that the target was captured from all sides and ensuring adequate overlap between the images. Unfortunately, due to time constraints and conditions on the excavation site, some scans lacked the white balance reference images, some lacked sufficient image coverage of the exterior coded markers, and the photo count between scans was also inconsistent, which resulted in differing levels of quality amongst the scans.

Even the higher quality scans still had some difficulties in properly combining models, specifically due to having some degree of drift in the model alignments. When the scans were aligned, specifically the scans targeting the burial pottery positioned in the central portion of the excavation area, the exterior marker positions of the different scans had a tendency to differ from each other by several centimeters. The drift was more prevalent and noticeable in these outer areas, being several meters away from the primary scan area. Compared to the outer sections, the central portions of the scans displayed significantly reduced degree of drift. Without the clear and consistent positioning of the markers between scans, this drift would have likely gone mostly unnoticed. However, the fact remains that the markers still failed to accomplish their main intended task of locking down the marker positions to allow for easy scan alignments.

While the marker positioning helped to roughly position the excavation scans, all of the scans had to be manually adjusted to some extent for proper alignment. In addition to slightly offset alignments, geometry differences were present when comparing the different scans, with the differences between lower quality scans created from smaller image counts and higher quality scans with larger images counts showing the biggest differences. These differences were still typically under 1cm, which is as close, if not slightly better to the resolution that could be reasonably expected when hand-drawing the excavation area using the surveying tools available on site[12].

7-2. Decimating Models and Avoiding Crashes

For the alignment of the excavation scans and the individually scanned pottery sherds, we decided to use the 3D software program Blender because of its open-source nature and wide array of community supported addons and plugins[13]. While the software has improved at handling large 3D projects, prior to aligning the models it was still important to manage the total size of the files that would be imported into Blender. The larger the overall file size, the more difficult it becomes to manipulate models within the program. The number of combined polygons used to create the 3D models, referred to as the polycount, needed to be high enough to have a reasonable geometric match with the actual objects, but not so high as to unnecessarily overinflate the file sizes of the models. Models in their original raw state can consist of a million or more polygons, and when multiple files of that size are imported into Blender, it can become extremely unresponsive and can eventually crash. To reduce the polycounts of the models, a process called decimation was used.

The decimation, or simplification process can be done within the photogrammetry program itself or in external programs, but the goal of this process is to reduce the number of polygons in the model in order to reduce the file size, while at the same time not reducing the polycount to the point that it is significantly different from the original model geometrically. A properly simplified model can look incredibly similar to the original model when textures are applied but will be significantly more performant. While the result of the simplification process was successful on that front, some unexpected complications in terms of model alignments came about as a result of this geometric simplification.

7-3. Aligning the Artifacts

Aligning the artifacts within the broader scan required some degree of trial and error. In the beginning, an add-on called “3 Points Align” which includes a function that can match the position of two separate meshes based on the corresponding points that a user selects was explored[14]. Ideally, to align the sherds with the excavation scans, three matching points between each sherd and the corresponding excavation scan would be identified and selected, and the alignment function would be run. Due to a lack of correspondence between identifiable feature points within the texture of the scans and the underlying geometry of the scans themselves and the necessity of using lower polycount models to avoid overwhelming Blender, this initial approach was unsuccessful.

The next approach was to try to align the artifact models manually within Blender. This approach was functional, but was far from efficient. The major problem with this approach was a limitation in the ways in which the 3D space could be navigated. 3D programs work within three dimensions, referred to as the X, Y, and Z axes, and there are several ways in which to control movement in these programs within the 3D space. You can constrain the movement to these specific axes, moving the object in just the X, Y, or Z, axis, you can use a combination of 2 axes while ignoring the third, and you can also choose to move the object based on your current viewpoint. Limiting movement along specific axes makes it easy to roughly get objects into position, but fine-tuning position and rotation often requires a combination of those rough adjustments followed by changing your viewpoint a number of times to better see the object's positioning. A lack of depth perception during this process can make it quite difficult to understand how far an object is away from your current viewpoint. While functional, this process felt much more difficult than it needed to be, especially considering how easy it would be to simply pick up the objects and set them into place in "real life". This frustration and realization led to the final approach of using a Virtual Reality (VR) headset and controllers to position the sherds within the broader model.

A Pico Neo 3 Link VR headset was used for this task, which was connected directly to a PC using a DisplayPort cable and adapter. While the ability to use a Wi-Fi connection was a possibility, using the DisplayPort connection allowed for the signal from the PC to be transmitted directly to the headset without any data downsampling required. This also ensured that lag between the computer and headset was minimal, helping to make the whole process much more comfortable for the user. While Blender has some built-in VR functionality, it only allows for a model to be viewed in 3D space, and doesn't provide for any additional interactivity with the models. A plugin, Freebird XR, was installed to solve this issue, providing the ability to select and move objects in Blender using the VR headset and controllers[15]. With the addition of FreebirdXR model interactivity was possible, but the headset didn't provide usable visual passthrough to view the space outside of the headset. This made interacting with reference materials to identify where the sherds should be positioned within the excavation space, as well as interaction with the Blender interface quite difficult. Overcoming these physical limitations of the hardware was accomplished through an additional piece of software, OVR toolkit[16]. OVR toolkit is a plugin that allows additional 2D windows to be added into the 3D viewable space in a VR headset. As such, a window showing the full Blender interface, as well as a window showing the reference images of the pottery sherd positioning in the excavation area could both be included within the headset view. These windows could be placed off to the side and used like extra monitors in the 3D space, allowing for quick reference and the ability to interact with additional Blender functions when needed (Figure 7).

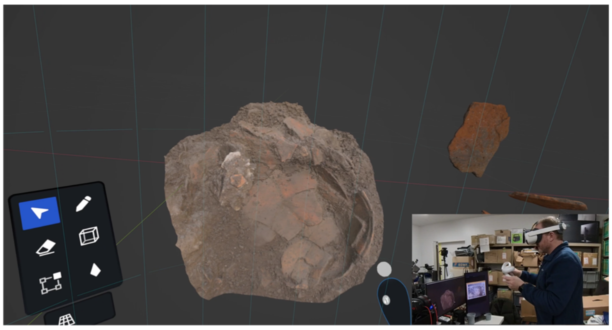

Figure 7 Composite image showing the view from inside the VR headset with a simultaneous view of the headset being used.

In the end, this combination of hardware and software allowed for the pottery sherd models to be positioned much faster and much more naturally than before. Looking around and viewing the model from different positions was much easier, and by zooming in and out from the model, it was possible to allow for more refined movements necessary for the final positioning of sherds within the model.

While this was a clear improvement from the previous approaches, there were still some minor drawbacks. The precision of movement enabled through the use of a mouse was still more refined than the VR controllers. To compensate, we found that grabbing a single controller with two hands helped to provide additional stability when trying to make final adjustments to the positioning of the models which worked well enough for most positioning tasks. This lack of fine and precise movements was also apparent when using the Blender menus, as correctly selecting particular models from the scrolling sidebar could be difficult at times. With the Pico headset lacking functional passthrough, not being able to use a physical keyboard also meant that keyboard shortcuts commonly used when navigating Blender couldn't be used, which slowed progress at times. These issues were relatively minor however, and in future projects, newer headsets with high resolution passthrough capabilities will likely offer some possible solutions to these problems.

8. Discussion

8-1. Initial Impressions

In spite of the various complications that were encountered, the end result of this project was 184 separate sherd scan models accurately positioned in the original locations and orientations in which they were discovered during their excavation. When the base excavation scans are removed, an observer can get a clear view of the entirety of the pottery assemblage, providing a significantly better understanding of the spatial relationship between the different pieces (Figures 8 and 9).

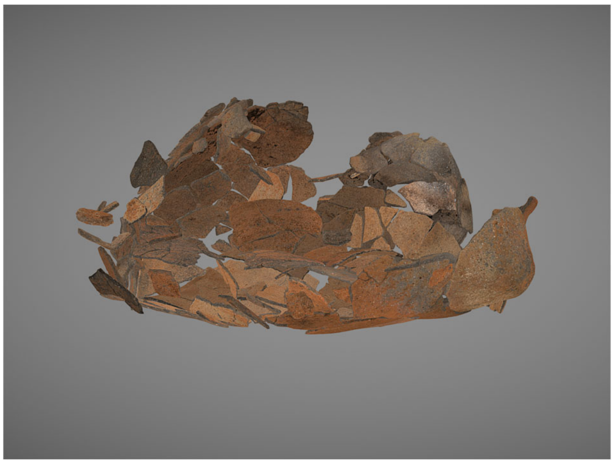

Fig. 8. 3D model of combined sherds viewed with the excavation scan layers removed and a QR code linking to the model.

(https://sketchfab.com/3d-models/sugisawa-burial-pots-e9e72b2e7df34165a8896eab75153ea2)

Fig. 9. 3D model of combined sherds positioned in context with a separate excavation scan.

Observers are able to quickly change their desired viewpoint and view all 184 sherds at once, something that would be impossible to do with traditional drawing and survey methods. This flexibility was especially useful when working to understand the depositional process of the burial pottery. We were able to quickly identify pottery sherds that could not have been positioned through a natural depositional process and were clearly moved at some point.

Another unexpected benefit of this project was how helpful the reference scan was during the refitting process. The burial pottery excavated and scanned for this project was very thin, generally only a few millimeters thick in most places. This made the pottery quite difficult to piece together. The breakage pattern occurs not only across the length and width of a piece, but across the depth as well. With very thin pieces like those from the Sugisawa burial pottery, the amount of available information across that depth axis is fairly small, which has been reduced even further through the weathering and degradation that took place over thousands of years. Having an easily viewable reference model of the pottery within its burial context proved to be a great help in trying to piece things together. An individual sherd could be selected and then the 3D model could be used to identify other sherds adjacent to that one or within the general vicinity. Pieces still had to be test fit together to confirm matches, but the 3D model provided a useful general guide for identifying matching pieces and helped to avoid relying solely on a trial-and-error approach based on rough shapes alone.

8-2. Room for Improvement

While touched on in earlier sections, it's important to review some of the most pressing issues and difficulties that were encountered during this project as a way to help improve the methodology for future endeavors. Starting at the beginning, the placement and capture of the machine-readable markers is the first area that needs improvement. The markers provide a method to properly scale and orient the 3D scan, and the clear capture of the markers on site should be considered almost as important as capturing the main object itself. Although the physical scale of the main scans at Sugisawa were relatively small and mostly focused on the burial pottery, on the outer edges of the scan where the markers were placed there was a noticeable amount of alignment drift, where the target positions didn't fully match between scans. While the drift was typically only a few centimeters at the outer portions of the scans and was minimal around where the burial pottery was located, the alignment shifts still prevented the automatic alignment of scans, and negatively impacted processing times. Ensuring a higher density of images would likely improve the situation, as would having additional targets closer to the main focus of the scan. At the very least, adding additional targets closer to the central portion of the scan would provide a clearer measure of the effect that alignment drift is having on the main portion of the scan.

The scanning of individual pottery sherds after the excavation is the next area where improvements can be made. When several people were working together, the scanning process took between 15 and 20 minutes when things were running smoothly. Scanning of multiple sherds at once took slightly longer as the mounting process was more involved, generally between 20 and 25 minutes per scan. Near constant supervision was required for the mounting of pottery sherds and the frequent camera position changes to raise or lower the camera, or to move the camera arm in or out in order to maintain the same relative distance during the scan. While there was a small amount of downtime between the start and end of an imaging ring, the process was by no means fully automated, despite the use of an automated turntable. Some improvements have already been tested on a similar digitization project at the Middle Jomon period Suwahara site in Yamanashi prefecture by Noxon[17]. A custom semi-automated photogrammetry scanner was designed and built to help improve the artifact scanning process. While the time required to scan the artifacts from Suwahara was similar to the artifact scan times for Sugisawa, the level of necessary interaction during the imaging process was minimal. This allowed for other work to be conducted while the artifact was being scanned with very little supervision. While the system has some strict limitations in terms of the size of objects that can be scanned and still struggled with some very small artifacts, overall, the newly built scanner was a clear improvement.

For the processing and positioning/alignment of scans, there are more improvements that can be made. There is significant room for automation in the model processing pipeline, especially relating to file management. For improving the alignment of artifact scans with excavation scans, two possible approaches stand out. Higher resolution scans could be used in order to better utilize the 3 Points Align tool. The overall project would need to be separated into smaller sections in order to avoid crashing the computer software, but once the positioning changes were confirmed, the adjusted coordinate and rotation values could be applied to lower resolution models allowing for the separated sections to all be combined together in the end. If the VR route was to be pursued further, ensuring that the equipment had functional passthrough capabilities would be a significant improvement, especially if keyboard and mouse inputs could also be utilized for fine-grained adjustments.

8-3. Moving Forward

In addition to the above-described improvements for similar projects in the future, there are some additional ways in which the current project could be expanded upon in the future. While some initial steps have already been taken, virtual refitting or reconstruction of the burial pottery from Sugisawa would be the next focus of the project (Figure 10).

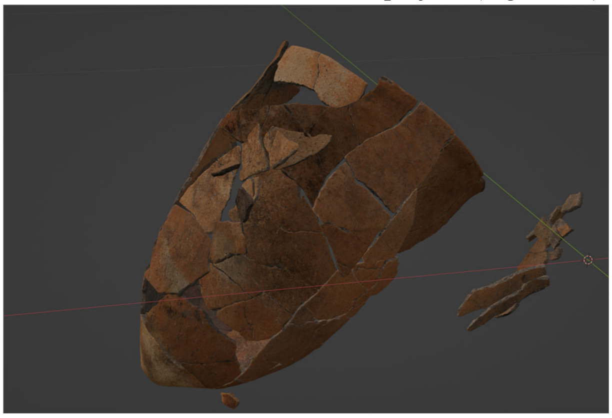

Fig. 10. Blender viewport showing digital refitting progress of the Sugisawa burial pottery.

The thin walls of the burial pottery sherds result in a very small cross section in which the pieces can be glued together. This leads to weak connections and the necessity of support structures in order to keep larger sections of the pottery together. If the refitting process is done within the digital space, however, those structural concerns are negated. As is a running theme, exploring this process hasn’t been without some difficulties. While the thin walls of the burial pottery had caused some difficulty in the physical refitting process of matching adjacent pottery sherds, these difficulties are amplified in some ways when trying to refit the pottery digitally. Edge matching in physical space involves a significant amount of tactile feedback that isn’t present when working digitally. There is no sensation of pieces “clicking” into place. While the general edge matching of pottery sherds can be done reasonably well within digital 3D space, the outward and inward facing angles in which the pieces match together has been a problem, resulting in the overall shape becoming somewhat oblong. Some digital refitting projects have attempted to counteract these problems by duplicating a large sherd several times and positioning the duplicates radially around a central point, which creates a reasonable representation of the overall pottery shape. Unfortunately, as the process of making Jomon pottery involves using a hand coiling technique instead of using a pottery wheel, Jomon pottery pieces are often asymmetrical. Additionally, as the pottery sherds comprising this burial pottery are relatively small compared to the whole, it has been difficult to identify contiguous pieces that could represent the overall profile shape of the pottery. Work is moving forward in the attempt to piece these pots back together, but progress is slow.

Finally, there is the issue of determining the best format and structure in which all of the data collected and created during the course of the project should be shared with researchers and the broader public. FAIR data principles are often referred to in discussions regarding the appropriate ways in which research data should be shared[18]. These principles aim for research data to be Findable, Accessible, Interoperable, and Reusable. However, 3D data, especially 3D data in the sphere of cultural heritage and the humanities in general, introduces a few complications to this approach. There are difficulties in standardizing culture related metadata across digital databases working in a variety of different cultural contexts[19]. Openly accessible model viewers still lack the ability to handle full resolution models in many cases, requiring the need for decimated and simplified versions of models in addition to the original high resolution models[20]. Different types of 3D data are better served by different 3D formats, making interoperability an issue in many cases. Digital storage requirements of 3D model projects can greatly exceed other types of projects depending on how exacting the expectations are for data preservation, especially if photogrammetry is involved. RAW image files, processed image files, raw models, processed models, and decimated models could all be required to be saved and archived depending on the standards applied.

There are also instances in which sharing data openly with the general public may not be the proper or ethical approach[21]. The location of certain archaeological sites might want to be initially hidden due to concerns of possible looting at the site. Objects or remains may have religious or spiritual significance to related groups or communities and access to the materials could be restricted out of respect to those communities. These technical, ethical, and functional problems are still being sorted out around the world and it's unlikely that a standardized, universal approach will ever be accepted or implemented. Currently only the decimated version of the model is being shared online with download restrictions in place, but options for a more open and FAIR minded approach is being explored with stakeholders.

[Notes]

1) One of the references cited is Yamagami [1999]. Here, Yamagami uses the concept of hospitality from Hattori [1994] and devotes a chapter to explaining it.

[Notes]

1) 立命館大学文学部 2012
2) 立命館大学文学部 2013
3) 立命館大学文学部 2015
4) 立命館大学文学部 2020
5) 矢野健一ほか 2024
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14) Barre 2024
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17) Ertl et al 2025
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