Computational photography, 3D modelling and online publication of basketry for Cache Cave (CA, USA)

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COMPUTATIONAL PHOTOGRAPHY, 3D MODELLING AND ONLINE PUBLICATION OF BASKETRY FOR CACHE CAVE (CA, USA).

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Abstract

Advanced 2D and 3D computer visualizations are increasingly being used for recording and documentation, analysis, dissemination and public engagement purposes. Recent technological advances improve considerably not only data acquisition, processing and analysis but also provide easy and efficient online presentation. This paper aims to evaluate the contribution of advanced 2D and 3D computer visualization and discuss the potential of 3D modelling for recording basketry technology and documenting the state of preservation of baskets. It explores the available analysis, integration and on-line dissemination tools, using as case studies recently excavated baskets from Cache Cave, Southern California. Results indicate that the proposed methodology, which incorporates Reflectance Transformation Imaging visualizations and photogrammetric 3D models, further processed using 3D modelling software and integrated analysis tools, and transformed to web-based format, is useful addition to the basketry analysis toolkit.

Spanish abstract

Visualizaciones computacionales avanzadas 2D y 3D están siendo usadas con mayor frecuencia para registrar, documentar y analizar materiales con fines de divulgación. Recientes avances tecnológicos han posibilitado el mejoramiento en la toma de los datos, así como también, ha mejorado el procesamiento y la presentación en línea de éstos. El objetivo central de este artículo es evaluar las contribuciones de las visualizaciones computaciones 2D y 3D para, más adelante, discutir el potencial que el modelaje 3D tiene, no sólo para el registro de la tecnología cestera, sino también para documentar el estado de preservación en el que se encuentra el material. Así, exploraremos las diferentes herramientas tecnológicas para el análisis y la integración de datos, que se encuentran disponibles en línea. Como caso específico, se utilizaran las cestas recientemente excavadas provenientes de la Cueva Cache, localizada en el sur de California. Resultados preliminares de esta metodología indican que procesar la imagen utilizando un software para modelar en 3D, acompañado del uso de otras herramientas integradas de análisis y la posterior transformación de la imagen a un formato para web, resultan un kit necesario e útil para el análisis de la cestería.

Challenges of Perishable Artifacts

Perishable artifacts often present unique problems for archaeologists, analysts, and heritage specialists alike, from in situ documentation, to recovery, analysis, curation, and subsequent dissemination to researchers, stakeholder communities, and the wider public. For instance, the fragility of many perishable artifacts remains an issue of critical concern throughout the chaîne opératoire of recovery on to dissemination. This is particularly an issue in the context of furthering access to such objects that often require specialized environmental controls for long-term curation. The site of Cache Cave, located in California, containing a remarkably extensive assemblage of perishable materials cached within a complex cave/rock shelter system, has presented challenges in all these aspects of dealing with perishable finds. Our concern is with establishing methods that usefully enable the creating of a visual database of perishable artifacts that can include initial discovery, post excavation analysis, and online dissemination. This paper details our findings on the utility and limitations of integrating visualization and computational techniques, along with online dissemination in this case study from Cache Cave. It evaluates 2D and 3D visualizations and computational tools based on their efficiency in recording basketry technology features, documenting the state of preservation of baskets, as well as their functionality for the integration of diverse records, and their ease of use for online dissemination of research outputs.

Advances in Visualization and Online Scholarship

Scholars underlined the benefits of sharing information to enhance scholarship and learning and its association with democratization, human rights, equality, and justice (Veletsianos and Kimmons 2012). In the field of cultural heritage, major museums and organizations embraced the 'open-access' movement, coupled with European and international initiatives such as Europeana and the 'ARIADNE' portal. The former is a large-scale search engine, which provides a single access point for digitized heterogeneous cultural heritage material from various European libraries, archives, museums and galleries (Petras et al. 2017). The latter delivers digital services, including a variety of visual media, for the archaeological community (Ponchio et al. 2016). In archaeology, the concept of openness, in the sense of open source software and open access to data and publications, has initiated discussions around the challenges of availability, interoperability, preservation and delivery of open archaeological data (Wilson and Edwards 2015). Recently, cOAlition S, an international consortium of research funders, launched the Plan S initiative for Open Access publishing, which requires that scientific publications that result from research funded by public grants must be published in compliant Open Access journals or platforms from 2020 onwards (Science Europe 2019).

Additionally, technological developments enhanced accessibility to artifacts via advanced computational photography tools, constantly evolving over the past four decades as a multidisciplinary field of research, of particular interest to researchers, artists, photographers, and engineers. Computational photography lies at the intersection of computer vision, image processing, and computer graphics and incorporates sequence of images and a broad variety of techniques (Durand and Szeliski 2007; Suo et al 2012). In the field of archaeological research, computational photography is useful for extracting features for research purposes (Miles 2018).

In the field of 3D digitization, there have been significant developments in practical, cost-effective and affordable techniques for reconstruction from 2D images, such as Reality Capture (Capturing Reality 2017), Agisoft Metashape (Agisoft 2019), and Virtual Structure from Motion (Wu 2015). 3D digitization techniques found applications in archaeological recording and documentation, analysis, preservation and broadened access, restoration support, study, dissemination, and teaching, but their contribution is also valuable for enriching context. At this point the importance of 3D recording for documenting, analyzing, and safeguarding cultural heritage is well understood, and the huge range of new possibilities is under examination, as demonstrated by the continuous research and development of the field. Reflectance Transformation (Malzbender et al. 2001; Mudge et al. 2006) and related imaging technologies, such as microphotography, transmitted and multispectral imaging, applied in a synergistic mode, lead to the development of integrated RTI approaches, which revolutionized the way researchers interact with artifacts. Texture topography and subtle surface variations, accessed via RTI visualizations, enable interactive and virtual visual analysis of artifacts. The digital surrogates, based on transparent scientific methodologies and principles lead to authentic, reliable representations that can remove physical barriers and are useful for collaborative distributed scholarship (Mudge et al. 2007), documentation and virtual visual analysis that would be either impossible, unethical or too difficult using conventional means.

Emerging technologies relevant to the online digital-based scholarship for cultural heritage repositories are the 3D Heritage Online Presenter (3DHOP) and the web RTI tools developed by ISTI-CNR in Pisa. The webGLRTIMaker tool and WebRTIViewer enables online publication of high-resolution RTI images (http://vcg.isti.cnr.it/rti/webviewer.php). Users can explore digitized artifacts in an interactive relighting mode online (Palma 2012). Similarly, 3DHOP is a framework for the creation of advanced web-based visual presentations of high-resolution 3D content (Potenziani et al. 2015). In addition, 'Cultural Heritage-Object' (CHER-Ob), the open source virtual research environment, offers a flexible, expandable integrated platform for collaborative cultural heritage research, compatible with commonly used imaging data types (two and 3D images, RTIs, CT) and textual information. Preliminary research showed enhance analysis, evaluation, documentation, sharing and management of 3D and 2D visualizations options provided by CHER-Ob. Among other advanced research functions, CHER-Ob offers automatic report generation in web-based format (Shi et al. 2016; Wang et al. 2018; Yale Computer Graphics 2016).

Visualization and Online Publication of Basketry

Although the field of cultural heritage informatics is developing rapidly, as demonstrated by the technological advances, the already existing platforms provide limited information for in-depth analysis of basketry. There are many digital libraries of basketry accompanied by 2D static images, which provide useful information for provenance, technology, decoration, but cannot visualize the three-dimensionality and the detail features of baskets. Characteristic examples are the Reanimating Cultural Heritage project and the University of Oregon Museum of Natural and Cultural History, which provide online access to basketry material via the http://sierraleoneheritage.org/ (accessed date April 11, 2019) and the https://natural-history.uoregon.edu (accessed date April 11, 2019) portals. In the field of RTI visualization, there are few relevant applications focused on textiles with less complicated geometry than baskets (Eastop 2016; Goldman et al. 2018). RTI has been applied for the study of impressions (Frank 2014), following the common practice of analysis of negative impressions in ceramics and other media for the recovery of data about woven artifacts that rarely survive (Adovasio 2004; Drooker 1992, Drooker 2001; Holmes 1884, Jolie 2010; King 1978; Petersen 1996; Pitblado et al. 2013; Soffer et al. 2000). In addition, the enhanced visualization of incisions via RTI provides information for representation of baskets and textiles (Lemke et al. 2015; Mock 2016). In terms of 3D visualizations, the earlier attempts to generate virtual basketry museums populated by 3D models (Isler et al. 2007) did not progress beyond the point of the computational design. The main problematic aspects of the existing platforms are the limited number of digitized baskets available online, the quality of digitization, the unstructured non-standardized metadata provided, the limited access/download and search options. For example, the Europeana digital library features only one 3D model of a palm basket with lid available in a PDF format from The Cyprus Institute – STARC, digitized during the CARARE project[1] (Cyprus Institute 2019). The Sketchfab cultural heritage content includes more than 500 baskets digitized by museums and 3D enthusiasts. Almost all digitized baskets, with few exceptions from the British Museum (https://sketchfab.com/britishmuseum) and the Santa Cruz Museum of Art and History (https://sketchfab.com/santacruzmah), can only be accessible online and are not available for free download, limiting the possibilities for comparative analysis.

Digital technologies, computer visualizations in the form of RTI and 3D models, and fabrication via 3D printing has been proposed for balancing between the core ideas of conservation (Kotoula 2017). A similar approach is recommended for friable materials, such as impressed shreds, in case of problematic preservation as an attempt to avoid damaged or contamination during the physical fabrication of molds from clay, latex, plaster or similar materials. This approach is meets conservation objectives for non-destructive analysis and is easy to perform, since the available 3D modelling tools make the creation of such negative molds trivial. Furthermore, this approach eliminates the need to borrow sherds on loan or transporting positive casts in clay. The former can be difficult and heavy to transport, while the impressions, depending on the casting medium, might have the positive casts obliterated if they are non-hardening. By extension, the digital versions would preserve the cast for restudy and easy data sharing.

Materials and Methods

Cache Cave

As indicated at the start of this paper, the site known as Cache Cave (CA-KER-10419) presents a series of challenges in terms of visualizing perishable remains. The site is a series of interconnected rock shelters comprised of a mudflow breccia and located on the Wind Wolves Preserve, South Central California: it is the largest cache site discovered within the traditional territory of the Emigdiano Chumash (Robinson et al. 2012). Caching was a common if poorly understood native practice across the region, with sites typically defined as small equipment stashes in discrete rock shelters (Bryne et al. 2016; Whitby 2012). Excavations from 2012 to 2018 at Cache Cave have revealed a wide range of perishable materials including cordage, bone, antler, shell, leather, wood, food residues and baskets (McArthur and Robinson 2016; Robinson 2017). Dates so far acquired indicated prehistoric human use of the shelters for over 2000 years including potential use of the cave in the ethnohistoric period beginning in the AD 1700s. This is important as California native basketry is considered amongst the finest basketry traditions ever developed, with the Chumash and their neighbors famous for range and sophistication of objects made from perishable materials (Dawson and Deetz 1965; Elsasser 1978; Mason 1904; Shanks 2010). Thus, Cache Cave offers the unique opportunity to investigate a long-term sequence of Californian perishable technology stretching from prehistory though to the ethnohistoric period. For the present study, recently excavated baskets, presenting a variety of shapes and dimensions, either complete or in fragmentary state, were selected as case studies. Table 1 summarizes the technical characteristics, dimensions and preservation state of basketry material presented in this paper along with a brief description in accordance with the technical terminology and standardized analytical procedures commonly used by analysts today (Adovasio 2010; Jolie 2014). Additionally, this paper presents visualizations of basketry in situ during the excavation of Cache Cave.

Data Acquisition and Processing

RTI visualizations were created following the Highlight RTI data capture method, recommended by Cultural Heritage Imaging (Cultural Heritage Imaging 2013) and in the Historic England guidelines (Duffy et al. 2013), in vertical and horizontal configurations using either one or two targets (reflective spheres) with an average size of approximately 190px. The data acquisition took place at the Wind Wolves Preserve in Bakersfield, California and the Santa Barbara Museum of Natural History. The datasets, consisting of an average of 61 raking and oblique light images, were processed with RTI Builder software, using the hemispherical harmonics (HSH) fitting algorithm (Schroer and Bogart 2011). RTI is an interactive relighting technique that forms a synthetized image derived from a sequence of raking light images. The user can select to view the object under examination as if it was lighted from different directions, to apply digital imaging filters, to change the intensity of lights. This enables a detail examination of the surface topography and a viewing experience that fills the gap between 2D digital photographs and 3D models. During viewing, the user can save 2D images in .jpg format (snapshots). The RTI snapshots included in this study were carefully selected to emphasize characteristics of the basketry material under discussion, such as the degradation phenomena or the decorative features. Polynomial Texture Maps and RTIs provide increased realism, including surface colors, self-shadowing, sub-surface scattering and inter-reflections, in comparison to bump and traditional texture mapping. Via RTI, experts and the public can experience views of the artifacts in a new way that is different to visual examination or handling. In the case of basketry, RTI potentially accentuates different aspects of construction and weave structure that can provide advantages over simple visual inspection and contributes towards an improved documentation, as it happens in other material types. Nevertheless, appropriate testing is necessary due to the limited applications of the technique in basketry material. Table 2 presents the metadata for the RTI visualizations discussed in this paper, including the equipment used for data capture. The metadata table follows the guidelines of the Archaeology Data Service, in accordance with published RTI data (Smith et al. 2018; Riris and Corteletti 2015).

As part of this study, two of the selected objects preserved almost complete, a small basket and a seed beater, were 3D digitized photogrammetrically with the Agisoft PhotoScanPro (version 1.4.2. build 6205) using datasets of 148 and 238 images respectively, captured with a NIKON D3100. For the in situ 3D digitization of Feature 66, 492 images were taken with a Nikon D800 and a Nikon AF-S 17-35mm f/2.8D lens, taped at 17mm. The camera was set to raw (.nef), ISO of 100, white balance set to flash, and lens at f9. Feature 66 was illuminated by four Nikon SB800 speedlights, each capped with a diffuser and synced through a Nikon SU-800 commander unit. Images were processed in Photoshop CC (version 18.0) and exported as JPEGs. Photogrammetry model was constructed in Agisoft PhotoScanPro (Version 1.3.0 build 3075), utilizing the new Visibly Consistent Mesh Generation (VCMG) (Agisoft 2018). Moreover, in situ 3D digitization of baskets during excavation was completed using the Reality Capture software (beta version 1).

Commonly used 3D packages, such as the MeshLab (Cignoni et al. 2008) and 3D Studio Max (Autodesk 2019) were employed for further processing of the 3D models. 3D modelling techniques, including slicing and rendering, were primarily used for dissemination, recording and documentation purposes as well as for revelation of basketry characteristics. Although in material studies the contribution of 3D modelling is associated to the virtual execution of impractical or ethically forbidden actions, this has not been the focus of this paper. The resulting files were accessed in CHER-Ob and automated reports were created in HTML format, enhanced with 3DHOP and web RTI components. Web-based visualizations of complex the visual media assets generated during this study are available online for viewing via the Ariadne visual media automatic service by following the links provided at the figure captions.

The processing of data and viewing of RTI images employed open access software. Similarly, MeshLab and CHER-Ob are open access. 3DS Max, Agisoft PhotoScan and Reality Capture are commercial software, which might be accessible via subscriptions of educational institutions. Alternatively, 3DS Max costs $190 per month but is available free for students. The minimum cost for the current version of Agisoft[2] is $179. Reality Capture costs $112 for a three-month license. Figure 1 presents a schematic explanation of the methodology employed.

Results and Discussion

Documentation of State of Preservation

In order to consider the effectiveness of our methodology with perishables such as those from Cache Cave, we considered the most common weathering effects in basketry material such as compression damage, deformations, detached fibers or elements, tears, breakage and loss, protruding fibers, dirt kinks, discoloration and disfiguring surface (CCI 2010; Mason 2018). Our 'digital surrogates' in the form of 3D models do appear to provide the necessary information for recording and documentation of the shape and the identification of distortions and deformations. We found that an efficient way to document and understand the extent of distortions in basketry is the use of 3D slicing modelling tools. These tools generate sections of 3D models that can be rendered non-photorealistically, and furthered processes using 2D imaging software, leading to visualizations that resemble archaeological drawings. This type of visualization is very common in other material types such as pottery. For example, the seed beater (CC-15-1933) presents a gradually increasing deformation in the horizontal sections starting from the handle (Figure 2a). Additionally, a deformation is observable in the vertical section. Probably these deformations are associated with the forces applied to the seed beater while it was still in use. This provides valuable interpretative information concerning the biography of the object before its deposition in the cave. The sections in different areas assist in not only recording, documentation and identification of the disfiguration for interpretation, but also can guide reshaping and repairs, if considered necessary for the long-term stability of the basket or for display. In the case of baskets without severe distortions, such as the tray shown in Figure 2b (CC-15-2134) the profile drawing can be used for classification purposes. Moreover, 3D models can be potentially used for monitoring purposes, by comparing the visualizations produced in different times, making use of the user-friendly open source software CloudCompare (CloudCompare 2019), or other similar tools.

Interactive relighting visualizations are also useful tools in recording heavily distorted baskets in fragmentary state. For example, the normal map of the badly deteriorated CC-14-1871 basket fragment shows the areas of major geometric transformation of the uneven surface as bright cyan color (Figure 3a-b). In that way, it is possible to understand the complex three dimensionality of the fragment via a 2D visualization. Computational photography techniques do not provide further evidence regarding discoloration compared to static 2D images but assisted in discerning discolored fibers from depositions. The basket CC-12-657 is characterized by the large areas of discoloration, which proved to be depositions of white color, as shown in the close-up RTI views (Figure 3c-f). The detached, protruding fibers and the areas of loss, tears and splits were more discernible in the RTI visualization than in static 2D images. Characteristic example is the basket CC-12-140, which presents breakage of fibers, splits and missing parts. The RTI renderings enabled better views of the surface morphology and emphasized the geometric transformation of the surface (Figure 3g-j).

The efficiency of RTI in recording surface detail in the form of tears and depositions is not comparable to 3D visualization. Nevertheless, the latter provides useful information for the shape of baskets that cannot be visualized in 2D. Additionally, volumetric, dimensional and morphological analysis via the comparison of measurements and shapes and their variations, which assists in the categorization of basketry, is based on 3D visualizations. Worth mentioning is that for the analysis of basketry in bad state of preservation, 3D digitization is highly recommended, because of the possible damage during lifting, transportation and storage. For example, Craig M. Lee et al. are documenting baskets and other perishable artifacts emerging from melting ice patches in the greater Yellowstone area of Montana and Wyoming (personal communication to E. Jolie 2018; Lee and Puseman 2017). In situ documentation enables a better understanding of the major alterations taking place during and after excavation and facilitates better post-excavation analyses of baskets and other perishable artifacts by perishables analyst or conservators in the lab. Indeed, images and models Lee and his collaborators generated were of value not just for in situ documentation but also understanding and excavating a 1,400 year old basket removed from an ice patch en bloc and sent to us on dry ice covered in matrix for study. As shown in Figure 4, a photogrammetric dataset of 46 images was processes in Reality Capture software, leading to a 3D model of part of the Cache cave during excavation.

Nevertheless, in situ photogrammetric data acquisition is challenging. For example, Feature 66, located in Cave 3, is a difficult to reach area within the Cache Cave system. Access involved a system of three ladders, scrambling, and limited climbing. Cave 3 can be described as a large void in the midst of tons of collapsed rock, with large boulders hemming in the West and South portions of the cave, held in place by the house size boulder forming the East wall of Cave 3. Though some rocks were solidly in place, others were precarious and could potentially shift or fall, which meant great caution was needed at all times. Adding to the physical dangers, Cave 3 is located in the dark zone of the Cache Cave system, with functionally no light entering the cave. A small LED lamp (approx. 80 lumens) aided in focusing and moving through the cave to document the finds. Due to the lamp’s low output it had no impact on the photograph exposures. Located at the convergence of a large overhanging boulder and East cave wall, Feature 66 was spatially confined and offered many challenges in terms of camera placement and lighting. In consideration of these conditions, all images were taken handheld which offered great mobility in tight quarters. The SB800's were individually mounted on JOBY GorillaPods and continually moved through the cave as needed, often with one speedlight being handheld just off camera to diminish negative impacts from shadows in each shot. A total of 532 photographs were taken to create a photogrammetric 3D model of Feature 66 in situ. The output 3D model is useful, especially in conjunction with standard plan drawings, in being able to provide visual evidence of the way that the large twined fragment was used to cache the other objects. Utilizing a 3D viewer allows investigating the feature from every angle. This can then be further illustrated by capturing screen shots of various views and combing them in 2D graphic form. For instance, it can be seen that an awl is embedded in a fold of the large basket fragment, while the two wooden vessels were nestled into the edge of the same basket (Figure 5). Equally, the model shows how the cache was nestled into a rock platform. There are disadvantages. Creating a viewable 3D model from so many images typically requires a reduction in resolution of each, so that fine detail can be sacrificed for ease of use. However, even though the 3D model is created by a large quantity of 2D photographs, it has advantages over those static views. First, it allows the view to visualize the topography of the archaeological features, which is not possible in any single 2D image. Second, it allows motion across and through that topography, enabling a scalable exploration of artifacts, natural features, and relationships. And perhaps most importantly, the model creates fluid space within which any perspective can be adopted, even ones that were not originally captured in any of the 532 photographs.

Recording Basketry Technology

Large areas covered by a thick layer of depositions render the weaving pattern of the baskets and their decoration completely or partially invisible. Close-up details of basket CC-14-1871 and the seed beater (CC-15-1933) reveal that the RTI renderings succeed in visualizing the texture of the basket in areas which appear as covered by depositions in the static 2D image (Figure 6a-d). Similarly, RTI visualizations of the basket CC-12-374 reveal the decoration of the basket, as shown in Figure 6e-h.

In general, we found that RTI is useful for recording basketry technology features. In RTI renderings the basic structure (side), beginning of strands (base), end of strands (rim), orientation of strands, active and passive elements and systems involved in the construction of basketry are emphasized. Figure 7 shows details of the non-work (convex) surface of the basket CC-15-2134 as if lighted from above in the top two rows of the left column. In the former detail, the normal, continuous coil start with 3-4 reinforcing stitches over the first couple of coils appear emphasized in RTI default rendering and normal visualization. The specular enhancement view is less informative. In the latter, the gaps between stitches and the stitches piercing the coil's bundle foundation become more apparent in RTI default, specular enhancement and normal map views. For the seed beater (CC-15-1933) Figure 7 shows details as if lighted from above in the tow bottom rows of the left column. The third row from the top presents RTI views of the 1/1 interval simply plaiting (interlacing), in which peeled-shoot weft strips pass over and under pairs of rigid elements acting as a single warp unit. The specular enhancement mode and the normal map visualizations are enhanced visualizations compared to the static 2D image as if lighted from above. Similarly, the details of the 2 ply, S-spun, final Z-twist cordage that serves to bind the seed beater's rim together while securing it to the handle that consists of the gathered warp rods wrapped with the same cordage, are more clear in the RTI views compared to the static 2D image as if lighted from above.

In the case of 3D models, our work found that the efficient identification of different basketry techniques depends on the quality of digitization and the rendering settings. Renderings without texture tend to provide a clearer picture of the technological features. Additionally, by manipulating the light settings, including the light direction, contrast and brightness, the user can gain a more informative view of the structural elements and their manner of engagement. Nevertheless, non-textured renderings dismiss important information derived from color variation, which is a key parameter for understanding basketry technology. Therefore, textured renderings are necessary for the examination of color decoration and the differentiation in the color of the weaving elements as they might derive from different species and processed following different techniques. For example, the color differentiation close to the base of the small basket, probably a decoration feature, is visible in the texture 3D renderings, providing a better understanding of the shape and the three-dimensionality. A detail from the same area in RTI mode emphasizes surface texture and retains color information, assisting the analysis of technological and decorative features (Figures 8a-d). As observed in feature 66, fine details of the basketry were lost in the rendering process, particularly in the case of larger baskets frayed edges. VCMG offered far better fidelity for minute basketry details, layering of basketry, and frayed ends—distinguishing individual strands, as shown in Figure 8e-f. Regrettably, the texturing of VCMG objects is of poor quality, with uneven surface coloring, blank pixel data, and variegated patterns of distortion forming throughout the texture.

Integration and Online Publication

Our analyses have demonstrated that interactive relighting visualizations succeed in emphasizing surface texture and by extension proved useful for documentation and analysis of baskets. 3D visualization provides useful information for shape of the baskets. They assist in condition assessment via virtual visual analysis, limiting the human-object interaction and avoiding unnecessary handling of the baskets. Most importantly, the combined 3D and interactive relighting digitization approach is particularly useful in case of complex basket types, such as the seed beater. As stated in the beginning of this paper, we also wanted to consider how disseminating visualizations of perishables could be achieved in order for other researchers to conduct their own virtual analyses. The most appropriate software for performing this type of combined virtual visual analysis is the virtual research environment, CHER-Ob. As shown in the CHER-Ob's screenshot in Figure 9a, the two sides of the seed beater visualized in RTI format as well as the 3D model were viewed in the image panel comparatively. Other than simultaneous virtual visual analysis, the multilevel annotation framework assists in documentation. For example, Figure 9b shows an annotated RTI view of a basket, using a combination of color-coded point, and surface annotations. After completing the comparative virtual visual analysis, a report in a web page format (HTML) can be created via the automatic report generation CHER-Ob function. This web page can be further enriched with advanced computer visualizations transformed using 3DHOP (Figure 9c). and webRTI tools (Figure 9d).

The visualizations along with the potential to access them online and/or within a combined virtual environment encourage collaborations between scholars. Beyond the scientific community, the visualizations can contribute in the dissemination to a wider audience for outreach and education purposes. Community archaeology projects employ computer visualization tools, such as the Scotland's rock art (https://www.rockart.scot/) and the Re-reading the British Memorial project (https://www.york.ac.uk/digital-heritage/research/portfolio/rereading/). Mixed, augmented and virtual reality are increasingly being used, providing enhanced accessibility to sites like the Pleito cave (https://www.youtube.com/watch?v=PJRHUcC0xa8; Cassidy et al. 2018). Furthermore, visualizations assist in public engagement and their online dissemination can potentially motivate members of the public to get further involved in archaeological projects. For example, gaining insights into the intangible aspects of lost Jewish communities via sharing their own family histories has been discussed as part of the Unfolding Communities project (http://judaica-unsleben.de/; Kotoula et al. 2019). A similar approach can be equally beneficial for the basketry material, considering the descendants of Chumash as well as the basket weavers. For the later, access to the digitized materials online might be useful for revitalizing weaving traditions and an actual support with tangible benefits. In that case, computational photography, 3D modelling and online publication might become the vehicle or medium for the development of interactive, collaborative relationships between Native American communities, the few remaining weavers and the archaeologists.

Conclusion

This study presented RTI and 3D visualizations of recently excavated baskets from Cache Cave, Southern California, as well as integration of data in CHER-Ob and online dissemination using web RTI and 3DHOP. Results indicate that advanced computer visualizations are particularly useful for recording and documentation of the state of preservation, such as deformations, distortions, depositions, discoloration, tears and splits. Furthermore, 3D in situ documentation provides valuable evidence for the appearance and characteristics of the basketry material in a point in time before any alteration or damage take places during excavation, transportation or storage. Additionally, the RTI and 3D models provided useful information for the weaving pattern and the decoration, enabling enhanced study of sides, bases and rims of baskets. The CHER-Ob software proposed for integration is not only the only available tool for simultaneous analysis of diverse data types, but also a powerful annotation tool, that proved useful for virtual visual analysis. The online dissemination tools used were particularly easy to use. Considering the above, basketry documentation using RTI and photogrammetry, as well as further processed using 3D modelling software and integrated analysis tools, and transformation to web-based format for online dissemination, are useful additions for the study of basketry materials. No longer are we limited by our onsite interpretations of the artifacts in-situ—which are temporally limited and inaccessible once the artifacts are removed. Instead, we are capable of continually revisiting our findings and questioning our presumptions based upon new data and insights. Furthermore, we can now share our findings and our interpretation simultaneously in publication.

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Notes

1. Identifier: b0f1e1fb7669fc444b359a343af7cb0e. Digitised at 01/5/2014. Last updated in Europeana at 30/1/2015. Available at https://www.europeana.eu/portal/en/record/2020720/DR_b0f1e1fb7669fc444b359a343af7cb0e.html

2. Agisoft launched Metashape and replaced PhotoScan after the completion of this study. A comparison between Metashape and Photoscan is available at https://www.agisoft.com/pdf/metashape_comparison.pdf (accessed date April 11, 2019).

Data Availability Statement

The dataset used in this study is stored in digital format and curated by the University of Central Lancashire, Preston, UK. RTI visualizations, 3D models and videos are available online from the University of Central Lancashire repository at https://doi.org/10.17030/uclan.data.00000184. The ARIADNE platform was used during the development of the study and the visualizations are available at:

- http://visual.ariadne-infrastructure.eu/3d/4f9c022d8e69ee445d63e05c6911f29f
- http://visual.ariadne-infrastructure.eu/3d/5fe7333ae466692d64279e9700f96a60
- http://visual.ariadne-infrastructure.eu/rti/12634f61fac30d44267a4f1d49551b45
- http://visual.ariadne-infrastructure.eu/rti/4ab586f534f461d04baaef5cba83487c
- http://visual.ariadne-infrastructure.eu/rti/73e5baad5d344c7c38a534c7b97f7cf7
- http://visual.ariadne-infrastructure.eu/rti/a52948eb543acd0e910e6ed97cd73f61
- http://visual.ariadne-infrastructure.eu/rti/d40e977cb2871acc3081aab38e75485c

Figure Captions

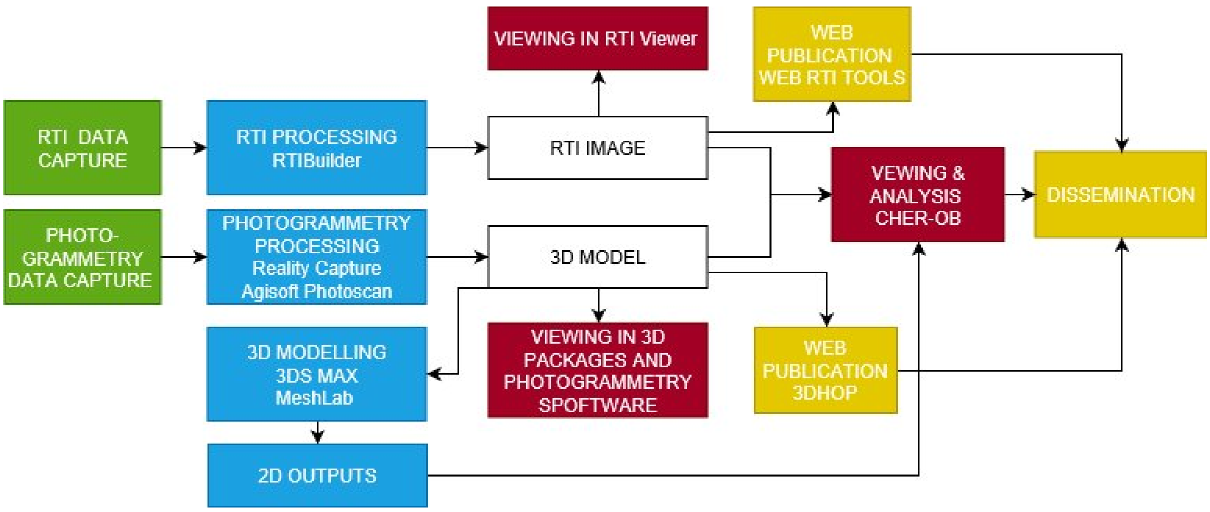

Figure 1: Schematic explanation of the methodology employed. Green color indicates data capture phase, followed by blue color for processing required for the generation of RTI files, 3D models and 2D outputs. Red color indicates viewing and analysis and yellow color shows tools available for dissemination of computer visualizations.

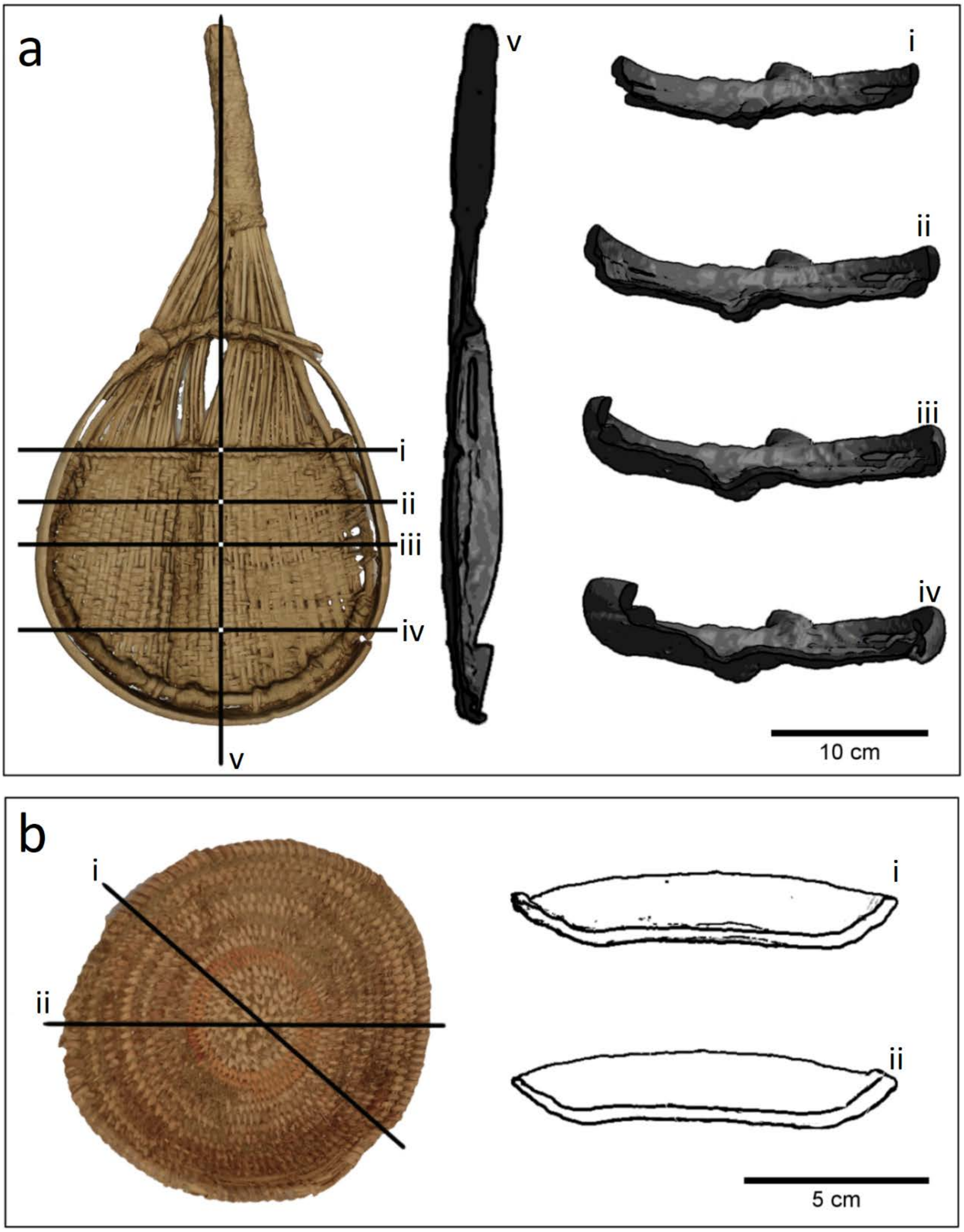

Figure 2: Seed beater (CC-15-1933) (a) and tray CC-15-2134 (b), sections generated in 3DS Max. 3D visualizations available online at http://visual.ariadne-infrastructure.eu/3d/4f9c022d8e69ee445d63e05c6911f29f, http://visual.ariadne-infrastructure.eu/rti/a52948eb543acd0e910e6ed97cd73f61, and http://visual.ariadne-infrastructure.eu/rti/4ab586f534f461d04baaef5cba83487c

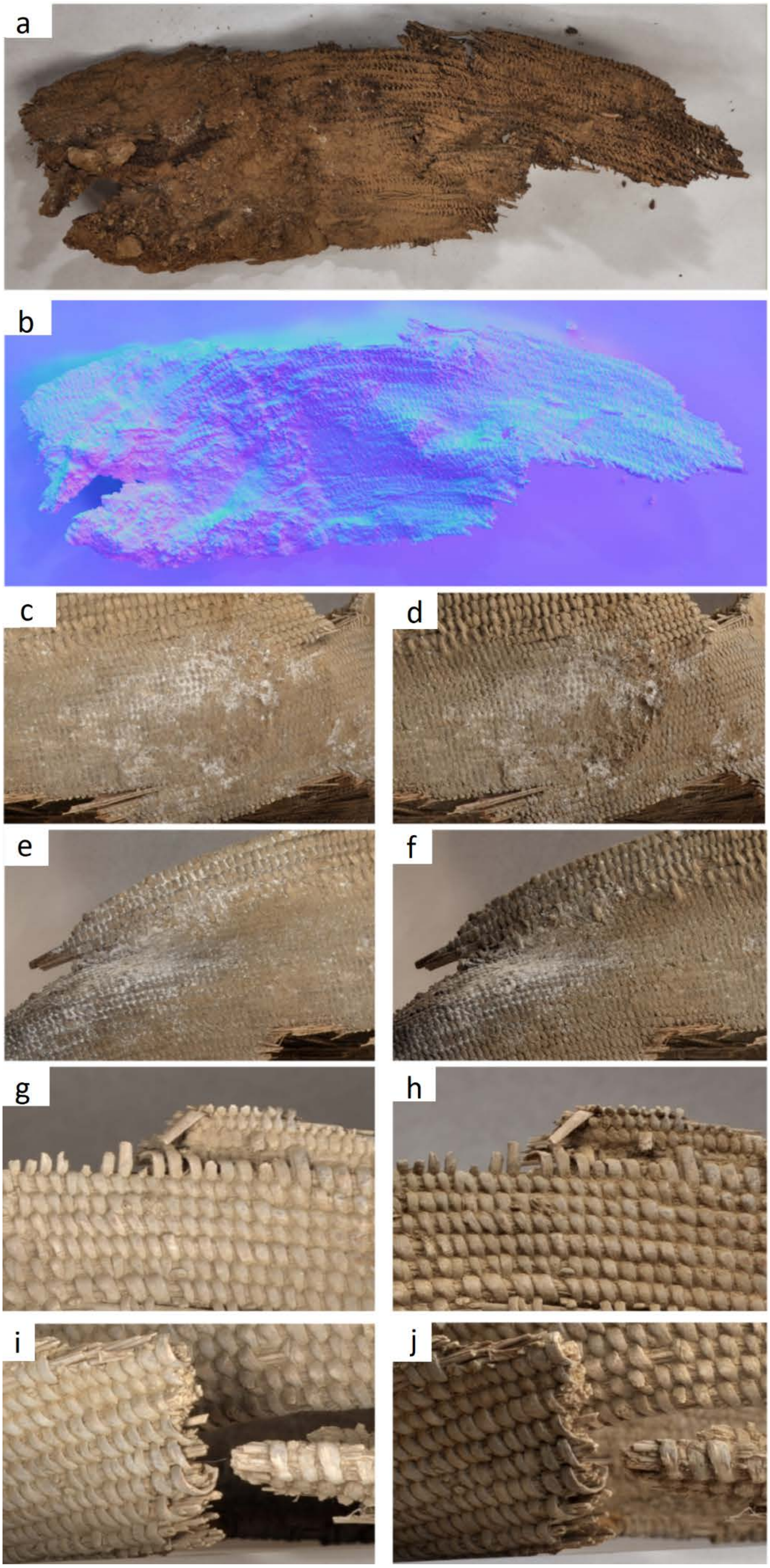
a
b
c
d
e
f
g
h
i
j

Figure 3. Basket CC-14-1871. Comparison of views as if lighted from above (a) and RTI normal map (b). Basket CC-12-657. Comparisons of RTI views as if lighted from above (c,e) and RTI visualizations in default rendering mode (d,f). Basket CC-12-140. Comparison of RTI view as if lighted from above (g,i) and RTI visualizations in default rendering mode (h,j). Visualizations available online at http://visual.ariadne-infrastructure.eu/rti/12634f61fac30d44267a4f1d49551b45, http://visual.ariadne-infrastructure.eu/rti/73e5baad5d344c7c38a534c7b97f7cf7 and http://visual.ariadne-infrastructure.eu/rti/d40e977cb2871acc3081aab38e75485c

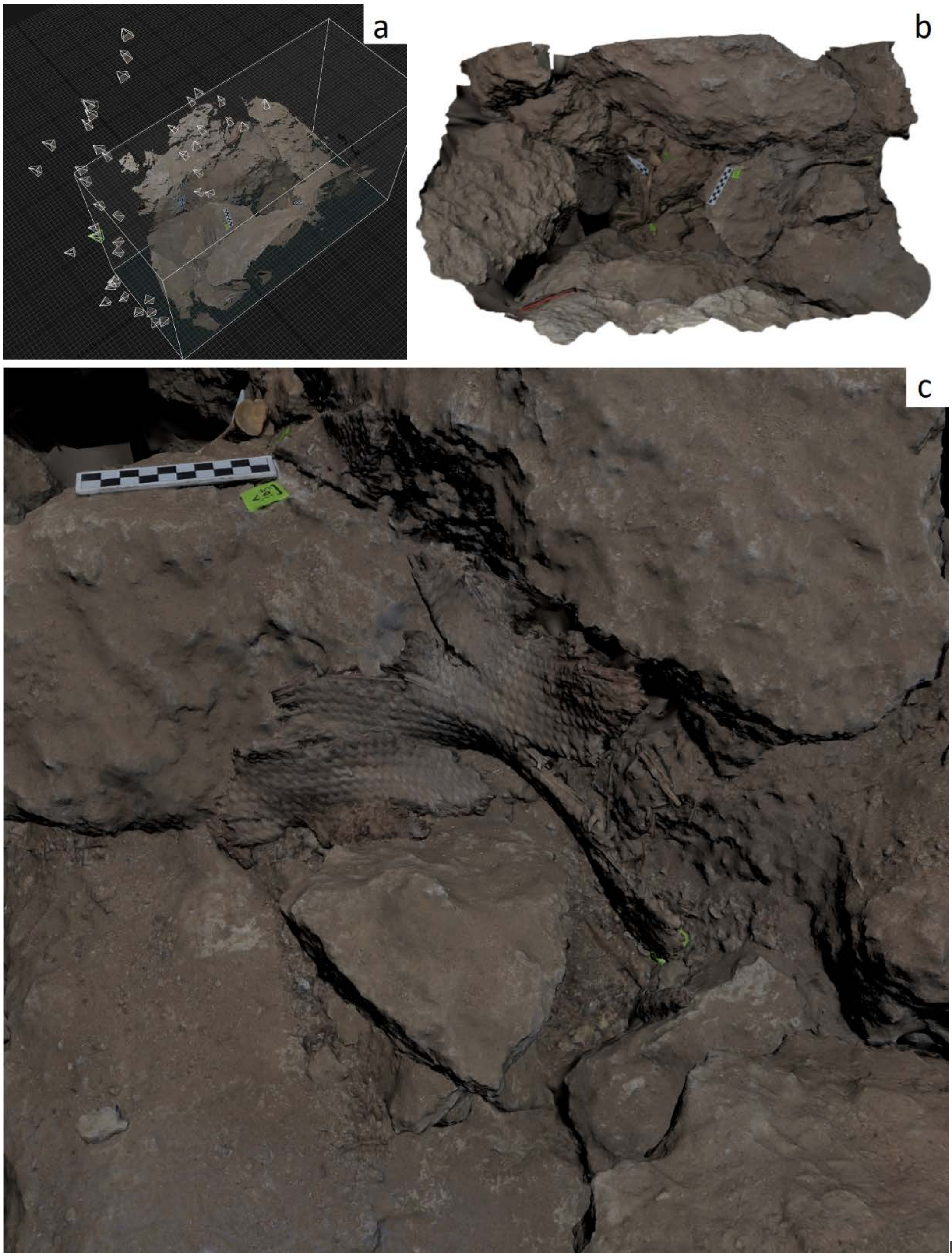

Figure 4: Cache Cave during excavation. Screenshot of Reality Capture showing the alignment of cameras (a). Renderings, general view of the reconstructed 3D model (b) and basket fragment detail (c). Visualization available online at http://visual.ariadne-infrastructure.eu/3d/5fe7333ae466692d64279e9700f96a60

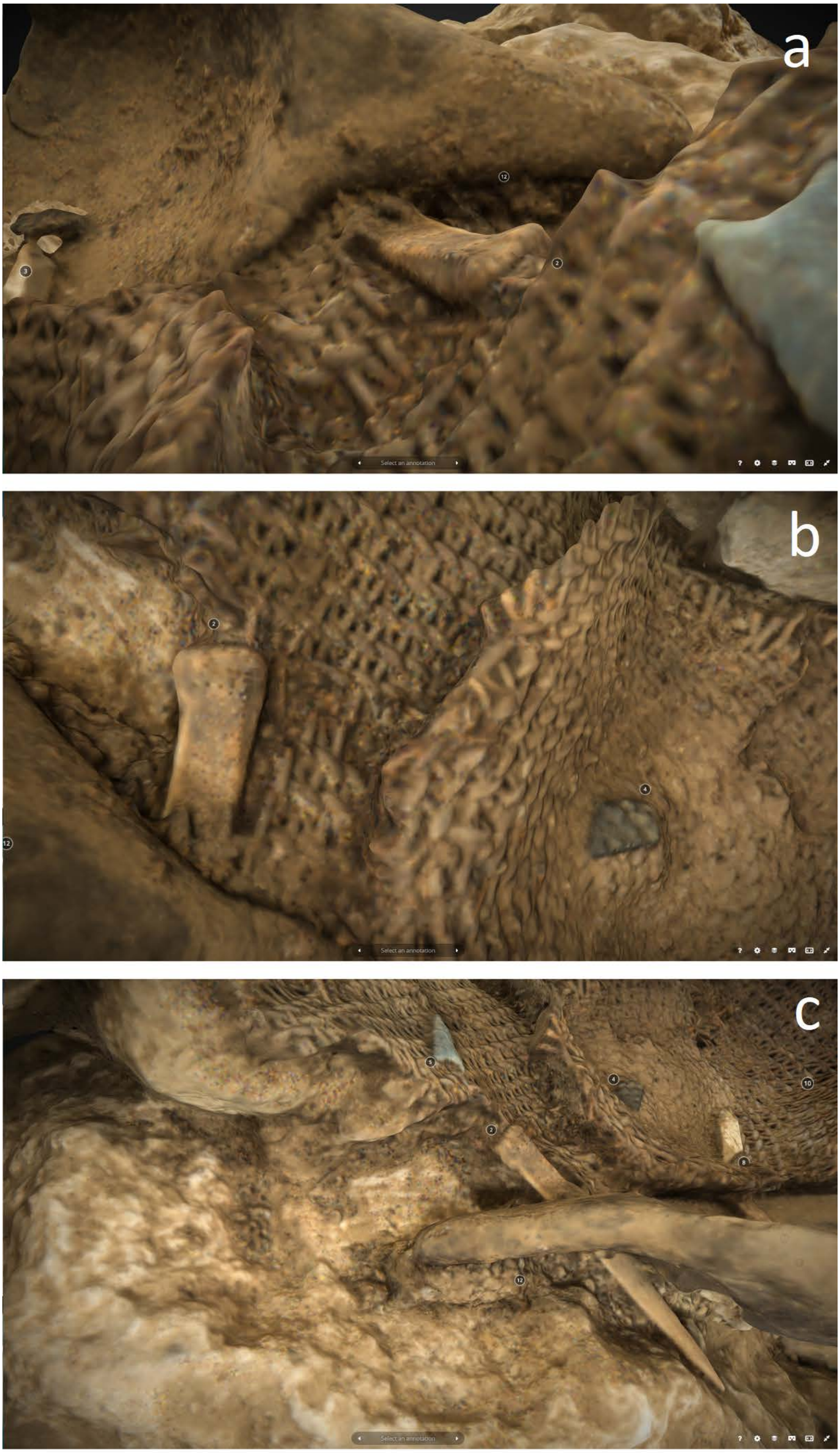
a
b
c

Figure 5. Three screen shots of the 3D photogrammetry model of Feature 66, Cave 3, Cache Cave, focusing on the relative position of the awl. Note how the awl is both above and below the large open twined basket, illustrating that the awl wrapped within a fold of the large basket.

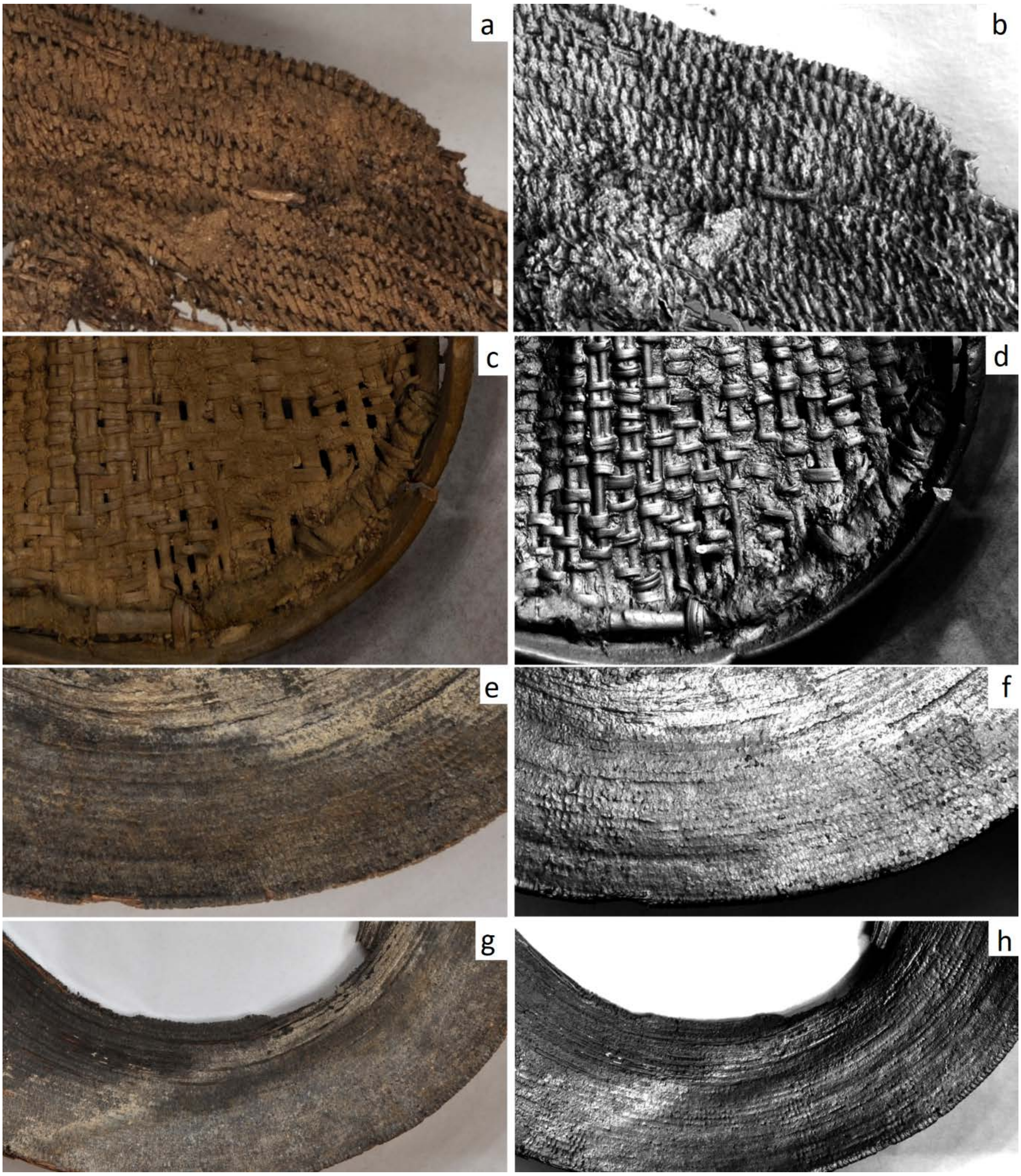

Figure 6: Comparison of views as if lighted from above and RTI visualizations in specular enhancement rendering mode. Basket CC-14-1871 (a,b). Seed beater CC-15-1933 (c,d). Basket CC-12-374 (e,f,g,h). Visualization available online at http://visual.ariadne-infrastructure.eu/rti/12634f61fac30d44267a4f1d49551b45 and http://visual.ariadne-infrastructure.eu/rti/a52948eb543acd0e910e6ed97cd73f61

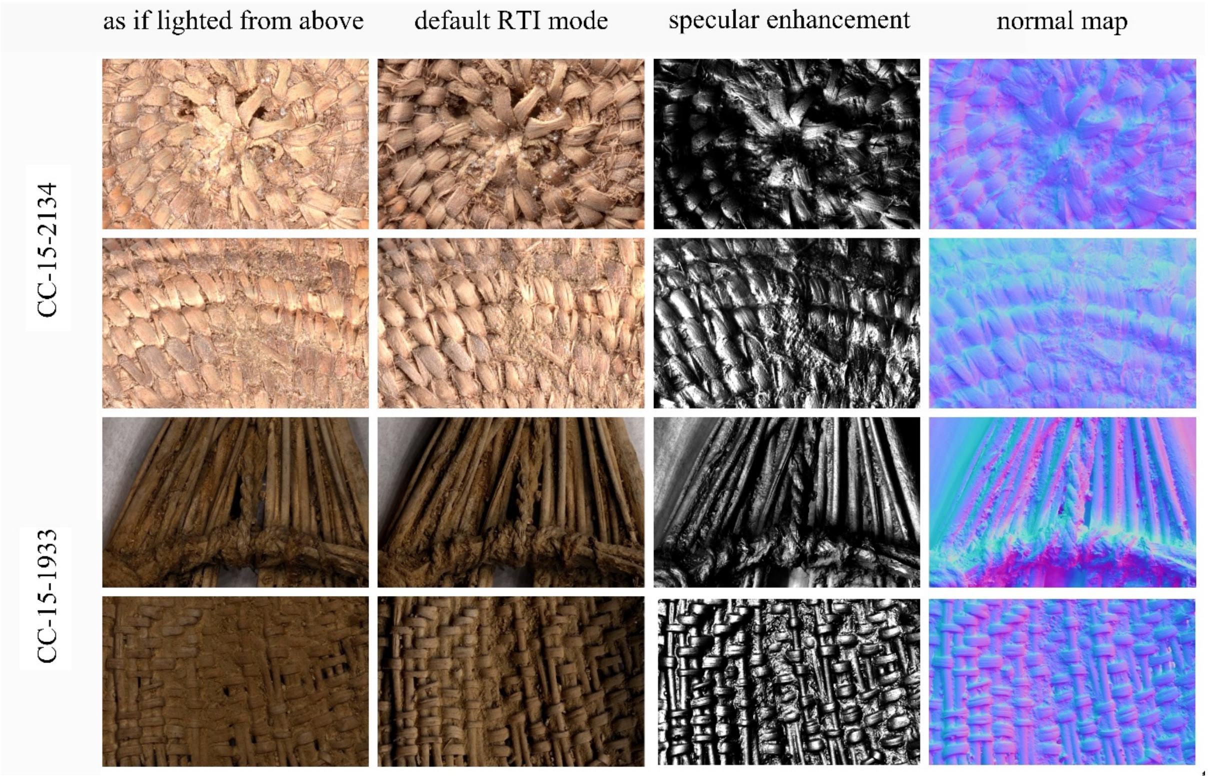

Figure 7: RTI details of tray CC-15-2134 and seed beater CC-15-1933, as if lighted from above, default rendering mode, specular enhancement rendering mode and normal maps. Visualization available online at http://visual.ariadne-infrastructure.eu/rti/4ab586f534f461d04baaef5cba83487c and http://visual.ariadne-infrastructure.eu/rti/a52948eb543acd0e910e6ed97cd73f61

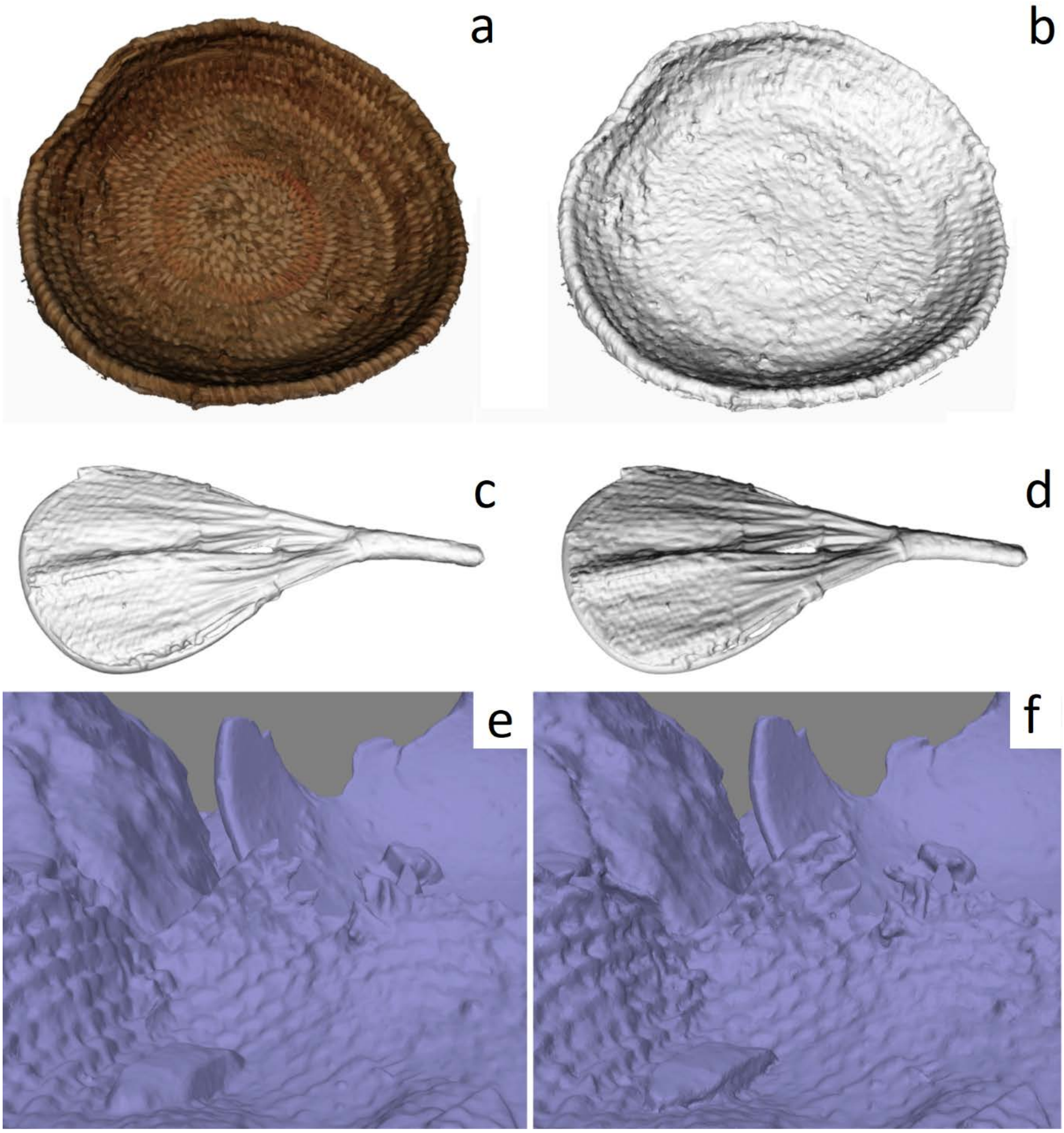

Figure 8: Tray CC-15-2134, colored and textured rendering (a). Seed beater CC-15-1933, non-colored rendering (c). Raking light rendering (b,d). Comparison of standard mesh formation (e) and the experimental Visibly Consistent Mesh Generation (f).

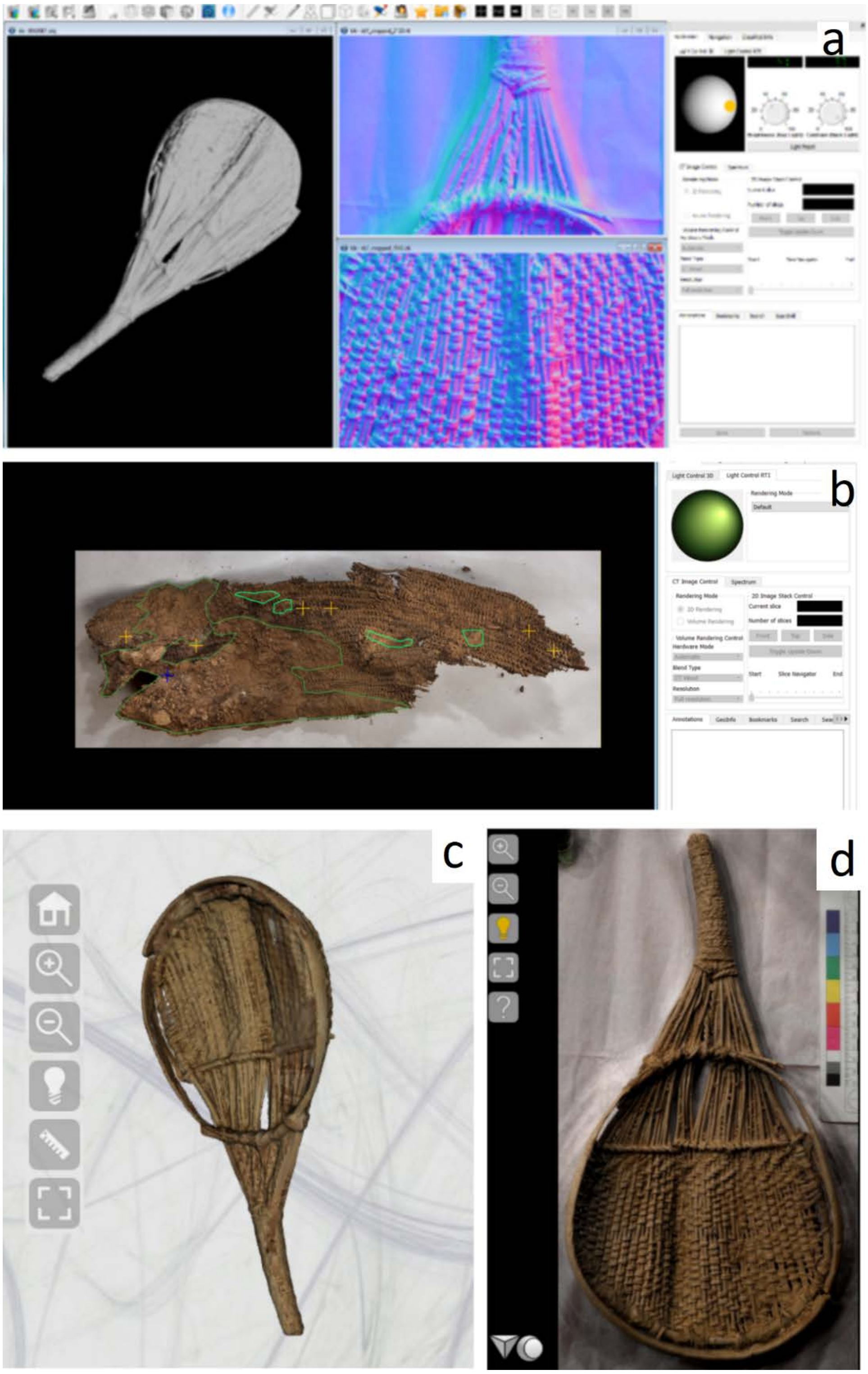

Figure 9: A CHER-Ob screenshot showing the comparative simultaneous analysis of seed beater (CC-15-1933) visualizations in 2D and 3D form (a). Fully annotated RTI view of a basket; green outline: depositions from the burial environment, yellow crosses: white colored depositions; blue crosses: damage (b). Web publication of seed beater (CC-15-1933), screenshots of 3DHOP (c) and Web RTI (d).

Table 1: Technical characteristics of basketry material included in this study

Catalog Number	Size	Preservation	Structure	Description
CC-12-140	18 cm long 24 cm wide, at least 6 cm tall	Incomplete basket. No start, no rim.	Close coiling, bundle foundation, noninterlocking stitch	Majority of this is replacement coils, either a brand new base or a restricted opening. Juncus bundle, possible sumac stitches. Plant/insect residue in interior.
CC-12-374	40.5 cm by 42 cm wide, 8 cm max height.	Incomplete basket. No base. No rim.	Close coiling, bundle foundation, split on both surfaces	Decorated (repurposed?) as parching tray. Central coils flare outward. Walls also flare outward. Juncus bundle, possibly juncus stitches. Decoration appears to be bracken fern root (Timbrook personal communication); Outermost preserved coil suggests decorative band. Woven-in decorative elements sparse and not perfectly symmetrical
CC-12-657	32 cm long, 27 cm wide, 17 max tall	Fragment from basket's body. No base.	Close coiling, bundle foundation, non-interlocking stitch	Possible burden basket. Faded stepped design elements. Final 6 coils on rim are replacements. Replacement rim is a self-rim.
CC-14-1871	34 cm long 11.5 cm wide	Fragment from basket's body.	Close coiling bundle foundation non-interlocking	Normal start; self-rim; evidence of mending with cordage
CC-15-1933	48 cm long	Complete seed beater.	1/1 simple and 2/2 twill plaiting	Alternation of plaiting interval for decorative effect. Rim hoop is secured with cordage and pitch. Cordage on hoop and handle is 2-ply z-spun final s-twist
CC-15-2134	10.3 cm diameter	Complete tray.	Close coiling bundle foundation non-interlocking stitch	Normal start self-rim with false braid or backwrap termination. Decorated with juncus and 2 shades of possibly sumac with bark left on or removed. Per Timbrook, has traits suggestive of Gabrilieno according to Dawson and Deetz (1965), including rim finish, grass bundle foundation, tucked fag ends.

Table 2: Metadata for digitization of basketry. Indoors data capture. No filter used. Light type: Visible light. Light source: Flash.

Basket		RTI Capture details				
Catalog Number	Thumbnail	Set up configuration	Number of images	Targets	Targets' size (px)	Camera ID[1]
CC-12-140		Outside view of basket. Vertical subject configuration	79	1 black plastic sphere	238x238	4
		Outside view of basket. Horizontal subject configuration.	55	1 black plastic sphere	234x234	5
CC-12-374		Outside view of basket. Horizontal subject configuration.	84	1 black plastic sphere	176x176	6
		Inside view of basket. Horizontal subject configuration.	79	1 black plastic sphere	164x164	6
CC-12-657		Outside view of basket. Vertical subject configuration.	83	1 black plastic sphere	188x188	6
CC-14-1871		Outside view of basket. Horizontal subject configuration.	57	1 black plastic sphere	230x230	5
CC-15-1933[2]		Inside view of basket. Horizontal subject configuration.	37	1 black plastic ball and 1 metal silver spheres	124	1
		Outside view of basket. Horizontal subject configuration.	38	1 black plastic ball and 1 metal silver spheres	120	1
CC-15-2134[2]		Inside view of basket. Horizontal subject configuration.	42	2 metal black and silver spheres	276	2
		Outside view of basket. Horizontal subject configuration.	31	2 metal black and silver spheres	242	2

Notes

1. Camera metadata ID KEY. 1: Camera NIKON D3100, Lens type AF-S DX Micro NIKKOR 40mm, ISO 100, Aperture f/8, Shutter Speed 1/15sec, Focal Length 24mm. 2: Camera NIKON D3100, Lens type AF-S DX Micro NIKKOR 40mm, ISO 100, Aperture f/8, Shutter Speed 1/15sec, Focal Length 40mm. 4: Camera NIKON D90, Lens type AF-S Nikkor 18-55 mm, ISO 200, Aperture f/8, Shutter Speed 1/60sec, Focal Length 26mm. 5: Camera NIKON D90, Lens type AF-S Nikkor 18-55 mm, ISO 200, Aperture f/8, Shutter Speed 1/60sec, Focal Length 25mm. 6: Camera NIKON D90, Lens type AF-S Nikkor 18-55 mm, ISO 200, Aperture f/8, Shutter Speed 1/60sec, Focal Length 18mm.

2. 3D digitized artefact.