

3D/VR in the Academic Library: Emerging Practices and Trends

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Foreword

More and more individuals, both within and outside higher education, are creating and using 3D, virtual reality (VR), and augmented reality (AR) tools and systems for research and learning. Applications span the full breadth of the disciplinary spectrum: 3D models of vanished historical spaces allow archaeologists and historians to test theories about their arrangement and use; VR environments allow students of anatomy to explore simulations of the human body; AR ties digitized archives and artifacts to physical locations, merging the past with the present; and 3D printing enables student artists and engineers to share prototypes of their designs.

The essays in *3D/VR in the Academic Library: Emerging Practices and Trends* capture just some of ways that 3D/VR is already having an impact on the creation and transfer of knowledge. Bringing together the insights of notable innovators in research, pedagogy, cultural heritage, and science, the volume signals an expansion of these technologies within education while simultaneously acknowledging serious challenges. The continued rapid development and expansion of 3D/VR may potentially transform learning, but keeping up with these changes can quickly overwhelm the capacity of any single department or organization. Decision makers face difficult choices as they seek to calibrate their investments in related tools and expertise to the priorities of their institutions. The interdisciplinary appeal of 3D/VR can generate productive collaborations among students, faculty, and staff with different academic, technical, and professional backgrounds, and contributing to these teams can be rewarding. At the same time, this very interdisciplinarity challenges accepted structures of authority: Where should this work take place? Who should lead it? In what venues should the work be shared with others? How should credit be distributed to contributors?

Other challenges arise from the adaptation of technologies developed for profit-driven industries to educational and nonprofit sectors. As VR technologies develop with the interests of big commercial players, and as the means of encoding 3D data change alongside VR hardware and software, academic and independent creators who value broad access, sharing, and sustainability must find ways of maintaining 3D/VR content so that it is susceptible to critique, reproducible, and repurposable.

To help confront all of these challenges, 3D/VR creators badly need the support of specialist librarians and archivists. As interdisciplinary meeting points; as service providers dedicated to providing the raw materials for research and learning; and as organizations dedicated to the collection, preservation, and distribution of knowledge, campus libraries already have staff with many of the skills needed for the wise application of new technologies to research. Expertise in research methodologies, in digital publication, in digital library development, in the use of metadata for discovery, in archival

appraisal—all of these skills are relevant to the creation of sustainable environments in which educational applications of 3D/VR can thrive.

One major concern—the digital preservation of 3D/VR data—is a common thread that ties the pieces of this volume together. The projects described by the authors are all quite distinct in their reasons for being and in their potential for reuse. Consequently, the preservation priorities for each body of work are different. For uses of 3D/VR to reconstruct vanished historical places or artifacts, preserving the context for each reconstruction, the motivation behind it, and the choices that experts make about the evidence considered are essential elements. Without the context, the rigor of the scholarship that underlies digital reconstructions can be obscured. In other cases, when researchers digitally scan contemporary natural and built environments in 3D, preserving “raw” scans of these environments in a common, nonproprietary format that is discoverable and reusable may be an important consideration. Opportunities for 3D capture may come only once, and the captured data can become the best surviving record of a place, artifact, or organism that will otherwise be lost to time. For works of pure invention, including games, visual art, and film incorporating 3D/VR, documentation of the creative process could prove critical for future artists and historians.

This volume’s editors draw upon the contributions of each author to outline practical steps forward for collecting institutions. Notably, they encourage librarians and archivists to envision pathways to 3D/VR preservation and access that entail collective action across institutions. Tackling the complexities of digital preservation for 3D data and VR applications can easily stretch skills and technical capacity at one organization well beyond its limits, so broad consultation will be necessary to inform the choices that each institution must make.

As VR for the home becomes ubiquitous, its uses for research and learning will continue to multiply. Documenting the variety of ways in which researchers, educators, and information professionals use 3D data and VR software should become a priority for academic libraries and archives, if only to inform future applications. For example, virtual environments already show great potential for research in philosophy, psychology, and neuroscience. In his article, “Are We Already Living in Virtual Reality?”¹ Joshua Rothman describes how experiments with “virtual embodiment”—a particular type of VR that allows a person to temporarily “become” someone else—suggest that it is possible to dramatically, perhaps permanently, alter people’s perceptions of themselves and others. Such experiences hold the potential for tremendous beneficence or tremendous harm. Mapping a future for 3D/VR in education will require more than sophisticated technical and financial insights; in time, drawing appropriate moral and ethical boundaries could prove even more vital. A fully nuanced understanding of the histories of 3D/VR and related technologies must be available to help future researchers and teachers cope with these challenges.

—Christa Williford

¹ *The New Yorker*, April 2, 2018

Introduction

3D/VR Creation and Curation: An Emerging Field of Inquiry

Zack Lischer-Katz, Kristina Golubiewski-Davis, Jennifer Grayburn, and Veronica Ikeshoji-Orlati

Three-dimensional (3D) modeling, 3D capture techniques, and virtual reality (VR) are becoming increasingly common in research and teaching. Following a period of intense, yet short-lived enthusiasm in the 1990s, VR has returned, showing great promise as a tool for enhancing scholarship and pedagogy in the context of higher education. VR refers to a set of technologies that create immersive digital environments, re-creating the perceptions of our everyday experiences in order to simulate places and things. Typically, this involves providing stereoscopic visual and aural information to the eyes and ears, which the system changes as a user moves their head, body, and hands. The release of the inexpensive Google Cardboard VR viewer in 2014 has generated significant interest, with more than 10 million viewers having been shipped (Vanian 2017). The release of affordable, fully functional VR headsets in 2016 (most notably, the HTC Vive and Oculus Rift headsets) is fueling experimentation in a variety of academic contexts, from library-based makerspaces and humanities classes (Figueroa 2018) to architecture and design programs (Enis 2016) and law schools (Dilbeck 2016). Experiments in the VR world aim to bring haptic and olfactory forms of perceptual information into the mix to create a greater experience of perceptual “fidelity,” that is, the closeness of the user’s experience of a simulated, virtual world to the user’s ordinary experience of the physical world (Bowman and McMahan 2007).

Throughout this report, we use the term *3D/VR* to stress the intertwined nature of 3D data/models and VR-related technologies (such as augmented reality), the latter of which may be understood as 3D viewing and visualization platforms. Although in some ways this is an oversimplification, conceptualizing 3D as the content and VR as the platform allows us to simultaneously consider the particular creation and curation needs of each aspect separately, as well as their interdependencies.

As 3D and VR tools are introduced into higher education contexts, they enable faculty and students to engage with highly detailed 3D data—from cultural heritage artifacts to scientific simulations—in new ways. The creation and use of 3D data have become more widely practiced thanks in part to the decreasing costs of the hardware and software for capturing and processing 3D data; photogrammetry, structured light scanning, laser scanning (LiDAR), computed tomography (CT) scanning, and other techniques are moving out of the lab and finding new applications in a plethora of new fields. With 3D and VR technology, a professor may take students on an immersive field trip to Stonehenge, changing the lighting to simulate various phases of solar events; an archaeologist may capture 3D scans of an archaeological excavation and share these data with a colleague on the other side of the world in the form of an immersive virtual exploration of the site; a biochemistry professor may explore complex protein structures with students; or a chemical engineer may simulate the movement of fluids in various porous rock materials.¹

Recent research has demonstrated the educational benefits of 3D/VR for teaching in a variety of fields, including architecture (Angulo 2013; Milovanovic et al. 2017), anthropology (Lischer-Katz, Cook, and Boulden 2018), and medicine (Kersten-Oertel, Chen, and Collins 2014), to name a few. More generally, 3D/VR has been shown to augment spatial analytic skills (Ragan et al. 2013), particularly in such areas as big data exploratory analysis (Donalek et al. 2014; Van Dam, Laidlaw, and Simpson 2002), design prototyping (Seth, Vance, and Oliver 2011), graph analysis (Ware and Mitchell 2005), and analysis of volumetric datasets (Laha, Bowman, and Socha 2014; Prabhat et al. 2008). In the humanities, 3D/VR has become a popular means of producing new, multimedia forms of scholarship, such as 3D digitization and VR visualization of medieval manuscripts (Endres, forthcoming), as well as making cultural heritage artifacts and sites more easily accessible to scholars and the public (Bentkowska-Kafel, Denard, and Baker 2016), and forming a “3-D digital heritage ecosystem” (Limp et al. 2011). There is also potential for 3D/VR to shape the structure and functioning of the academic library of the future (Cook and Lischer-Katz, forthcoming) by using VR to host traditional library services, such as collection browsing and searching (Cook 2018).

Because 3D/VR technologies are applicable to a number of fields, many academic libraries have become sites for cross-disciplinary research and experimentation in 3D and VR. Some digital

¹ Examples of currently available VR applications that support this type of work include Stonehenge VR Sandbox (https://store.steampowered.com/app/457650/Stonehenge_VR_SANDBOX/); Nefertari: Journey to Eternity, which is built on photogrammetric scans of Nefertari’s tomb (https://store.steampowered.com/app/861400/Nefertari_Journey_to_Eternity/); Nanome, which enables the exploration of chemicals, proteins, and nanotechnology (<https://store.steampowered.com/app/493430/Nanome/>); IrisVR, which supports architecture and interior design work (<https://irisvr.com/>); and Oculus Medium, which provides an artistic sculpting and modeling space in VR (<https://www.oculus.com/medium/>). These are available as of October 23, 2018.

humanities and digital scholarship centers, media labs, and maker-spaces, for example, have embraced the technology, often providing access and support for community members interested in exploring 3D and VR environments for the first time, meeting curricular goals, or examining research data. As 3D and VR projects scale up and move outside of the specialist disciplines where they have existed for decades (e.g., computer science labs, media arts programs), questions arise concerning skills development, interdisciplinary collaboration, publication, sustainability, preservation, and reuse. In addition to providing access to 3D and VR resources, the academic library, already a center for collaboration, instruction, research, and collection preservation, is well poised to provide leadership in this field.

Essays in This Report

The eight essays presented here emerged from talks given at 3D/VR Creation and Curation in Higher Education: A Colloquium to Explore Standards and Best Practices, a mini-conference that took place March 8–9, 2018, at the Bizzell Library at the University of Oklahoma in Norman, Oklahoma. Organized by the editors of this volume who, at that time, were Council on Library and Information Resources (CLIR) postdoctoral fellows working in academic libraries, the event was funded by the Alfred P. Sloan Foundation through a CLIR microgrant with co-sponsorship from the University of Oklahoma Libraries, University of California Santa Cruz University Library, and Temple University Libraries. Although the primary focus on 3D/VR was intentionally narrow in order to maintain a small, intimate group, many of the issues that arose also apply to other immersive technologies, including augmented reality (AR), mixed reality (MR), and extended reality (XR). By its nature, this report is a snapshot, a portrait of the varied professional objectives and workflows that have developed around 3D/VR at this moment, rather than a compendium of universal best practices that will be applicable across space and time.

Over the course of a day and a half, the schedule included moderated discussions by the organizers interspersed with presentations by the eight experts, each representing knowledge in one or more of the following areas: 3D content creation, VR visualization and analysis, 3D/VR-based educational deployment, and 3D/VR data curation. The invited speakers were intentionally chosen from diverse subject expertise backgrounds in order to stimulate cross-disciplinary conversation about how the unique challenges of 3D/VR are handled in a variety of circumstances. In addition to the eight invited experts, the participants included librarians, administrators, faculty, postdoctoral fellows, and content developers. This approach enabled the sharing of knowledge between practitioners in different communities of practice, thus fostering dialogue and developing holistic knowledge about these complex and multifaceted technologies.

By addressing the full 3D/VR lifecycle within a tightly knit community of experts and stakeholders, the organizers of this

colloquium aimed to identify points of tension and gaps in existing practices and knowledge in order to foster common understanding for the librarians and digital curators tasked with supporting and managing these new data types. In this context, content creators, faculty, librarians, digital curators, and preservationists talked across their projects, concerns, and needs. In particular, the conversations allowed participants to work toward a common understanding of when and how to support 3D/VR throughout production, dissemination, and archiving workflows for different projects. The presentations and moderated discussions bridged language and workflow gaps, allowing experts in 3D scanning and VR development to exchange knowledge with experts in project management and digital preservation.

Practitioners are quick to point out that 3D/VR projects do not exist in a vacuum, but rather are implemented alongside other research and teaching activities already supported by institutes of higher education. The first chapter introduces two collaborative frameworks for 3D/VR projects in which teaching and research become increasingly intertwined. In “Collaborative and Lab-Based Approaches to 3D and AR/VR in the Humanities,” Victoria Szabo presents Duke University’s “lab”-based model of collaboration by using a common topic or theme of investigation to find shared goals among a range of invested departments and stakeholders, including libraries. Groups composed of librarians, developers, faculty, and students unite with a common goal to produce, teach, share, and evaluate research using 3D/VR media.

The next four chapters focus more closely on the tools and workflows to create and distribute 3D/VR content, providing varying perspectives of how, why, and for whom these projects are created. These chapters focus on the unique concerns of digitization technology, model accuracy, artistic intervention, and optimization for sharing files in different contexts. Working at the University of Virginia, Will Rourk probes the distinction between 3D models and 3D data. In “3D Cultural Heritage Informatics: Applications to 3D Data Curation,” he stresses the importance of thinking of 3D as “dimensional data” within cultural heritage projects and introduces a full range of 3D technology and scholarly outputs: 3D data, 3D prints, VR experiences, animation, open-access models, etc. He outlines the different workflows for the capture technology, research outputs, and preservation strategies selected, and he describes the library’s role in what he calls “3D cultural heritage informatics (3DCHI).”

Zebulun M. Wood, Albert William, and Andrea Copeland focus on 3D/VR as a central project for classroom-based learning, using the Media Arts and Sciences classroom at Indiana University–Purdue University Indianapolis (IUPUI) as a collaborative space to build the Virtual Bethel project. “Virtual Reality for Preservation: Production of Virtual Reality Heritage Spaces in the Classroom” describes their students’ work on a highly detailed 3D model of a historically significant African American church that was being redeveloped in downtown Indianapolis. Incorporating historical research, community

relationships, 3D data capture, and digital creation, the authors describe developing students' skills, negotiating student group dynamics, building on existing community relationships, and addressing audience concerns and feedback. While their project does not address library participation, their workflow, focus on instruction, and use of archival content provide avenues for librarians to consider should the question of their participation in similar projects arise.

In "Using 3D Photogrammetry to Create Open-Access Models of Live Animals: 2D and 3D Software Solutions," Jeremy A. Bot and Duncan J. Irschick introduce the importance of animated 3D models of individual animals for the Digital Life Project. For this project, researchers at the University of Massachusetts–Amherst (with partners at the University of Oklahoma) developed new photogrammetric techniques for capturing accurate 3D data from living organisms, including frogs, sharks, turtles, and other animals. Capturing data from a living animal prone to unpredictable motion is a difficult procedure that requires a digital artist to register and stitch together the many images produced in the capture process in order to produce a complete model amenable to animation. The complex workflow described underscores both the technical mastery and digital intervention necessary to transform individual scans into a complete, animated model and, as the authors argue, makes open-source software an ideal choice to preserve and document the 3D model at various stages in the creation process.

"What Happens When You Share 3D Models Online (In 3D)?" focuses on the broader dissemination of 3D models online through WebGL and WebVR. Thomas Flynn introduces the ways in which cultural heritage institutions and libraries use platforms such as Sketchfab, a commercial platform to share and sell 3D content, to reach new audiences. Dissemination, however, is not preservation; Flynn notes that Sketchfab is not a repository and that the files it disseminates for sharing are necessarily derivatives and optimized for web browser sharing. The ease of sharing, annotating, and embedding data, nonetheless, provides the opportunity to engage with new and old audiences in unexpected ways and enables the dissemination of 3D models to a global community of scholars and enthusiasts.

The final three chapters address the complexities of sustainability and preservation of 3D/VR projects by introducing three ongoing initiatives to promote better standards and workflows across disciplines. In "Building for Tomorrow: Collaborative Development of Sustainable Infrastructure for Architectural and Design Documentation," Ann Baird Whiteside reports on work being conducted under the auspices of Harvard University Library's Building for Tomorrow project, funded through the Institute of Museum and Library Services (IMLS). This project is looking at the preservation issues related to curating architectural and design 3D data, particularly in regard to the archives of architects whose materials are increasingly born digital. Some common issues in her chapter that may be applicable to other academic contexts include the risk of file format obsolescence and the long-term accessibility of 3D collections. Whiteside focuses

on the future of 3D architectural data, an ongoing concern for industry and education alike for at least the past decade, showing the enhanced risks of proprietary formats to medium-term access and beyond. She also discusses the need to store multiple types of files for each architectural project, which is analogous to work done in digital humanities and other research where multiple types of media files are combined to create complex, interactive scholarly outputs. Furthermore, Whiteside underscores that, because of the complexity of the situation, any solutions to sustainability questions must be community-wide, rather than tackled on an institution-by-institution, ad hoc basis. Whiteside's chapter is particularly important in considerations of collective action and shared interinstitutional missions, since small institutions need to be able to adopt standards and best practices, but require the support of larger institutions to do so.

Jessica Meyerson's chapter, "3D/VR Preservation: Drawing on a Common Agenda for Collective Impact," introduces concepts from her work with the Software Preservation Network that can be applied to curating and preserving 3D/VR software into the future. While working with 3D/VR requires specialized workflows with robust version control, involves a variety of file formats and data types with multiple relationships between files, and depends on an amalgam of complex hardware and software platforms, Meyerson suggests that an examination of 3D/VR curation challenges can be guided by findings from other areas of digital curation. She identifies three major data curation challenges: (1) scale, (2) standards and interoperability, and (3) software and hardware dependence. To address these challenges, she argues for a collective impact approach, outlines the major components of this approach, and discusses how it could be implemented to support the development of standards and best practices for 3D/VR software preservation.

The final chapter reports on work being conducted by another IMLS-funded project, Community Standards for 3D Preservation (CS3DP). In "CS3DP: Developing Agreement for 3D Standards and Practices Based on Community Needs and Values," Jennifer Moore, Adam Rountrey, and Hannah Scates Kettler review existing projects that are tackling the curation problems of 3D/VR and identify gaps in these projects that need to be addressed. They argue for more consensus-building across different stakeholder groups around preservation standards. A critical aspect of creating 3D/VR preservation standards is balancing the need to structure workflows around a set of common practices with the need to keep new technologies flexible and open to innovation. Through two national forum meetings in 2018 and ongoing collaborative work online, CS3DP brought together various stakeholder groups working with 3D data to develop standards and best practices. The project formed working groups from assembled forum participants to structure stakeholder involvement and generate consensus on standards and best practices related to critical topics, such as metadata and intellectual property rights.

Directions Forward

The issues discussed in this report were chosen to prompt greater self-awareness for library professionals as they develop programs that use 3D and VR technologies and work to integrate changing scholarly demands and conventions with existing library services and policies. Across these eight essays, three critical approaches that librarians and digital curators need to address as they use 3D/VR to support their communities are represented: (1) treat the academic outputs that use 3D/VR as scholarly products; (2) build a 3D/VR scholarly community to support knowledge exchange across a range of stakeholder groups; and (3) develop technical tools, training, and infrastructure to support a 3D/VR research ecosystem.

Treat 3D/VR as Scholarly Products

Libraries and other institutions need to consider 3D/VR as scholarly products in their own right, rather than as illustrations or supplemental material. As such, these projects must be managed throughout their research lifecycle like other types of research data. The intellectual value of 3D/VR is still under debate within academic communities, but the library can lead the way in establishing the products of 3D/VR projects as scholarly outputs, which will encourage greater acceptance of their use in academia. In her chapter, Victoria Szabo points out that the scholarly standards governing the use of 3D/VR are still being developed. While Will Rourk emphasizes the need to rethink 3D/VR as *data*, Szabo argues that 3D/VR should also be taken more seriously as scholarly output and should be treated alongside the outputs of other types of research projects. Both approaches, *3D/VR as data* and *3D/VR as scholarly output*, are necessary perspectives and affect the ways in which libraries interact with scholars when supporting this type of research. Libraries can aid in the acceptance process by supporting peer review practices and developing publishing platforms for 3D/VR projects. To this end, libraries need to consider how 3D/VR should fit alongside other types of data and scholarly products, which will have an impact on scholarly services and research data management programs.

Build a 3D/VR Scholarly Community to Support Knowledge Exchange

Across the essays in this report there is a collective clarion call to action to build a scholarly community of knowledge- and skill-sharing around 3D/VR. The authors collectively ask: How can we—as content creators, users, curators, archivists, etc.—prevent the “silozation” of 3D/VR creation and curation practices and knowledge? Libraries can play a role in this de-siloization as a cross-disciplinary collaborative space. The expertise that libraries offer in data management and digital scholarship practices, together with their ability to engage community members, places them in a prime position to be partners in 3D/VR scholarship projects. Recent grant-funded projects designed to bring communities together and promote

knowledge exchange for 3D/VR are leading the way in addressing these types of issues. In this report, Ann Baird Whiteside describes Harvard University Library's Building for Tomorrow project, which brings together stakeholders in the architecture and design communities currently working with 3D data and trying to archive it for the long term; Jessica Meyerson lays out the model of the Software Preservation Network as a means of structuring knowledge exchange across networks of digital curation practice related to 3D/VR; and Jennifer Moore, Adam Rountrey, and Hannah Scates Kettler demonstrate through the CS3DP project how community-based working groups can help establish standards and recommended practices that are applicable to both large and small institutions in a variety of fields.

In addition to these innovative, grant-funded initiatives, these chapters demonstrate the importance of communicating across communities to promote effective knowledge exchange.² This sort of cross-disciplinary and cross-institutional communication can take the form of forums, white papers, conferences, publications, and the like, and they can collectively produce an active scholarly community composed of scholars and information professionals working together to develop knowledge in support of these complex technologies. Sustained and sustainable collaboration and coordination are essential and will help to balance the obligations of content creators with those of librarians and digital curators for preserving these new research data types and scholarly outputs. Although content creators can assist this process by choosing archival formats, capturing metadata, and preparing their materials for archiving throughout the data collection process, librarians should take the lead in providing information about standards and best practices and supporting 3D/VR creation and preservation workflows.

Develop Technical Tools, Training, and Infrastructure to Support a 3D/VR Ecosystem

In addition to identifying the need to reconfigure scholarly conventions and institutional expectations around 3D/VR and enhance communication and knowledge exchange across scholarly communities and information institutions, the essays in this report stress the growing requirements for technical tools, training, and infrastructure that are designed specifically to support a holistic 3D/VR research ecosystem. The evolution of such an ecosystem must be flexible and forward-looking enough to take into account the changing technical and scholarly landscape. As libraries are increasingly called upon to support knowledge exchange beyond traditional books and journals, the creation of novel types of research infrastructure will shape the

² A third IMLS grant-funded project, Developing Library Strategy for 3D and Virtual Reality Collection Development and Reuse (LIB3DVR) is also ongoing, but it was not discussed in these proceedings. LIB3DVR will be issuing a series of journal articles and a comprehensive white paper on its national forum meetings starting in the spring of 2019. More information can be found here: <https://lib.vt.edu/research-learning/lib3dvr.html>.

preservation and access expectations of constituents. By being part of the conversation, librarians can position themselves to better understand the needs of the 3D/VR community and the services that the library can support. The essays in this volume outline a number of approaches by which library professionals can increase their involvement in 3D/VR. Because every library and academic community approaching 3D/VR will be unique, we encourage each one to incorporate an appropriate mix of strategies from across the examples provided here.

Conclusion

Academic libraries of the twenty-first century have enthusiastically embraced digital technology and emergent media as new forms of information and data that must be managed and made accessible. With greater and greater frequency, the library itself is being seen not only as a site of knowledge preservation and access, but also as a place for experimentation and knowledge production. Library staff, moreover, play increasingly important roles in teaching, research support, project collaboration, technology consultation and instruction, digital publishing, and more. The future of 3D/VR as a scholarly and pedagogical ecosystem of tools depends on fostering close relationships among faculty, librarians, and digital curators. This report seeks to elucidate key dimensions of the current landscape of 3D/VR in academia, in the hope of developing common strategies for defining the library's role and nurturing effective relationships between libraries and the range of academic stakeholder groups. Developing these new skills and collaborations around emerging technologies such as 3D/VR can potentially enhance the profile and maintain the relevance of the academic library both as the custodian and curator of all forms of research and educational data, and as a catalyst for innovation in scholarship and pedagogy at the heart of the twenty-first-century university.

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Chapter 1

Collaborative and Lab-Based Approaches to 3D and VR/AR in the Humanities

Victoria Szabo

Abstract

This paper explores the interdisciplinary humanities lab model for collaborative work in 3D and virtual reality / augmented reality (VR/AR). It draws upon our experiences at Duke University with lab projects focused on historical and cultural visualization. At their best, shared digital projects promote engagement and deeper learning by students, expose new research questions for the diverse researchers and subject-area specialists involved, and result in applications that provide a deeper understanding of historic sites, objects, and phenomena to the wider public. Working with 3D and VR/AR in particular demands integration of in-depth critical, creative, and technical areas of knowledge. Interdisciplinary lab projects leverage the combined expertise and skill sets of subject-area faculty, librarians, technical staff, and students from various academic backgrounds. At the same time, however, such an ensemble approach to scholarship may disrupt the existing academic ecosystem, challenging disciplinary boundaries as well as institutional norms around teaching, research, labor, and resource allocation. By honoring diverse stakeholder goals, fostering critical conversations around theoretical and technical questions, and establishing standards for tools and methods beyond the individual case, lab partners from various institutions may be able to contribute both to their specific projects and to the advancement of sustainable and scalable approaches to future work in 3D and VR/AR at their own institutions and beyond.

Introduction

Scholars have begun to look to computationally generated 3D models, animations, virtual reality, augmented reality, and games to represent present, past, future, and fictive environments and objects. Complementing textual, image-based, and quantitative analyses with 3D visualizations is nothing new. Precursor technologies include illustrative 3D drawings, wooden architectural models, annotated exhibitions, immersive dioramas and tableaux, and even historical re-enactments. The study and creation of online texts, image collections, and time-based media archives is commonplace. Geographic information systems (GIS) and web mapping are supported in classrooms, libraries, and digital humanities centers as part of a broader spatial turn in humanistic teaching and research. Data visualization has experienced similar growth. Nonspecialists may also explore 3D and virtual reality/augmented reality (VR/AR) for conducting and communicating their teaching and research.

Nonetheless, the academic status of digital scholarship itself often remains ambiguous. Best practices for production and evaluation within disciplinary fields are still needed. Evaluation guidelines note benefits such as deeper student engagement with course materials or public access to scholarship. However, undertaking a digital project may—or may not—translate into creditable research activity. A digital experiment at times may fail, or a tool may fall out of favor or reach. This uncertainty can have a chilling effect on scholars who might advance the field.

The project-based humanities lab model of research and teaching offers a way to address the gap between discipline-focused objectives and digital expertise. In the lab model, participants from various backgrounds focus on a common academic question over a sustained period. The lab model complements other institutional structures by creating novel opportunities for faculty, staff, and students to collaborate across disciplinary bounds. At Duke University's Wired! Lab for Digital Art History & Visual Culture¹ and related initiatives, for example, first-year curricular experiments with 3D and VR/AR in the humanities led to the establishment of new graduate programs and to interdisciplinary and international collaborations around best practices for future research.

3D and VR/AR in Historical and Cultural Visualization

Why use 3D and VR/AR? For the Wired! Lab, possible objectives might include creating historical reconstructions of significant spaces and structures, imagining fictive spaces, annotating or recontextualizing objects of interest, exploring databases and networks across multiple dimensions, translating virtual archives into virtual museums, or creating virtual settings for the exploration of spatiality,

¹ <http://dukewired.org>

proxemics, and movements across space and time. We describe this activity more generally as “historical and cultural visualization.” Students learn about these topics in first-year seminars focused on art history topics, in thematic electives, and through participation in digital cultural heritage and museum exhibition projects. Some of our most advanced work in *Wired!* has taken place as part of the international Visualizing Venice group of researchers (Lanzoni, Giordano, and Bruzelius 2018).

The key concept that ties our digital humanities approaches together, and especially 3D and VR/AR, is the idea of the model. Whether we are modeling an object, an environment, or both, a conceptual model underlies our processes and informs what we develop. If we add to that a dimension of time or interactivity, we make use of that model in a process of simulation or virtualization. Key challenges for us in historical and cultural modeling in particular may include representing change over time, representing uncertainty, documenting process and underlying data, producing content collaboratively, allowing for counterfactuals and conflicting interpretations among experts, distinguishing between evidence-based and placeholder elements, and connecting to existing or future data and systems. And all of this is before we populate the models, program in any procedural interactivity, or build in any agents.

Such challenges exist in any kind of model—3D, digital, or otherwise—but are brought into greater relief when working with computationally produced 3D and VR systems. The same dimensional, representational qualities that provide greater immersive potential in 3D and VR systems also have a greater likelihood of being fudged in an attempt to produce a coherent whole, as Will Rourk demonstrates in his discussion of 3D data versus 3D models (see Chapter 2). Indeed, the software often demands filling in informational gaps, etc. Added to these challenges is a relatively high technology turnover rate in the field. Without deep understanding of the medium and critical engagement with its strengths and weakness, we end up in danger of providing what the most strident critics of 3D and VR abhor—inaccurate, expensive infotainment that does little to advance or communicate knowledge in the field. Providing data transparency, modularity, and iterability becomes important to counterbalance these effects. Creating a black box object in an expensive walled garden, a closed digital ecosystem, is also an almost certain way to limit the life span and impact of a 3D or VR/AR project over the long term. Therefore, scholars in the field need to understand what goes into these models and to be active partners in their creation and care.

The Digital Humanities Ecosystem

How then do we address the challenges of working with such complex technologies, while at the same time attending to disciplinary concerns? Within many academic libraries, digital scholarship has become an important area for partnership and support. As Joan K.

Lippincott and Diane Goldenberg-Hart have noted, library support of digital scholarship extends beyond digital humanities project support to include science and social science research. It also delves into broader infrastructure and training needs (Lippincott and Goldenberg-Hart 2014). Because 3D and VR/AR are such cross-disciplinary practices, academic libraries may be the ideal place to facilitate communication around their critical and creative use. At Duke, for example, interest in 3D and VR/AR exists in our engineering programs, computer science, campus information technology (IT), and the Innovation and Entrepreneurship program, as well as in the arts and humanities. 3D/VR also overlaps with game studies, medical education, civic awareness, and social justice. Many participants in various programs wish to use new media forms for studying, creating, and archiving, and they turn to the library for guidance and support. Even grant-funding agencies in the humanities now expect rich data, access, and sharing plans from the grantees. The need to find scalable solutions is becoming more acute. This need includes places for storing both working files and final presentational outputs, as Ann Baird Whiteside notes in Chapter 6.

Despite the good will and interest of the constituencies involved, and perhaps because the challenges are so complex and overlapping, it is sometimes unclear in any moment who in the university setting should be responsible for providing not only content storage, archiving, and production server access, but also instruction and training. Is it reasonable to expect librarians to take on this role? Or should the staff of departments and programs arrange to teach and support digital humanities methods? Perhaps teachers in writing programs could take on some responsibility for digital literacies and training. But how far should that responsibility go in the case of tools and methods that require a significant effort to master?

Regardless of who teaches them, digital tools and methods are sometimes treated as a set of skills to be acquired separately from their application to a disciplinary research challenge. Critical attention to underlying data structures, metadata standards, the assumptions of software packages, or the affordances of interactive media forms may seem a concern better suited to information science, media studies, or communication studies, not to mention geography, architecture, or media arts. More transparent software interfaces may seem to obviate the need for such extra-domain expertise. With their user-friendly interfaces and starter tutorials, they may yield more impressive outputs than ever before. Yet, their uninformed use may produce more critically questionable results. Digital projects that force consistency of data, elide uncertainty, cherry-pick examples, or eschew complexity and nuance are rightly critiqued. Critics might rightly argue that the alluring technologies of 3D and VR/AR do more harm than good.

The pedagogical challenge does not lie only in the fact that digital tools are being taught separately from specific projects, although students may find it harder to learn from examples too far afield from their disciplinary interest. A bigger issue lies in the follow-up

to the initial workshop session or tutorial video, when students (and researchers) apply what they have learned. Individual project support becomes more difficult to sustain at scale. This is where a project-based lab program can be helpful. Especially when undertaken with an eye toward developing models and precedents, in-depth collaboration on specific projects can yield more generalizable results. Diverse campus partners may collaborate on such an effort without having to commit to generalized support for everyone who attends a workshop. The lab model does not replace the library digital scholarship center. Rather, project-focused labs invite partners from libraries and information technology organizations to help create generalizable solutions and best practices that fit the scholarly questions at the heart of the lab's mission.

New Directions in Multimodal Scholarly Publishing

Today's digital humanities ecosystem produces and supports both print publications and digital scholarship. The Scholarly Communications Institute made digital scholarship an explicit focus of the 2015 Institute in Chapel Hill, North Carolina, for example.² The challenges to the norms of scholarly publishing are already clear. The next generation of scholars will be increasingly hybrid, having grown up with multimodal technologies throughout their schooling. More focus on rigorous peer review, rather than the medium of circulation, opens up possibilities for new platforms (Modern Language Association 2012; American Historical Association 2015; College Art Association and Society of Architectural Historians 2016). Online publication opens the door to other formats, both as supplements and as stand-alone resources. Digital does not necessarily challenge the primacy of textual exposition as the primary communicative mode of expression for many fields, as Edward L. Ayers (2013) notes. In the last several years that has begun to change, with consequences for our publishing systems.

With the support of the National Endowment for the Humanities Office of Digital Humanities, the Getty Foundation, The Andrew W. Mellon Foundation, and others, gaps between the form of the original production and its documentation are decreasing, and expectations are rising for the quality and accessibility of the work presented—including that in 3D and VR/AR. As it becomes more important to review projects in their original media forms, old substitutes for original work may no longer be accepted. Digital mapping projects may need geoservers to store and share vector and raster data, and presentation layers and models, but the support is uneven. Today in many cases scholars are still reduced to creating screenshots or video documentation of their VR/AR experiences, at least for archival purposes. Advances in WebVR and open 3D formats get us closer to being able to share such content in its "native" form more openly and transparently. Emulators and code repositories also hold promise.

² <https://trianglesci.org/2015-institute/validating-and-valuing-digital-scholarship/>

In the absence of other solutions, 3D and VR/AR experiences are likely to be served up from common commercial or open-source server platforms. Platforms like Sketchfab and the availability of Unity3D and Unreal as free presentation environments make it possible to share work in a format closer to the original than was possible before. Externally hosted digital objects appear as iframes or other types of embedded web objects. They have anticipated active lifetimes or what may be considered limited-time performances of technology exhibitions. The most lasting documentation may paradoxically be not in scholarly journals or websites but on social media and other generalist platforms like YouTube and Flickr. Valve's Steam Store is now allowing almost all content on its game store, for example, which may make it easier for some developers to share their work. Project code is often shared on GitHub, with GitHub Education paving the way for commercial options. It is up to practitioners in the field to think through the implications of these choices.

Whatever systems are put in place, whether homegrown, open source, commercial, or some combination of these, they should meet the development, collaboration, and sharing needs of scholars and researchers. Labs can be a great place to test possibilities. A lab with a research agenda can serve as a client or real-life testing ground for a proposed solution in a way that an internal test may not because the end products ultimately need to serve the scholarly community for which they were produced.

Labs in Series and in Parallel

An individual lab may operate within a larger network of labs, as well as within the context of university-wide curricular and research programs. Duke's Wired! Lab was formed in 2009 within the Department of Art, Art History and Visual Studies, with support from Information Science + Studies. It started out with an experimental class of five faculty and eight students who were interested in 3D modeling and the reconstruction of historical buildings and environments. The initiatives in the Wired! Lab today evolved from those beginnings and fall within one of two main research categories: Digital Cities/Urban Histories and the Lives of Things (Wired! 2018). Current Wired! Lab collaborators include faculty in art and architectural history, archaeology, visual and media studies; the staff director of the departmental Visual Media Center; the university subject-area librarian for visual studies; and a dedicated digital humanities specialist. We also work closely with the Nasher Museum of Art staff and the Rubenstein Library's Special Collections librarians on special projects. The group holds regular meetings and Friday afternoon project work sessions.

The disciplinary orientation of the Wired! Lab has been central to its high profile in art history circles. Wired! has embraced the "digital art history" label and focus for its work. It was founded by Caroline Bruzelius, an eminent art historian focused on medieval architecture with an interest in 3D modeling of cathedrals, and is now led by Paul

Jaskot, also a noted art historian who works on Holocaust architecture and geospatial analysis. These credits give Wired! academic clout. Undergraduates from a wide range of disciplines, as well as students pursuing MA, MFA, and PhD degrees, join lab teams as participants in lab-based courses and projects organized under the digital art history rubric. Lab projects take the forms of posters, papers, publications, exhibitions, apps, and VR experiences.

Wired! does not exist in isolation, however, nor could it achieve all it has without benefiting from the existence of other labs and programs. In 2011, just as the Wired! Lab was becoming more established, the GreaterThanGames: Transmedia Applications, Virtual Worlds, and Digital Storytelling Lab (GTG) was formed at the John Hope Franklin Humanities Institute. Like Wired!, GTG was built on a curricular experiment. In this case it was the Virtual Realities first-year course cluster, which ran from 2007 to 2009 and included courses from computer science, math, media studies, and classics. The game lab that followed made a substantive alternate reality game; held a semester-long mobile app development workshop attended by students, faculty, and staff; and developed art games in Unity and location-based AR apps. It also partnered with Wired! on an architectural history iPad app, Visualizing San Giovanni e Paolo. Although the lab disbanded in 2013, the teaching and research collaborations continued. My own work on augmented reality for digital city applications grew out of this experience (Szabo 2018).

Additional labs co-located with Wired! today include the Duke Art, Law and Markets Initiative (DALMI),³ the Emergence Lab,⁴ the DiG Digital Archaeology Lab, the Information Science + Studies Lab, the John Hope Franklin Humanities Institute Labs,⁵ and the shorter-term Bass Connections⁶ projects. We also work closely with the Visualization and Interactive Systems (VIS) Group, a cross-functional, cross-campus interest group/lab that includes the leaders of the Duke immersive Virtual Environment (DiVE)⁷ in the Pratt School of Engineering, as well as library representatives focused on digital scholarship, visualization, and GIS. Undergraduate, MA, and PhD students in Digital Art History and Computational Media, Arts & Cultures⁸ draw upon this whole network in writing their hybrid theses and dissertations.

Sharing Solutions

The key to collaboration lies in finding common ground around research topics of mutual interest. For example, in Wired! we became very interested in creating richly annotated, immersive architectural models that could be explored in both active and passive modes.

³ <https://www.dukedalmi.org>

⁴ <https://cmac.duke.edu/labs/emergence-lab>

⁵ <https://fhi.duke.edu/labs>

⁶ <https://bassconnections.duke.edu>

⁷ <http://virtualreality.duke.edu>

⁸ <http://cmac.duke.edu>

The interaction scripts developed there could be used in other contexts, such as in producing VR art projects and instructional content, but they were also useful for diverse other applications in the DiVE itself.

This possibility of sharing code builds upon a choice we made several years ago when we discussed the need for shared 3D workflows and pipelines, both for the purposes of introductory instruction and for more advanced VR implementation. We collectively embraced the decision to standardize on a Unity3D-based workflow, investing together in some professional licenses to make it work. Our shared goal was to make it easier to move from 3D model to immersive environment by providing a way for researchers to develop and display their own content in Unity3D, and then to export it to various platforms, including but not limited to the DiVE. Critically for our partners in engineering, our projects become interesting case studies for them, too, in terms of user interface design, graphics standards, and multimodal data management schemes. From our perspective, standardizing in Unity3D has made it easier for us to move into head-mounted display variations on immersive VR experiences originally conceived of as limited to CAVE-based installations only. We have also begun working with Unity3D plus Vuforia to create AR projects focused on generating 3D models from 2D images.

Current work with Wired! Lab postdoctoral researchers from Padua, Italy, who are working on visualizing the Scrovegni Chapel Giotto frescoes is an excellent example of how our “new” workflow is working across projects and teams. The historical researchers were interested in both representing the changing architecture of the building itself through interactive building information modeling (BIM) and in AR exploration of the frescoes contained within it. The DiVE researchers were interested in comparing VR/AR approaches with mobile-based approaches to the same materials for research purposes. The Padua team has begun to bring its existing Unity3D-based models into the DiVE and head-mounted displays. They are also exploring ways to layer information about the frescoes into a real-time AR tool for use by visitors. This research may not only benefit future projects with our local museum, but also lead to tutorials and platform choices to share with the other labs, library, and IT partners (Giordano et al. 2018).

Curricular Challenges

As anyone who works in 3D and VR/AR knows, integrating these technologies into teaching and research can be complicated when working with beginners, whether those beginners are first-year students or advanced faculty. One way to scaffold learning is to use our own projects as teaching examples, as the Padua example suggests, deconstructing them into tutorial sample files. Another is to create lab projects that students can participate in at different levels of the curriculum, and to create courses around projects that have a life beyond a specific class. For example, we have used the Duke campus

and Durham, North Carolina, community resources in both teaching and lab research.

Nonetheless, managing the balance between subject-area and technical instruction remains difficult. Regardless of who teaches technical topics, we wonder how and when to include tutorials as part of the core requirements of a course. We ask if it is better to separate technical instruction from primary classwork, and what the costs and benefits are of having students working in groups. We also ask whether we should privilege historical research over digital execution in final projects. Since many students from computer science and engineering are attracted to our courses, we debate whether we should allow them to flex their skills or expect them to learn how to do qualitative research. By having students work in cross-functional teams, we try to have them do a bit of both. This approach also prepares them for future roles in labs. These are areas of needed future clarification and research. Ultimately, the answers may be highly context-driven (in terms of student interest and skill level, discipline, course subject matter, and particular research questions).

Despite these efforts, the dream of perfect hybridity in teaching with digital technologies is elusive. While the use of some tools, such as readily accessible web-based presentation tools, is easy to teach in a single training session, more involved GIS, 3D, and VR/AR topics require greater degrees of scaffolding and explication. We have also created downloadable tutorials and some online instruction, and we are working with the libraries to develop more.⁹ Despite our best efforts to pack everything into a single course, we have determined that some topics, such as historical GIS, Unity 3D interaction design, physical computing, and web-based multimedia communications require their own courses for any depth of study.

Hybrid Futures

While a few of our faculty, such as Edward Triplett, former CLIR Fellow and now a departmental lecturer and Wired! Lab member, can move easily between historical research and technical wizardry, most faculty members are more accomplished in one area or another. We look to the next generation of scholars for more flexibility and for more collaborative teaching and research models than is currently the norm.

To produce this next generation of hybrid scholars, we invite graduate students into the labs to serve as research assistants to faculty and mentors to undergraduates. We also encourage them to develop projects of their own within the PhD Lab in Digital Knowledge,¹⁰ a lab I co-direct with Philip Stern from the Department of History, as part of the Duke Digital Humanities Initiative at

⁹ <http://www.dukewired.org/workshops/tutorials/>

¹⁰ <http://sites.fhi.duke.edu>

the John Hope Franklin Humanities Institute.¹¹ The PhD Lab Scholars program currently includes about 20 digitally curious graduate students from a wide range of humanities disciplines. We meet biweekly to share project work, and in between those sessions, we meet with technology-focused working groups organized by faculty, staff, and library partners. This year's working groups will focus on digital pedagogy, VR/AR, digital mapping, text analysis, and environmental humanities. We also invite our graduate students' faculty mentors to come and see what we are doing, offer critiques, and perhaps learn a bit themselves about what is possible.

The Duke Digital Humanities Initiative also supports a Digital Humanities Fellows Program at North Carolina Central University (NCCU), a distinguished historically black university with a strong community presence. The NCCU Fellows meet monthly at Duke and have established their own Digital Humanities Lab at their home institution. In the coming year, the faculty from NCCU will work with the Information Science + Studies and Wired! Labs on a local neighborhood history project using location-based 3D and AR to share archival materials and to document resident experiences. We hope this partnership will contribute both to positive community relations and to best practices for public-facing, accessible digital humanities research.

National and International Connections

These types of digital humanities projects benefit greatly from national and international connections. These connections include the Wired! Lab partnership in the Visualizing Venice group on research and training.¹² Visualizing Venice started out as an export of the "lab" model to our research partners in Venice and Padua. The group has multiple collective aims: to advance art history research, to advance training, and to explore new modalities of presentation and exhibition. From 2011 to 2016, among our other activities, the Visualizing Venice group taught thematically focused, hands-on, two-week summer workshops in Venice for junior scholars and young scholars interested in digital art and architectural history. The workshops allowed us to train the next generation of scholars on an international level and to reflect together on the next stages for our collaborations. Then in June 2018, with the encouragement of the Getty Foundation, we shifted focus to offer instead an Advanced Topics in Digital Art History: 3D Geospatial Networks Institute (#DAHVenice2018). Unlike our earlier workshops, which were targeted toward individuals, this opportunity privileged applications from interdisciplinary teams, building on our experiences with the lab model and extending it outward. Teams from 11 countries converged in Venice to share projects and ideas, reflecting a wide range of interests. Participants include architectural historians, art historians, and archaeologists,

¹¹ <http://digitalhumanities.duke.edu>

¹² <http://visualizingvenice.org>

as well as experts in GIS, 3D, BIM, and VR, with projects coming from various scales and perspectives. The project continues over the course of the year. We hope to establish a robust virtual community (or lab) in which we produce best practices, grant proposals, shared software resources, and joint publications. As organizers, we have already benefited from the group's counsel as we expand our project conceptually from the Visualizing Venice focus to the Visualizing Cities project. When we next meet as a group, in June 2019, we will workshop our deliverables in anticipation of public dissemination.

At the same time as the Wired! Lab and Visualizing Venice have pushed the boundaries of digital art history, we have also furthered the conversation about 3D and VR/AR as digital humanities methods. With the support of the National Endowment for the Humanities, Duke University hosted the two-week Virtual and Augmented Digital Humanities Institute¹³ in July 2018. Here our emphasis was specifically on the affordances of VR/AR as media forms, as noted in the project description. Participants from the disciplines of art history, literature, education, modern languages, history, media art, and classics met alongside engineers and developers, including our own VIS Group members, as well as local partners in key library units focused on mapping, visualization, and digital scholarship. A few local faculty who were digital humanities skeptics were also invited. The group discussed questions of ethics, longevity, the digital divide, access, and fair use, as well as favorite software, best practices for development, and project demonstrations. As with the Digital Art History group, we are seeking to generalize the lessons learned from particular projects into wider principles and best practices, while at the same time building a virtual community around our shared interests. This push and pull between media possibilities and disciplinary objectives, between common dreams and individual objectives, between open-ended possibilities and established values, will continue to animate our conversations over the coming months and years around 3D and VR/AR in humanities scholarship and beyond.

Within the Wired! Lab, and in other labs like GreaterThanGames and the PhD Lab in Digital Knowledge, we have found that what ultimately makes the humanities lab work is the participants' willingness to communicate; to share time, expertise, and resources; and to honor both individual and group project goals. For some participants, the hook is a scholarly question; for others, it may be about media, tools, systems, pedagogy, or publishing. Beyond the project focus that keeps everyone engaged, the secret of the lab model is that any self-identified working group can declare themselves a lab and behave accordingly. We had participants in Venice declare themselves a "lab" with laughter, but also a bit of elation. However empowering such a statement may be, the lab model also depends on the centralized infrastructure and vision of the libraries, departments, foundations, commercial entities, and community partners on which it relies. For 3D and VR/AR in the humanities—in all their complexity, expense, and potential—it will take all of us to advance the field.

¹³ <http://vardhi.org>

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Chapter 2

3D Cultural Heritage Informatics: Applications to 3D Data Curation

Will Rourk

Abstract

The physical elements of history directly link us with the heritage of diverse cultures. Artifacts, architecture, and historic sites, active or derelict, must be documented while they are extant; otherwise, the opportunity to maintain a connection with their historic narratives may be compromised or lost to time. Data collection technologies such as laser scanning, photogrammetry, and other three dimensional data recording techniques and devices allow the documentation of the conditions of a historic place or object with submillimeter accuracy. Libraries can cultivate the resulting high-resolution 3D data to provide a variety of modes for exploring, researching, preserving, or reconstructing physical historical features. The University of Virginia Library uses methods that implement the full scope of 3D data curation through the collection, processing, archiving, and distribution of data and its derivatives to the scholarly community. The application of these methods as an intrinsic role within libraries opens up a potential area of information science that can be identified as 3D cultural heritage informatics (LIB3DCHI). More specifically, LIB3DCHI can be described as a set of techniques that yield primary source data derived from the existing conditions of historic and culturally relevant objects, places, and sites. 3D technologies such as Web3D, computer-aided design (CAD), 3D printing, and virtual reality can help make a stronger connection to these objects, places, and sites by providing access to measured data about them through sensory-immersive technologies. Libraries are promoting democratized access to 3D assets as a means of providing new forms of knowledge to the scholarly community.

Introduction

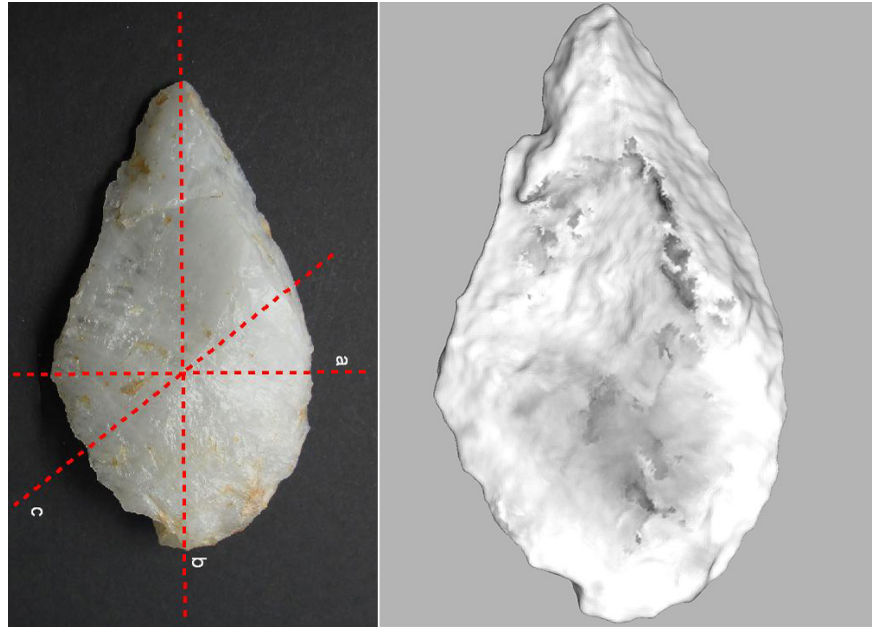
To maintain the connection between the physical elements of history and their historic narratives, it is essential to document the features of artifacts, architecture, and historic sites, both active and derelict. Data collection technologies such as laser scanning, photogrammetry, and other 3D data recording techniques and devices allow the documentation of the dimensions, scale, and geometry of a historic place or object with submillimeter accuracy. Libraries can curate the resulting high-resolution 3D data and provide a variety of modes for exploring, researching, preserving, or reconstructing physical historical features. The application of these methods within libraries opens up a potential area of Library Information Science that can be identified as 3D cultural heritage informatics (LIB3DCHI). At the UVA Library, LIB3DCHI is defined through the four fundamental stages of collecting, processing, archiving, and accessing 3D data.

Collecting 3D Data

At the heart of LIB3DCHI is the acquisition of precision data. Documentation of the existing physical conditions of material cultural heritage provides the fundamental base layer of data for LIB3DCHI. Producing reliable 3D data requires precision measuring instruments and techniques. 3D documentation technologies such as laser scanning, structured light scanning, and photogrammetry can provide measured data with millimeter to submillimeter precision. These technologies can provide two types of fundamental information about an object: surface geometry and color texture. Laser scanners and structured light scanners are metrology devices, and their main function is to collect surface data in three dimensions during the data collection phase. Lasers can detect surface variations from 2 to 0.2 mm, depending on the sensor. External measuring devices such as a meter stick or calibrated scale bars should be included when photographing the subject so measurements can be taken from the images and applied to the data when it is processed using photogrammetry software such as Agisoft Photoscan Pro (measurement is not allowed in Photoscan Standard).

Choosing the most appropriate technology to yield the most effective data depends on the subject matter to be documented. Scale and surface characteristics are the two most important features in determining which tool to use. For laser-based documentation technologies, shiny surfaces, mostly black, or mostly white, semitransparent textured surfaces may generate enough distortion to corrupt the surface data or even make it impossible to collect the data at all. Because of the properties of light, lasers tend to reflect off shiny or white surfaces, while they are absorbed into black textured surfaces. Structured light and photogrammetry may work better for such surfaces, as these techniques use less concentrated light to gather information. Structured light flashes a light pattern onto a surface, while photogrammetry uses images of the surface to generate data based

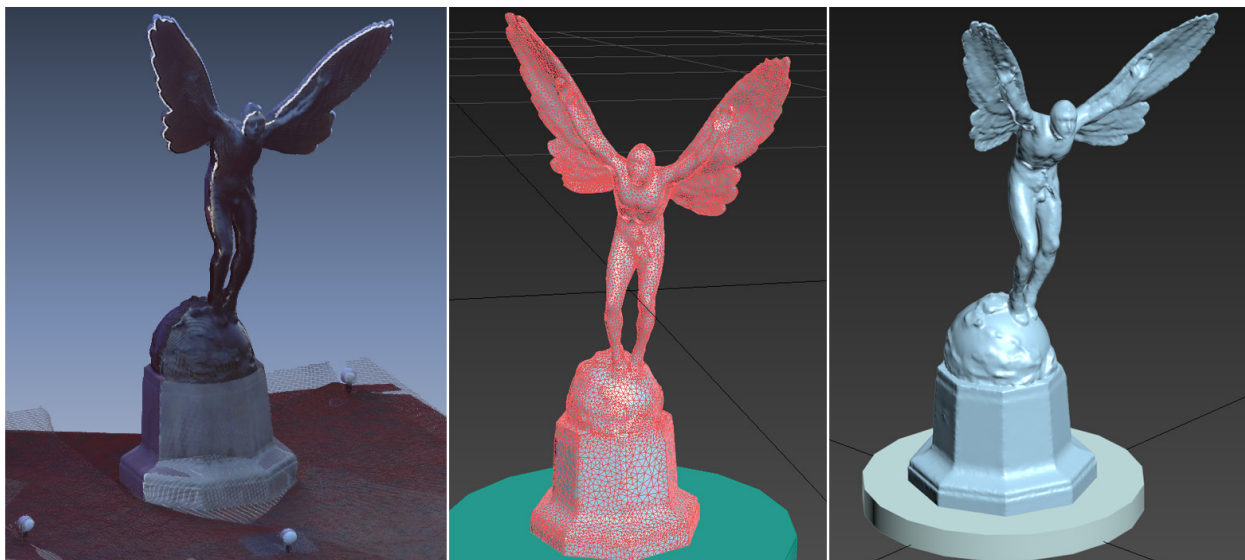
Fig. 2-1. Challenging surfaces: semitransparent, white textured quartz arrowhead (right image courtesy of Ben Ford, Rivanna Archaeological Services LLC)



on triangulation from a camera pair. As long as the surface is kept consistently lit with a minimum of texture changes like shadowing, reflections, or color shifts, then either of these techniques may succeed where laser light may fall short. The quartz arrowhead in figure 2-1 shows conditions that are not conducive to the use of laser scanning, but are more amenable to structured light scanning.

3D data collection techniques yield raw data in point cloud form. For example, laser scanners function by shooting a beam of light into the space all around the device, recording millions of points from surfaces that intersect with the laser. Photogrammetry produces similar data by generating sparse and dense point clouds during processing. The raw point cloud data are commonly captured in a proprietary file format, along with other metadata that may have been recorded by the scanning device. Raw data may not be readable in software other than what the manufacturer of the

Fig. 2-2. Stages of 3D data processing from point cloud to mesh



device has provided. In this case, the data must be processed and exported to other formats such as PLY, OBJ, DAE, PTS, or X3D to be usable in other software. Point cloud data can be converted to derivative 3D mesh formats and imported into other 3D software to be transformed into 3D content for a multitude of purposes. Figure 2–2 shows scan data from Gutzon Borglum’s *The Aviator* at different stages of data processing from point cloud to refined mesh, which is the most commonly used form of 3D content. The processing phase must preserve as much precision as possible of the raw point cloud data as they are converted to a 3D mesh.

Processing 3D Data

In documenting a site, place, or object, it may be necessary to collect several datasets to cover the entire surface of the subject. A scanning device can capture only surfaces that are visible to the scanner. Thus, in most cases, either the scanner or the subject will need to be repositioned to ensure that all surface data have been captured and the subject has been fully documented. Multistage scanning sessions will yield separate datasets that must be registered together to produce one cohesive dataset that accurately represents the documented subject.

3D data registration techniques depend on the technique used for documentation (e.g., laser scanning, photogrammetry). Targets, and other registration devices, such as spheres, checkerboards, and coded targets, can be placed in the environment during the scanning process to help ensure that datasets are merged accurately. Processing software will recognize standard targets and use them to precisely fit datasets together. Current software is able to find similarities between datasets, called correspondences, to perform registration without targets.

It must be emphasized that data are at the heart of LIB3DCHI. 3D data are commonly misunderstood as “3D models” or “3D pictures” in discussions of the content produced through 3D scanning. However, 3D documentation technologies provide the actual, measured conditions of a place or thing, not just an appearance of or similarity to the subject. Object dimensions can be obtained from measurements between any two points in a point cloud, and point clouds can contain millions to billions of points, yielding a multitude of dimensional measurements.

The fundamental structure of 3D point cloud data can be reduced to values for X, Y, Z, i, R, G, B such as the contents of the PTS file seen in figure 2–3. XYZ describes a point existing along three axes in space. RGB is a color value attributed to that point in space. The variable, i , is an angle of incidence value that describes how light is interacting with the surface at that point in space (California Department of Transportation 2018).

Along with the fundamental data, raw data from a scanner may include metadata that are produced by other sensors in the measuring device, including a global positioning system (GPS), altimeter,


```

MINGW64/c/Users/ADMIN/Documents/CulturalHeritageData/data
-11.57630000  3.13090000  192.23500000  -415  56  29  39
-11.57640000  3.12990000  192.23520000  -415  56  29  38
-11.57850000  3.15870000  192.23440000  -431  53  31  39
-11.57880000  3.15760000  192.23480000  -447  52  31  40
-11.57900000  3.15670000  192.23500000  -431  55  29  40
-11.57910000  3.15560000  192.23530000  -431  56  28  41
-11.57940000  3.15470000  192.23580000  -431  56  28  40
-11.57800000  3.15370000  192.23390000  -383  58  28  40
-11.57930000  3.15270000  192.23570000  -383  58  28  40
-11.57870000  3.15170000  192.23500000  -415  57  28  40
-11.58010000  3.15080000  192.23680000  -383  57  29  40
-11.57990000  3.14980000  192.23660000  -383  57  29  40
-11.57900000  3.14880000  192.23550000  -431  56  28  41
-11.57900000  3.14780000  192.23550000  -447  55  28  40
-11.57920000  3.14680000  192.23580000  -447  55  28  40
-11.57860000  3.14590000  192.23500000  -415  57  28  40
-11.57900000  3.14480000  192.23560000  -415  57  28  39
-11.57770000  3.14380000  192.23380000  -415  57  28  40
-11.57860000  3.14280000  192.23510000  -415  57  28  40
-11.58070000  3.15760000  192.23460000  -447  53  30  39

ADMIN@UL-DATAHORSE1 MINGW64 ~/Documents/CulturalHeri
data
$ tail -n 50 birdman.pts

```

Fig. 2-3. ASCII text readout of PTS formatted file contents showing X,Y,Z,i,R,G,B

temperature, resolution settings, and other information specific to the conditions in which the data were collected. The data can be output to a variety of modes that include, but are not exclusive to, 3D CAD-type modes, such as files for 3D printing, VR, Web3D, or interactive 3D environments. It is important for the archival record of the data to document the conditions under which the data were collected and produced. Careful archiving of source data and documentation metadata not only preserves measured 3D data, but also ensures repeatability of data collection and processing methods, facilitating the reproducibility of data output (Pedersini, Sarti, and Tubaro 2000).

Archiving 3D Data

Libraries must develop effective means to balance preservation and access in archiving the diverse forms of 3D cultural heritage data. Archiving strategies can be placed on a spectrum of preservation and access from long-term storage to immediate use. At one end of the spectrum are dark archives provided by the Academic Preservation Trust (APTrust), a collaborative consortium of higher education institutions managed by UVA; the APTrust's goal is to develop strategies for storage and successful retrieval of all forms of data going into the future.¹ APTrust provides storage of data in perpetuity and is not designed to allow immediate retrieval.

On the other end of the spectrum are archival solutions that offer immediate, open access to data. Developed at Harvard University, Dataverse is an open source, open data platform that has the ability to ingest just about any data file format and then publish it openly to

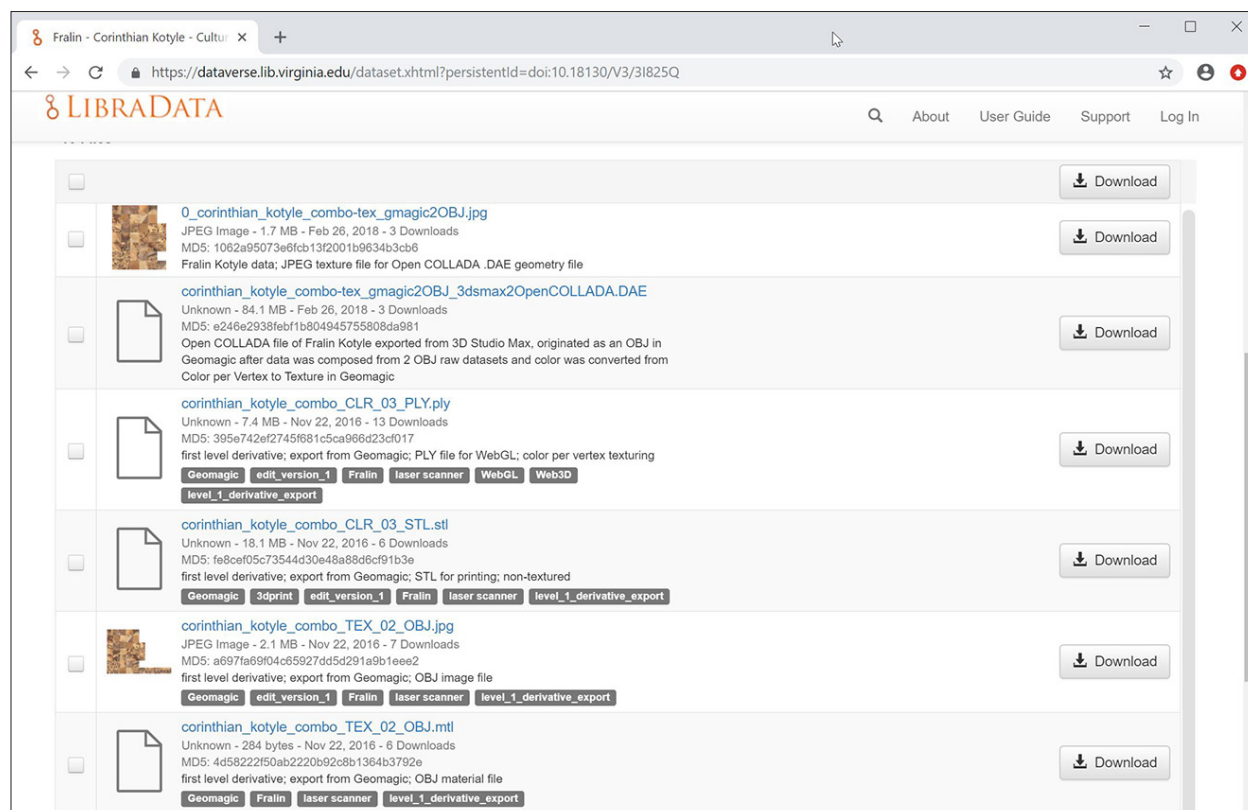
¹ <http://aptrust.org>

the world.² The UVA Library favors an open access approach to archives, incorporating Dataverse into its scholarly institutional repository, Libra, to allow open access to scholarship created by the UVA community. 3D formats can pose a variety of challenges to most repositories because of their diversity in format types, but Dataverse is extremely flexible. Once data have been uploaded and published in the UVA Dataverse, a SOLRscript creates searchable facets in Virgo, the UVA Library's search and discovery platform. Search terms in Virgo depend primarily on the parsing of key terms and description fields in Dataverse.


Dataverse allows open access to students, faculty, staff, and other teachers and researchers who wish to discover and download 3D primary source data, and then incorporate 3D data into their research and pedagogy. Although 3D technologies are widely utilized, little is understood of the differences in 3D formats. Understanding 3D is dependent on fully understanding how the content is generated. 3D content can be manually modeled using authoring tools like Sketchup, 3D Studio Max, or Blender. 3D data can be generated using laser scanners or through photogrammetric processes. Source content is different from the derivatives that are exported from 3D authoring, editing, and optimization software. Source content may be usable only by the tools that created it or the software that was used during data acquisition. Content must be exported to formats that are contingent on context, such as 3D printing, CAD, and VR. Problematically, Dataverse will ingest a variety of source files and their derivatives and dependencies, and present the content as a list

Fig. 2-4. Dataverse interface

² <https://dataverse.org/>



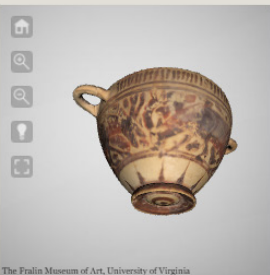
THE FRALIN MUSEUM OF ART
AT THE UNIVERSITY OF VIRGINIA



Corinthian Kotyle

Greek Vases Collection

Collect, Care, Conserve, Curate: The Life of the Art Object



The Fralin Museum of Art, University of Virginia

Greek Kotyle, ca. 600-575 BC


Corinth, Middle Corinthian black-figure, animal style, Archaic

Ceramic, 3 1/8 x 5 7/8 x 4 1/4 in, 7.94 x 14.92 x 10.8 cm

Gift of Joanne B. Robinson, 2008.12

Authoritative Record(s)


[View this object in the Fralin collection](#)



3D

Corinthian Kotyle


3D model of the Greek Kotyle



STL

Corinthian Kotyle

3D model of Corinthian Kotyle in STL format



Corinthian Kotyle

Photograph of the Greek Kotyle, ca. 600-575 BC

Fig. 2-5. Drupal interface with 3DHOP viewer for accessing 3D data in UVA Library Virgo

with no visual reference (figure 2-4). Therefore, scholars unfamiliar with 3D formats may have difficulty understanding how to use a particular file that is available in Dataverse.

In collaboration with the UVA Library, the UVA Institute for Advanced Technology in the Humanities (IATH) is developing a more user-friendly interface to access Dataverse assets and serve as an intermediary between Dataverse and Virgo. The interface uses the open-source web 3D viewer 3D Heritage Online Presenter (3DHOP)³ to provide an interactive 3D model for users to explore the data before download. It provides links for individual content formats according to potential use, for example, PTS, XYZ, or E57 for point cloud data or OBJ, PLY, STL, X3D, or DAE formats for mesh data. The interface in figure 2-5 presents the subject graphically and contextually with links to the repository, museum, or other collection source where the original subject is kept, providing a bridge between the technical data, or provenance, and contextual metadata (D'Andrea and Fernie 2013, 138-139; Denard 2009, 13).

³ <http://vcg.isti.cnr.it/3dhop/>

Accessing 3D Data

Once LIB3DCHI data have been archived and made openly accessible, scholars can use the data for a variety of academic purposes. Libraries are employing 3D content experts to help the scholarly constituency with a variety of tools, techniques, and information to use 3D data most effectively. The following examples illustrate 3D data use at the UVA Library.

3D Data Collections

The 3D Greek Vase Scanning and Printing Project (3DGV) project is an ongoing collaborative effort between UVA archaeology professor Tyler Jo Smith and the UVA Library. In early 2015, Smith received a grant to study 3D documentation and 3D printing of artifacts from the Fralin Museum of Art at UVA.⁴ Vases and other, similar artifacts of the Classical Greek period were scanned using a Creaform Zscanner 700CX laser scanner at a precision of 0.35 to 0.25 mm to collect the 3D surface and color texture data of the original. The data were processed and refined for 3D printing at a 1:1 scale in ABS and PLA plastic, typical to most printers today. While these types of printers do not replicate color texture from the 3D data, the geometric surface data can yield a nearly exact replica of the original vase's form. This enables students engaged in archaeology, art and architectural history, and other fields to directly handle artifacts, reducing stress and potential degradation of the original. This project continues today as new students are exposed to 3D documentation processes.

The dataset from the documentation of Fralin Greek artifacts has become a collection on the UVA Library's Dataverse, and the scholarly public can access all of the data openly through Virgo. Museums such as the Fralin are keen to open collections data to the public with the understanding that a Creative Commons CC0 license enables the wider community to download and gain full access to the data, unfettered by restrictive copyright protections. The Fralin has engaged in other projects with the UVA Library to document and provide access to other cultural heritage artifacts. In the spring of 2017, the Fralin hosted an exhibition entitled *Collect, Care, Conserve, Curate: The Life of the Art Object*, which explored various techniques and tools that museum conservators use for collection stewardship.

Figure 2–6 shows artifacts from the Fralin Mesoamerican and African collections that were 3D scanned and printed to provide facsimiles of artifacts for museum visitors to pick up and explore while the originals remained safe, but visible, behind glass. In addition to the physical reproduction, a 3DHOP web viewer was made available on an iPad kiosk for visitors to explore the fully color-textured object in 3D. Providing multiple forms of interaction from multiple derivatives of the 3D documentation data can bring scholars and the curious public alike closer to the physical reality of tangible cultural heritage.

⁴<http://archaeology.virginia.edu/3d-greek-vases.html>



Fig. 2-6. *Collect, Care, Conserve, Curate: The Life of the Art Object exhibit*

3D Scan-to-Print Technology for Accessibility

3D scan-to-print technology can be an effective solution for connecting the general public with invaluable artifacts and historic objects, but it can also be used to enhance interaction and appreciation of artwork for people with disabilities. At the Gari Melchers Home and Studio Museum at Belmont House, University of Mary Washington, Michelle Crow-Dolby teaches young children about the artwork of early twentieth-century artist Gari Melchers. She often works with children who have low vision disabilities that prevent them from fully participating in classroom activities. She looked to the UVA Library for help in finding a technical solution for these students. Crow-Dolby recognized the work that the UVA Library had done with 3D scanning combined with 3D printing and saw an opportunity for productive collaboration. The Library once again used a Creafom Zscanner to 3D-scan sculpture from Gari Melchers and 3D print a 1:1 replication of the original. Crow-Dolby now uses this technique to allow the children to interact directly with the sculpture, which visitors to the museum could not normally handle.

By providing a replica of an original artifact or artwork based on precision measured data, 3D scan-to-print output could be considered a form of 3D data in its own right. Digital data gathered by 3D documentation techniques are encoded in the physical form of the 3D print. It must be noted, however, that the physical replication of an artifact is not exact. The 3D scanning and printing processes degrade the precision of the information derived from the original subject. At best, laser scanning can provide a precision of only 0.25 mm of the surface of the original. The many minute details and nuances that exist below 0.25 mm are not recorded. Additional information, such as high-resolution photographs, scholarly accounts, and more descriptive metadata fields, must accompany the data record for preservation.

Historic 3D Reconstruction: LhasaVR

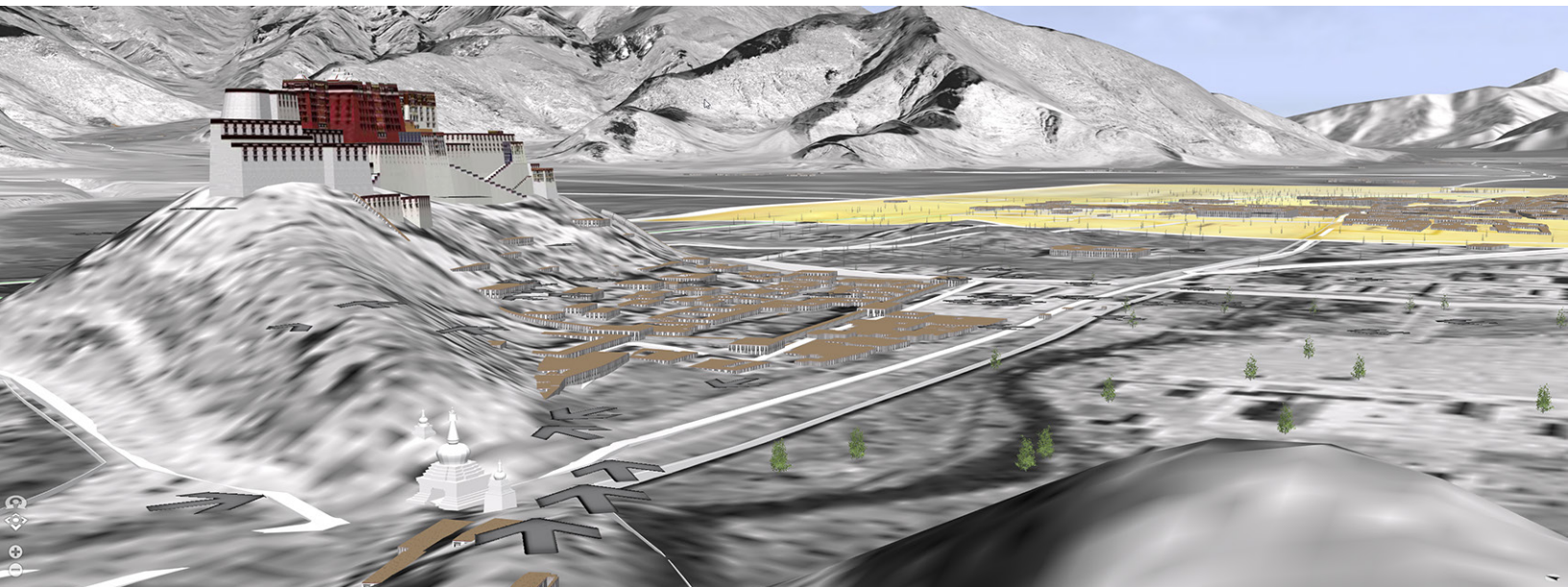
Before the development of 3D acquisition methods, manual 3D modeling was a standard method for 3D documentation of architecture and artifacts. Just as plan, section, and elevation renderings will remain the standard for architectural documentation, historic 3D reconstruction continues to be an effective means for generating cultural heritage data. This is especially true of non-extant places and things or time-dependent, ephemeral conditions of architectural and archaeological features that may have undergone renovation, restoration, or reconstruction. With careful research into historic documentation of a place or thing, 3D modeling can digitally re-create a cultural feature.

A massive 3D reconstruction project at UVA is the Lhasa VR project with the Tibetan and Himalayan Library (THLib).⁵ The main effort of this project was to build a comprehensive historical GIS of the Tibetan capital of Lhasa prior to the 1959 occupation by Chinese forces. More than 3,000 buildings have been razed or significantly altered since then. With the use of early twentieth-century maps and early high-altitude photographs, a comprehensive 2D map was created of the city and its immediate surroundings in the Lhasa-Kyichu River Valley. More than 3,500 features were identified by using Esri ArcMap mapping tools. Each feature was linked to the THLib database to create a map enriched by information. The 2D map was then converted to a 3D model by using the ESRI CityEngine procedural modeling tool and data from the THLib database to auto-generate buildings according to their historic characteristics. Higher resolution 3D models were produced in Autodesk 3D Studio Max and then imported into the CityEngine 3D GIS model.

The view of the 3D model in figure 2-7 is from the CityEngine Web Viewer utility, a free Web3D viewer for 3D GIS models

Fig. 2-7. THLib Lhasa VR project interface in ESRI CityEngine Web Viewer

⁵ <http://www.thlib.org/>



created with CityEngine. 3D models created in 3DS Max were based on architectural information provided by the nonprofit, non-governmental organization Tibet Heritage Fund. Projects such as Lhasa VR expand the use of 3D reconstruction models by using information systems such as GIS or BIM to link historic information to 3D data.

VR Pedagogy: Virtual Museums

The transformation of 3D data into pedagogical content is the fundamental goal of the 3D cultural heritage informatics process. The effective use of 3D content in the classroom is contingent on having tools that promote an engaging and meaningful experience. Immersive technologies such as VR can bridge the gap between physical history and cultural heritage data. 3D technologies play a crucial role in providing alternative modes of access to the physical world. Publicly accessible VR systems give users of both university and public libraries an opportunity to experience immersive content. The UVA Library provides public VR spaces that its scholarly community can use for teaching, learning, and playing. Playtime encourages students and faculty to become familiar with 3D content interaction and opens up a variety of potential tools and methods for interacting with 3D data. Using free software such as authoring tools in the Unity 3D game engine and the Steam VR platform, 3D and VR specialists at UVA teach pedagogical methods that are easy to learn and apply to a variety of academic fields. A method developed by Arin Bennett, VR/AR specialist with the UVA Library Scholars' Lab, and Will Rourke uses Unity 3D as the main platform to help students curate spatial narratives based on curriculum research topics. Narrative spaces are designed on the principles of museum spatial layout. A research topic is represented spatially by creating "rooms" in a virtual museum that relate to the arguments in a paper. The details of the argument are expressed by images, text, audio, or video objects placed in a room much like objects in a museum exhibition. The rooms are usually designed for a linear experience much in the same manner that a paper would be read. Interactions with these spaces are usually kept simple, enabling, at a minimum, the ability to "walk" from one space to another to see images or read embedded or linked text. Students who want to add more interactive features or create more specifically curated experiential elements can do so by learning Javascript or C# scripting, which are both native to Unity 3D. Scripting is not taught in the class, but learning how to build advanced interaction by downloading premade scripts is encouraged. The class is designed for base level novices with little experience in 3D modeling or content creation.

Students then lead their classmates in a tour of their research narrative while providing their own scholarly narrative. The 3D content is either output to a Web3D viewer in a webpage or converted into a virtual environment for an immersive exploration with VR headsets such as the HTC Vive or Oculus Rift. Both modes are networked and allow for multiple participation so that other students or

faculty can join in from other parts of the university, as well as from external institutions.

Open Access VR: 3DCHIVR

In collaboration with a team of researchers from James Madison University, the University of Mary Washington, and James Madison's historic home at Montpelier, staff at the UVA Library are researching methods for enabling open access to LIB3DCHI content in VR systems. Each of these institutions engage in VR systems-based interaction with their own constituency, while acknowledging that this content can easily be shared across networks with the broader scholarly community. This multi-institutional team has entitled their effort the 3D Cultural Heritage Informatics Virtual Reality (3DCHIVR) project, and their goal is to develop a platform for sharing content that is formatted for use in VR systems. The system is to be based on the model of open access, search, and discovery with Dataverse and Virgo at the UVA Library. To model how this system would work, the team is using the Steam VR platform to provide LIB3DCHI content collected and processed from laser scanners, photogrammetry, and historical 3D reconstruction. Participants sign up for free with Steam VR and can connect to one another in VR for a multiparticipant exploration of 3D documentation data of historic places.

Figure 2–8 shows a meeting taking place in data produced from two sites. At left is a 3D model of the Anatomical Theater, Academical Village, University of Virginia, produced for the JUEL Project (Jefferson's University, the Early Life) by IATH. At right is 3D data from laser scanning and aerial photogrammetry performed at the Warm Springs Bathhouses (ca. late eighteenth century) in Bath County, Virginia. 3D documentation data were converted into 3D VR content with little to no editing so that participants can explore an authentic replication of an actual historic site. Through networked VR systems, historical data can be easily distributed to the wider scholarly community for a firsthand experience of cultural heritage features. An open source, open access solution is the desired outcome.

Fig. 2–8. 3DCHIVR meeting in VR at the UVA Academical Village (ca. 1820s CE) and Warm Springs Bathhouses (ca. late eighteenth century CE)



Conclusion

The methods of LIB3DCHI help bridge the experiential gap between subject and scholar. One of the goals of scholarly research is to become more closely acquainted with cultural heritage through its physical record. Access to collections traditionally means examining artifacts behind glass, visiting a historic building in a remote or distant location, or working with media that express a likeness of the original such as in photographs, video, audio, or conjectural physical or digital 3D modeling. In most cases, the researcher is physically separated from the subject and connected primarily through media or other facsimile representations. 3D documentation technologies and methods such as laser scanning, photogrammetry, and historical reconstruction modeling can provide precise data that are useful for creating accurately measured representations of artifacts, architecture, archaeological sites, and other elements of physical cultural heritage. Web3D technologies can help conveniently distribute 3D content and data through web browser interfaces. VR is a powerful mode for exploring cultural heritage 3D content, as it immerses the scholar in a life-sized, scaled representation of historic subjects with tools to explore, annotate, and make inferences while sustaining discourse with other scholars and researchers within the global community. 3D printing can put accurately reproduced facsimiles directly into the hands of students and researchers who may otherwise have only limited tactile, visible, or other sensory interactions with the original subject.

3D technologies can strengthen a user's connection to the subject by providing access to measured data of historic objects, places, and sites through sensory-immersive technologies. Libraries are fostering democratized access to 3D assets as a means of providing new forms of knowledge to the scholarly community. By considering the creation, access, and preservation of 3D data, LIB3DCHI techniques help to ensure that 3D assets are meaningful and useful for research and pedagogy long into the future.

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Chapter 3

Virtual Reality for Preservation: Production of Virtual Reality Heritage Spaces in the Classroom

Zebulun M. Wood, Albert William, and Andrea Copeland

Abstract

The Bethel AME Church was the oldest African American church in Indianapolis. In November 2016, the congregation moved out of downtown, and the building that had housed the congregation since 1869 was sold. It is now being redeveloped into a hotel. Through the Virtual Bethel project, faculty and students in the Media Arts and Science (MAS) program at Indiana University–Purdue University Indianapolis (IUPUI) created a 3D virtual space of the physical sanctuary to preserve the cultural heritage of Bethel. During its creation, Virtual Bethel served as a curricular and co-curricular experience for the undergraduate students in the 3D graphics and animation specialization within class N441 3D Team Production, which was co-taught by Albert William and Zebulun Wood. Virtual Bethel, finished in 2018, was the first historical and cultural preservation project that used VR within our class, program, school, and Indiana University (IU) campus. Users can interact with various types of primary sources (e.g., photographs, video, audio, text) to learn about the underrepresented history of African Americans associated with the church. Virtual Bethel was created in a series of classes within the MAS Program in the School of Informatics and Computing (SoIC), IUPUI. Methods of

Virtual Bethel was funded by an Indiana University New Frontiers Grant in 2017. The authors would like to thank the team of the Advanced Visualization Lab (AVL), IUPUI: Thanks to Jeff Rodgers, Chauncey Frend, Tyler Jackson, and Michael Boyles for their unrelenting support of our programs and all-too-often thankless hours they put into our projects by fielding questions and inspiring all. We thank the students of Virtual Bethel, first Luke Brown for coming onto the project to embed and build a VR storytelling database, the first of its kind at IU, and for being at every public showcase and documenting everything. Thanks to original team Tyler Jackson, Rachel Davidson, Bryan Dinkens, Thomas Springer, Roxanne Wheeler, and Charles Yu, and to Skip Comer and Lisha Chen for creating our website and the ability to provide Virtual Bethel to the world.

We thank Online Resources, Inc. for the original 3D scan of Bethel AMC, and Kisha Tandy for providing research and for assistance in curating the Virtual Bethel Vignettes. Finally, we thank the Bethel AMC Congregation, especially Olivia McGee-Lockhart, for curating the mission, public showcases, vignettes, and accuracy of content within Virtual Bethel. Thank you for your continued partnership with our students, school, and university.

teaching a team of students to preserve historic spaces using VR are discussed, as are our philosophies toward productions when working with varying stakeholders' priorities related to data preservation, asset preservation, and cultural preservation.

Project Background and Significance

The Media Arts and Science (MAS) program in the School of Informatics and Computing (SoIC) provides undergraduate courses in 3D production and visualization. As a project-based course, N441 3D Team Production is designed to involve community partners in providing students with real-world, context-driven, hands-on learning opportunities. The course focuses on the creation of high-end, broadcast-quality animations through team-based learning. Students learn skills in areas related to production in a 3D project. These skills include preproduction tasks such as the development of a story, script writing, research, conceptual drawing, storyboarding, animatics, and project management. Production skills are explored in 3D asset creation, time management, file management, sound, and title sequences. Postproduction processes include final rendering, movie creation, and formatting for various playback devices. More recently, the program has embraced projects implementing and leveraging emerging technologies such as 3D printing, VR, and augmented reality (AR).

Founded in 1836, the Bethel AME Church was once a vital part of a thriving African American community in the heart of the Indiana Avenue Jazz District. Before that, Bethel played a vital role in the Underground Railroad. Bethel has significant meaning not just in African American history, but also in the local heritage of Indianapolis. Recently, the church site was rezoned for redevelopment, leaving the historic building—and the materials housed in the church archive for more than 162 years—in a vulnerable position.

Although the effort to digitally preserve the at-risk physical space is not innovative in and of itself within cultural preservation domains (e.g., Arc/k Project,¹ CyArk,² Iconem,³ MasterWorksVR⁴), the Virtual Bethel⁵ project incorporates associated digitized and born-digital archival materials into the virtual space to provide a new way of learning history and interacting with Bethel's primary sources. The project intends to develop this space as a virtual learning environment for undergraduate students' history and primary source education. The methods used to develop Virtual Bethel by engaging undergraduate students will be relevant to studies of other historic sites and archives with similar ambitions.

¹ <http://arck-project.org>

² <https://www.cyark.org>

³ <http://iconem.com/en/>

⁴ <http://masterworksvr.com>

⁵ <https://comet.soic.iupui.edu/bethel/>

Community: Respecting the Heritage and Institution's Members

Communication among the undergraduate N441 3D Team Production class, Bethel's church membership, and local historians connected the students easily with Andrea Copeland, chair of the Library and Information Science Department in the SoIC at IUPUI. Copeland focuses her research on facilitating connections between groups typically underrepresented by heritage institutions and community preservation infrastructures. Her research finds that trusted relationships are essential for reducing social distances and building connections among individuals, institutions, and knowledge. She has worked for several years with congregants from the Bethel AME Church. Working together on this project, we learned valuable lessons that can be used to support future community-driven heritage projects.

Course Description and Necessary Skills for Restoring 3D Scanned Structures

The N441 3D Team Production class allows students to work as a group and emulates the collaborative team environment found in the media and animation industry. The goal of the course is to bring students together to work on a common project. At this point in their undergraduate degree program, students have completed a number of prerequisites, including intermediate courses in 3D modeling, texturing and lighting, and animation. Virtual Bethel served as the first cultural preservation project using VR as a medium to engage students with the aim of educating the public. Regardless of the project assigned, students are encouraged to bring their existing knowledge and specialty (e.g., modeling, unwrapping, shading, materials, lighting, game development) to the team and investigate new skill sets that they may want to develop or that are needed to facilitate the success of the production.

We have found through teaching this course for five semesters over five years that students engage in this class for a variety of reasons with a range of positive outcomes. The course allows them to work together on a single project synergistically. Students can apply their existing skills and also find ways to implement other interests that they may not have yet developed. The course teaches them team dynamics and develops skills essential to the success of group work, including communication, leadership, organization, and accountability. Past class assessments indicate that the experiences students have in this class are far beyond regular class work in contributing to a larger team and serving the community, that they relish this experience, and that the overall result is a very satisfying academic exercise (Lombardi 2008; McLeod 2017).

At the beginning of class, we assess student strengths to compare the existing skill sets with a project's goals. We carefully look at student abilities, often recruiting students that we feel might benefit

from the experience and who can contribute specifically to certain portions of the project as it develops. We expect strong student leadership from within the group and encourage students to be accountable to their peers rather than to the instructors. We set up a data and communication structure that ensures all students begin interacting as soon as the class starts. We encourage the students to adopt a communication system that is easiest for them; many times, students have opted to use Facebook or other social media platforms. They also communicate daily and share files through a system used in the Indiana University infrastructure called IU Box.

Technical knowledge of the craft (in this case, animation) is, of course, critical to the success of the project; yet the students are encouraged to research the topics on their own early in the semester. Supplementary materials are gathered and provided in our course materials on Canvas, the campus learning management system. Knowing the history of the subject or the background of the story gives students more interest in the success of the project and their role within it.

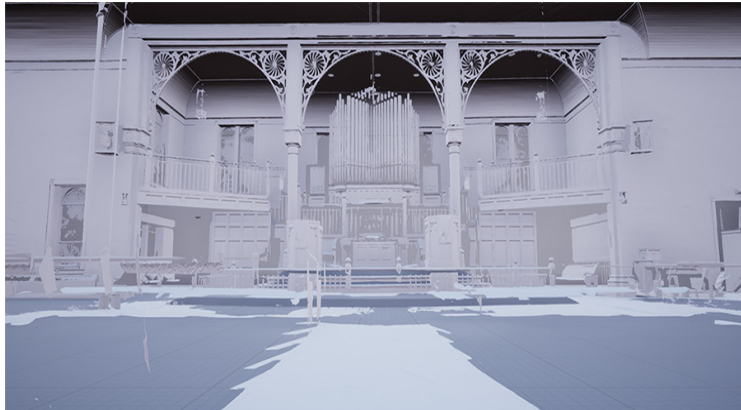
The Classroom as a 3D Production and Preservation Studio

In the fall semester of 2016, our N441 class was presented with the opportunity to re-create the historic Bethel AME Church in Indianapolis. We felt that a VR experience using 3D models and textures would be a powerful method of telling the story of this church. We also felt that this opportunity for community engagement was a perfect fit with the collaborative nature of the class, as IU strives to highlight its engagement and impact throughout the state. We presented the students with this opportunity in the first class meeting. They considered this a great use of their skills and time, and they were excited to be working to give back to the downtown Indianapolis community.

During our second class meeting, all students and faculty visited the church, which was within walking distance of our classroom, to experience the space that we would re-create. In early September 2016, on a warm, late afternoon with sunlight streaming through the stained glass windows, we spent more than two hours exploring every corner of the church. We took about 2,000 high-quality photographs to use as reference for the 3D models and textures that would go into the VR experience. We used a GigaPan robotic camera system to capture images that were stitched together to form highly detailed panoramas of the interior, and a Ricoh Theta camera captured low-resolution 360-degree images. All of these photographs were cataloged, archived, and used to help re-create the digital space. Measurements of some structures were also taken as references for scaling the models.

Before the start of the semester, Online Resources, Inc., a local 3D scanning company, had created laser scans of the interior of

Fig. 3-1. The original LiDAR scanned data (top), retopologized interior (middle), and fully textured and lit Virtual Bethel ready for viewing in VR (bottom)



Laser scan model provided by Online Resources, Inc.



Recreated 3D model of Bethel AMC from laser scan



Fully textured and lit Virtual Bethel

the Bethel AME Church for the project with a 100mm Surphaser LiDAR laser scanner. This data set was approximately 2.9 GB and contained 39 million polygons. Tests of the scanned data using the Unreal 4 game engine outputting to an HTC Vive VR system showed that, because of the density of the scanned mesh and size of the data set, we had to greatly reduce the scan so we could view Bethel in VR. The group decided early on to use the scan as a type of digital tracing paper, an excellent reference resource that could speed up our modeling workflow (figure 3-1). One of the first steps taken as we started to develop the church interior was to bring the

reduced scanned data into Unreal and scale it correctly. We simply placed a six-foot box representing the size of a human and compared it with the objects and space within the scene.

Students used Autodesk Maya 2016 as the software to model all of the assets. The scanned data were reduced using Pixologic Zbrush's decimation tools, then brought into Maya and scaled to their proper dimensions for use as a template. Objects that had been measured by students were used as references, and then the scanned model was brought to its proper relative scale based on unit settings (mm, cm, meter) in Maya.

Using the scanned data and reference photographs, our modelers were able to determine the basic shapes of each part of the specific objects and begin manual reconstruction. We needed to be cognizant of the number of polygons that this model contained so that it would show enough detail, but the number could not be so high as to hinder the Unreal 4 engine executable file when it was brought to VR and displayed in stereoscopy.

Production meetings, in which iterations of the virtual environment, individual assets, and interactions in the virtual environment were discussed, were held at the beginning of each week's class in a conference room, instead of our usual classroom. This allowed students to focus on all of the assets, brought them together as a team, and showed them how their contributions were affecting the big picture. The

team reviewed each student's work weekly, addressed concerns as needed, then tasked the students with moving forward on new assignments. We, the instructors, stressed to each student that others relied on their progress and thus adherence to deadlines was mandatory. Production meetings were followed by visits to the IU Advanced Visualization Lab⁶ to view the progress on the VR environment within the Unreal game engine. After the team meetings, the rest of the class was dedicated to lab/production time for all members to spend time interacting, working, and receiving individualized instruction from both faculty and team leads as needed. On artistic or preservation considerations, the students considered feedback from the client/public and adjusted the interactives based on the audience's reaction to the environment, primary resources within VR, or even the VR hardware itself. As we neared completion, some church congregation members and the church's pastor visited to see our progress. It was surreal to watch the members find the pew where they had always sat and to observe the pastor stand in his favorite spot to give a sermon. The students saw the impact of their work on the visitors and started to understand how this project was important for the community. This was a very powerful visit for all involved.⁷

As students completed 3D models for populating the VR environment, they kept records of their progress on a spreadsheet. As digital models were completed, students began unwrapping the 3D objects so they could be textured using Allegorithmic's Substance Painter. This process applied materials and colors to the 3D models to give them a sense of realism. To simplify the identification of particular materials, an internal team library was created for students to access materials that had been identified in Bethel. Materials represented surfaces in the real world (e.g., types of wood [cherry, oak, poplar], paint [glossy, matte, aged], metals [chrome, copper, iron], plastics [silicone, rubber, shiny, glossy]). As models were painted within Substance Painter, texture maps were exported for use in Unreal 4's physically based rendering (PBR) shaders, which experts in the video game and architectural visualization industry commonly use to make surfaces appear realistic.

After all models had PBR materials applied and were loaded into Unreal, various processes were used to optimize the scene. For example, the textures were tested to see whether there were errors, lighting was added to the scene to simulate light coming through the windows, navigation controls were optimized, and teleportation locations were created to permit navigation in the environment.

⁶ <https://kb.iu.edu/d/apel>

⁷ See a short video of Virtual Bethel in early production used to solicit additional support: Virtual Bethel Solicitation, October 14, 2016. Available at <https://vimeo.com/187085145>

Building a Campus Infrastructure for Virtual Preservation of Cultural Heritage

In projects such as Virtual Bethel, the prior knowledge, resources, and communication ability of support staff, faculty, project partners, and client partners are critical to project planning. Readily available hardware and software can ensure the success or guarantee the failure of projects. The MAS faculty have made several choices and adopted specific philosophies to ensure success across media projects of many kinds. Following are discussions of specific considerations concerning VR projects involving the digital preservation of spaces, including technical considerations; associated costs; student technical and artistic competencies; variations in student level of confidence and leadership; variations in peer-to-peer organization, communication, and accountability; and student learning outcomes.

Technical Considerations

The MAS program faculty and students make every effort to stay software agnostic, especially in relation to game development engines. In an age when software updates are daily and software companies are purchased every hour, it is impossible to anticipate which updates, plug-ins, or software will stop being supported or will be changed entirely. We encourage our faculty and students to test, vet, and hone their skills on multiple platforms. The Unity game development engine tends to enable easier porting to various head-mounted devices (HMDs), mobile devices, and app stores, while Unreal, until recently, has supported only higher rendering and realism capabilities. We built Virtual Bethel using the Unreal game engine because we wanted to develop contained systems for porting Virtual Bethel onto full VR, mobile devices, and web environments for maximum public access. This was a new process for us, and future projects in the program will benefit from the lessons learned.

Another important technical consideration is that 3D scans of objects, spaces, or both must be completed and delivered before the start of a production course semester. Geometry created from scan data is often best at the highest possible capture settings. Whether the data are captured via LiDAR, structured light, photogrammetry, or by other means, the bigger the dataset, the bigger the textures, and the larger and more frequent the photos, the better the end result. Given the temporal constraints of the academic semester, student productions cannot be delayed because of the need to recapture or find additional photography.

Associated Costs

VR projects like Virtual Bethel have substantial costs. The total support funded by Indiana University's New Frontiers Grant⁸ in 2017 was considerable at roughly \$59,000. Most of the funds covered the costs of student hourly labor outside of class time (texture artists, lighters, game developers, web developers, user experience [UX] researchers), faculty summer support, and a modest honorarium for our community partners. Nearly 10 percent of the budget was used to purchase server space for the website and invest in a mobile VR workstation with a laptop capable of showcasing iterations of Virtual Bethel to the public during its production so that students could receive feedback (Copeland et al. 2018).

Without an MAS or similar program, an institution is unlikely to have the necessary resources for such projects, including lab space, and hardware and software. The lab space, computers, display hardware, and 3D and game design software had already been purchased for teaching MAS students in the undergraduate and graduate program within SoIC, IUPUI. The core labs, IT 255 and IT 257, house 43 computers with Cintiq displays with the latest software and hardware for film, game and VR art, production, and development, as well as VR hardware, respectively (figure 3–2). Unless this infrastructure and the supporting IT staff already exist, projects like Virtual Bethel would be unreasonably expensive.



Fig. 3-2. 3D (left) and VR production (right) labs at the School of Informatics and Computing

In terms of labor, the three to five MAS students who worked during the digital replication of Virtual Bethel averaged a total of 15 hours per week, followed by two students who averaged ten hours per week in the second semester, and one student who worked over the last eight months embedding audio, interactions, and iterating on the story vignettes within Virtual Bethel once the project was funded at an average of 10 hours per week. Two students were paid outside of class after the first semester through the support of the IU New Frontiers grant for two additional semesters

⁸ <https://research.iu.edu/funding-proposals/funding/opportunities/new-frontiers/index.html>

to continue the development of the interaction portions of Virtual Bethel; to embed a curation experience; and to refine standardized workflows for creating multidevice VR executables for any audience or hardware such as Oculus, Vive (full VR), iOS and Android (mobile VR), and web-based versions of the experience (for those lacking HMD or mobile VR hardware). A graduate student with web development experience was also paid to develop the public facing website and store all of the content.⁹

Critical Decision-Making Points Through the Project Based on Stakeholder Feedback

Several critical decision-making points arose through the project, particularly in terms of VR navigation, curation of Bethel's story and history, implementation of audio and voice, protecting the cultural protocols of the Bethel congregation, and preservation community priorities with VR constraints.

Virtual Reality Navigation

During the first public showcase in the fall of 2017, we noted that many of the Bethel membership were elderly and took several minutes to learn to use VR navigation. Some members also were unable to stand because of their health. The decision was made and implemented immediately after that session to provide two modes of VR navigation when showcasing Virtual Bethel with HMDs: one standing mode with teleportation enabled, and a second sitting mode that would allow the user to transition to various locations preloaded in the Virtual Bethel sanctuary by clicking one button. Making the VR experience accessible to those who cannot stand or walk has become a key priority to building an alternative VR navigation interaction in projects for the future.

Curation of Bethel's Story and History

After the space was initially showcased to the local membership, Bethel resident historian and Virtual Bethel Curator, Olivia McGhee-Lockhart and several heritage partners were given the opportunity to experience the Virtual Bethel space. They expressed gratitude at the re-creation of the space, but said that the experience felt flat and lacked a sense of story, import, or exploration. We knew the space alone was not enough to educate or leave an impact on an audience, so we decided to embed interactive story vignettes (figure 3–3). The vignettes included short written content and surrounded digital versions of content such as scanned newspapers, ledgers, and photographs of Bethel and its membership. In the late fall of 2017, the team turned its attention to creating a database within Virtual Bethel so that it could outlive the VR team. Now Virtual Bethel can accept additional story vignettes that house various types of data.

⁹ <https://comet.soic.iupui.edu/bethel/>

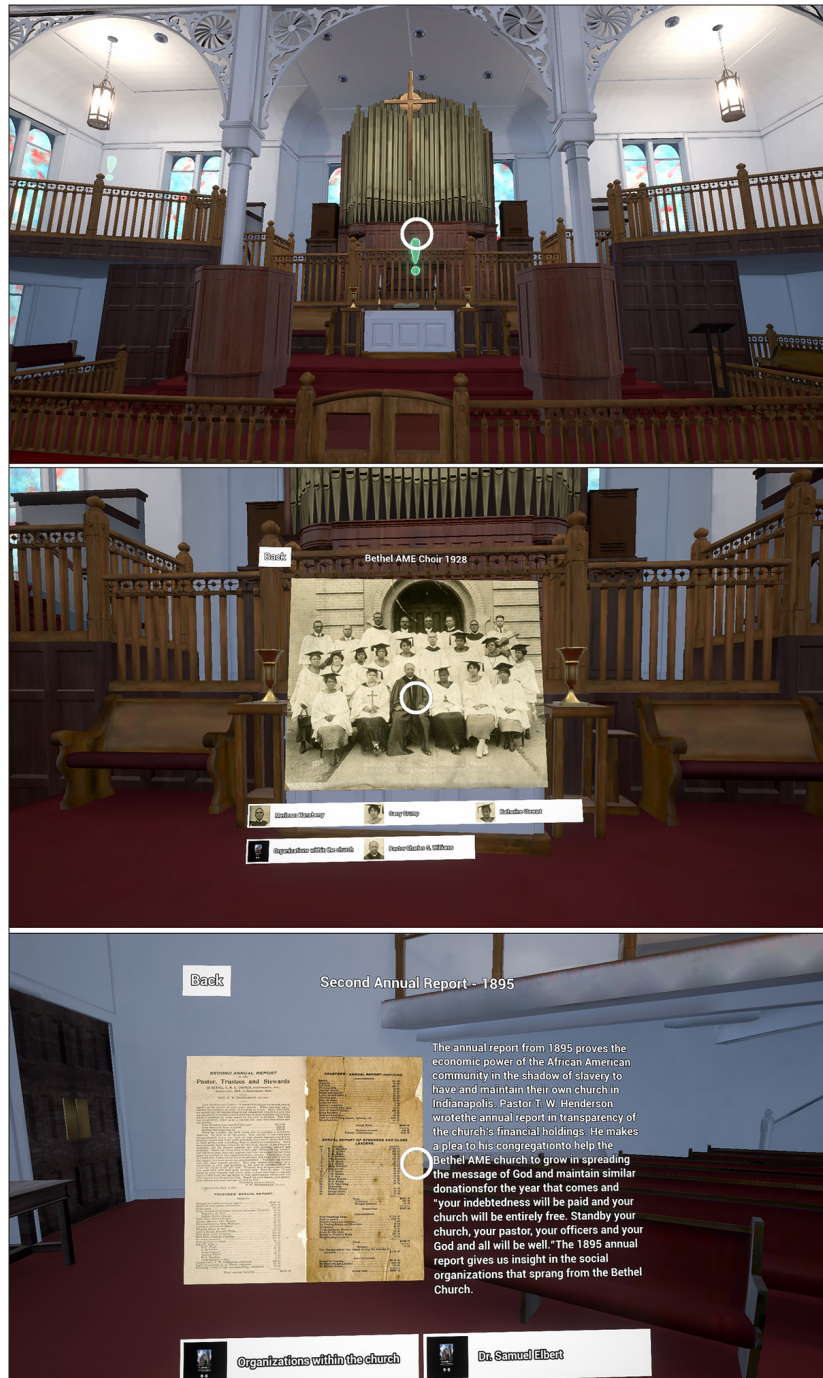


Fig. 3-3. Examples of interactive story vignettes

Implementation of Audio and Voice

On Martin Luther King Day, 2018, we were showcasing the latest version of Virtual Bethel, which then contained 20 story vignettes; we noticed several audience members saying that they would love to “hear” ambient church members and McGee-Lockhart, as a critical part of the vignette experience. As a result, McGee-Lockhart recorded audio for each vignette, discussing the history of specific parts of the church, and the audio was programmed to play upon interaction with the vignettes. This enriched the experience of the space for

users and enabled them to hear why each space was so important to its congregants and for the city of Indianapolis.

Plan for Sharing

Early in the relationship, because of the inexperience of project partners in both the game development processes and VR, we created contractual protections for Virtual Bethel that still make it legally difficult to share the project folders with interested parties. Our goal was to ensure safe, responsible, and ethical use of Virtual Bethel files, as we feared that ease of access could lead to unimagined and potentially harmful reuse of the digital files. We wanted to protect Bethel's membership from the possibility that a game or other interactive experience could be made based on the Virtual Bethel content without their express consent.

Preservation Community Priority Versus VR Constraints

Early in the project, stakeholders unfamiliar with the technical and hardware constraints of VR expected objects in virtual space to have the same level of realism and accuracy that objects have in real life. We explained to project stakeholders and community partners that varying levels of realism can be achieved based on the following factors: student labor force size, ability, and available time. We are very proud of our students' final version of Virtual Bethel and its level of realism/believability. In our opinion, it exceeds many other projects in both aesthetics and interaction.

Looking Ahead

As new technologies emerge, as virtual interactions become simpler to implement, and as alternate realities permit ever richer experiences, new opportunities are continually emerging for research and application. Looking forward, we suggest some areas of research in which to invest prior to building a virtual recreation.

Agnostic Platforms

Project partners and stakeholders at IU used Virtual Bethel's methodology to recreate various spaces, but with significant differences; for example, some teams used Unity game development engine, while our team had used Unreal game development engines. This meant that project teams frequently could not use the virtual artifacts and interactions that others created. Developing across multiple software platforms can be cumbersome and often leaves one team feeling left behind the other. In MAS, we have committed to creating projects in both Unreal and Unity game development engines to both increase the employability of our students and to stay current with trends in these industry-leading applications for next-generation interactions.

UX Standards and Institutional Documentation

There is little documentation for developing platform-specific interaction standards for virtual reality. Documenting virtual interactions that do (and do not) work well, sharing the code that creates them, and explaining the reasoning and context behind the choices made during their creation is therefore critical to building a project management and knowledge-sharing infrastructure. What works well in a full VR experience for navigation and interaction must be configured separately for mobile devices and again for web-based virtual experiences on a desktop computer. The Virtual Bethel team has committed to delivering VR environments for all major platforms and to documenting the processes of creating interactions for each platform to aid future IU teams. Creating tools that automate the development of navigation and interaction inputs across VR platforms and devices will expedite the testing, evaluation, and accessibility of virtual reality-supported historical and cultural preservation projects.

Advanced Capture Technologies

Capturing 3D artifacts and spaces is becoming cheaper, more efficient, and more accurate every day. For example, we can now use a combination of photogrammetry-produced high-resolution textures with highly accurate spatial data from laser scanning—an approach that was not available to us when the project started two years ago. Documenting methods for combining geometry and textures from multiple imaging tools will be important as advanced capture technologies and techniques change over time.

Quantifying Authenticity

Throughout the creation of Virtual Bethel, our core concern was to recreate the chapel for the congregants. Each of the stakeholders we spoke with—the engineers scanning the space, the librarians scanning documents and artifacts, our students, the Bethel membership, or the public at large—had their own definition of what was real, true, or believable in virtual reality.

We began to frequently ask the following questions:

- How can we quantify authenticity of virtual objects/spaces for different stakeholders when forced to remake spaces/artifacts for VR experiences?
- What are the dependent variables in defining authenticity?
- Do digital born artifacts have authenticity as a digital replica?
- At what point does digitized content made for AR or VR not represent the physical artifact on which it is based?
- How much freedom does a 3D artist have?

Much effort was spent educating all project partners and stakeholders on the geometry, texture, and lighting constraints of VR (and limitations of student ability) while also convincing them to capture the highest possible quality of scans for posterity.

We believe that virtual reality will become the interaction

medium of choice for audiences to learn about and experience history. Watching Bethel congregants, students, children and colleagues interact with, gain insights from, and understand the VR medium and how Bethel is being preserved in a new way leads our team to believe this is a much more natural, believable, and accessible media environment with which to engage, educate, and entertain. As hardware adoption and the public's comfort interacting with digital content increases, preservationists will no longer just preserve, but will also have the opportunity to lead the curation of and interaction with the objects, spaces, and time periods they protect (see Costa and Melotti 2012; Morcillo et al. 2017).

Accessibility for All

Media Arts and Science at IUPUI is committed to making available and representing its students' and project partners' hard work in as many ways as possible. Until full head-mounted displays are ubiquitous in homes around the world, we see it as necessary and ethical to create full, mobile, and web-based VR iterations of all of our projects to ensure that all audiences can learn from the virtual spaces we create.

Conclusion

Throughout its creation, Virtual Bethel has benefited the faculty, students, librarians, preservationists, community partners, and, most important, Bethel church members. Positioning a 3D/VR production as a focal point for heritage preservation inspired quick stakeholder buy-in, enthusiasm, and flexibility through collective understanding. All stakeholders embraced this emerging technology as a unique preservation method. The IUPUI Library has become a place to learn about emerging technologies, anticipate trends, and preserve the digital files of productions such as Virtual Bethel. The Virtual Bethel project has become an exemplar of what a library can offer its public and how an academic institution can leverage faculty and on-campus resources while integrating its students into authentic and engaging curricular and co-curricular projects. Undergraduate students led the VR production day to day, and the result, with a bit of organization and regular community feedback, was more than anyone could have imagined. We could not be happier. During its creation, Virtual Bethel inspired six other preservation projects and student teams of varying sizes at IU. Virtual Bethel's success has inspired the integration of MAS students and faculty in the virtual re-creation of several environments and time periods in and around Indianapolis. The collaboration of community members, historians, preservationists, librarians, student game developers, and 3D artists realizes a new opportunity to develop exciting experiences that are authentic, accurate, and informative, both inside and outside of academia.

We did not just scan the Bethel AME church, we did not just document the space, we re-created it. Furthermore, we are preserving it

in a medium that will far outlive the physical church or anyone on the team. We embedded within the VR environment access to more history than the real space could ever provide, separate from any single historian, member, or moment. We made it possible to add and amend new content to the Virtual Bethel database at any time. We believe projects like Virtual Bethel are redefining what the preservation of an endangered cultural heritage site means. The scanning of 2D and 3D objects is the first step in a much larger preservation pipeline, one in which an audience readily accesses a space that no longer exists, listens to voices that can no longer be heard, and holds artifacts that no longer can be held. Future audiences will demand to interact with and understand history on their own terms, while a new niche of VR curators will initiate preservation projects, provide access, and steward the experience.

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Chapter 4

Using 3D Photogrammetry to Create Open-Access Models of Live Animals: 2D and 3D Software Solutions

Jeremy A. Bot and Duncan J. Irschick

Abstract

Novel technological solutions emerging over the past five years have made it possible to consider previously unheard of re-creations of the world as it exists in its stunning, full-color, 3D topography. The potential value of the rendering of real animals for science, conservation, education, and story-telling is substantial. For scientists, 3D models of live animals provide valuable data for testing theories on body shape and movement, and they represent “avatars” of actual specimens for further analysis. For conservationists, the ability to use novel technological solutions such as virtual reality (VR), augmented reality (AR), or gaming applications to present real-life animals opens new doors for reaching the public. For educators, the ability to tell stories around a specific animal, instead of a generic animal, is significant. Drawing on our work with the Digital Life Project, we describe our process for using open-source software to recreate living animals in 3D, from photocapture to animation.

Introduction

The past decade has witnessed an upsurge in efforts to digitally preserve the world, such as 3D scanning of buildings (cyark.org) and corals (thehydro.us). Some methods for 3D scanning include magnetic resonance imaging (MRI), computed tomography (CT), laser or white light scanning, and photogrammetry (Huising and Gomes Pereira 1998; Bythell, Pan, and Lee 2001; Gignac and Kley 2014). Of these methods, photogrammetry has emerged as a flexible tool that can be used for various research applications (Debevec et al. 1998; Bythell, Pan, and Lee 2001; Dai and Lu 2010). Unlike the other methods listed, photogrammetry does not require expensive

hardware or software (Weinberg et al. 2004; Linder 2009; Falkingham 2012).

This chapter examines the practice and art of generating 3D models of live animals using photogrammetry—the science of deriving measurements in 3D space using photographs (figure 4–1). In particular, we focus on the technical workflow using open-source software (i.e., computer programs that are distributed with the original source codes, which allow them to be read and edited in their uncompiled state).

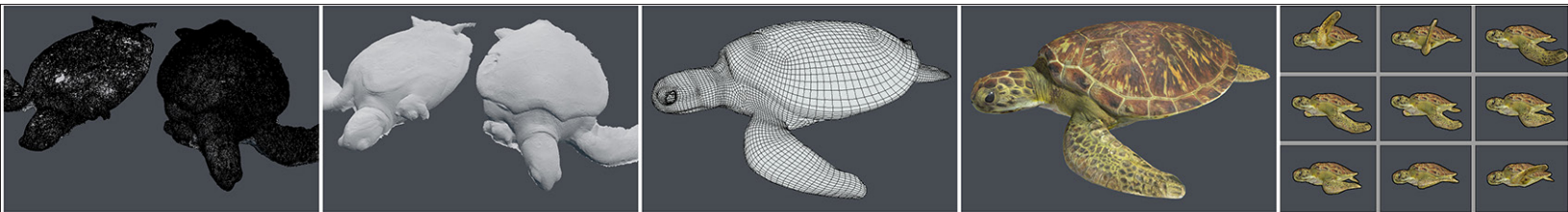


Fig. 4-1. A green sea turtle is scanned using photogrammetry software, remodeled, textured, and animated.

Re-creating live animals as full 3D models by means of photogrammetry is not simple. For entertainment purposes, a 3D artist creates a generic animal model using multiple reference photos from various animals, modeling in as much detail as necessary. For purposes of conservation, science, and education, the 3D artist is under more constraints as they must be faithful to the original details of a single animal. It is also important to realize that most 3D scanned models represent a single snapshot, with the subject frozen in time. This is an issue as animals are rarely static. The ability to record and demonstrate the movement of a living animal enhances storytelling elements and can provide new tools for scientists and educators. For example, a recording of a dinosaur in motion, if such a thing were possible, would expand our understanding of how these creatures moved. As behaviors affect structures, this helps us better understand the animal’s underlying anatomy, and even gives hints to the environments they traversed. Thus, in the review of our technical workflow, we also discuss the methods and mindset that we used for re-creating movement.

In this paper we first focus on the process of using 3D photogrammetry for the photocapture of objects. Second, we discuss the use of this method and other aspects of photography to photocapture live animals in different settings (e.g., field, laboratory). Third, we show how open-source software (e.g., Blender) can be used to reconstruct the resulting 3D meshes and then render a model in its final forms to create a VR- and AR-ready “asset” (Raitt and Minter 2000; Yirci 2008).

Uses for 3D Models of Living Animals

Lifelike 3D models of animals (i.e., those that appear in death much the same as they do in life) are valuable for several reasons. In many cases, such as with mammals and birds, scanning a dead specimen is very different from scanning a live specimen, both in terms of

the process and the result, whereas in other cases, the distinction will not be obvious. First, these 3D models can represent 3D digital voucher specimens. Traditionally, scientists collect live specimens in the field, euthanize them, preserve them with fixatives, and then deposit them in museums. Using photogrammetry, researchers can scan live specimens in the field or the lab and then create 3D models that are connected with metadata (e.g., museum accession numbers) for scientific analyses. Second, the 3D models can be used for computational modeling analyses, such as testing theories of how sea turtles or sharks swim. Third, the models have various educational uses, ranging from virtual and augmented reality (VR and AR) to 3D printing to demonstrate animal form and function (Blagoderov et al. 2012). Fourth, the models serve as a powerful tool for animal conservation programs. In the same ways that photography pioneered new ways of understanding animals, the use of VR and AR has similar potential to facilitate the visualization of live animals and demonstrate their uniqueness. Finally, the 3D models have potential commercial value, as unique 3D models from animals allow more specific content for various kinds of work, such as commercial movies or video games.

Capturing and Processing 3D Data Using Photogrammetry

Combined with computer software, digital photos can be used to generate a 3D polygon mesh and surface color texture files. Many popular photogrammetry software solutions can process all steps in the model-making process, from the capture of initial photos to the production of final textured 3D mesh (sidebar at left).

Software for Photogrammetry and 3D Mesh Manipulation

Photogrammetry software:

- RealityCapture by CapturingReality, <https://www.capturingreality.com/>
- PhotoScan by Agisoft, <http://www.agisoft.com/>

Open-source software tools that also handle various portions of the photogrammetry processing

- VisualSFM, <http://ccwu.me/vsfm/index.html>
- MeshLab, <http://www.meshlab.net>
- Bundler, <http://www.cs.cornell.edu/~snave/bundler>
- CMVS, <http://www.di.ens.fr/cmvs/>
- COLMAP, <https://colmap.github.io/>
- MVE, <https://www.gcc.tu-darmstadt.de/home/proj/mve/>
- MVS-Texturing, <https://www.gcc.tu-darmstadt.de/home/proj/texrecon/>
- OpenMVG, <https://github.com/openMVG/openMVG>
- OpenMVS, <http://cdceacave.github.io/openMVS>
- Theia, <http://www.theia-sfm.org>
- Meshroom, <https://github.com/alicevision/meshroom>

Technology Overview

The first step in scanning an object with photogrammetry is to take multiple photos of the subject at varying angles. Next, the computer software generates a 3D mesh by finding similarities between sets of photos. The matched patterns in each photo are triangulated, resulting in the conversion of pixels into points in 3D space. The process enables us to use these point cloud data to construct a polygon mesh. Having calculated the coordinates of the points and the positions of the camera, we can project the original photos onto the surface of the mesh to create a color texture map. Because photogrammetry relies on the ability to identify similar patterns between each photo, the process works best with detailed, nonreflective surfaces that are viewed under consistent lighting. For example, it is problematic to reconstruct shiny objects or objects with no obvious landmarks (e.g., a white sheet) with 3D software.¹

¹ The process of using photographs and videos to create 3D models via photogrammetry has been covered in other publications (e.g., Falkingham, 2012; Baqersad et al., 2017)

Single Camera

Because it is possible to reconstruct only what the lens can see within its viewing angle, the use of a single camera is best suited for situations in which the subjects being sampled are static, such as architecture, sculptures, or other inanimate objects. A static object allows the photographer to move around the subject, taking multiple pictures from various viewing angles, without having to worry that the subject will move between photos. For most living animals, therefore, the use of a single camera is unsuitable. When a subject moves with respect to the background while photos are being captured in sequence moves, the patterns in the photos will not align properly. If there are misalignments, the resulting 3D reconstruction will have inaccuracies, resulting in a lack of resolution or the presence of visual artifacts or noise. Further, lighting quality around a subject, both in the field and the laboratory, can vary considerably. Thus, the effective use of photogrammetry as a tool requires some skill in lighting and basic photography.

Multiple Cameras

To capture moving objects (e.g., animals), one method that the Digital Life² team has used is a multicamera rig (figure 4–2). Multicamera rigs can be configured in many sizes and shapes, and they have been most widely used for human 3D imaging, such as the xxArray system by artist Alexx Henry in Los Angeles. A typical multicamera rig consists of 4 to 30 cameras on some form of fixed system, such as tripods or sets of 80/20 metal rods, with all of them pointing

Fig. 4–2. Frog surrounded by a multicamera rig built by the Digital Life Project. Photograph by Christine Shepard.

² <http://digitallife3d.org>



toward a central area. The cameras are then synchronized to wireless triggers or wires, which ensures that all of them take a photo at the same time. An alternative method is the use of synchronized video with a common motion (e.g., a clapper or a ball drop in view of all cameras).

Our focus has been on creating multicamera rigs for work with live animals that vary in shape, size, and behavior. The Digital Life team focused on creating four different kinds of multicamera rigs, which together represent the Beastcam technology platform. These rigs are the handheld Beastcam, the Beastcam MACRO, the Beastcam ARRAY, and the Beastcam STAND. The handheld Beastcam is a four-camera system designed in part by Kasey Smart, Dylan Briggs, and Duncan J. Irschick. The system works through the synchronization of four small cameras on flexible arms that are triggered through wires. The Beastcam MACRO was designed by Trevor Mayhan for creating 3D models of small animals ranging in size from about 1 to 5 inches

in body length, such as small frogs or reptiles. The Beastcam ARRAY, developed by Zachary Corriveau, can hold more than 40 cameras and was funded in part to create 3D models of small reptiles. This system is best suited for small to mid-sized animals ranging from about 3 to 10 inches in length. Finally, the Beastcam STAND system was created by Michael Perriera originally for 3D models of houses, but the utility of this system for large animals soon became apparent. Each of these systems is field-portable. The inclusion of scale bars next to the model allows the user to reconstruct the scale of the specimen.

Aligning Images to Create an Accurate 3D Model

Especially with live animals, coverage of photos is typically insufficient to capture in detail every portion of an animal. The capture of additional images over occluded areas with a handheld camera can help to remedy this problem, even when the original animal has moved from the position in which all the cameras were synchronized. In the case of sea turtles, we used two scans (dorsal and ventral sides) along with individual images to create the full 3D model (figure 4–3). However, because the animal was often in a different pose when the dorsal and ventral sides were scanned, additional work was necessary to integrate the photos/scans into a single model.

The animal poses within the individual scans are adjusted so that the meshes align. This is accomplished by finding corresponding landmarks between the portions. These landmarks serve as reference points, allowing the photographer to scale the mesh portions so that they match in size. Once the rigid

Multimedia Data File Format Definitions

DNG: Photos taken with our cameras use this raw Adobe digital negative format. <https://helpx.adobe.com/photoshop/digital-negative.html>

OBJ: We use this open-source file format developed by Wavefront Technologies, a popularly used standard for storing 3D mesh data. It includes texture coordinate information (also known as UVs) that maps a 2D texture to the 3D model. When combined with MTL files, the OBJ file can manage material properties and link to the texture image files that have been applied to the mesh. In our process, we export our scans in this format as it is compatible with nearly all 3D animation software packages. However, it does not support skeletons, skinning, or animation data. http://www.cs.utah.edu/~boulos/cs3505/obj_spec.pdf

PNG: For our textures, we use this open standard lossless image format that supports 24 bit color depth with RGB or 32 bit RGB + Alpha. Commonly used for textures in 3D animation because of its color depth and lossless data compression and on the web as recommended by the World Wide Web Consortium (W3C). <http://www.libpng.org/pub/png/>

BLEND: This open-source file format is the native file type for Blender, our core 3D open-source animation tool set protected under General Public License v2. The format supports mesh geometry, UVs, materials, skeletons, skinning, and animation. Blender has been slowly growing in popularity since the free version was released in 2003. Currently, many game engines and 3D websites are directly supporting Blender's file format. We use .blend files throughout our 3D modeling and animation process. https://docs.blender.org/manual/en/dev/data_system/

elements of the animal have been used to bring the portions to a consistent scale, the poses of the extremities are aligned with one another. Rather than arbitrarily adjusting the points of the mesh, a temporary motion rig (used to allow the model to move) is placed within each portion so that limbs can be rotated into place. This procedure helps reduce the risk of distortions, thus preserving the proportions and anatomical structure of the animal modeled. Finally, the aligned mesh portions can be manually stitched together or used as a template onto which a mesh can be drawn.

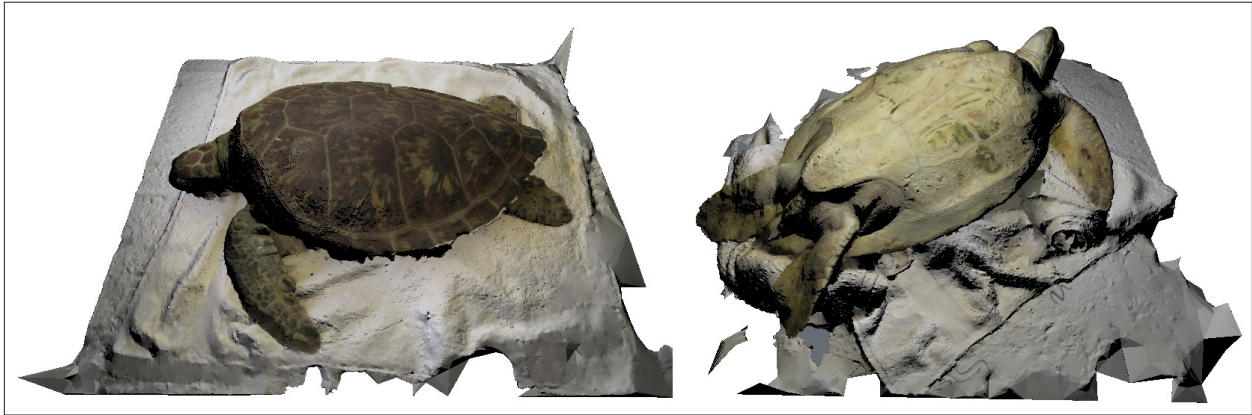


Fig. 4-3. The dorsal (left) and ventral (right) sides of a green sea turtle are captured in two separate scans using our multi-camera setup. The scans are processed separately within the Reality Capture (photogrammetry software), then brought into the Blender animation software for merging and cleanup.

Reducing the Polygon Count of 3D Mesh

The 3D mesh reconstructions from our photogrammetry processing have a high number of polygons, which should ideally be reduced to reduce processing time. The models exported from our photogrammetry software are in the OBJ file format, contain 3 to 6 million triangle polygons, and include fine surface details mixed with mesh artifacts typically caused by surface reflections in the source photographs (figure 4-4). Using our current camera type and configuration, we have found that meshes exported in excess of 6 million polygons add no useful details, but rather result in more unusable scan noise. Though many of today's computers can display these high-density 3D models, the processing performance of different systems varies widely.

Traditional Method: Simplifying Mesh Using Edge Collapsing

Processes traditionally used for reducing the number of polygons in a reconstructed mesh involve combining / collapsing the existing polygon edges (Yirci 2008). Many of these simplification tools have automated processes that will decimate the mesh to a specified reduction percentage.

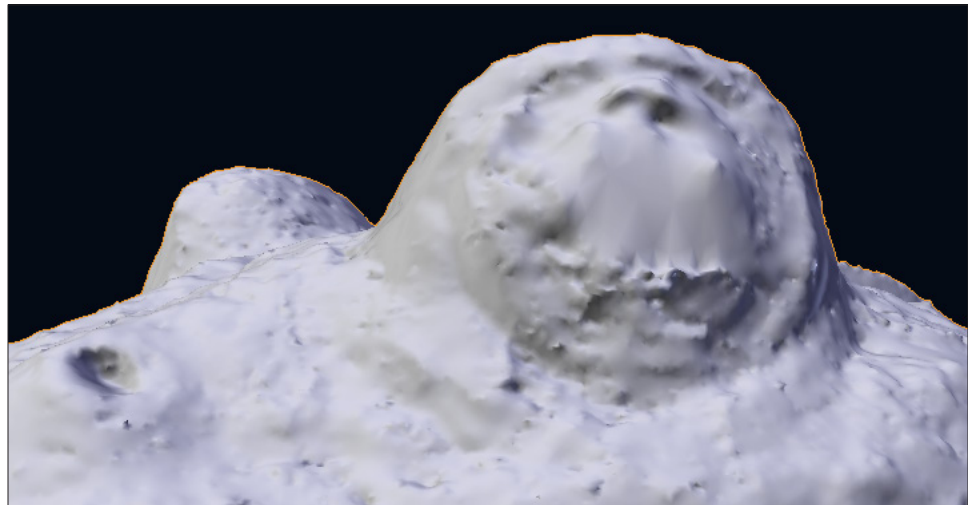


Fig. 4-4. This 3.2 million polygon mesh reconstruction of a pixie frog's face shows the eyes and a nostril. Surface reflections on the skin and eyeball have caused some noise artifacts that appear as sharp bumps, cavities, or wrinkles on the surface.

The decimated mesh is less dense than the original photogrammetry reconstruction (figure 4-5). Though the number of polygons in the decimated mesh is more manageable, the irregular, triangulated structure of the mesh does not produce the best results when used with mesh deformers common in 3D animation (e.g., skinning, lattices). Instead of using this approach, we have adopted an alternative method.

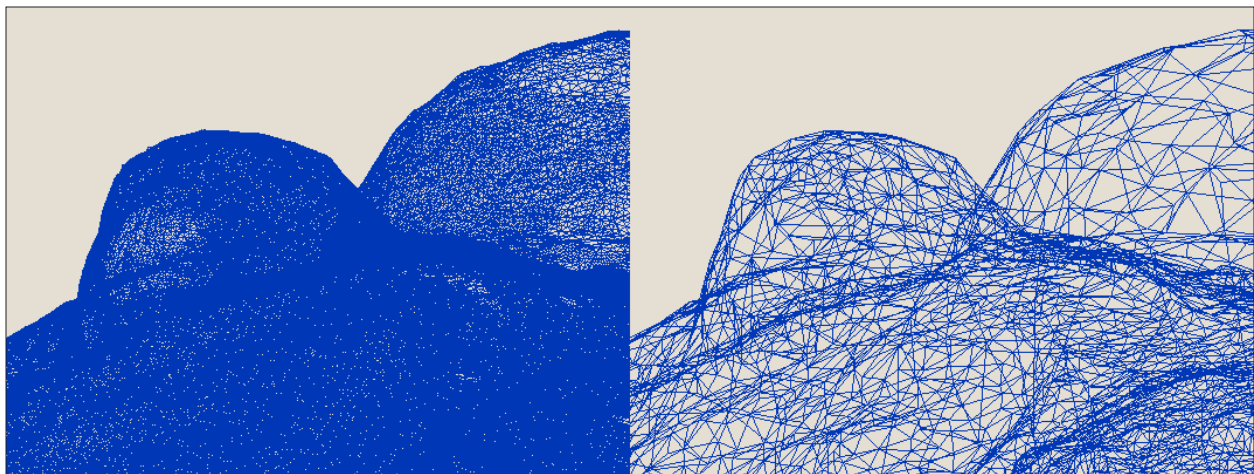


Fig. 4-5. The 3.2 million polygon mesh of the frog shown in figure 4-4 would be a challenge to work with on most computer systems (left). Using Blender's Decimate modifier, we reduced the mesh to 1/50th of its original polygon count, resulting in a workable number of 64,000 polygon triangles, which can be viewed or edited on even the most modest of computer setups.

Our Preferred Method: Simplifying Mesh While Optimizing the Mesh for Deformation

Converting the geometry and textures to an animation-friendly format is a task often left to “3D artists,” as it typically involves a manual process of 3D mesh reconstruction commonly referred to as *retopologizing*. We have two primary goals when simplifying the dense polygon mesh in preparation for animation:

1. Reduce the polygon count, enabling better 3D performance of the model in real time while maintaining the accuracy and high-frequency detail of the original scan (via “normal map” texture files).
2. Structure the polygon edges in a way that allows for better deformation when the mesh is bound to a skeleton for animation. For instance, in figure 4–6, the benefits of using quad polygons (right) over triangular polygons (left) are clear.

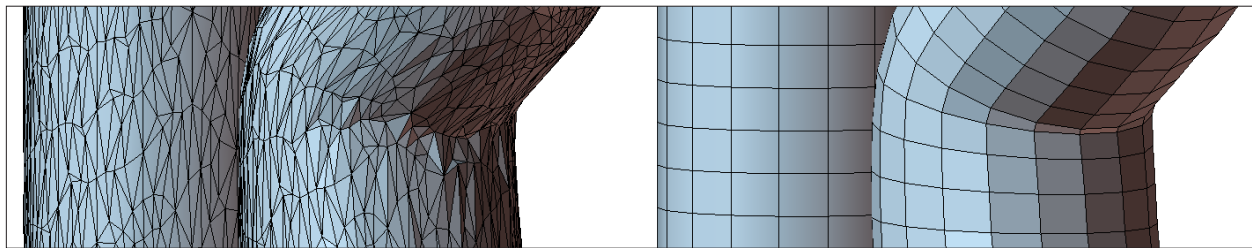


Fig. 4–6. A randomly triangulated mesh (left) is not based on the function of the underlying anatomy and therefore produces undesirable wrinkles and bumps in the mesh. A retopologized quad mesh (right) follows the flow of the limbs, with edge loops lining up with the creases in deformation, thus producing fewer undesirable distortions.

A reduced mesh can contain non-manifold geometry or intersecting polygons that occur when the decimate processes attempt to reduce natural high-frequency detail or surface noise generated in the photogrammetry processing.

A mesh that has been retopologized to include *primarily* quad polygons can be structured so that the polygon “edge flow” aligns with the direction of deformation (figure 4–7). These quad meshes are common in animated 3D models used in film, television, and video games (Raitt and Minter 2000).

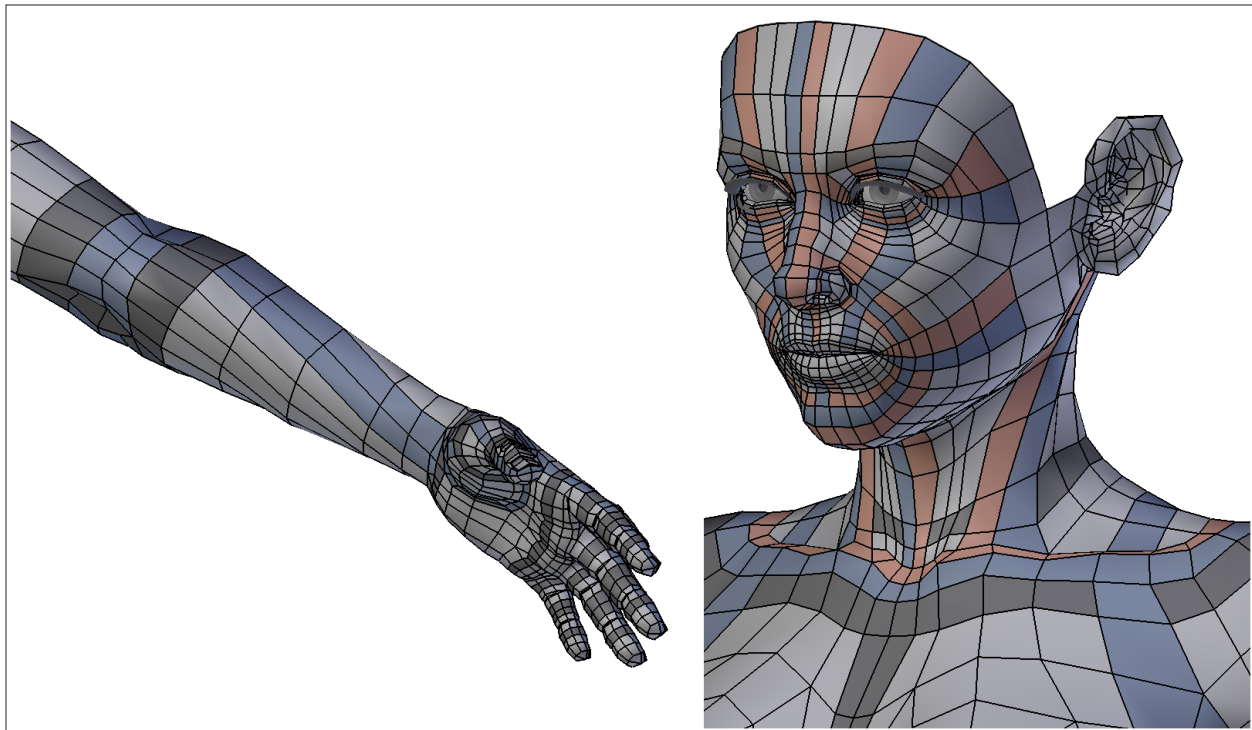


Fig. 4-7. This quad mesh of 10,000 polygons shows an edge flow that resembles the underlying muscle structure of a human. The arm (left) shows a slight twisting of the polygons as they move down over the forearm. The blue strip on the forearm resembles the flow of the brachioradialis muscle, which allows the forearm to twist inward and outward. The face topology (right) resembles the muscles that raise the eyebrows, surround the eyes for squinting, and circle the mouth for retracting for a snarl or pulling at the corners of the mouth for a smile. Model by Angela Guenette for the Blenderella modeling class,³ used with permission and licensed via CC BY 3.0.^{4,5}

Retopologizing is traditionally a manual process, though software tools are now available to assist this process by allowing a user to change the mesh structure by drawing curves on the surface. The algorithm guides the reconstruction of the mesh edges into a new quad mesh topology that follows these curves. Commercial 3D sculpting software packages that include automatic retopologizing include *ZBrush* by Pixologic, *3D Coat* by Pilgway, Autodesk's *Mudbox*, and The Foundry's *Modo*.

We use Instant Meshes,⁶ an open-source software solution, to begin the process of retopologizing our high-density meshes. With this software, we can create guide curves and export a reduced mesh consisting of mostly quad polygons with an edge flow that matches our guides. These guides not only simplify some of the cleanup process, but also give us quick edge flow results that align with the shape of the scanned animal (figure 4-8).

³ <https://ponderstudios.com/2017/09/07/advanced-character-modeling-workflow/>

⁴ <https://creativecommons.org/licenses/by/3.0/>

⁵ <https://creativecommons.org/licenses/by/3.0/>

⁶ <https://github.com/wjakob/instant-meshes>

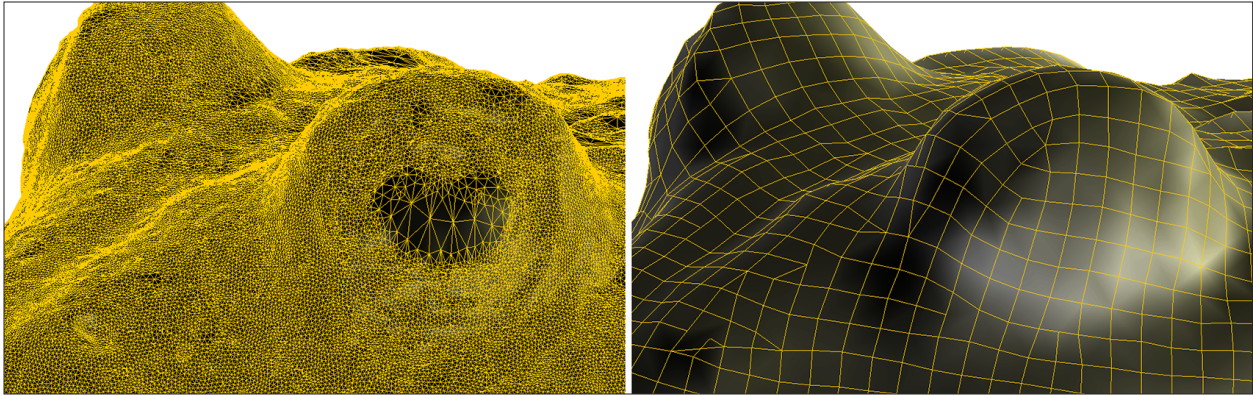


Fig. 4-8. In this comparison of the topology of the top of the frog's head, we can see that the original dense mesh of 3.2 million polygons (left) has been retopologized using Instant Meshes into an isotropic quad mesh of 60,000 polygons with an edge flow that preserves the silhouette (right).

In addition to the reduction of polygons and better edge layout for skeletal animation,⁷ the resulting edge flow simplifies the process for re-creating the UV maps for the textures.

Reconstructing Mesh Normals and UV Coordinates

It is important to accurately reconstruct mesh normal and UV coordinates as these elements dictate the overall color map of a 3D model, as well as ensure that the model can be effectively used in a wide variety of platforms.

UVs

The term *UVs* refers to UV maps or texture coordinates. The letters U and V denote the axes of a plane, since X, Y, and Z are used for the coordinates in the 3D space. For a 2D image texture to be applied to a 3D object, each vertex of a 3D mesh contains a pair of numbers (Us and Vs) that represent the location at which that particular vertex would plot on a scale of 0 to 1 on a square plane. The Us and Vs refer to the height and width coordinates. A UV map is visualized as a wireframe cage flattened into something that resembles a 2D clothing pattern or animal pelt. Marked “seam” edges enclose these pieces (UV “islands,” as Blender calls them). Many 3D software packages allow the user to create seams on the mesh (the shores to the metaphorical islands) by selecting edges in a 3D viewport and then marking the edges as seams (figure 4-9). Next, running an unwrap function cuts the mesh along its marked seam lines to flatten the mesh into a 2D plane. This function attempts to limit the stretching of the mapping by ensuring that the relative area and general shape of each UV polygon is similar to that of the source polygon on the initial 3D model.

⁷ Wikipedia defines skeletal animation as “a technique in [computer animation](#) in which a [character](#) (or other articulated object) is represented in two parts: a surface representation used to draw the character (called skin or mesh) and a hierarchical set of interconnected bones (called the skeleton or rig) used to animate (pose and keyframe) the mesh.”

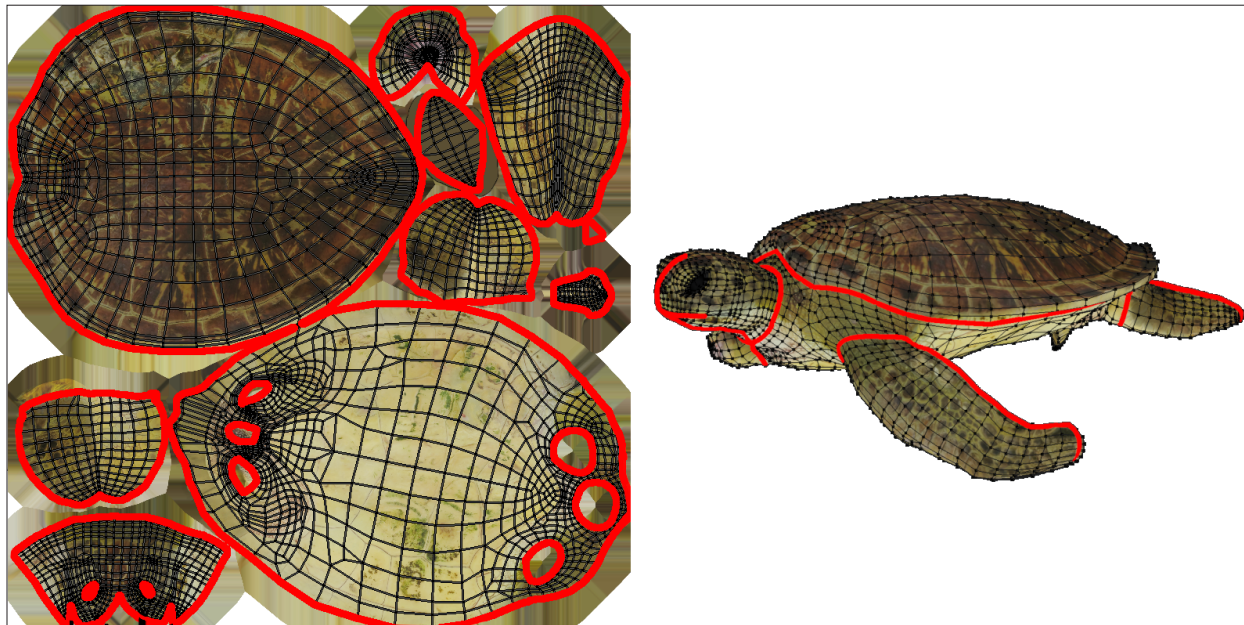


Fig. 4-9. UV texture coordinates on top of the color texture image with seams outlined in red (left) and 3D turtle model with edges marked as seams for automatic layout of UVs using Blender's UV unwrap function (right).

Most photogrammetry software has the capability to automatically generate the UVs for the resulting 3D mesh scan. However, these auto-generated seams can result in a map with fragmented texture files (see figure 4-10, left image).

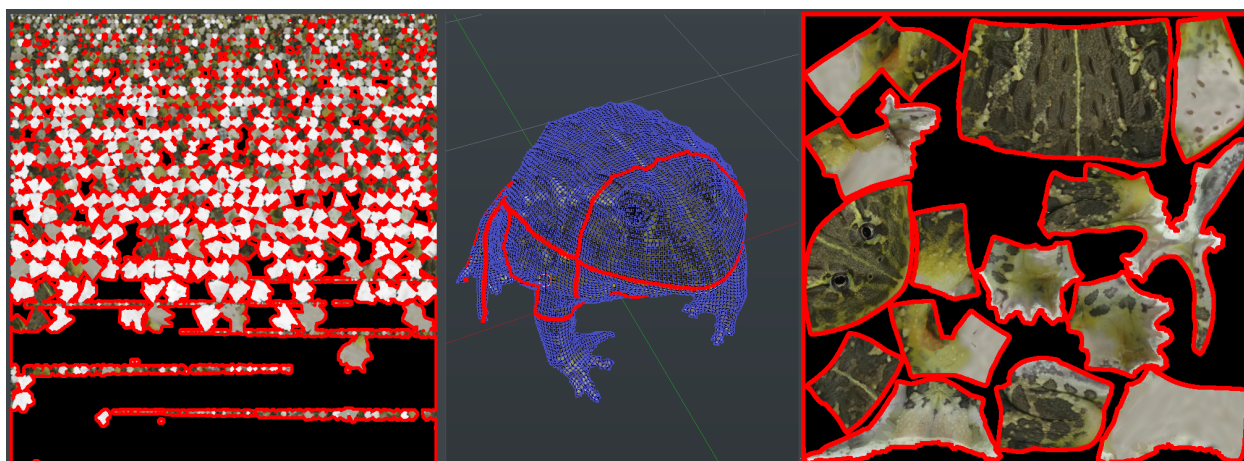


Fig. 4-10. The auto-generated UV maps on the scanned mesh are often quite fragmented, and while useful initially, they can be very difficult to work with when texture painting or manipulating the texture file using an external image-editing software (left). Seams are created on the retopologized frog model by selecting edges and marking them (middle). The color texture information can then be transferred from the original mesh scan to the new retopologized mesh via a baking process, which results in a texture file that is much easier to work with in the texture-editing process, though it may result in some unused texture space (right).

As the retopologization creates a new mesh, it is necessary to create a new UV map. A newer, cleaner edge flow will allow for seams to be easily marked using edge loop selection shortcuts in the animation software (figure 4-11). The resulting UV will usually contain dozens of UV islands, instead of the hundreds or thousands of islands that result from the original photogrammetry scan.

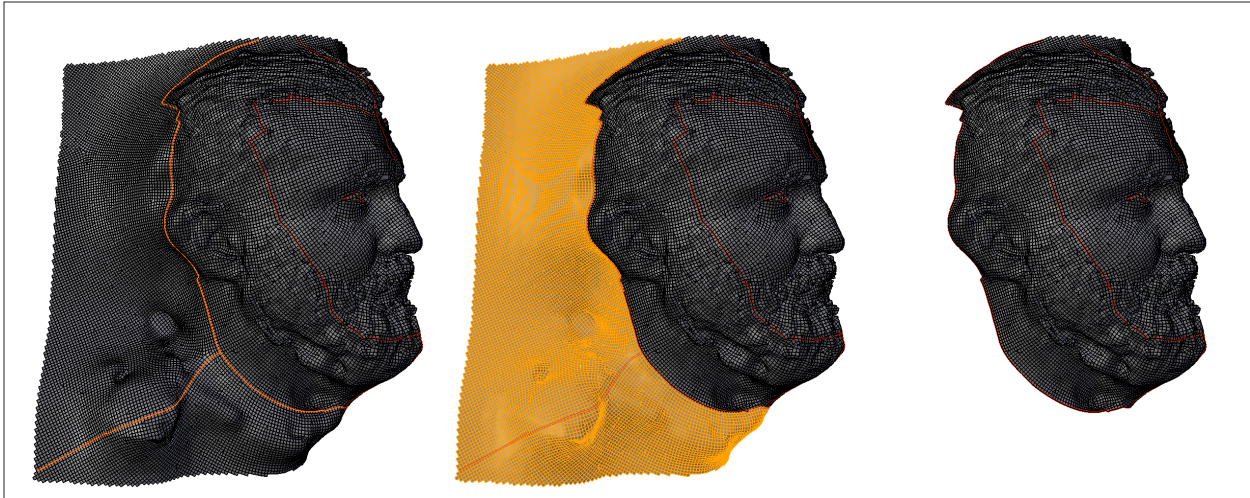


Fig. 4-11. The cleaner edge flow that can result from retopologization can also be used to cleanly trim unnecessary geometry from the scan. These split edges now create a boundary that makes it possible to select points on the mesh section to be trimmed, and then the “Select Linked” function will grow the selection until it hits the split edge boundary (middle). The selected geometry can now be deleted, resulting in a trimmed mesh with a less jagged silhouette (right).

Sometimes the new UV islands, if not organized efficiently, can result in some large gaps between the islands; these gaps represent unused texture space. Therefore, it is important to compare the original textured photogrammetry scan with the newly textured retopologized mesh to see if there is any loss in resolution or texel density⁸ (i.e., number of pixels per square meter in real life).

Normals

When describing a 3D mesh, normals are often used to describe the facing direction of the polygon vertice, edge, or face. A *normal*

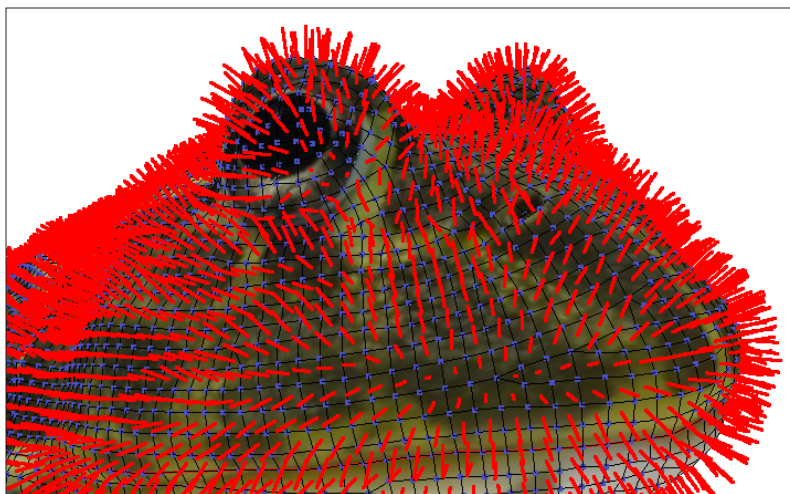


Fig. 4-12. The face normals (red) show a vector that is perpendicular to each face of the retopologized mesh.

is a vector that is typically perpendicular to each polygon face (figure 4-12). It is important to have normals facing in a consistent direction (preferably pointing outward), and they can be adjusted manually or automatically. Blender has some features that allow the normals to be automatically recalculated, smoothed, or flipped. Normals should be adjusted before the baking of the “normal map” in the next section (conversion of high-frequency mesh detail into a 2D image texture).

⁸ An infographic on texel density is available at <https://www.artstation.com/artwork/qbOqP>.

Recovering High-Frequency Geometry Details

The mesh retopologization reduces the polygon count and improves the edge flow, but the reduction removes the high-frequency details of the mesh. There are a few different ways to recover this detail. The following method brings back the fine details, but applies them to our more deformation-friendly retopologized mesh.

Multiresolution and Shrinkwrap Modifiers to Recapture High-Frequency Details

Like other 3D animation software packages (e.g., 3D Studio Max), the Blender 3D animation software package contains modifiers that allow us to alter our geometry without losing the original input mesh data. In most cases, these modifiers can be permanently applied to the mesh or cumulatively stacked, maintaining the original base mesh information and modification history so that we can track our progress. We use two modifiers for transferring the high-frequency scan data into our retopologized mesh. The Multiresolution⁹ modifier subdivides our mesh into levels, increasing the polygon count exponentially with each subdivision. This modifier can also store mesh edits that have been applied at the various subdivision levels. The Shrinkwrap¹⁰ modifier adjusts the affected mesh by morphing the surface to match that of another target mesh.

To retrieve the high-frequency geometry from our original scan, we use the Multiresolution modifier to first increase the polygon count of our retopologized mesh. The Multiresolution modifier adds subdivision levels where we can store the high-frequency details from our original scan, and it also gives us the ability to use Blender's geometry sculpting tools to smooth out some of the high-frequency surface noise or to add details back into the mesh that were lost during the photogrammetry processing. Pressing the Subdivide button within this modifier adds new subdivision levels; we can then use the Preview or Sculpt slider values to set the number of subdivision levels that we need (figure 4-13).

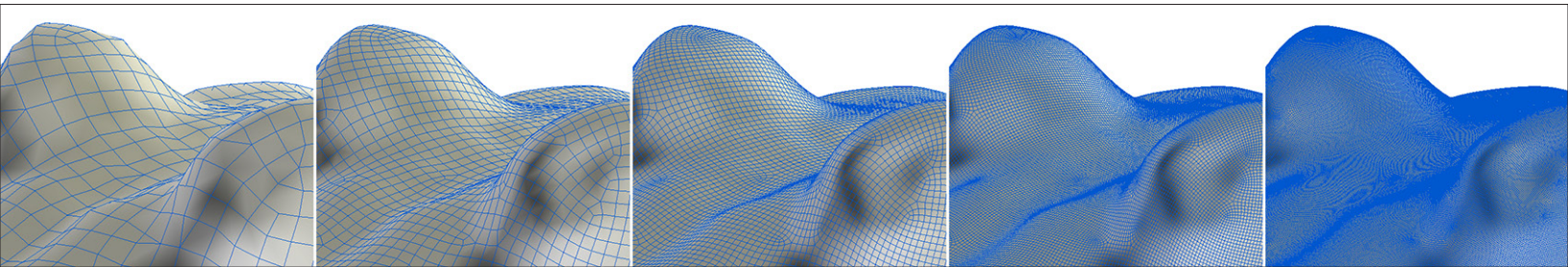


Fig. 4-13. The Multiresolution modifier in Blender receives an input mesh (far left) and is able to add subdivision levels, increasing the polygon count in steps to match or exceed that of our original 3.2 million polygon scan, eventually providing enough point data to capture the high resolution data from the original photogrammetry scan.

⁹ <https://docs.blender.org/manual/en/dev/modeling/modifiers/generate/multiresolution.html>

¹⁰ <https://docs.blender.org/manual/en/dev/modeling/modifiers/deform/shrinkwrap.html>

With the polygon count of our retopologized mesh increased, we can now use Blender's Shrinkwrap modifier to match the original photogrammetry mesh. As the name implies, it shrink-wraps the modified mesh by pushing out or pulling in the points of our now subdivided retopologized mesh to match that of the original scanned mesh (figure 4-14). The Shrinkwrap modifier has an option to automatically perform this point-to-surface matching, using projections of the surface normals in the positive or negative directions in the Project mode. The new surface position information from the Shrinkwrap modifier can then be permanently applied to, and stored in, the Multiresolution modifier at a chosen subdivision level by clicking the Apply button for the Shrinkwrap modifier in the stack. The Apply button will make the Shrinkwrap modifier's effects permanent by storing them within the Multiresolution modifier (the next modifier in the stack). Because this change is made permanent, the Shrinkwrap modifier is no longer needed and is automatically removed. The Multiresolution modifier stores these modifications within the subdivision level specified in the Preview numerical slider.

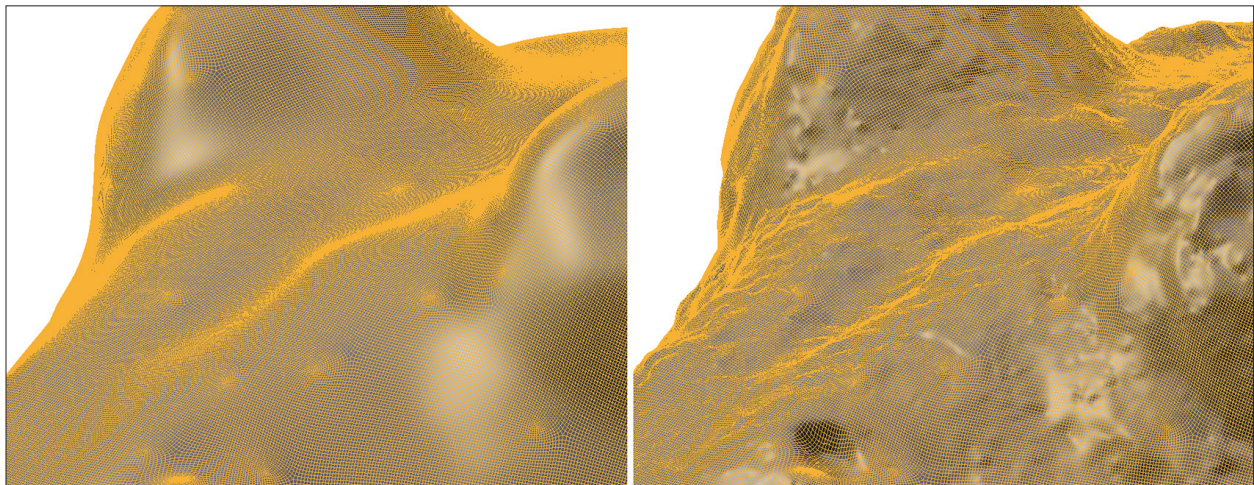


Fig. 4-14. The retopologized mesh with a Multiresolution modifier added at only four subdivision levels (left). While previewing four subdivision levels, a Shrinkwrap modifier is also added to the mesh, using the original 3.2 million polygon photogrammetry mesh as a target (right).

With the high-frequency details applied to the retopologized mesh via the Multiresolution modifier, Blender's sculpting tools can now be used. Unless the Multiresolution modifier's Apply Base button is pressed, the modifier will store the sculpting information and keep the base retopologized mesh unaltered. Though the information in this modifier can be accessed only from the Blender animation software, we can export the retopologized mesh with all the captured high-frequency details and sculpted updates at whatever subdivision level we choose, depending on the level of detail required for our specific needs.

Normal Maps: Storing High-Frequency Surface Detail Via Image Texture File(s)

If a lower polygon count is required, a normal map is commonly used to “fake” high-resolution surface detail. The normal map is a texture applied to the surface of the mesh that interacts with the lighting to create the appearance of high-resolution detail without the need for a high polygon count. This is significant for reducing the file size of the 3D asset and improves performance when the model is animated. In most cases, the differences between actual geometry and normal-mapped details are imperceptible to the average user.

The normal map works in combination with the mesh normals (direction in which each polygon face faces) in order to accurately calculate the way light interacts with the surface (figure 4–15). Therefore, if the mesh changes, the normal directions may change, and noticeable problems develop in the way in which light interacts with the normal-mapped surface. When dealing with organic meshes, the development of visible (hard) polygon edges is the most common problem.

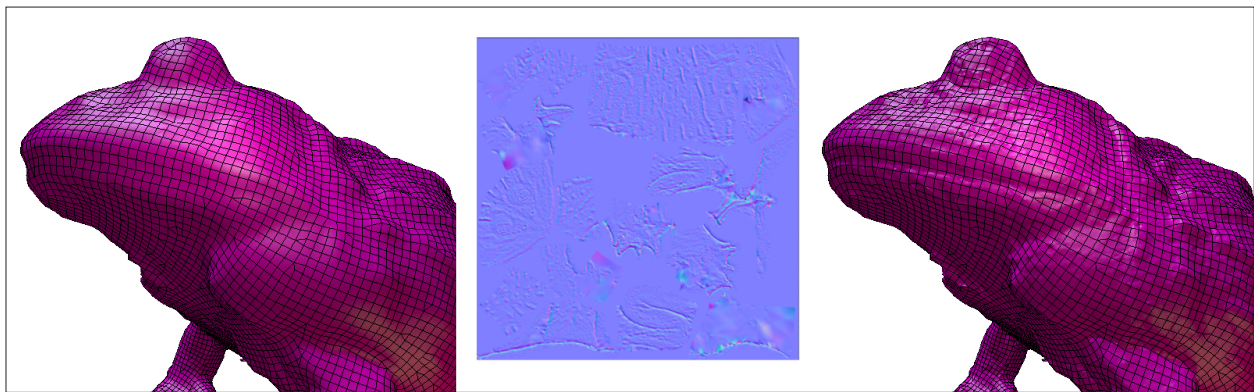


Fig. 4-15. The retopologized mesh (left) has a normal map image file (center) applied in order to change the way that light affects the surface, which creates the perception of high frequency polygon detail for users without increasing the total number of polygons (right).

The creation of a normal map involves two mesh objects: a source mesh that contains the high-frequency mesh details, and a lower polygon target mesh that will receive the normal map with the high-frequency details (figure 4–16). For this task, we work within a Blender file that contains a single mesh object that has the high- and low-resolution details required to make a normal map stored in its Multiresolution modifier. To create source and target objects, we duplicate the mesh object. We now remove the Multiresolution modifier from one of these objects, but not before determining the polygon density that best fits our destination platform (e.g., games, film, web). Testing will be necessary to determine the best performance for a particular platform, but generally a real-time graphics engine requires a lower number of polygons, while video content functions can handle a higher number of polygons.

On our lower resolution target mesh object, we use the Preview slider on the Multiresolution modifier to choose a subdivision level

that works for our needs and make this permanent by clicking the Apply button. To receive the normal map information, we create a new texture for the target mesh object. The Bake¹¹ options are found in the Render Properties panel. A normal map is baked by selecting both source and target meshes, setting the Bake Mode to Normals, and clicking the Bake button. Since Blender currently has more than one render engine, there are two methods to bake these textures. In Blender's current state, we have found that the Blender Internal render engine is faster than Blender's Cycles render engine. These normal maps are saved into a PNG image file format and applied to the low-resolution target mesh in the object's materials inside of Blender, or exported for use in other 3D applications.

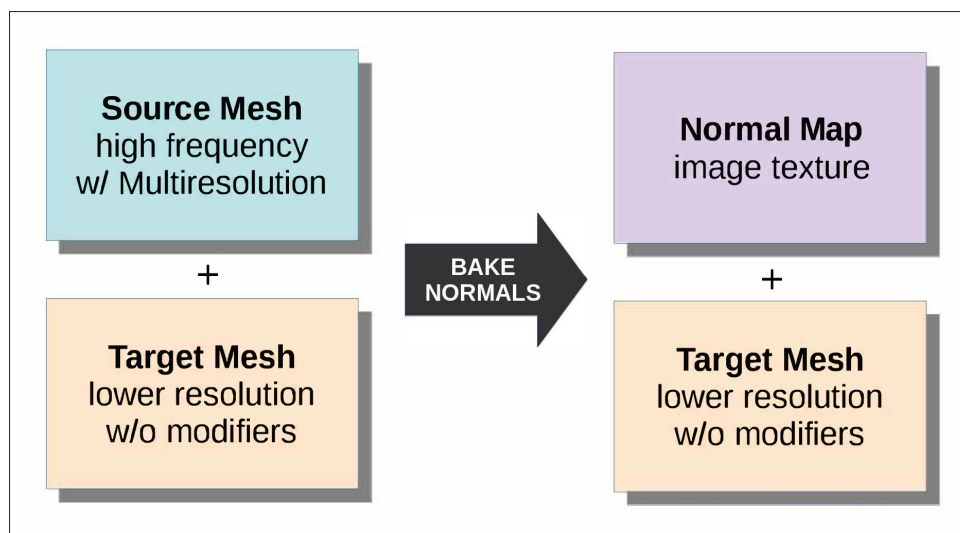


Fig. 4-16. The high-frequency source mesh and lower resolution target mesh are baked to create a normal map texture that is applied to the lower resolution mesh to capture the high-frequency details without the overhead typically needed for meshes with high polygon counts.

Rigging and Animating the Retopologized Mesh

The final steps for bringing our model to life involve the application of movement to a 3D rig. Because the details of creature rigging and animation are software specific, we will cover only basic theory, while pointing out considerations that apply to animal scans, particularly those that require the merger of multiple meshes.

Creation of the Skeletal Rig

Animation of a polygon mesh requires the creation of a skeletal rig. These rigs are composed of a hierarchy of bones (also known as *joints* in Autodesk's Maya) that give the polygon mesh a site to attach itself. When the joints are animated, each vertice of the mesh follows the influencing bone(s) based on a weight value, causing the mesh to deform. For example, a point that is weighted 100 percent to a single bone will follow the influencing bone by maintaining its relative

¹¹ Texture baking in Blender: https://docs.blender.org/manual/en/dev/render/blender_render/bake.html

positioning to the influence (i.e., the force applied to that part of the skeleton), while a vertex that has its weight split between two bones (50 percent to each) will maintain a position halfway between its relative positioning to each of the two influencing bones.

The process of attaching the mesh to the skeleton is commonly referred to as “skinning.” Most 3D animation software has a default or automatic bind process that can be useful for quickly binding the mesh to a skeleton with minimal manual weight “painting” work required. The automatic process looks for bones that are closest to each vertex and automatically assigns influencing weight values to each vertex. To customize the results of the automatic binding algorithms, extra bones can be added to the hierarchy (figure 4–17). Though a skeletal rig can appear similar to a biological skeleton, it is typically different; the rig’s primary goal is to produce the most accurate deformation results on the mesh geometry during animated motion.

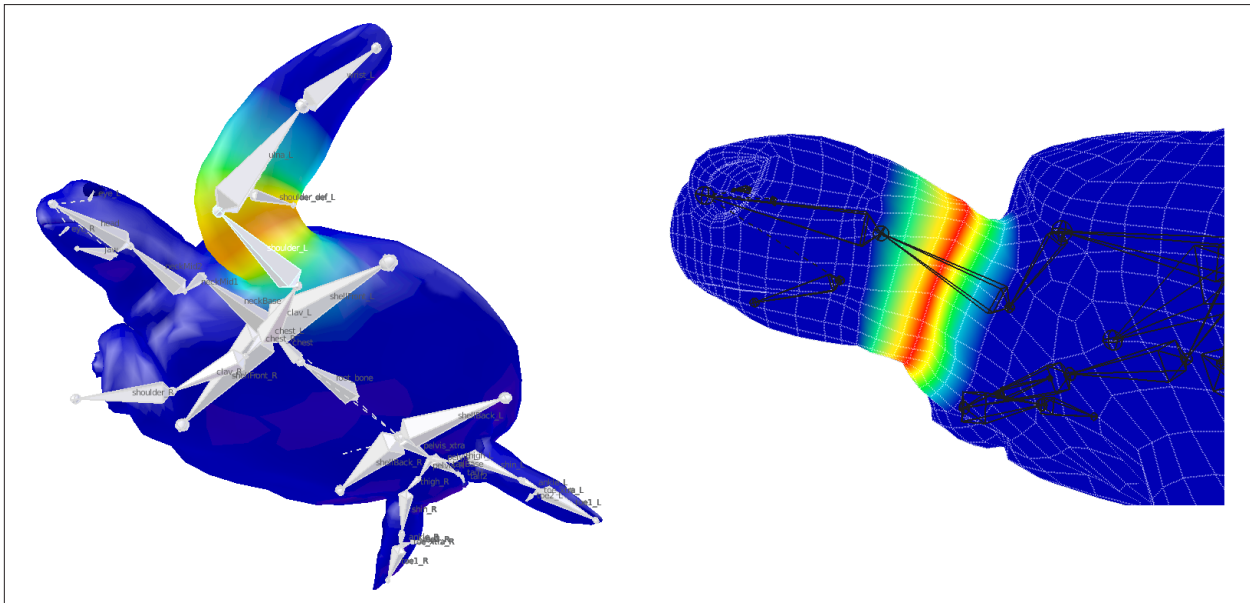


Fig. 4-17. Based on anatomical study and an understanding of mesh deformation via a skeleton (“Armature” as Blender calls it), bones are placed inside of a turtle mesh. The vertices of the mesh are bound to the skeleton, with each bone’s influence over the mesh displayed as a heat map. Additional bones are added inside the shell in order to prevent the turtle’s flippers from affecting the shell, keeping the shell rigid (left). The retopologized edge flow greatly simplifies the adjustment of these influence “weights,” as demonstrated by the edge rings influenced by the turtle’s neck bone (right).

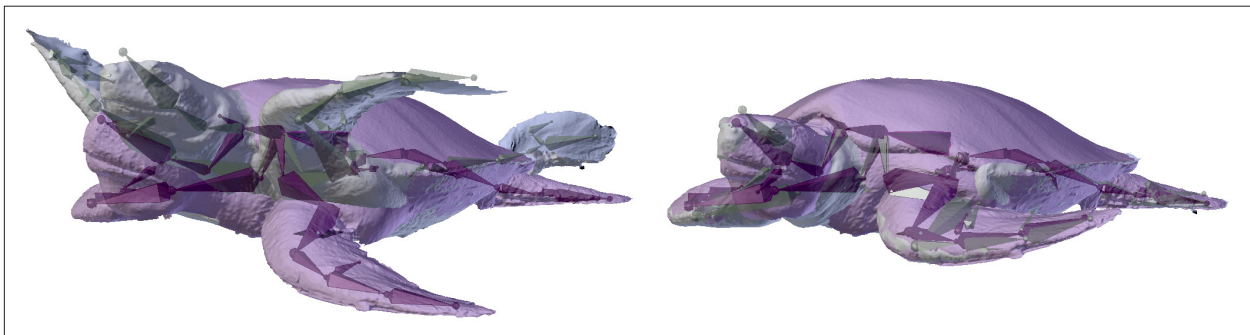


Fig. 4-18. Two scans capture the turtle in two halves, each in a unique pose (left). The purple mesh is displayed bound to a purple skeleton, while the gray mesh is bound to the gray skeleton via an automatic skinning process and aligned by manipulating the skeletons, which deform the two meshes (right).

In cases where multiple scans must be merged into a single model, a skeleton can be used to pose both halves of the specimen while preserving the proportions of the animal (figure 4–18). Instead of arbitrarily adjusting the points of the mesh manually, the halves of the mesh are posed using the skeleton to meet at an in-between pose. The alignment of the skeleton and mesh surfaces assists in the validation of the skeleton placement and mesh skinning.

Animation

Working with video of animal movements, we typically use the rigged/animatable model to create a repeating/cycling locomotion (e.g., Lasseter 1987; Kerlow, 2009). For a land creature, this involves a walk cycle. For most of our marine animals, we create swim cycle animations. Though our goal is to create accurate motions, animal movement is dynamic and not easily captured in a single animation. We are currently working on processes to more accurately apply animations to our models, increasing the level of detail and decreasing the time needed to create these animations. When working with animals of a similar structure, we aim to repurpose and refine previously created animations and workflows.

Conclusion

In this paper, we have provided an overview of the technical workflow of rendering live 3D animals using photogrammetry. Our workflow has value as it enables 3D artists, scientists, and educators to recreate complex 3D geometries in a scientifically accurate manner. The value of the full-color, accurate, and fully rigged 3D animal models is that they represent valuable starting points for many scientific investigations, as well as educational use for demonstrating biodiversity and animal form and function.

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Chapter 5

What Happens When You Share 3D Models Online (In 3D)?

Thomas Flynn

Abstract

As 3D content capture and production become increasingly accessible and affordable, more cultural institutions are contemplating the use of this format alongside established media such as 2D photography. This chapter addresses the possibilities and value of publishing cultural heritage-related 3D data online, in a real-time interactive format. Using existing projects and initiatives published on the Sketchfab platform by way of example, the chapter provides an overview of 3D within the cultural heritage sector.

Introduction

As the cultural heritage lead at Sketchfab, much of my work involves promoting the use of 3D within the cultural sector, including libraries, archives, and museums. This includes introducing organizations to the concept of 3D digitization if they do not already have a program in place and extolling the benefits of putting 3D models online if they are already creating digital 3D files.

This chapter will draw heavily on my personal experience advising cultural heritage professionals with regard to 3D and producing 3D content for national institutions; I will offer examples of how individuals and institutions within the Sketchfab community are using 3D to achieve their goals. While I heartily recommend a trial of Sketchfab to display 3D, regardless of which browser-based 3D viewer is used,¹ these examples highlight the value of dynamic, online interaction with 3D content.

A broad theme to keep in mind in discussing the creation and

¹ Other open-source and commercial viewers are mentioned in the following pages.

use of digital 3D models of cultural objects and spaces—especially online—is one of experimentation and, to a certain degree, skepticism. Since I began working in the realm of 3D for cultural heritage in 2014, I have seen the boom in 3D production matched with a boom in conferences, think tank activities, and online discussions about various aspects of the technology. At the same time, there is still some skepticism in a variety of fields about the value of 3D as more than just a fad or experimental technique.

Defining 3D

The term *3D* is often understood to describe various non-interactive and interactive experiences, including 2D renders (i.e., images, video) of 3D data, animated turntable presentations, 360-degree panoramas, all the way to complete virtual or augmented reality experiences.

Even when we say something like *3D data*, there are questions. Are we talking about vector or raster data? Point clouds or meshes? Textured or untextured? Animated or static? Raw or edited data? 3D scanned or computer generated?

With regard to the cultural and historical 3D content on Sketchfab, the vast majority of 3D models are surface 3D models produced via photogrammetry and, to a lesser degree, structured light, laser scanning, and computed tomography. A relatively small portion of the 3D models are born digital (i.e., a “3D representation of an item that may not have a specific real-world counterpart ... created using digital imaging or drafting software rather than scanning” [DeVet et al. 2018]).

The variation in understanding may result in part from personal experience. Somebody who has grown up with interactive games and computer-generated movies may expect the term *3D* to apply to the experience of 3D, whereas somebody who has been trained to use 3D imaging workflows in professional work may generally consider 3D to refer to quantifiable data. Understanding the variations in perceived meanings may help better define the best presentation method for 3D models for a given audience.

Based on my own experience with 3D, I would go so far as to suggest that the term *3D* means real-time interaction, that it indicates we are in control of our experience of the model or data and able to move to a different perspective at will. The ability to manipulate and not just spectate is a simple yet key reflection of how we explore physical objects in the real world, and digital 3D allows this to happen virtually. To experience the full value of true 3D is through dynamic, personal interaction.

Being explicit in our definition can help us avoid confusion as the cultural heritage community establishes metadata standards (e.g., the Community Standards for 3D Data Preservation [CS3DP] Project,² the International Image Interoperability [IIIF] Community

²<http://cs3dp.org>

Group on 3D³) and pursues ongoing digitization projects and collaborations. By considering 3D data separately from 3D experiences and services, we can perhaps build stronger and longer-lasting use cases for 3D in the cultural heritage sector.

Growing Popularity of 3D in the Cultural Heritage Community

With more than 650 museums using Sketchfab to share some of their collections in digital 3D, plus thousands more libraries, scientific organizations, individual researchers, imaging experts, and hobbyist 3D scanners using it, Sketchfab has become a go-to tool for the cultural heritage sector to display and disseminate 3D data online. As of October 23, 2018, there were 74,262 3D models in Sketchfab's Cultural Heritage & History category,⁴ 12,248 of which are downloadable under one of the following Creative Commons licenses:

- **CC BY—Attribution:** Depending on the non-commercial (NC), no derivatives (ND), and share alike (SA) choices, others may share, edit, and use the model, but they must give you credit for the original work.
- **CC BY-NC—NonCommercial:** Others cannot use your model commercially.
- **CC BY-ND—NoDerivatives:** Others may use and share the model, but it cannot be altered.
- **CC BY-SA—ShareAlike:** Depending on the NC choices, others may share, edit, and use the model, but derivative work must be shared under the same license. (Sketchfab 2018a)

Combined, the top ten most viewed 3D models in the category have been viewed more than 4,123,200 times.

The popularity of Sketchfab within the cultural sector can be attributed largely to the fact that it is a free,⁵ easy-to-use service with web browser and embed support. By supporting 3D annotations, audio, and animations, plus making it possible to view any uploaded model on the web in virtual reality (VR) and augmented reality (AR), the free Sketchfab app gives cultural organizations all they need to tell their stories using the objects and spaces in their care through 3D.

It can be inferred from the trending data in figure 5–1 that the annotation functionality—the ability to add a clickable hotspot to a particular part of a 3D model—first piqued cultural organizations' interest in the Sketchfab platform. When clicked, the hotspot displays a text or image pop-up and transports the 3D viewer perspective to a user-defined angle, zoom, and pan (figure 5–2). This

³ <https://iiif.io/community/groups/3d/#about>

⁴ <https://sketchfab.com/models/categories/cultural-heritage-history>

⁵ Anyone can join Sketchfab on the free Basic tier (<https://sketchfab.com/plans>); Sketchfab offers free Pro tier subscriptions and hosting to all cultural heritage organizations (<https://sketchfab.com/museums>).

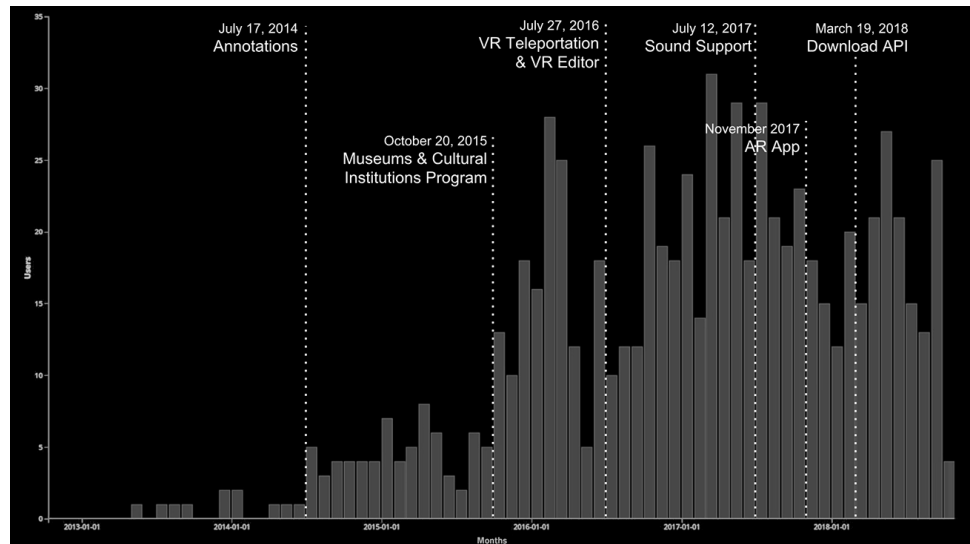


Fig. 5-1. Monthly sign-ups to the Museum segment on Sketchfab, 2013–2018

feature enables the creation of virtual tours around a 3D model, with contextual and other information linked directly to 3D navigation. It may also suggest that clever 3D technology must be underpinned by a relevant use case that truly adds value in a given application. What use is a 3D model on its own? Only when the model is presented with contextual information that is strictly linked to the 3D nature of the media does it attract users from the cultural sector.

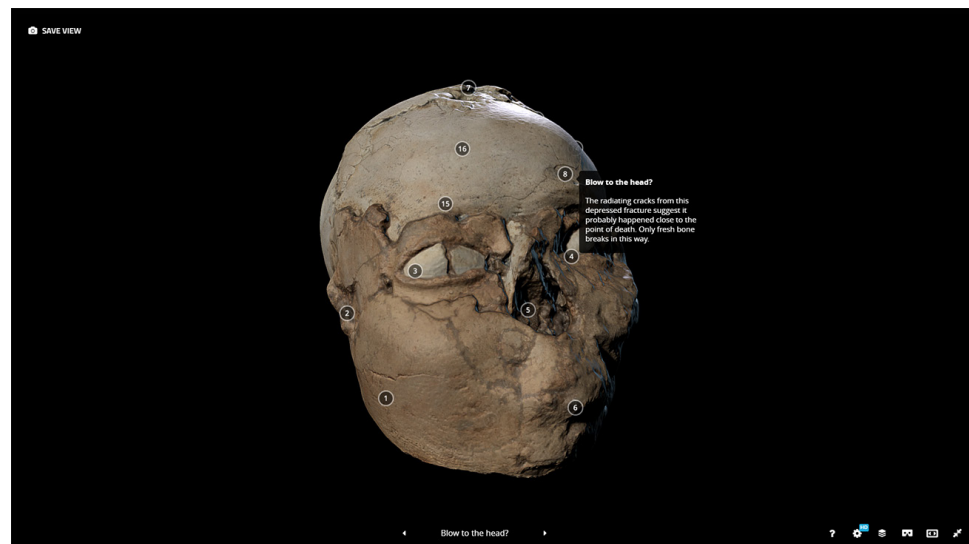


Fig. 5-2. The Jericho Skull—3D model by the British Museum on Sketchfab⁶ showing an active annotation

The ability to add annotations makes a 3D model more than the sum of its data; it creates a self-contained educational artifact, which is sometimes the main reason that organizations use Sketchfab to

⁶ <https://skfb.ly/RGHD>

share 3D content online. For example, Jonathan R. Hendricks, director of publications at the Paleontological Research Institution and adjunct associate professor in the Department of Earth and Atmospheric Sciences at Cornell University, explains the significance of the Digital Atlas of Ancient Life program:

The next step of our project is to annotate the existing models and incorporate them into both the textbook and into planned Virtual Teaching Collections, which will allow students access to organized, curated collections of virtual fossils when the real things are not available. (Jonathan R. Hendricks, personal correspondence, September 20, 2018)

The second uptick in museum sign-ups in late 2015 can be attributed to the launch of Sketchfab's cultural heritage program, which offers free PRO tier subscriptions for all museums and cultural institutions. This offer means that these organizations can use Sketchfab for free with the benefit of larger file uploads, more annotations, private models, and other advantages.

A final increase in sign-ups from museums could also be attributed to the addition of support for webVR (a new web standard for browser-based VR content) in 2016, which allows users to click a button on any online Sketchfab model and jump into a VR mode, viewable on smartphone/cardboard devices as well as on dedicated headsets. Although the long-term value of VR may still be under debate, the addition of webVR to Sketchfab may have interested audiences beyond cultural organizations in the platform. This means that anyone producing 3D content could also become a producer of VR experiences, with no coding required. The same 3D model viewable on a regular screen can now be presented in a way that affords a level of presence (the feeling of visiting a place or space physically) and an impression of scale for the viewer.

Certain functionality has not found widespread use. For example, the ability to add machine-readable tags to plot 3D models on a map⁷ would seem like a very practical feature, but it is seldom used at this point. Indeed, most institutions do not even tag their models on Sketchfab in a consistent manner or take advantage of Sketchfab's APIs⁸ to link 3D model data to their online collection databases to keep them connected and up-to-date.

The increasing need for meaningful ways to display 3D models, in particular 3D models of historical and cultural content, is also confirmed by the existence of several other online 3D viewers alongside the Sketchfab viewer, which was launched in 2012. These include the 3D Hop (2015)⁹ and the Universal Viewer (2012, 3D supported as of 2017).¹⁰ Both offer open-source and cultural heritage-centric 3D viewing experiences for those interested in self-hosting a 3D viewer.

The emergence of dedicated 3D viewers from large commercial

⁷ <https://labs.sketchfab.com/experiments/map/>

⁸ <https://sketchfab.com/developers>

⁹ <http://3dhop.net>

¹⁰ <https://universalviewer.io>

companies, such as Google (Poly, 2017),¹¹ Microsoft (Remix 3D, 2016),¹² and Facebook (3D Posts, 2017)¹³ suggests an even wider audience for all kinds of 3D content.

Audiences for Historical 3D Content

By publicly sharing 3D data online for viewing, download, and reuse, we gain insight into the active audience for such historical 3D models. While researchers often acquire 3D data as part of academic study or for condition documentation during collection assessments, a much larger and more general audience is to be found online for cultural and historical 3D data. This suggestion arises from observations of how users interact with cultural heritage 3D models on Sketchfab and how they share and reuse the same models both online and offline.

Use by Publishing Organizations

The simplest way to put 3D models online and show them to audiences is to use a 3D viewer. Sometimes, as with the Harvard Semitic Museum,¹⁴ Minneapolis Museum of Art,¹⁵ and Château de Versailles,¹⁶ this means adding links or embedding 3D models from respective institutional profile accounts on Sketchfab in official collection pages and exhibition websites. The Royal Academy of Fine Arts (Madrid) and the Museo Archeologico Nazionale di Napoli employed a simple, but elegant, in-gallery solution, displaying web-based 3D models of original artifacts alongside physical plaster casts by using Internet-connected tablets (Marqués 2017).

At other times, a third party uses 3D models published by one or more institutions. Sarah Bond, associate professor in the Classics Department at the University of Iowa, uses 3D models from multiple Sketchfab users in her undergraduate and graduate classes, in place of physical replicas. She explains the relevance for her course:

I have begun to integrate 3D models of inscriptions into my courses ... 3D models and digital humanities approaches to material culture provide ample opportunity for transporting students and the general public to “visit” and then translate inscriptions in situ. While nothing will ever replace doing squeezes and rubbings on-site, these are a close second when used in a browser, on a mobile device, or loaded into a VR viewer. (Bond 2018)

Services like Sketchfab provide a framework for existing web teams to create sophisticated 3D interactive displays. For example,

¹¹ <https://poly.google.com>

¹² <https://www.remix3d.com/discover?section=34b78f58881242e4ab611e4ab5ffaa78>

¹³ <https://developers.facebook.com/docs/sharing/3d-posts>

¹⁴ <https://semiticmuseum.fas.harvard.edu/3d-models>

¹⁵ <https://collections.artsmia.org/art/3520/the-doryphoros-italy>

¹⁶ <http://www.chateauversailles.fr/grands-formats/hameau-de-la-reine>

the Natural History Museum in London used the Sketchfab Viewer API and models hosted on the platform to power a custom in-gallery touch screen for teaching visitors about whale skeletons (Shakiry and Capewell 2017).

Outreach

Placing 3D models online is an extension of the work that museums, archives, and libraries already do to make their location-specific collections accessible to a wider audience. Being able to measure this outreach in some way is even more valuable. Each model on Sketchfab has some publicly visible statistics: the number of times the model has been viewed anywhere online and the number of Likes and comments from members of the Sketchfab community. For example, at the time of this writing, the 3D scan *Granite head of Amenemhat III*¹⁷ published by the British Museum had been viewed more than 111,000 times, had been downloaded 5,900 times, and had garnered 667 Likes and 53 comments since its publication in 2014. It is notable that most of the Likes are from nonacademic users. To put the cultural heritage content on Sketchfab in context with the wider community on the platform, consider that the 650 Sketchfab profiles in the Organization: Museum user segment (the label users give themselves upon signing up to the service) represent less than 1 percent of the more than 2 million registered accounts on the platform. The total number of models in the cultural heritage category (uploaded by both institutions and individuals) accounts for about 2 percent of the total number of 3D models uploaded to Sketchfab.

In addition to the direct views on Sketchfab, top embed referrals to the *Granite head of Amenemhat III* model include creativecommons.org; an educational resource site from Alabama Community College, .cgchannel.com (a computer graphics community site); and open-culture.com (an aggregator for publicly available online educational media). While potentially accessed by academics and museum staff, these sites are unlikely to be referred to as serious research portals. The thousands of viewers that the sites referred to the *Granite head of Amenemhat III* model on Sketchfab suggest a wider viewership for historical 3D data.

Sketchfab is, as far as the author knows, the only community in which it is possible to leave a comment directly related to an individual collection item—rendered in 3D or otherwise—from a museum, library, or archive. By commenting on 3D models, users show an interest beyond simply viewing items in a collection. Comments on the *Granite head of Amenemhat III* model range from simple thanks for the opportunity to view and download the 3D data to critiques of the data quality, questions about digitization workflow, and links to the data in new contexts.

Sketchfab also allows any user to create their own groupings of 3D models from other users in Collections. Such collections have many purposes. They may be simple collections of favorite models,

¹⁷ <https://sketchfab.com/models/64d0b7662b59417986e9d693624de97a>

collections created for specific uses (e.g., for use as artistic reference¹⁸), or collections intended to unite similar collections from different institutions.¹⁹

Interestingly, the Centre des Monuments Nationaux (CMN) in France does not publish 3D models on Sketchfab, but has created collections of 3D scans made by other users of monuments under its care.²⁰ Although some institutions and estates are protective of their collection's intellectual property, CMN wanted to encourage unofficial crowd-sourced digitization efforts. According to Mélanie Vialard, Mission stratégie, prospective et numérique at CMN,

At the moment, we don't have a lot of models nor data because we are just starting to think about it. We would like to know more about how to work with the communities on Sketchfab especially because some of our monuments are already on your platform like the Sainte-Chapelle or the towers of La Rochelle and it would be great to encourage these initiatives. (Mélanie Vialard, personal communication, July 3, 2017)

As 3D digitization tools become more accessible and simpler to use, many are taking up 3D scanning as a hobby and, increasingly, unofficial collections of historical 3D content are being posted online. As is the case with the models curated by CMN, hobbyist or commercial 3D scans fulfill a need where institutional capacity is lacking. There are, however, concerns about the diffusion of inaccurate or incomplete data. Daniel Pletinckx, the Cultural Technology Expert at Visual Dimension bvba suggests that

Qualified objects could get a visible quality stamp. ... The important point here is to connect with the CH [cultural heritage] domain, so that CH experts start to feel connected and responsible for 3D CH resources. This would also stimulate 3D producers to deliver quality as the quality level of some items is questionable. (Daniel Pletinckx, personal communication, September 3, 2018)

On occasion, Sketchfab has received and acted upon valid content take-down requests, as occurred when the Artists Rights Society, representing Henry Moore, requested the removal of several 3D scans of the artist's work from the platform. In this case, the copyright claim is clearer than, for example, when referring to ancient monuments. However, Sketchfab is Digital Millennium Copyright Act (DMCA)-compliant and has a clear process for resolving any infringement claims (Sketchfab 2018b).

In tandem with the decision to accept 3D models generated by the general public is the decision to release 3D data to the general public for download and reuse. Institutions publishing on Sketchfab have the option to enable 3D models to be downloaded under

¹⁸ https://sketchfab.com/demooon/collections/ref_sculpture

¹⁹ <https://sketchfab.com/Tlatollotl/collections/aztec>

²⁰ <https://sketchfab.com/leCMN/collections>

several types of Creative Commons licenses listed earlier. Along with individual researchers and hobbyists, cultural organizations have made more than 10,000 cultural heritage–related 3D models available for download and reuse.

The act of releasing 3D content under a generous license (i.e., permitting modification and reuse) means that cultural content can be reused in ways that are often unexpected. To take just a few examples, the effect of the British Museum releasing many of its 3D scans for download led to a bust of Zeus hosting a YouTube show as a VR avatar (Smith 2018), 3D printed museums in a school classroom (Quince 2014), a hologram of Sir Robert Bruce Cotton (Interactive Studio 2017), and a livestream of a 3D print of a Pacific island god statue (Museotechniki 2016).

In addition to the reuse of 3D scans for simple fun, there are examples of reuse for what might be considered more serious or worthy purposes. Archivist Abira Hussein has incorporated scans released by the British Museum in her work *Healing Through Archives* in multimedia webVR and tactile experiences,²¹ combining the 3D with 2D imagery, 360 panoramas, and audio interviews with the Somali immigrant population in London.

Some institutions, such as Réunion des musées nationaux (RMN)-Grand Palais²² and the Grand Rapids Public Museum, have begun to license 3D data for commercial reuse on the Sketchfab Store.²³ While the commodification of cultural data is not new,²⁴ the monetization of a relatively new medium—and one that can be used to create convincing replicas of cultural objects—has prompted some comment. Ethan Gruber, director of data science at the American Numismatic Society, tweets his response to the sale of cultural 3D content: “Beyond the ethical implications for profiting from heritage acquired (or stolen) via colonialism, you may run aground of the law in various jurisdictions regarding indigenous art” (2018).

The ethical question is bound up with the monetization of museums in general and should be discussed along with such topics as institutional funding streams, paid exhibitions, gift shops, and existing licensing models for other media and replicas. Regarding the legal question, Sketchfab (like most online media platforms) has channels in place for anyone to report rights violations and regularly acts on such reports to remove content and review licenses. Where there is lack of ethical or legal concerns, there is an opportunity for promoting the reuse of 3D content while creating a new revenue stream for cultural organizations.

²¹ <https://sketchfab.com/models/7eb598e50b6f42d5a035eac152b6963e>; <https://twitter.com/nebulousflynn/status/880396725722152960>

²² <https://sketchfab.com/francecollections/store>

²³ <https://sketchfab.com/grpm/store>

²⁴ For example, 2D image licenses from the Museum of Modern Art (<http://www.scalarchives.com/web>) and the Guggenheim Museum (<http://www.artres.com>)

Libraries and 3D

Like museums, many libraries and archives are currently publishing 3D content. The British Library²⁵ (figure 5-3), National Library of Scotland²⁶ (figure 5-4), Cambridge Digital Library,²⁷ and State Library of Queensland²⁸ have all found that they have something in their print and special collections that can be experienced digitally in 3D, and these are just the institutions on Sketchfab.



Fig. 5-3. Jane Austen desk—Open view 2 by The British Library on Sketchfab²⁹



Fig. 5-4. The Stag (stage set 1 of 5) by National Library of Scotland on Sketchfab³⁰

²⁵ <https://sketchfab.com/britishlibrary>

²⁶ <https://sketchfab.com/natlibscot>

²⁷ <https://sketchfab.com/CamDigLib>

²⁸ <https://sketchfab.com/slq>

²⁹ <https://skfb.ly/6xyxZ>

³⁰ <https://skfb.ly/6zF6G>

Publishing content online in 3D opens up new and unique ways for the general public to interact with artifacts. Adi Keinan-Schoonbaert, digital curator (Polonsky Fellow) for the Hebrew Manuscripts Digitisation Project at the British Library, explains in a blog post:

While a museum is more of a usual suspect for these novel technologies, libraries are perhaps less so. They are perceived to hold books, manuscripts, documents, or in short—compilations of two-dimensional text. But nothing physical that a library holds is in fact two-dimensional, and some items kept in libraries may be of unanticipated nature. Libraries have more potential to engage with 3D modelling and printing than one would expect. (Keinan-Schoonbaert 2016)

Although publishing 3D data can be seen as part of libraries' general goal to engage the public with their collections, it should also be considered (where appropriate) as a legitimate, yet underexplored way to fulfill research outreach targets.

3D can augment or add value to 2D media, but the value is limited by the kind of 2D or image artifact in question. Two examples illustrate the point. Figure 5-5 depicts a reuse of *Miniature of Dunstan as a bishop, writing a commentary of the Rule of Saint Benedict, with an inscription "S[an]c[tu]s Dunstanus,"* adapted from the British Library's Catalogue of Illuminated Manuscripts. In this case, the additional material information has been added to the 2D data of the manuscript³¹ to allow a viewer to experience changes in the appearance of gold leaf on the manuscript as it is viewed from different angles. This could be said to be a more authentic experience of the manuscript compared with an on-screen or printed reproduction of the same.



Fig. 5-5. Miniature of Dunstan as a bishop,³² adaptation by Thomas Flynn

³¹ <http://www.bl.uk/catalogues/illuminatedmanuscripts/ILLUMIN.ASP?Size=mid&IllID=52658>

³² <https://skfb.ly/69FL6>

Figure 5–6 illustrates the digital morphing of a map from 1888 with more modern elevation data added and contour lines overlaid. It is possible then to see the difference in the way that a particular area of land has been documented over time and the possible deviation in survey accuracy. Thus, figure 5–5 illustrates an artistic addition to augment the user experience, while figure 5–6 shows how the addition of scientific data can enable the user to view a historic document in a new way.

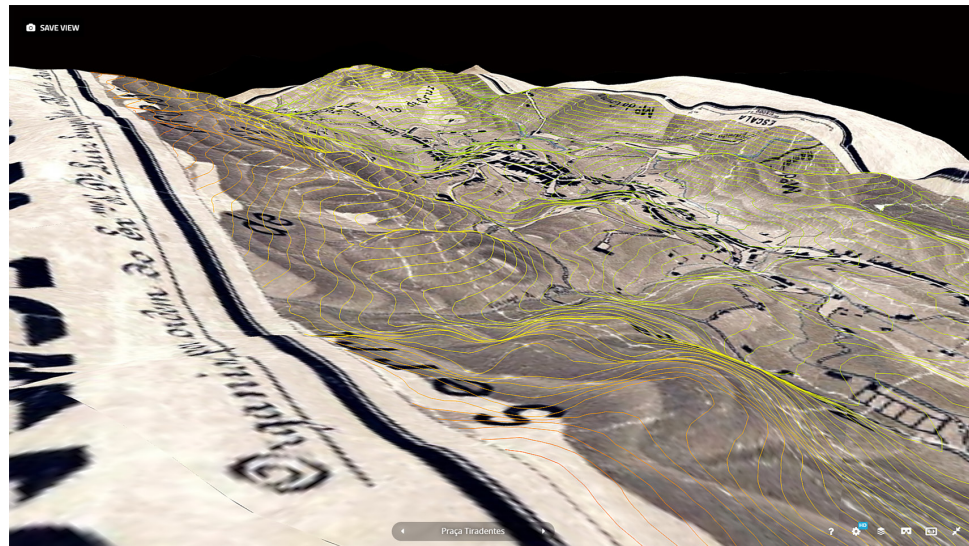


Fig. 5–6. *Planta da Cidade de Ouro Preto - MG - 1888,*³³ adaptation by Rolling Drone Geotecnologias

Conclusion

The potential use cases for 3D data have not yet been entirely explored. By putting 3D models online and making use of existing platforms and functionality, however, we are starting to get a sense of current possibilities and limitations, and to learn what audiences react to and enjoy. The biggest benefit of putting 3D content online may be that it increases the visibility of, and in turn engagement with, 3D data.

As examples of the use and reuse of 3D data are circulated, their value and usefulness will be challenged and contested. While the simple “technical magic” of 3D digitization can impress and excite now, the novelty will wear off and the focus will move to the question of how 3D can help achieve existing institutional goals.

In the last few years, many people who are producing or working with 3D data in the cultural heritage sector have moved from “wow!” to “why?” as they assume a more critical view of the value of 3D capture and display. As individual researchers; 3D community groups; museum, archive, and library staff; and those working in international think tanks take up the task of establishing standards and

³³ <https://skfb.ly/6BIqY>

recording project outcomes, we move toward a time when 3D data will play as ubiquitous a role as imagery, video, and text currently do in our everyday work.

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Chapter 6

Building for Tomorrow: Collaborative Development of Sustainable Infrastructure for Architectural and Design Documentation

Ann Baird Whiteside

Abstract

The use of 2D and 3D computer-aided design (CAD) and building information modeling software is now routine in architecture and design firms and in design education programs. CAD is particularly problematic for the libraries, museums, and archives responsible for the long-term management of design documentation as CAD is highly volatile, relying on proprietary mathematical algorithms to represent shapes and structures, and is packaged in complex, proprietary, and rapidly evolving software products that are expensive, digitally encrypted, and obsolete within years. Architectural museums and archives are facing a rapidly growing need to preserve digital information and are grappling with the need for technological tools, technical expertise in digital preservation, AutoCAD expertise, archival expertise, and repositories that can preserve and disseminate the archived data. Many institutions, especially smaller ones, lack the technical infrastructure and expertise to implement scalable preservation of design records. A community-based approach to building an infrastructure comprising technology, digital preservation strategies, standards, and education for archivists of these collections is critical if we are to preserve digital architectural records at scale. In 2017, the Frances Loeb Library at the Harvard University Graduate School of Design applied for a grant from the Institute of Museum and Library Services, Building for Tomorrow, to support the convening of a national forum under the National Digital Platform funding priority during 2018. The grant supported two priority-setting meetings of engaged stakeholders to frame a national/international collaborative infrastructure to support the long-term preservation of digital design data, specifically in the architecture and design fields.

Background

The preservation and management of architecture and design records have undergone significant change over the last 40 years as architects, engineers, and other designers move to the use of digital technology for design documentation. Archivists and librarians responsible for keeping this documentation have long been concerned about how it will be preserved. In architecture and design projects, many types of digital files are produced during planning and construction, and these files are important for long-term preservation for future renovations/restorations and scholarly research. Computer-aided design (CAD) is particularly problematic for the libraries, museums, and archives responsible for the long-term management of design documentation because CAD is highly volatile, relying on proprietary mathematical algorithms to represent shapes and structures, and packaged in complex, proprietary, and rapidly evolving software products that are expensive, digitally encrypted, and obsolete within a few years. Libraries and archives are increasingly under pressure to acquire these twenty-first century collections to support the next generation of architectural students and historians.

Since the introduction of CAD software in the 1960s, industries that design and develop our built environment have been moving from pencil and paper to computers and digital files. The earliest adopters of the new technology were the aerospace and automotive industries; they were followed enthusiastically by the fields of architecture and design. CAD allows architects to take previously unimaginable risks in their designs and to experiment with new forms and materials without building prototypes or performing expensive structural analyses until much later in the process. U.S. architects such as Frank Gehry led the way, and schools of architecture have been teaching the technical expertise needed to unite architecture, engineering, and software design. This has led to a new generation of architects who leverage technology and has opened new doors for innovation in design.

The use of 2D and 3D CAD and building information modeling (BIM) software is now routine in architecture and design firms. Designers typically use multiple types of CAD software throughout the design process, which is characterized by phases: concept, schematic design, design development, construction, and as-built. For many architects and firms, a building project now comprises tens of thousands of digital files that include 2D drawings; 3D models; video; images; and communications among architects, clients, contractors and other parties, including e-mail messages, contracts, specifications, requests for information, and architects' supplemental instructions. 3D models may consist of multiple interrelated files, requiring deep knowledge to understand, that are usually held by the project architect. In addition to 3D CAD models, there are hundreds or even thousands of detailed 2D-layer drawings produced for particular aspects of a building; there are 3D printed objects, and there are project "outputs"—for example, drawings or sketches of the building. There

are photographs and videos of the construction site, websites about the building, BIMs, and other multimedia related to the project. With CAD, architects and designers can modify files throughout the design lifecycle, allowing for a less linear and more flexible design process and more innovative design. Although the architecture profession has standards for managing design files, firms often use conventions that are easiest to use within the firm and may not be easily translatable to those outside the firm.

Several challenges are associated with the software in the architecture profession. There are multiple programs used throughout a design project; the software has highly robust functionality, which also makes it difficult to preserve; and the software is proprietary, making migration of the data to other software systems difficult. The software relies on complex mathematical algorithms to represent shapes and structures. Furthermore, software products change rapidly, and they are expensive, encrypted, and quickly become obsolete. Alex Ball, research officer at UKOLN in the United Kingdom and attached to the Digital Curation Centre (DCC) based at the University of Bath, described the issues in 2013 in this way:

The issue of poor interoperability between CAD systems and between versions is exacerbated by the rate of software development. In order to maintain a competitive edge, there is constant pressure on CAD vendors to release new versions of their software with increased functionality or fewer limitations. Not only does this create instability regarding file formats and their interpretation, it also means that individual versions of CAD packages can become obsolete rather quickly (Ball 2013, 10).

To preserve the records of significant building projects completely, all the digital information should be captured and linked or packaged together into a collection that can be easily searched and, once found, navigated and preserved over time.

In the analog and early digital world, the contractual deliverable to clients was a set of printed, wet-signed and wet-stamped drawing sets. We have moved to a model of electronically signed 2D and 3D files that can be manipulated to convey information that is at least as detailed as traditional printed plans. Further, over the last five years, students in architecture and design schools have been routinely using CAD for modeling, skipping the 2D drawing process entirely, meaning that the coming generation of architects will be producing documentation only in 3D models, adding urgency to the problem of preserving this type of documentation.

The impact of the shift to an entirely digital architectural production workflow on the record of architectural innovation and practice—in architecture libraries, archives, and museums—is only beginning to be understood. No longer can libraries acquire blueprints or drawings, a few images, and a scale model or two to represent a major work of architecture in their collections. Now they must acquire the 3D CAD models and 2D drawing files, BIMs, digital images, videos, and documents, delivered on a computer hard drive, often with no annotation whatsoever.

Fortunately, the standards for CAD are advancing so that options are emerging to represent CAD drawings and models in ways that achieve a degree of interoperability across systems and time. These standards are complex and offer many trade-offs. Such standards include *ISO 14641:2018 Electronic Document Management—Design and Operation of an Information System for the Preservation of Electronic Documents—Specifications*; *ISO 20614:2017 Information and Documentation—Data Exchange Protocol for Interoperability and Preservation*; *Industry Foundation Classes* (buildingSMART International 2018); *Standard for Exchange of Product Model Data ISO 10303* (STEP Tools, Inc. 2018); and *Initial Graphics Exchange Specification* (IGES 2018).

Different software programs support different standards, and each standard supports different aspects of the represented design. Archiving these digital design files raises a host of questions about the purposes that the digital designs should serve, their authenticity, and the best ways to manage such assets technically in the digital future.

To complicate matters further, multiple CAD software vendors supply the architecture, engineering, and construction industry, including Autodesk, Inc., Bentley Systems (Microstation), Dassault Systèmes (CATIA), and others. As with all digital software, file format obsolescence is a barrier to our ability to archive many digital design files. Architectural museums and archives are faced with a rapidly growing need to preserve digital information and are grappling with the needs for technological tools, for technical expertise in digital preservation, for AutoCAD expertise, for archival expertise, and for repositories that can preserve and disseminate the archived data. Over the last two decades, the risk of losing this portion of our digital cultural heritage has grown tremendously.

History of Previous Work (2003–2017)

Over the last 15 years, architectural practitioners, archivists, and technologists have been working on the problem of preserving digital design work. The Art Institute of Chicago initiated the first project in the United States; it lasted from 2003 to 2005 and was conducted by Kristine A. Fallon, an architect. The research project of the Massachusetts Institute of Technology (MIT), Future-proofing Architectural Computer-Aided Design (FACADE), took place from 2007 to 2009 and was conducted by technologists, librarians, and architects. The Society of American Archivists Design Records Section has been doing related research and surveys in the archival community since 2012. The 2014 International Confederation of Architecture Museums (ICAM) conference addressed these issues in several presentations. In November 2017, the Library of Congress, the Architect of the Capitol, and the National Gallery of Art hosted a summit, *Designing the Future Landscape: Digital Architecture, Design and Engineering Assets*, at the Library of Congress. Finally, the Canadian Centre for Architecture has led the effort for the profession, using tools and techniques from the digital preservation community.

Art Institute of Chicago

In 2003, the curatorial Department of Architecture at the Art Institute of Chicago undertook a study to identify requirements for creating and maintaining an archive of born-digital objects, with architect Kristine A. Fallon as principal investigator.

The first step of the study was to conduct a survey to determine how design firms were then using digital design tools, what types of digital design data were being produced, how important digital design data were to understanding the design process, and whether digital methods were the primary way that the firms did work. If digital methodologies were not already primary in their work, respondents were asked whether they thought that digital methodologies would be primary within five years. They were also asked to list the specific software products that they used in each use category. Survey respondents reported using digital design tools in all categories identified in the survey. The most frequently cited were in the areas of communication/presentation (94 percent) and documentation (93 percent). The least frequently cited use was for rapid prototyping (24 percent). More than half of the respondents reported using digital working methods primarily in data gathering, documentation, communication/presentation, and design exploration (Kristine Fallon Associates 2004).

The second step was to conduct in-depth case studies of projects ranging in scale from industrial design to urban design at nine U.S. design firms. The case studies showed that digital design tools are integral to the design process and digital images are central to design decision-making.

The third step was to validate that the findings drawn from the case studies could be generalized to the broader design community. This was done through an international survey, in which staffs at design firms were asked how they used digital design tools, how important the tools were to their practices, and which products they used.

The team also conducted research into earlier archiving projects and existing standards, methodologies, and products for collecting and archiving digital design data. It was found that no museum or archival institution had solved the key problem of ensuring long-term preservation of the numerous and rapidly changing data formats from digital architecture projects.

Basing their assessment on the Open Archival Information System (OAIS) reference model for a long-term data repository system (ISO 14721:2002), the team identified six distinct stages of the workflow (planning/programming, design, construction, closeout/commissions, operations/maintenance, and disposal) for bringing digital design data from design office to museum or archive and for making it accessible to the public.

The report included recommendations on procedures, technology and related requirements, and a start-up implementation plan. A summary of the recommendations includes the following guidelines:

- The design practitioner should organize, name, and maintain design data in such a way that a curator or archivist can discern the contents of data files and the time sequence in which they were produced. The designers should preserve important outputs—drawings, images, and animations presented to clients—in archival formats.
- Once the archive and a design firm have defined the content of a gift of digital design data, the design firm should prepare the Submission Information Package (SIP). SIPs should contain the content files and some level of descriptive information, including file-naming standards or project directory structure for a given set of files, and should be sent to the archive for ingest.
- Recommended archival formats suitable for inclusion in the SIP include the following:
 - PDF/A and TIFF
 - MPEG2
 - PNG
 - BMP
 - Extensible 3D
 - Universal 3D

The Art Institute of Chicago's report provides thorough recommendations and requirements for the implementation of a complete preservation plan for digital design records. Recommendations are included for institutional funding, hardware and software infrastructure, digital storage, data maintenance, cataloging and access, and personnel. The recommendations distribute the workload of digital preservation between creators and archivists, and assume firms and collecting institutions will have the technical infrastructure and technology expertise required.

MIT FACADE Project

In 2007, the MIT Libraries received an Institute of Museum and Library Services (IMLS) grant to develop a strategy for processing and preserving the digital outputs of architectural projects involving 2D, 3D, and other digital files. The FACADE project team worked with the offices of Frank Gehry, Moshe Safdie, and Thom Mayne to create a collection of digital material from these major architects. The collection was to include different 3D CAD modeling tools that the architects had used in their normal work practices and that could be used as a research test bed. The project team was provided with design files for specific projects for the research.

The research explored the best way to associate 3D designs with related 2D drawings, digital images and videos, e-mail messages and other communications, and BIMs. Specifically, what techniques should be applied to preserve native CAD models over archival timeframes? Is it necessary to preserve software, or is an emulation framework required? What additional process information is required to capture the building lifecycle, and how can that be stored in digital archives? What other annotations must be supported to

retain the architect's intentions and instructions to contractors and subcontractors who do the construction, and how should this information be kept? How do we archive this information into digital preservation repositories and make it accessible?

Five major areas of investigation were defined for the project: (1) analysis, identification, and description of major CAD formats; (2) analysis, design, and implementation of native CAD file ingestion; (3) management, preservation, and dissemination practices; (4) analysis and recommendations related to process documentation (relationships among various CAD files and versions, and between CAD files and other documentation); and (5) training, outreach, and dissemination of results to the digital library and digital preservation communities.

Material was acquired on a hard drive or set of DVDs, in the file system in use by the firm, and without annotation to help determine what was included. Of the test collections acquired, the size ranged from just under 20,000 files (10 GB) to almost 100,000 files (50 GB) for a building in progress. The 3D CAD models in particular were each very large (comprising one or more separate files), but usually few in number. The 2D CAD drawings and other files were smaller, but numerous. Each firm responded to requests for project files differently, depending on their own practices. As happens in the analog world when collections are acquired, some firms simply turned over all the files; others had already culled the project files for their own archives, in which case the team acquired a smaller set consisting of what the firm considered important to keep. Ideally, the team would acquire complete sets of data that included not just the designs and client presentations, but other archival material that is often of high historical value.

For each building, the team sought material from all stages of the project, including concept design, schematic design, design development, construction documents, and construction administration. While 3D models were the focus of the research on digital preservation, the context provided by the other materials in the collection (e.g., client presentations, correspondence with clients and contractors, and digital images) was key to understanding the models. Unlike analog architectural drawings, which show through line drawings the design intent of an architect, CAD drawings and models are intricate and multilayered, with layers combined to produce one file. The intent of the architect's design is integrated into the layers of the files and into the references between files. As a result, the combination of files, rather than a single file, is necessary to understand the architect's design intent.

The project team developed a set of recommended best practices to support a preservation strategy that covered all the materials received in a building collection. These recommendations included

- Special processing of 3D CAD models to generate derivative versions with greater long-term archiving potential than the native software format. The team identified the need for four versions with distinct formats to ensure long-term preservation:

1. Original (the originally submitted version of the CAD model)
 2. Display (an easily viewable format to present to users, normally 3D PDF)
 3. Standard (full representation in preservable standard format, normally IFC or STEP)
 4. Dessicated (simple geometry in a preservable standard format, normally IGES)
- Semi-automated conversion processing of other key design file formats (e.g., 2D drawings into PDF files).
 - Automated conversion processing of common digital file formats (e.g., Microsoft Office documents and JPEG images) as part of archive ingest.
 - No special processing for the remaining classes of file formats, although these will come under more generalized digital repository preservation strategies outside the scope of FACADE's focused concerns.

For the project, the team was able to acquire all the CAD software products used by the architects who contributed to the research collection, and the team had valid access to those products throughout the project. Should an archive need to keep CAD software in perpetuity to view older CAD models, the archive would have to continue buying license keys for the software forever and hope that those CAD companies do not go out of business. This is obviously not a realistic strategy for long-term preservation; ideally, access to software will be maintained for many decades. The team discussed this issue with representatives of several of the leading CAD software companies, and they were open to the idea of escrowing unrestricted copies of the software with appropriate libraries and archives. The team concluded that this was the best avenue to pursue.

The team performed a detailed case study of emulation as a strategy on the AccuDraw software on the Apple II platform (long since obsolete), and the team was able to view AccuDraw models by running the software in a simulated environment. The process and lessons learned were documented in detail, and the team felt that this approach was technically viable for preserving modern CAD software and data. However, the issue of legal access to the software via license keys remains a significant barrier.

Community discussions made it clear that many institutions, especially smaller ones, lack the technical infrastructure and expertise to implement the preservation models developed by the FACADE team and the Art Institute of Chicago. A key take-away was that a more community-based approach to building an infrastructure with technology, digital preservation strategies, standards, and education for archivists of these collections is critical if we are to preserve digital architectural records at a national or international scale.

Following the FACADE project, MIT and the Harvard Graduate School of Design did further work in 2011 and 2012. This included developing a more robust set of metadata fields for the description of digital design files and continuing work on a prototype of

the original accessioning tool built in the first FACADE project. The work was funded by a small grant from the Harvard Library and did not continue because of a lack of funding and changes in personnel at each institution.

Society of American Archivists Design Records Section

In 2013, the Society of American Archivists Design Records Section launched a CAD/BIM Task Force as a catalyst for a community-wide initiative to address the numerous legal, technical, and curatorial issues of born-digital architectural records. The work of the task force to date includes a survey of firms and architectural archives that was used to learn about holdings and current archival practices for born-digital design data, the development of a born-digital studies bibliography, and a report of the task force (Leventhal and Zalduendo 2013, 2014).

ICAM17 Conference

In September 2014, ICAM held its conference in Montreal and New York.¹ The opening session was devoted to the topic of archiving born-digital architectural materials.

Representatives from five international institutions of varying sizes described efforts at the institutional level to deal with digital design data. They discussed such issues as collecting strategies, software curation, and tools for archiving and description. The overall impression from across the presentations was that the complex problems inherent in preserving digital design data are multilayered and comprise many general challenges. Each institution was developing its own processes and methodologies, and many were not working across allied domains, such as digital preservation, from which they could adapt solutions and standards. The presentations made it clear that the problems would be better worked on collaboratively across institutions and across domains to take advantage of expertise at both the national and the international levels.

Library of Congress

In November 2017, the Library of Congress, the Architect of the Capitol, and the National Gallery of Art hosted a summit, titled *Designing the Future Landscape: Digital Architecture, Design and Engineering Assets*, at the Library of Congress (Leventhal 2018). The summit brought together 180 stakeholders in the architecture, design, and engineering professions, from creators to curators, to explore the issues and obstacles of long-term preservation and access to the records of their projects and to begin working toward sustainable solutions. The critical issues that arose through the summit were the need to identify the full array of digital design files created; the need to determine which design records, and specific types of data or information in those records, the various stakeholders need in the immediate and long-term future; and the need to develop better

¹ http://www.icam-web.org/data/media/cms_binary/original/1405105617.pdf

communication and information-sharing practices, which are critical to developing sustainable solutions to problems with the long-term preservation, access, and use of digital design files.

Having so many representatives from the range of digital design communities engaged in discussion at the summit indicated how pressing the issues of preservation are, as we risk losing vital cultural heritage information. Discussions highlighted the fact that advancements in digital preservation tools, such as BitCurator and Archive-matica, and collection management tools such as ArchivesSpace, offer technological support for the preservation of digital design files. The communities at the summit also recognized the importance of working with colleagues across domains to support the preservation efforts.

Building for Tomorrow

The research that has been done from various perspectives since 2003 has paved a path for understanding the digital preservation needs for 3D architecture and design files. We have tested different preservation methods and tools, and we have begun to engage the communities—from those working in creation through those working in preservation and access. To further this work, the Frances Loeb Library at the Harvard University Graduate School of Design (GSD) applied for a grant from IMLS² in 2017 to support the convening of a National Forum under the National Digital Platform funding priority during 2018. The grant supported two priority-setting meetings of engaged stakeholders—architects, architectural historians, archivists, librarians, technologists, digital preservationists, and others—who are framing a national/international collaborative infrastructure to support the long-term preservation of digital design data, specifically in the architecture and design fields. The infrastructure includes the ongoing integration of knowledge, standards, technologies, and management across generations of technology and practice. The first meeting, a day-and-a-half-long forum, was held immediately prior to the Society of Architectural Historians annual conference in St. Paul, Minnesota, in April 2018. The outcomes of the forum will be published in spring 2019 along with a set of strategic directions and actions forming the basis for a strategic plan of community-based work in the area of preservation for digital design records.

At a second meeting, a steering committee met May 30–31, 2018, at the Harvard University GSD. The goals of the meeting were to refine the group's strategic directions and actions, and to determine its immediate next steps. A significant area of focus in the plan is the development of connections to other communities that have intersections with this work, including the software industry, those working in the realm of 3D and VR, and those who provide digital preservation tools and technologies, in order to leverage expertise and find commonalities across disciplinary domains.

² <https://www.imls.gov/sites/default/files/grants/lg-73-17-0004-17/proposals/lg-73-17-0004-17-full-proposal-documents.pdf>

An outcome of the May steering committee meeting was a decision to build a formal coalition of stakeholders. A proposal for the structure of a Building for Tomorrow coalition of allied communities is being drafted and will be shared for community comment as part of the engagement strategy. Participants in Building for Tomorrow will engage design records community members who could not be present at the forum, specifically software vendors with whom we want to engage, and will convene a meeting of those working on three current IMLS projects focused on 3D preservation (Building for Tomorrow, Community Standards for 3D Preservation [CS3DP], and Developing Library Strategy for 3D Virtual Reality Collection Development and Reuse [LIB3DVR]). We will also convene another meeting of the steering committee, which we hope to use as a jumping-off point to formalize a Digital Architecture, Design, and Engineering (DADE) coalition.

Conclusion

Over the last year, as a result of the community work in this area and through the Building for Tomorrow meetings, several steps have been taken to help move this work forward in a community-based model. We have the tools, technologies, and technological expertise to preserve digital architecture, design, and engineering data, and we can apply them to this domain. Several efforts in the United States focus on developing standards for preservation for 3D data, and we need to collaborate across our communities to leverage the expertise across those domains. We need to garner the engagement of designers in practice to incorporate thinking about preservation at a far earlier stage in their careers. We need to push harder to engage the software industry in order to align incentives for preserving software with the need to preserve the files created using the software. We need to think about sets of services around the preservation of digital design files to meet the needs of institutions of various sizes. And, to be successful, the preservation of digital design files must be an effort across domains and institutions.

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Chapter 7

3D/VR Preservation: Drawing on a Common Agenda for Collective Impact

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Abstract

Digital curation is now part of the repertoire of all computationally dependent domains, requiring mechanisms for alignment to address common digital curation challenges that are beyond the scope of any individual organization or domain. This chapter explores the collective impact methodology (CI) and its application to cultural stewardship and digital curation challenges within and beyond the 3D and virtual reality (VR) discourse. To demonstrate the relevance of CI to 3D/VR preservation, the chapter provides a CI case study on software preservation that is experiencing early success in aligning efforts across sectors toward the long-term preservation and reuse of software. The chapter concludes by posing questions for consideration by 3D/VR practitioners as well as possible next steps to address one or more 3D/VR data curation challenges.

Introduction

In a 2017 article, John Wenzler argues that one of the greatest challenges to the realization of a sustainable scholarly communications infrastructure is the collective action dilemma—the inherent difficulty in looking beyond localized, organizational needs toward “‘conscious coordination’ in the management of the scholarly record” (196). Wenzler’s article inspired focused responses, including one regarding the development of financial mechanisms to sustain open scholarly infrastructure (Lewis 2017) and another advocating the use of social alignment mechanisms to direct the focus of individual institutions toward common goals (Neylon 2018). The collective action dilemma is characterized by Wenzler, Lewis, and Neylon as the primary challenge to the sustainability of an open

scholarly infrastructure. It is also a challenge faced by cultural stewards engaging in digital curation across the information management landscape.

Digital curation is now part of the repertoire of all computationally dependent domains, necessitating alignment mechanisms to address common digital curation challenges that are beyond the scope of any individual organization or domain (Digital Curation Centre 2018; Poole 2016). 3D and virtual reality (VR) data preservation¹ is treated here as both a digital curation use case—positioned at the intersection of some of the most difficult digital curation challenges, including scale, standards and interoperability, and hardware and software dependencies—and a boundary-spanning area requiring alignment of interests across a broad range of stakeholders, including the software industry, hardware manufacturers, academia, cultural stewardship organizations, standards bodies, policymakers, publishers, and (re)users of 3D/VR collections.

Collective Impact

As an alternative to the isolated impact of single organizations acting alone, collective impact (CI) is a collective action approach to complex social challenges that accounts for conflicting institutional or domain-specific priorities by design (Kania and Kramer 2011).

Kania and Kramer (2011) argue that successful CI initiatives share these five conditions:

1. A shared vision, or **common agenda** that engages all of the stakeholder communities²
2. A **shared system of measurement** that serves to measure the effectiveness of varied stakeholder activities and outcomes toward advancing the common agenda
3. **Mutually reinforcing activities** that leverage the unique contributions of each stakeholder group in a way that complements and amplifies the work of all stakeholder groups
4. **Constant communication** to demonstrate a commitment to fairness and evidence-based decision-making over time
5. A **backbone organization** with paid staff to plan, coordinate, and sustain the effort through facilitation, technological infrastructure, and data collection, synthesis, and reporting

¹ In this chapter, 3D/VR preservation refers to (1) preservation of the means (parameters, data, and software) to render the volume and surface of a 3D object mathematically and (2) preservation of the “technological system(s) that use interdependent hardware and software to place users in a computer-generated, three-dimensional environment that is immersive and interactive” (Campbell 2017, 7).

² Infrastructure studies make a useful frame for expanding the potential scope of stakeholder communities for software. Specifically, in their in-depth study of the WORM online community, Star and Ruhleder (1996) outline several key characteristics of infrastructure that apply to software, including embeddedness, transparency, reach, and scope. They also note that such infrastructure should embody standards and be learned as part of a membership, be built on an installed base, be fixed in modular increments, and be visible on breakdown.

The greatest concentration of CI case studies is found in the fields of education, public health, homelessness, youth development, urban and economic development, community development, and the environment (CCHD 2018). One of the longest running well-documented applications of CI is Strive Together, “a national, nonprofit network of 70 community partnerships” working “to ensure that every child succeeds from cradle to career, regardless of race, income or zip code.”³ Strive Together represents 12 years of experimentation, testing, and refinement of their “theory of action,” which serves as an invaluable resource for understanding the evolution of CI over time in response to shifting social and economic circumstances. Through this and other examples, John Kania and Mark Kramer (2013) have argued that CI emphasizes “complexity and emergence” as two characteristics of system-level challenges that CI is particularly well suited to address.⁴

Telescoping the 3D/VR Literature—Common Data Curation Challenges for Complex Data

3D/VR is a collective action problem, evidenced through a specific set of challenges that individual institutions or individuals cannot tackle including scale, standards and interoperability, and hardware and software dependence. We need a collective action solution to address these challenges if we want to progress past highly constrained and localized 3D/VR curation environments to ensure 3D/VR preservation over the long term.

According to Lischer-Katz, the challenge of archiving VR objects arises from the “complexity of [these] data objects, in terms of the variety of data types, relations between files, and dependencies on a variety of hardware and software platforms” (2017, 6). While 3D/VR is associated with disciplinary, format, and platform-specific challenges, many of the digital curation challenges cited in the 3D/VR literature are common for a broad range of complex digital data. These challenges include the implications of scale for stewardship and access, standards and interoperability, and dependency on specific hardware and software environments for meaningful access. By positioning 3D/VR preservation at the nexus of these common data curation challenges, we identify areas where collective action can make the greatest impact on long-term preservation.

³ <https://www.strivetgether.org/about/>

⁴ In “Collaborating for Equity and Justice: Moving Beyond Collective Impact,” Tom Wolff and coauthors summarize the limitations of CI, including the “failure to cite advocacy and systems change as core strategies, engage those most affected in the community as partners with equal power, and directly address the causes of social problems and their political, racial, and economic contexts.” The authors propose six principles for collaborative practice that promote equity and justice. These six principles inform a broader framing of CI discussed throughout the text of this chapter (Wolff et al. 2017).

Scale

The challenge of scale has many facets in 3D/VR preservation, including file size, volume of files, number of possible platforms and formats, and the geometric complexity of the environment or object that is represented by a 3D/VR rendering. While geometric complexity is unique to 3D/VR preservation, the volume, size, and range of potential formats to be curated or preserved for a single VR environment represent well documented digital curation challenges. For example, in the field of digital archives, digital corpora for a single user's storage media can easily come to tens of thousands of files (Sloyan 2016). In the context of distributed research project teams, the interdisciplinary Zuse Institute Berlin (ZIB) points out that "the trend in large-scale research data management constitutes a paradigm shift from previous local data storage in file systems and databases to the coordinated orchestration of unstructured, high-volume data maintained in distributed sites."⁵

Standards and Interoperability

In a digital curation ecosystem in which numerous tools are applied to a growing volume of digital assets at each phase of the workflow, standards and interoperability are key. The tools themselves frequently change, and granular metadata facilitates the reuse of outputs from one tool to another.

The business case for standardization and interoperability are based on two well-grounded assumptions: (1) standards facilitate interoperability by allowing the exchange of information across contexts, and (2) interoperability facilitates flexibility in the approach to data curation because the interpretation of the outputs of curation activities is not dependent on a given tool. For example, audiovisual preservation professionals have been particularly concerned with the persistence of embedded metadata due to varying levels of support for the metadata across the range of software applications used to render audiovisual files (Lacinak and Forsberg 2011). Similarly, in 3D/VR-based practice, "digital watermarking" describes a family of techniques that embed uniquely identifiable information about an information object in the object itself to address "security aspects of data and user authentication or data integrity protection" (Steinbach, Dittman, and Neuhold 2008). Digital watermarking makes it possible both to detect unauthorized uses of the intellectual property (e.g., the underlying 3D models) and to track the chain of custody through distributed technological infrastructures. Tools to support access to working 3D representations and reproducibility of those representations would have to be able to track specific instances of a model across systems. However, this level of interoperability relies on standardization around the specific properties and, in some cases, the machine-readable encoding standard used to represent these metadata.

⁵ <http://www.zib.de/research/large-scale-data-management-curation-analysis>

According to the principal investigator and the co-investigators of the Community Standards for 3D Data Preservation (CS3DP) project, there are currently no agreed upon standards for the preservation of 3D data (Moore et al. 2018). More specifically, establishing agreed upon schemas for provenancial metadata remains a challenge (Cohen-Boulakia et al. 2017). An agreed upon provenancial schema would facilitate interoperability among systems and tools included in the workflow, as well as interoperability of execution environments for reproducibility or replay. PROVdata is a schema adopted by some virtual heritage practitioners; however, equivalent standards do not exist in every domain that employs 3D/VR technologies (Koller, Frischer, and Humphreys 2010). One can hope for a common set of extensible elements that could permit searches for complex digital objects across domains (e.g., all models within the same coordinate system) and within a single domain (e.g., all models of a particular monument that have a low uncertainty quotient), similar to the implementation of Preservation Metadata Maintenance Activity (PREMIS) in digital repository and preservation systems to track presentation “events” over the life of a digital object.⁶

As community infrastructures grow to include distributed networks of shared software and data across participating organizations,⁷ it is crucial not only to track provenance and preservation events associated with assets across their life, but also to make that metadata discoverable. Such a system feature enables organizational and individual users to know the source location and to use the provenancial chain of events associated with the lifecycle of a digital object as a second-order data set.

Software and Hardware Dependence

According to the authors of “Research Challenges for Digital Archives of 3D Cultural Heritage Models”:

Anecdotal evidence suggests that digital models that are only two or three years old are losing their original functionality and information richness because of poor archival practice. CAD software products used to create virtual heritage models belong to a rapidly changing market segment, which means that updated versions are inevitable (on the order of every 18 months) and the full reuse of data (without loss of information) is not secured at all. (Koller, Frischer, and Humphreys 2010, 7:14)⁸

Likewise, findings from the Pooling Activities, Resources and Tools for Heritage E-research Networking, Optimization and Synergies (PARTHENOS) project include an existing and “important gap between open-source solutions . . . and the opaque alternatives of commercial black boxes . . . raising the question of our software dependency” (Alliez et al. 2017).

⁶ <https://www.loc.gov/standards/premis/>

⁷ For example, Software Heritage, Datacite Re3Data, EaaSI.

⁸ For an in-depth study of the longevity of computer-aided design, refer to Smith 2008.

Software and hardware dependencies have been similarly discussed in other data curation contexts, including time-based media conservation (Laurenson 2006), archives and special collections (Meyerson et al. 2017), and peer review in light of an expanding definition of a well-formed research object (Bailleul 2016, 42). Of the common 3D/VR digital curation challenges listed earlier, software dependence arguably has the broadest reach. All sectors and disciplinary domains use some form of software as part of their work process. While the function and user community for a specific software title varies widely, some software dependency challenges span domains.

The transition from a shared acknowledgment of the need for collaboration to a sustained effort aimed at system-level change is one of the key social infrastructure challenges that CI is meant to address. The American Library Association (2014), the Educopia Institute (Lippincott and Skinner 2014; Skinner, Drummond, and Halbert 2014; Skinner and McCain 2016), and the Institute of Museum and Library Services (2017) are among those who have embraced CI as a conceptual framework within cultural stewardship. Of these, the cultural stewardship CI case studies with the greatest extensibility to 3D/VR preservation have been undertaken by Educopia Institute, which has translated its strategies to collective action challenges that are topical rather than regional in scope. The Software Preservation Network (SPN) is the most recent affiliated community of Educopia, and is actively applying the CI framework to “Saving Software, Together.”

Software Preservation Network: A Case Study in Collective Impact

Before detailing SPN’s application of CI it is critical to outline the recurring challenges found in the software preservation discourse (Meyerson, Potterbusch, and Work 2018). Layering major events in digital preservation over the software preservation timeline highlights broader trends that have directly impacted the creation, preservation, and reuse of software and digital data, including changes to U.S. copyright law that favor copyright holders (Aufderheide et al. 2018); the period of annual price reduction for computational resources (Koller, Frischer, and Humphreys 2010); the growth of the institutional repository landscape (Lynch and Lippincott 2005); increasing acquisition of hybrid collections (Redwine et al. 2013); funder requirements for data sharing and reproducibility of computationally dependent research (National Institutes of Health 2018; National Science Foundation 2018); and a shift away from migration and toward emulation as a long-term digital access strategy (Bergmeyer 2011; bwFLA 2018; Granger 2000; Rosenthal 2015; Rothenberg 1999; Waters and Garrett 1996).

Whether your data is a simulation of climate change impact on ocean sea levels or a CAD file from 2000 or Deus Ex, there are four major software preservation challenges that recur in the discourse

over time, are applicable to any domain, and must be addressed through programmatic and strategic collaboration. These challenges are as follows:

Challenge 1: No single institution can feasibly locate, much less acquire or procure, all the software needed to address their existing born-digital data.

Implication: Coordinating collection development and sharing of software resources among cultural stewardship organizations is essential for long-term preservation.

Challenge 2: Intellectual property regimes in different nations are conflicting.

Implication: Leveraging existing legal tools across national contexts (and sharing a body of anecdotal evidence from researchers and practitioners, which is crucial to advocating for the expansion of stewardship and user rights) is necessary to ensure that intellectual property law does not restrict the preservation of and access to software.

Challenge 3: As distribution models change from physical installation media to software as a service, software libraries and executables are squarely and exclusively in the control of software producers.

Implication: Articulating and aligning the shared needs/interests of cultural stewardship organizations in order to represent community needs and capabilities in conversation with the software industry is essential to ensure that software producers do not dictate preservation decisions.

Challenge 4: There are no broadly adopted standards for describing the technical, provenancial, and relational properties of software.

Implication: To make software discoverable and preservable, it is essential to analyze the body of existing descriptive metadata standards for software and identify their common properties. Once a content-level ISO standard has been developed, creators and practitioners can use it to map their localized metadata implementation to the broader software preservation ecosystem.

In response to these challenges, the Software Preservation Network builds on existing collections and digital preservation infrastructure to support the specific preservation and access needs of software.

Common Agenda

A common agenda is a shared vision or goal for change that engages all of the stakeholder communities around a problem area. Historically, software preservation efforts have focused largely on technological developments or on attempts to tackle the full range of

challenges within a single domain. SPN exists as a commons for sectors to align and prioritize resource investment around shared challenges. This in no way obviates the need for more domain-specific initiatives, tools, working groups, and organizations. Instead, we want to help amplify that work and funnel some of that collective energy toward international-scale challenges to effectively promote cross-domain discussions that have representation from all of those areas. The common agenda that unites SPN's participants and supporters is to preserve software through community engagement, infrastructure support, and knowledge generation. SPN tackles this agenda across five core activity areas: law & policy, metadata & standards, training & education, research-in-practice, and technological infrastructure.⁹ Communication, governance, and advisory groups support the work of the five activity areas.

Shared Measurement

The SPN Research-in-Practice Working Group is focused on improving shared measurement through review and synthesis of previous software preservation (and related) research. The purpose of this synthesis is to create a Software Preservation Research Toolkit consisting of (1) a centralized longitudinal data effort to track progress and developments in the software preservation landscape, and (2) a set of data-gathering instruments that individuals can use to gather data about software preservation and curation in their local organization or community (Hagenmaier 2017). By aggregating findings from across contexts and survey instruments, practitioners in the field can more easily map the landscape of software preservation and curation, allowing us to focus energy and expertise more precisely and effectively.

Shared measurement—"collecting data and measuring results consistently on a short list of indicators at the community level and across all participating organizations" (Kania & Kramer 2011)—is one of the most difficult and also one of the most powerful components of collective impact. One key insight resulting from analysis of the software preservation discourse is that the only measurable change over time is an increase in the number of project-based and programmatic efforts addressing some aspect of software preservation. This measure does not, however, advance understanding of whether, how, and to what extent these efforts have enabled preservation, sharing, and long-term reuse of software. Without shared measurement, there is no empirically-grounded way for stakeholders to determine whether past and current efforts have successfully advanced the state of the field.

Mutually Reinforcing Activities

In addition to requesting that the SPN working group coordinators map their action plan items to strategic goals, SPN requested that the working group coordinators map their activities to the

⁹ <http://www.softwarepreservationnetwork.org/about/>

related activities of other working groups. A shared understanding of unique stakeholder contributions and roles allows each group to play to their strengths and interests while highlighting the value of participation to all groups. In a series of SPN all-hands strategy meetings held in January and February of 2018, network members articulated specific mutually reinforcing activities shared among working groups. Through the documentation of those activities, members reported increased trust in the process as whole.

SPN identifies affiliated projects in addition to mutually reinforcing working group activities.¹⁰ SPN's involvement in an affiliated project is first and foremost by tracking the project goals and measures of success against the collective agenda. Beyond shared measurement, SPN may shape an affiliated project or serve in an as-needed advisory capacity. Currently, SPN affiliated projects include Scaling Emulation as a Service Infrastructure (EaaS),¹¹ Fostering Communities of Practice for Software Preservation in Libraries, Archives and Museums (FCoP),¹² and Code of Best Practices for Fair Use in Software Preservation.¹³

Constant Communication

As mentioned earlier, meetings have been a crucial component of building SPN. The SPN Forum in 2016 resulted in the development of a community roadmap that drives the first SPN working groups and has been used as the foundation for iterative development of the current SPN mission, vision, values, and strategic goals. The 2018 SPN all-hands strategy meetings allowed all the current members of the network to clarify the relationships between group goals and broader strategic goals, provide real-time feedback about priorities, and identify gaps and opportunities. Between larger convenings of network members, monthly working group meetings, monthly working group coordinator meetings, quarterly advisory committee meetings, and bimonthly newsletter and e-mail communications, SPN stays in regular communication with both active participants and the SPN community at large. The minutes of all meetings are in a shared Google Drive, and meetings are always expected to result in time-bounded, distributed tasks that address the group's action plan. Ad hoc meetings also take place between different groups or sets of stakeholders.

Backbone Organization Support

SPN has undertaken, with some success, the coordination and management of the day-to-day facilitation work, including stakeholder engagement, communications, data collection and analysis, and other responsibilities. However, the last two years have shown that relying solely on dedicated volunteers for organizationally critical tasks can present challenges. Organizations have paid support roles

¹⁰ <http://www.softwarepreservationnetwork.org/projects/>

¹¹ <http://www.softwarepreservationnetwork.org/eaasi/>

¹² <http://www.softwarepreservationnetwork.org/fcop/>

¹³ <http://www.softwarepreservationnetwork.org/bp-fair-use/>

(such as communications specialist, financial manager, systems administrator, program manager) because certain functions are ongoing and critical for both the survival and the accountability of an organization. SPN, Community Standards for 3D Preservation (CS3DP), and Building for Tomorrow (B4T)¹⁴ are awarded grants with some staff hours and some travel support for external participants. While this level of funding may be sufficient for a two-year period in which volunteer participants work together to articulate the priorities for action, dedicated full-time staff are eventually essential to push the common agenda forward and track activities to the system of shared measurement.

In August 2018, SPN launched a membership and sponsorship campaign and a two-year seed funded project with the support of 19 members and counting.¹⁵ Membership and sponsorship are open to organizations in every sector committed to the preservation and long-term reuse of software. While the launch of the campaign is a direct response to the challenges of sustaining CI initiatives without dedicated resources, the formalization of governance and administrative operations will, by necessity, affect the dedicated community of individuals and organizations that have driven the effort thus far. 3D/VR practitioners should consider SPN and other documented CI efforts as a source of information that could improve their efficacy for 3D/VR preservation.

Conclusion: Collective Impact for 3D/VR Preservation

There are numerous points of intersection between the software preservation agenda, general data curation goals for complex data sets, and 3D/VR curation challenges. Listed below are several questions for the 3D/VR *community of practice* (Wenger 1999) to consider; these questions may inform collective action for the curation challenges unique to 3D and VR data:

- Because 3D/VR preservation encompasses numerous digital curation challenges, should 3D/VR preservation be framed as a *collective impact* problem? Or is it potentially more effective to focus on each major data curation challenge that bears particular relevance for 3D/VR?
- Where are the discussions about *community infrastructure* taking place? Who is leading them? Is there currently a backbone organization that can drive the alignment efforts necessary to sustain a CI effort for 3D/VR or associated digital curation challenges?
- Which 3D/VR *stakeholders* are missing from the current 3D/VR preservation discourse, and how might the problems be framed differently to ensure that those stakeholders become part of a sustained and evolving solution to the inherent data curation challenges?

¹⁴ <https://projects.iq.harvard.edu/buildingtomorrow/home>

¹⁵ <http://www.softwarepreservationnetwork.org/prospectus/>

- What forms of *shared measurement* make sense for a CI effort aimed at 3D/VR preservation?
- What are the major gaps or issues with the CI model? What are the blind spots, particularly for tackling 3D/VR preservation?

The following are recommended next steps toward a CI approach to 3D/VR curation challenges:

- Identify past 3D/VR project and programmatic goals and associated outcomes in multiple domains.
- Determine clear gaps in the landscape and use them to set a common agenda.
- Make the components of the agenda measurable, and explicitly identify key stakeholders that are well positioned to lead work related to specific components of the agenda.
- Publish the agenda for feedback, and elicit participation from stakeholder groups currently unrepresented in the 3D/VR preservation discourse.
- Track current and future project and programmatic goals and associated outcomes to the common agenda.
- Determine which existing organizations have the capacity to serve as the backbone organization for a 3D/VR collective impact initiative, and if this model is unsuitable, determine the most appropriate model to support that work.

Looking ahead, the enterprise of digital curation for 3D/VR data depends on the presence of actors at every level of participation; acknowledgment of the unique contributions of individuals, organizations, and domains; and a CI approach that enables the 3D/VR community to direct those contributions toward a common agenda. While the complexity of 3D/VR data raises many hurdles, most of the essential curation challenges can be addressed in concert with work being done in the broader digital curation community.

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Chapter 8

CS3DP: Developing Agreement for 3D Standards and Practices Based on Community Needs and Values

Jennifer Moore, Adam Rountrey, and Hannah Scates Kettler

Abstract

The pace and growth of 3D model creation has increased tremendously in recent years, a trend that will continue as technology evolves. The ever-present need to develop practices and standards to ensure the long life of this data type has never been more apparent to both 3D creators and data curators. In this moment, a community is coming together in an effort to increase the accessibility, discoverability, usefulness, and integrity of data. One such effort, the Community Standards for 3D Data Preservation, is focused on collective development of flexible and extensible best practices and/or standards for preservation, documentation, and dissemination of 3D data.

The Growth of 3D Data Creation and the Need for Curation

Technical advancements in creation and capture of 3D data and a reduction in costs have inspired intense growth and interest in creating, sharing, and using digital 3D data in the last decade. The digital 3D medium is still rapidly evolving; new users and creators are coming in from many backgrounds, often with different end goals. Yet, as users and creators, we are also at a point in the development and usage of 3D data at which many recognize the need for a system of standards—or at least guidance—for the documentation, preservation, and dissemination of 3D data. Locally developed standards are now starting to emerge independently in labs, museums, libraries, and businesses, often with little communication among stakeholders. This could be problematic for the larger community, as a system of standards optimized in isolation solely for

the needs of a specific field or discipline is unlikely to meet the needs of those in other fields and may even be completely unusable outside its home field. For example, a standard designed specifically for 3D models of archaeological sites and collecting events is unlikely to meet the needs of game developers and architects, and it may unnecessarily limit the discoverability of the content.

Collaboratively developed standards would increase accessibility, discoverability, and usefulness outside the field of the user or creator, and they would foster innovative applications and scholarly work by reducing the barriers to cross-disciplinary access. However, the more generalized standards require compromises, which means that they may not fully meet the needs of any specific field. Given the need for documentation and preservation standards in most fields using 3D data, the broader community is now choosing to come together at a powerful, formative time, asking questions not only about how information should be encoded for sharing and preservation, but also about what we value and how we can design a system that promotes those values. In other words, what kinds of things do we want our standards to encourage and facilitate?

Relationship of Data Curation and 3D Data Today

Historically, librarians, curators, and museum managers have been concerned with curation and preservation of scholarly works and physical objects. In SPEC Kit 354 produced for the Association of Research Libraries (ARL), the authors reported that two-thirds of ARL libraries surveyed were engaged in or developing data curation services in their libraries at some level (Hudson-Vitale et al. 2017). Over the last decade, digital data curation services and research on digital preservation have become part of the established mission of many libraries, but few have explored the complexities of 3D data curation in depth.

At first glance, 3D data may appear to be “just like any other data,” but this is not a full characterization. Like digital photographs or simulation results, 3D models are, in the most reduced sense, just bits and bytes. This means that some parts of the preservation process, such as file storage and fixity, are not substantially different for different data types. Of course, there is more to preservation than just storage. One could argue that the goal of preservation is to maintain an object, ensuring that it may be “used” (even if in a restricted way) over a longer period. For a 2D image repository to be useful, potential users need to be able to judge the suitability of an image for an intended purpose. They may need information about the photographer, location, date, subject, and licensing. In some cases, detailed information about the photography equipment and post-processing may be necessary. A 3D repository has a similar preservation mission—to make 3D data usable over a long period—but the information required to determine whether the data are fit for a particular

purpose is different. Because of the growth, complexity, lack of standardized documentation, and rapid change in 3D data formats and creation methods, the larger 3D community is only beginning to assess what is needed to ensure that 3D datasets remain sufficiently useful in order to consider them *preserved*.

It is important that more data curators and librarians are now exploring the problem of 3D data curation, but agreement among librarians and curators is not enough to ensure its preservation; standards for preservation are useful only if adopted by the creator and user communities.

Aligning Creators and Curators

The 3D/virtual reality (VR) ecosystem includes a broad array of communities and stakeholders that are involved in the creation, preservation, and dissemination of 3D data. Libraries, museums, and archives should engage with this large community to assess needs in 3D data curation and agree upon practices and standards. Indeed, the first step for the Community Standards for 3D Data Preservation (CS3DP) project, funded by the Institute of Museum and Library Services (IMLS),¹ was to develop a better understanding of stakeholders' needs in the 3D data creation and data curation community (Moore et al. 2017).

We distributed a survey to libraries, museums, university labs, and government agencies, and asked their staffs to share it with other interested parties. In our initial survey, we received more than 100 responses from individuals who worked with 3D data or had responsibility for curating data. Notably, 72 percent of all respondents said that they were not using documented best practices or standards for preservation, documentation, and dissemination of 3D data. Of this group, 69 percent said that they did not use them because they were unaware of such standards. The respondents who were using standards had largely developed them in-house. The survey data made it clear that we were at a critical point in standardization. Existing standards lacked buy-in or were so poorly known that local ad hoc standards were being created to fill in the gap. The increase in local standards was not indicative of a desire for independence or isolation in preservation practices, as the majority (85 percent) of respondents said they would like to collaboratively develop standards and best practices as a community (Moore and Scates Kettler 2018). Community members clearly recognized the barriers to collaboration and aggregation introduced by local solutions and were ready to work together on a more unified system of standards.

The CS3DP project emerged from the idea that the adoption of standards depends not only on meeting the needs of the community, but also on community ownership and stakeholder investment. We used the survey results to build a five-part framework for organizing ideas: (1) preservation best practices, (2) management and storage,

¹ LG-88-17-0171-17F

(3) metadata, (4) copyright and ownership, and (5) access and discoverability. These framework topics eventually led to working groups that focused on considering the details of each topic. However, unanticipated discussions during the planning and subsequent forum may have been some of the most important. For example, at the first gathering of CS3DP participants, many remarked that the wide variety of fields and backgrounds represented at the gathering was both unusual and much needed. In fact, the breadth of backgrounds and expertise was so diverse that we made it a priority to develop agreed-upon vocabularies for use in our discussions so that we could speak to one another with better clarity and understanding. Expertise was sufficiently diverse that we needed standards to even start to talk about standards! Questions that arose in discussions showed the desire of the community to work together and develop a general understanding of the current state of 3D preservation. Among the questions raised were “What is 3D data?” “What is it that should be preserved?” “How do we facilitate sharing without discouraging creativity and innovation?” and “What stakeholders are missing from these discussions?”

The next step in the process of developing 3D standards is including perspectives that were not adequately represented in the initial survey, including, but not limited to, those of indigenous and native communities, those from nations with technological bandwidths different from those commonly found in North America and Europe, and those from the entertainment industry. Targeted engagement with these communities in the form of actual relationships, not just consultations, is appropriate if the future of 3D data preservation is to take into account the actual breadth of the needs and requirements of all the users and creators of 3D content.

This concept was brought to the fore as Narcisse Mbunzama spoke as part of the first CS3DP forum on February 6, 2018. During the panel on discovery and access (Wittenberg, Nieves, and Mbunzama 2018), Mbunzama discussed the innovations in 3D in the Democratic Republic of the Congo (DRC) and use cases there that heavily rely on mobile devices for dissemination and access. The 3D data are shared via the DRC’s unreliable cellular and internet services, and are processed using basic computers. Yet, the contribution and scholarship surrounding 3D data is no less active in the DRC than it is anywhere else in the world. A standard and set of best practices for 3D preservation should account for the concerns of such active communities and should meet the needs and requirements of various types of users.

Bridging Efforts in the Community

The process of collaboratively building 3D data curation has only just begun in earnest. However, our efforts are building on and incorporating stakeholders from well-established projects such as

Morphosource,² Smithsonian 3D,³ Cultural Heritage Imaging,⁴ and FACADE (Smith 2008), as well as initiatives such as the Guides to Good Practice⁵ from the Archaeological Data Service and Digital Antiquity and the 3D Icons *Report on Metadata and Thesaurii* (D'Andrea and Fernie 2018), funded by the European Commission and other European-based funders. These efforts have been extremely valuable in setting the tone for discussions. Yet, they tend to be focused on particular disciplinary needs or specific 3D data creation methodologies. Because of this focus, the applicability beyond specific contexts of data creation is limited. We want to assess the previous work and build on it to develop 3D data curation practices and standards that will be broadly applicable and extensible to meet the needs of multiple use cases and user groups. Such a set of standards would support the creation of simplified, broadly applicable preservation systems as well as enhanced accessibility through data aggregators.

The CS3DP project is not alone in tackling the aforementioned concerns and is building connections with other projects. These bridges will facilitate communication about diverse needs and concerns and will promote the development of standards that will be used by a larger interdisciplinary community. The CS3DP team has tracked preceding efforts, and we continue to monitor current efforts to address the curation of 3D data, including the National Endowment for the Humanities (NEH)–funded forums on 3D in 2015 and 2016, which focused on the scholarly rigor, research output, and user experience rather than the preservation of 3D content (NEH 2018); a white paper resulting from the PARTHENOS Workshop held in France in late 2016 (PARTHENOS 2016); IMLS-funded 2018 forums, including Developing Library Strategy for 3D and Virtual Reality Collection Development and Reuse (LIB3DVR) (Virginia Tech 2018); Building for Tomorrow (Harvard University 2018); the International Image Interoperability Framework (IIIF) Community 3D Interest Group (IIIF 2018); and the CLIR 3D/VR colloquium (3D/VR Creation and Curation in Higher Education 2018). These groups' efforts, the cross-pollination of our teams, and the conversation that is continually growing more focused have proven invaluable in identifying problems to be addressed in 3D preservation, community standards development, and the formation of best practices.

In sharing our experience and utilizing our larger collective network, can we begin to deepen our understanding of each other's needs, current practices, and shortcomings for 3D data preservation? In the short term, the CS3DP team anticipates that the contributors to these projects will maintain cross-pollination and collective growth, and will move forward together to support widely applicable 3D data standards and recommendations.

² <https://www.morphosource.org/>

³ <https://3d.si.edu/about>

⁴ <http://culturalheritageimaging.org/>

⁵ http://guides.archaeologydataservice.ac.uk/g2gp/3d_Toc

Extensible Standards That Encourage Innovation Through Congruity

In an ideal 3D/VR ecosystem, 3D data standards and practices facilitate curation, but do not inhibit innovation, extensibility, and adaptability. The CS3DP team sees this as an imperative for any 3D standard or best practice. As articulated during multiple 3D practitioner gatherings (Humanities Heritage 3D Visualization 2015, LIB3DVR, CS3DP, Building for Tomorrow, and CLIR's 3DVR colloquium), a way forward is for the community to build a minimum set of standards and guides that include mechanisms for review, amendment, and a la carte extension. Although somewhat aspirational, we believe this can be accomplished by focusing on identifying the commonalities among disciplines, modalities, and use cases.

As we come to understand our common needs, we can build congruity through practical tools. Templates for documenting 3D data workflows that are both modality-specific and unobtrusive could provide a structure that fosters efficient dissemination, collaboration, and assessment of 3D data. Agreement on documentation could permit the evaluation of a 3D resource for specific tasks and contexts and could uphold and expose scholarly rigor. The community is working now to identify needs, extant methods, and vocabularies and to provide direction on how this documentation can be created and linked.

An analysis of ongoing requirements is taking place, which aims to make it possible for repositories to be optimized for long-term 3D data preservation and for access. Congruous 3D data repository requirements will support the discovery of 3D assets that are years old, allowing future scholars to reuse, re-create, and remix these data. Repositories will be able to describe which data holdings have been treated for preservation and persistence, which will in turn inform reusers about the data set's integrity. That sort of quality assurance permits datasets to be retrieved, studied, augmented, and cited to advance research or allow for the production of new scholarship. Through community consensus we will move toward interoperability by establishing preferred formats that will make vendor adoption practical. In multiple forums we have heard arguments for responsive platform design that can deliver heavy data for use in powerful, high-performance computers, as well as decimated data for use on small devices, such as a smartphone, which is particularly important for countries that depend on mobile accessibility.

We do not envision there being "one repository to rule them all," but the community may at some point be able to build a tool that aggregates metadata following the standards on which we agree. An aggregator would allow access from disparate repositories so that users could search across disciplines to find digital 3D assets. For example, an animator for the Discovery Channel could search for a 3D rendering of a plesiosaur and find a reconstruction offered from the University of Michigan with appropriate metadata that would enable them to determine whether the 3D asset would be useful,

appropriate, and accurate, without duplicating effort. Users should be able to download, derive, augment, and redistribute an object with its provenance attached as embedded metadata or, at the very least, clearly articulated and explained in related documentation.

Through a common understanding of what is central to 3D data, a community-developed approach to data curation will facilitate reproducible workflows and provide methods by which to evaluate the integrity of data objects. Established requirements will allow creators to reference guidelines that not only will support data management planning, but also will inform workflows and documentation of the data generated and the arguments created. Preservation of these data is essential in supporting the basis of scholarship. Curators value openness and sharing, but that must be balanced with cultural sensitivity, a rights structure that supports creator innovation, and proper recognition for novel forms of scholarship. Such a structure will also provide a basis for the measurement of 3D scholarship and thereby help to facilitate promotion and tenure based on these data.

Determining rights and attributions for creators and scholars is not the only consideration while developing common needs for 3D preservation. Understanding 3D data creation and ownership is problematic, as suggested by Angel Nieves in his talk at CS3DP Forum 1 (Wittenberg, Nieves, and Mbunzama 2018), because cultural heritage assets have been largely in the hands of the privileged. Adopting a lens grounded in diversity, inclusion, and equity by including additional voices of marginalized user and creator communities will ideally address some of the biases within digital collections that reflect a singular, sometimes predatory, cultural perspective. By integrating our communities' diverse needs and perspectives early in the establishment of a standard 3D data curation process and throughout its development, we can begin to build real relationships that address the prevalence of bias and violence done by the academy, archives, libraries, and museums. A best practice or standard steeped in the values of diversity, inclusion, and equity can promote social justice through the inclusive curation and preservation of 3D cultural resources.

Once the community of diverse 3D scholars and contributors has been established, we may yet succeed in creating an inclusive, collaborative 3D data preservation ecosystem. Community collaboration is necessary to build flexible standards and practices that afford librarians and data curators the tools that they need to support the 3D community's continued innovation, development, open dissemination, and further discovery of 3D research. With the appropriate consideration of different perspectives, we will generate the necessary fervor to support 3D research where we can share, use, find, and benefit from each other's data well into the future.

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Conclusion

3D/VR: Stakeholders, Ecosystems, and Future Directions

Zack Lischer-Katz, Kristina Golubiewski-Davis, Jennifer Grayburn, and Veronica Ikeshoji-Orlati

The essays in this report offer a glimpse at how 3D and VR are being used for their scholarly and pedagogical benefits. Supporting these technologies furthers the mission of academic libraries to ensure that their constituencies have access to scholarly information in all forms and formats. The potential benefits of 3D/VR technology can be fully realized only when the technology is properly integrated into research programs and teaching curricula, an area in which the library can lead. Yet, the essays also make it clear that there remains a range of critical considerations that library professionals need to keep in mind as they shepherd novel 3D/VR technologies into their institutions, especially as they find themselves supporting new and complex technical workflows, scholarly practices, and data curation and digital preservation requirements.

The great diversity in the range of stakeholders involved complicates the development of comprehensive technical tools. One of the benefits of the CLIR 3D/VR colloquium was that it not only brought together a diverse range of stakeholder groups and enabled knowledge sharing across often-siloed groups, but also helped to identify stakeholder groups that the planning committee had not identified before the 3D/VR discussion.

The box on the following page shows the stakeholder groups represented at the colloquium, including invited experts and other attendees from the broader University of Oklahoma academic community, as well as additional stakeholder groups that had not been included in the colloquium.

Diverse Stakeholders

The following stakeholder groups were represented at the CLIR 3D/VR colloquium:

- 3D technologies and architecture specialists
- Archaeological 3D data researchers
- Independent 3D animators
- Industry
 - Corporate 3D scanning practitioners
 - 3D model sharing platform representatives
- Library communities
 - Academic library administrators
 - Digital humanities librarians
 - Digital library applications developers
 - Digital preservation specialists
 - Digital scholarship specialists
 - Emerging technology librarians
 - Entrepreneurship librarians
 - Fine and applied arts librarians
 - GIS and anthropology librarians
 - Librarians of reference and instructional services
 - Postdoctoral fellows in data curation
 - Social sciences and humanities librarians
- Meteorologists
- Nonprofit preservation organization representatives from the Software Preservation Network and CLIR
- University faculty members with expertise in
 - Advanced medical imaging
 - Biology
 - English
 - Fine arts, sculpture
 - Journalism
 - Media arts and sciences faculty

The following groups, not represented at the colloquium, were also identified as stakeholders:

- Architecture libraries, archives, museums
- Industries
 - Aerospace
 - Automotive
 - Games and entertainment
 - Software development
- Museum patrons
 - Children with disabilities
 - Elementary school educators and students
- Museum staff
- Public library patrons
- Public library staff
- Students, undergraduate and graduate, in
 - Architectural history
 - Art
 - Computer science
 - Digital humanities
- Underrepresented communities
 - Communities with different technological bandwidths (i.e., impact of “digital divide”)
 - Elderly populations
 - Indigenous and native communities
 - Minority communities seeking to preserve their cultural heritage
- Other university programs/schools
 - Law school libraries
 - Schools of architecture

These expansive lists illustrate the wide range of communities that have an interest in the development of standards and best practices around 3D/VR technologies. No longer does this area of research interest only a small group of specialists. From schoolchildren to advanced researchers across multiple disciplines, the use and impact of 3D/VR are expanding rapidly and becoming increasingly mainstream.

In part because of this growing range of stakeholder groups, there is still much debate about who will lead the way in establishing the 3D/VR ecosystem identified in this report. For example, will researchers and other content creators, libraries and archives, or commercial platforms take the lead? Should the ecosystem be a centralized one or a more loosely associated network? It is clear that the key elements of any 3D/VR ecosystem should include the following tools and modules:

- A universal viewer that integrates with existing and emergent 3D creation workflows and VR visualization tools.
- Tools and metadata schemata that enable the documentation of production workflows, especially in cases where 3D data are hand-edited or reduced in some way through the production of scholarly outputs. These tools and schemata also should support metadata capture for preservation and rights management purposes.
- A storage and retrieval platform for 3D data, designed to support the full range of 3D data uses, including creation, 3D printing, visualization and analysis, and publication.

Libraries can take the lead in supporting these 3D/VR infrastructural components because they are the multidisciplinary hubs of academic institutions and have experience supporting the administration of information resources, as well as research and development around new scholarly technologies. Furthermore, they harbor a long institutional history of preserving and providing access to knowledge for academic institutions, and they can meet the needs of multiple departments simultaneously. For this reason, many libraries are currently working to support 3D/VR projects through a combination of providing training opportunities, such as workshops within the library, hiring staff to provide services in support of research projects, and working to create a communitywide framework for preservation.

Several models of partnership may be forged among technologists, faculty, and other interested stakeholders working toward the common goal of supporting current creation and preservation efforts using 3D/VR work in academic institutions. The diverse approaches discussed in these essays may guide librarians and digital curators alike as they approach the complex field of 3D/VR data creation, dissemination, and preservation. Of course, each institution has a set of unique local needs; thus, each case study presented herein offers unique challenges and solutions that provide directions for further experimentation and research. At the same time, cross-disciplinary communities in the field (e.g., Community Standards for 3D Preservation, Building for Tomorrow, the Software Preservation Network, and Developing Library Strategy for 3D and Virtual Reality Collection Development and Reuse, to name a few) are working toward a more cohesive model of addressing the standardization of preservation methods and training; they hope to integrate their findings into a holistic approach that addresses the needs of communities across national and international contexts. As more libraries take up the call to action around this topic, we hope that this report—presented as a snapshot of the current state of the field—can provide an entrée into critical engagement with the exciting field of 3D/VR and other emerging scholarly tools in the rapidly changing academic library of the twenty-first century.

Acknowledgments

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Glossary

360-degree video: Digital video files created by using either special lenses or multiple cameras to capture all angles of view (i.e., images 360 degrees around the camera setup). For playback on a computer monitor, the user selects the part of the scene to be viewed by means of a keyboard and mouse, and then moves the perspective around the recorded 360-degree scene. With a VR headset, users move their heads and bodies to see different viewing angles of the scene.

3D file formats: 3D meshes

- a. **X3D:** Open-source, royalty-free International Organization for Standardization–compliant standard that defines a 3D data file (encoded in a variety of formats, including XML, ClassicVRML, compressed binary encoding, and JSON encoding). It replaced Virtual Reality Markup Language (VRML) in 2001. It is actively maintained by the Web3D Consortium. File extensions include .x3d, .x3dv, .x3db, .x3dz, .x3dbz, and .x3dvz.
- b. **OBJ:** File format for encoding 3D geometry. Originally developed by Wavefront Technologies, it is now an open format and widely supported by 3D modeling software. OBJ files store only geometry information, so textures have to be stored in a separate file. OBJ files have the extension .obj. Because they are supported by most software programs, OBJ files are widely used—even though they lack a variety of functions, including internal texture mapping and embedded metadata capabilities.
- c. **DAE:** Open-source, International Organization for Standardization–compliant standard file format for encoding 3D data. Also referred to as COLLaborative Design Activity (COLLADA), DAE has provision for some metadata fields, can contain scale information, and is encoded as XML. It was originally designed as an interchange standard for moving 3D models between different 3D modeling and animation packages. Many 3D software packages can open and export DAE files. The nonprofit Khronos Group currently manages DAE. The file extension is .dae.
- d. **PLY:** File format developed at Stanford University by Greg Turk in 1994 to encode 3D geometry and some surface properties. It is also known as the Polygon File Format or, less commonly, the Stanford Triangle Format. The file extension is .ply. It has more functions than OBJ, but lacks the rich feature set, including embedded metadata, of DAE and X3D.
- e. **FBX:** Proprietary 3D file format developed by Kaydara and now owned by the large CAD modeling software corporation, Autodesk. Derived from FilmBoX, it is not openly documented, but it can be encoded as ASCII in a structured form that is human readable. The file extension is .fbx.

- f. **STL:** File format used by CAD software to encode 3D information. The name is derived from its use in stereolithography, a form of 3D printing. It is often output from 3D modeling software in order to enable 3D printing. It stores geometric information in a 3D, Cartesian coordinate system and does not carry surface texture information or scale information. The file format is .stl.

AR (augmented reality): Technologies that blend computer-generated images, sounds, and haptic sensory inputs with real-world sensations. Unlike VR technologies, AR does not cover up the user's sensory field completely, but "augments" it by adding additional layers of sensory information that complement real-world phenomena.

assets: A general term for individual components that compose 3D and virtual environments (see: *mesh*).

BIM (building information modeling): Use of digital tools to model the physical and functional properties of architectural spaces. It enables governments and businesses to plan for and manage critical infrastructure.

CAD (computer-aided design): Use of computers to assist in the creation of designs, including architectural and engineering designs. They can be 2D (taking the place of traditional drafting techniques) or 3D (taking the place of model building). Architectural and engineering design work is now done primarily using CAD.

decimate: To reduce the information in a 3D polygon mesh by simplifying its geometry (i.e., by reducing the number of polygons). This is often necessary to make it more practical to work with the resulting mesh files, which can otherwise be very large. Web-based viewers and virtual reality systems, because of the limitations of graphics processor power, have limitations on the quantity of polygons that can be displayed at one time without system slowdown.

GIS (geographic information system): System that displays, manages, and analyzes layers of spatial data.

LiDAR (light detection and ranging): Remote-sensing technology that measures distance using low-energy laser pulses. Often used in aerial surveys, LiDAR technology emits a laser pulse, which reflects off an object, and records its return delay to determine distance points. Compiled distance points can be used to generate 3D representations of target objects (see *point cloud*).

MR (mixed reality): Technologies that blend computer-generated images, sounds, and haptic sensory inputs with real-world sensations. MR is similar to AR in that digital layers of sensory input overlay real-world phenomena, yet MR technologies more convincingly "mix" virtual and physical reality through the real-time interaction between the two.

mesh: Generated from a set of data points (see *point cloud*) by software (e.g., Agisoft Photoscan and other photogrammetric processing software), a grid of triangles or other polygons that define the 3D surface of an object. Because the mesh is composed of geometric elements that have vertices (points) and lines, they can represent the same spatial information as a point cloud with fewer data points. In addition, this creates a “watertight” model that can be 3D printed or brought into a VR environment and analyzed as a solid object rather than a set of discrete data points floating in space. Meshes can also be generated from computer-aided design (CAD) projects, in which there is no original source object.

photogrammetry: Technique in which (at least) two photographs are taken from slightly different perspectives to calculate the three dimensional coordinates of a space or object. By measuring changes in the vertical (y axis) and horizontal (x axis) position of points in each photograph, the distance from the camera to the object in question can be calculated, producing the data on the depth (z axis). The basic technique dates back to the nineteenth century when surveyors and those producing topographical maps measured points in photographs and mechanically compared them to calculate precise spatial coordinates. Contemporary photography uses computers and sometimes hundreds of captured images to rapidly produce highly detailed 3D data that can be used to produce 3D models in the form of polygon meshes (see *mesh*).

point cloud: Set of data points that describe the x, y, and z spatial coordinates of real-world objects. Obtained by light detection and ranging (LiDAR) and photogrammetry techniques, these data points can number in the millions. When rendered graphically, they resemble a cloud of individual points suspended in space. Depending on the quality of the scanning process, there may be holes in the data that need to be filled in before the point cloud can be converted into a polygon mesh (see *mesh*) for 3D modeling and printing purposes.

retopologization: Process in which the surface of a 3D polygon mesh (see *mesh*) is replaced with a more efficient configuration of polygons. It can help reduce the file size and ensure that edges of polygons conform to the edges of the model features, which makes animation and other activities easier to accomplish. Tools provided with 3D modeling software are used in the process.

structured-light scanning: Highly accurate, 3D scanning process that involves superimposing patterns of light onto a physical object and a camera to capture information about the distortion of light patterns caused by contours of the object. Structured-light scanning can capture large sections of an object at once and can be quicker than some other capture processes, including photogrammetry and laser scanning.

texture map / UV mapping: Map that carries color and texture information of an object and defines how that information should be wrapped around a 3D mesh (see *mesh*). UV mapping is a common way of defining and attaching texture maps.

VR (virtual reality): Use of complex arrangements of computer software and hardware to re-create the sensory impression of real-world experience. Current systems use head-mounted displays (HMDs), hand controllers, and tracking sensors to produce interactive and immersive worlds composed of stereoscopic images and sounds. Some VR systems have started to provide haptic and olfactory interfaces as well as sound and image. In addition to HMDs, CAVE systems (employing large, multiscreened rooms and 3D glasses with head tracking) have been developed, but they are far more costly than the current wave of commercially available HMDs and require custom installation.

XR (extended reality): Overarching term encompassing the full spectrum of experience, from real-life to blended to full immersive reality (see *360-degree video, AR, MR, and VR*).

About the Editors and Authors

Editors

Kristina Golubiewski-Davis is interim director of the Digital Scholarship Commons at the University of California, Santa Cruz (UCSC), where she works to provide access to technologies that enable new modes of knowledge building, creates opportunities for students to integrate digital tools into their learning, builds partnerships with UCSC faculty and staff to facilitate digital research and scholarly publication, and develops spaces that foster experimentation and innovation. She previously held a CLIR postdoctoral fellowship at Middlebury College and received her PhD in anthropology at the University of Minnesota. Her dissertation focused on connecting measurable aspects of bronze swords to communities of knowledge during the Late Bronze Age. Throughout her career, she has been an advocate for working with 3D and digital technologies for research, outreach, and educational purposes.

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Authors

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Andrea Copeland is chair of the Department of Library and Information Science in the School of Informatics and Computing at Indiana University in Indianapolis. Her research focus is public libraries and their relationship with communities. Her current emphasis centers on connecting the cultural outputs of individuals and community groups to a sustainable preservation infrastructure. She is the co-editor of a recent volume, *Participatory Heritage*, which explores the many ways that people participate in cultural heritage activities outside of formal institutions.

Thomas Flynn began working with 3D for cultural heritage while at the British Museum, creating the museum's first online collection of downloadable 3D scans. He went on to co-found Museum in a Box (museuminabox.org) in 2015 and joined Sketchfab as cultural heritage lead in 2017. At Sketchfab, his work focuses on exploring the possibilities of accessible 3D digitization and online 3D and extended reality, and encouraging institutions large and small to share their 3D data, knowledge, workflows, and experiments in this rapidly evolving field.

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Jennifer Moore is the data services coordinator and anthropology librarian in the University Libraries, and program faculty in International and Area Studies in the School of Arts & Sciences at Washington University in St. Louis. She leads data management and curation initiatives, teaches and provides support for data analysis, and oversees the Libraries' 3D capture initiatives. She is a co-principal investigator on the IMLS-funded Community Standards for 3D Data Preservation project and is a partner on the IMLS-funded project, Building the Digital Curation Workforce: Advancing Specialized Data Curation.

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