Research Article

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Using 3D/VR for Research and Cultural Heritage Preservation: Project Update on the Virtual Ganjali Khan Project

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Abstract: This paper describes the Virtual Ganjali Khan Project, an ongoing research initiative that is using 3D scanning and immersive virtual reality (VR) technologies to document a large historical landmark in the desert city of Kerman, Iran, the Ganjali Khan Complex. It describes the intellectual merits of these emerging technologies for preserving and providing new forms of access to cultural heritage sites, outlines the procedures of data collection and 3D processing, and describes the current work and next steps of the project. This paper will be of interest to scholars and institutions considering using 3D and VR technologies for supporting cultural heritage preservation, digital humanities projects, or other types of interdisciplinary research.

Keywords: virtual reality, 3D scanning, Iran, Ganjali Khan complex, architecture

1 Introduction

The Virtual Ganjali Khan Project is a partnership between the College of Architecture and the University Libraries at the University of Oklahoma. The goal of the project is to digitally preserve, expand access to, and develop new scholarly tools for studying the Ganjali Khan Complex, a vast historical landmark in the desert city of Kerman, Iran. Original construction on the site began in AD 1596, making it over 400 years old, and it is approximately 5 million square feet in area. Figure 1 shows an image of the site

captured in July 2018 by the first author and Figure 2 shows a floorplan of the site produced by the first author.

The project is producing high-fidelity 3D models that will be used to build immersive virtual reality (VR) experiences of the Complex. The goal of the project is to expand access to information about this remote location in ways that transcend the limitations of traditional architectural data collection methods, aiding in the preservation of information about cultural heritage artifacts and spaces associated with the site (now at risk, given current geopolitical conflicts), and enabling new forms of analysis for historians, architects, and engineers, using 3D data collection and VR technologies. The project started in 2018 with initial documentation of the site using photography and is expected to be completed in 2022. This report provides a glimpse into current and future work, providing insight into the workflows and challenges associated with planning and executing these types of projects.

The Ganjali Khan Complex combines vernacular Iranian architectural elements in unique ways that have enabled its inhabitants to thrive in a very hot desert climate. The Complex illustrates the architectural forms of a culture of desert-living people in Iran who were among the earliest groups to create sustainable living conditions (Hashemi and Barmaki 2013). The project will extend current research on the ecological dimensions of Islamic culture (Foltz 2013) and expand understanding of how desert architecture makes harsh climates into habitable spaces (Fathy, Shearer, and Sultan 1986).

While this site is acknowledged as a landmark in Iran, its architectural elements have not been analyzed in great detail. Because of this, little is known about the development of the Complex, how its esthetic and architectural elements developed over time and have been integrated with each other, and the meaning that these spaces have had for its inhabitants.

Using 3D/VR technologies enables analysis of the Complex at human scale in high-fidelity, immersive models that the researcher can virtually enter and explore. Commenting on the limits of how people can interact with

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Figure 1: Preliminary study of the site: Drone view of Ganjali Khan complex (captured by Dr. Khosrow Bozorgi, July 2018, copyright Khosrow Bozorgi).

Figure 2: Preliminary study of the site: Documentation of Ganjali Khan complex (by Dr. Khosrow Bozorgi, copyright Khosrow Bozorgi, 2020).

traditional museum exhibits, Jessie Palud (2009) emphasizes the importance of engaging multiple sensory dimensions to enable understanding: “being able to touch things or to manipulate them contributes to a better experience and to better interpretation” (4). 3D and VR together make it possible to support “better interpretation”

of cultural heritage materials because they engage more of our senses and enable interactions with digital representations that potentially engage the full range of bodily motions. The capture of 3D data is also increasingly used as a method of data collection and for the creation of digital surrogates in museums and other institutions, which

bridges cultural heritage preservation and methods of scientific measurement, opening up new research, preservation, and exhibition possibilities. As Henry Chapman et al. (2013) suggest, “these new ways of engaging with objects offer exciting opportunities for providing access to the collection, for example, for school groups and for users that are visually impaired which would not normally be feasible due to the fragility of some of the objects” (20-1). Ann Bentkowska-Kafel and Hugh Denard (2012) emphasize a major strength of virtual cultural heritage projects as the ability to mobilize visual information in complex ways that enable new methods of analysis: “visual representations of ideas and phenomena can enable synthesis of potentially vast amounts of varied information with graphical precision, and can provide intuitive interfaces that facilitate understanding of spatial, temporal, acoustical and other data” (1). For instance, 3D data captured from an archaeological excavation can be analyzed in conjunction with visualizations of historic artifacts, documents, etc.

However, there are limits to the information that can be captured and presented using 3D/VR tools. Hindmarch, Terras, and Robson (2019) remind us that 3D scanning is only able to represent some aspects of physical objects in the world, providing high-fidelity capture of certain attributes of objects, such as their geometry, while leaving behind other aspects that are not as easily represented (e.g., weight). Color information can also be a challenge to capture accurately (Hindmarch, Terras, and Robson 2019). They stress that it is important to be cognizant of the limits of 3D tools and to clearly define the purposes of the models being created. In the case of the Virtual Ganjali Khan Project, the particular 3D techniques have been chosen because, if used properly, they are able to provide fairly precise measurements of the spaces being studied (for architectural analysis) and can capture color and texture information, which is important for representing the esthetic dimensions of the site.

Research has shown the benefit to researchers of using 3D/VR technologies for enhanced pattern recognition and increased discovery of novel features in geospatial data (Donalek et al. 2014). In this project, using 3D/VR can help researchers discover new patterns or textures in the tile work and ornamentation that are not visible in flat 2D images of the interior and exterior of the Complex, or identify subtle traces of repairs and additions that show the history of the building’s development and use (e.g., by adjusting the lighting, zooming in, exploring at multiple scales, etc.). Humanities scholars have found 3D/VR technologies to be useful for uncovering new details in seemingly flat artifacts, such as medieval manuscript pages (Endres 2019).

Utilizing 3D/VR technologies will also enable better understanding of how the design elements of the spaces work together to produce a hospitable interior environment of the complex even under harsh conditions, which has implications for developing sustainable architecture in an era of anthropogenic climate change. The 3D data being captured will hold interdisciplinary interest for researchers in a number of fields outside of architecture and cultural heritage preservation. 3D data collection methods produce precisely measured digital models that can support computational analysis of the spaces (including simulations of drafts, wind, temperature gradients, and sun positions), of interest to science and engineering fields.

Because of the complex technical procedures and the multiple decision-making points involved, the creation of 3D data requires special documentation to ensure research integrity. An important part of providing context through documentation is by capturing *paradata*, metadata about processes of data creation and interpretation. Bentkowska-Kafel and Denard (2012) articulate the importance of “reliably documenting the process of interpretation of historical materials and hypotheses that arise in the course of research” and explain that “paradata document the process of interpretation so that the aims, contexts and reliability of visualization methods and their outcomes can be properly understood” (1). The importance of capturing paradata will be discussed further in the later section, “Data Curation Plan.”

2 Project Goals and Background

The main goal of this project is to explore Iranian traditional architecture visually and intellectually in order to illustrate how its interior and exterior aspects are rooted in the dualities of its forms and functions. Together, 3D and VR technologies offer rich analytic capabilities for exploring this specific vernacular architecture in Iran that will inform our understanding of sustainability (Wescoat 2016) and contribute to our knowledge about local and global issues in architecture and urban living.

This project focuses on a unique culture that, over centuries, developed distinctive architectural forms of great beauty and utility that were able to successfully confront the harsh challenges of the desert environment. Central Iran has limited water supplies, a dry desert climate, and large variations in temperature from day to night. Yet for many centuries, its vernacular architecture has harnessed local resources and ingenious technologies to provide functional and comfortable spaces for its

people's everyday activities. For this reason, these ancient architectural techniques are highly relevant in today's world and the Complex offers rich examples of these techniques in unique configurations. One of the other research goals of this project is to show how architectural techniques and the way in which they interact together in this complex system have contributed to the long-term survival of people living in one of the world's harshest climates. This project explores the unique esthetic aspects that arose from the diverse influences on this architecture's development, the physical features of this distinctive architecture and the relationship of desert architecture to the human spirit. Exploring this specific vernacular architecture in Iran helps to inform our understanding of sustainable architecture, and produce new knowledge about local and global issues in architecture and urban living in the current era, extending Hassan Fathy's (Fathy, Shearer, and Sultan 1986) research on "architectural thermodynamics and human comfort in hot climates."

2.1 About the Site

The Ganjali Khan Complex articulates a rich architectural tradition in Iranian desert architecture that has accrued a legacy of valid responses to the perennial dictates of human concerns and environmental conditions. The environmentally adaptive and sustainable principles of the Complex are the legacy of sound and balanced building designs in desert architecture. The genius of such principles is that they are based upon the human scale, the body's "golden mean" proportions, and highlighting the vernacular use of appropriate construction materials will help researchers and others understand the profound reflections of the archetypal meanings of spiritual transcendence and cosmic unity inherent in desert architecture (Ardalan 1973; Critchlow 1976). As discussed earlier, the affordances of VR to support human-scaled engagement with 3D representations will enable the interpretation of architectural proportions from the perspective of people inhabiting and moving through the Complex. This approach provides opportunities for new insight into the architectural dialogue between indoor and outdoor spaces that represents the unique character of desert cities and amplifies the brilliance of the desert cultures that evolved and flourished in an inhospitable, barren region (see Figure 3 for an example of the Complex's interior spaces by the first author; see Figure 4 for an examples of the exterior of the Complex, with prominent wind catcher, captured by the first author). In such an environment, all buildings are designed with one major objective in mind

– to counter the harsh climate in a way that could be easily sustained for protection from both summer heat and winter cold. In the organization of desert cities, this consideration has entailed respecting and learning from the several millennia of the region's previous history, especially the contributions of earlier civilizations such as Sumer and from previous religions, such as Zoroastrianism. This project encourages new insight into how the desert architecture of Iran simultaneously articulates plurality and opposition. It supports an investigation of the variety of elements that constitute these compact urban spaces, including passageways, courtyards, and community buildings, and the ways in which these elements defend against the harmful winds, dust storms, and sun radiation of the desert. This desert architecture produces an infrastructure so dense that the massing of the houses within a city obscures the boundaries between them (Dutz 1997) and this project will enable detailed investigation of these dense urban spaces.

Producing high-fidelity 3D models provides resources for the production of new scholarly knowledge about the architecture and visual culture of Ganjali Khan, extending existing work on Iranian architecture (e.g., Godard 1965; Grabar 1964; Herdeg 1991; Hillenbrand 1994; Jairazbhoy 1972; Wescoat 2016). Having precise and accurate multi-dimensional data on the structure, design, and ornamentation of the Complex helps scholars understand how it was built and used. Better understanding how the elements of vernacular desert architecture interact with each other will also make it easier for designers to incorporate these elements into modern designs. Researchers such as Alp (1991), Alrashed, Asif, and Burek (2017), and Maleki (2011) have identified the benefits of integrating vernacular design elements into sustainable desert construction, and these designs hold rich cultural symbolism for the people who inhabit this type of architectural landscape (Sani and Shotorbani 2013).

For example, architectural elements such as the prominent "wind catchers" have been studied for their impact on cooling interior spaces (Aryan et al. 2010; Pirhayati et al. 2013; Valibeig, Nasekhian, and Tavakoli 2014), and there is growing interest in how architectural elements interact and work together to produce hospitable environments (Baghchesaraei and Baghchesaraei 2014; Esmaeli and Litkouhi 2013). However, there is still a gap in fully understanding how these elements physically shape the interior environment in complex ways and contribute aesthetically to the full human experience of these spaces.

The project also illustrates the unique esthetic aspects that arose from the diverse influences on the building of this architectural site (Creswell 1965; Foltz 2013),

Figure 3: Interior of Ganjali Khan complex bazaar (captured by Dr. Khosrow Bozorgi, copyright Khosrow Bozorgi, 2018).

Figure 4: Exterior of Ganjali Khan complex, including wind catcher (captured by Dr. Khosrow Bozorgi, copyright Khosrow Bozorgi, 2018).

expanding knowledge in the field of Islamic esthetics (Gray 1977) and culture. Scholarship in the study of Islamic architecture has shown that the architecture of desert cities illustrates important spiritual communication between buildings and people (Clark 1980; Holod 1978). The solid exteriors conceal the interior features in a way that suggests the inhabitants' connections to the life-giving

refreshment of nature – air, wind, water, shade, and greenery – in these structures' interiors. Producing 3D/VR data and representations of the Ganjali Khan Complex will enable exploration of the “indoor-outdoor” features of this architecture, which will help illustrate sustainability in terms of the connection between nature and inhabitants. These models will form the basis of an analysis that will

explore the theme “studying the hidden unity in organic planning of historical Ganjali Khan Complex,” establishing an intellectual and theoretical framework for studying sustainability (Bozorgi 2018). The technical approach of this project will enable researchers, students, and the public to virtually inhabit the space to holistically understand the experience of dwelling in and moving through the Ganjali Khan Complex, simultaneously supporting esthetic, architectural, and engineering research.

2.2 Background on the Technology

The use of 3D data capture to document spaces and artifacts has become common as a data collection method in the field of archeology (Milovanovic et al. 2017) and for the digital reconstruction and preservation of cultural heritage sites (Pfarr-Harfst 2016). 3D data capture, coupled with reconstructive modeling based on archaeological evidence, has been used in a burgeoning area of research, falling under the umbrella of *3D cultural heritage informatics* (Rourk 2019) or *virtual heritage* (Baker 2012; Bentkowska-Kafel and Denard 2012). 3D data collected from cultural heritage sites and artifacts can have many potential uses beyond the initial project. As Chapman et al. (2013) point out, 3D capture techniques produce

an archive of data that could be re-used in the future, both in terms of documented interpretations, but more importantly the scan data itself. The real value of the use of high-definition survey rests in the way in which data that was perhaps generated for a particular purpose can be re-tasked for additional purposes. (2013, 16)

The potential for data reuse is an added benefit that helps to rationalize the significant effort and cost of 3D data capture projects, and it also makes clear why appropriate data curation techniques are necessary for supporting data transparency and reusability, which will be discussed in more detail in a later section of this paper. 3D/VR cultural heritage projects can take many forms. They can involve content entirely modeled using 3D software, based on archival documents and photographs, as in the case of the seminal *Virtual Harlem* project (Carter 2015), or they can be modeled based on archaeological evidence as in the case of the *MayaArch3D Project*, which reconstructed the landscapes of ancient Mayan cityscapes (Richards-Rissetto and von Schwerin 2017). The *Rohwer Reconstructed* project created by the Center for Advanced Spatial Technology (CAST) at the University of Arkansas places 3D scans of artifacts within a modeled VR world that was based on architectural drawings and archival photographs of a

World War II-era Japanese-American internment camp in Arkansas (Center for Advanced Spatial Technology). A recent project that blends 3D scanning, 3D modeling, and VR is the *Virtual Bethel* project at Indiana University – Purdue University, Indianapolis (Wood, William, and Copeland 2019). This project used 3D data produced by laser scanning to guide the modeling of the interior of a historic African-American Church in Indianapolis that was soon going to be shuttered. It combined sound and animated 3D representations for storytelling and simulation of the embodied experience of visiting the Church when it was in active use. This project shows the potential these emerging technologies hold for producing new documentation for at-risk cultural heritage sites. These are only a few examples of the various ways in which 3D/VR technologies can be used.

Once completed, the 3D models produced through the *Virtual Ganjali Khan Project* will be viewable in a VR environment. When accessed using immersive VR systems, 3D models can be analyzed across all three-dimensions simultaneously via stereoscopic, interactive images (Lischer-Katz et al. 2019), which has been shown to enhance a researcher’s ability to make judgments (Ragan et al. 2013) and detect patterns in spatial data (Donalek et al. 2014; Laha, Bowman, and Socha 2014; van Dam, Laidlaw, and Simpson 2002). Rourk (2019) has suggested,

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. (2019, 36)

Similarly, Fernández-Palacios, Morabito, and Remondino (2017) have demonstrated ways in which VR technology “enables a non-destructive way for archaeologists, historians, and other academics to inspect archaeological sites, providing accurate and precise details of monuments (based on the resolution of the 3D model used), without damaging, dirtying or altering heritage sites” (46). Together 3D and VR provide the means of analyzing and engaging with cultural and architectural spaces beyond the limitations of traditional architectural methods, such as surveying, photography, and video recording. This configuration of technologies can create a *3D research ecosystem* (Limp et al. 2011) that supports enhanced analysis of cultural heritage sites. Furthermore, VR enables users to “walk through” architectural sites scaled accurately and in proportion to the human form (Poher and Cook 2016; 2019). This supports the interpretation of 3D data from the perspective of the human body and its relationship to space (Donalek et al. 2014), which is

particularly relevant to understanding complex architectural sites. The *Virtual Ganjali Khan Project* enables analysis at multiple scales, from precise micro-analysis of individual tiles in the corridors, to the macro scale of large elements of the Complex, to simulating what it is like to navigate and dwell in the space at human scale. This assists researchers in their studies of how the human body moves through the space, how the architectural elements connect and work together, and how the interior elements relate to the exterior elements, providing insight into the construction of the building and the ways in which its elements work together to create a sustainable environment.

Making the 3D models produced by the *Virtual Ganjali Khan Project* available through VR also benefits students, since it has been shown to enhance undergraduate educational experiences in fields that use models for student learning, such as architecture (Pober and Cook 2016) and anthropology (Lischer-Katz, Cook, and Boulden 2018). Paes, Arantes, and Irizarry (2017) found that immersive VR environments improved the spatial perception of architectural models for participants (in this study, architects and civil engineers) compared with a traditional computer workstation. Luigi et al. (2015) found that if VR reconstructions of real-world urban spaces are done in immersive and highly-realistic ways, users will perceive the attributes of these spaces in nearly identical ways, suggesting that essential informational attributes of a space can be convincingly rendered in VR for certain users. 3D/VR technologies have both clear research and pedagogical benefits that this project will take advantage of.

3 Project Phases

3.1 Phase 1: Summer 2018 and Summer 2019

This project began in 2018 and has been built upon the first author's longtime professional work, academic research, and teaching which focuses on all aspects of Middle Eastern architecture,¹ and an earlier video he produced, "Walking Through Ganjali Khan." The first author has done an extensive cultural study of Ganjali

¹ The first author founded a research center on Middle Eastern architecture, which investigates the architectural traditions of the region and the way these traditions, in the course of history, have been formed by social and cultural factors over the course of centuries; contemplates the consequences of modern dynamics that are placing new demands on architectural developments in the region; and makes plans based upon these insights for future activities in Middle Eastern countries.

Khan and has conducted extensive visual documentation of the site in the summer of 2018 and 2019 (via drone photography and videography). In Phase 1 of the project, the first author has created a digital area plan and built a preliminary 3D model of the site using SketchUp. This has enabled the production of physical architectural models of the Kerman Bazaar and Ganjali Khan Complex, and preliminary work on 3D animations of the site. In spring 2020, the Complex has become a design research theme for the graduate students in the first author's Architecture course at the College of Architecture.

3.2 Phase 2: Summer 2020 (or 2021)

On-site data collection in Iran for this project will be completed during visits to the site planned for summer 2020. The work of creating the 3D models and VR environments will take place back in the U.S. at the University from fall 2020 to spring 2021.² At the end of data capture, the first author and his team expect to capture over 250 GB of digital images, including over 10,000 interior images to be used for 3D processing via photogrammetric methods. In summer 2020 they will finish data capture of the central 15% of the exterior of the site, which represents its key elements, and will survey the site, create a plan view of the entire site, and create a 3D rendering that will aid in the assembly of the VR environment. The project team is applying for internal and external grant funding to support interdisciplinary collaborations between the University Libraries and the College of Architecture, to hire graduate and undergraduate student researchers to process 3D data and build the VR environments, and to purchase high-performance computer hardware and software in order to process the 3D data and produce 3D models and VR simulations of the Complex.

3.3 Phase 3: September 2020–May 2021 (or September 2021–May 2022)

The third phase of the project will involve processing the previously captured 3D data using photogrammetry software to produce high-fidelity, textured digital 3D models. Photogrammetry is a process of taking sets of still images in such a way that they can be converted using computer software into 3D models (Luhmann et al. 2014). By

² This timeline will be adjusted if current COVID-19 travel restrictions (as of May 2020) continue into summer 2020. The project timeline may need to be shifted to start in summer 2021 instead.

overlapping the capture of images in a precise way, the software is then able to calculate the Z-axis of visible surfaces based on differences between adjacent images, thus rendering a highly-detailed 3D model with accurate color reproduction. According to 3D imaging experts at Cultural Heritage Imaging, photogrammetry is fundamentally a process of measurement; therefore, a rule-based procedure will be used to capture the 3D data throughout the project. The photogrammetry processing work will be carried out using high-performance computer workstations at the University Libraries by library staff and student assistants.

The captured data sets will be assessed and loaded into Agisoft Metashape Pro, a professional photogrammetry software package. This advanced software uses the “structure from motion” method to simultaneously determine how light passes through the camera’s sensor and the camera’s position and orientation in relation to the object it is capturing. This method is widely used for 3D capture in archaeological research (Cornelis et al. 2014; Verhoeven 2011). When applied to each photo, this approach produces very precise camera calibration and orientation throughout the processing and refining stages of model creation. The software utilizes, in part, the EXIF metadata embedded within each image to align them and calculate the Z-axis.

3.4 Phase 4: Summer 2021 (Summer 2022)

The next steps of the project in Phase 4 include building an accurate area floor plan and a detailed 3D view (using SketchUp or Blender software), necessary for accurately assembling the 3D models and creating an accurate VR environment. The project will utilize custom VR software developed at the University Libraries already in use for research and teaching (described by Cook and Lischer-Katz 2019), which is built using Unity3D (<https://unity.com/>), a game engine and authoring platform that supports the development of VR programs. The locally-produced custom VR software provides a toolkit for analyzing complex 3D models, including the adjustment of lighting/sun position to see how ambient light falls in the space at different times of day, taking measurements, and capturing images and videos, which supports analysis of the dynamics of the space that cannot be derived with traditional survey methods or 2D imaging techniques. The 3D models created in Phase 3 will be viewed using the platform. The models used to support this project will be made freely available to the wider community at the end of the project.

3.5 Phase 5: September 2021–February 2022 (September 2022–February 2023)

Phase 5 will consist of dissemination and outreach. Curated tours of the VR environment will be developed by the project team, and the VR experience will be presented through a series of events at the Library and at the College of Architecture. The project team will also present the findings at academic and professional conferences to promote the use of the VR experiences in classes and by other scholars.

4 Project Outcomes

Project outcomes will consist of the VR environment software and a set of high-fidelity 3D models. The VR environment may be used to support such applications as remote, multi-campus instructional sessions and highly accurate measurement capabilities for this unique architectural wonder, without having to travel to Iran to be physically present at the site. The use of precisely captured 3D data from the site and the resulting models provide opportunities for other researchers to run simulations and create rich visualizations that will enable new understanding of how the architecture is able to sustain a comfortable interior and of the human experience of inhabiting the space.

5 Data Curation Plan

Curating 3D data and capturing important metadata about techniques and decision making throughout the research lifecycle is important for ensuring transparency in research outputs. Capturing sufficient information about production processes is necessary because “scholars in the field need to understand what goes into these models and to be active partners in their creation and care” (Szabo 2019: 14). Because of this, for this project, reports will be exported from the 3D modeling software and paradata will be captured using Cultural Heritage Imaging’s Digital Lab Notebook, which will help document the decisions made during the 3D modeling process, including selection of equipment and technical settings used.

Primary data will be collected in the form of 1000s of digital photographs, which form the raw data for 3D photogrammetric analysis. The first author will store this data on a harddrive that they will deliver to other members of the project team for processing, along with metadata

that describes when and where the images were captured. Checksums will be calculated and files will be backed up to cloud storage. The project team at University Libraries will accept the data, check it for errors (using Fixity software),³ and introduce it into the 3D data processing workflow, which will produce a set of digital 3D models (high and low resolution models). These files will be uploaded to the team's Open Science Framework (OSF) project site, which will make them available to all project team members. The project team will download the high-resolution models from the OSF site as needed in order to build the virtual reality (VR) environment using Unity. Github will be used to maintain version control for the VR project as it is developed. The final VR environment files (including the Unity project files, scripts, and the final executable file), will be archived to Zenodo,⁴ which will support access, citation, and reuse of the final VR project files. Each phase of the project will produce a different type of data and file formats:

- Phase 1: Initial scouting of site: Video and image files (MP4 and JPEG files).
- Phase 2 & 3: 3D Data Capture and Processing: Raw photogrammetry files will take the form of TIFF and DNG files (if any files are in proprietary formats, they will be converted to these formats). These will be stored on two harddrives (one held by the first author and one held by the project team at the library) and backed-up to cloud storage. Raw photogrammetry files will be retained and archived in case the 3D models need to be re-created at a future date as photogrammetry software improves.
- Phase 3: 3D Model Creation: Photogrammetry processing creates many different types of files throughout the processing and creation process. For the purposes of this project, the final high-resolution 3D model files will be saved. This will consist of X3D, OBJ, and related texture files in the form of PNG or JPEG files formats. These output files and the raw photogrammetry files from Phase 1 will constitute the primary archival data for this project, and will be archived along with the final VR environment project files.
- Phase 4 & 5: VR Environment Creation and Dissemination: The Library's VR software that will be used for viewing 3D files was built using Unity3D software. Working with this software produces Unity project files, script files, and the final executable project (.exe).

These materials will be made available to other researchers and students.

The data and project outputs will be archived locally on external harddrives, backed-up to cloud storage, and made available through online platforms such as Open Science Framework (OSF), Zenodo, and Sketchfab (for providing public access to low resolution access files; see Flynn 2019).

5.1 Data Storage and Preservation

3D data and VR systems have special sustainability and long-term preservation concerns and there is a lack of established standards and best practices for 3D data curation and preservation (Alliez et al. 2017; Lischer-Katz et al. 2019). Because 3D projects often involve multiple modalities of 3D data collection (e.g., photogrammetry, structured light scanning, LiDAR, etc.), data curators and librarians have pointed to the difficulty in working with these types of materials:

To complicate 3D data creation, much 3D work is done using a combination of the methods mentioned thus far. 3D data represents the gambit of individualized, single processing work (as with 3D scanning) but may be as complex as a 3D thesis or publication that combines 3D scanning, free-form modeling, data visualization, and traditional research methodologies (Moore and Kettler 2018: 4).

VR adds an additional layer of preservation complexity, requiring digital preservationists to draw on expertise from specialist areas of preservation work, including video game preservation and time-based media conservation, which often utilize emulation and migration of obsolete content as key elements of their preservation strategies. However, as Lischer-Katz et al. 2019 point out, “for 3D/VR, emulation and migration strategies appear to be more difficult because of the complex array of hardware peripherals and drivers that constitute a VR system. Migration to new software/hardware environments may be particularly difficult” (121). Since 2016, OU Libraries has been researching these preservation challenges (Cook and Lischer-Katz, 2019). Curating and preserving 3D/VR research products requires additional library and technology resources. Beyond the support provided by OSF and Zenodo platforms, which are currently free of charge, additional funding will be necessary to support the curation of the project's digital outputs and ensure their long-term preservation, adopting sustainable file formats, monitoring obsolescence risks, and establishing emulation/migration strategies.

³ <https://www.weareavp.com/products/fixity/>.

⁴ <https://zenodo.org/>.

During data processing, 3D model creation, and VR development phases, the project will utilize portable external harddrives for transporting data and for local backups, as well as enterprise cloud backups using Dropbox or Microsoft OneDrive for offsite storage, and Open Science Framework to support shared access to files for project team members. Public access copies of 3D models will be made accessible via Sketchfab and the final VR project files will be published and issued a DOI via Zenodo. Standards and best practices for long-term preservation of 3D data are still being developed and the project team is monitoring current efforts by various projects and organizations to develop guidelines, including projects funded by the Institute for Museum and Library Services (IMLS), such as Community Standards for 3D Data Preservation,⁵ LIB3DVR,⁶ and Building for Tomorrow.⁷ For instance, the Library of Congress has recently started issuing sustainability evaluations for a growing list of 3D file formats (including X3D, U3D, LAS, RTI, PTM, STEP, and IFC),⁸ which the project team will continue to monitor throughout the lifecycle of the project.

The project team is following other 3D/VR projects to see how they have handled the curation and preservation of their 3D materials. For instance, Murillo et al. (2018) identified three major preservation challenges in their recent *Virtual Bethel* project: the challenge of “defining the boundaries and phases of the collection”; “data degradation”; and “obsolescence of formats, software, and hardware” (4–5). They adopted an “archives perspective” for preserving the materials (consisting of digital images, 3D data, project files, processed models, and VR assets, among others), which entailed “preserving all file formats in the original order, or the creators’ folder hierarchy” and providing intellectual access “via a collection-level description, alongside contextual information documenting the creation process and software, hardware, and operating systems” (Murillo et al. 2018: 5). They note that this approach “excluded preservation of all commercial and proprietary software used in the project, as well as the hardware used” (Murillo et al. 2018: 5). Preservation strategies for commercial 3D and VR hardware and software are still a significant challenge that needs to be addressed by the wider preservation community in conversation with

commercial vendors. The Virtual Ganjali Khan project is also adopting an archives perspective, with a focus on preserving files in their original order, providing contextual information about the scholarly processes and workflows that produced the files, and providing collection-level descriptions for the project materials that will enable interpretation of the project after it is finished and archived.

To support efforts at transparency, the project team is exploring the usefulness of the Digital Lab Notebook, open-source software developed by Cultural Heritage Imaging, which provides tools for capturing paradata related to the equipment used and technical decisions made about image capture and 3D processing.⁹ As discussed earlier, an important part of providing context through documentation is through *paradata*, which is data about processes of creation and interpretation. Bentkowska-Kafel and Denard (2012) articulate the importance of “reliably documenting the process of interpretation of historical materials and hypotheses that arise in the course of research” and explain that “paradata document the process of interpretation so that the aims, contexts and reliability of visualization methods and their outcomes can be properly understood” (p. 1). Paradata is not just another form of metadata that is captured and archived alongside research data and scholarly outputs; but rather, it is necessary for interpreting those outputs in terms of how they were created and why. Bentkowska-Kafel and Denard (2012) emphasize the risk that a lack of paradata poses to the intellectual integrity of scholarly work that employs 3D methods:

The failure to provide this kind of intellectual transparency in the communication of historical content may result, among others, in visual products that only convey a small percentage of the knowledge that they embody; thus making research findings highly resistant to peer review and further discussion. It is argued therefore that an amount of paradata sufficient to provide genuine intellectual accountability should be published alongside other research outcomes and sustained beyond the lifespan of the technology that underpins visualization. (2)

The archiving and preservation of 3D/VR materials is still an emerging area of research and the project team is monitoring new developments in the field to ensure that research data and project outputs are sustainable into the future and that sufficient paradata are collected.

⁵ <https://osf.io/ewt2h/>.

⁶ <https://lib.vt.edu/research-teaching/lib3dvr.html>.

⁷ <https://projects.iq.harvard.edu/buildingtomorrow/home>.

⁸ https://www.loc.gov/preservation/digital/formats/fdd/browse_list.shtml.

⁹ http://culturalheritageimaging.org/Technologies/Digital_Lab_Notebook/.

6 Conclusions

The Virtual Ganjali Khan Project will produce digital resources that will have significant impact on historians, architects, urban planners, and designers, as well as students in these fields. It will successfully advance the field of scholarship by expanding knowledge of the Ganjali Khan Complex as a significant cultural heritage site and help to establish new methodologies of spatial analysis for scholarly inquiry. The affordances of 3D and VR to support human-scaled engagement with 3D data captured from architectural spaces will enable the interpretation of architectural proportions from the perspective of people moving through the Complex. This is particularly important because an essential part of this type of architecture is that its design elements are based upon the human scale, the body's "golden mean" proportions, and highlighting the vernacular use of construction materials will help viewers understand the Complex's visual culture, the archetypal meanings of spiritual transcendence and cosmic unity inherent in desert architecture (Ardalan 1973; Critchlow 1976). These tools offer intriguing new possibilities to support research in this area, and the decreasing cost of hardware and software is making 3D and VR more practical for use in a variety of scholarly fields. 3D/VR tools have great potential for expanding research and cultural heritage work, even as the preservation, archiving, and documentation challenges are still being addressed in the field. 3D/VR are still in the process of emerging as practical tools for these fields, but it is hoped that more and more projects, including the Virtual Ganjali Khan Project and the other projects discussed, will provide additional examples for other scholars to learn from and follow. Together, 3D and VR technologies form a powerful tool set for understanding historical and contemporary spaces in the world and for supporting architectural research and cultural heritage documentation and preservation in exciting and engaging ways.

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