CHAPTER 7

At-Risk World Heritage and Virtual Reality Visualization for Cyber-Archaeology

The Mar Saba Test Case

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INTRODUCTION

For years, humans have been fascinated with the preservation of material culture, from small artifacts to entire landscapes, and have seen them as having significant cultural value, as tangible links between them and their history.* However, though the ages, people have used the destruction of a cultural heritage as military and ideological tools to dominate others. In the Middle East, this has a long and well-documented history. For example, Jerusalem, the capital of ancient Israel, was systematically destroyed twice in antiquity,

* We are grateful to Father Ioannes and Father Vasilias of the Mar Saba Monastery for their enthusiastic support of and collaboration on this project and allowing us to carry out the field work at their home. Thanks also to Craig Smitheram for his help in the field. We also thank Matt Howland for his critical comments on this chapter and help with fieldwork; thanks to Stephen Savage for producing the Kidron Valley watershed map. The laboratory work for this research was carried out with funding support from the University of California Office of the President Research Catalyst Awards CA-16-376911, with Thomas E. Levy serving as principal investigator. Special thanks to Dr. Andrew Viterbi (La Jolla, California) for his generous support of this work; see –Fox 2015).

Thomas E. Levy, Connor Smith, Kristin Agcaoili, Anish Kannan, Avner Goren, Jürgen P. Schulze, and Glenn Yago, *At-Risk World Heritage and Virtual Reality Visualization for Cyber-Archaeology* In: *Digital Cities*. Edited by: Maurizio Forte and Helena Murteira, Oxford University Press (2020).

DOI: 10.1093/oso/9780190498900.003.0008

first by the Babylonians in 586 BCE (Magness 2012) and then by the Romans in 70 CE (Goodman 2007), with the aim of erasing the cultural identity and memory of a people. By the mid-twentieth century, during the 1948 Arab–Israeli War, systematic destruction of the Jewish Quarter of the Old City of Jerusalem took place again. The Jordanian commander Abdullah al-Tal, who was in charge of the Jordanian assault, justified the destruction of the Jewish Quarter, saying that had he not destroyed the homes, he would have lost half his men and that "the systematic demolition inflicted merciless terror in the hearts of the Jews, killing both fighters and civilians" (Fernea and Hocking 1992, 53). During the Jordanian occupation, thirty-four of thirty-five synagogues in the Jewish Quarter were destroyed (Jewish Virtual Library 2016). During this period, Palestinian refugees were relocated to the Jewish Quarter; following Israel's conquest of the Old City during the Six-Day War, the Jewish Quarter Development Company was established under the auspices of the Construction and Housing Ministry of the State of Israel to rebuild the Jewish Quarter. Following the Six-Day War, approximately 4,000 Palestinian Arabs left the area, were forced to leave, or were prevented from returning to the Jewish Quarter where they had lived during the Jordanian occupation (Central Bureau of Statistics 1968, 6; Dumper 2002). Unfortunately, in the Middle East today, with the birth of extremist ideologies typified by the Taliban and Islamic State (ISIS), the decision to consciously destroy cultural heritage sites with powerful explosives has become common.

Perhaps the most vulnerable places in the Middle East today for the destruction of cultural heritage are Iraq and Syria, where the on-going conflict and wars have led to museums, libraries, and other cultural repositories to be burned and looted, and UNESCO World Heritage sites destroyed. Many of these heritage and archaeological sites are at risk of destruction. Recently, in January 2016, examination of satellite imagery showed that Iraq's oldest Christian monastery was completely obliterated by ISIS, resulting in the loss of a major cultural icon for the Christian community in that country, as well as for the world (Smith and Deaton 2016). However, damage is not always so extreme, and many locations are being polluted, looted (Kersel et al. 2008), and/or generally neglected. Though there is no clear solution to this problem, public awareness and engagement are important first steps, with possible solutions now coming from cyber-archaeology. In this chapter, we describe the development of virtual reality (VR) models for the second oldest Greek Orthodox monastery in the Middle East—Mar Saba, located in the Judean Desert (figure 7.1). While the site is not in immediate danger of destruction, the adjacent polluted stream is damaging the local environment and cultural heritage features around the monastery.

Mar Saba in Israel/the Palestinian territories is not in imminent danger of destruction from human-induced conflict, like the Syrian and Iraqi examples noted. That said, before the Arab Spring in 2011, few thought that sites in

Figure 7.1 Overview of the Mar Saba Monastery in the Kidron Valley, in the Judean Desert of Israel/Palestine, with the helium balloon used for photogrammetry in this project.
Credit: Photo T. E. Levy, UC San Diego Center for Cyber-Archaeology and Sustainability.

Syria and remote parts of Iraq were in danger of destruction. In the Middle East, though, one should always expect the unexpected. Thus, recording all major heritage sites in the Middle East in the most effective ways possible should be a priority. In addition to the negative cultural forces that impact site preservation, there is a wide range of natural forces, such as earthquakes, floods, fires, erosion, and other factors, that can negatively impact the preservation of cultural heritage sites. Cyber-archaeology and virtual reality are two tools that archaeologists and cultural heritage professionals can use today to preserve sites digitally, as well as engage the public in heritage preservation, thereby mitigating the risks that cultural heritage faces in today's world.

Cyber-archeology is a relatively recent field that involves collecting and storing archaeological data in digital form, such that it can easily be accessed and visualized when necessary following a workflow best characterized as: digital data capture, curation, analyses, and dissemination (Levy 2013). If displayed to the right audiences, and through the right medium, the data can transport individuals across the world; more importantly, it can provide narrative regarding at-risk cultural heritage sites. As VR is a real-time interactive computer-generated experience for the viewer in a simulated environment, it can transport people to the heritage site, where they can experience the magnificence of the site and the environmental forces negatively impacting the site, such as pollution and erosion. This experience can influence viewers, both officials and the public, to appreciate the value of the heritage site and to support conservation and preservation. The challenge is finding effective ways to present the digital archaeological data to the general public in an interesting and engaging form.

Virtual reality, an emerging technology and innovative digital medium, has been slowly growing over the past years, only recently becoming widely acknowledged and expanded. The term "virtual reality," for purposes of this research, refers to several different systems that can be considered virtual environments. One major solution to virtual reality is a CAVE, an acronym for "cave automatic virtual environment," which consists of several screens and often multiple computers streaming content around a user (Knabb et al. 2014). A second and more recent form of virtual reality is the head-mounted display, appearing in the form of consumer-ready hardware such as the Oculus Rift or even the Google Cardboard. These devices contain two screens, one for each eye, which display an image and track head rotation when worn. Both systems offer an incredibly immersive experience, and can convey information in a way that involves deep engagement and interactivity.

With the continuing evolution of cyber-archaeology and the arrival of virtual reality as a viable medium for personal data visualization, the present goal is to display archaeological information inside such a virtual environment. This is a task that involves integrating technology that has been largely unexplored, with information already catalogued and stored in a database. The resulting virtual content should be stimulating, informative, and appealing enough to be part of a public display, and should be implemented across both CAVE and head-mounted display platforms to ensure a spectrum of availability. As explained, these VR CAVE platforms and head-mounted displays can provide important experiential learning experiences for policymakers, researchers, and the public, who can influence national and international heritage-preservation efforts.

SETTING: MAR SABA MONASTERY AND THE KIDRON VALLEY

The risks faced by world cultural heritage, especially in the Middle East, make it crucial to develop innovative models for making cultural heritage into assets, such as archaeological and historical sites, that are of greater economic value when preserved than when destroyed. The Milken Institute, Jerusalem's Financial Innovations Lab, has proposed creating "heritage districts" to conserve such archaeological sites (Milken Financial Innovations Lab 2011, 6). This would be a great tool for heritage site preservation and would benefit local communities at the same time. That is, the potential financial return from assigning a greater value to archaeological heritage is vast and untapped. It includes archaeo-diplomacy, archaeo-tourism, infrastructure growth, and educational outreach; it can provide a unique opportunity to enhance community development by generating job creation, rescuing fragile cultural assets, and funding exploration. Taken together, these goals help mitigate the standard risks to cultural heritage. As shown here, by constructing what we call the Cultural Heritage Asset District model of finance and management for the Kidron Valley watershed, we can strive to meet the model's needs as a sustainable, revolving partnership of multiple stakeholders. The result is conservation of cultural heritage resources.

Cultural heritage tourism is the fastest-growing sector of global tourism. Indeed, cultural tourism is the major element in international tourism consumption, accounting for over 39% of tourism arrivals, and it has become a driver for economic development in developing regions (Richards 2018). Emerging bi-modal distribution of age structure (characterized by peak millennials and baby boomers) are demographic drivers of demand for this cultural heritage tourism. This includes cultural consumption, cultural motivations, heritage conservation, and the relationship between those elements of cultural and the creative economy. This relationship between tangible and intangible heritage and attention to indigenous and other minority groups and geographical expansion all energize the need for conservation of cultural heritage for sustainable development.

Over the past twenty years, there has been an increase in the identification and preservation of cultural heritage sites. Twenty-six new inscribed properties were added to the UNESCO World Heritage list in 2016, making a total of 1,052 current sites. Global emphasis on cultural heritage preservation was evident in the 1995 proclamation by the UN World Commission on Culture and Development, which proclaimed "the explicit role of culture, such as built heritage, as a strategy against poverty in the third world countries, since the concepts of culture and of development are inextricably intertwined."[1] Continuing in this vein, there were agreements at the 1998 and 1999 UNESCO meetings in Stockholm and Florence, respectively, on "the vital impact of culture for economic development in future policy making."

Beyond sharing expertise from the public, private, and nonprofit sectors, effective financing and management structures for these districts must be self-sustaining, revolving instruments (MacDonald 2011), and must digitize to prevent degradation of and educate about cultural heritage (Skarin 2011). As mentioned, cultural heritage boosts job creation and household income. A European assessment of these efforts found that historic rehabilitation and conservation of cultural heritage sites created 16% more jobs than new construction, and that every direct job in the cultural heritage sector creates 26.7 indirect jobs (Rypkema 2008, Baycan and Girard 2011).

The Cultural Heritage Asset District model of finance and management proposed for the Kidron Valley meets these needs as a sustainable, revolving partnership of multiple sectors, the dual mandate of which is to increase local economic activity and to preserve the cultural heritage assets (Dimitriyadis et al. 2012). The model is based on similar tenets as the archeological development bonds and tourism improvement district model (Milken Institute 2008, Milken Financial Innovation Center 2011), which builds a sustainable public–private partnerships (PPPs) and ensures a revolving financial mechanism based on tax revenues, bond issuances, and other tools to stimulate local tourism and preserve local heritage assets (European Investment Bank Institute 2013). The model brings financially and culturally sustainable answers to meet the needs for innovation in the field of financing and management that can benefit cultural heritage conservation.

DATA AND PLANNING FOR A CULTURAL HERITAGE ASSET DISTRICT

A Cultural Heritage Asset District invests in a variety of assets capable of bringing visitors to the district along with the opportunity to share costs of infrastructure and revenues. Financing is based on capturing and leveraging incremental value that is created from strengthening the cultural assets and using the shared infrastructure (both physical and IT) so as to increase tourism to these sites, both virtually and through actual visits. This process begins with a needs assessment of infrastructure improvements, reuse and historical restoration possibilities, antiquity site maintenance, education and training, business development, and site operations management. Possible sources of financing would include user and entry fees, co-marketing revenues from sites generating income to support PPPs, and grants from government and private foundations. In the past, the economists involved in our Mar Saba work helped develop asset financing and identified a basic financial partnership model (see figure 7.2) that included a database for inputs to these financial and development sites. This information would then be applied to assessing the types of tourists (recreational, heritage, ecotourism) and destinations. By combining groups of sites into higher-value districts, we would create for each target the clusters, themes, and infrastructures to combine historical, environmental, and recreational assets in those districts. In essence, sites and projects would be combined into a pooled portfolio of district projects.

Therefore, the essential features of a Cultural Heritage Asset District are:

- High-value attractions capable of bring visitors to the district
- Sharing of costs and revenues throughout district to support these attractions
- Financing based on incremental value created by strengthening the attractions

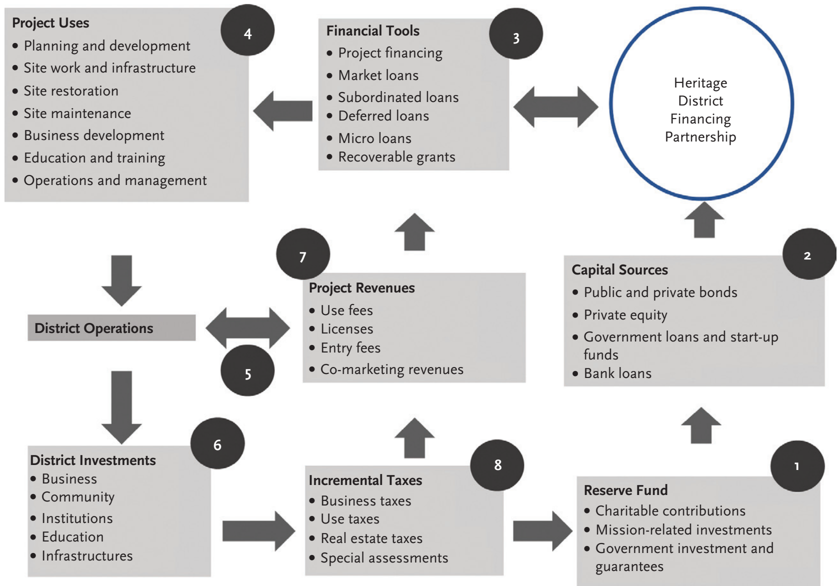

Figure 7.2 The Heritage Asset Financing model.

This model builds on the way classic economics considers generating value from an underutilized asset and recycling that value back into the asset or ecosystem surrounding it. Using the conceptual approach depicted in figure 7.2, our approach involved the following steps or stages for heritage districts to be developed and financed:

1. A combination of government funds and philanthropic contributions and investments are used to create a reserve fund.
2. Using these sources of capital, a combination of public and private funds, government loans, and bank loans are invested in a public-private partnership for heritage district financing.
3. The heritage district financing partnership uses a series of financing tools, including recoverable grants, micro loans for small businesses, market-rate loans and bonds, and project financing.
4. The financing tools are used to finance a series of activities needed to build the heritage district, including sites, projects, business development, and hard and soft infrastructures, and including physical and virtual access.
5. The activities allow the district to be open, offering a full range of tourism, education, recreation, and cultural experiences to onsite users and off-site virtual visitors (see Girardeau-Montaut, Daniel. 2011). These activities create direct revenues and indirect revenues.

6. The direct revenues, such as use fees, licenses, and entry fees, are used to pay for district operating expenses and repayment of debt.
7. Indirect revenues are used to provide credit and collateral support for meeting financial obligations and to provide supplemental capital to fund the reserve funding and reduce the exposure of the initial reserve funders.

This model is used to evaluate options for how to approach each asset, including preservation, restoration, adaptive reuse, or deployment of addition technologies.

The integration of cyber-archaeology in the project planning is integral, as well. It consists of building Cultural Heritage Asset Districts and decision support tools at the local level. Cyber-archaeology provides the way for archaeologists, government organizations, local societies, and other interested stakeholders to promote the Cultural Heritage District Asset over the internet, in media outlets, and in the different VR platforms (see figure 7.3).

THE CASE OF THE KIDRON–WADI EL-NAR WATERSHED

Our Cultural Heritage Asset District was formed around a natural watershed that served as the basis for settlement in the ancient world. Water is key to survival, so humans have organized their settlements and settlement strategies based on access to water sources. Thus, the watershed is the basic subsistence system that unites the region; it can be easily identified and mapped.

Consider that a watershed is a region of landscape that drains all the water falling upon it and running through it into a larger body of water. Watersheds combine with other watersheds to make a network of seasonal or and/or perennial rivers and streams that eventually drain into larger water bodies. As watersheds constitute distinct environmental zones, for preindustrial societies, these landscape units often reflected unified cultural systems, making them clear organizational and analytical units.

This chapter presents our preliminary effort at developing an economic model for the Kidron Valley, an important watershed that borders the holy city of Jerusalem (figure 7.3). The Kidron Valley—from Hebrew: נחל קדרון, *Naḥal Qidron*; also Qidron Valley; Arabic: وادي الجوز, and *Wadi al-Joz* for the upper segment near the Temple Mount and *Wadi an-Nar* for the remainder—drains into the western shore of the Dead Sea. The beginning of the Kidron Valley separates the east side of the Old City of Jerusalem's Temple Mount, where Solomon is purported to have constructed the First Temple, from the Mount of Olives. This is the holiest site in Judaism. As the Kidron River flows eastward through the West Bank's Judean Desert, it drops approximately 1,220 meters in elevation along its approximately 32 kilometer length. Accordingly, the Kidron Valley is exceptionally rich in history and archaeology. In addition

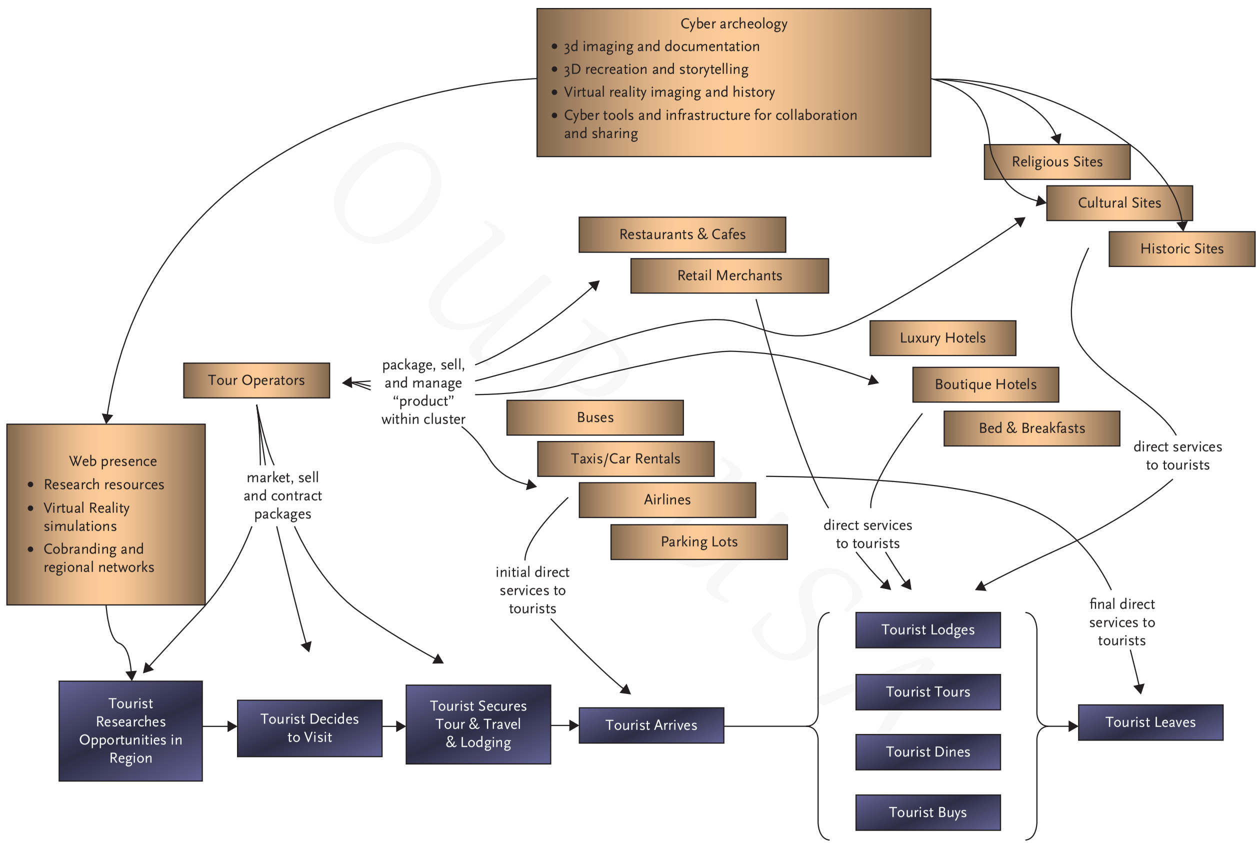

Figure 7.3 Model for Building Cultural Heritage Asset Districts.

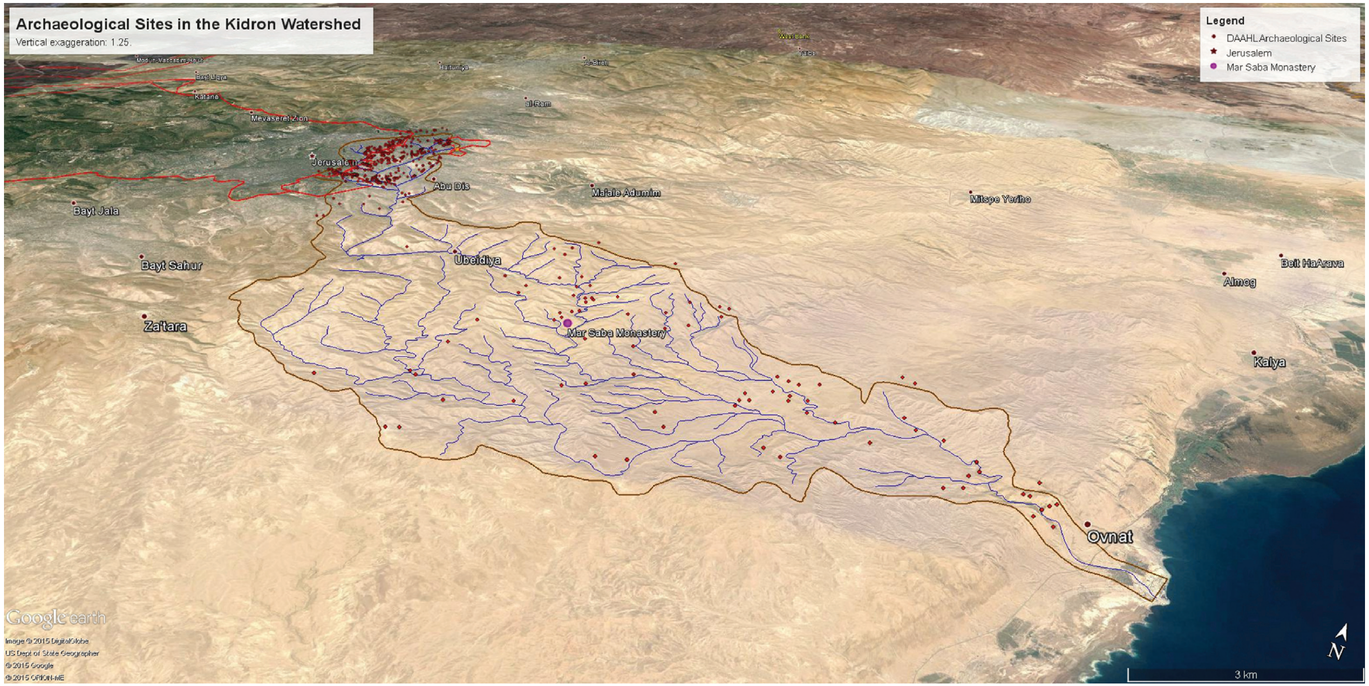

Figure 7.4 View of the Kidron Valley and Wadi El-Nar Catchment Basin.

to the Old City's Temple Mount (in Islamic tradition it is known as Haram esh-Sharif [Arabic: الحرم الشريف, *al-Ḥaram al-Šarīf*, "the Noble Sanctuary," or الحرم القدسي الشريف, *al-Ḥaram al-Qudsī al-Šarīf*, "the Noble Sanctuary of Jerusalem"]), the Kidron's drainage is at the confluence of Jerusalem's richest concentration of rock-hewn tombs dating from the First Temple period (ninth to seventh centuries BCE) and Second Temple period (c. 530 BCE–70 CE; Rahmani 1981).

Approximately halfway down the Kidron Valley, in the Judean Desert, is the Greek Orthodox monastery called Mar Saba (area = 90 m by 170 m, or c. 15,300 sq. m), situated on the south bank of the Kidron and constructed around 483 CE. It was founded by 'Sabbas the Sanctified of Mutalaska, Cappadocia, and today houses around twenty monks; it is the second oldest continuously occupied Greek Orthodox monastery, after Saint Catherine's Monastery in the southern Sinai Peninsula (Ganon 2014; Hirschfeld 1995, 5). Unfortunately, wastewater from eastern Jerusalem flows through the Judean Desert to the Dead Sea. The sewage that flows though the Kidron Valley is damaging for both the natural environment and cultural heritage resources such as the Mar Saba Monastery, as well as the hundreds of ancient sites in its vicinity. Indeed, approximately 12 million cubic meters of sewage flows through the Kidron Valley every year. This is damaging to the natural and cultural environments, as well as the ecosystem as a whole. But as the drainage flows through both Israeli- and Palestinian-controlled lands, finding a solution to this situation is a huge challenge. A number of possibilities have been proposed, addressing the complexities of this asymmetrical political setting where Israelis, Palestinians, and the Greek Orthodox Church are the primary stakeholders (Dombrowsky et al. 2010). The VR project described, thus, is an initial attempt to apply the methods of cyber-archaeology (Levy 2013), including data capture, curation, and dissemination within the context outlined here.

The Cultural Heritage Asset District model was predicated on the environmental cleanup of the river through construction of a wastewater treatment plant. The Kidron Sewage Treatment project (approved by the Joint Israel Palestinian Water Commission in 2017 and currently under construction) will enable further implementation of heritage site projects within the watershed. As explained earlier, the model combines the public and private sectors to create a business model for the watershed in terms of both direct and indirect economic activity, in both Israeli and Palestinian territories.

Project Financing

As illustrated in figure 7.5, a special purpose vehicle (SPV, or 1) is created as a single-purpose corporate entity. The SPV is owned by partners, including

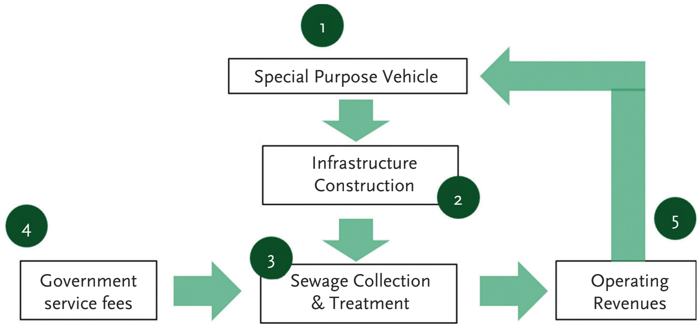

Figure 7.5 Project Model, showing direct revenues.

limited partnerships such as cash equity investors, a professional team, and contractors and operators. It is managed by a general partner that has the responsibility for all operations. The SPV hires all professional services, including the contractor for the design and (2) construction of the infrastructure and treatment plant itself. The SPV then (3) hires the operator for the collection, treatment, and distribution of services.

The SPV signs a long-term contract with the Israel Water Authority and the Palestinian Water Authority to provide the sewage collection and treatment services. In turn, the governments return a variety of tap-in, flushing, drainage, and water treatment fees (4) to the operator.

In addition to the direct government fees, the SPV is able to sell a variety of products, including gray water, compost, and energy sales on the market and sign long-term contracts to strengthen the (5) operating revenues (and underlying credit) of the project.

To strengthen the direct revenue, the project financing model includes several indirect revenue sources, as well. As part of the project plan, the infrastructure will support the growth of tourism and tourism-related revenues in the greater Jerusalem region. As shown in figure 7.6, new businesses and the expansion of existing businesses (6) will provide incremental value-added taxes, real estate taxes, improvement taxes, use fees, and license fees (7), which can make the case for a partial government guarantee for the project financing (8). Additionally, the incremental value created in the region will permit the use of revenues from events, services, and even a portion of the incremental taxes themselves from the expanded hospitability and tourism activities in the region, such as hotel rooms (9). These indirect revenues are based on the increases in tax revenues from the new infrastructure, which can provide additional reserve funding (10) for the project. All these direct and indirect sources support the plan for a project financing (11) for the SPV (Milken Innovation Center-Jerusalem Institute 2013).

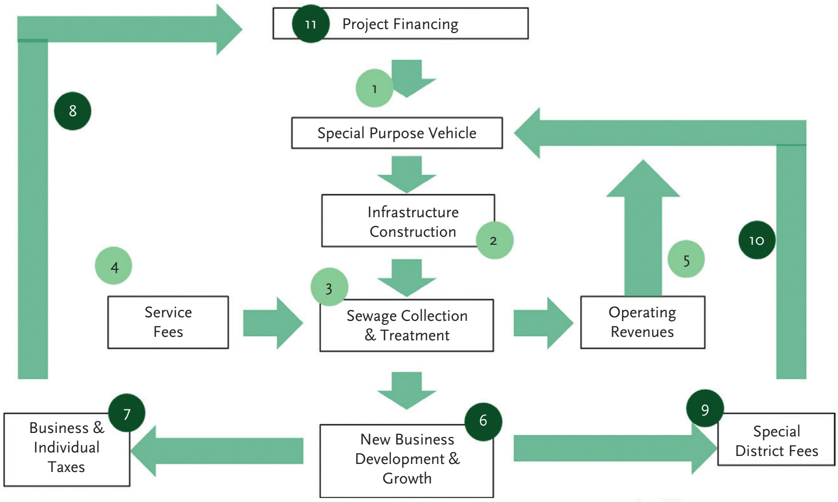

Figure 7.6 Project Model, showing indirect revenues.

Previous Research

There have been a variety of projects exploring the use of data visualization and simulation software for archaeological analysis. Since early 2008, there has been a gradual shift from text-based descriptions to 2D photography and then to 3D presentation, owing to improvements in the capability of perceiving data. The impact of 3D models is seen as revolutionary in terms of "registration, documentation, dissemination, presentation, and ultimately the preservation of cultural heritage." According to Mikropoulos et al. (2008), the process of recording archaeological information has five steps: digitization in 3D, processing and storage of 3D data, archiving and management of 3D data, visualization and dissemination of 3D data, replication and reproduction of 3D data. Our research followed this process and attempted to process and visualize the 3D data through the medium of virtual reality. Michael Bawaya (2010:140-141) described how archaeologist Sam Paley was able to use VR to simulate lighting conditions in a virtual throne room based on photos and eventually concluded that "the torches could have been fueled by several types of fish oil and positioned to enhance the art." Another research group utilized photogrammetry on rock cairns in the Tongass National Forest, in the United States, as a means to obtain new information on their functions and highlight their importance. That study attempted to encourage communication with the public on the preservation of archaeological and cultural heritage features, and found that PhotoScan Pro by Agisoft and digital photogrammetry were ideal for their situation (Chodoronek 2015).

Previous researchers have primarily focused their 3D visualizations on computer screens. But in order to immerse users in the archaeological sites and settings, more studies must be done in the field of virtual reality (Knabb et al. 2014, Levy et al. 2008). Indeed, recent advancements in the field of virtual reality have been made in the technology industry, especially in its capabilities for visualizing the past for public audience (Bittel 2013). As Pujol (2004) points out, virtual reality "defines virtual reconstructions as a vehicle for preservation, access and economic development at the service of archaeological remains valued for their artistic qualities." He believes that virtual reality has immense capability for presenting archaeological data to the public because its multimedia environment allows "different formats for presenting information [which] can be adapted to individuals" skills' depending how the audience would like to absorb the information (Pujol 2004). In the application presented here, our research highlighted the strong potential for virtual reality in our mission to preserve and digitize cultural data.

Data Capture and 3D Dissemination

In order to photograph the Mar Saba watershed, team members developed a custom balloon-based, low-altitude aerial photography (LAAP) system. This system consisted of a large Kingfisher Aerostat balloon (c. 2.29 m by 1.56 m, volume about 4.23 sq. m and lift about 3.39 kg) tethered to and manipulated by a ground-based operator. We used a Brooxes Gent-X Picavet cross-frame capable of holding a high-resolution (15.1 megapixel) Canon EOS 50D digital single-lens reflex (DSLR) camera equipped with an 18–135 mm lens. The camera was triggered by an intervalometer set to an interval of 10 seconds. This setup is well suited to yield the hundreds of high-resolution images appropriate for SfM processing.

As shown in figure 7.1, the monastery is located in a narrow valley, making it difficult to navigate the tethered balloon. The first day we tried to fly the balloon, winds blew so strong that we had to postpone the fieldwork for several days. While we were ultimately successful in using the balloon, there were a number of problems, including the very high cost of helium, the difficulty in moving the heavy tanks around the research area, and the narrow setting that made it difficult to maneuver the balloon into the correct location for image capture. Although the flight time for a balloon is almost indefinite, in the future we would use drones, in spite of their short flight time owing to battery charge. Our lab now uses both systems (Howland et al. 2014, Smith et al. 2014).

Since virtual reality can be interpreted as the "cyber" in cyber-archaeology, the main goal was to use existing data captured by archaeologists in the field at Mar Saba so as to create a visual experience for public display. Our team has prior experience with the Unity game engine, so the first step was to determine how large the amounts of data that could be imported and visualized in Unity—a program used most often to create 2D and 3D games. Furthermore, initial development was targeted for the Oculus Rift head-mounted display, as the CAVE system was still being built. The point cloud captured at the Mar Saba Monastery by photogrammetric processing of images taken by the balloon system consisted of roughly 85 million points, with a size of 2.2 gigabytes (Figure 7.7). Since many VR displays, especially the newest head-mounts, require a great deal of computational power, the starting goal was to display this point cloud, in some form, inside Virtual Reality without latency. To the team, this meant achieving a refresh rate of at least ninety frames per second, as is the expectation with VR experiences.

After initial testing, it was clear that the entire point cloud could not be displayed at once in VR. In fact, it was difficult just to import the data into Unity. Therefore, the next step was to reduce the point cloud using a program called CloudCompare, cropping it to a size that would allow for easy testing and viewing. At the conclusion of this process, a custom point cloud destructor was written, capable of reducing different levels of points in a point cloud such that the data can easily be viewed inside virtual reality. In order to achieve this, an algorithm was designed that skips over a certain number of specified points in a point cloud file, and then saves the new data into a new

Figure 7.7 CAVEkiosk 3D visualization platform, developed for the UC Office of the President, Catalyst Grant for At-Risk World Heritage and the Digital Humanities in the UC San Diego Geisel Library.
Credit: Courtesy T. E. Levy, Center for Cyber-Archaeology and Sustainability, UC San Diego.

file for quick loading next time. The correctness of this approach is based on the assumption that nearby points are grouped together in the data file, such that deleting neighbor points still allows for an accurate representation of the original site. Once ready, this system was integrated into the Unity application, such that any point cloud with a.off extension can be reduced and loaded automatically.

After we were capable of loading, displaying, and visualizing the point clouds, we attempted to create a mesh (Cignoni and Ranzuglia 2014), defined as a solid geometrical surface, out of the points. It seemed the points contained information about surface normals, but it was still difficult to make a mesh look realistic enough to be usable. The entire purpose of a mesh was to reconstruct the site from points, but for this particular site, the data weren't complete enough to create a fully coherent or complete Mar Saba. Additionally, these meshes were demanding in terms of performance and the frame rate often dropped below sixty frames per second, which is unacceptable for our goals. Following several attempts using Mesh Lab to create a connected version of the data, we decided to move forward and revisit the possibility for a mesh later in the project.

The next system for this project was designed to load 2D images, such as those taken from a generic camera, in order to support different forms of media for archaeological sites. Written entirely in the C# programming language (Microsoft), the photo loader can display up to twenty-four images at one time in three rows, with each picture acting as a point on an octagon. The images slowly rotate around the user, giving a 3D appeal to the initially 2D data. When the pictures are rotating, the user has the option to select a photo that will then emerge from the rotating rows and sit in front of the user for examination. Once the user is finished looking at the photo, he can send it back and it will take its correct place in the corresponding row. The loader is also capable of loading any number of images below twenty-four. It calculates how many images should be on the top and bottom rows by dividing the starting number of images by 3, and then all remaining images are placed into the center row. If the number of images in a single row is less than four, then that row will not rotate but, rather, just display in front of the user. Otherwise, the pictures place themselves geometrically around the user in their respective rows, such that a row with six images will have the layout of a hexagon, seven images a heptagon, and eight images an octagon. After eight images, the photos begin to get cramped, so the maximum number was placed at twenty-four to ensure at most three rows of eight images are loaded. This system can also result in cases that have only some moving rows—for example, with a total of ten pictures, there will be three images on the top on bottom rows and four in the middle. The four image row will rotate, but the ones with three images will not, based on the rule described earlier. This allows for some interesting and unique combinations with different amounts of images. To actually load these images, all a user has to do is type in a directory or folder where their images are located, and the system will always load the first twenty-four. Upon completion of the photo loading system, a very similar movie loader was designed to load movie files in Unity, and an audio loading system that can play specified sound clips whenever necessary. All of these were written inside Unity using C#, and are integrated with the VR system.

At this point, many of the pieces to create a full VR experience were in place. The technical portion was mostly over, and the largest challenge that remained was to connect all systems into an appealing, interactive, and enjoyable experience that can provide interesting narrative and full immersion. Since the goal was to load data for multiple different archaeological sites, the experience begins with a model of the Earth, and the user is standing upon a virtual "podium" with a screen in the center. This podium was an important consideration for the problem of motion sickness. When designing for virtual reality, it's vital that the user is always grounded and motion is intuitive in the experience; otherwise, the experience will be both ineffective and nauseating. By placing a user on the platform, there is no longer a feeling of floating, and motion can be justified as motion from the podium rather than the user, making it an effective method of transportation inside the experience.

On the three-dimensional Earth, there are several "points of interests," represented by large red arrows (https://daahl.ucsd.edu/DAAHL/). Each arrow is a different site that's been loaded into the system, and these points of interest can contain information ranging from point clouds and panoramas to two-dimensional images and audio clips. The designer of the site can also include brief text to be displayed when the POI is selected, which shows on the podium screen and is visible to the user. For actual selection and interactivity, the user interface uses Razer Hydra controllers, which track position and rotation in 3D. The hydras work together with a paradigm of pointing at objects to select them, using a line to indicate the direction of selection. Selecting a POI with this system causes the virtual monitor to display text information and buttons to access the other information.

With the podium comes a movement system designed to work with 3D controllers. There is a sphere in the center of the podium which, when selected, starts a movement mode. When moving, the speed of the podium matches the distance from the starting point of selection, allowing the user to move her controllers further for faster speeds. For example, if the user wants to go up, she will select and move her hand up. Rotations work in a similar way by rotating the controller. This allows users to move around the earth model and each individual archaeological site, but also select points of interest and move to them automatically if manual movement isn't desired.

At this point, most of the technical programming work was completed. This is the first time the details of the VR program are published in depth. As Mar Saba is in a contested area, it is not easy to visit. The programming described here enables visitors to the CAVEkiosk or those using a personal VR device to experience this important heritage site in new and exciting ways that only a physical visit to the site can improve on.

Results and Considerations for Improvement

The primary site for presenting the Kidron Valley Cultural Heritage Asset District is the Greek Orthodox Monastery experienced in the CAVEkiosk multi-panel 3D visualization platform (https://daahl.ucsd.edu/DAAHL/; https://ucsdnews.ucsd.edu/pressrelease/new_3_d_cavekiosk_at_uc_san_diego_brings_cyber_archaeology_to_geisel). Once all the components for each type of media were processed from the field, the main effort centered on connecting all these media assets with a point of interest (POI). POIs were added to one of NASA's high-resolution Blue Marble satellite images, file paths with pictures and audio were added to the POIs, and the system was mostly ready to go. Some initial narration was added as audio, but most of the demo focused on the Mar Saba site, which loaded a point cloud and contained even more POIs within the site.

This project was demonstrated to stakeholders as a rough outline of the system capabilities, and it was generally concluded that more improvements had to be added before a display was ready. Some parts are a matter of fine-tuning, such as preventing motion sickness, adding more archaeological sites, changing input mechanisms, and including more accurate and inspirational narrative to spread awareness about at-risk locations. Other aspects that will require additional work, such as deciding how to better present text, showing content in a more appealing way, making point clouds more visibly appealing, and in general ensuring that the project is enjoyable for a public audience. Currently, this digital cultural heritage project is primarily a large and explorable repository of data in virtual reality, whereas the ultimate goal is to present a motivating and captivating experience for any visitor to appreciate.

The VR portion of the project still needs considerably more work, which means there are many more ideas to be explored. The POI system integrated with the project is fairly intuitive for nontechnical individuals to use, but still requires a user to go through the Unity game engine and manually entire file paths and information. Therefore, although it wouldn't be too difficult for an inexperienced user to be able to create new POIs, the goal is to integrate archaeological site setup into the experience itself, such that archaeologists or nontechnical administrators could easily link data with the system and create new points of interest. This would involve entering some form of password to signify an administrator, and then the ability to create, set up, prepare, and customize media for new locations. An administrator could also create new tour paths, add text to locations, and narrate different locations to convey the importance of each cultural location. If this can be achieved, then anyone will be able to expand and grow the system, giving it a much longer life and significant amount of flexibility.

This project is destined to grow, as there is still a wealth of data and information available for integration with the POI system. Each site must be set up manually, so with the ability for archaeologists to expand it themselves, any sites both new and old could be visualized and presented.

Another requirement is the transition from 3D input mechanisms to simple controllers. Similar CAVE systems have used 3D controllers for an interface, which is why we worked with the Razer Hydras (http://www.razerzone.com/). However, it was later decided that a standard Xbox gamepad would be a better option. This form of controller is more familiar to the average audience and would thus be easier to learn. Additionally, as gamepads do not need to be moved to function, and they can be more strongly secured against theft. Another major obstacle was time frame.

CONCLUSION

In the Middle East, at-risk world heritage were in the headlines during the height of the horrific activities of the Islamic State (ISIS), which included destruction of famous heritage sites in Syria and Iraq. While political pundits may claim that ISIS has been defeated, the destruction of cultural heritage sites continues by looters, developers, conflicts, natural processes, and other factors. For these reasons, twenty-first-century archaeologists are obliged to consider the protection and conservation of archaeological and heritage sites before they begin to be destroyed. In this chapter we combined innovative approaches to digital archaeology, information technology, virtual reality, and economics to explore new ways of engaging stakeholders in those regions, as well as the public and governmental agencies to help in these efforts. This is only a beginning.

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