Pure Land: Futures for Embodied Museography

SARAH KENDERDINE, National Institute for Experimental Arts (COFA), University of New South Wales
LEITH K. Y. CHAN, Department of Industrial and Manufacturing Systems Engineering, University of Hong Kong
JEFFREY SHAW, School of Creative Media, City University of Hong Kong

8

This article describes the design and implementation of the *Pure Land* projects, consisting of two visualization systems and their respective applications, *Pure Land: Inside the Mogao Grottoes at Dunhuang* [2012] and *Pure Land Augmented Reality Edition* [2012]. Each installation allows participants to engage in different ways with a full-scale augmented digital facsimile of Cave 220 from the UNESCO World Heritage site of the Mogao Grottoes, Gansu Province, northwestern China. This project is a collaboration between the Applied Laboratory for Interactive Visualization and Embodiment (ALiVE), City University of Hong Kong, and the Dunhuang Academy. In the *Pure Land* projects, the digital facsimiles of this cultural paragon have been transformed, providing formative personal experiences for museum visitors. The projects integrate high-resolution digital archeological datasets (photography and 3D architectural models) with immersive, interactive display systems. This work is of great importance because the treasuries of paintings and sculptures at Dunhuang are extremely vulnerable to human presence and, in the case of Cave 220, permanently closed to public visitors. Comprehensive digitization has become a primary method of preservation at the site. Both installations have been shown to the public at a variety of museums and galleries worldwide—to critical acclaim. The projects contribute to new strategies for rendering cultural content and heritage landscapes and suggest the future for embodied museography. Here, each project is described in detail, including innovations in interface technological application and user experience.

Categories and Subject Descriptors: H.5 [**Information Interfaces and Presentation**]: Artificial, Augmented, and Virtual Realities

General Terms: User-Centered Design, Input Devices and Strategies, Interaction Styles

Additional Key Words and Phrases: Dunhuang, *Pure Land*, Cave 220, Mogao Grottoes, interactive, immersive, embodiment, Medicine Buddha, augmented reality, virtual reality, 3D modeling, photography, laser scan, high resolution

ACM Reference Format:

Sarah Kenderdine, Leith K. Y. Chan, and Jeffrey Shaw. 2014. *Pure Land*: Futures for embodied museography. ACM J. Comput. Cult. Herit. 7, 2, Article 8 (May 2014), 15 pages.
DOI: http://dx.doi.org/10.1145/2614567

1. INTRODUCTION

This article introduces two seminal digital installations at the vanguard of cultural heritage interpretation focused on the grottoes temples at Dunhuang, Gansu Province, in northwestern China. *Pure*

Authors' addresses: S. Kenderdine, National Institute for Experimental Arts (COFA), University of New South Wales; email: s.kenderdine@unsw.edu.au; L. Chan, University of Hong Kong; email: leithchan@hku.edu.hk; J. Shaw, CityU Hong Kong; email: j.shaw@cityu.edu.hk.

DOI: http://dx.doi.org/10.1145/2614567

Fig. 1. Visualization of *Pure Land*. Cave 220 in AVIE. Wireframe of the 3D model in the insert box. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

Fig. 2. *Pure Land AR* [2012], Shanghai Biennale, September 2012 to March 2013. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

Land: Inside the Mogao Grottoes at Dunhuang (hereafter *Pure Land*, see Figure 1) and *Pure Land: Augmented Reality Edition* (hereafter *Pure Land AR*, see Figure 2) integrate high-resolution digital archeological datasets (photography and 3D architectural models) with immersive, interactive display systems. These works allow visitors to interact with augmented 3D digital visualizations of Cave

220. The multilayered enhancements made to the underlying digital facsimiles of this cave can be interactively explored, analyzed, and understood as embodied 3D visual experiences that bring new life to the aesthetic, narrative, and spiritual drama of its mural paintings and sculptures. *Pure Land* was first exhibited to the public at Gallery 360, City University of Hong Kong, in 2012 to critical acclaim, and both installations have been the subject of subsequent worldwide attention (e.g., Choi [2012], Kennicott [2012], Liu [2012], Hunt [2013], and O'Brien [2013]).

As promoted by Julian Raby, director of the Sackler and Freer galleries at the Smithsonian Institute, *Pure Land* is the "exhibition experience of the future." By stimulating a palpable sense of "being there" and co-presence with the past, these installations are conceived as theatres of embodied experiences with a cultural imaginary located in the *here and now*. *Pure Land* was installed for the 25th-year celebrations of the Smithsonian's Freer-Sackler Galleries of Asian Art. Philip Kennicott [2012] of the *Washington Post* writes:

> A decade or more of efforts to use virtual reality to reproduce aesthetic experiences have generally led to unsatisfying, cumbersome and distracting technologies. The transient buzz of interactivity overwhelms the actual content or educational value. But the "Pure Land" cave is different . . . it points the way forward, demonstrating how the immersion environment can be used to let visitors actively explore and understand complicated cultural objects . . . at last we have a virtual reality system that is worthy of inclusion in a museum devoted to the real stuff of art.

The *Pure Land* projects not only provide benchmarks for the integration of archaeological data and interactive and immersive technologies but also give us fresh directions for the future of interpretive experiences in museums. Diverging significantly from former exhibition practices and contemporary cinematic viewing, *Pure Land* and *Pure Land AR* support the mobilization of the viewer to coalesce in virtual and real space. Other forms of virtual reality (VR) are often used for digital heritage such as the Oculus Rift, but these interfaces put significant constraints on social interaction between real people. Harnessing social dynamics is an important mission for creating museum experiences. A traditional CAVE has severe limitation on number of people and is hardly appropriate for museums with mass public.

By defining strategies for the embodiment for a large number of visitors at one time, *Pure Land* and *Pure Land AR* reactivate the history of the immersive view in museums. Through the fully embodied interface, they also reinvigorate archaeology with aliveness, extending the role of digital facsimiles to create new levels of aesthetic and interpretative experience. With the original under threat from burgeoning tourism and climatic change, the innovative digital strategies offered by the *Pure Land* projects and their successors may be the only way to keep the artistic and spiritual brilliance of the Mogao Grottoes alive for the cultural imaginary of this and future generations.

1.1 Mogao Grottoes at Dunhuang

Dunhuang was a religious and cultural crossroad for more than 1,000 years. In CE 366, the monk Le Zun, a traveler from distant western regions, paused at the foot of Sanwei Mountain at Dunhuang and was stunned by the scene before him. The monk named the place, settled down, and excavated a cave at the opposing Mingsha Mountain. Hence, the stage was set for the Mogao Grottoes, which would continue to be constructed over the next millennia. Also known as the Caves of the Thousand Buddhas, the Grottoes were a gateway to and from China on the ancient Silk Road, as well as a focus for trade between China, eastern and western Asia, and India from the 4th century BCE until the 14th century CE. These temple grottoes are not only a great art treasury marking the spread of Buddhism from India to China but also are an enduring record of the interplay across cultures of macrosocial forces—globalization. The caves, however, are more than a monument to faith. Their murals, sculptures, and scrolls also offer an unparalleled glimpse into the multicultural society that thrived for 1,000 years along the once-mighty corridor between East and West [Larmer 2010].

The golden era of Dunhuang began 300 years after Le Zun (CE 642, 16th year in the reign of Emperor Zhenguan of Tang Dynasty). On the precipitous cliffs spanning some 1,600 meters, 750 caves, 492 of them with mural paintings, are cleaved into the escarpment on three levels in a formation resembling a beehive. On its northern reaches, the caves were austere, unadorned places where the craftsmen and painters lived. The southern reaches of the site were markedly different: these caves, intended for enshrining Buddhas, were decorated on the outside with wooden eaves supported by elaborately painted and carved columns, and they were interconnected by plank ways that worshippers used to travel between caves. In total, there are 45,000 square meters of murals and more than 2,000 painted clay figures. Buddha statues, paintings of paradise, savior gods, saints, and angels adorn the walls. The inside entrances of many of the caves are painted with the portraits of patrons, merchants, and officials who sponsored the mural paintings as an enduring record of faith and wealth—generous donors would even grind precious stones into powder to christen the Buddhist realm of their ideals. Dunhuang is considered a singular and astonishing art repository and like none other in the Chinese Buddhist world. It was in this great era that Cave 220 (subject of *Pure Land* interpretations) was created (early Tang CE 618–705).

The caves themselves face significant conservation problems due to rising humidity weather and erosion, resulting in plaster disruption on the surfaces of the murals, discoloring, and fading. Increasing humidity corresponds directly to burgeoning numbers of tourists who want to discover this magnificent site. The estimated carrying capacity for the caves is about 3,000 people per day; however, during peak periods, there are almost 6,000 visitors a day at the site [Hunt 2013]. In most caves, the murals and statues are protected (and often optically hindered) by glass panels, and the only lighting is via low-intensity LED torches—one of them held by the guide who is explaining the narrative iconography of the paintings and sculptures. Thus, a real-life visit suffers from restrictive, albeit necessary, limitations. At Dunhuang, there is an obvious tension between the desire to show this rich and important treasury to the world and the ongoing protection of the caves. An extensive digitization program is part of an ambitious plan involving many of the world's best experts, to give access to the caves while at the same time protecting them (e.g., Wallach [2004], Dunhuang Academy [2010]). Holland Cotter [2008], a *New York Times* journalist, forecasts possible responses to the dilemmas faced at the caves:

> The short-term solution has been to limit the number of caves that can be visited and to admit people only on timed tours, but the deterioration continues . . . Digital technology will give visitors a kind of total immersion encounter with the caves impossible before now . . .

2. VIRTUAL REALITY AND AUGMENTED REALITY

With the reduction of the cost of computer hardware and the rapid development of PC-based graphics processors, VR environments are becoming more affordable and popular. Large high-resolution displays have been widely applied in various domains [Ni et al. 2006]. A variety of different VR system have been designed and developed, such as the original 4-sided CAVE [Cruz-Neira et al. 1993], 17-sided pentagon-shaped StarCAVE [DeFanti et al. 2009], and the AVIE [McGinity et al. 2007] with a circular 360-degree screen (*Pure Land*). Head-mounted displays (HMDs) are also very popular in VR systems. As opposed to large screens, typical HMDs shut down the user's connection to the real world and feed the visual and audio signal to user's eyes and ears directly, but there are some other designs that use the see-through display or a head-mounted camera to allow the user to access the outside world. All of these systems give the user the immersive experience of entering a computer-generated virtual world.

In contrast to VR, AR attempts to embed synthetic supplements into the real environment rather than immersing a person into a completely synthetic world [Bimber and Raskar 2005b]. In fact, by

Fig. 3. Reality–virtuality continuum [Milgram et al. 1995].

looking at the reality–virtuality continuum of Milgram et al. [1995] (Figure 3), AR and VR are collectively described as the mixed reality, with different positions on the continuum. AR is orientated to the real environment, and VR, at the right-most position, orientates itself in a virtual environment.

The beginnings of AR date back to the work of Sutherland [1968] in the 1960s, where he used a see-through HMD to display 3D graphics. However, not until the past two decades has there been enough activity to define it as a significant area of research. Since then, research in AR has been growing at a rapid pace [Azuma 1995; Azuma et al. 2001]. Development of free software toolkits, such as the ARToolkit [Kato and Billinghurst 1999] for rapid building of AR applications, also helps to increase the popularity of AR.

There are two main streams of AR: video monitor AR and projector-based AR. In video monitor AR, the user sees the augmented image by some kind of display. A daily life example is the overlaying of real-time information onto live sport broadcasting images. In this case, the display is the television or a mobile phone. HMDs are also heavily used in building AR systems. Since HMDs block the user from the physical world completely, HMDs intended to be AR devices usually come with an additional camera for the user to see the outside world as well as the augmented images. Sometimes optical see-through HMDs are used instead of carrying a camera.

In projector-based AR, the user does not need to use a display to see the augmented image. Instead, the augmented image is projected directly on a physical object. The idea is to replace a physical object with a neutral object in order to project imagery to reproduce the original or enhanced appearance. This special type of AR is also called *spatial augmented reality* [Bimber and Raskar 2005a] or *projection mapping*. In addition, this form of AR has become more popular recently as some interesting applications have been shown to the general public, such as projecting images and animations to a large building to create a variety of optical illusions.

No matter which display or technique is used to integrate augmented images with the real world, one of the most important issues is the tracking and registration. Without accurate tracking, the generated image will not be able to merge with the real environment correctly. Tracking in AR is significantly more difficult than in VR, because VR applications usually only involve tracking of the user's head and the interface device. However, in AR applications, the system needs to track the objects in the physical environment as well as the user. Obtaining correct registration means that the virtual and real objects must stay properly aligned to produce the illusion that the virtual and real objects exist and interact with each other [Thomas and Lau 1990].

Traditionally, we use a monitor to see the output from a computer and use a keyboard and a mouse to input information or control the computer. This way of interaction works well in our daily life. However, in the case of using large or special displays such as HMDs, using a mouse and keyboard no longer fulfills the user's need. In the virtual environment, the user is interacting with everything surrounding the user. Sometimes the user is even unable to see the controlling devices directly, as in the case of navigating the virtual environment using a HMD. As with the development of VR and AR, 3D user interface design (3DUI) [Bowman et al. 2004] has become so important that it has grown into a research area of its own.

Today, even inexperienced users can create video content using widely available animation software (open source), such as Unity 3D. Furthermore, with the emergence of relatively low cost AR and 3D devices (e.g., Google Glass, Oculus Rift), the affordability of the virtualization environment will be significantly increased for future adopters. In digital heritage, VR for public audiences has thus far been largely constrained to CAVE-based works despite a lively discourse. Important initiatives such as the Virtual Archaeology Review have begun to chart developments in this field, but little has moved beyond traditional screen modalities when it comes to display. The situation is not the fault of researchers but a lack of diversification in immersive system design and, importantly, cultural organisations willing to take on the challenges and opportunities demanded by high-fidelity virtual environments.

Research into new experiences for AR is exemplified by such European Union projects as Cultural Heritage Experiences through Socio-Personal Interactions and Storytelling (CHESS), aiming to integrate interdisciplinary research in personalization and adaptivity, digital storytelling, interaction methodologies, and narrative-oriented mobile and mixed reality technologies, with a sound theoretical basis in museological, cognitive, and learning sciences [Keil et al. 2013]. As mobile devices become more powerful in terms of interactivity, data gathering, and Internet access, AR apps are becoming increasingly popular for heritage mapping (e.g., Historypin).

3. *PURE LAND* AND *PURE LAND AR*

3.1 *Pure Land*

Exploiting the high-resolution photography and laser scanning data recorded by the Dunhuang Academy at Cave 220, *Pure Land* reframes and reconstitutes the extraordinary wealth of paintings found in the caves at Dunhuang inside an immersive 3D, 360-degree visualization system—the Advanced Visualization and Interaction Environment (AVIE) [McGinity et al 2007]. Inside its panoramic enclosure (10 meters in diameter and 4 meters in height) visitors engage in a surrogate true-to-life experience of being inside this cave temple and seeing its magnificent Buddhist wall paintings at a one-to-one scale [Kenderdine 2013a].

Following an interpretive script and art direction by the Dunhuang Academy and project sponsor Friends of Dunhuang Hong Kong, the project's team was able to redraw, restore, and recolor key iconographic elements in the wall painting. The team was also able to create 3D animated objects and 3D video-captured dance sequences where such animation is implied to highlight the painting's original intent. A single user interface, operated by one of the visitors or a docent, provides interaction with the digitally rendered cave, allowing the user to reveal key elements in the mural paintings on its walls. As well as offering a powerful space of embodied representation, *Pure Land* uses various digital image processing techniques, 2D and 3D animation, as well as 3D cinematography to further develop its experiential and interpretative capabilities [Kenderdine 2013a].

A skilled docent leads the tour as up to 30 visitors begin their experience in a scene covering the full expanse of the escarpment of cave entrances, where important iconographic elements from 50 significant caves are presented (Figure 4). Choosing to enter Cave 220, visitors are suddenly surrounded by total darkness, which is only relieved by the docent's virtual torch beam, slowly revealing the nature of the cave space and its wall paintings and sculptures. This initial immersion in the virtual cave is meant to simulate what the viewers' rather limited experience would be if they were visiting the real Cave 220. Visitors are familiarized with one of the most powerful interactive tools available—a virtual 3D "magnifying glass" that takes advantage of the system's very high resolution photographic datasets (Figure 5). A circularly framed portion of the screen—the magnifying glass—can pan anywhere over the cave's wall surfaces and zoom progressively into the finest details of the cave's paintings. As the zoom factor increases up to 10 times, so does the size of the magnification window, which appears to

Fig. 4. *Pure Land*, escarpment image browser. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

Fig. 5. Magnifying glass and animated 3D model of a *ruan* classical instrument in *Pure Land* [2012]. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

detach itself from the plane of the painting and float closer and closer to the viewer. In effect, what is being simulated is the real-world dynamic of a viewer approaching closer to the mural to examine it in more detail; however, in *Pure Land*, this greater detail enlarges and approaches the stationary viewer, a digital *trompe l'oeil* effect that has a powerful perceptual impact [Kenderdine 2013a].

The figures and objects in these paintings are dramatized by means of interactive digital effects that reveal their painterly beauty and underlying narrative meanings. Using pigment studies by the Dunhuang Academy and a laborious process of hand painting, "restored" Medicine Buddhas are activated for viewers as a layer, floating out in 3D space in front of the original painting (Figure 6). Particular objects within the painting, such as six incense burners beneath the feet of the Buddhas

Fig. 6. Recolored Medicine Buddhas, 2D layered animation in *Pure Land* [2012]. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

and numerous musical instruments of traditional Chinese and Central Asian varieties (being played by two groups of musicians in the painting), have been studied and transformed into fully textured 3D models. These elements can be activated to float out in front of the painting, where they then rotate in two axes to reveal their forms and features. Two performers from the Beijing Dance Academy were filmed in 3D and inserted ("composited") into the mural scene, giving the painting yet another dimension of "aliveness" [Kenderdine 2013b].

The interactive features of *Pure Land* allow this world to be transformed from a mimetic representation to a navigable space, rich with layered interpretation and fully illuminated—impossible if one were there in person. In addition, although the work was built for general public interpretation, its features also have significant potential as scholastic tools. The ability to navigate up to the roof inside the digital model provides scholars with unparalleled access to iconography that is hard to reach, as the magnifying glass provides close-up views while maintaining context within the overall painting.

3.1.1 *Pure Land Technical Implementation.* The first version of *Pure Land* was developed in the 360 interactive VR system named AVIE [McGinity et al. 2007]. There are three primary components to the AVIE system for *Pure Land* application: the image generator, the 3D stereoscopic projection subsystem, and the user interface. The image generator consists of six high-performance workstations running in a cluster mode. In the cluster, there are a master and five slave machines. The 3D VIA Virtools™ was chosen to be the graphics engine, and each member of the cluster is running an exact copy of the virtual scene of the Cave 220. All of the events and activities that happen within the virtual world are synchronized among the members of the cluster via a high-speed network. Each of the slave workstations is responsible for rendering the 3D stereoscopic images to one of the five active projectors of the projection subsystem. Each projector can produce a high-definition resolution of 1,980 by 1,200 pixels running at the refresh rate of 120Hz. The images from different projectors are then projected on the

Fig. 7. *Pure Land AR* [2012], Shanghai Biennale, September 2012 to March 2013. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

circular screen, seamlessly blended to create a single 360-degree scene. Combing all projectors, the total resolution is 9,900 by 1,200 pixels. In practice, due to pixel loss from geometric correction to the curve screen and edge blending, the effective resolution of the whole system is about 8,500 by 9,00 pixels. The size of the circular screen is 9 meters in diameter and 4 meters in height, and it can easily fit in 30 visitors at a time. By putting on the active shutter glasses, visitors are able to see the stereoscopic images. Combined with the surround sound system, visitors are fully immersed in the virtual environment. The user interface consists of a gamepad-like controller and visual/audio feedback. The controller is connected to the master computer in conjunction with an Intersense InertiaCube™ sensor. The sensor detects the orientation of the controller and helps to move the pointer/cursor on the circular screen. With the different combinations of the buttons assignment and the movement of the pointer, the user, usually a docent, is able control the device to manipulate different interactive tools or trigger various animations. Two other versions have been produced, one using a mini iPad for general public use where buttons are assigned to predesigned sequences, and the other a fully automated version running as an immersive film, with voice-over used for mass public settings (where there are nearly 180 visitors per hour, with 30 visitors per session).

3.2 *Pure Land AR*

Pure Land AR [Chan et al. 2013] uses mobile media technology to create a complementary AR rendition of the same data from Cave 220. Walking around inside the exhibition space with tablet screens in hand (Figure 7) visitors are able to view the architecture of the cave and explore its sculptures and wall paintings as they appear on viewers' mobile "windows"—a kinesthetic revealing of the painted architectonic space. In this installation, the walls of the exhibition room (which share the same scale as the real cave) are covered with one-to-one scale prints of Cave 220's "wireframe" (see inset in

Fig. 8. *Pure Land AR* [2012], Shanghai Biennale, September 2012 to March 2013. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

Figure 1) polygonal mesh, providing users with visual cues as to what to explore. These derive from the Dunhuang Academy's original "point cloud" laser scans of this cave. Inside a virtual model, the high-resolution photographs of the cave's paintings and sculptures are digitally rendered onto this polygonal mesh to create the composite 3D representations that are then presented to the visitors on the tablets as they navigate the exhibition space. Infrared cameras track the position and orientation of the visitor tablets, whereas computers render the appropriate views of the digital cave, transmitted via WiFi, in real time.

Throughout the process, the tablet screen shifts from being considered as an object in and of itself to functioning as a mobile framing device for the staging of a "virtual" rendering of the real cave that relies on an intricate spatial tracking system. This is not a passive televisual environment but an interactive performance. Cave 220 is being exactly mapped between real space and the digital model. In this instance, *Pure Land AR* is activated in the twists and turns of the handheld screen. By moving the monitor around the space, the viewer can examine three walls of the cave, and by holding the tablet aloft, he or she can also see the magnificent ceiling painting. Thus, the tablet reveals the cave as something that is apparently located in the real space of the gallery. As the visitor/user entertains the various possibilities of moving through the space with the tablet, the changing views of the cave are fluidly and accurately shown on the screen. In this way, the classic trope of a "window on the world" is virtually enacted. And given that this world is bounded by Cave 220's walls, when the viewer brings that window into contact with the exhibition wall surface, its painting appears at exactly a one-to-one scale within the frame of the tablet screen (Figure 8).

For this installation, which has an area equal to the actual Cave 220 (24 square meters), two mobile tablets allow two users, and typically groups of 3 to 10 people, to follow the tablets around. This method has proven to be successful, reinforcing the social qualities of the interpretive experience. *Pure Land*

Fig. 9. *Pure Land AR* [2012], Shanghai Biennale, September 2012 to March 2013. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

AR thus demonstrates the dynamics of a single-user, multispectator interface that is important to the notion of museums as places of socialization. A group of people will always surround the user and will follow, direct, gesture, prompt, and photograph the user's view of the world. This dynamic is integral to the interpretation and performance of the work [Kenderdine 2013a] (Figure 9).

The conjunction between the actual wireframe image on the exhibition walls and the lifelike cave rendering seen on those walls via the tablet window operates in the borderline between the indexically real and the phantasmally virtual—between re-embodiment and disembodiment. *Pure Land AR* thus weaves a set of subtle paradoxes into its web of virtualization and actualization, and these paradoxes feed the kinesthetic excitement that is clearly evident in visitors' astonished enjoyment of this installation. It thus aligns with the technologies of telepresence that virtually transport the viewer between the present location and another place—in this case, from the exhibition space to Dunhuang [Kenderdine 2013b].

In the annotated version of the same installation (Figure 10), descriptive texts were added to the virtual window, identifying key features. This version is to be used for experimental research in immersive teaching and is highly didactic, contrasting strikingly from the purely experiential version already described. The annotations are intended to help visitors comprehend the underlying iconographic elements. Flipping the iPad quickly forward and backward activates this addition feature. One of three languages can be chosen: traditional Chinese, simplified Chinese, and English. The text annotations are synchronized to orientation, and detailed descriptions are only visible within a small range of proximity to the wall. Farther away from the wall, a metalevel description of the entire Sutra is visible.

3.2.1 *Pure Land AR Technical Implementation.* There are three main components in the *Pure Land AR* system: the display interface (tablet), the optical tracking system, and image generators. They

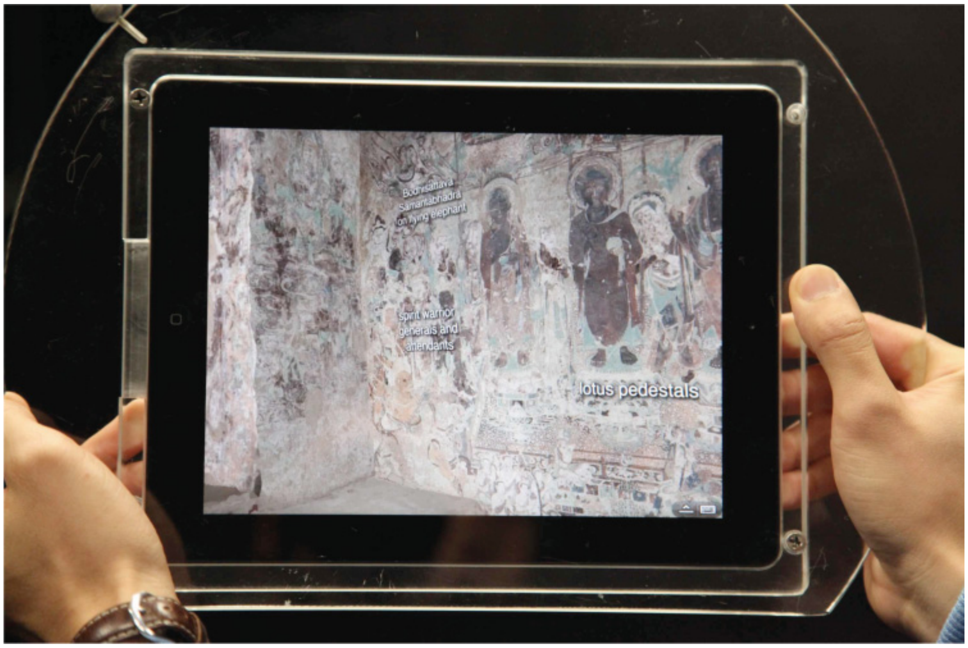

Fig. 10. *Pure Land AR* [2012], annotated. Image © Applied Laboratory for Interactive Visualization and Embodiment, CityU Hong Kong.

are used as the tangible display interface devices for users to reveal the virtual world. The tablets are installed in acrylic cases with attached retroreflective markers. The cases protect the tablets and prevent users from interfering the application running in the devices. The 3D model of the cave consists of around 1.3 million polygons, with 1.5 gigabytes of texture. Instead of rendering the image from the tablets themselves with their limited CPU power, the images are rendered and streamed from two high-performance computers via a wireless network in real time. Client applications of the software Splashtop® run on both tablets to receive the streaming video signal.

For the tracking system, the application uses NaturalPoint® OptiTrack™. This tracking system uses retroreflective marker technology to track targets with the infrared light source that is built into individual cameras. Twelve infrared cameras are mounted on the top edges of the installations' three-wall structure to provide a range of coverage of about 6 by 3 meters. The data is processed on a third computer. To track the tablets, at least three markers need to be attached to each of the targets. By analyzing the images obtained by the cameras at different angles, the computer in the tracking system is able to recognize and calculate the 3D position and orientation of the tablets in real time. During normal operation, it is often the case that the user will place the tablet directly against the physical wall to examine the mural at a one-to-one scale. In the virtual scene, it is equivalent to placing the projection reference very close to the cave walls. To achieve seamless results, the ability to track the tablet to millimeter movement is essential, and this is the primary reason for choosing an optical tracking system over other tracking technologies, such as a tablet's built-in inertial orientation sensor. Since it is not practical to place head-tracking markers on the heads of visitors in a gallery environment, the position of the virtual camera is derived from the tablet's coordinate. The camera is set at the center of the tablet with the perpendicular distance of 40 centimeters, which is approximately the eye position of an average adult holding the tablet with two hands.

With the tracking system in place, the tracking information is then broadcast to the computers (image generators) through the Ethernet using the Virtual Reality Peripheral Network (VRPN) protocol. The two tablets require two computers for image generation. These computers, with 3D VIA Virtools™ as the graphics engine, are responsible for acquiring the tracking data and rendering the images to match the motion of the tablets in real time. To achieve this, a 3D virtual scene was built with exactly the same setting as the physical setup in the tracker's frame of reference. Virtual cameras are attached at the approximated eye positions of the users, and the images are rendered from the cameras and fed to the screen of the corresponding tablets via the wireless network for the presentation of the virtual world to the users. Some of the special effects used in the 360-degree version of *Pure Land* (e.g., the restored images of seven Medicine Buddha paintings) are randomly triggered to enhance the richness of the content. With the help of the Splashtop® Streamer, these final rendered images are continuously compressed and sent to the tablet screens.

In a text-annotated version, the predefined texts are placed strategically close to different features of the painting. By default, all annotations are hidden and only become visible when the visitor holds the tablet interface stationary at particular points and distance from the wall. Each annotation has its own optimal range of visibility. In this way, the annotations of large features will not be intermingled with those of smaller features. In addition, the angle of the texts changes with the angle of the viewer's position.

4. CONCLUSION

With the original caves under threat from large-scale tourism and environmental threats, the innovative digital strategies offered by the *Pure Land* projects and their successors may be the only way to keep the artistic and spiritual brilliance of the Mogao Grottoes alive for current and future generations. Cave 112 has recently been optimized for AVIE, and there are plans for expansion to more caves. Ultimately, the *Pure Land* projects provide a visualization paradigm that could encompasses all caves. The projects signify benchmarks for the integration of archeological data and interactive and immersive technologies. They also give us fresh directions for the future of interpretive experiences in museums. Diverging significantly from former exhibition practices and contemporary cinematic viewing, *Pure Land* and *Pure Land AR* mobilize the viewer to coalesce his or her experiences in virtual and real space. By defining strategies for the embodiment of these experiences for visitors, these installations reactivate the history of the immersive view in museums and reinvigorate archeology with aliveness, extending the role of digital facsimiles to new levels of aesthetic and interpretative experience.

ACKNOWLEDGMENTS

Sections of this article were published previously in Kenderdine [2013a]. *Pure Land* and *Pure Land AR* have been produced by the City University of Hong Kong's Applied Laboratory for ALiVE in partnership with the Dunhuang Academy, sponsored by the Friends of Dunhuang Hong Kong and directed by Prof. Sarah Kenderdine and Professor Jeffrey Shaw. Computer programming was managed by Leith Chan and Mo Luk.

REFERENCES

Ronald Azuma. 1997. A survey of augmented reality. *Presence* 6, 355–385.

Ronald Azuma, Yohan Baillot, Reinhold Behringer, Steven Feiner, Simon Julier, and Blair Macintyre. 2001. Recent advances in augmented reality. *IEEE Computer Graphics and Applications* 21, 6, 34–47.

Oliver Bimber and Ramesh Rasker. 2005a. Modern approaches to augmented reality. In *Proceedings of ACM SIGGRAPH 2005 Courses (SIGGRAPH'05)*. Article 1.

Oliver Bimber and Ramesh Rasker. 2005b. *Spatial Augmented Reality: Merging Real and Virtual Worlds*. A K Peters/CRC Press.

Doug A. Bowman, Ernst Kruijff, Joseph J. Laviola, and Ivan Poupyrev. 2004. *3D User Interfaces: Theory and Practice*. Redwood City, CA, Addison Wesley Longman.

Leith K. Y. Chan, Sarah Kenderdine, and Jeffrey Shaw. 2013. Spatial user interface for experiencing Mogao caves. In *Proceedings of the 1st Symposium on Spatial User Interaction (SUI'13)*. ACM, New York, NY. 21–24.

CHESS Project. Available at http://www.chessexperience.eu/v2/.

Christy Choi. 2012. Virtual cave shines a light on the past. *South China Morning Post*, March 16, 2012. In Chinese, a representative article by Yu Zeut Bat, *Hong Kong Economic Journal*, March 23, 2012.

Holland Cotter. 2008. Buddha's caves. *New York Times*, July 6, 2008. Available at http://www.nytimes.com/2008/07/06/arts/design/06cott.html?pagewanted=1.

Carolina Cruz-Neira, Daniel Sandin, and Thomas Defanti. 1993. Surround-screen projection-based virtual reality: The design and implementation of the CAVE. In *Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH'93)*. ACM, New York, NY. 135–142.

Thomas A. Defanti, Gregory Dawe, Daniel J. Sandin, Jurgen P. Schulze, Peter Otto, Javier Girado, Falko Kuester, Larry Smarr, and Ramesh Rao. 2009. The StarCAVE, a third-generation CAVE and virtual reality OptIPortal. *Future Generation Computer Systems* 25, 2, 169–178.

Google Glass. Available at http://en.wikipedia.org/wiki/Google_Glass.

Historypin. Available at http://www.historypin.com/.

Katie Hunt. 2013. Buddhas in 3-D: Technology and the battle to preserve Asia's heritage. *CNN*, January 15, 2013. Available at http://edition.cnn.com/2013/01/15/world/asia/china-digital-caves/index.html?hpt = hp_c5.

Hirokazu Kato and Mark Billinghurst. 1999. Marker tracking and HMD calibration for a video-based augmented reality conferencing system. In *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality*. IEEE Computer Society, Washington, DC, 85.

Jens Keil, Laia Pujol, Maria Roussou, Timo Engelke, Michael Schmitt, Ulrich Bockholt, and Stamatia Eleftheratou. 2013. A digital look at physical museum exhibits: Designing personalized stories with handheld augmented reality in museums. In *Digital Heritage International Congress 2013.* 685–688.

Sarah Kenderdine. 2013a. Pure Land: Inhabiting the Mogao Caves at Dunhuang. *Curator: The Museums Journal* 2, 199–218.

Sarah Kenderdine. 2013b. Preservation and interpretation: Digital representations of the Mogao Caves at Dunhuang. *Orientations* 44, 4, 84–89.

Phillip Kennicott. 2012. "Pure Land" tour: For visitors virtually exploring Buddhist cave, it's pure fun. *Washington Post*, November 30, 2012.

Brook Larmer. 2010. Caves of faith: In a Silk Road oasis, thousands of Buddhas enthrall scholars and tourists alike. *National Geographic*, June 2010. Available at http://ngm.nationalgeographic.com/2010/06/dunhuang-caves/larmer-text.

Melinda Liu. 2012. Virtual tourism: China's Dunhuang Buddhist Caves go digital. *Newsweek*, December 17, 2012. Available at http://www.thedailybeast.com/newsweek/2012/12/16/virtual-tourism-china-s-dunhuang-buddhist-caves-go-digital.html.

Matthew McGinity, Jeffrey Shaw, Volker Kuchelmeister, Ardrian Hardjono, and Dennis Del Favero. 2007. AVIE: A versatile multi-user stereo 360° interactive VR theatre. In *Proceedings of the 2007 Workshop on Emerging Displays Technologies: Images and Beyond: the Future of Displays and Interaction*. ACM, New York, NY, 2.

Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. 1995. Augmented reality: A class of displays on the reality–virtuality continuum. In *Proceedings of the SPIE Conference on Telemanipulator and Telepresence Technologies*. 282–292.

Tao Ni, Greg S. Schmidt, Oliver G. Staadt, Mark A. Livingston, Robert Ball, and Richard May. 2006. A survey of large high-resolution display technologies, techniques, and applications. In *Proceedings of the IEEE Conference on Virtual Reality*. IEEE Computer Society, Washington, DC, 223–236.

Oculus Rift. Available at http://www.oculusvr.com/.

Jane O'Brien. 2013. Digital Chinese caves preserve history. *BBC*, January 6, 2013. Available at http://www.bbc.co.uk/news/magazine-20802947.

Pure Land: Augmented Reality Edition. Available at http://alive.scm.cityu.edu.hk/projects/alive/pure-land-ii-2012/.

Pure Land: Inside the Mogao Grottoes at Dunhuang. Available at http://alive.scm.cityu.edu.hk/projects/alive/pure-land-inside-the-mogao-grottoes-at-dunhuang-2012/.

Ian Sutherland. 1968. A head-mounted three dimensional display. In *Proceedings of the December 9–11, 1968, Fall Joint Computer Conference, Part I (AFIPS'68)*. ACM, New York, NY, 757–764.

Graham A. Thomas and Henry Y. K. Lau. 1990. Generation of high quality slow-motion replay using motion compensation. In *Proceedings of the International Broadcasting Convention (IBC'90)*. 121–125.

Hallan Wallach. 2004. High-resolution photography at the Dunhuang Grottoes: Northwestern University's role in the Mellon International Dunhuang Archive. In *Ancient Sites on the Silk Road: Proceedings of the Second International Conference on the Conservation of Grotto Sites, Mogao Grottoes, Dunhuang, People's Republic of China*, N. Agnew (Ed.). Getty Conservation Institute, Los Angeles, CA.

Received March 2014; revised May 2014; accepted May 2014