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Monticello Through the Window

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Abstract

We present a case study in the use of virtual environment technology for cultural heritage applications, describing a collaborative effort to construct two cultural heritage exhibits for a five month exhibition at the New Orleans Museum of Art. To illustrate the factors that shape museum exhibit design, we explore the initial conceptual phase and discuss our reasons for choosing certain designs. We describe the two exhibits that we built in turn, focusing on equipment and on robustness. Although little went awry during the exhibition, we explain how certain equipment did fail and how we had prepared for such crises by keeping spare equipment on-site. Finally, we report on the success of the undertaking and close with some thoughts and advice for researchers attempting similar museum-oriented projects.

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1. Introduction

The New Orleans Museum of Art (NOMA) recently concluded a five month exhibition, *Jefferson's America and Napoleon's France*, commemorating the bicentennial of America's Louisiana Purchase in 1803. On exhibit were many period artifacts and personal items belonging to Thomas Jefferson and Napoleon Bonaparte. Jefferson was not just America's third president and author of her Declaration of Independence, but also an inventor, farmer, scholar, and architect. Jefferson's well-known architectural accomplishments include the University of Virginia and his mountaintop home, Monticello, which graces the back of the American 5 cent coin. The museum curators wished to convey Jefferson's love of and achievements in architecture, of which he wrote in 1809:

> Architecture is my delight, and putting up and pulling down one of my favorite amusements.

Unfortunately, since Monticello is located one thousand miles away from New Orleans, the museum needed a way to virtually transport visitors there.

Our research group from the University of North Carolina at Chapel Hill and the University of Virginia had already visited Monticello to capture 3D models of the site in 2000. To this end, the Monticello curators referred the NOMA curators to us. We forged a collaboration that provided us with an opportunity to demonstrate some of our research results to the public. NOMA also profited from the partnership, receiving two exhibits that offer 3D views into Jefferson's home. The first, which the museum titled *Virtual Monticello* (Figure 1), is a life-sized rear projected virtual environment. The second, *Jefferson's Cabinet*, is a barrier stereogram cre-

Figure 1. **The Monticello library.** We created this 3D model, for use in the *Virtual Monticello* exhibit, with a laser scanner and digital camera.

ated in collaboration with (art)^n, a Chicago-based group of artists.

This paper traces the history of the project from the initial conception through the exhibition conclusion, highlighting not just our successes but also the missteps that might serve as forewarning to future researchers attempting similar heritage projects. In the next section we describe the exhibit ideas and justify the high-level design choices that we made. In Section 3 we discuss our creation of *Virtual Monticello* including model capture and user tracking. Section 4 treats the construction of *Jefferson's Cabinet*. We describe the results of the project in Section 5, including how we dealt with on-site equipment failure. Finally, we conclude with our impressions of the project and suggestions for those attempting similar projects in the future.

2. The Concept

A number of factors guided the exhibit design including cost, quality of experience, throughput (measured in visitors per day), and perhaps most important, robustness. The museum curators expected several hundred thousand visitors and we designed our exhibits to handle the abuse. As of May 2002 we had narrowed our focus to four possible exhibits. We now discuss all four ideas and why we ultimately chose to accept or abandon each one.

Kiosks. We first considered building a number of kiosks, which visitors could use to navigate through a model of Monticello. Each kiosk might have consisted of a flat panel display and a trackball or joystick with which a user could interactively explore a portion of Monticello, enabling him to walk up to interesting objects to investigate them more closely. In order for all visitors to experience the exhibit, we considered outfitting a room with ten or twelve kiosks. Even then, some visitors would not have been able to use one. We would have partially alleviated this problem by projecting one computer display onto a large screen for all to see. We also considered reducing the hardware expense by using modern programmable game consoles in place of commodity computers. The kiosk idea was ultimately rejected for several reasons. Similar 3D navigation experiences, in the form of video games, can be had on home computers, and we felt that it wouldn't be especially exciting for visitors. Also, to make the kiosks most interesting, the acquired model of Monticello should ideally include multiple rooms scanned at high quality, a daunting challenge for the scanning team. Finally, the museum had originally proposed a large room in which to house the kiosks, but later exhibition designs did not include this extra space.

Shader Lamps. Raskar et al. introduced the concept of *shader lamps*, whereby projectors are used to illuminate physical objects [1]. We considered building a 3D computer model of Jefferson's library and constructing a physical scaled model using a stereo lithography printer. Then we could have lit the white physical model with projectors, for example simulating sunlight varying from dawn to dusk or a candle passing through the room at night. Clearly, this would have been a unique exhibit and a good way to expose the public to our research work. We made a prototype by constructing a model of a dollhouse and lighting it, as shown in Figure 2. However, the Shader Lamp construction process is very labor intensive because it requires precise modeling and calibration to achieve the intended effect. Even in the simple case of the dollhouse, light from the chair texture bled onto the floor. We decided that for the museum setting we would have to design an automatic calibration procedure, perhaps with cameras as sensors. Furthermore, the object would have to be protected behind glass at the museum, which would make proper projector

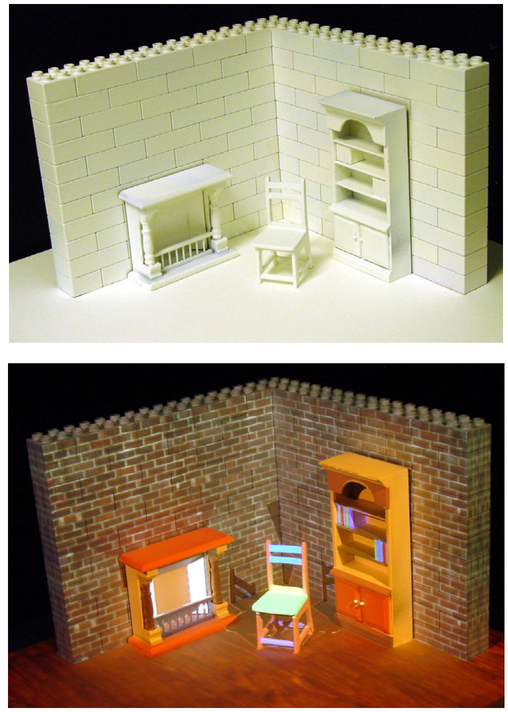

Figure 2. **Shader Lamps.** We built a computer model of this dollhouse to prototype construction of a Shader Lamps exhibit of Jefferson's library. We painted the dollhouse furniture and walls with white paint (top) and illuminated the model with two carefully calibrated projectors (bottom). Precise calibration and modeling is difficult to achieve so some green light intended for the chair appears on the floor.

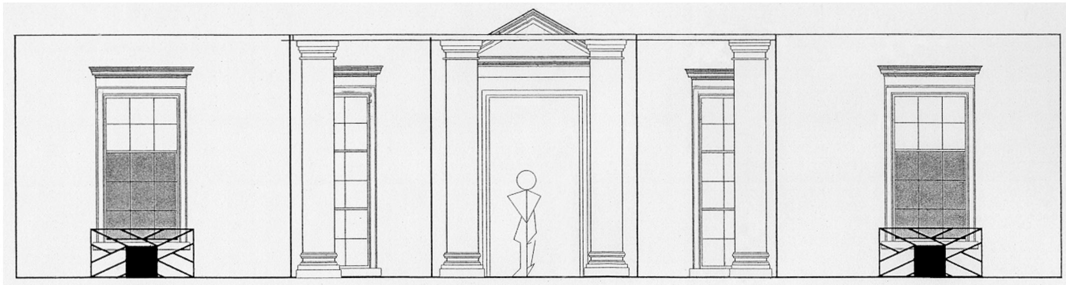

Figure 3. **Monticello facade.** These plans illustrate the 17m wide facade of Monticello built for the NOMA exhibition. A *Virtual Monticello* exhibit was installed in the leftmost and rightmost windows. Notice the wrought iron barriers in front of the windows that we replaced with wooden fences in the final plans to prevent magnetic tracker distortion.

placement difficult. The finished model would only be 0.4m across and would be difficult for many visitors to view at once, creating a bottleneck on the exhibition floor. Ultimately, we decided not to pursue this project because it seemed too complex to complete on time.

Through-the-Window. The concept for this exhibit is a projected stereo environment whereby visitors look "through" a window into Jefferson's library, one of his private rooms at Monticello. We were inspired by a display system created for the Office of the Future project [2]. Not only is looking through a window a natural and familiar mode of user interaction, but it also helps bound the production effort by limiting the range of possible views seen by the visitor. In essence the visitor is looking at a stage set, and all that needs to be modeled is one-half of the room.

In Mr. Jefferson's final years, people looking through his office windows in hopes of seeing their former president often interrupted him at his work. This anecdote served as the storyline for the *Virtual Monticello* exhibit, which was housed in a 17m wide facade of Monticello. We assembled two *Virtual Monticello* exhibits, one for each side of the facade, as shown in the plans in Figure 3. At the request of the museum staff, who were concerned about crowd congestion on the museum floor, we made both sides identical to decrease the temptation to try both windows. Creating two identical exhibits also decreased the relative cost of each one. *Virtual Monticello* will be described in greater detail in Section 3.

Barrier Stereogram. The concept for this exhibit follows the *through-the-window* theme by providing a stereo view into Jefferson's cabinet, his office in the private quarters. Though perhaps not as exciting and dynamic as *Virtual Monticello*, the barrier stereogram was less expensive to produce. Furthermore, it is extremely robust to museum mishaps as the final product is no more than a special photograph set between a lightbox and a barrier array, and mounted on the wall. The stereogram is very bright and serves to draw visitors towards it; it is also large enough (1m by 0.75m) for multiple visitors to observe it at once. Our barrier stereogram exhibit, *Jefferson's Cabinet*, will be discussed in more detail in Section 4.

3. Virtual Monticello

The *Virtual Monticello* exhibit is a life-sized, rear-projected, stereo virtual environment housed within a facade of Monticello. We constructed two such identical exhibits, one for each side of the facade. A model of Jefferson's library is projected in polarized stereo onto the 1.3m by 1.0m screen, which is set up to look like an exterior window of the home. This gives the illusion that the visitor is looking through the window and into the home.

We believe that the life-sized display provides a much richer experience than that provided by a smaller image. This is true even when the smaller image also exhibits stereo and motion parallax, as the barrier stereogram does.

3.1. Data Acquisition and Processing

Making 3D models of objects or environments is a surprisingly difficult problem. Some researchers have made notable progress on the scanning of objects such as statues [3, 4]. Others have explored the documentation and re-creation of archaeological sites [5, 6]. We have concentrated on indoor environments [7]. This exhibit presented us with an opportunity to show our results to the public.

We created a 3D model of Jefferson's library with the 3rdTech DeltaSphere 3000 laser scanner, a commercial version of a scanner that our research group previ-

Figure 4. This image shows one window of the Monticello facade where the *Virtual Monticello* exhibit was installed.

ously invented [8]. This scanner captures very accurate and dense range samples, which we merged into a unified mesh using the iterated closest point algorithm. We texture mapped the model with color images taken from the DeltaSphere's center of projection [7]. Then, we simplified the mesh to facilitate interactive rendering. Finally, we enlisted the help of a local artist to clean up the model by filling holes and fixing certain texture maps. Figure 1 is an example rendering of the completed library model.

We made three visits to Monticello in 2002 to scan the first floor rooms. Because Monticello is open to visitors during the day, we could only scan at dawn or during the evening until about 11:00 PM. Since all of our scans were necessarily performed without sunlight, we were forced to rely upon whatever lights we could set up. The color photography from our first scan was disappointing because of the poor lighting installed in the rooms. Accordingly, on the final two scans we hired a professional architectural photographer to help us light the rooms. His lighting equipment and expertise proved invaluable in creating a high-quality color model. Our through-the-window paradigm was also helpful in reducing the difficulty of model acquisition: since users can only see a portion of the room, we were free to place the lights where they helped the most as long as we kept them outside of the virtual window's field of view.

3.2. Stereo Display

Behind the screens and unseen by the museum visitors are the projection rooms that house our equipment. In each room we built a freestanding truss for the two projectors that provided the freedom to adjust the projectors' positions and the stability to keep the calibration from deteriorating. Both projectors are mounted on their sides and equipped with circularly polarized lenses. We chose Mitsubishi XD300U-XGA projectors because their expected lamp lifetime of 4000 hours exceeded the length of the exhibition, and because we calculated that they would be sufficiently bright despite the lighting attenuation due to polarized lenses. We choose a Stewart Filmscreen TechPlex 150 rear-projection screen; this screen material is non-depolarizing and is rigid for easy mounting in the window frame.

On the external side of the facade museum visitors view the projection screen through polarized glasses. We considered using disposable glasses, but abandoned the notion because the cost of hundreds of thousands of pairs would have been prohibitive. Furthermore, commercially available disposable 3D glasses use linear polarization; we preferred circular polarization since we find that users often turn their heads somewhat in the through-the-window setting. Non-disposable aviator-style glasses are often used for 3D movies and are available with circular polarization; however using these would have required the museum to hand out, collect, and sanitize many pairs of glasses every day. Instead we custom designed and machined 50 pairs of polarized glasses out of PVC; one pair is shown in Figure 5.

We opted for a handheld "opera glasses" design inspired in part by a 19th century stereopticon; additionally, we built six special pairs of glasses that house tracker sensors. The handheld design and bridge piece, which extends to touch the forehead, helps to keep the lenses away from the eyes and thus reduces the likelihood of spreading conjunctivitis. A rubber skirt is used to keep stray light out. The heavy PVC material makes the glasses resistant to the abuse that is inevitable in a museum environment. We also provided instructions to NOMA for cleaning the glasses with mild soapy water.

Figure 5. **The stereo glasses** were custom designed for this exhibit and constructed from PVC material. The bridge piece keeps the device away from the eyes to thwart eye infections and a rubber skirt keeps out stray light.

Figure 6. **The Jefferson's Cabinet** stereogram was built in collaboration with $(art)^n$. As users approach this 1m by 0.75m exhibit, the barrier layer causes the eyes to see two different images, creating the stereo effect.

3.3. User Tracking

We considered several possible tracking solutions, always with cost and robustness in mind. We first considered the HiBall optical tracker, which offers great accuracy and responsiveness [9]. Unfortunately, in addition to the expense the HiBall requires a ceiling grid infrastructure that could not feasibly have been installed in the museum. We also considered camera-based methods that would track a dot affixed to the polarized glasses. In our experience, these methods are not robust enough. In the end we decided to use magnetic tracking, which though less accurate than some optical trackers is a more mature technology and is generally more robust to abuse. The size of the facade eliminated one potential problem, the close proximity of two magnetic sources.

We chose the Ascension Flock of Birds magnetic tracker with Extended Range Transmitter because the sensors are small and difficult to break. Furthermore, the Ascension tracker uses pulsed DC magnetic technology that is less susceptible to distortion from the latent metal that we knew would be embedded in the museum's concrete floor. We also evaluated the Polhemus FASTRAK, but found that it performed inconsistently in our working environment. Having decided to use magnetic tracking, we had to be watchful for any metal in the environment. Even though we'd specified metal-free construction for the Monticello facade, at the last moment we had to correct the original facade design plans, shown in Figure 3, to remove a wrought iron gate that was to be placed between the visitors and the screen!

At any given moment, only one user can be tracked under each of the two window displays. Therefore, most users hold untracked polarized glasses and see a 3D image whose projection appears to be strangely warped. This is very similar to the case when multiple users are inside a CAVE display [10]. The tradeoff was necessary because of the heavy visitor throughput that NOMA required, throughput that could only be met by not tracking all users. When traffic is light, the docent on duty hands the tracked glasses to all visitors. However, when the museum is very busy, some visitors miss the tracked experience.

3.4. Systems Issues

The *Virtual Monticello* exhibit consists of a great many individual pieces, many of which we engineered ourselves. At the system's core is a 2.4 GHz PC running Windows 2000 with an nVidia GeForce 4 graphics card. We deliberately chose a graphics card that was one generation old in order to ensure more stable drivers. On the visitors' side of the wall, the system's user interface consists solely of the tracked glasses and a single control button used by the docent. We chose an industrial strength button because we knew that it would be pressed thousands of times.

We went to great lengths to have spare equipment on site for every single item that could break, as well as instructions for how to fix common problems. For example, we left spare projector lamps and instructions on how to replace them, as well as an entire spare projector. We placed the computers and trackers on uninterruptible power supplies to guard against power failures during summer thunderstorms.

We also took the time to put our machines on a virtual private network, accessible only to us. We installed remote access software so that we could work on the machines after-hours to make updates and in case of emergencies. As described in Section 5, these precautions proved invaluable in quickly troubleshooting equipment failures and for making last minute software changes.

4. Jefferson's Cabinet

Our second contribution to the museum exhibition was a 1m by 0.75m barrier stereogram (Figures 6, 8) that we built in collaboration with $(art)^n$ of Chicago. The artists at $(art)^n$ have developed and patented a barrier stereogram technology that they call a *PHSCologram* [11]. A physical barrier, composed of very thin vertical stripes, blocks the path of light rays to the eyes, except in one direction. By vertically interleaving multiple images onto the rear piece of film as columns of pixels, the two eyes see different images, thus achieving the stereo effect. The viewer sees different images as he moves right and left, producing motion parallax.

Since the images span the horizontal but not the vertical axis, they do not capture the full light field and the perspective of the scene appears distorted as the viewer

Figure 7. **The railcam** captures densely spaced photographs with minimal user intervention. This candid photograph shows author Nathaniel Williams and architectural photographer Charles Shoffner working with the railcam in Monticello's parlor.

moves up and down or forward and backward. In addition, the limited number of images can capture only a limited field of view, so that if the viewer moves too far, say to the left, the scene blurs and then shifts back to the view from the right. Despite these limitations, the intrinsic stereo and motion parallax of a PHSCologram provide a compelling and captivating illusion of depth.

PHSColograms are typically built from a set of synthetic images rendered from a 3D model. However, we decided to try to build one from a very dense set of digital photographs. Not only could we achieve higher fidelity by capturing the images directly but also the room in question is cluttered with intricate or highly specular objects that are difficult to scan well. Proper positioning of the camera was crucial for producing a good result. To collect the images for the PHSCologram we first built a scanning apparatus that we dubbed the *railcam*. As illustrated in Figure 7, the *railcam* consists of a six-megapixel Kodak DCS-760 camera mounted on a one-meter-long linear positioner. We wrote a computer program to automatically control the camera position and shutter. We used the program to acquire 64 equally spaced images. Quick image acquisition was important for two reasons. First, our scanning time at Monticello was limited and expensive. Second, the scene was not entirely static, though we wish it were so; the clock hands move visibly and the dawn sky brightens as the viewer moves from right to left.

As with the acquisition of the library model, we had Jefferson's cabinet lit professionally to facilitate production of good color photographs. Understandably, the curators did not give us completely free reign in working around Monticello's priceless artifacts. For example, we were not allowed to remove the highly reflective UV-blocking film from the windows. As the UV shield stirred in the ventilation's breeze, we captured large motile specular highlights that made the windows appear very strange. Our only recourse was to manually paint out the windows from each image and to produce computer generated windows in their place. This task alone consumed over 50 hours and demonstrates that the final say is always with the curators in working around irreplaceable artifacts.

5. Results

We believe, and the NOMA curators agree, that our exhibits were a great success. We estimate that 110,000 people attended the exhibition between April 12th and August 31st, 2003.

Even after extensive design and consultation with the museum curators, experience during the first days of the exhibition convinced us to make some changes to the system. The *Virtual Monticello* exhibit was designed to run for 60 seconds each time the docent pressed the control button. The idea was to limit the amount of time that each visitor would spend at the exhibit (throughput was of great concern to the museum curators). However, observation of the docent's interactions with the visitors convinced us that this 60-second timeout was not only unnecessary, but also too cumbersome. The docent was typically turned away from the screen speaking with visitors, and would not notice that the display had timed out and dimmed. Furthermore, the docents were very good at moving the tracked glasses from one visitor to another. We did away with the timer and have had no reports of problems.

We also decided to guard against tracker failure by designing a trackerless system mode. We could have had the system display a static, stereo image; that is of some interest to visitors because they don't normally see life-sized stereo. However, a great deal of the depth illusion is provided by motion parallax. We decided to obtain motion parallax by implementing an automatic side-to-side rocking motion. The docent can put the system into rocking mode by holding the control button down for five seconds. The trackers worked well but the museum staff used trackerless mode on days when there were too many visitors and not enough staff.

We were pleasantly surprised by the robustness of the *Virtual Monticello* system; we expected many more equipment failures than actually occurred. The only significant breakdown was a graphics card failure. We were unable to diagnose this remotely because the museum staff could only tell us that "the computer won't boot." Fortunately, we planned for such failings and had left a spare PC in the projection room. We talked them through the machine swap over the phone. Once the network was set up we were able to log in remotely to install the necessary calibration files and software updates.

Every other problem occurred on the visitor side of the screen. One tracker sensor cable failed. The museum staff reported that tracking would stop intermittently but that they could restart it by jiggling the cable. Fortunately we had several spares onsite with which to replace it. The polarized glasses suffered the greatest attrition; 15 of the 50 that we manufactured were broken during the first 100 days. The museum shipped the broken ones back to us and we were able to repair most fractures and return them. Surprisingly, the majority of the breaks were beam stress fractures and not the joint failures that we anticipated. However, the overall attrition of glasses was consistent with our expectations.

6. Conclusions

We have described our experiences designing and constructing two through-the-window exhibits for the New Orleans Museum of Art. This paper focused on the system design and engineering needed to ensure a robust product and enjoyable visitor experience.

The fact that the five-month exhibition proved largely trouble-free convinces us that the conservative engineering of the system was justified. If we had the freedom to alter the past, we would order equipment earlier in the process. It took much longer than we expected to obtain the projection screens, so we did not see the results of the complete system until we installed it in New Orleans.

In the end, we were quite happy with the experience delivered by both of our exhibits. We believe that the through-the-window technique provides one of most compelling virtual experiences available today. It presents high-resolution life-size imagery, grounded in our case by the familiar physical props of a real window (shutters, mullions, trim). The user interface – look through a pair of glasses and walk around – is intuitive for users of any age. While a high-quality head-mounted display with good tracking can provide a more immersive experience, the expense, visitor throughput, robustness, and sanitary issues of such equipment do not lend themselves to a museum environment. The window metaphor also allows us to focus the attention of the user, ensuring that each visitor gets a good view of the intended subject (head-mounted displays are notoriously easy to get lost in). We would certainly recommend through-the-window display for similar cultural heritage dissemination projects.

The barrier stereogram was a more experimental venture; since we had no prior experience with PHSColograms, we were unsure how it would look. We were delighted with the vivid imagery and attention-grabbing stereo effect without glasses or tracking. The barrier stereogram provides a passive look into Jefferson's study viewable by several visitors at once; it proved a nice counterpoint to the *Virtual Monticello* display, which provides a more active and dynamic experience but works best for the single visitor wearing the tracked glasses. The stereogram is also simple and robust; it has no moving parts and was no more difficult for the museum to maintain than their valuable paintings.

We hope that our experience will be useful to computer graphics researchers attempting similar cultural heritage projects with museums in the future.

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Frederick P. Brooks Jr. suggested the PHSCologram. Keith Miller from (art)^n spent many hours working with us to get the PHSCologram right. We enjoyed the collaboration and are looking forward to more.

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Figure 8. **Jefferson's cabinet exhibit stereo pair.** View this pair of images "cross eyed".