Immersive Art: Using a CAVE-like Virtual Environment for the Presentation of Digital Works of Art

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Abstract: Digital works of art are often created using some kind of modeling software, like Cinema4D. Usually they are presented in a non-interactive form, like large Diasecs, and can thus only be experienced by passive viewing. To explore alternative, more captivating presentation channels, we investigate the use of a CAVE Virtual Reality (VR) system as an immersive and interactive presentation platform in this paper. To this end, in a collaboration with an artist, we built an interactive VR experience from one of his existing works. We provide details on our design and report on the results of a qualitative user study.

Keywords: Virtual Reality, Digital Works of Art, CAVE, Interaction, User Study

1 Introduction

Figure 1: **Left:** The work of art *Tarnen & Täuschen III* by Tim Berresheim, which was transformed into an interactive Virtual Reality experience. **Right:** The artist immersed in his work of art in the *aixCAVE.* © Tim Berresheim

Modeling software, like Cinema 4D, is frequently used as a tool to create digital works of art consisting of abstract or concrete 3-dimensional scenes. Using common presentation channels, like print or video, they constitute an unalterable artifact that cannot be influenced by its viewers, thereby turning them into passive onlookers. In an attempt to explore alternative presentation channels, a collaboration with artist Tim Berresheim was initiated with the goal to create an interactive experience from one of his works of art using Virtual Reality (VR) technology. Viewers were to be made an active part of the work of art with the ability to influence it, thereby creating a more captivating experience. To this end, the artist selected one of his works for conversion into an interactive VR application that can be explored using a CAVE automatic virtual environment (CAVE) VR system.

So far, several art projects that employed either Augmented Reality (AR) or VR technology have been carried out. Due to the nature of AR, related projects always involve the real world to a certain extent. Either, users are given an alternate view onto an existing physical work of art without any form of involvement [COL, ARA]. Or, they are enabled to create entirely new pieces based on the real world [Mot, SO09]. Even though possible, AR-based projects usually do not allow users to actually enter a work of art and are often limited to small-screen devices. In contrast, VR-based projects almost always are centered around users entering the work of art presented. In her CAVE-based work *Uzume*, Gemeinböck [Gem04] has viewers engage in an interaction with an abstract, virtual being that reacts to users' tracked motions in unforseeable ways. Kogler [Kog] uses CAVEs to re-explore some of his architecture-related ideas in a new setting. The project *World Skin* by Benayoun [Ben] uses a CAVE to place visitors directly in a stylized virtual war zone. Using a tracked camera input device users are enabled to influence the virtual environment (VE) by photographing it and thereby explore the relation between war and media in a critial way. Heller [Hel] utilizes a CAVE for his project *Virtual Anima* which he uses to present an artistic visualization for a planned real world project. Keefe et al. [KFM+01] use a CAVE to create a 3D painting application that can be used to create entirely new pieces of art. Various kinds of art-related VR projects have also been carried out at the Electronic Visualization Laboratory [EVL]. Compared to the aforementioned projects, we take a slightly different approach in that we start from an existing work of art which is transformed into an interactive VR experience while retaining as much of its original form as possible.

The specific CAVE system used for the collaboration is the *aixCAVE* at RWTH Aachen University [Uni]. It consists of five walls—only missing a ceiling—with a footprint of 5.25m × 5.25m × 3.3m (w × d × h). The images are generated using a back-projection system consisting of 24 active-stereo projectors (four projectors per wall and eight for the floor). Each projector features an HD+ resolution of 1920 × 1200 pixels. For tracking, the *aixCAVE* is equipped with a camera-based optical infra-red tracking system.

The work of art chosen by the artist is called *Tarnen & Täuschen III* [Ber] and is shown in Figure 1. It consists of 400,000 particles that are arranged in organically-looking groups. They are placed in a box-shaped room with one inclined wall and a lamp attached to another one. Usually, this work of art is presented using a Diasec mounting sized 190cm × 230cm (w × h). For presentation in the *aixCAVE*, the scene was reproduced in such a way that its enclosing room matches the physical extents of the *aixCAVE*. This way, users can navigate the entire virtual room by means of natural walking, thereby avoiding the use of artificial navigation approaches that might negatively impact the user's presence. To assume arbitrary perspectives onto the scene, users simply have to walk through the system.

The main challenges of transferring the work of art into the *aixCAVE* were twofold. The first challenge was to ensure that the speed at which the work of art was being rendered was sufficiently high to allow for a smooth interaction experience.

The second challenge was in designing an interaction concept that facilitates our initial goal of creating a captivating interactive experience for viewers. We argue that a successful design has to exploit the elements offered by the work of art instead of introducing new and alien ones. At the same time, usability aspects have to be considered, such that the resulting application can also be used by VR novices. After all, we were not trying to build an expert system for the exploration of scientific data sets and the like, but rather an artistic experience for the average layman. Therefore, it is important that users can focus on the actual interaction experience without having to wonder about how to interact. The basic idea for our design thus was derived from the constituent particle system. We evaluated the finished design by means of a qualitative user study.

Summarizing, the contribution of this paper is two-fold. First of all, we describe the transformation of a non-interactive, artist-created work of art into an interactive VR experience. Second, we evaluate our design and compare it to its non-interactive counterpart in terms of a qualitative user study.

2 Interaction and Artistic Effects

Our aim is to allow any observer to experience Tim Berresheim's *Tarnen & Täuschen III* in her own way and with her own senses. To this end, we designed an interaction concept based on the motions of the user's hands influencing the artwork's particle system. Through these physical movements, we want to involve the user in the virtual work of art and thereby captivate her in our immersive VE. In order to detect hand movements, tracking targets are attached to the backs of the user's hands (see Fig. 2, left).

Figure 2: **Left:** The hand targets enabling the interaction with the work of art. **Right:** Slinging particles away by fast hand motions.

In a cooperation with the artist, we defined nine particle effects with related motions triggering them. These effects range from restoring the original particle structure over varying modifications to a complete destruction. Regarding the physical movements, we distinguish two types of interaction: first, the modification of a locally limited area of the work of art by directly touching the particles, called *direct interaction*, and second, predefined *bi-manual gestures* to indirectly interact with the complete particle system.

2.1 Direct Interaction

Direct interaction is arguably the most intuitive and natural way of interacting with the work of art. By moving a hand slowly through a group of particles, close-by particles are linearly translated outwards by an offset, returning after the hand has been moved away again. Through this, users are meant to feel the structure of the arrangement. If the viewer moves her hand quickly through the particles, however, she slings affected elements away (see Fig. 2, right). This is done by calculating a velocity vector per particle $\vec{v_p}$ based on the direction vector between the position of the hand $\mathbf{p_h}$ and the particle $\mathbf{p_p}$ as well as on the magnitude of the hand's velocity $||\vec{v_h}||$:

$$\vec{v_p} = \frac{\mathbf{p_p} - \mathbf{p_h}}{||\mathbf{p_p} - \mathbf{p_h}||} \cdot ||\vec{v_h}||$$

In addition, particles are subject to a gravity-like force that eventually makes them fall down onto the floor. This way, users are given the ability to destroy pieces of the artwork.

2.2 Gestures and Their Detection

The complete particle system can be affected by performing gestures, which trigger different kinds of effects. We conciously chose these gestures to be bi-manual such that they clearly differ from direct interaction, thereby reducing the probability to accidentally trigger them. Even more importantly, using both hands allows us to create spatial analogies between the gestures and their associated effects. Through this, we want to make gestures easier to remember. However, technical limitations pose a challenge to finding natural mappings: gesture recognition is a non-trivial process such that detection issues might arise, especially when motion patterns become more complex. Thus, in an attempt to reduce recognition issues by simplifing gestures, we sometimes abstracted motion patterns while keeping them associable. However, since the system will eventually fail to recognize gestures from time to time, we determined the need for a feedback channel reporting instantaneously whether a gesture was successfully recognized or not. To minimize the impact of such a channel on immersion, we used an element that already existed in the artwork: the lamp. While performing a gesture, the lamp emits orange light. The recognition result is indicated by changing the light's color to green for success and to red for failure.

In order to reduce the probability for false detections, a common starting pose, which we do not expect to be accidentally assumed, is used for all gestures but one. For this neutral pose, both arms are stretched horizontally forward with the hands' backs pointing upward.

2.3 Reset

The *Reset* allows for the restoration of destruction or modifications dealt to the work of art. It is triggered by moving the outstretched arms horizontally towards each other, ending in the neutral pose. This indicates the collection of all individual particles from all throughout the virtual room before automatically rebuilding the original particle system.

2.4 Translation

As the particle system is initially located close to two adjacent walls, the user is hindered in a free exploration. To resolve this limitation, we enable her to translate the complete system to another location. Starting from the neutral pose, she determines the new position via a virtual marker attached and thus translated by her dominant hand. After choosing a new position, the non-dominant hand performs a circular motion, symbolizing a scene refresh. As a result, the particle system floats to its new position while its overall form is preserved.

2.5 Pulsation

Although the original work of art was designed as a static sculpture, its particles are supposed to evoke an impression of dynamism. To further emphasize this, users can apply a *Pulsation* effect to the entire particle system, which is supposed to make it look like a breathing organism with its own heartbeat. The effect has all particles continuously circle around their initial positions. For each particle, the initial conditions when starting this oscillation slightly differ, such that each particle describes its own unique path. Through this, we want to give each particle an individuality. To indicate that all particles belong to the same particle system, all of them are given the same orbitting speed. Initially, each particle is translated by a predefined vector $\vec{t_i}$ and assigned a predefined velocity $\vec{v_i}$ that is orthogonal to the offset vector. Next, all particles are continously pulled to their initial positions via the attraction vector $\vec{a_i}$. The velocity of the ith particle at time t_{j+1} is calculated by

$$\vec{v_i}(t_{j+1}) = \vec{v_i}(t_j) + \Delta t \cdot \vec{a_i} \cdot f_{strength} \quad \text{with } \Delta t = t_{j+1} - t_j$$

The value chosen for parameter $f_{strength}$ in combination with the lack of a damping factor results in the oscillation described before.

The effect's associated gesture has users move their arms from the neutral pose in an inverse V shape, as known from some exhalation relaxation exercises. At the *Pulsation*'s start, the particle system first collapses. Afterwards, the original shape is regenerated after which the actual *Pulsation* starts. Performing a *Reset* stops the particles' motion.

2.6 Explosions

Moving the hands upwards in a V shape triggers the *Gluing* (see Fig. 3), an effect modifying the particle system's shape. By this, the particle systems explodes hurling the elements against the walls of the enclosing room. Since the individual elements are considered to be gluey, they stick to the walls. This kind of destruction adds two new aspects to the experience. First, the effect incorporates the surrounding room, especially the ceiling, directing the user's attention to the complete work of art. Second, the glued particles are a kind of explosive drawing of the original particle arrangement retaining some structures of the original shape. If the hands are moved sideways instead of upwards, a variation of the burst is triggered. Here, the particles are deflected from the environment and either fall to the floor or float. This depends on the state of gravity, which can also be influenced by the user.

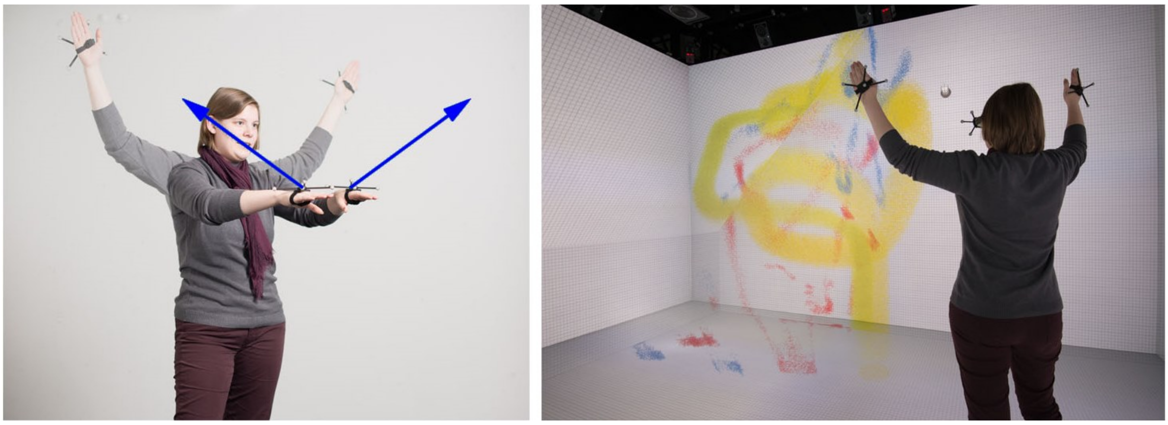

Figure 3: Moving the hands upwards in a V shape (left) triggers the *Gluing* (right).

2.7 Hand Tracing

The *Hand Tracing* (see Fig. 4) effect also presents the original shape of the particle system from a different perspective, combined with the aspect of a living organism. All particles are first mapped onto a sphere's imaginary surface, whose center $\mathbf{c_p}$ is linked to the position of the user's dominant hand. The new position of the ith particle $\mathbf{p_i'}$ is given by:

$$\mathbf{p_i'} = \mathbf{c_p} + \frac{\mathbf{p_i} - \mathbf{c_p}}{||\mathbf{p_i} - \mathbf{c_p}||} \cdot r_p$$

with $\mathbf{p_i}$ being the initial particle position in the original work of art and r_p the sphere's radius. While translating the sphere by moving the hand around, single particles are torn out, following the remaining parts like a swarm. The faster the sphere is moved around, the more particles are set free. If the movement stops, all particles converge to the initial mapping on the sphere's imaginary surface, given by the following equation:

$$\vec{v_i}(t_{j+1}) = \frac{\vec{v_i}(t_j) + (\mathbf{d_i} - \mathbf{p_i}(t_{j+1})) \cdot f_{Convergence} \cdot \Delta t}{||\vec{v_i}(t_j) + (\mathbf{d_i} - \mathbf{p_i}(t_{j+1})) \cdot f_{Convergence} \cdot \Delta t||} \cdot f_{TracingSpeed}.$$

Based on the ith particle's velocity vector $\vec{v_i}$ for the last time stamp t_j and the time-weighted distance vector based on the particle's destination point $\mathbf{d_i}$ and the actual position $\mathbf{p_i}$, the new velocity for each particle can be computed. Furthermore, the predefined parameter $f_{Convergence}$ ensures a slow convergence while $f_{TracingSpeed}$ allows for a constant, predefined tracing speed over all particles emphasizing the swarm characteristic.

To initiate this effect, a gesture that indicates the selection of all particles has to be made. This is done by a motion of pulling out an invisible box, starting from the neutral pose. For termination, the *Reset* is executed.

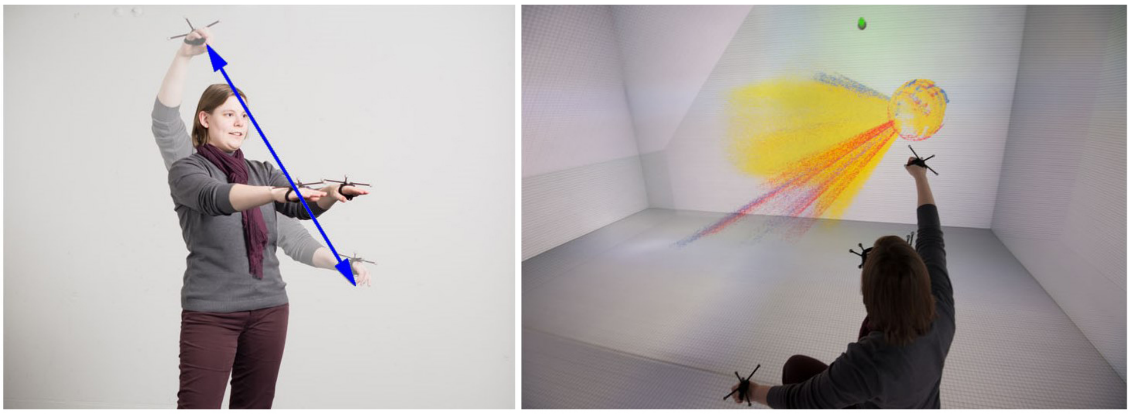

Figure 4: Pulling out an invisible box (left) triggers the *Hand Tracing* (right).

2.8 Vaporization

Another effect destructing the particle system is *Vaporization*. Here, the particle system is going up in dust, carried away by the wind (see Fig. 5). For this, not only the particles' positions are changed, but also their sizes are continously decreased during the flight down to zero extents. As turbulence of dust is often characterized by swirling motions, we abstracted this movement to circular motions. Starting from the neutral pose users rotate their left hand clockwise and their right hand counter-clockwise to trigger the effect.

Figure 5: Rotating the left hand clockwise and the right counter-clockwise (left) triggers the *Vaporization* (right).

3 Particle Physics Simulation

In this section we provide details on the particle physics simulation. First, we discuss our simulation approach after which details on the used acceleration techniques are provided.

3.1 Simulation Approach

In general, the simulation approach is split into four steps: (1) application of visual effects, (2) particle advection, (3) collision handling, and (4) particle displacement. Due to the vast amount of particles in the scene, all steps should be performed as efficiently as possible.

For steps (1) and (2) we employ a simplified forward Euler integration approach to meet this goal. Instead of directly using the classical Euler integration scheme

$$\mathbf{p_i}(t_{j+1}) = \mathbf{p_i}(t_j) + \vec{v_i}(t_j) \cdot \Delta t + \frac{1}{2} \cdot \vec{a_i}(t_{j+1}) \cdot \Delta t^2 \quad \text{and} \quad \vec{v_i}(t_{j+1}) = \vec{v_i}(t_j) + \vec{a_i}(t_{j+1}) \cdot \Delta t,$$

where $\mathbf{p_i}$, $\vec{v_i}$, and $\vec{a_i}$ are the position, velocity and acceleration of particle i at time points t_j and t_{j+1}, we instead use the simplified equations

$$\mathbf{p_i}(t_{j+1}) = \vec{p_i}(t_j) + \vec{v_i}(t_{j+1}) \cdot \Delta t \quad \text{and} \quad \vec{v_i}(t_{j+1}) = \vec{v_i}(t_j) + \vec{a_i}(t_{j+1}) \cdot \Delta t.$$

Furthermore, we directly calculate velocities for all visual effects instead of accelerations, leaving the artificial gravity as the only acceleration that is being considered. While these simplifications increase the already inherent error of the Euler integration scheme, we did not encounter any noticable visual artifacts during our tests.

The collision handling of step (3) is performed for particle-wall collisions. To resolve them, for each wall it is checked if a particle lies in front or behind of it. If the position $\mathbf{p_i}(t_j)$ of a particle i is found to lie behind a wall k, first, an intersection point $\mathbf{q_i}$ is determined based on the particle's previous position $\mathbf{p_i}(t_{j-1})$ and the direction vector $\vec{d_i} = \mathbf{p_i}(t_j) - \mathbf{p_i}(t_{j-1})$. By reflecting the vector that points from the intersection point to the particle's current position $\vec{r_i} = \mathbf{p_i}(t_j) - \mathbf{q_i}$ using the wall's normal vector $\vec{n_k}$, the particle's corrected position $\mathbf{p_i'}(t_j) = \mathbf{q_i} + reflect(\vec{r_i}, \vec{n_k})$ and velocity $\vec{v_i'}(t_j) = \frac{reflect(\vec{r_i}, \vec{n_k})}{||reflect(\vec{r_i}, \vec{n_k})||} \cdot ||\vec{v_i}(t_j)|| \cdot f_{dampening}$ can be calculated. The last formula's dampening factor $f_{dampening} \in (0.0, 1.0)$ is used to modulate the velocity to simulate a loss of impulse. While we considered handling particle-particle collisions as well, this turned out to be too costly to perform.

Finally, in step (4), the particle displacement resulting from direct interaction (see Sec. 2.1) is applied to each particle's position by adding an offset vector to it.

3.2 Calculation Acceleration

For the acceleration of calculations, we use various approaches. To speed up the rendering of particles we use an established billboard rendering technique [DDSD03]. This dramatically reduces the number of polygons that need to be rendered without affecting visual quality. However, as we could not incorporate shadowing into our application for performance reasons, the VE-based artwork's lighting looks quite different from the original's.

Physics calculations are sped up by using a custom-made parallelization approach. The particle population is equally distributed over all available threads. Due to the nature of the calculations, a roughly equal payload distribution is maintained at all times. After all threads have finished updating the particle positions, these positions are uploaded to the GPU to draw the particles. In order to neither stall the CPU nor the GPU while they are waiting for each other to finish their respective operations, we use an optimized GPU data transfer approach [Ven]. This way, both—the CPU and the GPU—are able to perform calculations in parallel at all times. Finally, to reduce the number of particle-wall collision checks, a bounding volume hierarchy was created. This way, only those particle-wall pairs are considered for which the particle is in a certain slab around the respective wall's surface. All these approaches allowed us to maintain interactive framerates at all times.

4 Evaluation

We performed a user study to ensure that the chosen interaction approach is suitable in the given context. Also, we wanted to get an understanding of the qualities of the interactive experience that we created, especially in comparison to the usual presentation channels.

4.1 Approach to Evaluation

The evaluation was performed by means of a qualitative within-subject user study, which consisted of two main phases. At the beginning of a test session, subjects had to fill out a pre-study questionnaire providing demographic and context-relevant information. Next, the first phase commenced, in which participants were asked to look at the original work of art in form of a A3-sized printout. Right after this phase, a questionnaire concerning the subjective impressions of the work of art and its presentation form had to be filled out. In the following second phase, each participant was to experience the work of art by means of the presented VR application. To this end, subjects were first given an oral introduction to the system by a supervisor, who explained the individual gestures to them. Following the introduction, participant and supervisor entered the *aixCAVE* together. After an initial training session, in which the participant could briefly try out all possibilities under supervision, a free exploration session commenced. In this exploration session, participants were free to use the system in any way desired and could talk to the supervisor if questions should arise. Finally, a questionnaire regarding the subjective impressions on using the VR application had to be filled out.

On average, test sessions lasted about 40 minutes. To have subjects state their subjective impressions, questionnaires consisted of a series of pre-defined statements. Participants could express their degree of agreement towards these statements by means of a 5-point Likert scale or yes/no answers, where appropriate. A value of 1 indicated full disagreement, while a value of 5 indicated full agreement. The results for a selection of statements are shown in Figure 6.

Statement	**Avg.**	**Std.dev.**	**Median**
I like works of art.	3.82	0.53	4
The graphics/visual quality of [games/paintings] is of great importance to me.	3.59	0.87	3
I liked the work of art.	3.47	0.87	3
I like the visual effects.	4.59	0.62	5
The effects blended well with the work of art.	4.24	0.83	4
I perceived the work of art more intensely.	4.53	1.01	5
I felt like being in the work of art.	4.41	0.87	5
The interaction was intuitive.	3.35	1.06	4
The gestures were easy to understand.	4.24	0.9	4
The direct interaction felt natural.	4.53	0.87	5
The targets on my hands hampered [presence].	2.06	1.44	2
Assuming I have access to the system, I intent to use it.	3.94	1.2	4
I preferred the work of art in 3D.	4.59	0.7	5

Figure 6: Several statements of the study to which users had to express their agreement using a 5-point Likert scale (1 = totally disagree, 5 = totally agree).

4.2 Results and Discussion

In total 17 subjects participated in the study (5 female). The average age was 26.4 years (std.dev. 5.35 years). All participants had correct or corrected-to-normal sight. Experience with VR systems varied. Six participants used them less than once a year or never, four at least once a year, four at least once a month, and three once a week. Except for two, all participants had contact with hand-gestures before in form of game consoles, VR systems, or mobile devices. When asked if they like works of art an average response of 3.82 (std.dev. 0.53, median 4) was given. Five participants had a regular contact with art at least once a month and another seven at least once a year. Visual quality seemed to matter to most participants (avg. 3.59, std.dev. 0.87, median 3).

Before experiencing the work of art in the *aixCAVE*, subjects had to rate it based on its usual presentation form. When asked if they liked the work of art responses yielded an average of 3.47 (std.dev. 0.87, median 3). While these results represent a mixed rating, most subjects seem to have liked the work of art. A number of 14 subjects further indicated that they liked the particular perspective chosen by the artist. All participants indicated that they could guess the scene's 3D structure, despite the 2D presentation form. However, only one participant stated that she felt being present in the work of art. This indicated that the chosen presentation form did not evoke any feeling of presence at all.

The VR-based presentation of the work of art was rated next. Subjects generally indicated that they liked the visual effects, giving an average response of 4.59 (std.dev. 0.62, median 5). At the same time they stated that the effects suited the work of art well (avg.

4.24, std.dev. 0.83, median 4) and that they perceived the work of art more intensely (avg. 4.53, std.dev. 1.01, median 5). Overall, participants felt like being part of the work of art (avg. 4.41, std.dev. 0.87, median 5). In general, visual effects were rated very positively. Results indicate that all effects are well-suited in the given context, which is a hint that the approach of designing effects based on constituents of the work of art is a worthwhile approach. No major issues regarding the effects were identified, even though four participants negatively noted the lack of shadows, which were removed for performance reasons.

Responses concerning interaction were mixed to positive. Participants rated overall interaction with an average score of 3.35 (std.dev. 1.06, median 4) with respect to intuitiveness. Subjects seemed to understand the gestures well (avg. 4.24, std.dev. 0.90, median 4). Direct interaction was also received positively (avg. 4.53, std.dev. 0.87, median 5). The use of hand targets did not seem to negatively affect presence too much (avg. 2.06, std.dev. 1.44, median 2). One interesting observation is, that even though gestures do not seem to be particularly intuitive, they were still easy to understand. As a result, we conclude that design should focus on easy to remember links between trigger and effect instead of trying to attain perfect natural mappings. Results indicate that hand targets were found to be clearly intrusive, but did not impact presence too much in the given context. More critical interaction issues arose from gesture recognition failures, which made it difficult to use some gestures for some subjects. Also, one user noted that she disliked the rigid start position for the gestures.

Regarding the overall system, participants generally indicated an intention to use the system if it was available to them (avg. 3.94, std.dev. 1.2, median 4). Compared to the traditional presentation form, subjects seemed to prefer the VR approach for the given work of art (avg. 4.59, std.dev. 0.7, median 5). Considering all results, we argue that the use of VR technology as an alternative presentation platform was successful. While some points for improvement were identified, the general intention to use the system were rather high. The fact that participants seem to have preferred the VR presentation form over the traditional one is a strong indication that it is worthwhile to also consider VR in other scenarios.

5 Conclusion

We described how VR technology can be employed to create an immersive and interactive presentation platform for digital artworks. Based on a specific work of art by artist Tim Berresheim, we developed a well-suited interaction design. This VR experience was evaluated by means of a qualitative user study, whose results indicate a successful design. For the future, it is planned to present the VR application as part of an exhibition by Tim Berresheim in collaboration between RWTH Aachen University and the Ludwig Forum Aachen [Lud].

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