# Triggering Immersion in Public Spaces: A Comparative Study of Interactive Digital Art Installations

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**Abstract.** Immersion is part of any human experience, whether it is governed by the contingent world or by artificial, virtual spaces. In the cultural sector, immersive technologies are increasingly employed in contemporary artworks, installations, exhibitions and live performances. In this paper, we present and compare four multi-user interactive digital art installations, which are characterised by their varying degrees of technical immersivity (VR headsets, 360-degree space, video wall with floor projection, or sphere projection), their sensing capabilities (hand and head tracking, centre of gravity and joint tracking, motion tracking and multi-touch), their inherent interactivity (single or multi-user interaction, human-machine interaction), and the supporting stimuli (audio, visual, or tactile). These installations were exhibited in different public environments (art gallery, third place/cultural centre, shopping mall, museum), where the subjective user experience of 532 volunteers was studied along different immersion factors (spatial presence, affordance, enjoyment, and cybersickness among others). The impact of user characteristics like gender, age and prior experience with immersive technology was also evaluated. While spatial presence increases with the technical immersivity of the installation, the results suggest that factors like affordance and realness are more impacted by aspects such as interaction design and installation aesthetics. The evaluated user characteristics were found to have little or no impact on the immersion experience.

**Keywords:** immersion · multi-user · installation · art · VR · public space · museum · comparative study · user study.

## 1 Introduction

The use of immersive technologies is becoming more and more widespread across different sectors of the cultural and creative industries, ranging from live performances such as concerts [2] and dance shows [21] to exhibitions and entire museums dedicated to immersive art installations [38]. While many user studies in this context focus on the application to educational [12, 22, 42], museum-based [1, 17, 40] and touristic [29] purposes, little research, so far, has investigated how different technologies impact the way in which users engage with immersive art works.

Moreover, the existing literature predominantly emphasizes experiences using head-mounted displays (HMDs), privileging individualized and enclosed forms of immersion. In contrast, a growing number of public installations employ open, shared, and spatialized immersive configurations that allow for collective engagement. These include room-scale projections, sensor-based environments, or interactive screens embedded in architectural settings. Yet, these configurations remain

underexplored in XR research, particularly in terms of how they shape presence, engagement, and social interaction. In this study, we adopt the concept of presence as the psychological sense of "being there" in the mediated environment [36], and engagement as the sustained attention and affective involvement of the user in the experience [26]. Social interaction refers here to the observable communicative and behavioural exchanges between co-present users, including both verbal and non-verbal cues [9]. These dimensions are central to understanding immersive art as they mediate how users relate to the environment, to the artwork, and to each other.

In this study, we present a comparative field investigation of four distinct interactive digital art installations, each featuring multi-user interaction in public or semi-public environments. These installations were exhibited in an art gallery, a museum, a shopping centre, and a community cultural venue. By comparing these diverse setups, we aim to identify how specific immersive features (e.g., type of interface, openness of the space, narration) influence user engagement, emotional responses, and patterns of social behaviour. This work contributes to a better understanding of how immersion is constructed in shared cultural settings, and offers insights for the design of future XR-based artistic experiences.

## 2 Related Work

### 2.1 Definition and Dimensions of Immersion

The terms *immersion* and *immersive (experience)* have become ubiquitous in recent years and generally refer to the sensation of *being plunged into* or *feeling surrounded* by a different reality or environment, akin to the feeling of being immersed or submerged in water. However, a precise and universally accepted definition (especially within the academic discourse) is still lacking [7]. Moreover, there are several related concepts that are often mentioned in connection with immersion, or even used synonymously.

In this paper, we will follow the proposition put forth by Freitag et al. [7] who distinguish *immersion* (referring to the subjective experience or psychological state of a user) from *immersivity* (describing the technical characteristics of an installation or artwork that can elicit immersive experiences) and we will use the term *(spatial) presence* in this study (cf. section 4.1) to describe the feeling of "being inside" the virtual or mediated environment [35, 15].

More broadly, we rely on the theoretical framework proposed by Khenak, Vézien, and Bourdot [14, 15], who conceptualize immersion as a dynamic construction involving the user, the system, and the context. Their model proposes a multi-layered view of immersion, encompassing several interrelated dimensions: *sensory* (e.g., display fidelity, audio-visual quality), *motor* (e.g., gestural interaction, spatial navigation), *cognitive* (e.g., situational understanding, attentional engagement), and *social* (e.g., co-presence, interpersonal interaction).

In addition, Skarbez et al. [34] emphasize three key elements in the creation of immersive experiences: *plausibility* (the sense that events are credible and respond coherently), *spatial presence* (the feeling of being located within the mediated environment), and *user engagement*. According to this perspective, immersion is not solely a function of technological complexity, but also of the extent to which the virtual environment aligns with users' perceptual and cognitive expectations.

Finally, Grassini and Laumann [10] highlight the role of individual differences in shaping immersive experiences. Their review shows that factors such as attention, mental absorption capacity, and personality traits (e.g., openness to experience) significantly influence how immersed a user feels. They argue for greater consideration of these psychological variables in immersion research.

Taken together, these perspectives suggest that immersion cannot be reduced to a purely technical property or a uniform psychological state. Rather, it emerges from a complex interplay of system features, environmental context, social configuration, and individual user characteristics. This view is particularly relevant for understanding immersive experiences in multi-user interactive installations deployed in real-world cultural settings, such as those examined in the present study.

### 2.2 Immersive Technologies in Cultural and Public Spaces

Cultural spaces, such as museums and galleries, are increasingly adopting immersive technologies to enrich visitor experiences. They combine 360-degree projections, interactive virtual environments, and digital installations to offer deep immersion into cultural content. For instance, VR headsets transport visitors into historical reconstructions, while AR enhances real artworks by adding layers of supplementary information, enabling a multi-sensory interaction with the exhibits [32].

However, the use of immersive technologies in public spaces presents unique challenges and opportunities. These spaces include open-access areas such as public squares, parks, and building facades. In these environments, immersive digital art can capture attention unexpectedly, interrupting the habitual behaviours of passers-by and creating spontaneous artistic experiences. These immersive interventions, integrated into urban landscapes, offer dynamic artistic engagement where users are often surprised, altering how they engage with the artwork.

Yet, implementing these technologies in public spaces raises several practical challenges. Users are not always equipped or prepared to engage with digital devices, and the infrastructure (such as VR or AR equipment) can be limiting, reducing the effectiveness of the immersive experiences. These challenges demand innovative design solutions to optimize the impact of immersion in unpredictable environments.

### 2.3 User Characteristics in Immersive Experiences

Previous research has already considered how parameters such as age, gender, and prior experience with immersive technology can affect immersion. Strikingly, the results found across the literature vary considerably and are often contradictory. For instance, several studies report significant gender-related effects [5, 11, 16, 31, 37], while others find no clear or consistent differences [23, 24]. Regarding age, studies generally suggest no or only slightly negative correlations with presence [23, 24]. Prior experience with immersive technology, by contrast, has been more consistently associated with enhanced user engagement and presence [6, 31].

These findings highlight the need to further explore how user characteristics shape immersive experiences in real-world settings. While demographic variables are often reported, they are rarely analyzed in depth or used to explain inter-individual variations in presence, engagement, or social interaction.

Beyond demographic variables, immersive tendencies — defined as the individual predisposition to become cognitively and emotionally engaged in mediated environments — have also been investigated as potential predictors of presence and user engagement. The Immersive Tendencies Questionnaire (ITQ) [30, 41] was developed specifically for this purpose and has been widely used in VR research. Although some studies suggest that immersive tendencies can influence dimensions such as presence, enjoyment, or attention, the strength and consistency of these effects remain limited, particularly in ecologically valid or public settings. These individual differences remain underexplored as potential moderators of immersive experience in real-world contexts.

## 3 Multi-User Interactive Digital Art Installations

This section presents the studied installations, their main characteristics and the environments in which they were exhibited. Table 1 summarizes and compares the characteristics.

| | **MB** | **LP** | **AF** | **ES** |
|---|---|---|---|---|
| **Video interface** | VR headset | 360-degree video projection on 2 m inner and 10 m outer cylindrical 4 m high screens and circular floor video projection | LCD video wall (4 m × 5 m) and floor video projection (4.8 m × 7.7 m) | Spherical video projection (1.6 m diameter) |
| **Audio interface** | VR headset speakers | 8 central and 8 peripheral spatially distributed loudspeakers and 2 subwoofers | 4 spatially-distributed loudspeakers integrated into the wall and 2 top loudspeakers | 8 loudspeakers spatially distributed around the equator ring and 4 external ambiance loudspeakers |
| **Interaction mode** | 6-DOF VR, hand tracking | person pose detection and tracking using 16 centrally distributed Kinect V2 cameras | person pose detection and tracking using 11 laterally distributed Kinect V2 cameras | motion and touch detection using 16 infrared cameras spatially distributed around the equator ring and 2 wide-angle infrared cameras |
| **Experience duration** | 17.5 min | 20 min | open ended | open ended |
| **Experience includes a storyline** | yes | yes | no | no |
| **Number of simultaneous users** | up to 8 | up to 20 | unrestricted (usually 1-5) | unrestricted (usually 2-10) |
| **Exhibition space** | art gallery | third place (cultural and shopping centre) | passageway in shopping mall | museum |
| **Admission** | admission fee (see section 4.1) | free | free | included in museum admission |
| **Participants included in the study** | 134 | 266 | 71 | 61 |

**Table 1.** Overview of the four considered installations and their main characteristics.

### 3.1 Presentation of the Installations

***Memory Box*** (MB) is an interactive, 6-degrees-of-freedom virtual reality experience for up to 8 simultaneous users. As part of the trans-media exhibition *L'Expérience Monroe* about Marilyn Monroe, *Memory Box* was exhibited during 6 months in the art gallery *Galérie Joseph* in Paris, France. The roughly 17 min long experience presents different scenes from Monroe's childhood and early career, as laid out in her autobiographical novel *My Story*.

During the experience, users find themselves in changing locations (e.g., an abstract cylindrical room, a battlefield during the Korean War, out on the ocean with the sun setting on the horizon) while watching subjects and objects from Monroe's memories appear and disappear. The story is recounted by Marilyn Monroe's spirit which is visually represented by a shape-shifting particle cloud and acoustically embodied by specific sounds and the voice of French actress Stéphanie Sphyras (audio in French language with optional English subtitles). Apart from several original photos, the environments, characters and objects shown in *Memory Box* are figurative or stylized and often composed of particle clouds (Figure 1, MB1). Users can interact with these particles using their hands of which they see a virtual representation inside the VR environment. In particular, users can attract or repel the cloud representing Marilyn's spirit by making a fist or performing a stop gesture, respectively.

On a technical level, the installation, as considered in this study, used eight HTC Vive Focus 3 headsets, each paired with a Dell Precision 5820 computer. The VR application was deployed using SteamVR and streamed to the headsets over WiFi for which a dedicated router and network were set up. Interaction within the VR environment relied on hand tracking, so no controllers were needed (Figure 1, MB2). Each user followed their own storyline, which depended on their own interactions. However, stylized avatars were rendered when other VR users were close in the physical space.

***The L∞p*** (LP) is a platform for creating, producing and disseminating new augmented experiences of performing and digital arts. It consists of a cylindrical structure (11 m in diameter, 4 m in height) which can be entered by up to 20 users simultaneously. It is equipped with 14 video projectors and five LED moving head wash lights projecting onto two 360-degree cylindrical screens (an outer 10-m-diameter cylinder and a central 2-m-diameter cylinder) and the floor (Figure 1, LP2). Moreover, 16 Kinect V2 cameras mounted onto the central cylinder enable the detection and tracking of users, while 16 loudspeakers, together with 2 subwoofers, positioned on the central cylinder and around the outer cylinder screen, provide spatialized audio. One Shuttle XPC nano mini-PC per Kinect camera is used for real-time streaming of the three-dimensional body pose data of the users while the main computation work (integration of the body pose data, interaction processing, graphics rendering, audio playback) is done by two Dell Precision 7920 computers.

During the period considered in this study, *The L∞p* was exhibited in the cultural and shopping centre *Les Ateliers des Capucins* located in Brest, France. *Les Ateliers des Capucins* can be qualified as a typical *third place*, featuring several shops, cafés and restaurants as well as a cinema, theatre, library, museum and a leisure space where individuals, friends and family can meet or do indoor sport activities. Visitors of LP could participate in a 20-minute-long experience called *Spacetime Prospectives* about the concept of the arrow of time as it can be addressed by thermodynamics, special relativity, general relativity, and quantum physics. During the experience, multiple varying environments (e.g., abstract empty spaces that get populated by timelines or arrows of time, outer space with colliding planets, the Atlantic Ocean on which Columbus' ship sails towards the Americas; an infinite chess board, ...) were shown, following a fixed sequence, and narrated by several male and female voices. Visitors could not influence the progress or order of the environments but could interact with different elements in them (e.g., stimulate vibrations in the timelines, collide with moving planets, leave virtual footprints on the floor, or induce waves in the ocean). The experience was in French, free of charge and accessible, six days a week, from 11AM to 7PM, during two months.

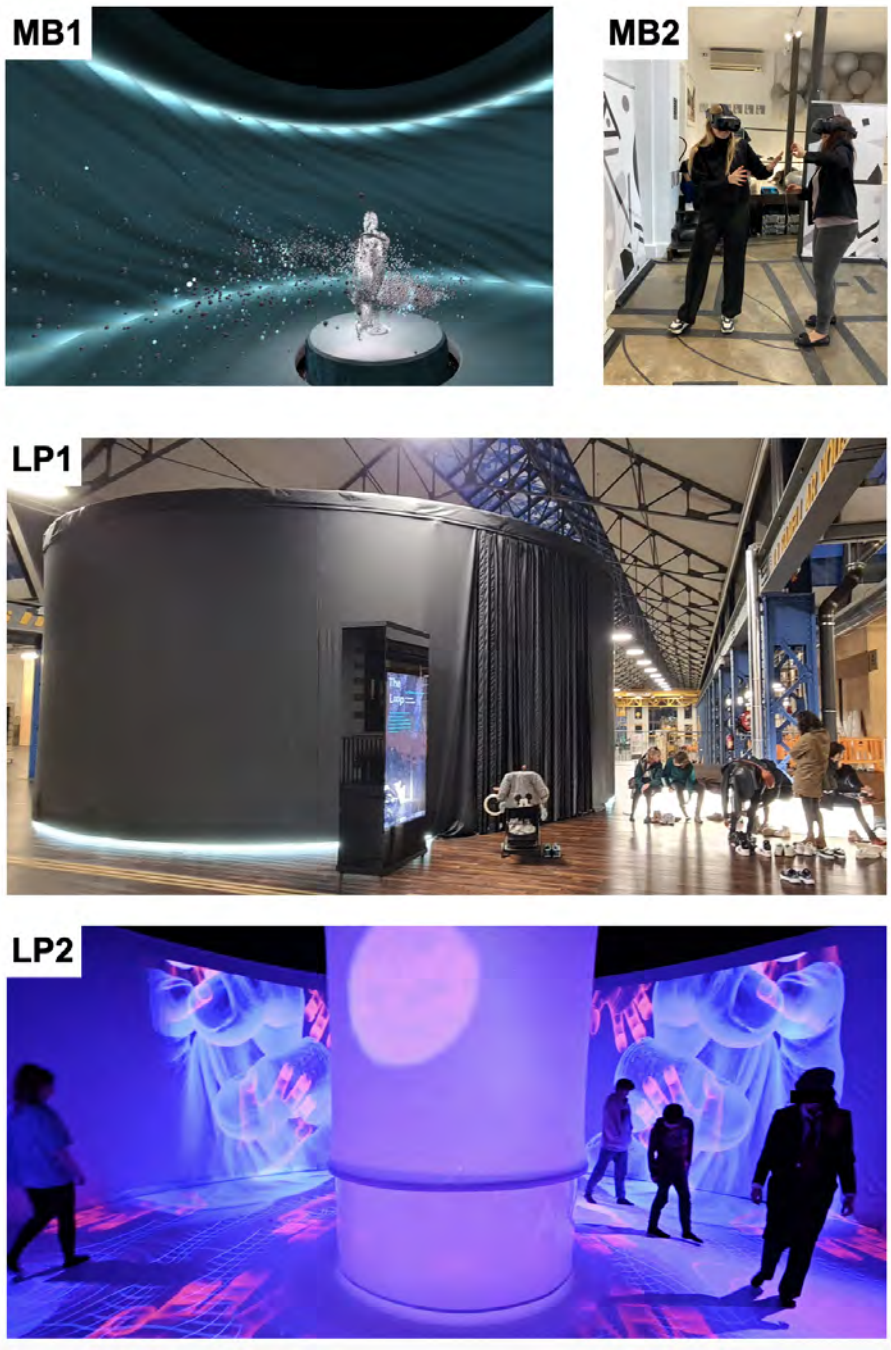



**Fig. 1.** Photos of the installations *Memory Box* and *The L∞p*. MB1: Marilyn Monroe's spirit, represented as a particle cloud. MB2: Users of *Memory Box* wearing VR headsets and using their hands to interact in the virtual environment. Their gestures show that they were aware of the presence of other users. LP1: External view of *The L∞p* and visitors taking off their shoes before entering the structure. LP2: Users inside of LP moving around the central cylinder screen and causing a virtual grid to warp under their feet.

***Ariadne's Fibres*** (AF) is a permanent, digital artwork consisting of a video wall (5 m wide and 4 m high) composed of $4 \times 2$ 4K LCD screens (Figure 2 AF1), a floor video projection zone (7.7 m $\times$ 4.8 m) created with two 23,000-lumen-strong video projectors mounted 9 m above the floor (Figure 2 AF2 and 3), 6 amplified ambient loudspeakers with 4 spatially distributed into the wall and 2 suspended on the ceiling over the floor. Eleven Kinect V2 cameras were distributed around the wall and connected to mini-PCs to enable real-time streaming of body poses. Two HP workstations (one Z4 and one Z8) process the user inputs (body pose and movement), compute interaction results, render the graphics and control the audio output. The artwork was commissioned by *Forum des images* and the City of Paris and is installed in the shopfront of *Forum des images* where it is freely accessible every day from 6AM to 12PM. *Forum des images* itself is located in the shopping mall *Forum des Halles* and specifically in a busy passageway (*rue du cinéma)* that connects (among other places) a large cinema to the entrance of the metro and local train system.

In its idle state, the visuals of *Ariadne's Fibres*, displayed on the video wall and projected onto the floor, are comprised of three main elements: a bright background of periodically changing colour, a real-time heat convection simulation, and a layer of slowly growing and moving drops that display videos related to the current program proposed at *Forum des images* (Figure 2, AF1). When passers-by enter the interaction zone of *Ariadne's Fibres*, they are detected by the Kinect cameras and an associated avatar appears. This avatar resembles the user in shape and size and follows their movements and poses. However, instead of a solid body, the avatar is composed of anatomical fibrous systems (nervous, blood, lymphatic, or muscular systems) and sometimes shows bone structures. The appearance of the avatars as well as their dynamics (are the fibres stiff or supple) are partly governed by the local weather (live weather data streamed via openweathermap.org) and change with the seasons. By moving in front of the installation, users (or rather their avatars) can interact with the drops and even generate droplets which will spawn from the end of their nerve fibres. Moreover, their presence introduces a new heat source into the convection simulation, thereby stimulating turbulences (Figure 2, AF2).

***The Eye of the Sun*** (ES) is a motion- and touch-sensitive digital sculpture consisting of two hemispheres with a diameter of about 1.6 m which act as a spherical screen for two internal video projectors. Upon arrival, visitors find themselves face-to-face with a giant human-like eyeball (Figure 2, ES1) which looks at them, periodically blinks, squints or changes its iris colour, and which follows visitors around as they move and try to walk around the eye. The result is a reversal of the established roles — it is now the artwork that curiously watches the human observer. When the visitor returns the curiosity and performs the correct gesture, the eye opens up to reveal its interior: an interactive simulation of the surface of the Sun, showcasing images of the solar corona captured at different far-UV wavelengths by NASA's SDO spacecraft [27].

The two hemispheres on which the images of the eye or the sun appear are connected by a 15 cm thick central disk that houses the two video projectors alongside the required optical equipment (lenses and mirrors), a network router, a sound card, and several power supplies and cables. Moreover, 16 infrared cameras, 8 loudspeakers and several ventilation fans are positioned around this technical equator. While the cameras are used to detect motion around the eye, the loudspeakers provide spatialized sound effects when the eye blinks, squints, moves or when certain interactions are performed. Finally, two more wide-angle infrared cameras are installed centrally on both sides of the equator disk allowing for hand detection through the semi-transparent hemispheres. This enables multi-touch interactions with the eye and especially the sun where users can trigger ripples in the solar surface (Figure 2, ES3), cause coronal mass ejections or swipe between eleven

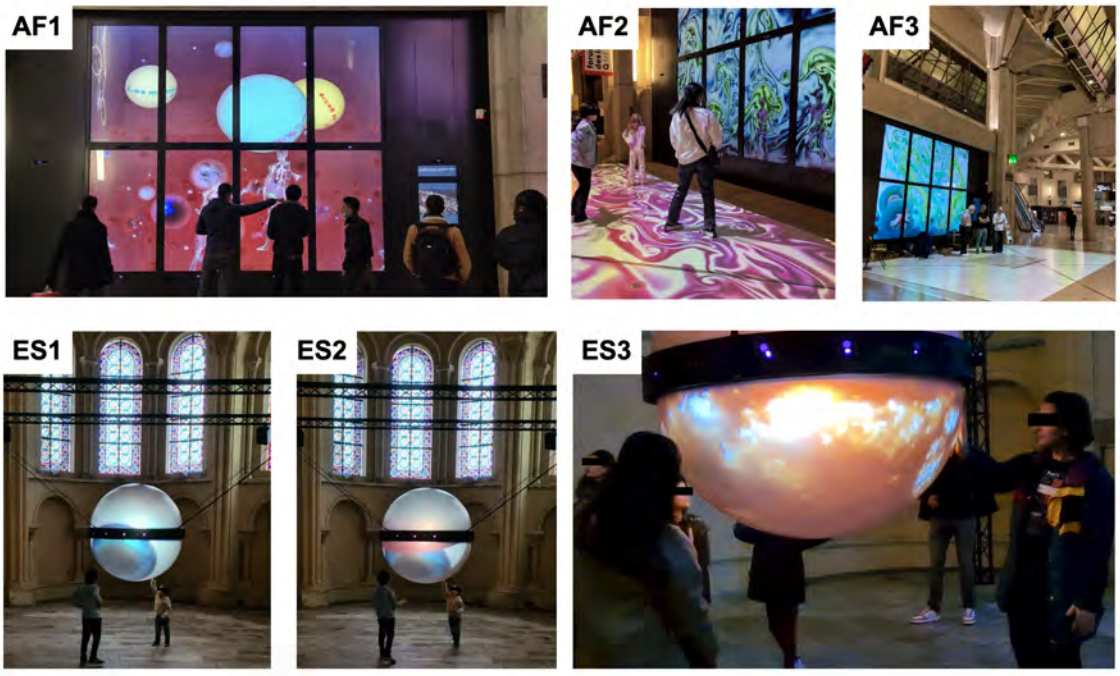



**Fig. 2.** Photos of the installations *Ariadne's Fibres* and *The Eye of the Sun*. AF1: Users interacting with their avatars and the many video drops and droplets. AF2: Users interacting with their avatars and causing convection turbulences on the screens and on the floor. AF3: The video wall and floor projection of *Ariadne's Fibres* during technical maintenance. ES1: Young users interacting with the eye. ES2: The eye squinting after being touched. ES3: Users exploring the surface of the Sun and causing coronal perturbations with their touches.

coronal layers, corresponding to different wavelengths. The user detection, interaction, graphics and audio are controlled by a Dell Precision 7920 computer located a few meters away from the spherical sculpture and connected to it via two RJ45 cables for sensor, video, and audio signals.

For the exhibition considered in this study, *The Eye of the Sun* was installed at the *Museum of Arts and Crafts* in Paris and more precisely in the apse of the church *Saint-Martin-des-Champs* belonging to the exhibition spaces of the museum. The spherical sculpture was suspended on a 4.5 m tall aluminium structure, erected specifically for this occasion. Eight more loudspeakers as well as two subwoofers were installed on and around the aluminium structure to provide the ambient soundscape and a standard 24-inch computer screen was attached to one of the aluminium pillars to represent a "thermometer", indicating the temperature and wavelength of the current coronal layer when in sun mode. The installation was included in the usual museum admission fee and was accessible for the general public during the event *Nuit Blanche 2024* and for the two weeks following the event.

## 4 Method

### 4.1 Participants and Experimental Design

We conducted a comparative field study to assess the subjective user experience, understood here as the individual experience of immersion, spatial presence, enjoyment, and comfort during interaction with each of the four interactive installations. Participants were recruited on site immediately after completing one of the experiences. Recruitment was carried out in naturalistic settings: *The L∞p* (LP) and *Ariadne's Fibres* (AF) were hosted in public cultural and shopping centres, while *The Eye of the Sun* (ES) was part of a temporary exhibition in a museum and *Memory Box* (MB) was presented at an art gallery.

Participation was voluntary. In the case of MB, three groups of participants were identified: visitors who paid to access both the exhibition and the VR experience; visitors who paid only for the exhibition and were invited to try the VR experience free of charge in exchange for participation in the study; and invited guests with free access to both components. For all other installations, the experience was free of charge (excluding standard museum admission in the case of ES).

A total of 532 complete questionnaires were collected: 134 for MB, 266 for LP, 61 for ES, and 71 for *Ariadne's Fibres*. Only fully completed responses were included in the analysis. Table 2 presents a detailed breakdown of the number of participants per demographic group and installation.

### 4.2 Procedure and Condition Overview

Participants were approached by a member of the research team or a staff facilitator upon exiting the installation. They were briefly informed about the study's aim and procedure and assured that their participation was anonymous, voluntary, and could be withdrawn at any time without consequences. Digital informed consent was obtained at the beginning of the questionnaire. It should be noted that, rarely, technical problems were encountered during the experience (e.g., frozen image or complete crash of the software). Affected users were not asked to participate in the study.

The questionnaire was made available in both French and English. It was administered via tablet or mobile device in a quiet area adjacent to the installation. Completion time averaged between 8 and 12 minutes.

| | | MB | LP | AF | ES |
|---|---|---|---|---|---|
| **Gender** | Female | 90 (67.2%) | 171 (64.3%) | 36 (50.7%) | 34 (55.7%) |
| | Male | 44 (32.8%) | 94 (35.3%) | 32 (45.1%) | 25 (41.0%) |
| | Other | 0 (0.0%) | 1 (0.4%) | 3 (4.2%) | 2 (3.3%) |
| **Age cohort** | <20 years | 9 (6.7%) | 41 (15.4%) | 19 (26.8%) | 19 (31.1%) |
| | 20-29 years | 17 (12.7%) | 74 (27.8%) | 24 (33.8%) | 21 (34.4%) |
| | 30-39 years | 21 (15.7%) | 73 (27.4%) | 8 (11.3%) | 5 (8.2%) |
| | 40-49 years | 27 (20.1%) | 33 (12.4%) | 6 (8.5%) | 4 (6.6%) |
| | 50-59 years | 36 (26.9%) | 30 (11.3%) | 8 (11.3%) | 5 (8.2%) |
| | $\geq$ 60 years | 24 (17.9%) | 15 (5.6%) | 6 (8.5%) | 7 (11.5%) |
| **Prior experience with immersive technology** | No prior experience | 36 (26.9%) | 45 (16.9%) | 2 (2.8%) | 11 (18.0%) |
| | Not very experienced | 59 (44.0%) | 113 (42.5%) | 23 (32.4%) | 26 (42.6%) |
| | Somewhat experienced | 18 (13.4%) | 78 (29.3%) | 26 (36.6%) | 12 (19.7%) |
| | Experienced | 16 (11.9%) | 24 (9.0%) | 12 (16.9%) | 7 (11.5%) |
| | Very experienced | 5 (3.7%) | 6 (2.3%) | 8 (11.3%) | 5 (8.2%) |

**Table 2.** Number of responses to the questionnaire per demographic group and installation.

### 4.3 Measures and Instruments

To evaluate the immersive experience and individual predispositions to immersion, we used two standardized and validated self-report questionnaires: the SP-IE (Spatial Presence for Immersive Environments) questionnaire and the Immersive Tendencies Questionnaire (ITQ), both available in French and English.

**Spatial Presence for Immersive Environments (SP-IE)** The SP-IE questionnaire [14, 15] was developed to assess the user experience in immersive systems, with a particular focus on virtual environments and VR technologies. It builds on established presence questionnaires such as the ITC-Sense of Presence Inventory (ITC-SOPI [20]), the Presence Questionnaire (PQ [41]), and the Igroup Presence Questionnaire (IPQ [33]), while introducing updated factors tailored to contemporary immersive technologies.

The instrument consists of 20 items, rated on a 5-point Likert scale, and covers seven subscales: Spatial Presence (SP, 4 items), Affordance (AFF, 4 items), Enjoyment (ENJ, 3 items), Realism (REAL, 3 items), Attention (ATT, 2 items), Cybersickness (CYB, 2 items), and Social Presence (AVAT, 2 optional items used only when avatars are present).

In the present study, the SP-IE was used not only to measure spatial presence, but to provide a multidimensional evaluation of the immersive experience. In line with our broader research goal, this approach allowed us to investigate not only whether each installation was immersive, but also which experiential components—such as realism, affordance, or social presence—contributed most to users' perception of immersion.

To evaluate internal consistency, we calculated Cronbach's alpha for all subscales with three or more items and Pearson's correlation coefficients for subscales with only two items. The results are presented in Table 3 and can be considered comparable to those reported in [14]. However, we found that the introduction of two modified subscales could improve reliability: *SP-mod*, excluding

item 3 ("My sensory experiences..."), and *AFF-mod*, excluding item 11 ("I could easily examine the content of the environment"). These modified factors will be considered in the following analysis.

| Factor | Items | $\alpha$ or $r$ | Values reported in [14] |
|---|---|---|---|
| **SP** | 3, 5, 7, 9 | $\alpha = 0.66$ | $\alpha = 0.75$ |
| **SP mod** | 5, 7, 9 | $\alpha = 0.73$ | n.a. |
| **AFF** | 11, 12, 14, 16 | $\alpha = 0.69$ | $\alpha = 0.67$ |
| **AFF mod** | 12, 14, 16 | $\alpha = 0.72$ | n.a. |
| **ENJ** | 1, 2, 6 | $\alpha = 0.74$ | $\alpha = 0.63$ |
| **REAL** | 10, 15, 17 | $\alpha = 0.73$ | $\alpha = 0.67$ |
| **ATT** | 8, 13 | $r = 0.42$ ($p = 0$) | $r = 0.44$ ($p = 0$) |
| **CYB** | 4, 18 | $r = 0.33$ ($p = 0$) | $r = 0.37$ ($p = 0$) |
| **AVAT** | 19, 20 | $r = 0.59$ ($p = 0$) | $r = 0.59$ ($p = 0$) |
| **All items** | | $\alpha = 0.85$ | $\alpha = 0.81$ |

**Table 3.** Cronbach's alpha ($\alpha$) and Pearson's correlation coefficient ($r$) for the factors of the SP-IE questionnaire. For Pearson's correlation coefficient, the corresponding p-value is stated in parentheses. For reference, the values calculated during the original questionnaire validation in [14] are given in the right-most column.

**Immersive Tendencies Questionnaire (ITQ)** The ITQ [30], originally developed by Witmer and Singer [41] and adapted to French by Robillard et al. [30], measures individuals' predisposition toward immersive engagement. It includes 18 items, rated on a 7-point Likert scale, divided into four factors: Focus (6 items), Involvement (5 items), Emotional Involvement (4 items), and Gaming Tendencies (3 items).

The overall internal consistency of the ITQ in our sample was satisfactory ($\alpha = 0.79$), consistent with prior reports for both the French ($\alpha = .78$) and English ($\alpha = 0.81$) versions. However, factor-specific reliability varied: Focus ($\alpha = 0.63$), Involvement ($\alpha = 0.45$), Emotional Involvement ($\alpha = 0.66$), and Gaming Tendencies ($\alpha = 0.60$). The relatively low alpha for the Involvement factor suggests potential item heterogeneity.

### 4.4 Data Analysis

The analysis of the collected data was guided by six initial hypotheses, formulated in light of prior research on immersive experiences in public and cultural settings.

First, we hypothesized that installations with higher technical immersivity would elicit stronger immersive experiences, as reflected by higher scores across key SP-IE dimensions. Specifically, we expected MB to score highest in SP mod, followed by LP, AF and ES. This hypothesis is grounded in the assumption that more immersive systems (e.g., VR headsets or interactive projections) elicit stronger feelings of "being there" through increased sensory richness and interactivity [32]. While spatial presence (SP mod) remains the central indicator, we also expected that other experiential factors, such as perceived realism (REAL), affordance (AFF mod), and social presence (AVAT, when applicable), would follow a similar trend. This multidimensional perspective reflects our broader

objective of identifying which components of the user experience contribute most to the perception of immersion in public interactive installations (**H1**).

Second, we expected that more immersive systems would also result in higher levels of cybersickness. This is consistent with prior research showing that immersive systems involving strong visual motion or limited user control can increase sensory conflict and discomfort [11, 37]. In particular, LaViola [19] emphasized that visually induced motion sickness in virtual environments often stems from a mismatch between visual, vestibular, and proprioceptive inputs—a phenomenon exacerbated in highly immersive systems (**H2**).

Third, we anticipated a slight decrease in presence and enjoyment among older participants. Although findings regarding age are mixed [23, 24], some studies suggest that lower familiarity with interactive technologies and slower adaptation to novel environments may negatively influence immersion (**H3**).

Fourth, we assumed that participants with prior experience using immersive technologies would report higher affordance and lower cybersickness scores, in line with studies showing that technological familiarity can enhance the richness and interpretability of immersive content while simultaneously reducing susceptbility to simulator sickness [11, 31] (**H4**).

Fifth, we did not expect significant gender effects on SP-IE outcomes, as the literature on this topic remains inconclusive and often contradictory, with some studies reporting effects [11, 16, 31], while others find no significant differences [23, 24] (**H5**).

Sixth, we hypothesized that participants with higher immersive tendencies, as measured by the Immersive Tendencies Questionnaire (ITQ), would report stronger immersive experiences. This includes higher scores in SP-IE dimensions such as spatial presence, enjoyment, and attention. While some studies support the predictive value of immersive tendencies for presence and engagement [30, 41], these effects remain modest and context-dependent, especially in real-world or public settings (**H6**).

To test these hypotheses, mean scores were computed for all SP-IE and ITQ subscales for each participant. Normality of distributions was assessed using the Shapiro-Wilk test, which indicated that several subscale scores were not normally distributed. As a result, non-parametric statistical methods were applied throughout the analysis.

Group differences across the four installations were examined using Kruskal-Wallis tests for each of the seven SP-IE factors. The same test was used to compare participant subgroups based on age and prior experience with immersive technologies. The effect size of the Kruskal-Wallis tests was calculated as $\eta^2 = (H - k + 1)/(n - k)$, where $H$ is the result of the Kruskal-Wallis test, $k$ the number of groups and $n$ the total number of participants in the groups [28].

To further explore pairwise differences, post-hoc Mann-Whitney U tests were conducted with Bonferroni correction of the p-values for multiple comparisons. Gender differences were also examined using Mann-Whitney U tests within each installation. Note that in the latter case, no correction was applied to the p-values as installations were considered and discussed individually (i.e., the family size $m = 1$ and thus the uncorrected and Bonferroni-corrected p-values are identical). The rank-biserial correlation $r_{rb}$ was calculated as the effect size of the Mann-Whitney U tests.

All analyses were conducted using Python with the Pingouin statistics package (version 0.5.4) [39], and results were cross-validated using JASP (version 0.18.3) [13]. A significance threshold of $p < .05$ was used for all statistical tests. Regarding the effect size, we followed the interpretation guidelines for $\eta^2$ provided in [28] (small effect: $\eta^2 < 0.06$, moderate effect: $0.06 \leq \eta^2 < 0.14$,

large effect: $\eta^2 > 0.14$) and for $r_{rb}$ the recommendations by Gignac and Szodorai [8] where $|r_{rb}| \approx 0.1,\ 0.2,\ 0.3$ indicates a relatively small, typical, or relatively large effect, respectively.

## 5 Results

### 5.1 Technical Aspects and Immersivity of the Installation

**H1 – Effect of Installation Type on Immersive Experience** To test H1, we compared the SP-IE factor scores across the four installations. As shown in Figure 3, Kruskal-Wallis tests ($df = 3$ in all cases) revealed significant differences for SP mod, AFF mod, REAL, CYB and AVAT. Pairwise comparisons using Mann-Whitney U tests (Table 4) confirmed that MB scored highest for SP mod, followed by LP, AF, and ES, supporting the expected correlation between spatial presence and the technical immersivity level of the installation. A generally similar trend is found for the subscale AVAT with the only statistically significant difference, however, being observed between MB and ES which yielded the highest and lowest scores, respectively.

Importantly, the scores for perceived realism and affordance were higher in the technically less immersive installations AF and ES, with differences to MB and LP being statistically significant in almost all cases. The possible implications of these results are further discussed in section 6.

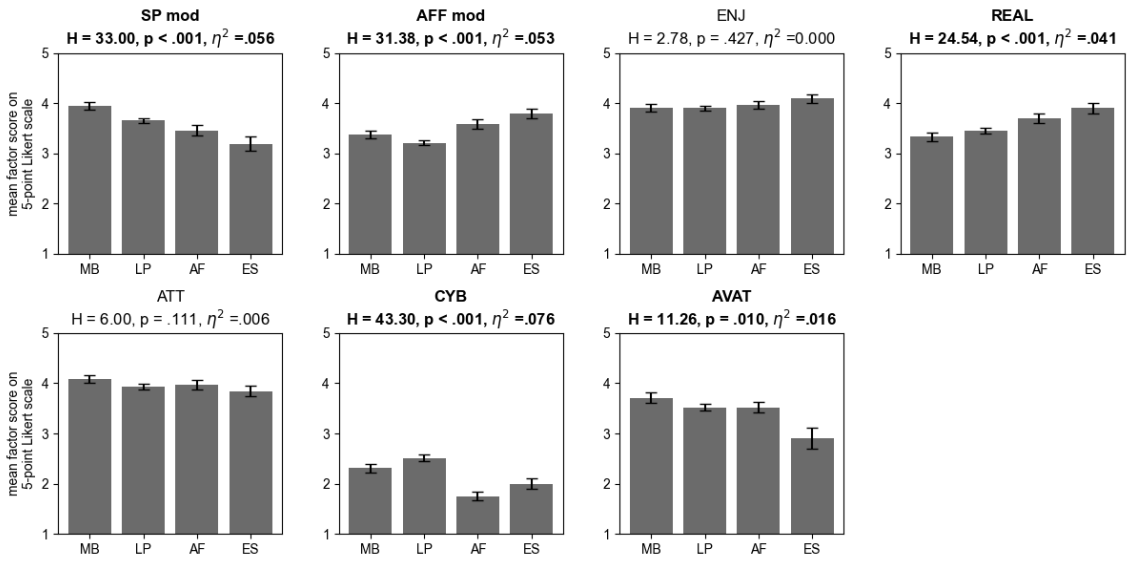



**Fig. 3.** The SP-IE factor scores for the different installations. The bar height indicates the group mean while the errorbars correspond to the standard error within each group. The results of a Kruskal-Wallis test are stated in the plot titles and factor with significant group differences are marked in bold.

**H2 – Cybersickness and Immersion Level** Consistent with H2, the analysis revealed significantly higher scores for cybersickness (CYB) in MB and LP (Figure 3, Table 4), the installations

| | | MB vs LP | MB vs AF | MB vs ES | LP vs AF | LP vs ES | AF vs ES |
|---|---|---|---|---|---|---|---|
| **SP mod** | $\Delta$ mean | **0.29** | **0.50** | **0.76** | 0.20 | **0.47** | 0.26 |
| | $U$ | **21836.5** | **6356.0** | **5768.0** | 10754.0 | **10219.5** | 2484.5 |
| | $p_{\text{bonf}}$ | **0.001** | **<0.001** | **<0.001** | 0.421 | **0.009** | 0.863 |
| | $r_{rb}$ | **-0.225** | **-0.336** | **-0.411** | -0.139 | **-0.260** | -0.147 |
| **AFF mod** | $\Delta$ mean | 0.16 | -0.21 | **-0.42** | **-0.37** | **-0.58** | -0.21 |
| | $U$ | 19669.0 | 4098.5 | **2768.5** | **7163.5** | **4747.0** | 1711.5 |
| | $p_{\text{bonf}}$ | 0.531 | 0.602 | **0.002** | **0.010** | **<0.001** | 0.218 |
| | $r_{rb}$ | -0.104 | 0.138 | **0.323** | **0.241** | **0.415** | 0.210 |
| **ENJ** | $\Delta$ mean | -0.0004 | -0.07 | -0.19 | -0.07 | -0.19 | -0.13 |
| | $U$ | 18111.0 | 4696.0 | 3650.0 | 9136.5 | 7025.0 | 1886.5 |
| | $p_{\text{bonf}}$ | 1.000 | 1.000 | 1.000 | 1.000 | 0.596 | 1.000 |
| | $r_{rb}$ | -0.016 | 0.013 | 0.107 | 0.032 | 0.134 | 0.129 |
| **REAL** | $\Delta$ mean | -0.12 | **-0.36** | **-0.57** | -0.24 | **-0.45** | -0.21 |
| | $U$ | 16379.0 | **3662.5** | **2458.5** | 8045.5 | **5488.0** | 1756.0 |
| | $p_{\text{bonf}}$ | 1.000 | **0.038** | **<0.001** | 0.323 | **<0.001** | 0.354 |
| | $r_{rb}$ | 0.081 | **0.230** | **0.398** | 0.148 | **0.324** | 0.189 |
| **ATT** | $\Delta$ mean | 0.15 | 0.11 | 0.24 | -0.04 | 0.09 | 0.13 |
| | $U$ | 19858.5 | 5332.5 | 4873.0 | 9368.5 | 8691.5 | 2374.0 |
| | $p_{\text{bonf}}$ | 0.343 | 0.878 | 0.169 | 1.000 | 1.000 | 1.000 |
| | $r_{rb}$ | -0.114 | -0.121 | -0.192 | 0.008 | -0.071 | -0.096 |
| **CYB** | $\Delta$ mean | -0.20 | **0.56** | 0.31 | **0.76** | **0.51** | -0.25 |
| | $U$ | 16230.0 | **6468.0** | 4955.5 | **13721.0** | **10671.0** | 1811.5 |
| | $p_{\text{bonf}}$ | 0.838 | **<0.001** | 0.096 | **<0.001** | **<0.001** | 0.586 |
| | $r_{rb}$ | 0.089 | **-0.360** | -0.213 | **-0.453** | **-0.315** | 0.163 |
| **AVAT** | $\Delta$ mean | 0.19 | 0.19 | **0.80** | -0.002 | 0.61 | 0.61 |
| | $U$ | 19917.5 | 5433.0 | **5202.0** | 9569.0 | 9608.5 | 2514.5 |
| | $p_{\text{bonf}}$ | 0.312 | 0.539 | **0.012** | 1.000 | 0.140 | 0.640 |
| | $r_{rb}$ | -0.118 | -0.142 | **-0.273** | -0.013 | -0.184 | -0.161 |

**Table 4.** Pairwise comparison by means of Mann-Whitney U tests of the different installations for each of the seven SP-IE factors: $\Delta$ mean = difference between mean factor scores, $U$ = result of Mann-Whitney U test, $p_{\text{bonf}}$ = Bonferroni-corrected p-value, $r_{rb}$ = rank-biserial correlation. Statistically significant differences are marked in bold.

with the highest degree of immersivity. This trend aligns with expectations from the literature on sensory conflict in VR systems and further validates the link between increased technical immersion and the likelihood of cybersickness symptoms. Interestingly, cybersickness scores in LP (the 360-degree projection room) were slightly higher than those reported for the VR experience MB. A possible explanation for this is discussed in section 6.

### 5.2 User Characteristics

**H3 – Effects of Age on Presence and Enjoyment** To investigate the role of age, Kruskal-Wallis tests were conducted for each SP-IE factor across age groups within each installation ($df = 5$ in all cases). As shown in Figure 4, significant age-related effects were observed in MB for SP mod ($H = 19.72$, $p = .001$, $\eta^2 = .110$) and AFF mod ($H = 16.70$, $p = .005$, $\eta^2 = .088$) and in ES for the AVAT factor ($H = 13.94$, $p < .016$, $\eta^2 = .163$). In MB, older participants reported lower spatial presence and affordance, partially supporting H3. However, no consistent effect of age was found in LP and AF, and enjoyment (ENJ) remained stable across age groups. Overall, these results suggest that age may influence certain immersive dimensions, but the effect is selective and context-dependent.

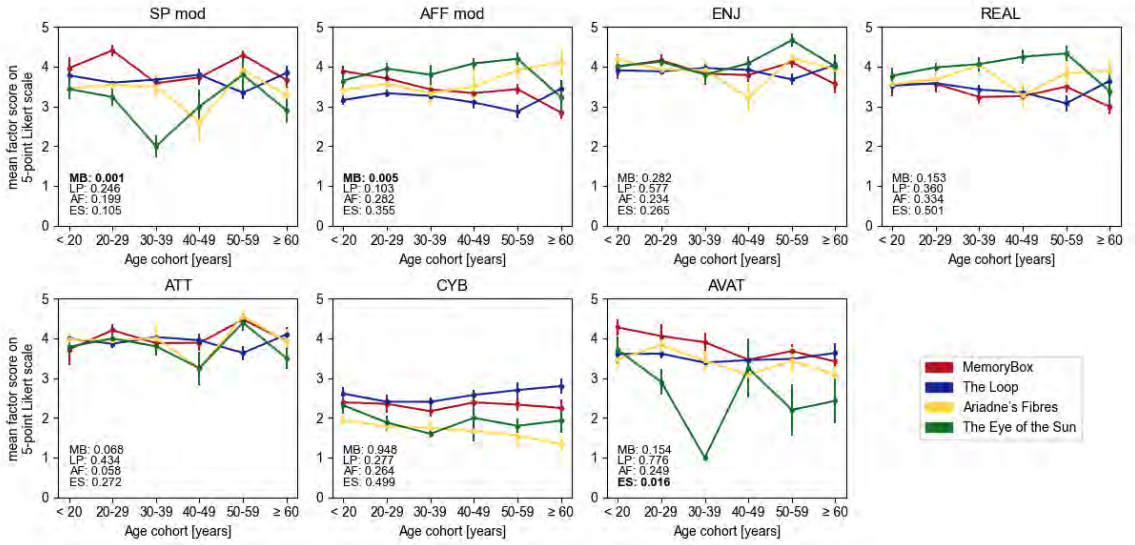



**Fig. 4.** The **effect of age** and installation type on the mean score for each of the seven SP-IE factors. The marker indicates the group mean score while the errorbars represent the standard error within each group. The p-value of a Kruskal-Wallis test is stated for each factor and installation at the bottom of the subplots, df = 5 in all cases. Significant differences are highlighted in bold.

**H4 – Prior Experience with Immersive Technologies** Figure 5 shows the SP-IE factor scores as a function of the user's prior experience with immersive technology for each of the four

installations. Again, Kruskal-Wallis tests were performed ($df = 4$ in all cases) with the corresponding p-values stated in each subplot. Statistically significant group differences were found in MB for the factors AFF mod ($H = 10.85,\ p = .028,\ \eta^2 = .052$) CYB ($H = 11.41,\ p = .022,\ \eta^2 = .057$) and AVAT ($H = 12.14,\ p = .016,\ \eta^2 = .064$) and in ES for AVAT ($H = 11.99,\ p = .017,\ \eta^2 = .145$). For MB, a clear positive correlation between affordance and prior experience as well as a negative correlation with cybersickness were observed, supporting H4 and agreeing with previous works.

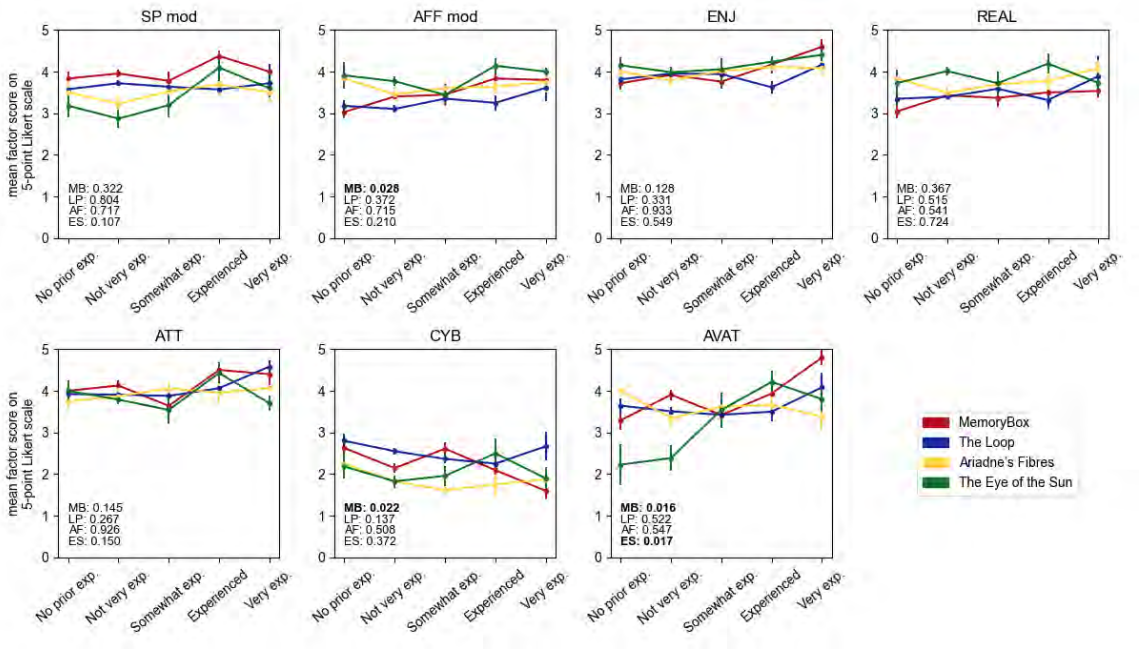



**Fig. 5.** The **effect of prior experience with immersive technology** and installation type on the mean score for each of the seven SP-IE factors. The marker indicates the group mean score while the errorbars represent the standard error within each group. The p-value of a Kruskal-Wallis test is stated for each factor and installation at the bottom of the subplots, df = 4 in all cases. Significant differences are highlighted in bold.

**H5 – Gender Differences in SP-IE Factors** Participants were asked to indicate their gender with the options "female", "male", and "other". Due to the very small number of participants in the "other" category (6 out of 532), this group was not included in the statistical comparisons, as the sample size was insufficient to support meaningful analysis. To test H5, we compared responses between male and female participants using Mann-Whitney U tests across all SP-IE factors and for each installation. The results are presented in Table 5. Statistically significant differences were found in MB (CYB), LP (SP mod, ENJ, ATT, and CYB), and AF (CYB). Contrary to H5, these results suggest that gender may influence certain dimensions of the immersive experience—particularly

cybersickness and attentional engagement—even though the effect is not consistent across all installations or factors.

| Installation | Quantity | SP mod | AFF mod | ENJ | REAL | ATT | CYB | AVAT |
|---|---|---|---|---|---|---|---|---|
| **MB** | $\Delta$ mean | 0.20 | -0.19 | -0.02 | 0.20 | 0.14 | **0.34** | 0.15 |
| ($df = 132$) | $U$ | 2280.5 | 1791.0 | 1922.5 | 2262.0 | 2208.0 | **2434.0** | 2171.5 |
| | $p$ | 0.152 | 0.368 | 0.785 | 0.179 | 0.268 | **0.029** | 0.357 |
| | $r_{rb}$ | -0.152 | 0.095 | 0.029 | -0.142 | -0.115 | **-0.229** | -0.097 |
| **LP** | $\Delta$ mean | **0.34** | 0.22 | **0.30** | 0.24 | **0.37** | **0.36** | -0.08 |
| ($df = 263$) | $U$ | **9799.5** | 9031.0 | **9576.0** | 9162.0 | **9871.5** | **9575.0** | 7756.5 |
| | $p$ | **0.003** | 0.094 | **0.009** | 0.058 | **0.002** | **0.009** | 0.635 |
| | $r_{rb}$ | **-0.219** | -0.124 | **-0.191** | -0.140 | **-0.228** | **-0.191** | 0.035 |
| **AF** | $\Delta$ mean | 0.010 | 0.20 | -0.02 | -0.05 | 0.21 | **-0.34** | 0.11 |
| ($df = 66$) | $U$ | 577.0 | 657.0 | 603.0 | 573.0 | 710.0 | **357.0** | 627.0 |
| | $p$ | 0.995 | 0.317 | 0.740 | 0.975 | 0.094 | **0.006** | 0.525 |
| | $r_{rb}$ | -0.002 | -0.141 | -0.047 | 0.005 | -0.233 | **0.380** | -0.089 |
| **ES** | $\Delta$ mean | 0.04 | 0.06 | 0.10 | 0.04 | -0.17 | 0.01 | 0.15 |
| ($df = 57$) | $U$ | 434.0 | 430.0 | 482.5 | 423.0 | 387.5 | 412.0 | 439.0 |
| | $p$ | 0.896 | 0.944 | 0.374 | 0.981 | 0.559 | 0.844 | 0.831 |
| | $r_{rb}$ | -0.021 | -0.012 | -0.135 | 0.005 | 0.088 | 0.031 | -0.033 |

**Table 5.** Comparison of **female and male populations** by means of Mann-Whitney U tests for each of the seven SP-IE factors and for each of the four installations. The degrees of freedom (df) for each installation are stated below the acronym. $\Delta$ mean = difference between female and male population scores (i.e. $\Delta > 0$ corresponds to a higher score in women and vice versa), $U$ = result of Mann-Whitney U test, $p$ = p-value, $r_{rb}$ = rank-biserial correlation. Statistically significant differences are marked in bold.

**H6 – Relationship Between Immersive Tendencies and SP-IE Factors** To test H6, we computed Pearson correlation coefficients between each of the four ITQ factors (Focus, Involvement, Emotional Involvement, and Gaming Tendencies) and the seven SP-IE factors. All correlations were weak but statistically significant ($|r| < 0.25$, $p < 0.05$), suggesting limited associations between immersive tendencies and reported experience. H6 may therefore be considered not or only partially supported.

While this result indicates that participants with higher immersive predispositions tended to report slightly stronger spatial presence, attention, or enjoyment, the magnitude of these effects was small. This suggests that although individual differences may play a role in shaping immersive experiences, contextual factors—such as the nature of the installation and its level of technical immersivity—likely have a stronger influence.

These findings are consistent with the view that immersion is not solely a trait-dependent phenomenon, but emerges primarily from the interaction between user dispositions and situational features of the environment.

## 6 Discussion

A field study was conducted to compare four different multi-user interactive digital art installations, characterised by varying technical characteristics (in particular regarding the audio-visual hardware and immersivity levels) as well as different narrative contents, stimulus types, and interaction modes (Table 1). Moreover, the installations were exhibited in four distinct environments and visited by different audiences with slightly varying demographic backgrounds (Table 2).

In line with H1, the results show a clear correlation between the experienced spatial presence (SP mod) and the level of technical immersivity of the installation. The highest scores were reported for the VR experience MB, followed by the 360-degree projection room experience LP. Cybersickness was also strongest for these two installations, as expected in H2. However, users in LP reported significantly higher scores than users in MB, despite the fact that a fixed physical reference system (provided by the floor, video projectors and the inner and outer cylindrical screens) could be seen by the users at all times. One possible explanation for this is that the virtual objects projected onto the screens in LP often moved. This led to a conflict between the visual stimulus, which indicated a moving frame of reference, and the sensory information provided by the user's feet and inner ear, which indicated a resting frame of reference. Conversely, the virtual environments produced in MB involved static reference systems (walls and floor), ensuring that the user's head motion and visually perceived information matched. Considering the installations AF and ES, the lower cybersickness scores can be explained by (and indeed expected from) their open integration with the surrounding physical environment, as well as the configuration of the video screens and projection surfaces. Interestingly, CYB scores for the digital sculpture ES were higher than those reported for the video wall and floor projection setup AF. While this difference was not statistically significant, it suggests that other factors besides visual stimuli may be responsible for cybersickness symptoms. Further studies could address this question.

A key finding of the study is that the perceived affordance (AFF mod) and realness (REAL) which were found to be highest for the motion- and touch-sensitive sculpture ES. There were statistically significant differences between ES and both MB and LP. Moreover, users of AF reported significantly higher scores than LP users for AFF mod and than MB users for REAL. Both ES and AF were designed as open-interaction installations without any explicit narration. In contrast, MB and LP featured a clear storyline which was apparent in the image sequences and narrated by one or multiple voices. In terms of interacting with virtual objects, users in MB could primarily attract or repel particle clouds which often only manifested after a short delay due to the programmed inertia of the particles. In LP, users could trigger different events through their position and movements within the 360-degree installation. However, the comparatively large number of simultaneous users (often 15-20) may have caused individual users to become confused about the correspondence between virtual events and their own physical actions. By comparison, interactions in both ES and AF may have provided users with a faster and clearer feedback on their actions. In ES, the virtual eye would follow users as they turned around the sculpture and touching the sphere would result in an immediate reaction in the projected images onto them (e.g. the eye would start squinting or there would be ripples in the solar corona radiating out from the position of the user's hand). Similarly, in AF, the avatars directly mirrored users' movements in terms of both the avatar's position on the screen wall and its pose. Therefore, it could be argued that ES and AF provided a simpler and more intuitive way of interacting. A dedicated follow-up study focusing on users' understanding of and appreciation for these interaction modes could further elucidate the importance of interaction design for affordance, perceived realness and the overall sensation of immersion.

Regarding the factor enjoyment (ENJ), it should be noted that comparable scores were reported for all four installations, and the Kruskal-Wallis test revealed no significant differences. Therefore, the results do not suggest a preference for a particular type of immersive technology, and no particular enjoyment-related bias should affect the other factors. A similar argument can be made for the factor attention (ATT).

When comparing the immersive art installations, it is also important to consider their specific characteristics in the context of public or semi-public exhibition environments. Unlike controlled laboratory settings, these spaces are inherently unpredictable: Users may encounter the installation unexpectedly, share the space with strangers, or divide their attention between the digital content and the surrounding physical environment. These conditions affect not only the depth of immersion but also the user's ability to engage with interactive features. For instance, the ambiguity in LP regarding who triggered a given visual effect may have been exacerbated by the presence of many simultaneous users. Similarly, in open setups like AF and ES, users could easily move in and out of the experience, creating a more fluid but also potentially more fragmented engagement. These findings underline the need to further investigate how immersion unfolds in real-world public contexts, where co-presence, shared agency, and environmental noise are not constraints to eliminate, but parameters to design for.

In addition to the comparison of the technical properties of the installations, this study also evaluated the influence of individual user characteristics on their immersive experience. Gender-related differences were observed in particular for users of LP where women reported significantly higher scores for spatial presence, enjoyment and attention. Cybersickness was also significantly higher in women in the technically more immersive installations LP and MB. Interestingly, the opposite result was observed for AF where male participants reported higher CYB scores. However, it should be noted that the overall CYB score was lowest in AF. Previous studies looking specifically at VR experiences also reported stronger cybersickness in women than in men [3, 11, 37] as well as a greater sense of presence [11] or enjoyment [16]. However, Felnhofer et al. [5] observed opposite results and other studies observed no significant differences [4, 18, 23, 24, 31]. This leads to an inconclusive overall picture.

Regarding age, no statistically significant effect was observed, except for the VR installation MB. Here, older participants reported a lower affordance and the Kruskal-Wallis test indicated a significant difference for spatial presence, however, without any clear positive or negative correlation emerging from the graph in Figure 4. The Kruskal-Wallis test also yielded a significant result for the AVAT factor for users of ES. However, this can be related to the very low score in the 30-39 years age cohort which most likely represents a statistical outlier. The absence of a clear age effect on immersion is mirrored in the results of previous studies [3, 23, 24]. A significant decrease of spatial presence with age was only reported by Kober et al. [18].

Considering Figure 5, a weakly positive correlation between the factor score and the prior experience level is observed in most cases, except for cybersickness which decreases with increasing experience. However, statistically significant effects according to a Kruskal-Wallis test were only observed for the VR installation MB and the factors AFF mod, CYB and AVAT, and for the installation ES and AVAT. Positive correlations between prior experience with VR experiences or video games and presence are reported in the literature [4, 6, 31] as well as a negative correlation with simulator sickness [11]. Overall, it appears that a greater prior experience with immersive technologies can facilitate or slightly enhance immersive experiences. Experienced users may understand and exploit the offered interaction possibilities more easily which can be crucial for a rich experience (especially for HMD-based VR installations). Moreover, users reporting a higher prior

experience may simply have a personal predilection for such technologies and may therefore show greater appreciation for such installations and a higher motivation to engage with them.

Lastly, no large effect was observed for the self-reported immersive tendencies. A weakly positive correlation ($0.1 < r < 0.25$) was found between each of the four ITQ subscales and the SP-IE factors, except for CYB for which no correlation ($|r| \leq 0.07$) was observed. Further research is needed to understand if indeed individual tendencies play a subservient role for immersive experiences or if instead these results are a consequence of psychometric shortcomings of the ITQ (see analysis of Cronbach's alpha in section 4.3).

## 7 Limitations

The diversity of the installations we considered, which differed in terms of their technical properties, content, narrative, user interaction modalities, exhibition interaction environment and audience, allowed us to investigate a wide spectrum of immersive, multi-user scenarios. However, as many variables were varied simultaneously between the four installations, it is difficult to ascertain which factors account for the observed differences in the user experience. Follow-up studies could focus on specific hardware aspects and consider a single exhibition environment to allow for more precise conclusions to be drawn.

Moreover, the results of the internal consistency analysis (i.e. Cronbach's alpha and Pearson's correlation coefficient) suggest that the psychometric properties of the SP-IE questionnaire and ITQ could be improved. In the case of the SP-IE questionnaire, this could involve adding items to the two-item factors of SP-IE (ATT, CYB and AVAT), for example. More generally, future studies should combine subjective user experience data (collected through questionnaires) with behavioural data (assessed, e.g., through the analysis of user trajectories, interaction time and interaction intensity). Such a multimodal approach would not only offer a more comprehensive view of the immersive process, but also allow capturing implicit or non-verbal dimensions of engagement that self-reports may overlook. Ultimately, this could help better characterize immersion in context and identify the mechanisms that facilitate or constrain it.

## 8 Conclusion and Perspectives

Demand for immersive experiences in the cultural and creative sectors is steadily increasing, whether for educational or entertainment purposes in museums or at live shows. This field study of four interactive multi-user art installations represents another step towards a better understanding of the strengths and challenges of different immersive technologies and their application in public, multi-user contexts.

While the results of this study confirm that high-immersivity setups, such as HMDs and 360-degree video projection spaces, can more easily elicit strong sensations of spatial presence, they also highlight the fact that immersion is a complex, multi-layered psychological phenomenon. In particular, it appears that an effective and intuitive interaction design that provides direct and clear feedback appears to be one of several key factors for a rich and satisfying immersive user experience. Furthermore, individual user characteristics such as the prior experience with immersive technology may also play a significant role.

Our study opens up several perspectives for future research. Firstly, different interaction modalities could be investigated in more detail by assessing not only the perceived affordance of an

installation but also the user's comprehension of it. Scales like the *MeCue* questionnaire [25], which includes cognitive, emotional and sensory dimensions of user experiences, could also be considered for this purpose. Secondly, the impact of aspects such as the installation aesthetics (e.g., abstract *versus* photo-realistic style, anthropomorphic *versus* non-human avatars), installation narrative or the presence/absence of a clear storyline may be evaluated. In this context, an interesting question is how user interaction can be effectively incorporated into storytelling to produce non-linear narratives, and finally how artwork can or should depart from gameplay. Thirdly, future studies may explore different approaches to multi-user interaction in immersive art installations, particularly by comparing collaborative interaction and individual, independent interaction modalities. Finally, subjective user experience data could be combined with behavioural measurements, for example by quantifying interaction aspects such as duration, intensity, and frequency of specific movements, or through real-time emotion detection.

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## References

1. An, J.: Assessment and application of digital museum visitors' emotional experience based on virtual reality technology and emotion recognition algorithm. PRESENCE: Virtual and Augmented Reality **33**, 255–268 (07 2024). https://doi.org/10.1162/pres_a_00425, https://doi.org/10.1162/pres_a_00425
2. Cercle: Odyssey. https://odyssey.cercle.io/ (2025), [Accessed 01-05-2025]
3. Chang, E., Kim, H.T., Yoo, B.: Virtual Reality Sickness: A Review of Causes and Measurements. International Journal of Human–Computer Interaction **36**(17), 1658–1682 (Oct 2020). https://doi.org/10.1080/10447318.2020.1778351, https://www.tandfonline.com/doi/full/10.1080/10447318.2020.1778351
4. De Leo, G., Diggs, L.A., Radici, E., Mastaglio, T.W.: Measuring Sense of Presence and User Characteristics to Predict Effective Training in an Online Simulated Virtual Environment. Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare **9**(1), 1–6 (Feb 2014). https://doi.org/10.1097/SIH.0b013e3182a99dd9, https://journals.lww.com/01266021-201402000-00001
5. Felnhofer, A., Kothgassner, O.D., Beutl, L., Hlavacs, H., Kryspin-Exner, I.: Is Virtual Reality made for Men only? Exploring Gender Differences in the Sense of Presence. In: Proceedings of the International Society on presence research. pp. 103–112 (Oct 2012)
6. Freeman, J., Avons, S.E., Pearson, D.E., IJsselsteijn, W.A.: Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence. Presence: Teleoperators and Virtual Environments **8**(1), 1–13 (02 1999). https://doi.org/10.1162/105474699566017, https://doi.org/10.1162/105474699566017

7. Freitag, F., Molter, C., Mücke, L.K., Rapp, H., Schlarb, D.B., Sommerlad, E., Spahr, C., Zerhoch, D.: Immersivity: An Interdisciplinary Approach to Spaces of Immersion. Ambiances (Dec 2020). https://doi.org/10.4000/ambiances.3233, http://journals.openedition.org/ambiances/3233
8. Gignac, G.E., Szodorai, E.T.: Effect size guidelines for individual differences researchers. Personality and Individual Differences **102**, 74–78 (2016). https://doi.org/https://doi.org/10.1016/j.paid.2016.06.069, https://www.sciencedirect.com/science/article/pii/S0191886916308194
9. Goffman, E.: Behavior in Public Places: Notes on the Social Organization of Gatherings. Free Press, New York (1963)
10. Grassini, S., Laumann, K.: Questionnaire Measures and Physiological Correlates of Presence: A Systematic Review. Frontiers in Psychology **11**, 349 (Mar 2020). https://doi.org/10.3389/fpsyg.2020.00349, https://www.frontiersin.org/article/10.3389/fpsyg.2020.00349/full
11. Grassini, S., Laumann, K., Luzi, A.K.: Association of individual factors with simulator sickness and sense of presence in virtual reality mediated by head-mounted displays (hmds). Multimodal Technologies and Interaction **5**(3) (2021). https://doi.org/10.3390/mti5030007, https://www.mdpi.com/2414-4088/5/3/7
12. Illsley, W.R., Almevik, G., Westin, J., Hansén, J.B.A., Fornander, E., Hallgren, E., Lagercrantz, W., and, P.V.: The edutainment scan: immersive media and its deployment in museums. Museum Management and Curatorship **40**(1), 18–35 (2025). https://doi.org/10.1080/09647775.2024.2357066, https://doi.org/10.1080/09647775.2024.2357066
13. JASP Team: JASP (Version 0.19.0)[Computer software] (2024), https://jasp-stats.org/
14. Khenak, N.: Vers un modèle unifié de la présence spatiale et de ses facteurs : application à l'étude de la téléprésence en environnements immersifs. Theses, Université Paris-Saclay (Oct 2020), https://theses.hal.science/tel-03098258
15. Khenak, N., Vézien, J.M., Bourdot, P.: The Construction and Validation of the SP-IE Questionnaire: An Instrument for Measuring Spatial Presence in Immersive Environments. In: Bourdot, P., Interrante, V., Nedel, L., Magnenat-Thalmann, N., Zachmann, G. (eds.) Virtual Reality and Augmented Reality, vol. 11883, pp. 201–225. Springer International Publishing, Cham (2019). https://doi.org/10.1007/978-3-030-31908-3_13, http://link.springer.com/10.1007/978-3-030-31908-3_13, series Title: Lecture Notes in Computer Science
16. Kim, S.J., Laine, T.H., Suk, H.J.: Presence effects in virtual reality based on user characteristics: Attention, enjoyment, and memory. Electronics **10**(9) (2021). https://doi.org/10.3390/electronics10091051, https://www.mdpi.com/2079-9292/10/9/1051
17. Kim, Y., and, H.L.: Falling in love with virtual reality art: A new perspective on 3d immersive virtual reality for future sustaining art consumption. International Journal of Human–Computer Interaction **38**(4), 371–382 (2022). https://doi.org/10.1080/10447318.2021.1944534, https://doi.org/10.1080/10447318.2021.1944534
18. Kober, S.E.: Effects of Age on the Subjective Presence Experience in Virtual Reality. In: Proceedings of the International Society for Presence Research 15th International Conference on Presence. pp. 149–157. Facultas, Vienna (2014), https://api.semanticscholar.org/CorpusID:53651666
19. LaViola Jr, J.J.: A discussion of cybersickness in virtual environments. ACM SIGCHI Bulletin **32**(1), 47–56 (2000). https://doi.org/10.1145/333329.333344
20. Lessiter, J., Freeman, J., Keogh, E., Davidoff, J.: A Cross-Media Presence Questionnaire: The ITC-Sense of Presence Inventory. Presence: Teleoperators and Virtual Environments **10**(3), 282–297 (06 2001). https://doi.org/10.1162/105474601300343612, https://doi.org/10.1162/105474601300343612
21. Li, B.: Le bal de paris. https://www.blancali.com/spectacle/le-bal-de-paris-de-blanca-li/ (2025), [Accessed 01-05-2025]
22. Liu, Q., Mi, G., Shmelova-Nesterenko, O.: Research on immersive scenario design in museum education. In: Zaphiris, P., Ioannou, A., Sottilare, R.A., Schwarz, J., Fui-Hoon Nah, F., Siau, K., Wei, J., Salvendy, G. (eds.) HCI International 2023 – Late Breaking Papers. pp. 167–175. Springer Nature Switzerland, Cham (2023)

23. Lorenz, M., Brade, J., Klimant, P., Heyde, C.E., Hammer, N.: Age and gender effects on presence, user experience and usability in virtual environments-first insights. PLoS One **18**(3), e0283565 (2023). https://doi.org/10.1371/journal.pone.0283565
24. Martingano, A.J., Duane, J.N., Brown, E., Persky, S.: Demographic differences in presence across seven studies. Virtual Reality **27**(3), 2297–2313 (Sep 2023). https://doi.org/10.1007/s10055-023-00805-z, https://link.springer.com/10.1007/s10055-023-00805-z
25. Minge, M., Thüring, M., Wagner, I.: Developing and validating an english version of the mecue questionnaire for measuring user experience. Proceedings of the Human Factors and Ergonomics Society Annual Meeting **60**(1), 2063–2067 (2016). https://doi.org/10.1177/1541931213601468, https://doi.org/10.1177/1541931213601468
26. O'Brien, H.L., Toms, E.G.: What is user engagement? a conceptual framework for defining user engagement with technology. Journal of the American Society for Information Science and Technology **59**(6), 938–955 (2008). https://doi.org/10.1002/asi.20801
27. Patel, A.: SDO | Solar Dynamics Observatory. https://sdo.gsfc.nasa.gov (2024), [Accessed 11-09-2024]
28. R: Documentation for package 'rstatix' version 0.7.2 —Kruskal-Wallis Effect Size. https://search.r-project.org/CRAN/refmans/rstatix/html/kruskal_effsize.html (2025), [Accessed 08-07-2025]
29. Robaina-Calderín, L., Martín-Santana, J.D., Muñoz-Leiva, F.: Immersive experiences as a resource for promoting museum tourism in the z and millennials generations. Journal of Destination Marketing Management **29**, 100795 (2023). https://doi.org/https://doi.org/10.1016/j.jdmm.2023.100795, https://www.sciencedirect.com/science/article/pii/S2212571X23000343
30. Robillard, G., Bouchard, S., Renaud, P., Cournoyer, L.: Validation canadienne-française de deux mesures importantes en réalité virtuelle : l'immersive tendencies questionnaire et le presence questionnaire. In: 25e congrès de la Société Québécoise pour la Recherche en Psychologie (SQRP). Trois-Rivières, Québec, Canada (Nov 2002)
31. Sagnier, C., Loup-Escande, E., Valléry, G.: Effects of gender and prior experience in immersive user experience with virtual reality. In: Ahram, T., Falcão, C. (eds.) Advances in Usability and User Experience. pp. 305–314. Springer International Publishing, Cham (2020)
32. Sanchez-Vives, M., Slater, M.: From presence to consciousness through virtual reality. Nature reviews. Neuroscience **6**, 332–9 (05 2005). https://doi.org/10.1038/nrn1651
33. Schubert, T., Friedmann, F., Regenbrecht, H.: The experience of presence: Factor analytic insights. Presence: Teleoper. Virtual Environ. **10**(3), 266–281 (jun 2001). https://doi.org/10.1162/105474601300343603, https://doi.org/10.1162/105474601300343603
34. Skarbez, R., Brooks, Jr., F.P., Whitton, M.C.: A survey of presence and related concepts. ACM Comput. Surv. **50**(6) (Nov 2017). https://doi.org/10.1145/3134301, https://doi.org/10.1145/3134301
35. Slater, M.: Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. Philosophical Transactions of the Royal Society B: Biological Sciences **364**(1535), 3549–3557 (Dec 2009). https://doi.org/10.1098/rstb.2009.0138, https://royalsocietypublishing.org/
36. Slater, M., Wilbur, S.: A framework for immersive virtual environments five: Speculations on the role of presence in virtual environments. Presence: Teleoper. Virtual Environ. **6**(6), 603–616 (dec 1997). https://doi.org/10.1162/pres.1997.6.6.603, https://doi.org/10.1162/pres.1997.6.6.603
37. Stanney, K.M., Hale, K.S., Nahmens, I., Kennedy, R.S.: What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience. Human Factors **45**(3), 504–520 (2003). https://doi.org/10.1518/hfes.45.3.504.27254, https://doi.org/10.1518/hfes.45.3.504.27254, pMID: 14702999
38. teamLab: Borderless. https://teamlab.art/e/tokyo/ (2025), [Accessed 01-05-2025]
39. Vallat, R.: Pingouin: statistics in python. Journal of Open Source Software **3**(31), 1026 (2018). https://doi.org/10.21105/joss.01026, https://doi.org/10.21105/joss.01026
40. Verhulst, I., Woods, A., Whittaker, L., Bennett, J., Dalton, P.: Do vr and ar versions of an immersive cultural experience engender different user experiences? Computers in Human Behavior **125**, 106951 (2021). https://doi.org/https://doi.org/10.1016/j.chb.2021.106951, https://www.sciencedirect.com/science/article/pii/S0747563221002740

41. Witmer, B.G., Singer, M.J.: Measuring Presence in Virtual Environments: A Presence Questionnaire. Presence: Teleoperators and Virtual Environments **7**(3), 225–240 (Jun 1998). https://doi.org/10.1162/105474698565686, https://direct.mit.edu/pvar/article/7/3/225-240/92643
42. Zhou, Y., Chen, J., Wang, M.: A meta-analytic review on incorporating virtual and augmented reality in museum learning. Educational Research Review **36**, 100454 (2022). https://doi.org/https://doi.org/10.1016/j.edurev.2022.100454, https://www.sciencedirect.com/science/article/pii/S1747938X22000239