The L∞p — A 360-degree immersive and interactive stage for collective space-time experiences

BÉATRICE ALBERT, Université Paris-Saclay, CNRS, AgroParisTech, IDEEV, ESE; La métonymie, Le sas, France
EMMANUELLE FRENOUX, Université Paris-Saclay, CNRS, Laboratoire Interdisciplinaire des Sciences du Numérique (LISN), France
GAËLE MISIAK, CERVVAL, France
GÉRARD KUBRYK, Université Paris-Saclay, CEA, CNRS, Inserm, Biomaps; Forum des images; La métonymie, Le sas, France
GUILLAUME JUNOT, La métonymie, Le sas, France
IZABELA FAGUET, Université Paris-Saclay, Centrale Supélec; La métonymie, Le sas, France
MATTHIEU COURGEON, CERVVAL, France
MICHÈLE GOUIFFÈS, Université Paris-Saclay, CNRS, Laboratoire Interdisciplinaire des Sciences du Numérique (LISN), France
NICOLA LORÈ, Université Paris-Saclay, CEA, CNRS, Inserm, Biomaps; La métonymie, Le sas, France
SAMI KORHONEN, La métonymie, Le sas, France
TIM SCHNEIDER, Université Paris-Saclay, CNRS, Laboratoire Interdisciplinaire des Sciences du Numérique (LISN); La métonymie, Le sas, France
VINCENT HULOT, La métonymie, Le sas, France
XAVIER MAÎTRE, Université Paris-Saclay, CEA, CNRS, Inserm, Biomaps; La métonymie, Le sas, France

Advances in immersive technology continue to enrich the breadth, depth, and intensity of the audience experience. *The L∞p* is a 360-degree immersive and interactive stage for the creation and dissemination of new augmented forms of live performance and digital installation that engage artists, scientists, and audiences, say experiencers, in an unconstrained multi-sensory collective experience. In one of the settings, experiencers stepped into *Spacetime Prospectives*, a series of tales about time and space as described differently by

Authors' Contact Information: Béatrice Albert, Université Paris-Saclay, CNRS, AgroParisTech, IDEEV, ESE; La métonymie, Le sas, Gif-sur-Yvette, France; Emmanuelle Frenoux, Université Paris-Saclay, CNRS, Laboratoire Interdisciplinaire des Sciences du Numérique (LISN), Orsay, France; Gaële Misiak, CERVVAL, Brest, France; Gérard Kubryk, Université Paris-Saclay, CEA, CNRS, Inserm, Biomaps; Forum des images; La métonymie, Le sas, Orsay, France; Guillaume Junot, La métonymie, Le sas, Orsay, France; Izabela Faguet, Université Paris-Saclay, Centrale Supélec; La métonymie, Le sas, Orsay, France; Matthieu Courgeon, CERVVAL, Brest, France; Michèle Gouiffès, Université Paris-Saclay, CNRS, Laboratoire Interdisciplinaire des Sciences du Numérique (LISN), Orsay, France; Nicola Lorè, Université Paris-Saclay, CEA, CNRS, Inserm, Biomaps; La métonymie, Le sas, Orsay, France; Sami Korhonen, La métonymie, Le sas, Orsay, France; Tim Schneider, tim.schneider@lisn.fr, Université Paris-Saclay, CNRS, Laboratoire Interdisciplinaire des Sciences du Numérique (LISN); La métonymie, Le sas, Orsay, France; Vincent Hulot, La métonymie, Le sas, Orsay, France; Xavier Maître, Université Paris-Saclay, CEA, CNRS, Inserm, Biomaps; La métonymie, Le sas, Orsay, France.

Manuscript submitted to ACM

the laws of physics. With *The L∞p*, we intend to set the experiencers' imaginations in motion and augment the experience of time and space in many ways.

CCS Concepts: • **Applied computing → Media arts**; • **Human-centered computing → Empirical studies in interaction design**.

Additional Key Words and Phrases: Interactive Art, Digital Art, Audio-visual, 360 degree projection, Real and Virtual Environments, Multi-User, Tracking, Kinect Camera, Spacetime, Symmetry, Quantum Physics, Field Study

ACM Reference Format:
Béatrice Albert, Emmanuelle Frenoux, Gaële Misiak, Gérard Kubryk, Guillaume Junot, Izabela Faguet, Matthieu Courgeon, Michèle Gouiffès, Nicola Lorè, Sami Korhonen, Tim Schneider, Vincent Hulot, and Xavier Maître. 2025. *The L∞p — A 360-degree immersive and interactive stage for collective space-time experiences.* 1, 1 (December 2025), 9 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 Introduction

In the upheaval of recent years, Blanca Li's *Le Bal de Paris* [9], developed by BackLight, involved ten spectators equipped with VR headsets dancing with the company's dancers on the stage of a virtual social world. London's Royal Opera House, with Figment Production, opened the opera to hyper-reality for four lucky spectators equipped to see, hear and touch a 15-minute multi-dimensional virtual opera in a box built on the Opera House stage itself. The Finnish National Opera is also trying to go elsewhere with Violet Disruption and Vitamin Studio, bringing not artists but avatars to the stage. Opera Beyond is developing an XR stage design platform to make virtual and augmented reality tools available to directors, set designers, lighting designers and producers. Charles Ayats' and Vincent Dupont's creative project *No Reality Now* equips all spectators in a room with VR headsets for a double show between the magic and augmentation of theatre and those of digital immersion, while the dancers, dressed in motion-tracking suits, move around the stage [4].

Advances in immersive technology are an important driver of the experience economy in cultural centres. Immersion is now seen as a requisite for art whether it is live performances, installations, or exhibitions. It may be overused with the mere idea of surrounding the spectator or visitor with videos or paintings. It may be enforced by capturing the experiencer's senses with head-mounted displays (HMDs) and headphones or by confining the experiencer in a controlled environment — typically a dark and isolated room – with a set of video and sound projections like at Atelier des Lumières [3], the Musée océanographique de Monaco [6], or at SAT [2]. It might also be embedded in public spaces to induce unconstrained immersive experiences in an open environment where spectators would then be passers-by with no intention whatsoever to follow the proposed reality shift. Immersion in public spaces is thus a challenge that we propose here to investigate in *The L∞p*, a 360-degree immersive and interactive stage for collective space-time experiences.

2 Related work

The L∞p was created upon the art-science work *See me through you* [10] which was originally created and exhibited at the Cité des Sicences et de l'Industrie, Paris, France. In *See me through you*, visitors find themselves immersed in deep space, gravitating around a black hole and witnessing space-time distortions as described by general relativity. The distortions are created by the mass of the black hole at the center of the installation and made visible by the light of galaxies that follow the visitors around. Through an interactive 360-degree video and sound projection, visitors were both the observers and the distant celestial bodies of the others at the same time. Visitors could see themselves through them. The hard- and software developed for the video projection systems and multi-user tracking in *See me through you* laid the technical basis for the creation of *The L∞p*.

Fig. 1. *The L∞p* is a 360-degree coaxial 2 m and 10 m cylindrical audiovisual projection immersive and interactive system integrated in a 11.3 m outer cylindrical black box. Top: External view of *The L∞p* and visitors taking off their shoes before entering the structure. Bottom: Visitors inside of *The L∞p* moving around the central cylinder screen and causing a virtual grid to warp under their feet in LP2.

The L∞p also benefited from Pierre Jodlowski's pioneering work *Grainstick* [7]. Created in 2010, the installation heralded the emergence of new spatialised interactive musical forms that allowed exploring the relationship between space, body and sound, and the way in which different art forms (music, dance, theatre, film and design) approached the notion of space in relation to the body and sound, in the light of advances in technology (spatialisation of sound,

Fig. 2. Top row: The Arrow of time 1 (LP1) in *The L∞p*, an immersive and interactive 360-degree tale; Left: Time arrows as fishes following Boids flocking behaviours; Middle: A child running after a planet before breaking it breaks into pieces when approaching the big crunch; Right: Promoting wave formation under Christopher Columbus' boats. Bottom row: The Arrow of time 2 (LP2) in *The L∞p*, an immersive and interactive 360-degree tale; Left: Flying time arrows as birds following Boids flocking behaviours; Middle: Chessboard where space and time are swapped with squares illuminated at the visitors' presence; Right: Quantum time clock with entangled entities associated with visitors.

image synthesis) and scientific knowledge (physics, cognitive science) of the time. Christophe Berton's scenography for *Grainstick* was designed for the general public as a single entrance 10 m cylindrical visual and sound immersive space where users could interact in a highly intuitive way and navigate through a range of characteristic sound and visual proposals that they could immediately grasp, but which gradually reveal a richness of evolution and construction that took them far beyond a simple demo.

3 Technical details and implementation

The L∞p is a platform for the creation, production and dissemination of new augmented experiences of the living and the digital. It consists of a black cylindrical structure (11.3 m in diameter, 4.5 m in height) which can be entered by up to 20 users simultaneously (Figure 1, top) and which inside is equipped with 14 video projectors, projecting onto two 360-degree cylindrical screens (an outer 10-m-diameter cylinder and a central 2-m-diameter cylinder) as well as the floor (Figure 1, bottom). Moreover, 16 Kinect V2 cameras mounted onto the central cylinder enable the detection and tracking of users, while 16 loudspeakers, with two subwoofers, positioned on the central cylinder and around the outer cylinder screen, provide spatialized audio. One Shuttle XPC nano mini-PCs 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 equipped with a total of five Nvidia Quadro A4500 graphics cards. *The L∞p* represents a 360-degree stage where the tools of art and science are merged to forge a new grammar with which new narratives of immersion and interaction can be written and represented.

4 Exhibition *Spacetime Prospectives* at *Les Ateliers des Capucins*

During two months, *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 a cinema, a theatre, a library, a museum, several shops, cafés and restaurants as well as a leisure space where individuals, friends and family can meet or do indoor sport activities. Visitors of *The L∞p* could freely participate in one of the two interactive, 20-min-long experiences entitled *Spacetime Prospectives* about physical concepts concerning time, space and symmetries. In both tales, the presence of experiencers activates one of the multiple universes that could derive from Albert Einstein's theory of special relativity. Events are then spatial, temporal or luminous. Evolving masses define space and time. Effects can occur before causes. Space and time are identical. Time can be fixed and rational or flexible and emotional, it flows back and forth. It loops, stops or jumps indefinitely. When visitors enter *The L∞p*, they become the centre of reference for the generation of lines that fade in all kinds of shades of blue onto the outer and inner cylinders. These lines are fired from the entrance in opposite directions on the external cylinder (Figure 2, top row, left). The soundscape becomes more prominent. Sound waves propagate with timelines. Localized in space, voices emerge and build a dialogue. They resonate wherever participants move:

Voice 1: The arrow of time was never really very well released. Do we even know if it ever left?
Voice 2: Some still attach meaning to it. Others, another.
Voice 1: Does it care? Hasn't it left? Hasn't it defined the first elements of reality? The arrow.
Voice 2: A cause precedes an effect.
Voice 1: Only if it goes straight. If we follow it. The arrow.

In the first scenario (LP1), time flows periodically such that night and day follow each other without a beginning nor an end, the time arrows associated to each visitor travel away like flocking birds (Figure 2, top row, left), the big bang and the big crunch alternatively give birth and death to our universe, Christopher Columbus goes back and forth from 15 March 1493 to 4 August 1492, from East to West, and the arrow of time might remain suspended. Visitors can see dawn and dusk on Earth, change their appearing period according to the quantity of motion they have, interact with the ocean that Columbus' boats cross, induce waves while moving around, precipitate the tide and promote a storm (Figure 2, top row, right), reveal galaxies out of the deep universe, deviate the trajectories of planets, crack them, and bring the universe to collapse (Figure 2, top row, centre) so they finally appear as vertical lines in a large clock. Along the way, they were invited to play red light, green light during which the whole installation would stop and turn red when and where someone had moved.

In the second scenario (LP2), time and space are exchanged such that visitors are all invited to walk the same way, along the single arrow of time (Figure 2, bottom row, left), along an infinite Möbius ribbon, while events start happening by surprise, there and not there. Visitors walk into a running clock on the floor. They are grasped by hands into a space-time grid that their presence distorts (Figure 1, bottom). They become entangled with entities that appear where they are walking (Figure 2, bottom row, right). They turn on every square of a big chessboard they are jumping on

(Figure 2, bottom row, middle). On the shore, they leave footprints in the sand and repulse the sea water that comes toward them from a central clepsydra.

The experiences were in French, free of charge and accessible, six days a week, from 11 a.m. to 7 p.m., during a period of two months. LP1 was played the first month. LP2, the second. LP2 was developed in light of the first feedback we collected and the observations we could make during LP1. We especially tried to limit complex multi-visitor interactions and enforce intuitive single-visitor interactions.

5 *Spacetime Prospectives* study

The L∞p was included in a comparative field study [14] together with three other experiences of varying degrees of immersivity in (1) virtual reality (VR)[1], (2) floor and wall video projection[11], and (3) spherical video projection [12]. Subjective user experiences were assessed for each installation using a questionnaire that primarily addressed the spatial presence in immersive environments (SP-IE) [8]. The SP-IE questionnaire consists of 20 items rated on a 5-point Likert scale, with the following subscales:

Spatial presence (SP): evaluates the sense of "being there" (4 items),
Affordance (AFF): assesses how well the environment supports interaction (4 items),
Enjoyment (ENJ): participant enjoyment (3 items),
Reality (REAL): evaluates the perceived realism of the environment (3 items),
Attention (ATT): attention paid to the activity (2 items),
Cybersickness (CYB): captures any discomfort or motion sickness (2 items),
Social presence (AVAT): measures the perception of other users' presence when avatars are present (2 optional items).

Two hundred and sixty visitors of *The L∞p* volunteered to participate in the study and a detailed presentation of the study methodology and results has been published previously [14]. It was found that *The L∞p* induces a slightly weaker sensation of spatial presence than the VR experience but a stronger sensation than the other two installations considered. The mean scores of the seven subscales of the SP-IE questionnaire are reported in Figure 3 for the two scenarios of *The L∞p* LP1 and LP2.

The perceived affordance (AFF) was significantly higher in LP2 than in LP1 ($p = 0.006$) together with a slightly higher but not quite statistically significant attention (ATT) paid to the activity ($p = 0.193$). Interestingly enough, the user's age did not seem to affect the experience along any of the investigated subscales of the spatial presence (see [14]) which aligns with the findings of previous studies evaluating the effect of age on immersive experiences [13]. Indeed, the reported data suggest that *The L∞p Spacetime Prospectives* can be considered "all ages". Finally, significant differences in spatial presence (SP), attention (ATT), and cybersickness (CYB) were found between male and female (see [14]) users with slightly higher scores for female users as observed in other studies [5] but in contradiction for spatial presence (SP) and attention (ATT) to others [13].

Beyond the technical challenges raised by such an immersive and interactive installation, there were also several unexpected issues regarding user interaction with the installation, which can largely be attributed to its novelty or visitors' unfamiliarity with this type of experience. *The L∞p* was originally conceived to be openly and freely accessible to visitors of *Les Ateliers des Capucins*. However, many children (often poorly or not at all supervised by their parents) regarded the structure as a playground. They ran around, brought their shoes and even bicycles inside, tried to catch the virtual objects and threw themselves against the screens. Overall, *The L∞p* was very popular and the number of

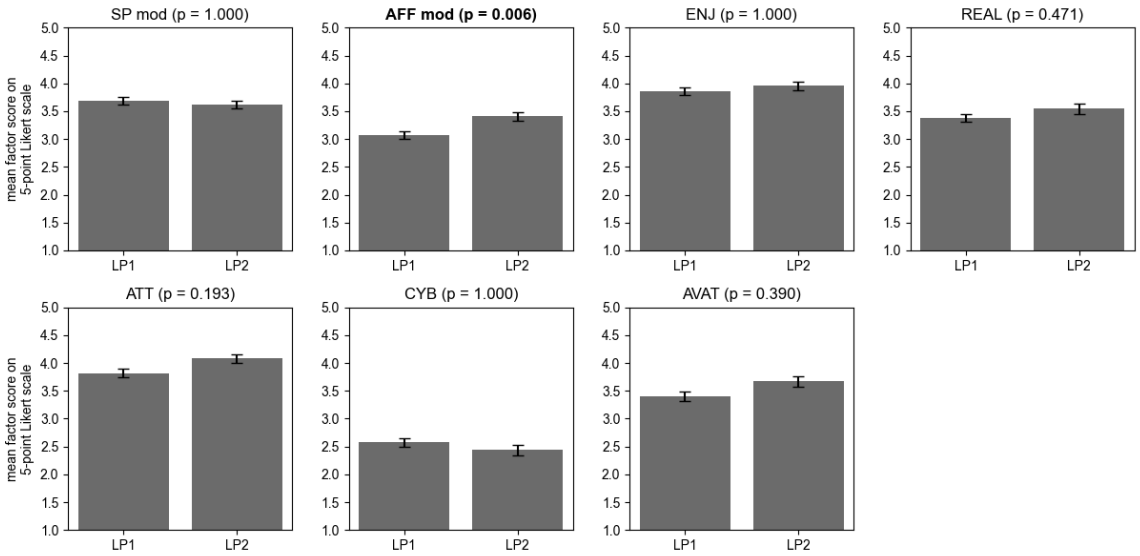

Fig. 3. The SP-IE factor scores for the two scenarios, LP1 and LP2, in *The L∞p* on spatial presence (SP), affordance (AFF), enjoyment (ENJ), reality (REAL), attention (ATT), cybersickness (CYB), and social presence (AVAT). The markers indicate the mean value while the error bars correspond to the standard deviation. The p-value of a Kruskal-Wallis test is stated for each factor. The scores for LP1 and LP2 were similar across most of the factors. A significant difference was observed only for AFF with participants reporting a higher affordance in LP2.

visitors far exceeded the capacity of the enclosed space. This quickly led to the structure degrading, resulting in the inner cylinder screen tearing from its mount, and *The L∞p* had to be closed for maintenance. At the other end of the interaction spectrum, most adults remained passive spectators during the experience, often missing out on the proposed interaction possibilities. Two principal measures were taken to address this situation. Firstly, access was regulated by introducing 20-minute sessions and putting a security guard in charge of controlling visitor entry and exit. The guard also reiterated the rules of conduct inside *The L∞p*, which had previously only been presented on a note at the entrance. Secondly, each session now began with a short introductory sequence in which a voice, accompanied by visuals, briefly explained the general concept of the installation, asked young users to behave calmly and encouraged adult users to participate actively. While these measures proved effective, they also altered the initial intention of *The L∞p* to provide free access and an unbiased experience.

6 Conclusions

The L∞p is a digital installation providing a 360-degree, interactive stage for creating and disseminating new augmented art forms, ranging from multi-user experiences to live performances. Bringing together artists, scientists and audiences, the system offers a new approach to developing unconstrained, multi-sensory, collective experiences. From January to April 2024, *The L∞p* was exhibited at the cultural and shopping centre *Les Ateliers des Capucins* in Brest, France. There, visitors could experience two 20-minute, interactive, multi-user experiences (*Spacetime Prospectives* LP1 and LP2) that explored the physical concepts of time, space, and symmetry. Despite the difficult and varied physics concepts underlying *The L∞p*, visitors' spatial presence was felt in both scenarios (SP >3.5). Implementing a more direct interaction mode in

LP2, which provides users with clear and immediate feedback on their actions, could further enhance the experience, as revealed by the reported higher affordance in LP2 than in LP1.

The L∞p could be used in future research to further explore the influence of adaptive systems on the subjective user experiences of immersion. Adaptive systems have the potential to tailor immersive experiences to the needs of individuals and groups, thereby further promoting everyone's spatial presence. Personalisation can occur at two levels:

(1) Behavioural adaptation: Systems can detect whether a user is passive or active and adjust the complexity of interactions accordingly. For example, novices may benefit from simplified tasks, while experienced users could access advanced features.
(2) Physiological feedback: Biometrics such as heart rate, skin conductance, or breathing patterns can inform real-time adjustments. For example, environments could adapt lighting, sound, or interaction speed to reduce stress or enhance comfort.

Integrating these techniques into immersive installations is expected to create adaptive experiences that respond dynamically to users' emotional states, thereby enhancing engagement and satisfaction. Human-machine interaction is an obvious key to immersion, as is already understood in the gaming industry.

Acknowledgments

The authors thank Alain Lelièvre and Romain Roget, Les Ateliers des Capucins, for the exhibition in Brest, as well as Gabriel Poirier-Quinot and Thomas Faguet for setup and strike. This work is partly funded by the European Union's Horizon Europe research and innovation programme within the project Artcast4D (www.artcast4d.eu) under the grant agreement N°101061163. It is also supported by the Graduate School of Engineering and System Sciences at Université Paris-Saclay through the art-science Chair programme.

References

[1] Anseau Delasalle, Stéphanie Sphyras, Benoit Nguyen Tat, Ikse Maître, Matthieu Courgeon, Gaele Misiak, Daniel Yvinec, and Cédric Genachte-Le Bail. 2023. *Memory Box.* Presented in L'Expérience Monroe, 27 may-25 June 2023, at Forum des images, Paris, France. https://newimages-hub.com/lexperience-monroe/. [Accessed 30-06-2025].

[2] Société des arts technologiques. 2025. Expériences à vivre à la SAT — Montréal. https://sat.qc.ca/. [Accessed 30-06-2025].

[3] Atelier des Lumières. 2025. Atelier des Lumières | Digital immersive art center in Paris. https://www.atelier-lumieres.com/en. [Accessed 30-06-2025].

[4] Vincent Dupont. 2013. No reality now. https://vincentdupont.org/portfolios/no-reality-now/. [Accessed 30-06-2025].

[5] Simone Grassini, Karin Laumann, and Ann Kristin Luzi. 2021. 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). doi:10.3390/mti5030007

[6] Monaco Info. 2025. Immersion — l'exposition événement. https://monacoinfo.com/video/immersion-lexposition-evenement/. [Accessed 30-06-2025].

[7] Pierre Jodlowski. 2010. GrainStick - 2.0. https://brahms.ircam.fr/fr/work/grainstick-2.0. [Accessed 30-06-2025].

[8] Nawel Khenak, Jean-Marc Vézien, and Patrick Bourdot. 2019. The Construction and Validation of the SP-IE Questionnaire: An Instrument for Measuring Spatial Presence in Immersive Environments. In *Virtual Reality and Augmented Reality*, Patrick Bourdot, Victoria Interrante, Luciana Nedel, Nadia Magnenat-Thalmann, and Gabriel Zachmann (Eds.). Vol. 11883. Springer International Publishing, Cham, 201–225. doi:10.1007/978-3-030-31908-3_13 Series Title: Lecture Notes in Computer Science.

[9] Blanca Li. 2025. Le bal de Paris. https://www.blancali.com/spectacle/le-bal-de-paris-de-blanca-li/. [Accessed 01-05-2025].

[10] Ikse Maître, Matthieu Courgeon, Michel Bertier, Jean-Marc Bonnet-Bidaut, Hervé Dole, André Füfza, and Roland Lehoucq. 2015. *Vois moi à travers toi.* Presented in L'Odyssée de la lumière, 17 March-1 November 2015, at Cité des Sciences et de l'Industrie, Paris, France. www.e-sas.org/see-me-through-you. [Accessed 30-06-2025].

[11] Ikse Maître, Vincent Hulot, and Matthieu Courgeon. 2018. *Ariadne's Fibres.* Permanent art work since 2018 at Forum des images, Paris, France. www.e-sas.org/ariadne-s-fibres. [Accessed 30-06-2025].

[12] Ikse Maître, Tim Schneider, Matthieu Courgeon, Vincent Hulot, Frédéric Auchère, Frédéric Baudin, Éric Buchlin, and David Poirier-Quinot. 2024. *Ariadne's Fibres.* Presented in *Nuit Blanche 2024* at museum of Arts and Crafs, Paris, France. https://www.arts-et-metiers.net/musee/nuit-blanche-2024. [Accessed 30-06-2025].

[13] Alison Jane Martingano, Ja-Nae Duane, Ellenor Brown, and Susan Persky. 2023. Demographic differences in presence across seven studies. *Virtual Real.* 27, 3 (May 2023), 2297–2313. doi:10.1007/s10055-023-00805-z

[14] Tim Schneider, Céline Clavel, Gérard Kubryk, Michèle Gouiffès, Emmanuelle Frenoux, Matthieu Courgeon, Gaële Misiak, Vincent Hulot, and Xavier Maître. 2026. Triggering Immersion in Public Spaces: A Comparative Study of Interactive Digital Art Installations. In *Virtual Reality and Mixed Reality*, Despina Michael-Grigoriou, Gabriel Zachmann, Regis Kopper, Sang Ho Yoon, Stefanie Zollmann, and Patrick Bourdot (Eds.). Springer Nature Switzerland, Cham, 267–291.