Mixed-Reality Art as Shared Experience for Cross-device Users: Materialize, Understand, and Explore

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ABSTRACT
Virtual reality (VR) has opened new possibilities for creative expression, while the 360-degree head-worn display (HWD) delivers a fully immersive experience in the world of art. The immersiveness, however, comes with the cost of blocking out the physical world, including bystanders without an HWD. Therefore, VR experiences in public (e.g., galleries, museums) often lack social interactivity, which plays an important role in forming aesthetic experiences. In the current study, we explored the application of a cross-device mixed reality (MR) platform in the domain of art to enable social and inclusive experiences with artworks that utilize VR technology. Our concept of interest features co-located audiences of HWD and mobile device users who interact across physical and virtual worlds. We conducted focus groups (N=22) and expert interviews (N=7) to identify the concept's potential scenarios and fundamental components, as well as expected benefits and concerns. We also share our process of creating *In-Between Spaces*, an interactive artwork in MR that encourages social interactivity among cross-device audiences. Our exploration presents a prospective direction for future VR/MR aesthetic content, especially at public events and exhibitions targeting crowd audiences.

KEYWORDS
Virtual reality; Mixed reality; Cross-device; Group audience; Grounded theory; Taxonomy

1. Introduction

Today, many artists and engineers collaborate on their combined efforts to explore the potential of technology in enhancing the expression and experience of creativity (Jeon, Fiebrink, Edmonds, & Herath, 2019). Virtual reality (VR) stands out as one such technology that enables creativity to transcend real-world constraints, offering immersive experiences that evoke the sensation of existing within the artwork itself (Doyle, 2015). Public places like art galleries, museums, and exhibitions are increasingly embracing VR technology to provide visitors with captivating and aesthetic experiences (Pantile, Frasca, Mazzeo, Ventrella, & Verreschi, 2016; Shehade & Stylianou-Lambert, 2020). However, the immersive nature of VR, facilitated by head-worn displays (HWDs), often disconnects users from the physical world around them, inevitably excluding bystanders who are not wearing HWDs. While this setup can enhance the private experience for individual visitors, it disrupts the "public-private duality" within shared social spaces, where visitors balance between "conviviality" of exchanging ideas and "introspection" of building personal engagement with artwork (Debenedetti, 2003). In addition to an individual's cognitive and emotional engagement with the artwork, interactions with others, such as companions or visitors who happen to be in proxim-

ity, also play an important role in forming aesthetic experiences (Heath, Luff, Lehn, Hindmarsh, & Cleverly, 2002). Visitors, intentionally or unintentionally, share emotional responses, gestures, and conversations that shape their perceptions and engagement with the artwork (Goffman, 1981). Moreover, visitors anticipate experiencing art collectively and interacting with others, an established practice of sociality that is hindered by the inability to see or understand what others are experiencing, particularly in the company of companion (Parker & Saker, 2020).

To restore the social context while incorporating VR into art, several researchers and artists developed platforms where multiple HWD users can view VR artwork together in a shared space (Layng, Perlin, Herscher, Brenner, & Meduri, 2019; Sinigaglia, 2018). The platforms visualized HWD users as avatars in the virtual world in varying levels of detail, from location to body movements, so that they know each other's direction of attention. The HWD, however, is not always a feasible or preferred medium for everyone. Certain user groups have physical characteristics that are not supported by standardized HWDs (e.g., children) or are prone to VR-related physical discomforts like nausea and loss of balance. These populations are often excluded from experiencing what is offered in VR. Moreover, visitors may feel uncomfortable wearing a publicly shared device over their face due to various reasons such as wearing glasses, having applied makeup, or sanitary concerns. In an effort to invite these bystanders into the experience, some VR booths mirror HWDs on large screens, offering a glimpse into what is happening inside the virtual world. Although this method somewhat exposes the VR experience to the bystanders, what is displayed on a mirrored screen depends solely on the actions and perspectives of the HWD user. Bystanders do not have the agency to control the viewing perspective and, therefore, cannot actively experience the artwork.

One approach to include non-HWD users as active participants is providing additional device options, such as hand-held devices to view and interact with the virtual environment (Drey et al., 2022; Olin, Issa, Feuchtner, & Grønbæk, 2020; Peter, Horst, & Dörner, 2018; Thomsen, Nilsson, Nordahl, & Lohmann, 2019). For example, the non-HWD users with a motion-tracked mobile device can experience the same virtual environment as the HWD user through their standalone windows to the virtual world (Grandi, Debarba, & Maciel, 2019; Gugenheimer, Stemasov, Frommel, & Rukzio, 2017). This way, the VR content can be delivered as a mixed reality (MR) experience for users as they are connected to both virtual and physical worlds. Motivated by the use of asymmetric viewing portals to a shared virtual space, we aim to explore the application of a cross-device MR platform in the art domain. This will be especially beneficial in public events, where a diverse array of visitors is encouraged or expected to engage with one another and their surroundings. The artwork, accessible through both HWDs and mobile devices, has the potential to engage a wider spectrum of audiences.

This inclusive approach allows for real-time shared experiences and opens up new creative possibilities for utilizing asymmetric device settings. While we recognize the potential benefits of utilizing a cross-device MR platform for both creators and audiences, its application in creative works remains relatively unexplored. With little to no existing artwork that invites non-HWD users as equally independent and active audiences to experience the virtual world, the current study investigated potential scenarios and characteristics of MR art that utilize the platform with asymmetric device options. The following sections are structured to respond to the research questions below:

- How does the cross-device MR provide new expressive dimension for artists? (RQ1)
- What fundamental components comprise the concept of cross-device MR art for co-located audiences? (RQ2)
- What are the potential benefits and concerns of cross-device MR art for co-located audiences? (RQ3)
- What potential scenarios of cross-device MR art can be suggested? (RQ4)

To achieve these goals, we performed a study in three stages: materialize, understand, and explore. The materializing stage provides an example of how an artist utilizes the concept (RQ1) and presents the hands-on experience of creating a work of art titled *In-Between Spaces*. The understanding stage comprised interviewing potential stakeholders, both creators and audiences, regarding the applications of the concept in the art domain. We analyzed collected data and generated a taxonomy that presents the concept's fundamental components (RQ2) and expected benefits and concerns (RQ3). In the final stage, we explored potential scenarios based on what we learned from the previous stages to answer the fourth research question (RQ4). The overall process of the present study is shown in Figure 1.

We envision a cross-device MR platform to facilitate socially engaging and more accessible VR/MR experiences, offering a meaningful direction for future aesthetic experiences in this realm, particularly for public art events and installations. Our exploration of the studied topic can inspire practitioners in the fields of digital and interactive art, encouraging them to integrate social and inclusive aspects into their VR-based artworks. We anticipate that our discoveries will be beneficial to software developers interested in devising tools to support creativity within three-dimensional immersive environments. Moving forward, researchers can delve deeper into investigating how different characteristics of artwork influence audience perception and the overall experience, enriching our understanding of the intricate dynamics at play within immersive artistic contexts. Notably, our study intersects with the domains of art and Human-Computer Interaction (HCI) encompassing the interconnected components identified by Jeon et al. (2019): interaction, creativity, embodiment, affect, and presence. This underscores the relevance of our findings to the broader HCI community, offering valuable insights that can inform future research and development efforts.

2. Related Work

2.1. Cross-Device MR

The growing popularity of VR and its application to diverse fields led to efforts to make VR technology more accessible to a broader user population. To lower the barrier, researchers have developed platforms that utilize non-HWD devices as additional viewports to interact with virtual environments. Previous works on the use of heterogeneous device options used phrases such as "asymmetric VR" (Drey et al., 2022; Grandi et al., 2019; Peter et al., 2018; Thomsen et al., 2019), "cross-device VR" (Olin et al., 2020), and "cross-dimensional MR" (Thoravi Kumaravel & Hartmann, 2022). Non-HWD device options ranged from a static table top (Ibayashi et al., 2015) to a mobile device with an independent perspective inside the virtual world (Freiwald, Gollek, & Steinicke, 2021; Grandi et al., 2019; Gugenheimer et al., 2017; Olin et al., 2020).

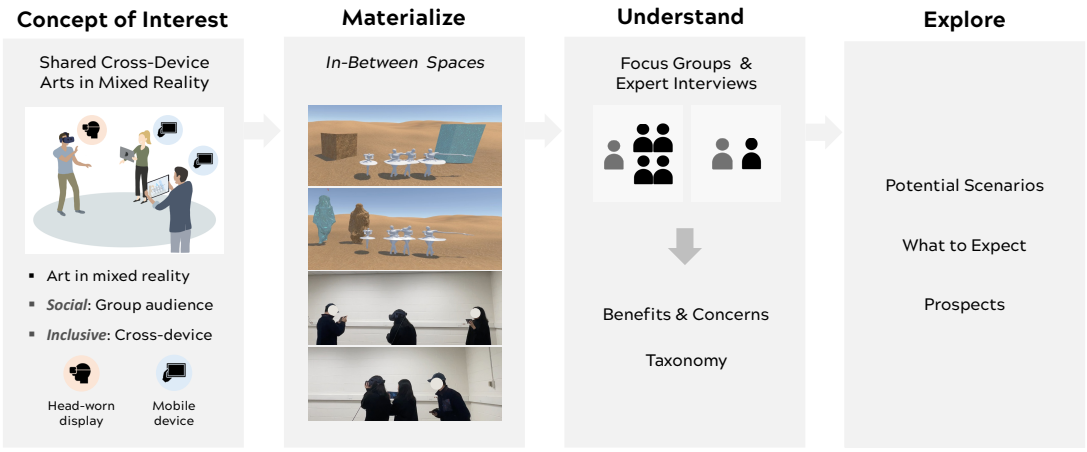

Figure 1. The overall research process: defining the concept of interest; materializing the concept by creating *In-Between Spaces*; understanding the concept by interviewing potential stakeholders; and exploring the concept based on potential scenarios and their benefits/concerns.

The integration of non-HWD users into shared virtual space with the HWD user has predominantly been explored within collaborative work (Grandi et al., 2019; Ibayashi et al., 2015; Olin et al., 2020; Thoravi Kumaravel & Hartmann, 2022) and educational domains (Drey et al., 2022; Thomsen et al., 2019). While previous studies have examined the effects of cross-device interaction on performance and communication efficiency in task-oriented settings, there is a notable gap in understanding how this integration impacts the experience of art, particularly in contexts devoid of specific tasks or objectives. Choosing VR as the medium for artwork typically emphasizes its immersive qualities and sense of presence, aspects that may be compromised when experienced through a two-dimensional handheld screen. The current study seeks to explore the implications and considerations of introducing alternative device options in the context of art experiences.

In the current paper, we adopt the term "MR" (Mixed Reality) to describe an environment where the physical and virtual worlds are integrated and mapped to each other, incorporating physical world attributes such as locations and behaviors of multiple users into the virtual environment in real-time. More specifically, among the classifications proposed by Speicher et al. (2019), MR as denoted in the current study falls into the notion of "alignment". This definition is consistent with several other scholarly works (Barba & Marroquin, 2017; Regenbrecht, Meng, Reepen, Beck, & Langlotz, 2017; Yannier, Koedinger, & Hudson, 2015); however, it diverges from the commonly accepted understanding along the Reality-Virtuality Continuum (Milgram & Kishino, 1994; Skarbez, Smith, & Whitton, 2021), where MR is often depicted as a broader concept encompassing a spectrum of realities between the real and virtual environments.

2.2. Art in VR

In contemporary artistic discourse, the transformative potential of VR technology in reshaping artistic practices and audience experiences is increasingly recognized. VR serves as a platform for representing reality, aligning with one of the fundamental objectives of art (Jeon et al., 2019). This capability is exemplified in cultural heritage

preservation efforts, where historical locations and architectural marvels are recreated in virtual environments, enhancing accessibility for a wider audience. For instance, Benjamin Britton's *LASCAUX*, an interactive reconstruction of the ancient painted cave, allowed viewers to explore the cave with a 360-degree headset and joysticks, aiming "to reflect humanity and inspire peace, respect, and consideration" (Britton, 1995). Additionally, existing artworks can be curated, rearranged, and displayed in virtual worlds, enriching the experience with additional visual, auditory, narrative, and interactive elements (Carrozzino, Colombo, Tecchia, Evangelista, & Bergamasco, 2018; HTC, 2017; Kang & Yang, 2020; Schofield et al., 2018). Several VR art platforms, such as V21 Artspace (https://v21artspace.com/) and VOMA (https://voma.space/), have emerged to broaden access to culture and heritage by digitizing museum tours and curating virtual galleries. These platforms mainly focus on the artifacts created in physical space and integrate them into virtual space as a "digital solution for accessibility, archiving, audience development and engagement." The Museum of Other Realities (https://www.museumor.com/) is another VR platform that curates artworks, focusing on virtual space creation.

VR technology has ushered in a new era of artistic expression, transforming traditional mediums and pushing the boundaries of creativity. Across various artistic disciplines, from visual arts to narrative storytelling and performance art, VR has revolutionized the way artists engage with their craft. For instance, VR tools enable artists to sketch and create in 3D space using intuitive gestures and body movements (Arora, Habib Kazi, Grossman, Fitzmaurice, & Singh, 2018; Deering, 1995; Google, 2017; Keefe, Feliz, Moscovich, Laidlaw, & LaViola Jr, 2001). The immersive nature of VR allows artists to break free from the constraints of 2D surfaces, offering new avenues for exploration and experimentation. Moreover, VR has emerged as a powerful tool for narrative storytelling, as highlighted by John Bucher's exploration in "Storytelling for Virtual Reality" where filmmaker Chris Milk's asserts that VR is "the ultimate empathy machine" (Bucher, 2017). This sentiment underscores VR's potential to deeply engage audience and elicit emotional responses by stepping into the shoes of characters and experience stories in a deeply immersive way. Additionally, VR technology enables audience interaction and participation, with sensors and devices capturing input from viewers as they navigate virtual environments (Domingues et al., 2014; HTC, 2016). This interactive element adds a dynamic layer to artistic experiences, blurring the lines between creator and audience and inviting collaboration and engagement on new levels. As VR continues to evolve and innovate, its potential to reshape artistic expression and storytelling becomes increasingly apparent. However, it is important to recognize the limitations inherent in the commonly utilized HWD, which facilitates immersion in the virtual world but may not be suitable for all users, and often comes at the cost of disconnecting users from other audience members. In the current paper, we explore the integration of mobile devices as an additional VR viewport to address these challenges, potentially inviting a broader population and enhancing social engagement within VR art experiences.

2.3. VR Art for Group Audiences

Understanding the importance of social aspects in experiencing art (Heath et al., 2002), researchers and artists have put effort into creating VR-based artworks for co-located group audiences. Advances in technology and experts enabled artists to successfully incorporate features of interpersonal interaction and synchronous experience in the

shared virtual space. In an immersive storytelling project called CAVE (Layng et al., 2019), multiple HWD users sitting in physical proximity watched and listened to a narrative together in a virtual world. Six-degree-of-freedom HWDs tracked users' head movements so that the audience could be aware of others' nonverbal reactions (e.g., attention and gaze) while wearing the HWDs. In the case of Natan Sinigaglia's *We Live in an Ocean of Air*, the exhibition allowed up to six HWD users in a room to explore the artwork together in VR as a group (Sinigaglia, 2018). The artist utilized the visuals in the virtual world along with projection, sound, and olfactory feedback to fully immerse the audience in the experience from the moment they enter the room. During the experience, each audience member wore additional devices that track their body movements and breath, which are visualized and shared in the virtual world. The multimodal and synchronous interaction with the virtual world and other audience members amplified the artistic experience.

Some researchers and artists created asymmetric VR art experiences with a mixture of HWD and non-HWD users. The Invisible Walls project (Lankes, Hagler, Kostov, & Diephuis, 2017) utilized body tracking technology to visualize the spectator—audience without HWDs—as artistic avatars in the virtual environment and on the wall, using projection. Audience members wearing HWDs could communicate with the spectators, adding a social component to the experience. Although the experience was enriching for HWD users, who were able to interact with the spectators and manipulate their virtual representations, the spectators remained in what might be described as supporting roles. In another project, Body RemiXer (Desnoyers-Stewart, Stepanova, Riecke, & Pennefather, 2020), both HWD and non-HWD users had their bodies and movements tracked and projected on the surrounding two walls as clouds of particles. When two visitors made physical contact with one another, the corresponding clouds merged into one. The visual cues encouraged both groups of audience members, with or without HWDs, to interact with one another and take active roles in creating a collective and shared experience. By providing the audience with an option to participate as either an HWD user or a non-HWD user, both projects created social, inclusive, and artistic immersive experiences. However, audience members who did not wear HWDs had no access to the 3D virtual environment. In the current study, we focus on MR art where non-HWD users are equally engaged audiences as HWD users in the virtual piece of the artwork.

3. Method

This section describes the procedure of the study's first two stages: materializing and understanding the concept. In the first stage, we created an artwork, *In-Between Spaces*, to demonstrate an example of an artist utilizing the concept of cross-device MR (RQ1). In the second stage, we interviewed potential stakeholders to identify the concept's fundamental components (RQ2) and potential benefits and concerns (RQ3). The interview involved experiencing *In-Between Spaces* and discussing a set of interview questions. For data analysis, we followed the grounded theory approach to extract, categorize, and structure the ideas that arose during the interview. We created an initial draft taxonomy after focus group interviews, then repetitively revised it based on comments collected in expert interviews to create the final taxonomy.

3.1. Materialize: In-Between Spaces

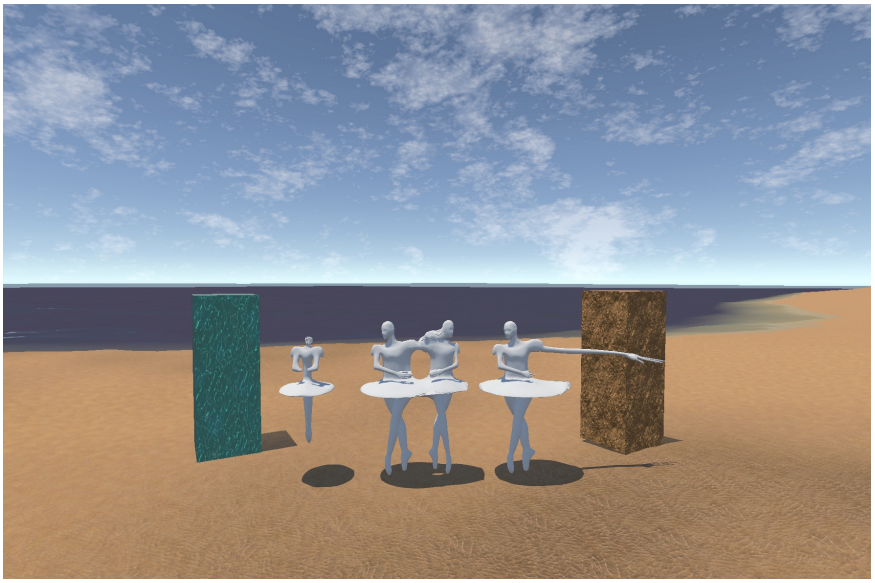

Figure 2. Virtual environment of *In-Between Spaces* with a central sculpture of ballerinas and two virtual avatars in rectangular prisms.

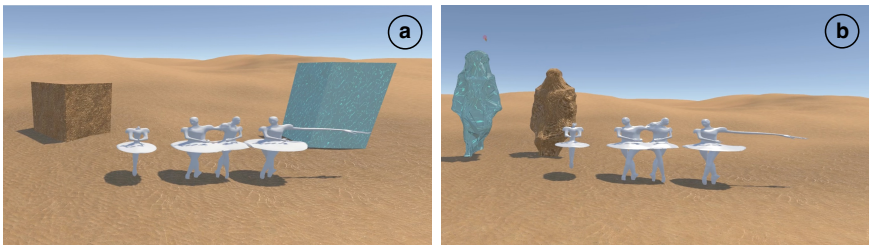

Figure 3. (a) Virtual avatars in the form of rectangular prism representing static status of the users. (b) Virtual avatars in the form of walking humanoid representing dynamic movement of the users.

3.1.1. The Artwork

After defining our concept of interest, we asked a professional media artist with extensive experience in VR-based artwork (the fourth author of the current paper) to create an artwork utilizing the concept. We demonstrated to him a platform which we developed prior to the current study that enables a shared, cross-device MR experience for one HWD user and multiple mobile device (e.g., tablet or mobile phone) users. Without making any request regarding the content or theme of the artwork, we informed the artist about the following components of the platform:

- A tracker with 6-degrees-of-freedom (6DOF) is attached to a mobile device and serves as a "window" into the virtual environment.
- The platform supports one HWD user and up to 9 Android mobile device users.
- The position and orientation of each user's device in the physical space are mapped into the virtual environment, which is synchronized with other users.

The artist created *In-Between Spaces*, an artwork comprising a virtual environment that can be explored as a group of three audience members with a mixture of one HWD user and two tablet users. Using either an HWD or a motion-tracked tablet display, the audience explores the virtual environment of desert and ocean with a central sculpture of ballerinas (Figure 2). Location and perspective of all devices in the virtual space are mapped to appear the same as in the physical world. Each audience member is visible to the others in the virtual environment as one of three virtual avatars: one dressed in rocky and sandy clothing, one with an animated water texture, and another with an animated cloud texture. When an audience member stands still with no movement registered from their device, the corresponding avatar appears as a rectangular prism (Figure 3(a)); as the audience member moves, the avatar blends into a humanoid character in a walking animation (Figure 3(b)). The size of the sculpture changes based on the aggregated distance of all audience members from the sculpture: shorter distances make the sculpture bigger, while longer distances make the sculpture smaller. Each distance is measured between the tracker attached to the user's tablet or HWD and the tracker used to locate the sculpture, automatically through Unity. The size alteration is most noticeable when all audience members are either approaching or moving away from the sculpture, whereas when some are moving towards and others away from the sculpture, the change is less perceptible.

3.1.2. Technical Development

For motion tracking of the tablets, we used VIVE Trackers 3.0 and two VIVE Base Stations 2.0 alongside a VR-available desktop PC. We attached the trackers to the back of Galaxy Tab A7 tablets and tracked their movement. To enable both HWD and tablet users to interact within the same virtual environment synchronously, we used the Unity Real-Time Development Platform and Photon Unity Networking (PUN) to connect movements and avatars between users. In the Unity Scene, the desktop PC collected position and rotation data from the trackers to allow PUN to then update the tablets, which acted as individual clients. Each device joined the server as a client with a corresponding tracker identification number. The PC would then send that device the associated tracker's data to update the live camera feed on the mobile device. This allows the system to synchronize co-located users inside the virtual environment simultaneously with 6DOF.

3.2. Understand: Data Collection

3.2.1. Focus group interviews

Voluntary participants with previous experience in virtual reality were recruited following a recruitment and consent form procedure approved by the university's Institutional Review Board (IRB). A total of 22 participants (P1–P22; 11 males and 11 females) with an average age of 24.18 (SD = 4.83) took part in the study. Among them, nine had backgrounds in engineering, five in science, five in humanities, and three in art. Participants predominantly had previous VR experience in gaming, with only a few reporting research-related exposure. Three participants mentioned prior experience with immersive art. When asked about their level of enjoyment as a creator ("How much do you enjoy creating artworks?") and as an audience ("How much do you enjoy visiting art galleries?") of art on a scale from 1 (strongly dislike) to 5 (strongly like), responses averaged 3.50 (SD = 1.01) and 3.64 (SD = 1.14), respec-

tively. Participants had diverse level of preferences and experiences in art, and all had previous experience with VR. Groups of 3–4 randomly selected participants attended each focus group session, and a total of seven group sessions were conducted for the current study. During each session, a brief description of the background and purpose of the study was given, followed by an ice-breaking activity to create a comfortable environment for active discussion. Participants then experienced the artwork, *In-Between Spaces*, as a group to familiarize themselves with the concept to be discussed. Participants were initially asked for their preference of device (HWD or tablet) to view the virtual environment. Equipped with their chosen devices, participants were escorted to a designated area and allowed to explore the artwork as long as they wanted, but no longer than 10 minutes. Participants were allowed to switch devices during the experience. After the demo, participants were asked to ideate and discuss potential scenarios of cross-device MR art that would be meaningful and preferred to experience. Participants were encouraged not to limit their ideas to what they had experienced with *In-Between Spaces* and to expand upon others' comments. Participants were also asked about their expectations of the benefits and concerns about the studied concept. The questions provided to guide the discussion were as follows:

(1) What type of art content would be meaningful to experience?
(2) What kind of interaction would you like to have?
(3) How would you want to appear in virtual world?
(4) What would be the benefits of this system for art consumers?
(5) What would be the benefits of this system for artists?
(6) Do you have any concerns about using this system?

The sessions lasted approximately 1.5 hours, and participants were compensated with $15. All sessions were video-recorded.

3.2.2. Expert interviews

A total of seven experts (E1–E7) with a minimum average of 10 years of research, teaching, or artistic practice experience related to virtual reality were recruited following recruitment and consent form procedures approved by the university's Institutional Review Board (IRB). Four were faculty members with backgrounds in immersive technologies, while the other three were professional artists with experiences in immersive media for creative works, as well as in research or teaching. Experts were interviewed individually in a one-on-one format. The interviews followed a procedure similar to that of the focus groups: a brief introduction, a short experience with the artwork, and a semi-structured interview. Experts had a similar list of questions to those for focus groups, with an additional question to review the current structure and labels of taxonomy, and were asked to comment if any components were missing or misleading. The questions for the expert interviews were as follows:

(1) What type of art content would be meaningful to create or experience?
(2) How would the medium affect creating or experiencing artwork?
(3) What type of interaction would be meaningful to create or experience?
(4) What type of user appearance in virtual world would be meaningful?
(5) What would be the benefits of this system given its social setting?
(6) What would be the benefits of this system with its increased accessibility?
(7) Do you have any concerns about using this system?
(8) Do you agree with the following structure and components? Is there any additional component you believe is important enough to be added?

As the expert interviews were conducted individually, the moderator participated in the VR experience to simulate interpersonal interaction. Two experts were unable to participate in person and were interviewed using Zoom. During the Zoom interviews, recorded videos of the artwork's virtual environment and a group audience enjoying the environment were shared as a substitute for a participatory demo experience. The entire session lasted no longer than one hour, and participation was voluntary, without monetary compensation. All sessions were voice-recorded.

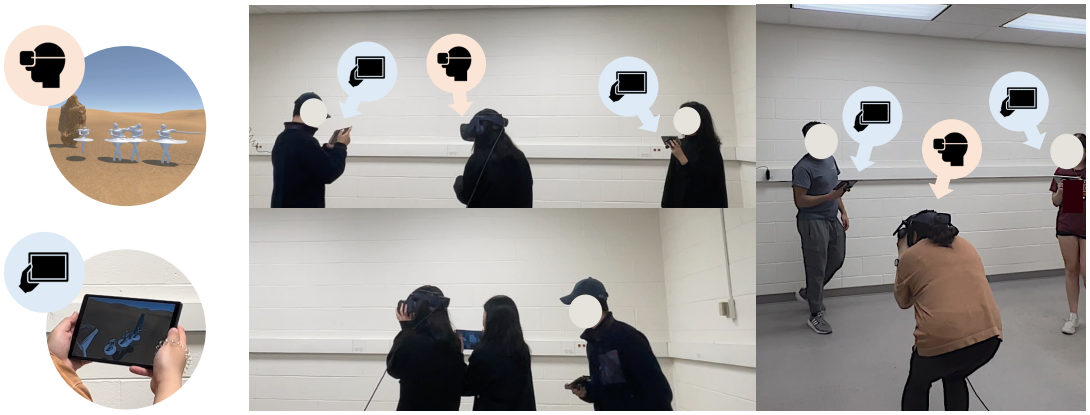

Figure 4. An overview of audiences experiencing *In-Between Spaces*: Two circular images on the left show sample screen views from an HWD and a tablet, respectively. Two images on the right show three audience members experiencing *In-Between Spaces*.

3.2.3. Data analysis

For data analysis, two members of our research team transcribed and reviewed recorded videos. We followed the grounded theory approach, a qualitative research methodology that aims to develop insights grounded in empirical data (Glaser & Strauss, 2017; Muller, 2014). This method involves a systematic process of data collection, coding, and analysis to elicit concepts that emerge from the data itself rather than being imposed by preconceived theoretical frameworks. Given the limited existing resources on the studied topic, we opted for this method to develop an understanding of the constituent elements comprising cross-device MR art for group audiences. Grounded theory emphasizes the significance of staying close to the data, enabling concepts to emerge organically from the empirical evidence. Two researchers collaborated in conducting the coding procedures using Delve (delvetool.com). The researchers began by meticulously examining each piece of information, breaking it down into discrete parts, and extracting 38 open codes or "attributes". Subsequently, the researchers proceeded to axial coding, wherein they organized and synthesized these codes to identify relationships between them. This stage aimed to explore how different codes relate to each other and to identify higher-order themes or categories that encapsulate the underlying structure of the data. Engaging in an iterative cycle of data collection, coding, and analysis, the researchers continuously refined and revised the structure until no significant new insights or categories emerged from the data. Ultimately, the final taxonomy comprised 3 dimensions, with 10 sub-categories ("components"), encompassing a total of 34 attributes. To ensure the robustness of the taxonomy, three other members of our research team reviewed and finalized its structure.

4. Results

4.1. Materialize: The Artist's Epilogue

In this section, we present the auto-ethnographic reflection undertaken by the artist on the creation of *In-Between Spaces*:

When planning the process for creating an artwork in this medium, using this particular set of interfaces and allowances, the artist was faced with the decision of whether to make something that could exist independently of this medium or something in which the interfaces were integral to the artwork. In other words, should he make a virtual artwork that could be just as easily appreciated by one person with an HWD as three people with mobile devices, or two people on desktop computers? Or should he make an artwork that integrates the uniqueness of one HWD user and two mobile device users, co-occupying a shared virtual space? Furthermore, how could he best leverage the mixed reality nature of the medium, with the tablet users also able to see the physical space around them? This was partly an artistic question, but it was also practical. Would making a work that does not leverage the unique medium be better for this interdisciplinary research, and the kind of qualitative study being performed with the audience, or would it actually skew the results? If the goal is partly to create a platform for other artists to use in the future, what kind of work would best illustrate the potential of this medium?

Before detailing the artist's approach to these questions, the following paragraph describes the material origins of the primary focus of the artwork. The central sculpture of ballerinas was an idea that he had been itching for an opportunity to work on, and it gave him a point of departure. It spawned from a collaboration with his friend, Mariam Eqbal, and her animation, *In-Between Frames*. Mariam processed a photograph of a ballerina in a flat-bed scanner by dragging the image across the scanner while it was scanning, producing a new hyperreal image of an impossibly extended and distorted body. Mariam did this repeatedly to create many images which she formed into an animation. Our artist took several frames of the animation and created 3D models to match the form but in an imagined third dimension. He then created blend shapes between these 3D models so they could seamlessly morph into each other. Finally, he recruited an undergraduate student, James Kiscaden, to work with him as a collaborator and create a physical version of one of the 3D models. The ballerina has now been translated from a physical being to photograph to a scanned image to an animation to a 3D model to a blendshape and finally back into a physical, three dimensional incarnation.

In the end, the artist opted to make something in which the particular nature of the medium is necessary for the artwork itself. This was accomplished both through the design of user interactivity that modifies the virtual artwork as well as a unique approach to user avatars. To fully leverage our new medium, he wanted the virtual sculpture to animate based on the interactions of the viewers. This way, the virtual sculpture could hyper-realistically extend the possibilities of the physical sculpture in the same way that Mariam's scans extended the photograph of the dancer. In the current iteration, the interactions of three viewers (two tablets and one HWD) with both the sculpture and with each other are used to modify the virtual sculpture in size and blendshape in an aggregated manner.

Beyond the sculpture, he needed to create a virtual setting for the sculpture. Initially, he used a 3D model of the room in which we were working and experimenting. Over the course of the artwork, the 3D model of the physical space blended into a

videosphere of Mariam's original animation. Unfortunately, this incorporation of a 3D model quickly became untenable as we moved repeatedly between different lab spaces. For the current study, the artist created another virtual setting of *In-Between Spaces* as a scene of desert and ocean; the liminal environment of the beach, where land meets water.

Lastly, there was a need for the users' presence to be represented in the virtual space, especially for the HWD user. Since the HWD user cannot see the physical presence of the tablet users, their presence needed to be visualized in the virtual space for the safety of the HWD user. Beyond this necessity, designing avatars became another opportunity for leveraging the nature of this medium, in which the positions of all users are tracked. The artist wanted to create an avatar system that would fit within the aesthetic bounds of the rest of the work. Thus, the avatars are not standard humanoids and are not customizable. The avatars of *In-Between Spaces* start as rectangular prisms, roughly the height of a person. As the device moves, implying movement from the user, the rectangular prism blends into a humanoid character in a walking animation, rotated in the same direction that the tablet is facing. The humanoid character is never totally distinct, as the blend is never fully completed. It remains halfway between block and character, distinctly capturing the feeling of being a person without being any particular person with particular recognizable features. As the device stops moving, the avatar blends back into a rectangular prism. He has long been interested in finding ways to represent people in virtual spaces that show them as people while also maintaining a level of genericness. This is often extremely difficult, as there is no such thing as a generic or default human. He feels this iteration successfully captures some level of genericness, while still making a number of presumptions about the human being represented (four limbs, upright, roughly 5 to 6 feet tall, etc.).

The last question he asks himself, in reflecting on this work and this medium, is whether every artwork made using this medium, by any artist, should incorporate the medium itself so directly into the artwork. He is in the process of making a second artwork that maintains the avatars while discarding the interactivity of the sculptural centerpiece. As he views the work and watch others view it, he will be curious to observe whether the interactivity latent in this medium is presumed, understood, or beneficial. Also, although not included in this iteration, there are two modes of interaction in the artwork. In the first mode, the aggregate behaviors of all the users together are mapped onto parameters. In the second mode, behaviors from each individual are mapped onto parameters. Experimenting with these modes will help us determine if the users are able to perceive the effects of their aggregate behaviors without being informed of the mappings. In future work with this new medium, he would like to explore options for rapidly scanning and creating a 3D model of the physical environment that can be blended with an imagined virtual environment.

4.2. Understand: Taxonomy

To investigate fundamental components of cross-device MR art (RQ2), we asked potential stakeholders about their expected scenarios and features of artwork. After conducting focus group interviews, we created a draft taxonomy comprising five dimensions: art content, interaction with artwork, user role, user representation, and interaction among users (see Figure A1 in Appendix A). We shared and discussed this draft with seven VR experts, then updated the taxonomy into a structure of three dimensions: artwork, audience, and communication. The most critical change between the two

Table 1. Final taxonomy on cross-device MR art for group audiences.

Dimension	Components	Attributes
Artwork	Engagement	Passive
		Active yet confined
		Active and creative
	Interaction mode	As a group
		As an individual
	Time of creation	Live
		Completed
	Artwork content	Visual elements in virtual environment
		Visual elements in physical environment
		Additional sensory elements
		Story
		Information on artwork
Audience	Virtual avatar goal	Embodiment
		Self-expression
		Awareness of other audience
		Differentiation among audience
		Integration with artwork
	Virtual avatar content	Location
		Posture
		Gaze direction
		Emotion / Facial expression
		Background information
		No virtual avatar
	Device composition	Head-worn display (HWD)
		Mobile device
Communication	Communication topic	Point of interest
		Impression or emotion
		Related information
	Communication modality	Verbal in physical environment
		Nonverbal in physical environment
		Verbal in virtual environment
		Nonverbal in virtual environment
	Communication scale	To the group
		To an individual

drafts was eliminating components that categorized creative and aesthetic elements of art. It was E02 who had the biggest influence on the decision: "the more you try to define an artwork to be fine-tuned for a specific type of thing, the more you peel off layers of making the artwork itself." Although we asked diverse participants to discuss the potential works of art, we found it nearly impossible, and eventually inadequate, to be comprehensive and definite in labeling creativity. Therefore, we removed components that categorized visual features and interaction source of artwork as well as the representation style of users as avatars. Instead, we added components about interaction mode (as a group vs. as an individual) and time of creation (live vs. completed) of an artwork. Table 1 shows the overall structure of the final taxonomy presented in the current study. The attributes serve as distinct characteristics of a scenario or a building block, collectively constituting the components within a broader category. These components, in turn, are organized under the umbrella of dimensions, representing the overarching categories that encompass them. The following sections describe dimensions, components, and attributes highlighted in **bold**.

4.2.1. Artwork

Previously, without a narrow focus on a specific domain or purpose, Jonas et al. (2019) conducted a review encompassing a range of prototypical and commercial applications from both academia and industry, with a focus on existing and prospective features

of social VR applications. They subsequently developed a taxonomy identifying three dimensions: the environment, the self, and interaction with others. In our targeted interest in the art domain, we identified a similar structure, with our three dimensions being the **artwork**, the **audience**, and **communication**.

The artwork dimension delineates features and characteristics composing the art content itself. When brainstorming potential scenarios of cross-device MR art, interviewees often drew upon their past experiences at art galleries or museums. Analogous to works of art in the physical world, the level of **engagement** afforded to the audience to interact with the virtual artwork spanned from passive observation to active collaboration. As **passive** observers, the audience envisioned viewing non-interactive artworks such as paintings and sculptures that do not respond to their behavior. For responsive and interactive art, the audience anticipated being able to make changes or induce visual or audio effects based on their behavior, albeit within mechanisms predetermined by the artist (**active yet confined**). Other examples included making **active and creative** contributions to the artwork, such as painting over a plain sculpture.

In *In-Between Spaces*, the **interaction mode** was designed to consider the audience **as a group**, with the artwork responsive based on the integrated behaviors of all audience members. Upon recognizing the interaction mechanism, interviewees collectively exerted efforts to elicit reactions from the artwork, which in turn encouraged communication among audience members. For instance, they might say, "could you stand there?" Interviewees also expected the artwork to respond to their individual behaviors **as an individual**, anticipating reactions when attempting to touch or push through it.

The **time of creation** for an artwork can be presented as either a **live** performance or delivered as a **completed** piece. P12 reported, "I would like to see the artist drawing live, come in and start drawing" and "see the change by time," expressing a desire to witness the artistic process unfold in real-time. E03 described a potential scenario of a live dance performance featuring a dancer wearing sensors, accompanied by additional visual effects.

When discussing **artwork content**, interviewees presented a range of diverse ideas, spanning from **visual elements in the virtual environment** such as virtual art pieces to observe (e.g., sculptures, paintings, visual effects) to entire virtual art spaces to explore. P01 envisioned, "the whole room [being] an art piece and you walk through it, or there is a path you follow through." P11 suggested, "imagine if the whole creation of the drawing is [an] artwork and that you could kind of step anywhere into that artwork". Additionally, several interviewees highlighted the expressive potential afforded by the platform, owing to the nature of mobile devices allowing them to perceive both realities simultaneously. For example, E03 imagined a performer in the real world in front of the audience, with additional visual effects visible through mobile devices. Many interviewees emphasized the importance of integrating **visual elements in the physical environment** into the artistic experience, stating, "seeing a sculpture in a classroom like this isn't as great as if the whole room was built around it (P02)."

To enhance the immersive and artistic experiences, various types of **additional sensory elements** were discussed. Most frequently mentioned was an auditory dimension, such as a soundtrack serving as background music and specific sound effects triggered by audience behavior. Additionally, incorporating other sensory elements, such as olfactory or tactile stimuli, could further enrich the experience. For example, the artwork, *We Live in an Ocean of Air* provided a multisensory experience with

sound and scent, in addition to visual elements inside and outside of VR headsets. Furthermore, P09 highlighted the potential for other genres of art with **storylines**: "musical art, and even theatrical productions could see new, innovative works that would be slightly or completely reliant on VR technology.". He emphasized that the immersive environment could enhance the narrative of the piece and vice versa, enriching immersive artworks. E03 envisioned incorporating a story with a prompt or role, akin to playing a video game or solving a puzzle together, to make the experience more engaging and social. Lastly, interviewees suggested that providing **information about the artwork**, similar to captions in museums and galleries, would be beneficial, "especially when there is a lot going on in the artwork (P02)."

4.2.2. Audience

The **audience** dimension starts with presenting different goals of virtual representation for artists to consider when designing avatars. How individuals are portrayed in the virtual world can be categorized based on the level of representation and customization, as well as the method of manipulation and traversal (Jonas et al., 2019). Designing the appearance and control mechanisms of virtual avatars has been an important topic in social VR, with implications for user perceptions and experiences such as embodiment (Latoschik et al., 2017; Spanlang et al., 2014), presence (Heidicker, Langbehn, & Steinicke, 2017; Latoschik et al., 2017; Roth et al., 2016), and communication (Roth et al., 2016).

Such factors hold particular relevance in the art context as well. The first component, **embodiment**, describes a sense of being aware of one's location, a sense of having control over its movements, and a sense of owning the virtual body (Kilteni, Groten, & Slater, 2012). Upon entering the virtual environment, some interviewees initially failed to recognize that the avatars were, in fact, representing themselves in the virtual space and "were confused about whether they were part of the artwork (P03)." When discussing their virtual appearance, several interviewees expressed a desire for the opportunity to **express themselves** via avatars, suggesting options for "users the opportunity to choose their own avatar and user name. The avatar could perhaps be a preset model ... or perhaps the platform could provide the user with a sort of a character creator (P09)."

Another important objective of virtual avatars is providing **awareness of other audience**. Interviewees noted that avatars "encouraged conversations with other [audience members] (P07)" and enabled individuals to "see what other people are looking at, and you can talk to them more about it (P02)." Additionally, virtual avatars can serve to **differentiate audience members** from one another and let each other know who is who to communicate and interact with. Mentioned examples included the use of usernames, customizable avatars, and incorporating unique audience characteristics such as roles and appearances.

Lastly, interviewees mentioned the importance of designing avatars in **integration with artwork**. One expert remarked that the avatars in *In-Between Spaces* seemed to add "meaning into the artwork itself rather than being non-diegetic material (E02)." However, several interviewees raised concerns about avatars obstructing views of the central sculpture, suggesting that "having a function to make the avatar invisible would be nice ... when you are blocking the artwork (P08)." Another expert drew parallels with experiences in traditional art museums: "there are definitely times where I prefer not seeing other people because they are wracking the experience (E01)." Ultimately, the impact of avatars on the art experience, whether the avatars are beneficial or

not to the experience "would depend on the content (E03)", depending on various factors, including the nature of the artwork, avatar design, and most importantly, on the artist's intention. E02 noted that while avatars may initially appear as distracting elements within the experience, they could be part of or eventually align with the artist's intention, and emphasized, "the question is that 'does it enforce the idea of the art or does it distract the idea of the art?'" This sentiment underscores the need to critically assess the role of avatars within the context of the artwork and their impact on the overall artistic concept.

Following the goals of virtual avatars, interviewees discussed what information to include as **virtual avatar content**. The most commonly mentioned was the **location** of audience members in the virtual environment. For HWD users without a view of the surrounding physical space, it is especially important "to know where other users are, which makes you comfortable to move around by knowing not to bump into somebody (P01)". Interviewees also mentioned the awareness of others' **posture** and **gaze direction** enhances interpersonal experience: "if someone is reaching out to something or crouching down at something, then [I] would want to do the same and talk about what the person is looking at (P01)." Tablet users found it easier to perceive such cues in physical space beyond their devices, allowing them to better discern **emotion and facial expressions**. Interviewees expressed a desire for this information to be available to HWD users through virtual avatars. However, concerns were raised about the technical feasibility of delivering detailed information and the willingness of viewers to wear additional sensors. Virtual avatars can also convey **background information** about the audience, such as their role and gender identity, aiding self-expression and differentiation among the audience. Lastly, there is an option of having **no virtual avatars** to represent the audience. Several interviewees shared concerns over virtual avatars negatively impacting the aesthetic experience and wanted "an option to make [blocking audience] invisible (P13)."

To create more accessible and social experiences, we explored the use of asymmetric device composition, offering audiences the choice between commonly available **mobile devices** and more VR-focused **HWD**. The initial demo of *In-Between Spaces* tested this cross-device setup, providing one HWD and two tablets as device options. This setup served to explore how artists could integrate the platform into their artwork and to familiarize interviewees with the concept. In the epilogue (Section 4.1), the artist of *In-Between Spaces* deliberates on whether to incorporate the unique characteristics of each device into the artwork itself or to maintain versatility of the artwork across all devices. For example, while HWD offers a fully immersive view into the virtual world, mobile device users can easily transition between the physical and virtual worlds and adjust their perspective by moving the handheld device. Depending on the artist's intention, they may choose to experiment with these asymmetric device compositions, emphasizing their distinctive characteristics, or treat them as equivalent "windows" or "cameras" into the virtual world. Alternatively, the artist may opt for more symmetric device options, such as mobile devices with different display sizes. The potential benefits and considerations of employing asymmetric device compositions are further discussed in Section 4.3.

4.2.3. Communication

In Social VR, the communication and interaction dimension encompassed functions such as muting other users, activities such as event planning, and communication methods such as physical expression (Jonas et al., 2019). During the early phase of

virtual reality, Biocca (1992) anticipated that communication in virtual environments would closely mirror real-world interactions, viewing the technology as an extension of existing communication codes, techniques, and conventions, rather than a complete overhaul. This notion has been echoed in many social VR applications, which strive to replicate face-to-face interactions, including nonverbal communication (Maloney, Freeman, & Wohn, 2020; Perry, 2015; Smith & Neff, 2018) and spatial navigation (McVeigh-Schultz, Márquez Segura, Merrill, & Isbister, 2018).

In the context of art, the **communication** dimension encompasses the **topics**, **modalities**, and **scales** of interpersonal communication. While experiencing *In-Between Spaces*, interviewees often shared **points of interest** that caught their attention. For instance, a tablet user pointed at a specific physical location where the elongated fingers of a sculpture ballerina were located in the virtual space. After making eye contact with another tablet user, they both approached the virtual hand, sparking a brief conversation. Intrigued by the discussion, a HWD user joined in by following the movement of their avatars and expressed their **impression and emotion**: "These fingers are really long. Does it go into my body?", "Oh, what you guys are doing is so funny."

Interviewees shared their past experiences of discussing **related information** about artwork in art galleries, and anticipated similar conversations while engaging with VR-based art. P10 expressed the sentiment that increased dialogue about an artwork enhances appreciation and fosters the discovery of new insights: "if more people are talking [about an artwork] you find an appreciation to it ... discovering [new] things about art ... sharing art appreciation." Some interviewees enjoyed listening to others, although not actively participating in the conversations: "I am not comfortable talking to strangers in general, but it was more fun because I could hear them talk about the same thing and it helped me notice the details too (P12)."

Returning to the discussion of *In-Between Spaces*, both HWD and tablet users frequently communicated **verbally in physical environment**. In addition to verbal communication, tablet users utilized **nonverbal modality in physical environment** such as hand gestures and eye contact. However, the HWD user was limited in perceiving the physical space and relied on representations in the virtual environment, such as avatar location and movement (**nonverbal in virtual environment**). Following the experience, interviewees suggested that additional features within the virtual environment would facilitate communication between HWD and tablet users. One proposed feature was the ability to highlight or point at specific objects or locations in the virtual space to share a point of interest, particularly with HWD users who have limited access to detailed gestures or behaviors from other audience members. Regarding sharing impressions and emotions, E01 and P20 mentioned using simple emojis that do not require additional use of complex technology or devices.

Interviewees often envisioned scenarios involving larger audience groups in expansive environments and discussed the use of **verbal communication in virtual environment**, similar to an in-game chat. Depending on the type of communication or intention, the audience could choose whether conversations were public (**to the group**) or private (**to an individual**), enabling the initiation or participation in small chats during the artistic experience. P01 commented that this feature will prevent the experience from devolving into unintended chaotic scenes: "That's better than 20 people shouting (simultaneously)."

4.3. Understand: Benefits and Concerns

The following section outlines the identified benefits and concerns associated with the implementation of a cross-device MR platform in art (RQ3). Through the analysis of feedback gathered from focus groups and expert interviews, we explored these aspects from the viewpoints of various stakeholders. The discussions primarily revolved around the utilization of a mobile device as an additional medium for viewing the virtual environment, facilitating shared experiences, and fostering social interaction among co-located group audiences.

4.3.1. Benefit 1: Shared cross-device experience as group audiences enriches the aesthetic experience

Following their participation in *In-Between Spaces*, interviewees expressed favorable sentiments regarding the platform's ability to facilitate socially engaging encounters with art. For instance, P01 appreciated "the idea of being in a shared space, to walk around together, see each other, and talk to each other, or even wave to each other." Interviewees anticipated that such interactions would enhance the enjoyment of public art events. Moreover, the platform fostered communication among audience members who were previously unfamiliar with one another. P10 highlighted the pleasure derived from conversing and sharing laughter with fellow attendees, noting that it contributed to a sense of ease and camaraderie: "talking and laughing with other [audience members] ... makes you a bit more comfortable." This social dynamic was particularly pronounced for tablet users, who could discern facial expressions and body language more easily. P02 highlighted the limitation of wearing an HWD, noting, "[I] missed being able to see emotions in someone else, [which is] a big part in experiencing art." She further remarked, "tablets were definitely helpful in being able to see them."

4.3.2. Benefit 2: Use of mobile devices enables inclusive VR art experience

Interviewees expressed anticipation regarding the integration of mobile devices as additional access points to virtual reality (VR) art experiences, foreseeing broader inclusivity across diverse audience demographics. Specifically, they anticipated that the implementation of a cross-device system would offer extended engagement opportunities without adverse effects such as dizziness or motion sickness. Additionally, interviewees welcomed the potential inclusion of younger and older family members in VR-based art experiences. P12 recalled feeling discomfort after using a head-worn display (HWD) for an extended period, highlighting the simplicity of using tablets as an alternative viewport: "with the tablets, it's just a screen, easy and convenient.". P09 emphasized the potential of tablets to enable older individuals to participate in VR experiences without experiencing adverse effects, envisioning opportunities for intergenerational engagement and enjoyment: "The best interaction to have with VR [...] would be to have friends and family play together. The addition of tablets would allow even those in older generations to experience and have fun with this newer medium."

4.3.3. Benefit 3: Use of mobile devices adds a physical dimension to VR art experience

Interviewees expressed appreciation for the use of mobile devices in a mixed reality setting, which facilitated a connection between the physical environment and the virtual space. They noted that mobile devices introduced an additional dimension of the

real world into VR art, offering new possibilities for creating engaging experiences for audiences. Interviewees highlighted the seamless transition between and simultaneous viewing of the physical and virtual worlds. P01 likened cross-device art in mixed reality to "an own genre of art itself [...] (where) the artist has to consider not only the appearance of art, but also how people in the space would experience the art." P09 further elaborated that "with VR and MR, artists can create more interactive and dynamic pieces, [...] (making) their messages more potent with the immersive environment."

4.3.4. Concern 1: There is a discrepancy in the experience between using an HWD and a mobile device.

With a different field of view provided by HWD and mobile devices in the virtual environment, the audience may perceive different levels of immersiveness, leading to distinct reported experiences. P01 expressed a preference for HWD, "which even with peripheral vision can enjoy the experience, whereas you have to move around [with] the tablet a lot to see more." Concerns were also raised about the lower video quality on tablets, potentially impacting the overall experience compared to HWD: "Maybe because they were old. This may provide a different experience from the [HWD] user." P03 was "worried about dropping the tablet." P17 highlighted the perception of HWD users as the "main characters" or primary audience for the experience. Similarly, P02 favored HWD and explained that "especially to see the art, I would feel I am not getting the full experience if not using the [HWD]." However, he acknowledged that "some people may not be able to use the [HWD], and tablets could be an option for them." These insights underscore the importance of considering device-specific preferences and limitations in designing immersive experiences to cater to diverse user needs and preferences.

4.3.5. Concern 2: Audience has different expectations for an HWD and a mobile device.

During the interviews, participants expressed distinct expectations based on the device they would use. HWD users enjoyed hands-free interaction, while tablet users were constrained by holding the device but had a broader view of their surroundings. P18 highlighted the potential for HWD users to be excluded from social interactions, describing an instance where a tablet user tried to engage an HWD user in an activity, but the latter was preoccupied with other tasks: "when we (tablet users) were like, 'hey, can you try running,' but [the HWD user] was busy with sculpture and everything." P18 further elaborated on how the different capabilities of HWD and tablet users influenced their interactions. For example, tablet users could easily communicate by pointing at objects, while HWD users might not perceive such gestures, leading to greater communication among tablet users. This observation suggests the possibility of segmented interaction among user groups based on the device they use, highlighting the need to consider device-specific dynamics in designing immersive experiences.

4.3.6. Concern 3: Virtual avatars may distract the audience from aesthetic experience

Interviewees expressed concern about potential interruptions to the aesthetic experience caused by avatars. During their interaction with *In-Between Spaces*, several interviewees noted instances where avatars obstructed their view of the central art piece. P08 proposed that "having a function to make oneself invisible would be nice

[when] you are blocking the artwork for someone" and suggested an idea of "[when] moving, you [become] visible, and when static, you become transparent." Additionally, some interviewees expressed enjoyment in exploring each other's avatar changing in shapes and asked if they were paying *too much* attention to the avatars rather than focusing on the central sculpture. Upon discussing this with the artist, it was noted that audience engagement with avatars was considered an integral part of the artwork. Lastly, P11 raised concerns about the potential for chaos in scenarios involving larger or more energetic audience groups, highlighting the importance of managing group dynamics during immersive experiences: "We were pretty civil today, but I could see how chaos would start."

5. Discussion

5.1. Explore: Potential Scenarios

In this section, we discuss existing real-world examples and literature related to the previous stages' findings. The goal of this section is to provide examples of potential scenarios and inspire readers expand their own ideas of cross-device MR art for group audiences (RQ4).

5.1.1. Transformation of VR art into MR art

Virtual museums have been striving to offer social and shareable experiences while broadening access to culture and heritage for diverse audiences. Platforms like V21 Artspace (https://v21artspace.com/) and VOMA (https://voma.space/) exemplify this approach by providing virtual tours of museums and curated collections from around the world. By offering non-HWD device options for experiencing VR art spaces, these platforms aim to extend artwork exposure to wider populations. Motion-tracked mobile devices facilitate embodied experiences in 3D space, enhancing the sense of immersion akin to real-world gallery visits. This setup enables visitors to navigate virtual galleries and engage with others in a shared digital space.

One potential scenario for enhancing VR experiences into MR involves integrating spatially mapped physical sites as satellite locations. These sites would facilitate richer social interactions among visitors interested in virtual artworks, without the barrier of wearing HWDs. Embodied experiences enabled by motion-tracked mobile devices can foster a high level of social presence, characterized by conversation patterns that closely resemble face-to-face interaction (Smith & Neff, 2018).

Moreover, MR platforms offer exciting possibilities for live artworks. For instance, E01 mentioned the video of a Disney animator drawing a character in 3D space using Google's Tilt Brush and expected it to be more engaging if seen live in a cross-device MR platform. The audience can observe the creation process from any angle one wishes to stand on. The artist can also create or perform art based on how the audience reacts or even collaborate with them. In addition to the progression over time, E03 saw the integration and discrepancy between the virtual and the physical worlds as new dimensions for the artist to utilize. This will be mainly targeting audiences with mobile devices who can easily make transitions between the two worlds. E03 pictured an artist performing in front of the audience while additional visualizations appear on tablet display that overlays to the artist's performance. The virtual components could be something metaphorical or visual effects that are difficult or unable to deliver in the physical world (e.g., computer generated imagery in movies). E03 further imagined

individual interactions with the audiences such as presenting visual effects to specific individuals only based on their distance to the artist.

The methods of connecting the physical world with the virtual one can vary in scope from utilizing a single object to an entire space. Initially, the artist of *In-Between Spaces* envisioned 3D scanning the physical surroundings of where the art is presented and blending it into the imagined virtual environment. In fact, the unpolished interior of the experiment space that is incongruent with the virtual world was often reported to have negative effects on the overall aesthetic and immersiveness of tablet users. The artist also created a physical form of the central sculpture, and the current version of *In-Between Spaces* locates the physical sculpture to appear in the exact location as it does in the virtual world. The sculpture is a bridge that connects the two spatially mapped realities. Other artists and researchers have utilized additional technologies and platforms such as projections, CAVE (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992), cyclorama (panoramic display), or video walls to expand aesthetic virtual worlds. In addition to visuals, the use of background music and other modalities can be used to create an integrated experience beyond the visuals inside the display, and also to emphasize the mood of the experience (Bates, 1992; Goslin & Morie, 1996).

5.1.2. Interactive art for group audiences

Many modern works of art are "orchestrated by but not [solely] performed by the artist" (Kwastek, 2013). Technology-based interactive art installations provide real-time feedback on the audience's behavior, while participatory art (Tate, 2016) directly invites the audience to participate in the creative process. Such input can either lead to a temporary response or a cumulation that remains and affect future audiences. This concept of lingering effect was introduced in Cornock and Edmonds (Cornock & Edmonds, 1973)'s categorization of interactive art. Unlike the other three, the fourth interaction type, 'dynamic-interactive (varying)' referred to the art that depended on the history of the audience's interactions with the work.

Designing interactive art for group audiences provides an additional dimension to consider: the dynamics between the audience members as a factor in interacting with the artwork. For example, in *In-Between Spaces*, the central sculpture was designed to change in size based on the aggregated distance between the audience members and the artwork. The change was evident if all of the audience members moved in coherence, either towards the sculpture or away from the sculpture. However, the audiences often walked in varying directions and were unable to notice the mechanism behind the size change was based on their movements and, more specifically, on their distances from the sculpture. When they finally became aware (after being notified by the moderator), the audience began to encourage one another to move in certain directions. This became a trigger of communication within the group as they encouraged others to move in certain directions or to specific locations. In interactive media art, the technical processing often serves as a black box (Kwastek, 2013) to the audience. It can be the artist's intention to make the audience recognize it after several interactions. Using group dynamics of the audience can be an interesting factor to use, but it will add complexity to the mechanism for the audience to understand.

5.1.3. Artifacts of experience and memories

Interviewees highlighted the potential of cross-device MR platforms as captivating content to either experience or possess. P16 noted the idea of artworks created on such

platforms being enjoyed during private group gatherings, with an example scenario: "a high-end art consumer could now buy someone's performance art and display it in their big fancy mansion." This perspective illuminates a shift in the perception of MR art from mere ephemeral experiences to tangible artifacts of cultural and aesthetic value, worthy of acquisition and display in prestigious settings. Moreover, P17, drawing from her background in tourism, provided insightful suggestions on how these platforms could seamlessly integrate into existing events. She proposed enriching experiences such as visits to historic sites or wine tastings with the incorporation of sensory elements like taste and smell, enhancing the immersive quality and engagement for participants. This forward-thinking approach not only enhances the allure of MR platforms but also aligns with the evolving landscape of tourism, where technological advancements are increasingly leveraged to elevate the visitor experience (Leung et al., 2022; Omran, Ramos, & Casais, 2023; Sustacha, Banos-Pino, & Del Valle, 2023). Indeed, the growing trend of tourism sites incorporating VR technology further underscores the potential of cross-device MR platforms as transformative mediums. With their heightened accessibility and inherently social nature, these platforms hold promise as powerful tools for enhancing not only individual experiences but also collective engagement within the realm of cultural and leisure activities.

Interviewees also highlighted the transformative potential of cross-device MR platforms in shaping how we experience and preserve memories. P20 envisioned these platforms as powerful tools for not only capturing but also preserving significant life events and experiences. By blending physical and virtual content, individuals can create immersive recordings that encapsulate the essence of special moments. Moreover, the ability to share these recordings with loved ones allows for the collective reliving of cherished memories, fostering deeper connections and strengthening bonds. Furthermore, the incorporation of both physical and virtual elements in these recordings adds a layer of richness and depth to the overall experience. Interviewees expressed excitement about the prospect of reliving moments with all senses engaged, from sight and sound to touch and smell. Imagine being able to revisit a wedding ceremony or a family vacation and not only see and hear the surroundings but also feel the warmth of the sun on your skin or the scent of the ocean breeze. This multisensory approach to memory preservation promises to revolutionize how we reminisce about and cherish the most meaningful moments in our lives. In addition, interviewees noted the social aspect of these platforms, emphasizing how they facilitate shared experiences and communal reminiscence. Being able to collectively revisit past events with friends and family strengthens social bonds and fosters a sense of belonging and connection. As technology continues to advance and these platforms become more accessible, they hold the potential to become invaluable tools for preserving our collective memories and enriching our shared human experience.

5.1.4. Virtual representation of the audience

Studies have shown that the sense of embodiment in a virtual avatar has a positive effect on a user's presence in VR (Biocca, 1997; Skarbez, Brooks, & Whitton, 2017; Slater, 2009). It is known that how the virtual avatar is designed, including appearance, control level, and perspective, can impact the level of avatar embodiment (Fribourg, Argelaguet, Lécuyer, & Hoyet, 2020). In *In-Between Spaces*, the artist chose to represent the audience using avatars that convey their movement level (walking or static) and location. These avatars were not customizable and were predefined by the artist to fit within the aesthetic theme of the artwork. During interviews with participants, they

often mentioned the desire to express oneself through virtual avatars. In fact, a consistent self-presentation on their physical self and a platform-specific self-presentation is known to be the main constructs for self-presentation in social VR (Freeman & Maloney, 2021). It is also notable that the way the audience prefers to appear in the virtual space may differ by the platform and also with whom they are experiencing the art. Previous literature describes selective self-presentation or performance in digital social space in relation to constructing self-identity and customizing performance depending on different social settings (Goffman, 1981).

In addition to designing the appearance of avatars, deciding which information to include and deliver via avatars is also important. The most basic and commonly shared content is location, which is essential for an HWD user to avoid collision with other audience members present in the physical space. If, for any reason, the artwork is to be designed without virtual representation of audiences, the HWD user will need an additional alert system to avoid collision with mobile device users who are not visually represented in the virtual space. Beyond safety, avatar content plays a vital role in shaping nonverbal communication of the HWD. During the demo session, tablet users often mimicked others' behavior, such as crouching down to see the lower part of the artwork or leaning forward to have a close look at a particular section. Being able to notice the direction of others' attention made it easier for them to initiate conversation and share thoughts. However, with no visibility to the physical world, the HWD user had to rely on what is represented in the virtual world (e.g., other's location). To foster the HWD user's nonverbal communication with others, the level of information conveyed using avatars is important. Previous research represented gaze directions in virtual avatars utilizing a 6DOF headset (Layng et al., 2019). Other projects integrated additional tools such as Kinect, OptiTrack, and VIVE trackers to track full-body motions and represent them in the virtual environment (Desnoyers-Stewart et al., 2020; Podkosova & Kaufmann, 2018; Zhu et al., 2016). Facial expression is another social cue that people commonly use as a communicative component (Frith, 2009). With the growth of social VR applications, researchers have worked on technologies such as facial electromyogram to enable facial expression recognition while wearing an HWD (Cha & Im, 2022).

5.2. Explore: Design Considerations

From analyzing potential scenarios and expected benefits and concerns of the studied concept, we noticed pairs of strengths and weaknesses following the introduction of mobile devices, as well as possible conflicting ideas on designing avatars for group audiences. Here, we discuss what can be expected and what needs to be considered to find the right balance when creating shared, cross-device art in mixed reality for group audiences.

5.2.1. Navigating the Duality of Cross-Device: Balancing Access and Immersion

Interview participants generally expressed positivity towards the potential applications and benefits of implementing mobile devices to experience MR art. The introduction of mobile devices was praised for inviting previously excluded bystanders to the genre of art with an extended level of creativity, particularly to share the experience with families and friends who did not previously participate due to voluntary or non-voluntary reasons. However, they also pointed out that mobile devices, with limited display sizes and the requirement to hold them with both hands, led to inconsistency in the experi-

ence. This led to some comments questioning whether the cross-device platform could deliver a truly "shared" experience that is identical for all participants.

Another concern we had regarding the cross-device platform was the potential reaction from the VR artists, who may oppose the idea of diluting or altering the intended delivery of their artistic vision. While mobile devices offer accessibility to a broader audience, they may fall short in terms of providing the immersive experience that is often a primary benefit of choosing VR as a medium. In the film industry, several filmmakers have expressed disappointment with the shift towards smaller hand-held device screens for consuming content, as opposed to the traditional movie theaters (Lee, 2017; Reynolds, 2013). Without the intended size of the screen and sound system, their efforts to acheive the level and direction of theatrical experiences seemed futile.

However, on the other side of this argument, there is a debate about finding a balance between quality and approachability. Fortunately, the majority of experts we interviewed were open to embracing a new medium and even excited about utilizing the newly introduced dimensions to experiment with their ideas, especially for mobile device users who are connected to both physical and virtual realities. Nonetheless, this situation presents an opportunity for artists to leverage the unique capabilities and strengths of each device, creatively incorporating these differences into their artwork.

5.2.2. Navigating the Avatar System: Social Interaction and Artistic Integrity

To ensure a safe and socially engaging experience for users wearing HWDs alongside co-located audiences, the inclusion of a virtual representation of the audience, such as an avatar system, becomes integral in the design of MR art. Through interviews and literature review, we discerned the audience's expectations regarding the avatar's appearance, content, and functionalities. A prevalent desire was to express one's identity through the selection of virtual representations. While acknowledging these expectations, it is imperative for artwork to uphold its thematic coherence and intended message delivery. For instance, in the case of *In-Between Spaces*, the artist deliberately crafted the avatars to maintain a degree of uniformity both in the visual aesthetics of the virtual environment and in human forms, rendering them as non-customizable avatars. While interviewees found these avatars intriguing and believed they enhanced the artistic and social experience, concerns were raised that they could potentially overshadow the central art piece, diverting attention away from it. However, in the case of *In-Between Spaces*, this aligned with the artist's intention to foster interpersonal interaction by drawing attention to the avatars and encouraging audience engagement with them. Consequently, the avatars were considered integral elements of the artwork.

While incorporating virtual representations of co-located audience members is crucial for safety and facilitating social interaction among groups, virtual avatars can potentially interfere with others' aesthetic experiences. Instances of avatars blocking artworks, as reported in *In-Between Spaces*, exemplify this issue. Despite well-designed avatars, certain circumstances may disrupt the flow and immersion of the experience or even render it impossible to fully appreciate the artwork. As a potential resolution, artists may opt not to visualize the audience in the virtual world. However, this decision could increase the risk of collisions among audience members sharing the space, particularly for HWD users who rely solely on virtual representations and cannot see others beyond them. Recognizing the potential influence of avatar systems, artists should carefully consider their intentions regarding avatars when crafting artwork in this medium. For instance, if avatars serve primarily as practical tools for audience

location tracking and differentiation, they should be designed thoughtfully to avoid overshadowing the artwork itself.

5.3. Explore: Prospects

In the current study, we explored the application of a cross-device MR platform in the domain of art, supporting a shared experience for co-located audiences. From our work, we expect to benefit those who are also interested in configuring, experimenting, and delivering creative art via the medium of VR and MR technologies in a social and inclusive manner. First, we constructed a taxonomy with a collection of potential and expected attributes of the studied concept of art. Categorized into three dimensions of artwork, audience, and communication, the taxonomy provides an easy understanding of the concept that has been relatively unexplored before. Artists can utilize the taxonomy that describes a technical platform for its features and characteristics which they may find adequate to actualize and deliver their creativity and messages. We also expect the taxonomy to be useful for software and platform developers who are interested in devising tools to support creative works of artists and designers by understanding potential components and features. The study can also inspire practitioners in both fields of VR and art, including researchers and artists, to experiment different attributes and their roles in audiences' behavior, response, and aesthetic experiences. Understanding potential attributes and their impact will also benefit designers outside of the art domain to utilize 3D immersive environments in consideration of aesthetic perspectives or dynamics of group audiences.

5.4. Limitations and Future Work

In the current study, we investigated the utilization of a cross-device platform to exploit its potential benefits in enhancing accessibility and promoting social interaction within VR art experiences, which traditionally have tended to be solitary and individualistic. There is a scarcity of literature examining the active involvement of non-HWD users in VR art experiences, as well as limited research exploring the integration of mobile devices as additional viewports to actively engage with VR art experiences. Therefore, we employed a research methodology centered on gathering insights from key stakeholders through interviews. It is noteworthy that while existing studies on VR art primarily focus on user experiences within the virtual environment alone, our study extends beyond this scope by considering the fusion of both virtual and physical spaces through the MR platform. This distinction underscores the unique challenges and opportunities presented by MR platforms in facilitating immersive art experiences for group audiences. However, due to the scarcity of VR-based art experiences available to the public for group enjoyment, particularly using asymmetric mediums, interviewees struggled to conceptualize the relatively unfamiliar concept within the limited timeframe. Some interviewees asked the moderator to clarify the scope of the concept for discussion. Most previous VR experiences of participants were concentrated in the game domain, and they often made analogies to their knowledge from gaming. To facilitate an understanding of the studied concept, participants experienced *In-Between Spaces* prior to their participation in the study. The exposure to a single piece of artwork may have posed an anchoring effect during the ideation process.

The study drew upon a relatively small participant pool whose perspectives served as the primary resource for the findings reported herein. While participant backgrounds

spanned engineering and humanities with varying degrees of interest in art experiences, the majority hailed from academic institutions, including a mix of students, researchers, staff, and faculty members. Given the nature of the study methodology, the taxonomy provided may not represent a fully comprehensive and definitive list of components constituting cross-device MR art experiences. However, as this area of interest is still in its nascent stages, it requires further exploration and expansion. With continued research on the topic, the taxonomy presented in the current paper can be refined and updated. In the meantime, the insights offered herein serve as a catalyst for showcasing the potential of this relatively underexplored medium for creating and enjoying art, with the aim of inspiring artists and content creators to leverage the technology in their works. As the use of this technology becomes more widespread and additional research is conducted, the taxonomy presented here will inevitably evolve and be revised accordingly.

Future studies have the opportunity to delve deeper into understanding audience behavior, with a particular focus on the social and inclusive aspects of VR-based art experiences. Conducting observations or field studies at open public venues would offer authentic and nuanced insights into how individuals interact with and perceive the studied concept. These studies could shed light on how cross-device MR art installations can serve as platforms for fostering connections, sparking dialogue, and promoting cultural exchange among diverse audiences. Furthermore, such research could inform the development of guidelines and best practices for creating VR-based art experiences that prioritize accessibility, diversity, and inclusivity, ensuring that these immersive technologies are welcoming to all individuals, regardless of background or ability.

6. Conclusion

The advent of new technologies continually reshapes the landscape of artistic expression (Colton & Wiggins, 2012). As artists harness the capabilities of innovative tools and platforms, they venture into uncharted territories, pushing the boundaries of traditional artistic conventions. As demonstrated in *In-Between Spaces*, incorporating a handheld device alongside the more commonly used 360-degree headset provided the artist with fresh avenues for experimentation. Thus, new technologies serve as powerful tools enabling artists to craft immersive, interactive, and dynamic artworks that capture the essence and aesthetics of the digital age, challenging our perceptions and broadening the horizons of artistic possibility.

The project's initial goal of creating a cross-device MR platform to foster a more social and inclusive MR experience was widely recognized and reiterated by both perspectives of creators (artist of *In-Between Space*, expert interview) and audiences (focus groups). These benefits will be particularly pronounced and crucial in public settings where group audiences and interpersonal interactions are expected, as well as in art contexts where interpersonal communication or influence is integral to forming rich and complete art experiences.

While concerns have been raised regarding how artists perceive the cross-device setting and its impact on their intended work created within three-dimensional space, artists can leverage the unique characteristics of this asymmetry to become part of their artwork. Indeed, it is not solely the semantic value of the artwork, but also the inherent technological characteristics that shape interaction design, which collectively contributes to the overall art experience (Taipale & Rousi, 2022). Just as artists do

with existing mediums, whether they be material, technological, or genre-based, the choice of medium and how to exploit its characteristics lies entirely within the artist. The current paper, therefore, serves as a guide, presenting another potential medium for future artists, designers, and creators, empowering them to leverage the explored concept to actualize and convey their messages as intended. Moreover, we anticipate that our findings will inspire practitioners in the realms of art and technology, as well as those working at their intersection, to conceptualize meaningful and inspiring aesthetic experiences that transcend current boundaries. By encompassing key interconnected components between art and HCI, our work holds relevance for the broader HCI community. It offers insights that can guide future research and development endeavors aimed at comprehending and enriching user experiences within immersive art contexts, with a focus on inclusivity and social aspects. Through this, our work contributes to advancing the HCI field by promoting deeper understanding and enhancement of user interactions within immersive artistic environments.

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8. Appendices

Appendix A. Taxonomy Development Procedure

Dimension	Components	Levels
Art content	Visual	2D object
		3D object
		3D space
	Supplementary	Physical space
		Music
		Story
		Information about artwork
Interaction with artwork	Source	Collision with virtual artwork
		Collision with physical object
		User movement
User role	Relationship to artwork	Passive
		Semi-passive
		Semi-active
		Active
	Device options	Symmetric (HWD only)
		Asymmetric (HWD and mobile device)
User representation	Representation content	None
		Location
		Movement
		Gaze direction
		Emotion
	Representation style	Realistic - Unrealistic
		Representational - Abstract
		Static - Dynamic
	Representation goal	Self-awareness
		Self-expression
		Awareness of other's location
		Differentiate other users
		Appropriateness with artwork
Interaction among users	Communication in physical world	Verbal
		Action
	Communication in virtual world	Visual
		Message
	Conversation topic	Point of interest
		Impression/Feeling
		Information
	Conversation target	Group
		Individual

Figure A1. Initial taxonomy draft shared during expert interviews. Colored in grey indicates removed components in the final draft.

Table A1. Number of mentions on attributes in the final taxonomy.

Dimension	Components	Attributes	Focus Groups (N=7)	Experts (N=7)
Artwork	Engagement	Passive	7	7
		Active yet confined	6	5
		Active and creative	4	5
	Interaction mode	As a group	2	4
		As an individual	7	6
	Time of creation	Live	3	7
		Completed	7	5
	Artwork content	Visual elements in virtual environment	7	7
		Visual elements in physical environment	4	4
		Additional sensory elements	3	4
		Story	3	2
		Information on artwork	3	1
Audience	Virtual avatar goal	Embodiment	2	1
		Self-expression	3	2
		Awareness of other audience	1	4
		Differentiation among audience	2	0
		Integration with artwork	6	5
	Virtual avatar content	Location	7	6
		Posture	3	4
		Gaze direction	2	2
		Emotion / Facial expression	1	0
		Background information	1	1
		No virtual avatar	4	1
	Device composition	Head-worn display (HWD)	7	7
		Mobile device	7	7
Communication	Communication topic	Point of interest	3	2
		Impression or emotion	3	0
		Related information	1	4
	Communication modality	Verbal in physical environment	5	6
		Nonverbal in physical environment	5	2
		Verbal in virtual environment	1	1
		Nonverbal in virtual environment	3	2
	Communication scale	To the group	2	4
		To an individual	7	6