Designing public VR installations:

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ABSTRACT

Virtual Reality (VR) installations using head-mounted displays (HMD) are becoming increasingly popular in public spaces. However, VR's immersive nature engages only the HMD wearer and excludes everyone else in the public space, and there is little design knowledge of how to engage those not wearing an HMD. To address this, we draw from our experiences of having designed seven public VR installations to present a design space around the dimensions of "agency" and "interest" with four user engagement frames to articulate twelve different user roles. To guide designers to support all roles and to transition users between those roles, we complement the design space with a set of design tactics for public VR installations. We hope that these combined contributions will help designers engage more people with VR installations so that ultimately more people benefit from what VR has to offer.

CCS CONCEPTS

• **Human-centered computing** → Interaction design; Interaction design theory, concepts and paradigms.

KEYWORDS

Virtual Reality, Public, Audiences

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1 INTRODUCTION

Technical advances and reduced costs have led to a surge in head-mounted display (HMD) based Virtual Reality (VR). While VR was initially confined to labs, there is now a widespread interest among developers to create content for the general public [33] and VR installations can take place in public spaces [44, 61] such as pubs and bars, university lounges, offices, trade shows, conferences, and museums [15, 53]. However, due to VR's immersive nature, many public VR installations allow only the user wearing the HMD to benefit from the VR content, excluding everyone else in the public space not wearing an HMD [18].

Current VR experiences are optimized for the HMD wearer. Current HMD technology uses stereoscopy, head and hand tracking, and sound and vibrotactile feedback to optimally immerse the HMD wearer in a virtual world that extends beyond the confines of a rectangular two-dimensional display. HMD wearers have the agency to naturally control their gaze, to move, and to interact with other objects in the environment, all of which make them feel more immersed while, at the same time, isolating them from other people in the same space. Consequently, people who do not have access to an HMD, and those waiting for their turn to be part of the VR installation experience, find it difficult to become engaged. We find that limited knowledge exists about how to engage these *potential* users who inhabit the same physical space as the VR installation. For simplicity, hereafter, we will be using the term 'user' to indicate both 'people who are directly interacting with VR technologies (user)' and 'people who will potentially be interacting with VR technologies (potential user)' [57].

Current knowledge about user interactions with public interactive systems is largely based upon user studies from the field of ubiquitous computing, that utilized public screen displays, derived from explanatory models such as the honeypot effect [21], user trajectories [3], and user roles and phases of interaction [72]. Prior work in the field of ubiquitous computing around interactive public displays [7, 14, 21] is relevant in so far as the interactions are also limited to a few participants. However, VR installations—in which only the HMD wearer can be immersed and interact with the content—are different from public screen display installations in so far that multiple people can simultaneously see and experience the digital content. These differences mean that visitors to VR installations without HMDs are disadvantaged because they do not have the same view as the HMD wearer [55]. Furthermore, while public screen display studies have identified different user types and phases of interaction for different experiences, and a few studies offer engagement models, surprisingly few have analyzed the interaction and engagement of all users who share the physical space of VR installations and the opportunities for interaction designers to engage all non-HMD wearing users [9].

To extend the engagement with VR installations to everyone else not wearing an HMD in the public space and consequently pave the way towards better public VR installations, we draw upon our experiences of having designed and exhibited seven public VR installations. We use these experiences to articulate two key aspects of public VR installations: first, people who engage with a public VR installation assume different user roles, between which they transition throughout their engagement; and second, targeted

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design interventions can improve the user transitions between roles, keep users engaged, and engage more users beyond the HMD wearer.

In keeping with the concept of interactional trajectories [3] and with research showing that interactivity can beneficially amplify both public display usage and user engagement [71], we argue that people can have different levels of "agency" (control over intention, action, and movements) over and "interest" (defined feelings of emotional attachment to and focus on the VR installation, other users, and the experience) in the VR content. We propose that different combinations of interest and agency can be mapped to a design space for public VR installations across four different user engagement frames: first, *the peripheral frame*, which comprises the outer edge onlookers who are undecided about taking part in the VR experience; second, *the audience frame*, which comprises the assembled viewers who are committed to taking part in the VR experience; third, *the performance frame*, which comprises those users who are actively participating; and, fourth, the orchestrator frame, which comprises the professional users who support the experience of users in the performance and audience frames.

This article goes beyond previous studies [3, 21, 72] in two important ways. First, it extends prior work around public technology engagement by conceptualizing public VR installation usage based on twelve different user roles that we have situated in a novel design space. Second, based on these observations, we provide a set of design tactics to guide design work that supports multiple user roles and assists users to transition between user roles while remaining engaged. We hope the accounts of our VR installation experiences, alongside the design space and design tactics, will be useful to conference organizers, exhibition managers, and museum curators. We hope to support discussion and reflection, as well as the identification of targeted improvements for VR installations, all of which will lead to VR user experiences that extend beyond HMD wearers. We also hope that these combined contributions will help designers engage more people with VR installations so that ultimately more people benefit from what VR has to offer.

2 RELATED WORK

Supporting interactions between people and interactive systems in public spaces is an ongoing HCI challenge [64]. This challenge involves attracting passers-by [47], characterizing users based upon their interactions with the system [21], and supporting the various roles that users can assume [23, 24]. We now discuss what we learned from prior investigations in this area, especially work on the honeypot effect, user roles, and the framing of interactive public user experiences, to better understand the user journey in the context of VR installations.

2.1 Honeypot effect

The honeypot effect describes how people's attraction to a system can be influenced passively by users who are already interacting with that system [21]. The effect has been studied extensively in relation to systems that display a screen publicly so that its content can be observed and, in some cases, shared by everyone in the same space [7, 14, 48, 72]. The honeypot effect is not limited to screen experiences and can also be observed in non-digital public displays such as art installations [40]. However, there is evidence that interactivity increases public display user numbers and enhances user engagement with those displays [71]. VR installations are a form of public display and, inspired by the honeypot effect and work on interactive screen experiences, we examined the activities of users who share the space of a VR installation.

2.2 User roles

Researchers often define user roles to describe the engagement of a user in phases and zones of interaction with the public display. For example, Benford et al. [3], defined seven user roles to describe the engagement of users with a system: "participant," "spectator," "audience," "bystanders," "actors," "operators," and "orchestrators." However, the nomenclatures, descriptions, and granularity of user roles vary across prior research and are often unique to the context of the experience [20]. For example, work on user roles in theatre studies considers different forms of theatre and distinguishes between observer, participator, and reviewer roles [2]. Reeves et al. [55] examined the user's performance with an interface and distinguished between the user roles of performers (who use technology in front of and with spectators) and spectators (who learn from performers to increase their proficiency and thereby decrease the likelihood of social embarrassment) [55, 69]. Tang et al. [68] used the user roles of bystander, spectator, and actors to describe the interaction of users in public spaces. Wouters et al. [72] defined passers-by, bystanders, audience members, participants, and actors to describe user interactions with a large screen display, as well as a dropout role—into which users from every stage can transition—as something particular to interactive installations with larger numbers of participants. We also noticed that some user roles such as the passer-by, spectator, and bystander roles are better understood than others and more commonly used in different user experiences. We considered several of the user roles in our design space and identified additional roles specific to public VR installations.

2.3 Transitions between user roles and framing

Prior research has started to group user roles into frames to facilitate interpretation and better understand each user role's overall function in a public system. Benford et al. [3] distinguished between an audience that is part of a performance frame as well as orchestrators that shape the experience from behind the scenes. In keeping with this trajectory [3] of engagement, we argue that people can have different levels of "interest" in and "agency" over the digital content and that the different combinations of interest and agency map to clearly distinguishable user engagement frames with particular user roles within a public VR experience.

Researchers also identified that users of interactive public systems transition between interaction and engagement phases. A study involving the observation of audience behavior with a public installation identified that users transition between distinct interaction threshold phases [43]. Benford et al. [3] conceptualized a model of interactional trajectories that describes a user's interaction phases in various zones of interactivity. Wouters et al. [72] developed a spatiotemporal model of user role trajectories and contextual influences detailing various role transitions of users interacting with a large-screen public interactive system. However,

Figure 1: Exploration of a virtual replica of a physical cave.

Figure 2: Setup with table and carpet to mark the HMD-wearer’s interaction space, and a large display.

researchers have also identified that users need to be motivated and stay engaged to complete the intended user journey. Studies in media and performance recommended using technology as an enabler to assist with the transition of user roles [34]. Wouters et al. suggested the deployment of triggers to persuade users to participate and to ease the transition between user roles. However, designers have not yet been offered a structured understanding of VR installations comprising user roles and strategies on how to design for those roles and the transitions between them. We provide a design space that extends our current knowledge of user groups involved in VR installations through a set of frames, and we provide a set of design tactics to support the design for specific user roles and the transitions between user roles, aiming to maintain user engagement throughout their journey.

3 VR INSTALLATIONS

Outlines of the seven VR installations upon which this research draws are provided below, including selected images, a brief description of each experience, and a summary table of their technology setups. Each subsection header includes the installation name, the date and location of its exhibition, the duration of the installation, and the number of visitors who used the HMD (HMD wearers).

3.1 Pure Land Unwired, 2015, USA: Exhibited for 2 days / >70 HMD wearers

Showcased at a visualization conference, Pure Land Unwired (PLU) offered a virtual recreation of the world heritage “Dunhuang Cave 220” constructed from laser scans and ultra-high-resolution photography [29, 52] (Figure 1). Users explored a virtual 1:1 scale model of the cave and its visually rich murals and statues [16], while listening to ambient music. Visitors could also see the cave renderings on a large display screen (Figure 2).

3.2 Grand Prix VR, 2015, Australia: Exhibited for 3 days / >500 HMD wearers

Exhibited to the public at the Australian Formula One Grand Prix, Grand Prix VR (GP) featured a virtual, room-scale car garage including interactive content (which was triggered by the user’s proximity to interactive panels) and an F1 racing car that HMD wearers could explore and sit in (Figure 3). Thousands of people who visited the

Figure 3: Grand Prix VR garage and Formula 1 car.

Figure 4: Setup with display monitor, fan, and invigilator.

GP exhibition venue (event tent) could view the virtual environment on a large display screen (Figure 4).

3.3 Out of Space, 2015, Singapore: Exhibited for 6 weeks / >200 HMD wearers

Out of Space (OoS) provided an abstract, procedurally generated virtual art experience centered around the idea of big data. The environment consisted of semi-transparent cubes of a different hue (Figure 5). Each hue emitted sounds. Exhibited in an art gallery (Figure 6), the HMD wearer could move within the tracking area and hear melodies and rhythms of sound based on their proximity

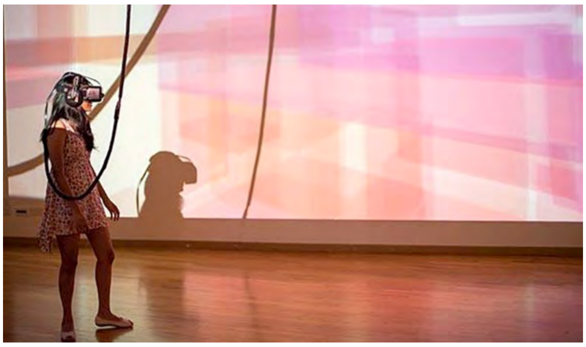

Figure 5: User immersed in Out of Space, wearing a HMD connected with a long cord to a computer.

Figure 6: Setup with large projection screen, and computer on top of the exhibition cabinet connected to the HMD.

to the different cubes. Users could also travel to different virtual levels by activating a virtual elevator triggered by their proximity to solid-colored cubes.

3.4 If Only. . ., 2017, Australia: Exhibited for 3 months / >1,000 HMD wearers

Exhibited at a national public art gallery, "If Only. . ." (IO) provided an interactive experience to complement the design of an architectural pavilion. The physical pavilion design transplanted a familiar object (a car wash facility) into an unfamiliar surrounding (the art gallery) [49]. The VR installation provided visitors with an interactive virtual replica of the pavilion (Figure 7). HMD wearers were encouraged to engage with the concept of 'dematerialization' (the use of alternative materials) by changing the materials of the car wash surfaces with the VR controller, which affected the virtual pavilion's look and feel and changed the shadow patterns on the ground. Visitors could view the virtual environment on a large display screen while queueing (Figure 8).

3.5 ImpactVR, 2017, Australia: Exhibited for 1 day / > 50 HMD wearers

Showcased to a technical audience of game developers at an industry conference, ImpactVR (IVR) comprised a haptic VR installation in which HMD wearers could engage in a sword fight with a virtual opponent and feel the impact of the sword via a handheld prop (a plastic sword) (Figure 9). A Rethink Robotics robot, Baxter, provided the haptic experience (Figure 10).

Figure 7: The virtual view of "If Only. . .", including (in the foreground) a selector that can color the floor and mesh walls and (in the background) a replication of the physical garden.

Figure 8: Rope dividers to guide people queuing for "If Only. . .", and a large display monitor pointed at the queue.

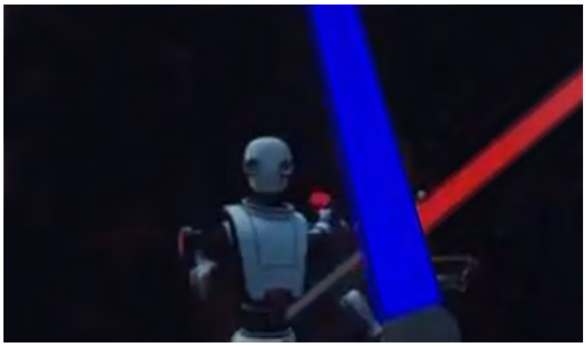

Figure 9: Impact VR simulated the impact of crossing swords with a virtual opponent.

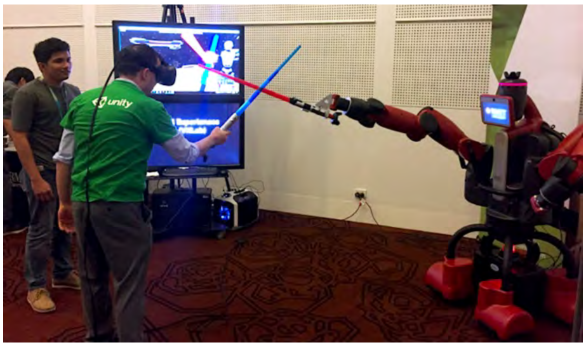

Figure 10: Setup, including a large display monitor and two sword props. The robot movements animated the virtual character in the game and simulated the impact of the sword.

3.6 You Better Eat to Survive, 2017, Canada: Exhibited for 4 days / >70 HMD wearers

You Better Eat to Survive! (YBETS) showcased the entertainment potential of multisensory VR installations. The YBETS game was designed for two participants [1], with only one of them wearing an HMD. The HMD wearer plays a character who is stranded on a virtual island (Figure 11). This character must find food because the character has not eaten for days and is on the brink of falling into unconsciousness but also needs to find a flare gun to call for help. The player not wearing the HMD needs to help the HMD wearer find real, physical food (which is distributed in the real-world environment, and which the HMD wearer is unable to see). Not finding real food counteracts the HMD wearer's vision, which progressively fades to black (which, in the game, represents a fall into unconsciousness). Both participants need to communicate to navigate these physical and virtual worlds. They come together as one "shared body" with the non-HMD wearer embracing the HMD wearer from behind and using their hands, as though they were the HMD wearer's hands, to feed the HMD wearer (Figure 12). Through a sensor connected to the HMD, the system detects chewing activity. The game responds to this activity by restoring the HMD wearer's vision (they regain consciousness in the game) and allowing them to continue to search for the flare gun and seek rescue.

3.7 New Pholiota, 2018, Australia: Exhibited for 2 weeks / > 1600 HMD wearers

New Pholiota (NP) accompanied an architectural exhibition for the general public of a full-size replica of the heritage-listed house, "Pholiota," which demonstrated low-cost home construction [25]. The VR installation (Figure 13) allowed visitors to walk around the physical structure and used a mobile phone-based cardboard VR headset to give them views of the reconceptualized virtual renderings of the physical replica (Figure 14). Visitors could place their mobile devices against tags embedded in the model and then view the virtual renderings through their cardboard headsets to match the renderings to the physical structure and feel the environment.

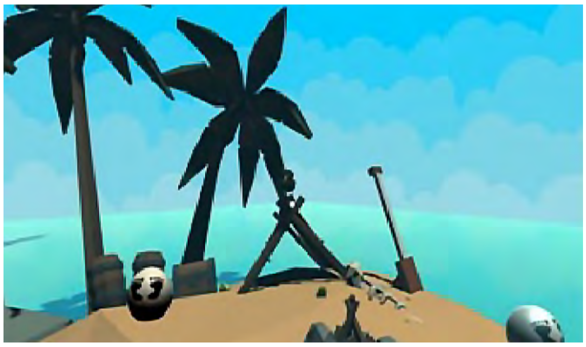

Figure 11: View through the HMD.

Figure 12: Setup, showing invigilator, inflatable palm tree prop, food on tables, and second participant feeding the HMD wearer.

Figure 13: The HMD view of New Pholiota, showing the heritage-listed house.

3.8 VR installations' technology and space setup summary

Table 1 below summarizes the technology and space setup for each of the seven VR installations:

4 DATA ANALYSIS

This research draws upon our work on seven VR installations between 2015 and 2018. These installations were designed across three

Table 1: Technology and space setup for the VR installations

	Screens	User Tools	User Tracking	Audio	Virtual/Physical Space Management
Pure Land Unwired	Oculus Rift DK2 and large display monitor.	Leap Motion Controller (hand input).	Wireless backpack and Kinect v2.	Noise Canceling Headphones.	Desk (separating viewers from users). Carpet (defining VR limits). Operator / Invigilator
Grand Prix VR	Oculus Rift DK2 and large display monitor.	None.	Laptop wired to HMD and Kinect v2 10m HDMI and audio cable.	Noise Canceling Headphones connected with long cable to computer.	Invigilator-managed cables. Operator and Invigilator.
Out of Space	Oculus Rift DK2 and large projection.	None.	Laptop wired to HMD and Kinect v2. Cable from ceiling to HMD via bungee cord.	Noise Canceling Headphones connected with long cable to computer.	Invigilator.
If Only. . .	HTC Vive and large display monitor.	HTC Vive Controller.	Laptop wired to HMD and standalone HTC Vive lighthouses.	Noise Canceling Headphones connected via Bluetooth to computer.	Invigilator. Rope dividers separating queue.
Impact VR	HTC Vive and large projection.	Plastic sword.	Mobile computer wired to HMD.	No audio.	Rope dividers separating queue. Invigilator / Operator.
You Better Eat to Survive!	Mobile phone-based VR headset and large display monitor.	Sensor tracks HMD wearer's chewing action.	Headset tracking.	Noise Canceling Headphones connected via cable with headset.	Non-headset wearing user.
New Pholiota	Mobile phone-based cardboard VR headset.	None.	VR tags determine the space to interact with mobile phone.	No audio.	Invigilator. Physical replica matched with virtual environments.

Figure 14: The physical replica of the New Pholiota house.

different labs, exhibited internationally (at seven public venues), and experienced by thousands of people. The analysis was performed post hoc after all of the VR installations were completed. We analyzed the data from this work to characterize the user roles and generate design tactics. This collated data consisted of participant interview records, 38 hours of raw VR exhibition video footage from multiple camera angles, installation design plans, project team notes, and invigilator feedback.

Following an in-the-wild [56] qualitative HCI research approach, we looked for similarities and differences between VR installation users' behaviors captured by our cameras. We used systematic qualitative interpretation (inductive thematic analysis) of the available video data [6] to understand user practices and experiences. In line with Blandford et al. [5], two researchers worked independently to complete an open coding of a representative sample of 10% of the video data sourced evenly from all installations. This involved coding the video data for users with behaviors identified by other publications [3, 55, 68, 72] and identifying and labeling new behaviors using an open coding process. The research team consolidated the results of the open coding session into an initial coding tree through a series of discussions and arrived at a set of common behavior patterns grouped into user roles. The first author then used this initial coding tree to code the remaining material, providing us with a list of user roles further discussed and refined with the third

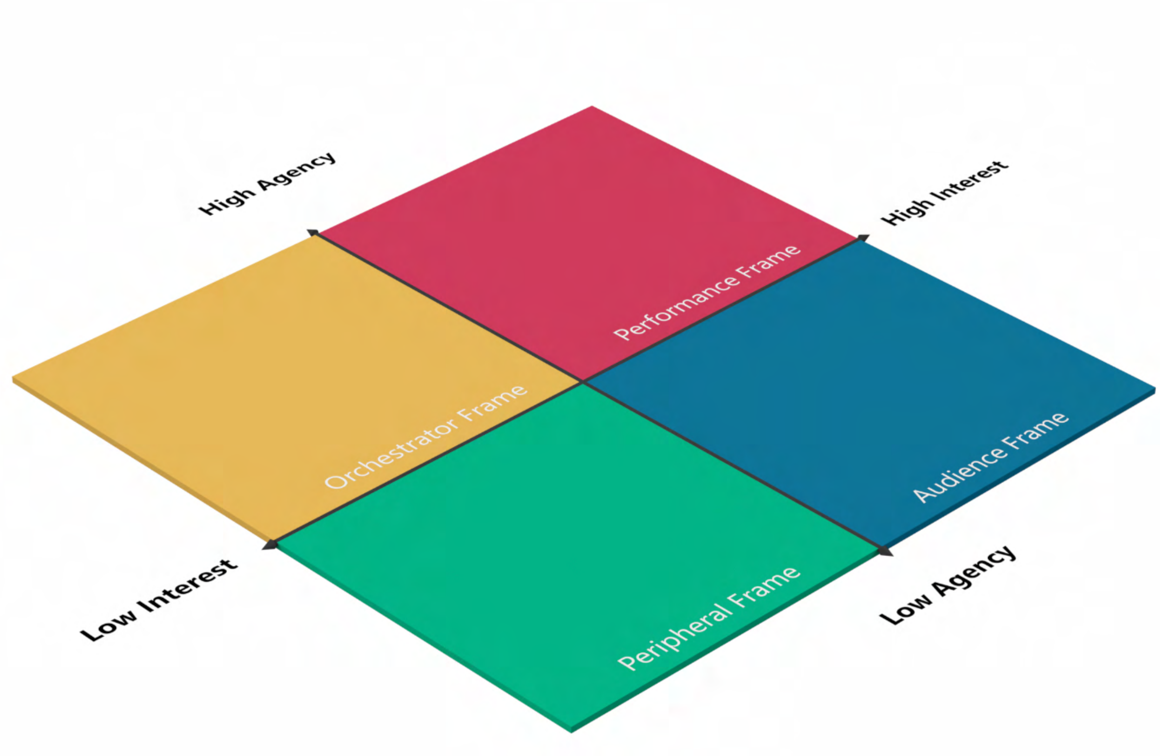

Figure 15: Design space of public VR installations.

author. While some user roles such as passer-by, bystander, and queuer appeared quite frequently in all of our installations, other user roles only became apparent through the consolidation of data from other works. Inspired by Benford et al. [4], all researchers then used a process of reflection across all VR installations realized by the authors and also studied, as reported in prior publications. This process involved revisiting the works followed by a critical analysis of the problems we encountered with each VR installation and the solutions we developed for subsequent installations to derive the design tactics specifically focused on enhancing engagement, drawing upon the user roles' analysis and reviewing the other data noted above. Finally, several workshops were held among the authors to consolidate and classify the design tactics.

5 DESIGN SPACE AND ENGAGEMENT FRAMES

Visitors to our public VR installations had different experiences depending on their level of engagement. This engagement ranged from very unengaged, where they simply kept walking past the exhibition, to very engaged, where they became fully immersed and exercised full agency in the VR installation. Following the concept of trajectories [3], we have mapped each user's journey in the VR installation, and we propose a design space consisting of two key dimensions (interest and agency) depicted as a two-dimensional continuum to articulate user engagement. We draw these two dimensions in a 2x2 space (Figure 15), similar to prior research on understanding interactive user experiences [45, 46]. The vertical dimension describes how much agency users have over the VR installation, defined by their capability of having control over intention, action, and movements [30]. The horizontal dimension describes user interest (a key factor in HCI user engagement theory) as defined by their feelings or emotions that cause attention to focus in on the VR installation, other users, and the experience [10].

The two dimensions divide the design space into four user engagement frames. The green-colored "peripheral" frame depicts user roles with low to medium interest and agency and it comprises mostly outer edge onlookers who are undecided about taking part in the VR experience. The design space's blue-colored "audience" frame depicts user roles with medium to high interest and low to medium agency. These users are generally committed to taking part in the VR experience, are located close to the VR setup, and are able to learn about the VR experience and interpret and influence the actions of users who are in the performance frame. The red-colored "performance" frame depicts user roles with medium to high agency and medium to high interest. These users are at the "heart" of the VR installation, and they can control both their own user experience and the experiences of people in the audience frame (at least to some extent) by being able to control the HMD view (including virtual props). Lastly, the yellow-colored "orchestrator" frame typically depicts professionals (including invigilators and the original designers showcasing the system) who exhibit low to medium interest and possess medium to high agency. These users have an in-depth understanding of the VR installation and can provide technical support and interact with users from all other frames. However, their in-depth familiarity with the content makes them less interested in their own experience.

6 USER ROLES

We now describe the twelve user roles we encountered in our public VR installations, and situate them in the proposed design space frames.

6.1 Users in the peripheral frame

6.1.1 Passer-by. A passer-by is a person passing by the VR installation. Passers-by can be characterized by a low sense of agency (hardly any control over the VR content) and a low sense of interest. They typically browse many other exhibits in the same physical space and, if the VR exhibit manages to pique their interest, they may stop at the exhibit and transition to the bystander role.

6.1.2 Bystander. Bystanders commonly have a low sense of agency over the VR content (they are usually located a little closer than the passer-by and could distract the HMD wearer if no precautions are taken), but they show more interest in learning about it than the passer-by. They often walk slowly and stop at a "safe" distance away from the VR installation to avoid attracting the attention of users in the orchestrator frame, such as actors or invigilators ("worried" that they might be approached). Bystanders generally avoid eye contact with the invigilator due to their reluctance to engage. Instead, they direct their (often fleeting) attention to the exhibition's visual elements. Bystanders can transition into the spectator role if they are sufficiently "attracted" by the promised user experience conveyed by the visuals, the currently immersed HMD wearer, or the number of spectators.

6.1.3 Spectator. Spectators commonly have a higher interest in the VR content than bystanders and become part of the audience if they move closer to the VR installation and closely follow the performing users on the stage, the HMD view on a display monitor, or interact with the HMD wearer. Usually, a larger audience is associated with a better perceived VR installation (we found that exhibition managers took this view). We often observed the honeypot effect [21, 72] at work in these situations, as passers-by and bystanders noticed the presence of spectators, paid greater attention to the VR installation, and transitioned into the spectator role. Should a spectator's interest increase further, they might decide to join the VR installation queue and transition to the queuer role.

6.1.4 Reflector. Reflectors are often spectators who have previously visited the VR installation. As a result, they are more interested in the experience, and they reflect on and re-evaluate their own user experience while watching other HMD wearers. Reflectors are motivated to become queuers again if they see a way to improve their performance or discover unseen VR content. Previous experience provides them with a higher agency as they require less time to familiarize themselves with the HMD and the controller, which means they can spend more time immersed in the VR content. For example, in IO, we observed several users who revisited the exhibition and were more assertive about their choice of surface materials in the virtual carwash, designing a particular look and feel.

6.2 Users in the audience frame

6.2.1 Queuer. Queuers are usually former spectators or reflectors who are sufficiently interested in the VR content to join or re-join the queue. While the queuer waits, they usually observe multiple HMD wearers and are vicariously exposed to multiple loops of the VR installation. They might also undergo accidental training. As they observe VR "performers" (explained below), the queuer learns about fundamental interactions with the system, such as using controllers to interact with virtual objects. The queuer has a slightly higher level of agency than users in the peripheral frame because they can influence the experience of other queuers and the HMD wearer. For example, the queuer can positively influence the experience of others by exchanging information and sharing their excitement about the upcoming experience. On the other hand, they can also negatively influence the experience of others by complaining about the long wait time and pressuring other queuers and HMD wearers to go through the virtual content more quickly. Queuers usually transition into the anticipator role.

6.2.2 Anticipator. Anticipators are usually excited former queuers who are about to take part in the VR installation. They are at the front of the queue or in the process of being "geared up." Anticipators can display a high level of excitement in advance of their VR installation experience. Anticipators can be inspired when they see the viewpoint of an active HMD wearer (a performer or an appreciator, as described below) on the display monitor. They can feel emotions almost as strongly as they will during the VR installation itself [66]. For example, anticipators are often inspired to copy or even outdo a performer they have seen entertaining the nearby audience. Anticipators have a slightly increased sense of agency over the VR installation than queuers. While, physically, anticipators are still at the head of the queue, they are typically very close to the HMD wearer, allowing them to offer verbal or even physical input in the form of feedback, cheering, and nudging. They might make "back-seat" suggestions for the HMD wearer to try different VR content actions because, at this point, the anticipator has observed prior users' behavior and learned a lot about the VR experience. We found that anticipators often pursue social interactions with the HMD wearer, particularly if they are members of the same visitor group or family. During the process of being "geared up," the anticipator's agency increases as they go through five stages of transition from reality into VR [63], starting with gaining physical contact with the VR equipment and props, which gives them a tactile sense of the controls and an opportunity to practice.

6.3 Users in the performance frame

6.3.1 Partaker. Partakers are HMD wearers who have completed queuing and are usually sufficiently interested in the VR content. When users enter a new VR experience, participants generally begin with a proprioceptive analysis by examining how the system manages the location, movement, and action of their body parts, before they engage with the VR content. As such, we believe that most people begin as partakers, primarily concerned with becoming familiar with the VR environment and then engage with the "actual" content that the designers developed and quickly transition into the role of performer or appreciator. However, some users do not enjoy the feeling of being watched and are conscious of how others might perceive their actions, especially as they cannot see such reactions when wearing the isolating HMD headset. Consequently, when they are in the VR installation, partakers who cannot transition into performer or appreciator roles make limited physical movements, exhibit limited desire to interact with the virtual world fully, and show a general unwillingness to let themselves become immersed. Nevertheless, if partakers are offered sufficient time and guidance to learn how to operate the equipment, they can transition into user roles with greater interest levels and agency.

6.3.2 Performer. Performers are HMD wearers who are usually highly interested in the VR content, possess high agency over it, and enjoy being on the VR installation floor. They turn the floor into a stage and take pleasure in entertaining any audience. However, unlike the appreciator (see below), performers are less interested in the VR content and more interested in the opportunity to perform. In GP, IO, and IVR, we noticed that this interaction with the audience could become so dominant that it limits the performer’s ability to fully immerse and explore the full extent of their virtual world agency. In addition, for the performer, receiving feedback from the audience, such as laughter and cheering, is often more exciting and thrilling than the VR content. However, headphones can often diminish this feedback (as discussed later in this paper).

6.3.3 Appreciator. Appreciators fully appreciate the VR content, are intrinsically interested in experiencing the virtual content, and enjoy a high level of virtual world agency. Appreciators do not see their participation in the VR installation as a performance and, consequently, do not intentionally engage with their audience. Instead, appreciators allow themselves to become fully immersed in the virtual content. They also often show a desire to increase their level of agency and, to do so, they use the invigilator to learn more about the VR installation. For example, appreciators often seek to learn about “Easter Egg” features that give them privileged access to content.

6.4 Users in the orchestrator frame

6.4.1 Operator. Operators are professionals (often the designers of the VR installation) situated in the orchestrator frame. Operators generally have extensive and intimate knowledge of the VR content and therefore possess the most agency among all the user roles. Operators can navigate and interact with environments in ways that a performer or appreciator might not discover. For example, in YBETS, the operator knew where to locate the hidden items on the island to collect them quickly. However, due to their intimate knowledge of the VR installation and their exhibition responsibilities, operators are usually not interested in exploring the content.

6.4.2 Actor. Actors are responsible for gaining the attention of passers-by, in the absence of a performer or an appreciator; for example, when the exhibition opens and people begin to arrive. Actors usually have extensive knowledge about and agency over the VR content, which they use to control the virtual content in a way that is compelling to watch on a display. However, actors are performing a task and are usually not interested in the VR content; they are happy to transition to the invigilator role as soon as another user expresses interest in trying the HMD.

6.4.3 Invigilator. The invigilator is responsible for looking after other users in the audience and performance frames. The invigilator usually assists users, explains the basics of interacting with the system, leads them into the VR space, and monitors them from a distance, helping as required. At the end of the user’s VR experience, the invigilator assists with gearing them down and releasing them back into the exhibition space. Figure 16 maps all user roles in the design space.

7 DESIGN TACTICS

We now present a set of design tactics to engage users across all four frames of the design space and in their respective user roles and facilitate their transitions between those roles. There are three groups of design tactics: increasing interest to transition user roles; increasing agency to transition user roles; and maintaining both interest and agency throughout the user journey.

7.1 Increasing interest

We believe that the following design tactics can heighten the interest of the five user roles who exhibit low to medium interest in the VR installation (passer-by, bystander, spectator, reflector, and partaker); “moving” them along the interest dimension of the design space.

7.1.1 Use physical props. We recommend using physical props to increase user interest, conceptually and materially, by extending the virtual world into the physical exhibition space. It is well known that physical and digital props can increase visitor engagement in museums [36]. Nevertheless, props and furniture in a VR space can introduce safety and tripping hazards and are, as a result, often removed from shared and social VR spaces [18]. In YBETS, we used an inflatable palm tree to decorate the VR installation; in PLU, we provided users with a stylish computer backpack to enable the VR experience; in NP, we provided a physical replica of the heritage-listed house that could be explored as a physical model but also as a rendered visualization via mobile HMDs; in IVR we provided users with a plastic sword and used a robot to provide a haptic experience. In YBETS, we also used physical food, integrating it into the virtual deserted island story, to mediate the interaction between the HMD wearer and the non-HMD wearer. We observed that users in the peripheral frame could be motivated to transition to the audience frame if the visual appearance of props is appealing. Moreover, we found that food aromas played an important role in attracting users from the peripheral frame to the exhibit. Using a substitutional reality approach [62]—providing HMD wearers with a tactile user experience of virtual objects via tracked props that embellish simple physical objects with virtual designs—can also increase the interest of users in the performance frame. We also discovered that certain props, such as the futuristic-looking computer backpack and the IVR sword, seemed to amplify the interest of users in “performer” roles who took the opportunity to use them. These users posed for pictures taken by friends and showed off special moves (moonwalking with PLU and martial arts inspired sword fighting in IVR). Moreover, as discussed by prior work [65], sound effects add aural effects to the experience,

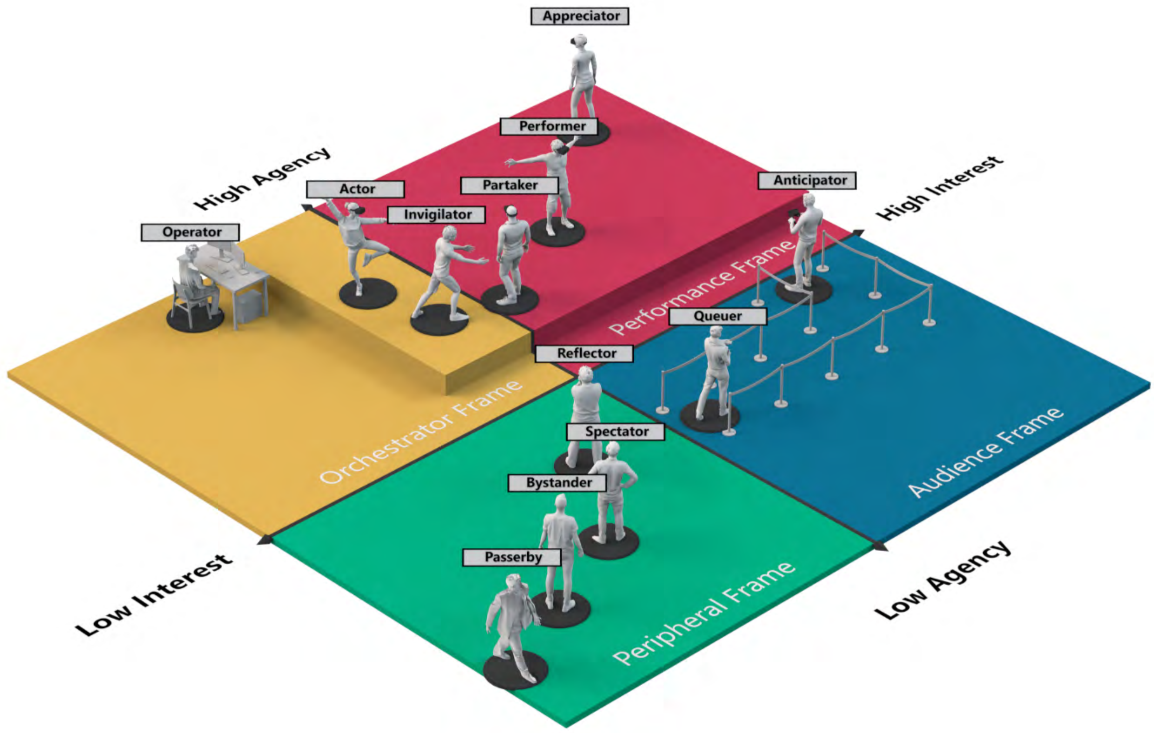

Figure 16: Design space of public VR installations, depicting 12 user roles across four engagement frames. Their position indicates their level of interest and agency in the VR installation. Their posture indicates typical behavior or activities for the role.

and, in the case of IVR, the humming and impact sounds of the sword prop increased the interest of users in the audience frame. We recommend using physical props, as they are relatively inexpensive, easy to deploy, and integrate into VR experiences via a range of tracking solutions.

7.1.2 Increase propensity for immersion. We found that partakers were often not very likely to transition into performer roles because of their reluctance to perform to an audience, or because they had difficulties letting themselves become fully immersed and enjoy the VR content. We recommend increasing HMD wearer interest by providing a carefully designed virtual environment to generate curiosity, increase interest in the virtual world to distract potentially self-conscious users (partakers) from the surrounding audience, and assist their transition to the appreciator role. In PLU, we provided a virtual replica of a cave based on a high-resolution 3D scan, and ultra-high-resolution photography facilitated the close inspection of the environment's statues and wall paintings. Noise-canceling headphones can further isolate the user from audible distractions. An appropriate soundtrack deepens their immersion, allowing users to concentrate on the virtual content to increase their propensity for immersion. OoS, for example, enveloped users in a procedurally generated environment of harmonious color spaces and melodies that changed as they explored the space. Furthermore, we see the potential for further work on increasing the proprioception of users [17], improving the sound design to entertain the HMD wearer [60] and reduce the potential for physical world distractions at VR installations.

7.1.3 Share the VR content. We recommend sharing the content of the VR installation to excite and increase non-HMD wearer interest. Current approaches to sharing include the provision of more HMDs to increase opportunities for sharing VR installations [59], and large screen displays and floor projections for sharing virtual content [19]. Content has even been shared via a translucent screen surrounding the HMD wearer and visible to users in the peripheral and audience frame [27]. However, most of the VR installations we encountered engage users in the peripheral and audience frame by sharing a video stream of the HMD on a display monitor. Many VR installations favor this approach because the solution is cost-effective, easy to implement and deploy, and addresses the challenge to provide users, particularly those in the peripheral frame, with an idea of the work [35]. Indeed, during our work on PLU, OoS, IO, IVR, and YBETS, we found that we could position the display monitor so that it could be watched by user roles in both the periphery and audience frames. Sound and music similarly enhance the experience for users in these frames. We believe designers should be able to do more with such live streams, embedding them into the overall VR installation in more sophisticated ways. For example, the large-scale OoS projection, and the sound of the experience around the HMD wearer, offer compelling hints to people in the audience frame about their upcoming immersive experience and provide a much more immersive aesthetic that frames the HMD wearer in the environment. We are also intrigued, in this regard, by the previously suggested use of biosensors to convey the VR user's affective responses to the audience [58] and thereby increase interest through sharing.

As HMDs become more affordable, we also encourage the use of additional HMDs to allow users in the audience frame to fit and adjust them while awaiting their turn. For example, the VR theme park rollercoaster ride Costiality [12] uses this tactic intelligently to transition user roles in the audience frame: users enter the queue with an HMD and instructions on adjusting its fit. An instructional video played through the HMD further increases interest and keeps users engaged while learning about the virtual characters they will encounter during the ride.

7.2 Increasing agency

We now present tactics to facilitate user transitions along the agency dimension of the design space.

7.2.1 Use the queue time to train VR skills. We recommend increasing the agency of users in the performance frame by better preparing them for the VR experience while they queue. Waiting queuers can learn the required VR user skills so that they possess the necessary knowledge to interact with the content to make the most out of the—often short—VR installation experience. Timely training helps users in the audience frame, such as anticipators, to transition more effectively into user roles in the performance frame. While VR equipment has become more advanced, interactions still commonly require specific body movements and button presses on a handheld controller, and these skills require training. Even appreciators, who possess extensive VR experience, can require instructions because there is (so far) no common standard across VR systems. Integrating VR skills training while queueing is efficient because users do not need to spend as much time learning the required skills during the actual experience. It also increases users' enjoyment and enhances their agency while they are in the audience frame. For example, in IO, we provided queuers with a reusable card containing instructions on how to use the controllers and interact with the virtual content.

7.2.2 Immerse users before the VR experience begins. We recommend that designers include users in the audience frame in the VR experience of the HMD wearer. Prior research found that bystander roles can interrupt HMD wearers and affect their experience [51]. To include non-HMD wearers in the experience of the HMD wearer, other researchers utilized large display screens with motion-sensing technology [26] or floor projection paired with tracked mobile displays [19]. Being included in the VR experience is of particular benefit for anticipators because they can gain a better understanding of the game mechanics, engage in meaningful interactions with the HMD wearer, and facilitate the increased immersion of the HMD wearer.

On the one hand, a rapid throughput of users in VR installations is almost always favorable to minimize wait time and provide as many users with the experience as possible. On the other hand, immersion takes time [63, 70] and it is an important component for users to experience agency [39]. These two competing objectives present a challenge for public VR installations. Our video data captured at PLU, OoS, and IO showed that (especially novice VR) users can often feel a bit overwhelmed when they were launched directly into the content of the experience. We found that users require at least 30 seconds to get "used" to the virtual environment with respect to this challenge. In response, we provided IO users with a virtual lobby before the VR experience commenced. The virtual lobby offered a subtle introduction, which gave HMD wearers time to orient themselves, to get used to the new environment, and slowly prepare for immersion in the VR installation's experience. The introduction explained the artwork and offered training in the operation of the basic controls and movement schemes. We found that all-in-one headsets particularly helped anticipators immerse themselves in the virtual lobby environment until the performer/appreciator finished their turn. We contend that the confidence users gain through this introduction could assist users, especially those likely to become partakers, to make a faster transition into performer or appreciator roles.

7.2.3 Employ other users. We recommend that designers increase the agency and safety of users in the audience frame by making them part of the HMD-wearer's experience. Public VR installations are often temporary and commonly installed in locations not purpose-built for VR, which means that the environment often contains physical risks for the HMD wearer that need to be managed [28, 42]. For example, due to the HMD wearer's inability to see the physical environment, they might walk into building pillars, bump their head on low-hanging structures, or fall down steps. Providing carpet (PLU), crowd control barriers (IO), and chaperone systems that display the boundaries of the interaction space are just a few ways to constrain the HMD wearer's movement and manage physical risks. Of course, users in the orchestrator frame, such as the invigilator in GP, can manage physical risk by observing the HMD wearer and subtly steering users in the performance frame to ensure they stay in the interaction space. Prior work also sought to help HMD wearers to traverse larger spaces in small environments, for example, through redirected walking [54] and jumping [22], body resizing [32], or by subtly directing their movement [37]. Other work sought to manage entire groups of VR users to optimize space use through motion-tracked props [73] or by physically moving the users [50]. However, these risk management responses can reduce the HMD wearer's immersion and interaction freedom and they are not always suitable for public VR installations because they require additional development time [37], cost, and space [54], and are limited to specific content such as narrative games [38]. We highlight that designers can also consider integrating user roles from the audience frame in the design of the VR experience to manage the physical risk of VR installation and increase the agency of users in the performance frame at the same time. For example, we found that the PLU queue could serve as a divider between the HMD wearer and people in the periphery frame. YBETS successfully integrated a non-HMD wearer into a cooperative VR experience with a HMD wearer. The non-HMD wearer physically embraced the HMD wearer (appreciator), controlled the HMD wearer's movement in the physical space that contained structural obstacles (such as pillars in the middle of the room) and provided gameplay hints as to where to find food. This arrangement (including the interactions between the HMD wearer and non-HMD wearer) provided additional physical risk management, increased the agency of a user from the audience frame incorporated in the game, relieved responsibilities of users in the operating frame such as the invigilator, and provided physical input and a social context between the HMD wearer and non-HMD wearer and the audience.

7.3 Managing interest and agency

This section presents tactics to manage interest and agency throughout the user journey.

7.3.1 Accessible VR Equipment. Reaching out to touch things is a fundamental human behavior, and, consequently, we recommend that designers consider making the VR equipment accessible and "graspable" for users before they are immersed in the VR installation. To transition queuers to anticipators in IO, we provided anticipators with a controller of the same kind used in the experience so that they could familiarize themselves with the controller's shape, handling, touch-sensitive surfaces, mini joysticks, and buttons [67]. Displaying such equipment close to the queue entrance appears to encourage bystanders and spectators to come closer to the exhibition [72], and spectators become part of the audience frame. Spectators—particularly those unfamiliar with VR equipment—can gain confidence by grasping the controllers and familiarizing themselves with the HMD and are more likely to transition into queuers. We propose that designers consider placing interactive stations along the queue to maintain interest and agency by offering small games that provide interaction training tasks to get users used to the controllers. As previously suggested [74], designers could even implement these training moments into augmented mini-game experiences.

7.3.2 Customize exit and return strategies for different user roles. We recommend providing users with the agency to exit the VR experience at any time and maintaining interest until they return to the VR installation. Having discussed the engagement of different user roles *into* the VR installation, we also highlight that the different user roles can help designers consider how to help people *exit and return to it.* In line with the dropout role identified by Wouters et al. [72], we recommend that designers consider customized exit strategies for different user roles. We found that if passers-by and spectators were not interested in the VR installation, they simply kept walking or walked away. These actions were straightforward to support as an exit strategy in all our VR installations because we made it easy to physically re-enter a thoroughfare. In IO, we found that we needed to support queuers in exiting the queue without losing their place as the wait times for this VR installation were very long (a queue of 10 users meant 30 minutes waiting time). As a response, we used wide queuing lanes that allowed for an easy exit. To ensure that users did not lose their opportunity to partake, we sent them a text message to their mobile phone ten minutes before their turn, asking them to return to the VR installation. This worked particularly well within the museum environment as users could look at other exhibits while waiting for their turn.

We found that HMD wearers might wish to end their VR experience and leave the VR installation early, sometimes because of the social pressure of performing in front of others and sometimes because they did not find the content sufficiently engaging. We also considered that users might want to remove the headset early due to cybersickness. However, due to the generally short duration of HMD wearer experiences of our installations, we did not encounter such situations. We found it useful to provide instructions during the setup phase for those users who might decide to leave early. These instructions explained that if users wanted to leave early, they could signal by raising their hand or by simply taking off their HMD. We found that, without these instructions, participants were often unsure if they were allowed to leave, and they would wait for an end signal.

Performers, on the other hand, often enjoyed the virtual environment so much that they did not want to leave. This delay can hold up the queue and reduce the throughput rate. Knibbe et al. [31] suggest some design strategies to support the exit experience, such as slowly fading to a real-world view, fading to black, or overlaying ending messages to lessen the impact of abrupt environmental changes. We found that the YBETS rescue mission's endpoint was a clear conclusion to the VR experience and that HMD wearers knew that it was time to take off the HMD. If the flare gun was not found and the mission was not finished, a timer signaled when the moment had arrived to exit the VR experience. Similarly, in PLU, OoS, and IO, a clear endpoint was signaled by a timed *fade to black* at the end of the VR experience and a message displaying that it was safe to take off the headset. We found that clear duration timing mechanisms allowed for effective throughput management.

We acknowledge that it can be more straightforward to implement exit tactics (like those above) for game-like VR experiences and less straightforward for open VR installations. For example, NP had no desired winning or losing end state and, consequently, no ideal point to employ a *fade to black*. Ideally, we believe that the duration of the VR experience in the virtual world could be adjusted dynamically based upon sensor-detected information on the number of people in the queue.

8 LIMITATIONS AND FUTURE WORK

All design work has limitations where practice-related conceptualizations are developed [13]. In this respect, we acknowledge that our work only provides a starting point for designers to move towards a fuller understanding of the design of public VR installations. The study minimized potential bias by bringing together craft knowledge of designing the seven VR installations across three different labs and by extending prior work that mostly derived its user roles based upon studies of single systems (e.g. [11, 20, 35, 51]). However, we were not able to validate the proposed user roles and design tactics past our own experiences, which may limit the generalizability of the identified user roles and design tactics and should therefore be regarded as practical advice "from the trenches". Future work on other VR installations might identify more user roles and design tactics. Nevertheless, we present a starting point for designers to orient themselves when designing VR installations through the four engagement frames of our design space and present the first set of design tactics based on a large corpus of VR installations. Furthermore, we imagine that the models itself could be extended by adding dimensions in addition to agency and interest. Future work could, for example, explore the impact of the design of a particular setting (e.g., private and public) of the VR exhibition and examine the impact of the environment in addition to the VR content.

We acknowledge that our VR installations followed the traditional 'single user and waiting line' model and were developed by small research teams. Therefore, our installations may have favored certain types of user roles whilst eluding others. Future work should explore alternative VR installations, such as designed for theme parks that aim to immerse multiple users at the same time, that go beyond the traditional public VR model that we have investigated to unlock our work's true potential.

We conducted high level analysis to focus more on the identification of the roles, and their overall characteristics to present the design framework. However, a detailed analysis on the number of visitors, demographics, roles, and timing of when the shifts between roles occurred could be useful for future VR exhibition work.

Also, our research does not address practical "external" factors that designers may not control, such as marketing budget, available physical space, availability of staff to serve as facilitators, time restrictions, and hygiene requirements responding to current challenges. We have also not yet sufficiently considered roles regarding people living with a permanent or temporary disability or people with low vision, many of whom can be severely limited in their ability to engage with VR installations. We also acknowledge that, given the wide range of VR installations, not every design tactic is relevant for every VR installation. We also stress that our tactics cannot replace the need for careful consideration of the context of each new VR installation.

While our work is focused on VR installations, we believe that our insights may also be relevant to other social VR settings. As VR systems are increasingly also used in the home, such as the living room, where other household members share the same space but might not be HMD wearers, our work might also benefit those who design VR for such private spaces, therefore aiding the whole VR community. In addition, we believe that our work might also be of interest to designers of other immersive experiences that do not involve a HMD but might similarly benefit from considering different user roles, including CAVE [8] and Dome [41] installations, and possibly even augmented and mixed reality experiences. We leave such investigations for future work.

9 CONCLUSIONS

In this paper, we have presented a public VR installation design space that aims to help designers support the different roles users can assume in the same physical space. Our design space reminds designers that multiple user roles exist, each with their own expectations, demands, and needs. The design space spans four different engagement frames via the dimensions of agency over and interest in the VR content. Using the design space, we articulate twelve different user roles. With respect to these user roles, we also present a set of design tactics to increase and maintain user engagement (interest and agency) and support user transitions between roles so that more people engage with VR installations and benefit from what VR has to offer.

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