A Design Space for Social Presence in VR

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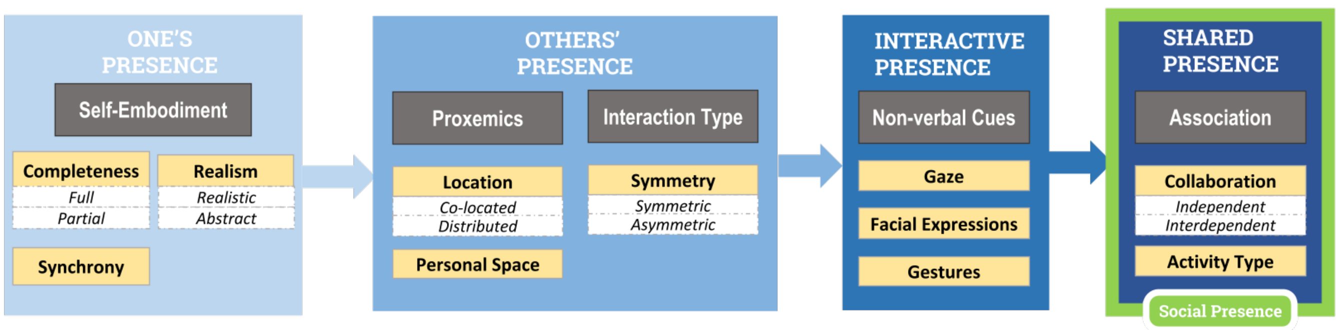

Figure 1: Our proposed five-dimensional design space to leverage social presence in virtual reality applications. The layers of presence are a hybrid psychological model we define based on prior work [49, 59]. The dimensions are identified via thematic analysis of our literature corpus. The themes are in accord with prior work (e.g. [46]). However, our contribution is identifying commonly used elements in literature and mapping them to the hybrid psychological model to systematically help developers build engaging social VR experiences.

ABSTRACT

After the outbreak of COVID-19, creating believable social virtual environments to substitute face-to-face interactions became vital. Social presence is essential for creating realistic and engaging social virtual reality (VR) experiences. However, mimicking realistic social presence within virtual environments is an ongoing research endeavor. In this paper, we fill this gap by reviewing (N = 347) and analyzing (N = 68) the existing literature about social VR across four venues during the past 9 years to elicit a novel design space for techniques and design parameters that enhance social presence and identify open research opportunities and common design trends across various social VR domain areas. We conclude that asymmetric interactions are under-explored due to their novelty. Additionally, self-embodiment and non-verbal cues are key features for social presence in social VR applications. We envision that our work will aid in shaping users' virtual experience through building believable social VR experiences.

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CCS CONCEPTS

• General and reference → Surveys and overviews; **• Human-centered computing → Virtual reality**; **HCI theory, concepts and models**.

KEYWORDS

Social VR, Social Presence, Immersive VR, Symmetric Interaction, Asymmetric Interaction, Design Space, Design Guidelines

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1 INTRODUCTION

The outbreak of COVID-19 triggered the need to develop high quality and realistic social virtual environments that replace normal social interactions. Virtual reality (VR) is becoming a prominent medium for fostering realistic social experiences in plethora of domains such as communication, heritage, traveling, and entertainment (e.g. [25, 34, 65, 70]). Conveying the user's actions in the virtual environment (VE) enables others to understand the social context and interact properly with the VE and the user. Consequently, a cornerstone challenge in designing an enjoyable and engaging social VR experience is supporting *social presence*. *Social presence* is the ability to feel others present with you in a virtual environment [8]. High presence in the virtual environment leads to closer emotional responses and reactions to those experienced in the real world [7, 43, 59]. Additionally, social presence positively correlates to enjoyment and trust [46].

Despite the importance of maximizing social presence in VR experiences, design guidelines for the process are relatively underexplored. Parsons et al. provided a psychological model to describe various levels of social presence [49]. The model gauged social presence via the ability to understand others' actions and appropriately react to them. Oh et al. [46] complemented this work by providing a recent comprehensive literature review on designing for social presence in VR. Their work covered a holistic spectrum of factors affecting social presence namely immersive, contextual, and psychological factors. However, they did not provide a process that systematically maximizes social presence for VR experiences.

Our paper complements prior work by defining a detailed design space that optimizes social presence in VR applications. To this end, our **contribution** is *three-fold*: (1) proposing a five-dimensional design space to support all levels of social presence in VR (see Figure 1), and (2) highlighting common design parameters based on the domain of the VR application (see Figure 4), and (3) identifying open opportunities for exploring social VR interactions (see Figure 8). Although our work is not intended as a comprehensive account for the research efforts within the last nine years, our proposed design space bridges the gap between the psychological and the contextual models by (1) defining concise functional design dimensions leveraging VR interactions, and (2) extending Parsons' model [49] by mapping our identified dimensions to different layers of social presence identified by Parsons et al. [49], creating a progressive workflow of social presence (see Figure 1).

Our results show that social presence is achievable through optimizing five dimensions, investigating design parameters in asymmetric interactions is an open research opportunity, and *Self-Embodiment* and *Nonverbal Cues* are critical building blocks for designing an engaging social VR experience. We envision that our work will provide researchers and practitioners with design guidelines to build engaging social virtual experiences that capitalize on the human's natural social intelligence.

2 PSYCHOLOGICAL BACKGROUND

Immersion is defined as the framework where place illusion occur [47, 66], which is when a user believes that the virtual environment (VE) is real [47]. Slater et al. hypothesize that increasing the interaction modality in an environment increases its immersion rate [66]. *Presence* is the subjective feeling of "being there" within a virtual environment [47, 73]. High level of presence is related to how deep users are immersed in the environment, as well as, their ability to "act there" in the VE [60]. Consequently, presence is defined in terms of immersion and identity expressiveness [2, 11, 51].

Social presence is defined as the ability to feel others present with you in a virtual environment [8, 9, 67]. Parsons et al. define social presence as a function of intent [49]. They define *intent* as the ability to understand others' motives through analyzing the actions they carry. It is described via a three-layered chain which we adopt in this paper to describe our focal point, *social presence*. The three layers must be achieved in the following order and are described below with examples adopted from Parsons' work in the context of being at a party. The first is *others' presence*, which is the lowest level of social presence. It represents the ability to recognize motor intentions or the ability to carry out an intention (e.g. recognizing the availability of others for social interaction). Next level is the *interactive presence*, which is the ability to recognize both motor and proximal intentions. Such ability allows people to recognize others intent towards them (e.g. noticing someone staring at you). The final and highest level of social presence is *shared presence*, which is the ability to recognize all three intentions, namely motor, proximal, and future-directed intentions. It allows users to identify others who share similar high-end goals. (e.g. after noticing someone who is staring at you, you initiate a conversation to check common interests). Within this manuscript, we use the aforementioned layers of Parsons' model to reflect on the literature and distill design guidelines for social presence.

3 METHODOLOGY

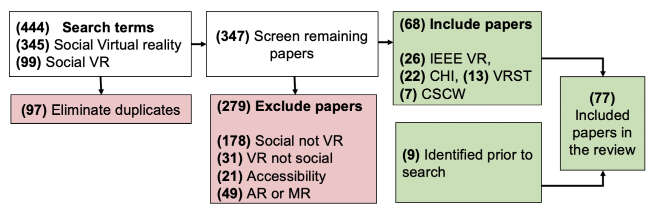

Figure 2: The literature corpus filtering process. The excluded papers are denoted using red boxes and the included are denoted by the green ones. 24 papers (35%) utilized *non-immersive* social VEs in their solutions. The numbers denote the papers fitting in each category. 38% of the papers are in IEEE VR conference, followed by 32% of the papers are in CHI conference, followed by 20% from VRST and finally 10% from CSCW.

We conducted a systematic literature review in the past 9 years (2010-Feb 2019) using both the ACM and IEEE Digital libraries. We applied an "AND" search query using each of those terms *Social VR* and *Social Virtual Reality*. Our search covered both full text and meta-data search (title and abstract). The year refinement was enacted to account for the launching of new immersive technologies that highly affect presence. For example, the first OculusRift prototype was introduced in 2010. Our target was to cover Human-Computer Interaction (HCI), Virtual Reality (VR), and Social Computing literature to gauge different design techniques utilized in social virtual environments. Based on the result of our search query, we selected *four* venues that had the highest number of publications, given our search constraints, targeted literature, and scope. The four venues were: the ACM conference on Human Factors in

Computing Systems (CHI) (N = 171), the IEEE conference on Virtual Reality and 3D Interfaces (IEEE VR) (N = 124), the ACM conference on Computer-Supported Cooperative Work and Social Computing (CSCW) (N = 88), and the ACM Symposium on Virtual Reality Software and Technology (VRST) (N = 61). Although our work is not a comprehensive account for the research efforts within this period, it draws on recent trends in applications and distill common design guidelines for building social VR experiences, similar to the work done by Khamis et al. [24]. For a comprehensive account of the recent literature on social presence in VR, we encourage the reader to check [46].

Figure 2 gives a detailed account of the literature filtration process and the final corpus distribution within venues. After merging the results and removing duplicates, we had 347 papers. After thoroughly reviewing each of the papers, many papers were excluded from further analysis. Typical reasons were: false positives of VR papers that lack a social aspect (9%) or social papers that lack a VR solution (51%), augmented reality and mixed reality papers (14%), and social VR solutions designed for accessibility papers (6%). The exclusion of the accessibility context is attributed to the heterogeneity within this user group, as sensory substitution might be needed. Thus, we cannot make claims about the applicability of the functional requirements of this user group. Therefore, 68 papers (20%) were analyzed and presented within this manuscript.

The surveying process consisted of *four* iterations, as shown in Figure 3. During iteration 1, one author, P1, tagged each paper with multiple themes. Initially, the themes were: (1) the main contribution of the work, (2) the setting of the work conducted, in terms of its interaction type and location setting, and (3) whether social presence was statistically evaluated or not. While P1 decided on the initial themes, another co-author, P2, was included to discuss and cluster the themes. Therefore, additional open tags were added organically during analyzing the corpus. Afterwards, P1 and P2 discussed the allocation of papers and the emergence/merging of (sub)dimensions during iteration 2. Thus, two researchers identified *five* design approaches frequently used to enhance social presence.

To ground our technical dimensions, we map each dimension to a level in a hybrid psychological model in order to understand the progression of social presence in VR prototypes. We built the hybrid model using (1) Parson's psychological model to define the layers of social presence and (2) extended it by introducing "one's presence" from Schuemie's model [59] as a prerequisite to social presence. We hypothesize that the user needs to feel present in the environment to perceive the presence of others in the same environment. Therefore, our work complements Schuemie et al.'s work as they identify one's presence (presence) and social presence as two separate constructs. Afterwards, one researcher, P1, re-tagged the included papers using the new technical dimensions. Thereafter, we conducted morphological analysis and identified open research opportunities to support the social context in VR.

4 DESIGN SPACE DIMENSIONS

Figure 1 summarizes the dimensions identified as a result of our analysis to the corpus and maps each to the hybrid psychological model proposed earlier. We denote dimensions supporting the sense of *one's presence* i.e. presence by (□ □ □), *others' presence* by (■ □ □), *interactive presence* by (■ ■ □), and *shared presence* by (■ ■ ■). We describe here each dimension, while shedding the light on (1) examples from the latest research contributions that led to identifying it from the corpus and (2) design recommendations distilled from the discussion and lessons learned of papers utilizing the dimension. Finally, an exemplary scenario is used as a use case to demonstrate how and when to apply each design recommendation.

4.1 Self-Embodiment □ □ □

4.1.1 Description. This dimension refers to the users' feeling of owning their virtual representation (avatar). It supports *one's presence* in VR and has three sub dimensions: (1) **COMPLETENESS** which refers to the amount of represented body parts (e.g. showing hands only vs. full body avatar in the VE), (2) **REALISM** which refers to the resemblance degree of the avatar to the real world (e.g. showing robot hands vs personal modelled hands in VR), and (3) **SYNCHRONY** which refers to the sensory feedback used to communicate the natural body behaviour (e.g. when a person is clapping, the clapping movement is displayed "visual feedback" and the sound is played "auditory feedback").

4.1.2 Literature Analysis. Several studies evaluated the effect of avatar representations on users presence in non immersive environments (e.g. [10, 15, 51, 72]). Their findings reveal that avatars that reflect the identity of the user increase the user's presence in the environment, which confirms that adequate user representation significantly affects social presence in social immersive environments [52, 67]. This notion was confirmed by McEvoy et al. [41], as participants exhibited higher presence rates while watching a bullying incident video than that while viewing the incident in VE. Participants reported that they would have felt more involved or present if the avatars looked more realistic. We present below an overview on the research done to explore the impact of each sub-dimension on social presence.

COMPLETENESS: Full body user representation significantly enhanced social presence in immersive environments. Smith et al. conducted a user study to evaluate the adequacy of social VR as a communication medium. In their study, participants carried out two activities (negotiating layout and furniture placement) in three different environment settings: (1) face-to-face (real world), (2) embodied avatars (VR), and (3) no embodied avatar (VR) [67]. During the third setting, participants reported difficulty in both negotiation and placement. Moreover, the researchers had to render the hand in the placement task, as participants failed to move the furniture without knowing the hand location. The study showed that embodied VR setting established significantly higher social presence score than that of the no embodied VR one, even during the placement activity. Consequently, full body avatars impact social presence better than partial ones.

REALISM: Primitive avatars had a positive impact on social presence [67]. For instance, Roth et al. [56] conducted a user study to evaluate the effect of reduced social information in an immersive social virtual context. They utilized abstract avatars that don't support facial animation or gaze and concluded that the reduction of social information significantly reduced performance. However, there

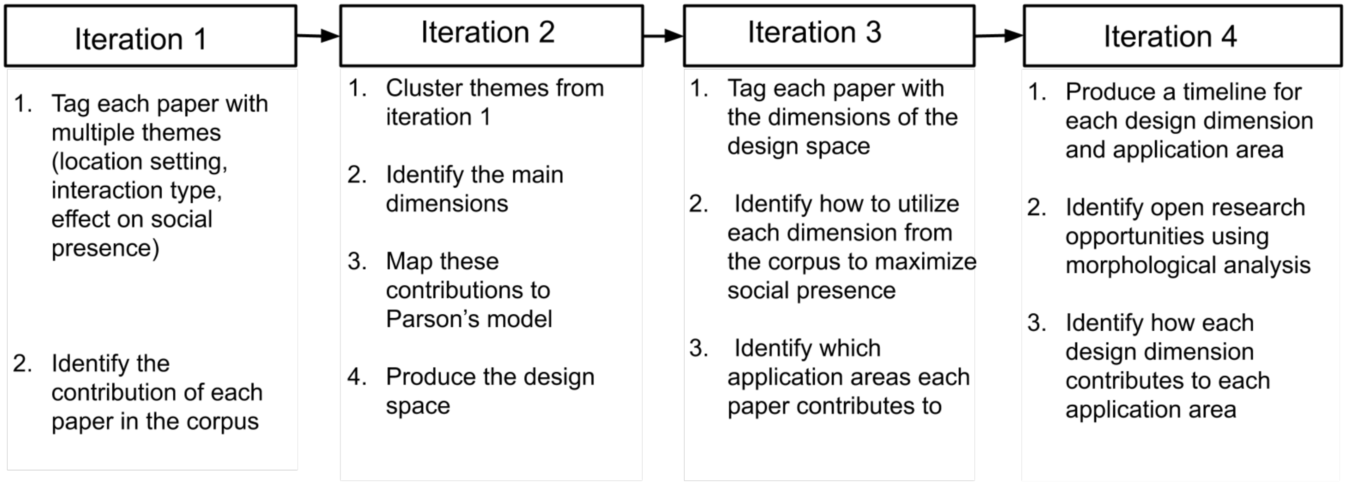

Figure 3: Our methodology in analyzing the corpus. Iteration 1 uses closed tags to label the corpus. Iteration 2 produces the design space by clustering the themes obtained from iteration 1. Afterwards, iterations 3 re-tags the corpus in the light of the design space, and iteration 4 determines the open research areas and main design trends.

were no significant effects on social presence. Moreover, Wong et al. conducted a user study that evaluated the effect of self similar avatars on users in a rescue game context [72]. Their findings convey that avatars that are similar to the users enhanced immersion, as it increased the user's sense of ownership; however, there was no statistical analysis on the effect of realism on social presence. Malleson et al. [38, 39] designed a platform that uses stereo DSLR setup along with depth cameras to create realistic avatars with audio-based lip animation. However, no user study was conducted to evaluate the effect of the solution on neither presence nor social presence. Latoschik et al. complemented Malleson's and Wong's work by investigating the effect of avatar realism on social presence [28]. The avatars were generated by capturing the users image using 40 DSLR cameras. Their user study revealed that realistic avatars enhanced human-likeness rates significantly, evoked high virtual body acceptance rate, and insignificantly affected social presence rates. However, participants reported potential uncanny valley effects due to excessive realism. *Uncanny valley* is the nonlinear relation between human-likeness and familiarity that arises from a disparity between appearance of the character and the way it moves [60]. The uncanny valley can be avoided by abstracting the avatar's features or creating smooth and realistic motion [28, 47, 60].

Synchrony: Creating synchrony between the visual feedback and another modality, namely *proprioception, motor, tactile, or audio* feedback is a common approach to enhance the sense of self embodiment. Motion tracking devices support designers in the creating *visual-proprioception synchrony*, where the virtual body parts are rendered where the real body parts are expected to be (e.g. [2, 11, 47, 51]) and *visual-motor synchrony*, where the virtual body moves the same way as the real one (e.g. [11, 20, 36, 51]). On the other hand, creating *visual-tactile synchrony* (e.g. [32]), which is experiencing touch in the real world when it is seen in the virtual world, and *visual-audio synchrony* (e.g. [50]), which is synching visual and audio signals (e.g. when participant walks, (s)he can hear their own footsteps) is still an on-going research challenge. Including several modalities was proved to increase overall presence and social presence rates [48]. For instance, Lee et al. [32] included several modalities in their user studies, where participants reported significantly higher social presence scores when using all the aforementioned modalities. In conclusion, embodiment via modality synchrony is highly dependent on the used hardware and the quality of motion tracking mechanisms.

4.1.3 Design recommendation. Self embodiment is achieved through providing user representation that is not excessively realistic. It (1) entails a full body representation that the user can identify with and consider their own, and (2) mirrors the user's movements adequately via dual modalities.

4.2 Proxemics ■ □ □

4.2.1 Description. This dimension refers to the location and distance between the participants. It supports *others' presence* in VR and has two sub dimensions. The first is **location** with two possible values: (1) co-located, where all participants are in the same physical space (e.g. labs), or (2) distributed, where a subset of the participants is in a different physical space (e.g. across continents). The second sub dimension **personal space** is a distance continuum variable that represents the inherent virtual environment restrictions to protect the personal space of the users.

4.2.2 Literature Analysis. We present an overview of the studies that utilized different location settings and explored the effect of proxemics on social presence.

Location: Thirty nine percent of the studies in the corpus designed their social VR system in a co-located setting (e.g. [5, 26, 74, 75]). During those studies, participants often used verbal communication extensively during their interactions within the VE.

A key advantage was the physical presence of the users in the environment supported establishing others' presence.

Although social interactions are more intuitive in co-located settings, there is a need to support remotely located users. Consequently, several studies in the corpus propose solutions to social VR in a remote context (e.g. [13, 14, 33]). However, this introduces network latency as a new challenge to social VR systems [30]. High network latency reduces the quality of the social VR experience, which led to building optimized architectures to mitigate this challenge [17, 30]. The results show that using proper network optimizations, high rates of social presence can be reached [17]. Additionally, remote social VR platforms require more accurate tracking systems and proper space mappings to prevent violations.

Personal space: When participants are physically co-located, meanwhile immersed in the virtual environment, violations to intimate proxemic zone might occur, which cause discomfort among participants [13, 42, 64]. Therefore, space mapping mechanisms are needed to avoid such incidents [19, 53]. However, proxemics are challenging in remote settings as well. For instance, one participant reported severe discomfort from a harassment incident in a remote study, where another user tried to force feed him [43]. To address this challenge, Bera et al. [4] and Rivera et al. [54] developed systems that predict the trajectory of each group member (group cohesiveness) [4] and plan collision free paths for avatars and agents to navigate within large spaces [54].

4.2.3 Design recommendation. Co-located settings are the easier design to establish others' presence. While remote settings offer more flexibility for the user's location, optimizing network overhead is crucial to maintain the experience quality. Generally, it is essential to reflect physical world social interactions inside the VE in a way that respects the users personal space to avoid discomfort.

4.3 Interaction Type ■ □ □

4.3.1 Description. This dimension refers to the immersion distribution of individuals in a social experience. It supports *others' presence* in VR and has one sub dimension, namely **Symmetry**. It has two possible values: (1) symmetric, where all the users are fully immersed in the VE (eg. Facebook's Spaces), or (2) asymmetric, where only one user fully immersed in the VE while others are just shown a "window" to the virtual world (eg. a user wearing a head-mounted display (HMD) with an experimenter in a lab).

4.3.2 Literature Analysis. Although social interactions within and outside the VE can impede immersion [8, 9], context-related activities improve social presence. Thus, multiple studies addressed this trade-off by embedding the interaction within the virtual activity scenario via different interaction types.

During symmetric interactions, all participants in the scene are equally immersed. Although eighty eight percent of the corpus provided social VR solutions in a symmetric setting, only twenty six percent investigated the setting impact on social presence (e.g. [3, 17, 44]). The findings of these studies reveal that immersion significantly enhances one's presence in the VE which reflects positively on social presence, as others' presence is established. However, symmetric interactions require the availability of multiple HMDs, which is challenging in co-located lab settings [18].

Gugenheimer et al. were among the first to design an asymmetric interaction system that fosters social interactions to support immersion within co-located VR interactions [18]. Only nine percent of the corpus investigated asymmetric interactions due to its novelty (e.g. [1, 22, 30]). The studies focused on increasing the social presence of non-HMD users and including them in the VE. Therefore, their systems supported social interactions outside the VE, such as non-HMD user grabbing HMD user's hand in the real world. Those interactions were mapped accordingly in the VE. Consequently, it enhanced the social presence for the HMD user. However, asymmetric systems are still a novel technology that comes with all its challenges. A key challenge is the disparity of the power distribution between the HMD and non-HMD users [18, 19]. However, this challenge is addressed in the last dimension of the design space, namely *Association*.

4.3.3 Design recommendation. Asymmetric interactions are preferred in co-located settings with large groups of bystanders participating in the virtual experience. Such interaction can augment social interactions inside and outside the VE, maximizing the social presence for HMD and non-HMD users. However, maintaining a balanced power distribution needs to be carefully considered to avoid feelings of displeasure. In conclusion, symmetric interactions are simpler to design for, as all users have the same capabilities.

4.4 Non-verbal Cues ■ ■ □

4.4.1 Description. This dimension refers to the non-verbal cues used by people to convey intention (e.g. waving hands in greeting). It supports *interactive presence* and has three sub-dimensions: **gaze**, **facial expressions**, and **gestures**.

4.4.2 Literature Analysis. In social interactions, people rely heavily on nonverbal cues that are absent in the VE. Thus, the social context is not fully transferred in VR, which impedes the social interaction [13]. Consequently, several studies attempt to augment such cues within the VE (e.g. [5, 16, 61, 63, 76]) to correctly perceive and understand others' intentions. We summarize some of the research endeavours to pinpoint the impact of the cues on social presence.

Gaze: Steptoe et al. evaluated the effect of augmenting visual cues such as gaze, pupil size, and blinking in the VR scene on social presence and the ability to distinguish truths from lies [68]. Although there was no significant effect on social presence, participants could better judge the partner's integrity because of the cues [68]. Vidal et al. also evaluated the impact of embedding gaze direction on social interactions in a semi-immersive VE [71]. The participants conveyed their awareness of others in the environment; i.e. high social presence. Lynch et al. [37] investigated the importance of gaze in conveying a participant's intended path and in avoiding collision. Their study concluded that gaze had an insignificant effect on the collision avoidance behavior of participants. Moreover, Krum et al. [27] conducted a user study to investigate the perceived eye contact in the VE, given three different gaze behaviors (extensive, real life, random). Participants perceived significantly more eye contact in the real life gaze behavior than that in extensive gaze behavior. Additionally, Roth et al. [55] conducted a user study to evaluate the effect of augmenting nonverbal cues in the VE on social presence. Their study concluded that perceiving eye contact significantly increased the user's social presence in the VE. Thus, gaze tracking refines conveying social intents.

Facial expressions: Roth et al. built a system that captures facial expressions and body motion through depth cameras [57, 58]. Additionally, Murphy [44] and Lugrin [35] developed systems that captures facial expressions through video cameras and depth sensing devices, respectively. However, there was no evaluation of these augmentations on social presence. Mavridou et al. [40] developed a face tracking solution that accommodates immersive environments. Their solution utilizes EMG technology to detect muscle tones along with accelerometer, gyroscope and photo-plethysmograph (PPG) pulse rate sensors to provide information about posture and state. Bönsch et al. [6] conducted a user study to investigate the effect of emotions (happy, angry) and group size (1,3) on personal space preference. Their study concluded that users maintain significantly larger distance from *one angry* avatar and *group of three avatars*. Jun et al. found that facial expression synchrony between the avatar and the user significantly affects presence [23]. Thus, the impact of facial expressions on social presence is an open research opportunity.

Gestures: Controllers limit conveying hand gestures. Several studies investigated replacing the controllers with gestural interfaces (e.g. [9, 43]). However, the technical limitations of the motion-capture technology hinder detecting statistically significant effects of gestures over traditional controllers on social presence. Regardless, participants evaluated the gestural solutions positively. For example, participants reported high involvement and awareness of the people in the VE when they used only hand tracking to create non-verbal gestures that conveys a message [43]. Similarly, participants preferred body and hand gestures to keyboard and mouse during the interaction in VE [8, 9]. The impact of the technology's accuracy on social presence is confirmed via the findings of Smith et al [67]. After using accurate motion trackers on the joints, there was no statistical difference in social presence between VR and face to face communication. Similarly, Tang et al.'s solution that captures the movement using Kinect cameras led to significantly higher social presence [69]. Thus, the impact of gestures on social presence is also an open research opportunity.

4.4.3 Design recommendation. The cue type depends on the system goal. For instance, if the user is manipulating objects, then augmenting natural gestures in the VE would increase social presence. However, if the system is designed for networking, then gaze and facial tracking would support social presence, as social cues would be mimicked.

4.5 Association ■ ■ ■

4.5.1 Description. This dimension refers to creating collaborative activities and dependencies between the skills of multiple participants in the same VE, which supports *shared presence* in VR. It has two sub dimensions: **collaboration** and **activity type**. **Collaboration** could either be set to independent, where each user needs no others to perform an action or interdependent, where a user's skill set needs to be complemented by other users. For example, one user can navigate in the VE, while another is responsible for shedding the light. The **activity type** refers to the mechanics of exchanging the skills between participants.

4.5.2 Literature Analysis. Since users' power disparity can significantly detract from the VR experience, interdependence limits the users skills within the VE to create a need for cooperation. We present an overview of the activities adopted in the literature and analyze their effect on social presence.

Collaboration: Shared presence is the highest level in achieving social presence. It is achieved via sharing a global goal with others [49]. Thus, social interdependence could foster it. To explore this hypothesis, Gugenheimer et al. investigated the impact of social interdependence on enhancing social presence in asymmetric setups via balancing the power distribution. They added interactions like the HMD user navigates through the VE and the non-HMD user sheds light on dark areas in the environment for HMD user to see [18]. They compared their setup "ShareVR" to a 2D non immersive game setting (Baseline). ShareVR established significantly higher social presence results. Similarly, Wienrich et al. [73] evaluated the effect of interdependence on social presence through a user study, where users had to solve a task collaboratively in two conditions (interdependence, no interdependence). Their results show that social interdependence significantly increased social presence and cooperation among participants in the VE. Although, interdependence significantly enhances social presence, most of the studies in the corpus adopt independent activities. Thus, the effect of interdependence on social presence is underexplored.
Activity type: Nunes et al. [45] investigated different collaboration and competition features and their effect on the user's performance and presence in virtual exergames via testing four different setups. However, no statistical analysis was conducted between these setups. Gugenheimer et al. extended their work in "ShareVR" to focus on the impact of activity type on the social presence. They built a new and more compact asymmetric co-located prototype, named "FaceDisplay" [19]. They conducted a study exploring the interactions within VR games using competitive and collaborative activities between HMD and non-HMD users. HMD users reported negative rates for enjoyment and engagement during competitive tasks, as the non-HMD users had higher power viewing the real and virtual worlds. However, HMD participants reported significantly higher social presence rates during the collaborative game compared to the competitive game. Thus, activity type needs to be carefully considered in an asymmetric setting as the user's power distribution is not balanced. Their study concludes that social presence can be significantly enhanced in an asymmetric setting. Additionally, placing common ground or theme to the activity has a positive effect on social presence. For example, Smith et al.'s activities were all centered around a certain apartment. They believe that this notion contributed to the high social presence rates [62, 67].

4.5.3 Design recommendation. Interdependent collaborations are recommended for asymmetric interactions to establish shared presence. The activity type should be carefully considered to avoid disparity in the power distribution among users. For instance, collaborative activities are preferred in co-located and asymmetric settings because they will augment social interactions in the VE. However, competitive activities are preferred in a symmetric setting, where all the users have the same privileges.

4.6 Example for Applying the Framework

We provide a speculative example for designing a *virtual brainstorming* solution to show how designers can use our design space. Multinational and interdisciplinary teams need to collaborate remotely, after the prevalence of tasks outsourcing. Thus, there is a need to support virtual design activities, such as brainstorming. It involves interactive physical activities and moderation which requires high social presence. We approach the design problem systematically after understanding the context.

A designer shall first think about *supporting self-embodiment to enhance one's presence*. Users would probably like a full-body avatar that reflects their identity and mimic their physical movements. Therefore, full abstract avatars will be a suitable user representation, as abstraction overcomes social domination. The user expects the avatar to mirror their movements, as well. Thus, at least Visual-motor synchrony is needed. Next, the designer would think about *the location constraints of the use case to establish others presence*. In a multinational team, distributed locations of team members could be expected. Introducing personal space constraints preventing others from bumping into the user is also appropriate within a professional environment. Afterwards, (s)he would consider *the appropriate interaction type*. In the scenario, multiple team members are in each branch but only one HMD is available for them. Thus, asymmetric interactions are needed. Next, (s)he would consider *supporting interactive presence by reflecting non-verbal cues*. Gestures will enhance the communication granularity, meanwhile gaze and facial expressions are not necessary. Lastly, (s)he would consider *supporting interdependence to reach shared presence*. We will need interdependent interactions because of our asymmetric setup. The activity in this scenario must foster collaboration and equal power to support the brainstorming goals. One could think about assigning different roles to HMD and non-HMD users by (1) limiting the task board modification to HMD users (within VE) and (2) providing the non-HMD users with a third person view of the task board and the ability to submit the final task board to the other team in order to balance the power distribution.

5 DESIGN TRENDS IN SOCIAL VR

In this section, we (1) categorize the application domains of social VR experiences to better understand the design trends (see Figure 4-A), (2) examine the prevalence of different applications and design (sub)dimension across the corpus four venues, as illustrated in Figures 6 and 7-A, and (3) review the recent design dimension and application trends for social VR solutions (see Figures 5 and 7-B). We coded applications using two criteria: (1) the main goal as defined in the study, and (2) the dimensions utilized in developing each application. The percentages reflect the ratio of the studies tackling each application area in the corpus. For each area, we discuss the deployment history and relevant design (sub)dimensions.

5.1 Design Dimensions Trends

***Self-Embodiment* and *Nonverbal Cues* are trending**

Since gestures are heavily dependent on motor-synchrony and require similar hardware techniques, *Self-Embodiment* and *Nonverbal Cues* are one of the most trending design dimensions that researchers use to support presence and social presence in their solutions, as shown in Figures 4-B and 4-C. Recently, novel *Synchrony* approaches were proposed to ensure smooth and realistic avatar animations in the VE (e.g. realtime tongue animations [36]). *Synchrony* and *Realism*, are frequently employed together to avoid the uncanny valley effect. Meanwhile, *Facial Expressions* are experiencing a recent spike, *Gaze* is infrequently considered in social VR design, as shown in Figure 7-A. However, it is beginning to regain attention recently (see Figure 7-B). On the other hand, *Completeness* is the least popular subdimension, as only two studies considered this design parameter in the whole corpus.

***Association, Interaction Type,* and *Proxemics* are starting to attract attention**

Since asymmetric social VR solutions came into view, *Activity Type* and *Collaboration* are experiencing recent spurs. We attribute this renewed interest to accommodate the variations in immersion that asymmetric interactions pose on the design of VR experience. For instance, interdependence was employed in order to balance the power distribution between HMD and non-HMD user (e.g. [18]). Competitive activities are problematic in asymmetric setting [19], as well. Moreover, asymmetric interactions opened room for designing more gestures that enable non-HMD users to interact as adequately within the VE as the HMD user. Following the same pattern, recent spikes in *Facial Expressions*, *Gestures*, and *Synchrony* renewed the interest in exploring the effect of these design aspects on participant's personal space preference. Moreover, recent studies introduced novel preventive machine learning approaches to avoid violations to personal space within virtual environments.

5.2 Application Design Trends

Gaming (32%): The focus in this domain is eliciting high feelings of engagement and enjoyment through maximizing social presence rates by augmenting *Nonverbal Cues*, *Association*, and *Interaction Type* (e.g. [1, 12, 18, 31]), as shown in Figure 4-B. Usually, game design centers on activities and actions performed within the game. Therefore, *Activity Type* is the most considered subdimension. On another note, *Personal Space* was recently utilized in the social VR gaming scene. Therefore, the effect of *Proxemics* in social VR games requires further investigation. Social VR Gaming, as shown in Figure 5-A, started to peek in 2015, and is now the most prevailing application area for Social VR solutions.

Communication (19%): The focus of social VR platforms designed for networking is providing rich communication to foster smooth interactions among users. As shown in Figure 4-B, four dimensions were utilized in studies that proposed social VR solutions for communication, namely (1) *Self-Embodiment*, (2) *Nonverbal Cues*, (3) *Proxemics*, and (4) *Association*. Designing for communication in

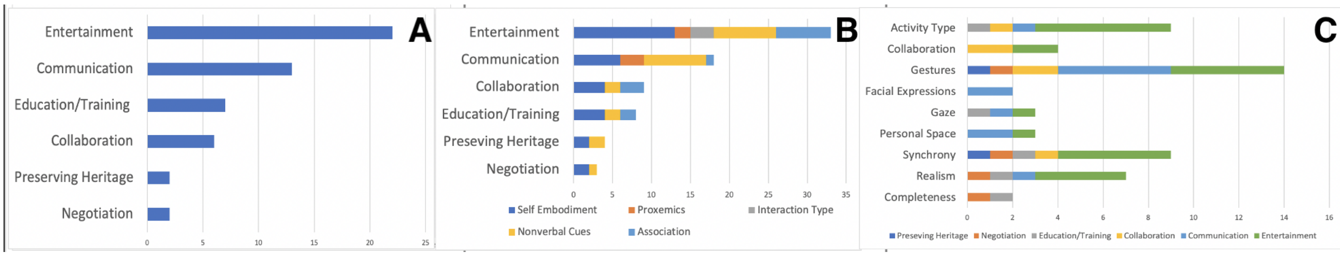

Figure 4: A: Social VR Applications Distribution. Gaming is the most popular social VR application, meanwhile, Preserving Heritage and Negotiation are the most novel. B: The prevalence of the design dimensions in each application area. *Self-Embodiment* and *Nonverbal Cues* are the main design dimensions used to support presence and social presence in social VR environments. C: The frequency of subdimensions in each application area. *Activity Type* is the most utilized design aspect in Entertainment application area. *Facial Expression* is only utilized in Communication applications.

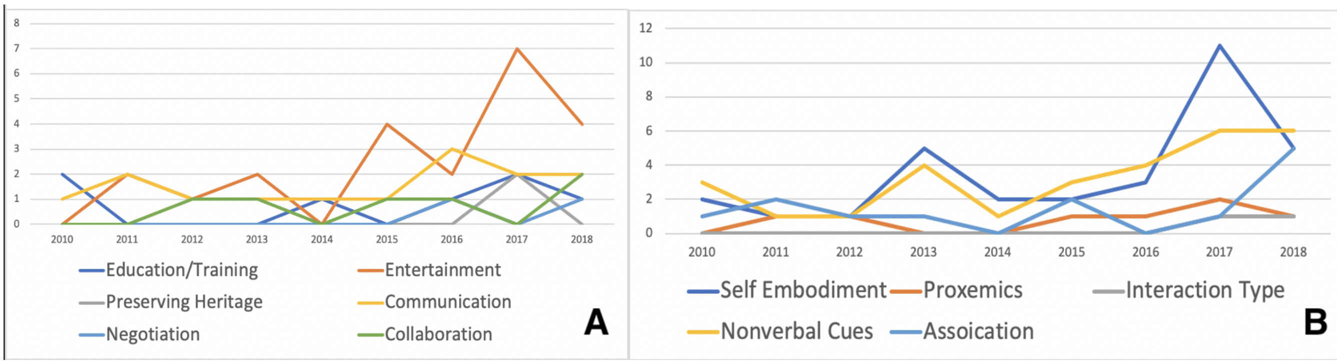

Figure 5: A: Social VR Applications Timeline. Preserving Heritage and Negotiations are one of the newest social VR domains, meanwhile, Collaboration and Education are becoming popular. B: Timeline of the design dimensions utilized to support social presence in social VR experiences. *Association* and *Self-Embodiment* are experiencing a recent spike in literature.

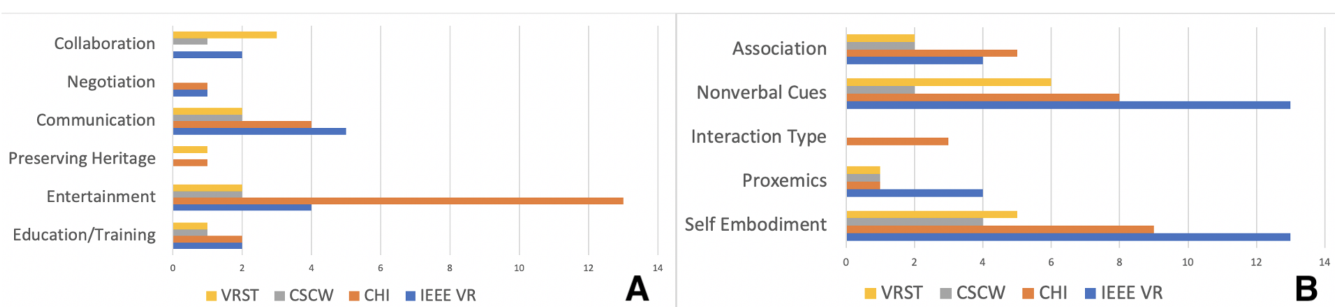

Figure 6: A: Application frequency across venues. CHI social VR solutions are centered on Entertainment, meanwhile IEEE VR social virtual environments focus primarily on Communication. As for CSCW and VRST, their solutions target Communication and Collaboration respectively. B: Dimension prevalence across venues. IEEE VR studies incorporate various action parameters, such as *Self-Embodiment* and *Nonverbal Cues*, meanwhile CHI papers are concerned with investigating *Interaction Type* the most.

social VR focuses primarily on utilizing *Gestures* and *Facial Expressions* as well as respecting *Personal Space*, as illustrated in Figure 4-C. We believe that *Proxemics* may also be used in a communication scenario to provide social signaling cues (eg. when a user approaches a group) [55].

Education and Training (10%): Social VR is an attractive platform for practical learning [77]. Unlike gaming and communication, the focus of educational social VR solution is performance, which requires adequate communication channels and participation, if needed [29]. Therefore, *Self-Embodiment*, *Nonverbal Cues*, and *Association* are employed extensively in the development of

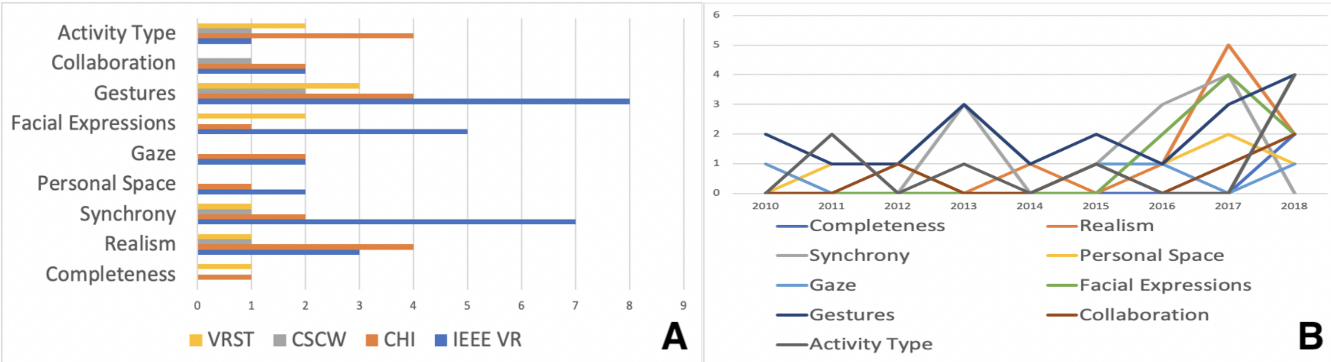

Figure 7: A: Subdimension Distribution across Venues. IEEE VR social VR solutions rely on *Gestures, Facial Expression,* and *Synchrony* the most, meanwhile CHI social VE design centers on *Activity Type, Realism,* and *Gestures. Completeness* was only examined by VRST and CHI studies. B: Subdimensions Timeline. Including different *Gestures* in the social VE is always in demand, meanwhile *Completeness* is the most recent and the least explored aspect. *Facial Expressions, Synchrony,* and *Personal Space* are recently peaking.

social VR solutions for education and training (see Figure 4-B). Surprisingly, educational social VR applications are among the few applications that utilize *Completeness*, as shown in Figure 4-C. We hypothesize that rendering all body parts enhances user performance meanwhile performing a task [67]. Moreover, *Gaze* was the only subdimension used from *Nonverbal Cues* (see Figure 4-C). Parmar et al.'s study [48] clarifies the importance of *Gaze* in educational VR applications, as participants in their study reported that they felt that their dancing agent didn't know they existed in the VE, and wished if the partner looked and smiled at them, once they entered the VE. Figure 5-A shows that education and training gained attention in 2010 and started to peek again in 2017. We hypothesize that with the development of new immersive VR tools, education and training will gain more attention, as these applications require three dimensions two of which rely heavily on immersive solutions.

Collaboration (9%): The focus of this domain is to enrich communication among users to foster collaboration. Therefore, the studies focused on *Self-Embodiment*, *Nonverbal Cues*, and *Association* dimensions. Figure 4-C shows that *Gestures* is the only *Nonverbal Cues* subdimension utilized along with *Synchrony* from *Self-Embodiment* in collaborative VR applications, which implies that collaborative platforms rely more on action design parameter than they do on appearance ones. Although collaboration enriches communication, *Proxemics* were not considered while developing collaborative platforms. Thus, the impact of *Proxemics*, especially *Personal Space* on social presence should be further explored.

Preserving cultural heritage (3%): Preserving cultural heritage is a newborn application area of Social VR solutions that was first introduced in 2017, as shown in Figure 5-A. This domain requires minimal social interactions. Therefore, *Self-Embodiment* and *Nonverbal Cues* are the only employed dimensions for this application in the form of *Synchrony* and *Gestures*, as illustrated by Figures 4-B and 4-C respectively.

Negotiation (3%): Similar to heritage preservation, this is a novel area introduced in 2016, as shown in Figure 5-A. *Self-Embodiment* and *Nonverbal Cues* are frequently used to develop these applications in the form of *Synchrony* and *Gestures*, as illustrated by Figures 4-B and 4-C respectively. Surprisingly, *Realism* and *Completeness* are considered when designing social VR platforms for negotiations. We believe that *Realism* is utilized to minimize social anxiety experienced in face-to-face interactions, meanwhile *Completeness* and *Synchrony* are utilized to convey more subtle cues (e.g. posture) about the parties present in the negotiation.

6 FUTURE RESEARCH OPPORTUNITIES

Asymmetric interactions are becoming popular

Several studies in the past nine years considered four design dimensions, namely *Self-Embodiment*, *Proxemics*, *Nonverbal Cues*, and *Association*, as shown in Figure 5-B. However, a new dimension, *Interaction Type*, was created in 2017. We envision that asymmetric interactions will gain more attention, as it (1) introduces plethora of unexplored research areas (see Figure 8) and (2) targets a wider range of users that cannot afford full immersion in the virtual environment (VE) due to economical or health limitations.

Gaze and facial expressions are relatively unfrequented

Gaze direction is a prevalent method for social signaling. It transitions the user from *others' presence* to *interactive presence*. Thus, researchers focus on developing gaze tracking VR solutions. However, a key limitation is face occlusion by the head-mounted displays (HMDs). Consequently, new HMDs[1] are integrating mobile eye-trackers into the set. For instance, recent work (e.g. [21]) is exploring the design space for gaze interactions using head-mounted displays (HMDs). Similarly, sensor-based face tracking approaches are proposed to facilitate facial expression detection (e.g. [40]) while wearing HMDs. We envision further explorations of gaze and face tracking to account for the new technological advancements.

[1]Example: Tobii Eye-tracking HMD (https://vr.tobii.com)

		Location																			
		C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D
Interaction Type	Symmetric		Smith and Neff [67] (F) George et al. [17] (P) Total: 2	Wauck et al. [72] (R) Latoschik et al. [28] (A) Total: 7	Ratan and Raslan [51] (R) Total: 3	Doucette et al. [11] Total: 8	Bourdin et al. [7] Total: 3	Shriram et al. [64] Total: 2	Erickson et al.. [13] Total: 1	Vidal et al. [71] Total: 3	Steptoe et al. [68] Total: 2	Bernal et al. [5] Total: 6	Roth et al. [58] Total: 3	Wong and Gutwin [74, 75] Total: 9	Tang and Wang [69] Total: 7	Khooshabeh et al. [25] Total: 3	Erickson et al. [13] Total: 3		Shami et al. [62] Total: 3	Brondi et al. [8, 9] Total: 3	Moustafa et al. [43] Total: 5
	Asymmetric					Arnold [1] Total: 1								Hsu et al. [22] Total: 1	Le et al. [30] Total: 1		Siri et al. [65] Total: 1	ShareVR [18] Total: 2		FaceDisplay [19] Total: 1	
		Completeness		Realism		Synchrony		Personal Space		Gaze		Facial Expression		Gestures		Independent		Interdependence		Activity Type	
		One's Presence						Other's Presence		Interactive Presence						Shared Presence					

Figure 8: A heat map demonstrating the usage of the design space to classify the literature. The papers' density is color coded using a scale from red (highest) to green (lowest). Grey denotes unexplored areas in the corpus. Each cell contains an example from the literature and the total number of papers in the corpus exploring the design parameters. Location values are denoted as (C) for co-located setups and (D) for distributed setups. Completeness values are denoted as (P) for partial body parts and (F) for full body. Realism values are denoted as (A) for abstract depictions and (R) for realistic depictions.

Designing effective avatar looks is challenging

Designing avatars that express the user's identity is critical for user's presence (one's presence in Figure 1), as excessively realistic avatars produce high uncanny valley rates, which detracts from the user's overall experience and presence. Therefore, reaching the right balance of avatar realism is still an ongoing research challenge, regardless of the interaction type utilized in the VE. Moreover, avatar *Completeness* is highly linked to *Synchrony*, as displaying full body requires full body tracking. However, few studies investigated the effect of avatar *Completeness* only on social presence.

Designing for shared presence is worth re-visiting

Association is pivotal in virtual environments to support shared presence. Researchers focused on *Association* in either symmetric experiences or co-located ones in 2011, as shown in Figure 5-B. With the development of asymmetric VR solutions, *Association* started to peek in 2018. Consequently, investigating the effect of augmenting interdependence and different activity types among users in an asymmetric VE on social presence is still an ongoing research endeavor, especially in distributed environments.

Personal space explorations are returning

In this corpus, studies investigated the effect of appearance parameters (e.g. group size, emotional state) on personal space preferences (e.g. [6]). Consequently, the effect of action parameters (e.g. gestures, gaze) on personal space preferences needs further explorations, especially in asymmetric interactions. Moreover, 50% of the analyzed personal space studies propose collision avoidance mechanisms to prevent personal space violations (e.g. [5, 54]). However, the effect of employing such mechanisms on the quality of the user's experience needs further investigation.

7 CONCLUSION

In this paper, we reflect on nine years of research to support social presence in VR experiences. We present a five-dimensional design space distilled from analyzing the literature in this period. Our analysis shows that *Self-Embodiment* and *Nonverbal Cues* are essential for any social VR experience, and asymmetric interactions are under-explored in the current literature due to their novelty. Additionally, *Activity Type* is the most considered design aspect in social VR gaming solutions, meanwhile *Completeness* is only considered in either educational or negotiation activities in social virtual environments. Furthermore, VR game design (*Entertainment*) incorporates appearance parameters, meanwhile social VEs that target *Communication* rely on action parameters, especially *Gestures*.

Although the four venues cover various design parameters and application areas, the focus on different design aspects and application areas may vary in our selected venues. For instance, CHI studies focus primarily on *Collaboration*, *Activity Type*, and *Gestures* along with appearance parameters, such as *Realism*. On the other hand, 52% of IEEE VR analyzed studies propose novel approaches that aid in incorporating actions parameters (e.g. face, full body tracking approaches). Meanwhile, VRST and CSCW covered various design parameters and application areas equally. To enhance social presence, current research focuses on manipulating appearance parameters (e.g. realism) in symmetric settings, meanwhile relies on action parameters (e.g. interdependence) in asymmetric ones. However, reduced social presence rates lessen social anxiety, which enhances the quality of social VR applications that target negotiation. Therefore, further research is required to investigate the impact of all the dimensions in various co-presence setups. We believe that our work will guide designers in creating social VR platforms that cater for all levels of social presence (Others', Interactive, and Shared Presence). Finally, we envision that our work will aid researchers to identify open research opportunities as well as build engaging social VR experiences.

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