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"Nice to see you virtually": Thoughtful design and evaluation of virtual avatar of the other user in AR and VR based telexistence systems

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ABSTRACT

This paper presents two studies investigating how physically remote telexistence users wish to see other users visualized as virtual avatars in a) augmented reality, and b) immersive virtual reality while conducting a collaborative task. To answer this research question, a telexistence system was designed and implemented with simple avatar designs. After that, visual examples of alternative avatar representations for both use cases were designed by thoughtfully altering the visual parameters of 36 virtual avatar examples. The avatar designs were first evaluated in a user study with 16 participants in conjunction with using an implemented telexistence system. As a follow-up an online survey with 43 respondents was used to record their preferences regarding virtual avatar appearance. The results suggest that users prefer the other user to be represented in a photorealistic full-body human avatar in both augmented reality and virtual reality due to its humanlike representation and affordances for interaction. In augmented reality, the choice for a hologram full body avatar was also popular due to its see-through appearance, which prevents a mix-up with a real person in the physical space.

1. Introduction

During the COVID-19 epidemic, a vast number of people were laid off or obligated to start working from their homes. They consequently were required to switch face-to-face meetings and teaching online almost over-night, meaning that telepresence [31] through different kinds of video conferencing tools became their daily reality. In addition, for academics the epidemic has resulted in either the cancellation of conferences or a shift to virtual attendance either over video conference systems or virtual reality (e.g. IEEE VR'20). In these online platforms, it is often possible for users to decide how to display themselves, but not to specify how they see other people. Telexistence systems [59] have proven necessary for long distance communication. These systems, in addition, add to the diversity of communication methods and therefore make people's professional and social networks more resistant to adversity.

The selection of a user's own avatar in terms of self-representation has been widely studied [11,28,55,62], particularly in the area of games and virtual environments where avatars can be sculpted to portray individuality and variability [47,51,55]. The effect of real self to the virtual self [55] and vice versa [3,64] has been mapped thoroughly in 3D virtual environments where most people prefer a realistic representation in terms of gender and species [36], whereas some favour an idealized version of oneself [11,55]. Although a realistic avatar gives a stronger self-presence [54], it has been suggested that self-discrepancy decreases social presence in multiuser social virtual environments (VEs) at the interpersonal level [55]. Prior research has focused on what type of avatars people would like for themselves, but not how they want to perceive others in augmented reality (AR) and virtual reality (VR) specifically in the context of telexistence. This study takes a different approach and aims to investigate: How users would like to see other users, in other words, what is their preferred person perception in collaborative AR and VR based telexistence system? Through a thoughtful design exploration and two user evaluations involving various avatar styles, this paper investigates how much of an avatar's body should be visible and how realistic the perceived avatars should be

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in the aforementioned use cases.

This paper is structured as follows (Fig. 1). First, the related works on avatar designs in telepresence and telexistence systems are presented. Then, the implemented AR and VR based telexistence system, the design of the used avatars, and the collaborative task are introduced. Next, the design process of 36 comparable virtual avatar examples for the study is described. Following this groundwork, the results of both a user study with 16 participants and a follow-up survey with 43 respondents investigating preferred virtual avatar designs in two use cases: mobile AR and immersive VR are presented. Next, the findings are discussed with focus on a methodological reflection before the paper is concluded.

2. Related work

Telexistence was introduced and defined in the 1980s by Tachi and later described by him as: "*the general technology that allows a human being to experience a real-time sensation of being in a place other than his/her actual location and to interact with the remote environment, which may be real, virtual or a combination of both*" [59]. Telexistence is often associated with telepresence [31], which means telecommunication via technology, such as video based telepresence systems for workspace related remote collaborative tasks [46], attending conferences [32], and participating in family life if with accessibility challenges [15]. Telexistence however, has a broader scope as it includes telexistence in virtual environments (VEs) as well as in the real environment where physically remote people can work, travel, shop, and spend time together [20,59,45,60]. While the first telexistence systems, such as [58], had remote robots equipped with different types of sensors and displays, the recent technological development of VR and AR [57] has enabled new types of telexistence systems utilizing virtual avatars instead of robots [2,17,38]. Nowak and Fox define an avatar as: "*a digital representation of a human user that facilitates interaction with other users, entities, or the environment*" [34]. An avatar is used for identification, recognition, and evaluation of others [36]. The benefit of using virtual avatars as opposed to robots is their affordability, scalability, and ability to adapt into operating from almost anywhere on Earth. Given avatars virtual nature, their visual appearance can be easily modified to fit different use cases and users. While the teleoperation of physical machinery with a robot is easier, digital avatars are more suited into tasks that require communication or collaborative design. However, using AR technologies digital avatars can also have a reach to the physical environment. Due to the versatility of avatars in AR and VR, different kinds of collaborative telexistence systems with virtual avatars have been proposed by prior research (e.g. [2,7,17,27,30,37,38,43,44,45]).

2.1. Avatars in VR and AR based telexistence and telepresence systems

Avatar designs for VR and AR application pose challenges especially on highly realistic or photorealistic avatars. When visual presentation of avatars closely resembles that of their users', it evokes high levels of perceived competence and social attraction [34–36]. How people present themselves and how they perceive others' avatars, show almost similar variability in social behaviour and interactions as direct interactions between humans [12,34,47]. Considering the time people spend in VEs, and possibly will be spending in the future, understanding how users perceive others in such environments is critical to ensuring successful communications. These systems can alter people's perception of not just themselves [3,14,64], but also their perceptions of others in the real world [24]. For example, when attractive computer-generated avatars are shown to users, people perceive realistic portrayals less attractive than they would if they had been shown less attractive avatars [24]. This can be explained by the contrast effect [18,21], which describes a change in perceived quality when alternating between contrasting stimuli. Visual cues in communication are mostly processed automatically and they can even overrun the information presented through other channels if the messages are contradicting [61]. This contributes to the importance of visual representation of avatars in interpersonal communication with VR and AR.

In AR based telexistence systems, the photorealism of an avatar increases the feeling of co-presence, in other words, the sense of the remote person 'being there' [37]. The immersive nature of VR creates a heightened experience of empathy when observing fellow avatars and a strong embodiment of surrounding (virtual) space and identification with one's own avatar [52,56]. This can be observed for instance as strong reactions to shocking stimuli like seeing avatar's dismemberment [52]. Casanueva and Blake [7] found that realistic human-like avatars produced greater sense of co-presence than cartoon and unrealistic looking avatars in VEs. Further, avatars with gestures, directed gaze, and facial expressions produced significantly higher co-presence as compared to static avatars [5,7]. The use of context also impacts on how people are needed to be seen by other users. It is reported that in a professional context, such as educational setting, the avatar should look like the corresponding person in reality [40]. In AR applications, the use of context brings its own challenges for portraying avatars, as the environment will occlude due to the presence of avatars. As such, their visual aesthetic properties need to be carefully considered [4,6]. Despite the technological advances in avatar based communication in AR [2,17,38], the user experience and psychological aspects of avatars in such systems needs more investigation [13,48]. Due to the blending of the physical and virtual in AR applications, the options for interaction and communication in such applications differs from VR.

Prior research proposes different ways to present users in telexistence systems. Beck et al. [2] used two projection-based multi-user 3D displays to present users whose avatars were reconstructed in real time (i.e. volumetric video) in their group-to-group telepresence system. In Holoportation, the remote users are presented as high-quality 3D models [37]. In an AR-based tele-conference system by Jo et al. [17], cartoonish looking 3D avatars are augmented on a chair. Mekuria et al. [30] present a highly realistic 3D natural user realized from 3D video and synthetically authored, i.e. procedurally generated, 3D graphics content. In a mixed reality collaborative environment, both robots and cartoonish looking avatars were used by Oyekova et al. [38]. People can be also presented in telexistense systems via real-time video streaming [42]. Piumsomboon et al. [43] present an adaptive avatar called Mini-Me for mixed reality remote collaboration between a local AR user and a remote VR user. Mini-Me is shown as a realistic yet simplified full body avatar in VR, whereas the AR avatar is shown as a hologram. In VR, Mini-Me also shows user's gaze direction and body gestures while it

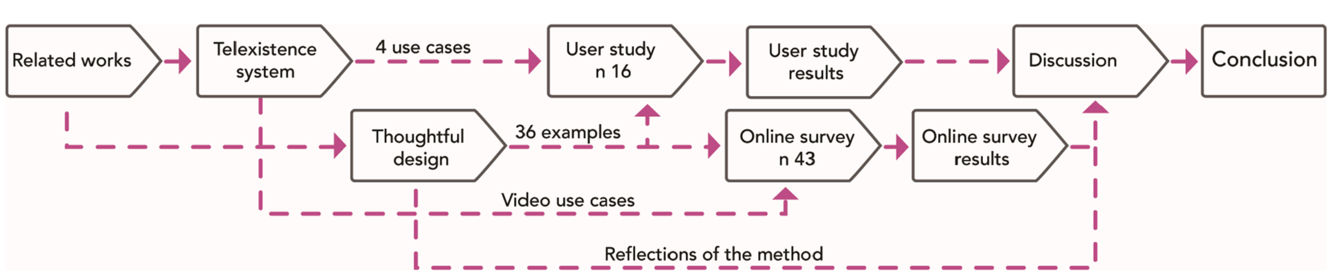

Fig. 1. Structure of the contribution.

transforms in size and orientation to stay within the AR user's field of view [43]. In later study, Piumsomboon et al. [44] combine video with AR and VR interaction with an adaptive photorealistic full body avatar. In a tele-immersive sports application, users are visualized as cartoonish looking 3D avatars [45]. Even though many ways of presenting users have been presented in implemented systems, the focus of these studies has not been on obtaining a qualitative understanding of user preferences for how users would like to see each other's avatars during collaborative tasks.

3. Telexistence system

As shown in the prior section, there is a growing interest in using VR and AR technologies for collaborative tasks. However, these technologies are typically used separately rather than utilizing the possibility of combining the two into a comprehensive mixed reality experience. In recent years, research has started to look more into this direction and promising approaches have been presented [19,20,43,44]. The system described in this paper focuses on combining avatar-based interactions between VR and AR users, enabling users to meet and interact with each other in the same place but through different realities: one user in the real world (Fig. 2A) and another in its virtual counterpart (Fig. 2B) as suggested in [20]. In this cross-reality setting the avatar acts as a link between the two realities.

For the first study, a telexistence system where two remotely located users can connect with each other and accomplish a small collaborative task through augmented and virtual reality gear (Figs. 3 and 4) was designed, with the detailed technical implementation reported in [19]. In the task, the users must assist each other to locate items in the virtual environment which they cannot see by themselves. A VR and two AR clients were implemented. Two AR clients were needed to be able to test the effect of a) mobile of-the-self technology (ARM, Fig. 2b) and b) more advanced technology: smart glasses with the motion capture suit (ARMC, Fig. 3b) on user perceptions of the avatar design.

In the mobile AR use case, one user had a tablet device with a mobile augmented reality application (ARM, Fig. 3a). The space had a poster with an AR marker which the user needed to point their device towards. Another user was wearing virtual reality gear (HTC Vive) with hand controllers (VRM, Fig. 3b) which tracked hand movements to the avatar. Users could communicate with each other through an audio connection. The users were shown to each other as virtual avatars. The VR user's virtual avatar was a simple humanoid avatar that had a torso with moving hands and was augmented on the real environment (Fig. 3c). The AR user's virtual avatar (Fig. 3d) had a similar torso but with static hands and was shown in a virtual replica of the real environment. The reason why the AR user's avatar's hands were not moving is that although the tablet device could track the position of the user, it could not track their hands.

In motion capture AR use case, both users were wearing an Xsens motion capture suits. In addition, the VR user wore the same virtual reality gear (HTC Vive) with hand controllers in order to transform hand movements to the avatar. Given the use case this user was called as VRMC (Fig. 4b). The AR user had also ODG R7 smart glasses (ARMC, Fig. 4a). Users could communicate with each other through an audio connection. The VRMC user's virtual avatar had a similar avatar as in the earlier use case (a torso with moving hands) and was augmented on a real environment (Fig. 4c). The ARMC user's virtual avatar (Fig. 4d) was an authentic looking full body human avatar shown in a virtual replica of the real environment.

3.1. Collaborative task

A simple collaborative game was implemented for the user study to evaluate the mixed reality collaboration in both use cases. A large room was used as the game area (Fig. 3a; Fig. 4a; & Fig. 7). An accurate 3D model of this room was created for the VR user (Fig. 3d; Fig. 4d & Fig. 7). It is important to note that the VR user shared the same game area but was physically in another room (Fig. 3b & Fig. 4b) distanced from the AR user (Fig. 3a & Fig. 4a). In both use cases the participants could move freely in their small, designated areas.

The use scenario of the game consisted of two phases. First, the VR user guided the AR user to find a key that was only visible to the VR user. For guidance, the VR user used their voice, position, and hand movements. After reaching the correct position, the AR user made a predefined gesture (i.e. spread fingers in front of the device camera) with their hands to grasp the key that was then transferred to the hand of the VR user's avatar. Second, the AR user guided the VR user to use the key to open a chest that was only visible to the AR user. For guidance, the AR user used their voice, position, and in the ARMC use case also their hand movements. After reaching the correct position, the VR user touched the chest with the key to open it. In the game, the location of the key and the chest was changed for every user study pair.

4. Thoughtful design of virtual avatars

As the virtual avatars used in the implemented system are remarkably simple, alternative virtual avatar options were investigated for presenting the other user in both AR and VR settings. In order to create comparable design examples for the study, a three-step method by Pakanen et al. [41] was applied. The steps are: *background study*, *design*, and *evaluation*. In the background study, existing applications and related research are benchmarked to identify the options that exist for representing user interface design features. The identified designs are then categorized under themes as based on their visual similarity. Following this, new designs are created to represent the variety of the existing designs. Then, the existing designs are evaluated in a user study [41].

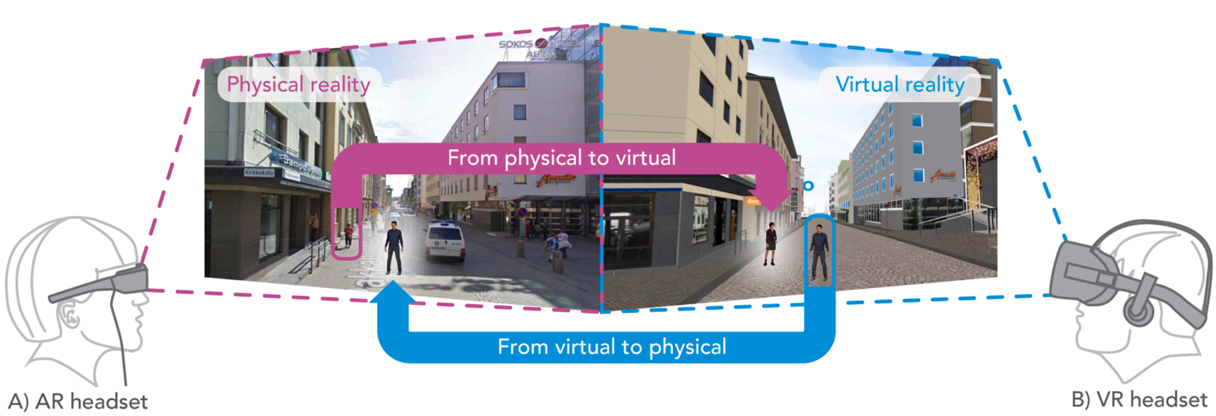

Fig. 2. AR and VR based telexistence system allows different located users be present in same place in different realities through AR glasses (A) VR headset (B).

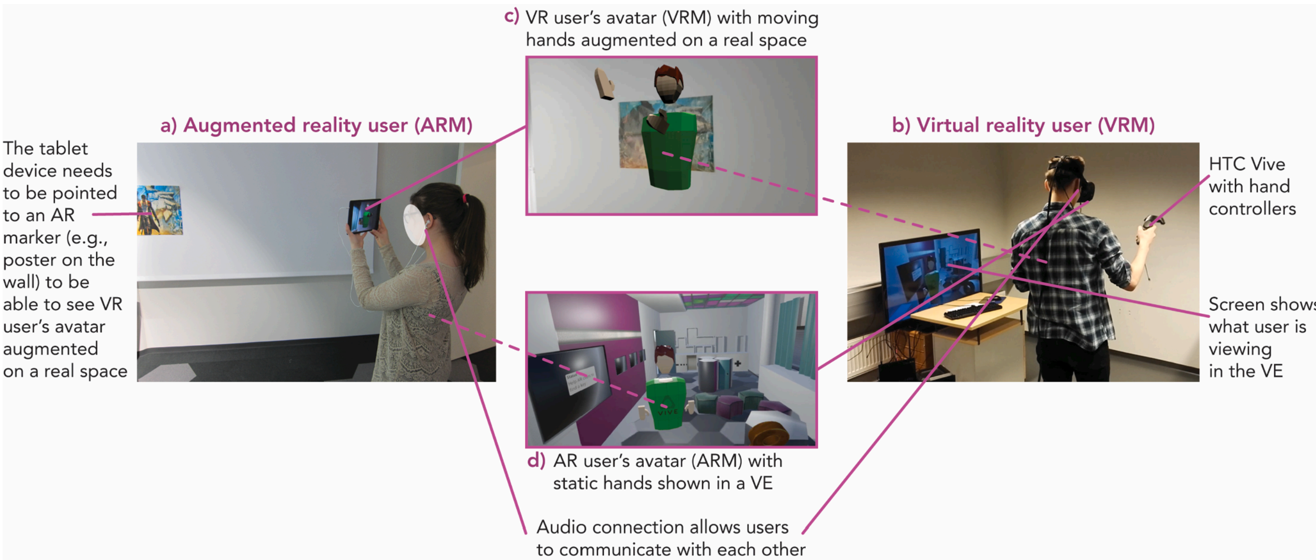

Fig. 3. Telexistence system used by ARM (a) and VRM (b) users. The users are presented to each other as virtual avatars: VRM avatar (c) with moving hands augmented on a real environment and ARM avatar (d) with static hands shown in a virtual environment.

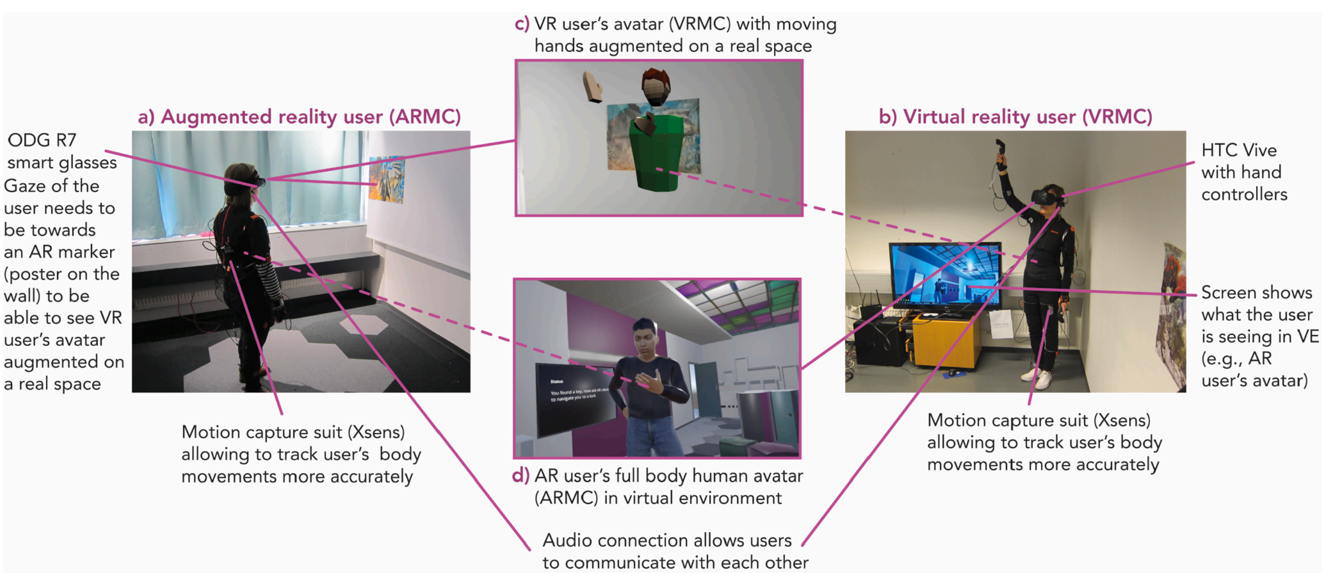

Fig. 4. Telexistence system used by motion capture suit ARMC (a) and VRMC (b) users and their virtual avatars: VRMC avatar (c) with moving hands augmented on a real environment and ARMC avatar (d) shown in a virtual environment.

4.1. Background study

Screenshot images were collected from related works and through Google image search. Different keywords were used to locate humanlike avatar designs: 'virtual avatar', 'avatar', 'avatar design', and 'virtual avatar design'. The search was expanded based on the found images. In Fig. 5, the identified avatar designs have been categorized as based on their visual characteristics. Due to the limited space, only a representative sample is shown.

In previous research, the visual appearance of humanlike virtual avatar designs was mostly cartoonish [7,12,14,17,22–26,33,35,36,38,45,43,47,66]. However different types of fantasy figures [33,36,28], such as Furries [53] and robots [7] were also common. Some of the studies are quite old [7,33,36] and the designs are therefore quite polygonal-looking for modern users who are used to high-fidelity graphics. Recent graphical quality improvements of both head mounted VR and AR gear, as well as VR scenes, allow for graphically richer and more realistic looking virtual avatar designs in telexistence systems, enabled through real-time video streaming [42,62] or photogrammetry and image processing [21,62]. In addition, deep learning powered real-time editing of avatars is becoming increasingly powerful [21,62]. Therefore, more recent studies have been using realistic or close to photorealistic avatar designs [2,30,34,42,44,54,62,64]. The colour representation of the avatars has been mostly chromatic, with a few monochromatic exceptions [7,9,65]. Also translucent avatars have been used in forms of shadows [9] or holograms [37,43,65]. In addition, designs have had different degrees of full-body ranging from showing just eyes and mouth [33,36] or the head of the avatar [25,33,35,36,54] to combination of hands to head or eyes [63,65]. Some designs featured a torso with hands [22,26,42] or a torso with parts of the legs [9,28,30,43]. Yet, full body avatars [2,23,7,12,14,17,21,23,24,37,43,44,47,53,64,66] have been the most popular choice for representing the user.

Many of the collected images have been from implemented systems

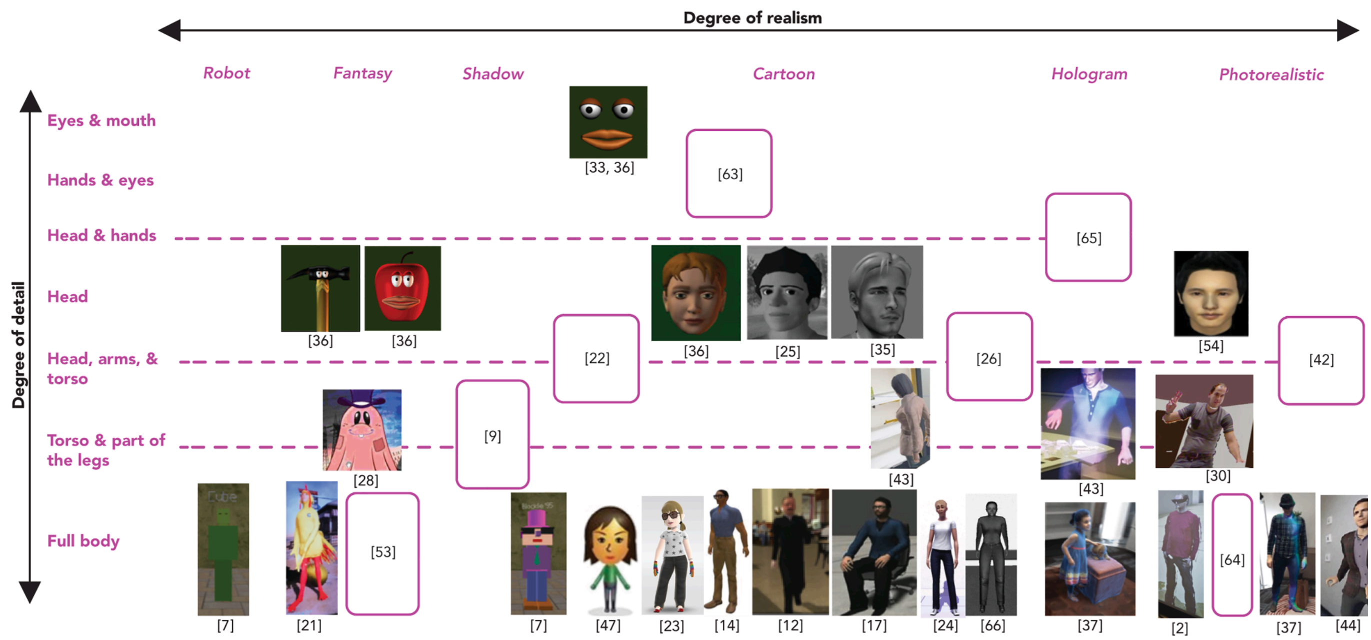

Fig. 5. Identified avatar designs categorized based on their visual characteristics.

and they have not been compared against any other avatar designs in the user studies. Some other studies have, however, investigated how people should be visualized as virtual avatars with comparative avatar designs [2,7,17,33,36,37,48]. However, many of these papers did not show the examples or lacked a thoughtful design of the avatar examples [7,11,14,21,28,33,36,47,54,55]. These alterations of the avatar's visual parameters can potentially impact participant selections. Designers and researchers introduced, for example, unnecessary changes to the comparable options, such as alterations to the avatar's face which differ from the baseline [7,33]. In some studies, the body weight of comparable male avatars was changed between the examples, however not with the female equivalent [24]. In the same study a female avatar with hair was compared against an avatar which had lost all her hair [24]. Most of the studies have also used a limited number of examples, ranging from two to eight [7,12,14,24,47,54,66]. Only one prior study utilized 30 fairly comparable examples [36], however the variation of visual parameters between the designs was not systematic as the examples varied substantially between the compared options, for example by different faces on the avatars.

Based on the background study, the following main categories were selected to achieve a representable collection of different body types for the avatars: *Full body*, *Torso with arms & ½ thigh*, *Torso with arms*, *Head & hands*, *Eyes & hands*, and *Eyes & mouth*. For the avatar visual representation style, the *Photorealistic*, *Hologram*, *Cartoon*, *Shadow*, *Robot*, and *Furry* were selected.

4.2. Design

In order to take a more thoughtful approach with avatar design, Pakanen's [39] later clarifications were followed. These clarifications emphasise the need for comparability between the created designs, called as Visual Design Examples (ViDEs), as a critical factor for the trustworthiness of the anticipated user experience (AUX) study results. Recommendations suggest that ViDEs should be uniform in their size, colour theme, orientation, visual style, and presentation technique. As suggested in [39], one designer created all the final examples after the team agreed on presentation style. The designs were carefully considered by altering the different visual representations (Fig. 6, A–F) with selected body types (Fig. 6, 1–6) and made a clear set of ViDEs for the study. All ViDEs were created in Adobe Photoshop, with Adobe Illustrator being used to create the body for Shadow, Furry, and Robot avatars, as well as facial features for Cartoon avatars.

The created designs were based on full female and male body photos (Fig. 6), purchased through Adobe Stock. The designer made the peoples' faces more symmetrical and the skin look more plastic/porcelain (i.e., modelled to be more doll-like) by applying filters to achieve the look of a *Photorealistic* avatar (Fig. 6A). Following this, the designer created the *Hologram* avatar (Fig. 6B) by applying greyscale and different effects on the Photorealistic avatar designs. *Cartoon* avatars were made from the Photorealistic avatars by colouring the clothes as well as redrawing eyes, eyebrows, lips, and hair to make them more cartoonish looking (Fig. 6C). Next, the designer created *Shadow* avatars (Fig. 6D) by redrawing body shapes in Illustrator and filling these with a white colour (40% opacity). A turquoise line was added to show the gaze of the of the remote user. After that the designer created bodies for *Robot* avatars (Fig. 6E) and *Furry* avatars (Fig. 6F) in Illustrator. Female and male Furries' bodies [53] were redrawn and a uniform colour theme was applied (Fig. 6F). Finally, the designer made body alterations from *full body* (Fig. 6, 1) avatars by fading out avatar legs from ½ thigh (*Torso with arms & ½ thighs*, Fig. 6, 2), removing legs completely (*Torso with arms*, Fig. 6, 3), removing also torso and arms until the wrists (*Head & hands*, Fig. 6, 4), removing most of the head by cropping square area around the eyes (*Eyes & hands*, Fig. 6, 5), and finally removing skin around the eyes and mouth (*Eyes & mouth*, Fig. 6, 6).

Finally, as suggested by [39], the application context should be clear for the viewer, therefore, the examples should be presented on the corresponding application background rather than separated. To present virtual avatar designs in realistic application contexts, the designer placed both the male and female ViDEs on a real picture of the room and on its virtual replica (Fig. 7). All the final ViDEs are shown in;

- The VR user's avatar shown on real environment (Fig. 7a)
- The AR user's avatar shown in virtual environment (Fig. 7b).

Finally, an identifier was added to each picture and the order of the ViDEs was randomized for the study.

5. User study

This paper focuses on user experiences with the implemented

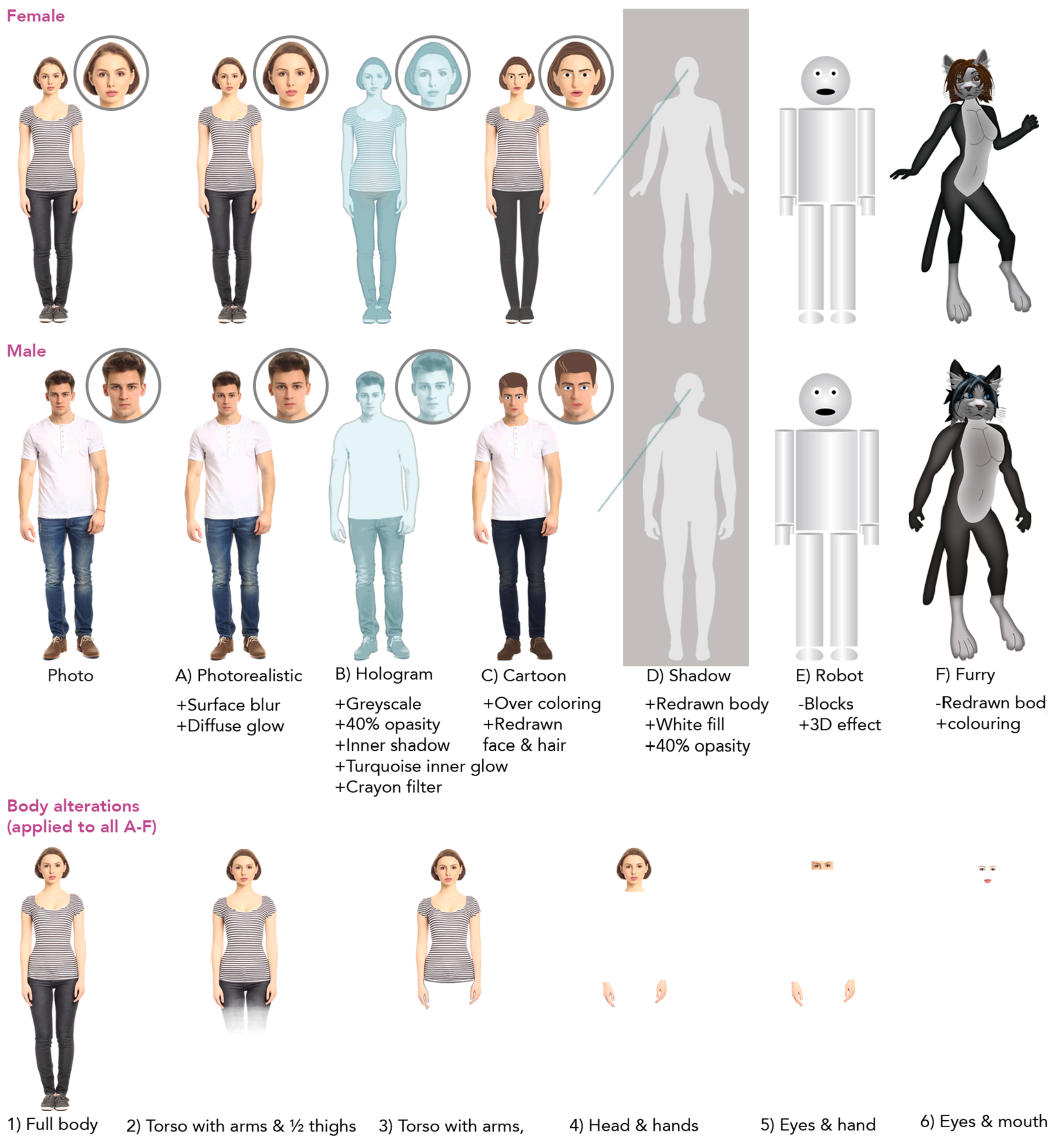

Fig. 6. Original photo of female and male as well as resulted full body virtual avatar designs: A) Photorealistic, B) Hologram, C) Cartoon, D) Shadow (here on grey as design is translucent white), E) Robot, and F) Furry. Body alterations (1–6) were made to all avatar types (A-F).

avatars, interaction with them, and possible use cases that might impact the avatar design. In addition, the user preferences with the 36 created virtual avatar designs (ViDEs) for presenting the other user in AR and VR use cases are charted.

5.1. Participants

The telexistence system was tested with 16 users. The participants ages varied from 23 to 41 (Table 1) with a mean age of 28. Eleven participants were male, five participants were female (Table 1). Every participant owed a smartphone, however only 6/16 owed a tablet device. Ten of the participants had prior experiences with 3D games. Additionally, 13/16 had played games that were controlled by hand and/or body movements. 3D virtual worlds such as Second Life were familiar to 6/16 participants. Ten of the participants had used VR HMD equipment before, but only two of the participants had prior experience in AR applications or hardware. Finally, twelve of the participants had used devices that allowed them to experience 3D content. Participants received a movie ticket worth approximately 10 EUR as compensation for their participation.

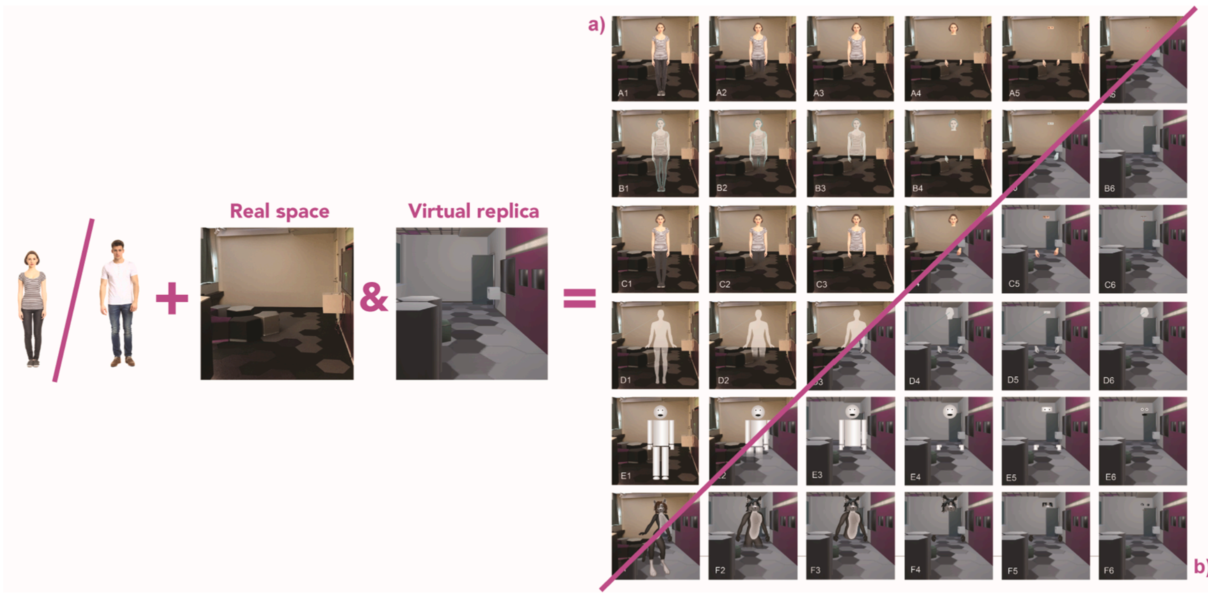

Fig. 7. Virtual avatar designs. VR user's avatar augmented on a real environment (female avatar ViDEs) (a) & AR user's avatar shown in virtual environment (male avatar ViDEs) (b).

Table 1
Participant's demographics and assigned study conditions.

Participant	Age	Gender	1st condition	2nd condition
1	23	M	ARM	VRM
2	27	M	VRM	ARM
3	25	M	ARM	VRM
4	27	M	VRM	ARM
5	23	F	ARM	VRM
6	21	M	VRM	ARM
7	36	F	ARMC	VRMC
8	35	F	VRMC	ARMC
9	24	M	VRM	ARM
10	23	M	ARM	VRM
11	22	F	ARMC	VRMC
12	26	M	VRMC	ARMC
13	28	M	VRMC	ARMC
14	41	M	ARMC	VRMC
15	27	F	ARMC	VRMC
16	33	M	VRMC	ARMC

5.2. Procedure

After filling out a background questionnaire on demographic information and prior experiences with the technologies in question, participants were assigned in pairs to predefined conditions. The study introduced a total of four conditions: mobile augmented reality ARM (Fig. 3a), virtual reality VRM (Fig. 3b), motion capture augmented reality ARMC (Fig. 4a), and motion capture virtual reality VRMC (Fig. 4b). Each participant tested both the VR and AR conditions, resulting in eight users per condition, see Table 1 for assigned study conditions in order of appearance for the participant. The reason for not adopting a full within-subject study design was the long time that was required for wearing and initializing the motion capture suit as the sensors were attached to different body parts using individual straps. Furthermore, the aim was to minimize the effect of recollection bias on the study's results.

The user study procedure consisted of the following steps:

- Ice breaking task:
  - Participants were asked to greet each other and after that to locate some notable objects in the environment.
- Task 1 & 2:
  - Participants were asked to guide each other to find hidden objects based on instructions given by the other participant who sees the object: the ARM/ARMC user is instructed to find a hidden virtual key by oral and/or gestural (not possible in ARM) instructions given by the VRM/VRMC user. When key is found by the ARM/ARMC user, it is transferred to the VRM/VRMC user and is instructed by ARM/ARMC to find the hidden chest and open it with the key to complete the task.
  - After the task completion, participants were asked to fill a co-presence questionnaire with 6 statements (findings reported in [19] and therefore not in focus of this paper).
  - Then participants were asked to change the roles and same procedure was applied again. After the equipment was taken off, the participants were guided to the post interview.
  - Semi-structured interview with following questions:
  - Describe your experiences with the system?
  - What kind of feelings this kind of interaction with remote user brought up?
  - What did you think about using this kind of technology for remote collaboration?
  - How the communication/interaction between users went?
  - What was easy/natural and what was difficult/unnatural in the interaction?
  - Were there any critical moments in the interaction, if yes describe it/them?
  - How aware were you of events occurring in the real world around you? (Results reported in [19] and therefore not in focus of this paper).
  - What do you think of current VR and AR avatars appearance?
  - Can you come up use case/s where this kind of system could be used?
  - If this kind of system would be available for you, how willing you would be for using it, select a number between 1 and 10 and what would you use it for?
- Task 3 Avatar drawing task:
  - Participants were given coloured pencils and a simple template consisting of two circles with AR or VR texts above them. They were then asked to draw or write how they would have liked to see virtual avatar in AR and VR contexts. Participants were also instructed that if both avatars should look the same, then they do

not need to draw both. After participants finished the task, they were asked to explain their ideas.

- Task 4 Ranking of ViDEs:
  - Participants were given a form and shown 36 ViDEs (shown in mixed order) of virtual avatar designs attached to a wall (Fig. 8) and asked to rank best, 2nd best and the 3rd best option for first AR user's avatar shown in a virtual environment and second VR user's avatar augmented on the real environment. Based on the gender of the participant, either male or female ViDEs were shown (male avatar ViDEs were located in another room).

5.3. Data collection and analysis

Two video cameras were used in both the AR and VR setting to record user interaction with the system and audio communication. The post interview took place in the same room as AR setting; therefore, video was recorded also during the interview to capture participants replies and discussions as well as their gestures. Video cameras were placed in the corner of the room, behind the participants to make the experience less invasive. The study duration ranged from 27 min to 77 min, of which the interview part ranged from 18.5 min to 31 min. To analyse the semi-structured interview responses, general qualitative coding principles [8] were applied. The analysis was initiated by watching and transcribing the video recordings. The focus of analysis was on gaining an understanding of the participants' experiences with the implemented avatars and perceptions and needs for the virtual avatar's appearance. For the ranking tasks, users' rationales for the selected designs were collected and categorized based on similarities. In the analysis of ranking task results, Borda count [50] was used to weight user preferences. Three-points were assigned to the respondent's first choice, two points to the second choice, one point to the third, and zero to all other possible choices.

6. User study results

First, the participants perceptions of the implemented avatars are presented. Then, interaction challenges based on implanted avatars are explained. After that, participants suggestions for the avatar design as well as their ranking of the avatar ViDEs are presented.

6.1. Perceptions of implemented avatars

6.1.1. ARM, VRM & VRMC avatars

Participants described the current ARM, VRM & VRMC as: *simple* (P1, P2, P4, P5, P6, P15), *basic* (P2), *low fidelity* (P3, P4), *blocky* (P13) or *boxy* (P7, P8), *sketchy* (P14), and *robotic* (P11). As P13 stated on the VRMC avatars appearance: "*What I saw in this room, was just a face and blocked body, so it was boring…it was more like retro beam style, so maybe this would need improvement.*" In addition, avatars legless appearance raised confusion, as stated by P7 during use: "*I can see a green boxy guy; hands are separated from the body. I cannot see legs,* [Name of P8] *legs are not showing.*" P15 and P16 were discussing the same topic during post interview and P15 stated: "*It was a bit weird that it did not have legs so it was like hovering in there.*"

Many participants (P4, P7, P8, P11, P12) had difficulties in identifying avatar appearance during the interaction, as described by P8 while using the system: "*Is that* [Name of P7]*? I looked that there is just some weird red box with green under it, I was able to see only avatars head.*" P8 explains in the post interview: "*In the beginning, I did not even realize it was a human being* [avatar] *as I saw just a ball shape with little hair.*" The problem was related to AR marker interaction as explained by P11 and P12: "*I did not actually see properly because I could see it for a while and then every time I was turning my head it was gone, so I could not really see it, I think it was green, I don't remember?*" (P12) "*Yeah, green*" (P11).

6.1.2. ARMC avatar

ARMC avatar was perceived to look and behave more like a *real human* (P8, P12, P11) with "*sufficient level of detail*" (P13) and as *nice* due to the full body representation (P15). As stated by P15: "*I think the avatar* [ARMC] *was quite neat and cool…You could see all the movements even when another user was laughing, you can see it based on their posture that something is happening.*"

The avatar's appearance and size caused some negative comments. P14 stated when seeing ARMC avatar: "*There he is, nice to meet you virtually, quite low poly though, but it is ok, I am used to it, I am 8 bit.*" For a few participants (P7, P11, P13), the ARMC avatar looked a bit strange, as described by P11: "*yeah, real human, but a weird one* [laughs]." P12 explains what made avatar look a bit weird: "*It had long legs, it had really long legs*". Other participants called it as "*handsome guy* [ironic laughs]" (P13) and "*basketball player*" (P7). The different appearance of the ARMC avatar raised some concerns, such as P8 asked: "*Why the other avatar was so different?*"

6.2. Interaction challenges caused by the avatar design

For some mobile AR and VR users the task 1 and 2 were easy to accomplish due to the easy to discover and reach location of the hidden items in the scene. These participants (P1, P2, P3, P4) commented that the simple design of ARM, VRM, and VRMC avatars fulfils their use

Fig. 8. Participants evaluating ViDEs of AR users' avatar design in VE during ranking task.

purpose. As P3 and P4 discussed: "*In some sense, maybe they achieved their task* "(P4) P3 carries on: "*Yea, it doesn't have to be like HD 3D modelling… but I guess in this task we were mainly concerned with the position of the avatar and for that purpose they were sufficient.*" However, the pairs (P6 & P5, P7 & P8) whose task completion was not so easy, perceived the implemented avatars as way too simple and therefore causing serious issues with the interaction. During the interaction, P7 sounded frustrated: "*Go left, more left…No other direction… Left, no right…Oh what side it is?… yes, going to right direction, it is just above you, there, there is the chest …. You need to take steps forward and not backward, I thought I was looking to your face, but seems that I am looking at the back of your head* [avatar]. *Oh shit, I cannot perceive which side that is.*" The participants (P5, P6, P8) suggested improvements to the avatar design based on their complicated interaction experiences, such as adding a face in order to see where the avatar is facing as well as the gaze direction.

ARM interaction was also commented to be limiting as user cannot use hands (P1, P2, P15, P16). As P1 and P2 discuss: "*I think on the tablet side it is a bit difficult as you are holding the tablet, so it is a bit…*" (P2), to which P1 carries on: "*you cannot use your hands.*" P15 described the mixed feelings when interacting in AR motion capture suit setting: "*In the VR it is really clear that you are in there, you are like a 3D model and you have your hands* [avatar hands] *and you can move around the environment, but in here* [AR setting] *it is sort of mixed …What I can see with the glasses is just the avatar, so I am not sure whether I am also supposed to be an avatar, so if I put my hand in front of the glasses should I see my hand or like a rendered hand?*"

6.2.1. Interaction through the AR marker

Several participants (P3, P6, P7, P8) had difficulties with interacting through AR marker. In the post interview, participants perceived this interaction as complicated and unnatural, as explained by P6: "*I was trying to get good view on how far the key is from me, but then I could not get proper view as I had to keep it in the poster.*" Another participant (P3) stated: *"I had to walk backwards because I had to keep pointing the tablet to the poster so that is a bit unnatural.*"

Interaction through the AR marker also hindered the feeling of presence of the other user which was not the case in the VR setting as participants were generally more immersed and felt the presence of the other user. As described by P15: "*While I was in here* [AR] *I didn't quite understand that the other person was actually in the same space, it was more like I saw a ghost or Figure or something running around, maybe it was because the avatar was missing …all the time, so I did not feel like a we were both in this room…, while in there* [points towards the VR setting]*… I felt like we were in same space.*" P12 complemented this by stating: "*In there* [VR setting] *you could feel that she was just next to you.*"

For many participants (P1, P2, P3, P4, P7) hearing the voice of another user helped in the AR setting in creating a feeling of another user in the same space. As stated by P7: "*If there would have not been voice, it would have made a feeling that you are communicating with a computer, audio connection humanizes it."*

6.3. Suggestions for the use case and context

Even though some participants acknowledged that use cases would be highly task dependent (P3, P7, P11), several participants suggested different use cases for this kind of system: *games* or *multiplayer games* (P1, P6, P7, P9), *meetings* (P5, P6), *demonstration* (P2), *remote guiding* (P2, P3, P4, P14), *training how to play instruments* (P4), *remote teaching* (P4, P10), *enhancing remote communication* (P7, P8, P11), *couching in sports* (P3, P10), and *enabling travel experiences* (P5, P12, P14, P15).

6.3.1. Personal use

Several participants (P3, P4, P13, P15) envisioned it to be useful in familiar contexts such as their homes or their relative's homes in guiding them remotely with tasks they are not capable of conducting alone and that cannot be easily done via phone. P13 described a use case with a child: "*If my child is at home while I am travelling, I could help him with specific task at home, such as electricity.*" P4 described a use case with his grandmother: "*When my grandmother needs help with the computer…I try to give her verbal instructions, but they simply are not enough her to complete the task, if I could see her environment and how she does things maybe I could give clearer instructions to her.*" P2 saw potential for using it for remote guidance of how to fix a bicycle (P2).

Participants (P7, P8, P12, P11) also suggested that the system could be used for connecting to friends and family, as described by P8: "*It think it would be cool if the virtual reality could be, for example, your apartment and if you or your partner is travelling or something, you could still start watching the same movie and on the sofa, you can have the feeling of other person.*" P11 perceived that the system could enhance Skype and other communication means. One pair (P15 and P16), however, had privacy concerns, as described by P15: "*Someone could invade into your… virtual home even though you do not want people to "come" in your home.*" (P15).

Two participants (P12, P15) wanted to enable travel experiences to someone who cannot personally travel or join to the trip due to illness, for example (P12). As P15 explains: "*I guess if you could go somewhere… for example, go to woods…and scan the location and then someone else could like remotely join the same area, then it would be really nice…*[and] *useful.*" P14 suggested using it for guidance in unfamiliar place: "*An AR experience with another guy as an avatar to guide you through a city."*

6.3.2. Professional context

Three participants (P4, P12, P14) commented that the system would be beneficial in work and especially in an industrial context. As suggested by P14: "*In the industrial environment, supervisor or boss could come to instruct you how to open a valve or do something… to guide you. Because industrial context is very complicated environment and if you are there for the first time or you do not know what to do.*" It was also perceived as good as it allows experts to help local workers to solve technical problems (P12) or supervise the construction site (P14) in remote locations without the need for physically travelling to the site.

Remote teaching was mentioned by two participants. However, they perceived it from different viewpoints. P10 suggest using it for specific teaching context: "*It could be…virtual laboratory where another guy would show where things are.*" P8 was thinking of broader use cases: "*Of course you go thinking how much you could virtually take part into classes from home with the glasses* [HMD]*…and could you afford it, but I could see myself looking for the glasses at 8.15* [earliest lectures start at 8.15 AM]."

6.4. SET drawings

Half of the participants drew full body avatar for both the AR and VR use cases, however some preferred to have different body for AR avatar, such as drawn by P5 in Fig. 9, a. Full body for AR user's avatar in VE (ARM/ARMC) were drawn by P2, P4, P7, P10, P13, P14, P15, and P16. For the VR user's avatar (VRM/VRMC) in real environment, full body was drawn by P2, P4, P5, P7, P10, P13, P15, and P16 (Fig. 7a). The second most favoured body type was a torso with face, arms and hands (4/16). This avatar-style was drawn for VRM/VRMC avatar by P3, P6, P8, P9 and for ARM/ARMC avatar by P3, P5, and P9. One participant (P9) explained why he draw an avatar without legs: "*No legs, as they did not have legs in the current system, so I thought are they needed as they will end up going inside of the ground."* Three participants (P8, P11, P12) did not indicate in their textual or oral explanations the body type for the avatar. Two participants drew torso with arms and hands and 1/2 legs and face (P1, P14) for VRM/VRMC avatar and only P1 drew the same body for ARM/ARMC avatar. One participant drew torso with face (P6). Most of the drawings suggested human like avatars (15/16), but in addition also robot (P3), blocky character (P10), or creature (P14) were suggested as solutions at least for the VRM/VRMC avatar. Such as P3 stated while drawing: *"Personally, I think it is ok to have something very abstract* [draws a floating robot such as Eva in Wall-E]." While drawing P14 stated: "*Actually, … could you do monsters? Crazy …your boss would*

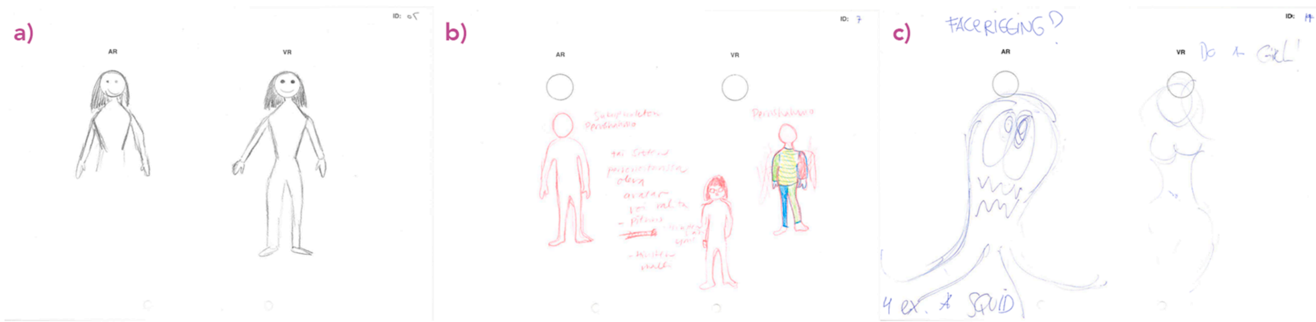

Fig. 9. SET drawings of the participants: P5 (a), P7 (b), and P14 (c).

be like a monster [laughs], *face rigging, can you do that?*" (P14) In his drawing (P14) monster is squid and has text below it: "*4ex a squid*" (Fig. 9c).

Two participants drew or commented that the both the AR and VR avatars should look alike (P4 & P8), as stated by P4: *"Why they should be different?"* However, many participants draw different avatars for AR and VR use cases. Some went for imaginary characters like Indiana Jones (P9) for VR. Four male participants (P4, P11, P13, P14) wanted to have a woman avatar for VR. P4 stated while drawing: "*I will go for woman in VR."* P14 then stated while drawing (Fig. 9c): *"Do a girl…would it be hard to do a more realistic avatar?*" P12 explained a proper reason for that: "*Gender needs to be the same as another user…I would like to see a girl if another user is girl, as I could hear her voice* [P11] *but I was seeing a guy avatar, so it was*…[makes confused sounds]."

Some participants preferred to have as realistic appearance as possible (P15, P16), however some other participants (P3, P4, P7) suggested that the humanoid avatar could be simple and have customizable features like in computer games. P4 stated: "*If the avatar would be for training purposes, I would like it to be more like P3 so that I know that I am communicating with him or collaborating with him. It doesn't have to look like him, but at least have his name on or initials.*" Similarly, P7 commented: *"I was thinking about that it could be genderless basic character, but in the way that it would look human like, preferably customizable avatar, so that you could pick from the variables; height, colour of the hair, shape."* (P7). However, two participants (P1, P2) pointed out that in multiuser situations basic customizable avatars might not be enough as stated by P2: "*Even if you use the Vive in online it is confusing who is who…. let's say that P1 could choose colours of his clothes or shoes, regardless of the possible combinations, someone else could come there with same combination."* P2 therefore suggested adding a real profile picture of the user that would pop-up when avatar is gazed, however it should not be masked on the face of the avatar as this could look odd.

P7 focused on how avatar could be used for guiding after frustration from not been able to communicate clearly directions with the current avatar designs and stated: *"…if it cannot be made clearer especially on this side* [VRM/VRMC avatar] *then it could have different coloured hands and legs so that it would be easier to guide based on those: 'like use your yellow hand'*." (Fig. 9b). P8 agrees: "*That was a good point that if the hands would be different colours so you would use them in guiding* [no need to know which one is left]." To which P7 replies: *"Except you will not see your hands in AR."*

6.5. Ranking of the ViDEs

6.5.1. Virtual reality user's avatar augmented on a real environment (VRM/VRMC)

Participants preferred an as realistic and full body representation of avatar as possible for the virtual reality user's avatar augmented on a real environment (VRM/VRMC). The distribution of votes of ViDEs is presented in Fig. 10. A non-parametric Kruskal-Wallis test indicated no significant differences between the sums of calculated points ($\chi2(8) = 10.320$, $p = 0.243$), in part due to our limited sample size for the user study. *Photorealistic full body* avatar (A1) received the highest number of points in the Borda count (22), 5/8 motion capture suit users (VRMC) chose A1 as the best option, whereas only 2/8 of tablet users chose it. The second highest option *Hologram full body* avatar (B1) with 16 points. B1 was chosen by 2/8 as the best option by both motion capture suit wearers and tablet users. Third highest was *Photorealistic torso avatar with arms and ½ thigh* (A2) with 15 points.

Only a few participants commented something while selecting preferred options, such as P8 stated when seeing the options: "*The avatar could have been done in this cool way?*" Two participants commented on the hologram avatar while ranking the options. P8 stated: "*Maybe it could be like that [hologram], so that you could see through it, as during the use it was difficult as your avatar was all the time on the way.*" P16 reflected back on the earlier drawing task and stated: "*Now if I could do the drawing task again, I would suggest realistic [photorealistic] face with translucent body. This [hologram full body avatar] is like ghost, I do not like it.*"

6.5.2. Augmented reality user's avatar in virtual environment (ARM/ARMC)

Participants preferred a realistic and full body representation of the augmented reality user's avatar shown in a virtual environment (ARM/ARMC). The distribution of votes of ViDEs is presented in Fig. 11. A non-parametric Kruskal-Wallis test indicated no significant differences between the sums of calculated points ($\chi2(8) = 8.814$, $p = 0.358$), in part due to the limited sample size for the user study. *Photorealistic full* body avatar (A1) received the highest number of points in the Borda count (29); the two second highest were *Hologram full body* avatar (B1) and *Cartoon full body* avatar (C1), which both received 13 points. Third was *Photorealistic torso with arms and ½ thigh* (A2) with 12 points. 7/8 motion capture suit users (ARMC) chose A1 as the best option, whereas tablet users votes distributed a lot and only 2/8 chose the same option (B1).

While selecting two pairs were considering the use contexts for avatars, such as (P12) asked: "*What situation is this for?*" P7 and P8 were discussing on possible use case: "*Depends on the use case, but in the meetings, etc. it would be the best to have as realistic humans as possible, but in some game where all are having like these* [furry] *that would be fun I guess* [laughs] (P7). P8 laughs and states: "*I think the cat woman is really freaky…It would be really strange if there is like normal looking person* [avatar] *and then this kind of bunny character* [avatar] *next to it… Everyone has like big boobs and latex on.*" One pair (P3 & P4) was questioning the technical possibilities and P4 asked: "*I wonder what is the difference between these* [points to A1 and C1]*, is it only the shoes?"* By help of P3, the participant noticed that A1 is more realistic looking. This led to a discussion what is technologically possible to implement: "*Of course you have to realize it will not look as good as this* [points to A1]." (P3) To which P4 states: "*I would go for this* [points to C1] *as I think it would be more realistic in terms of possibilities, but maybe this is* [points to A1]." P3 then carries on: "*This is more realistic…, I mean is it technically*

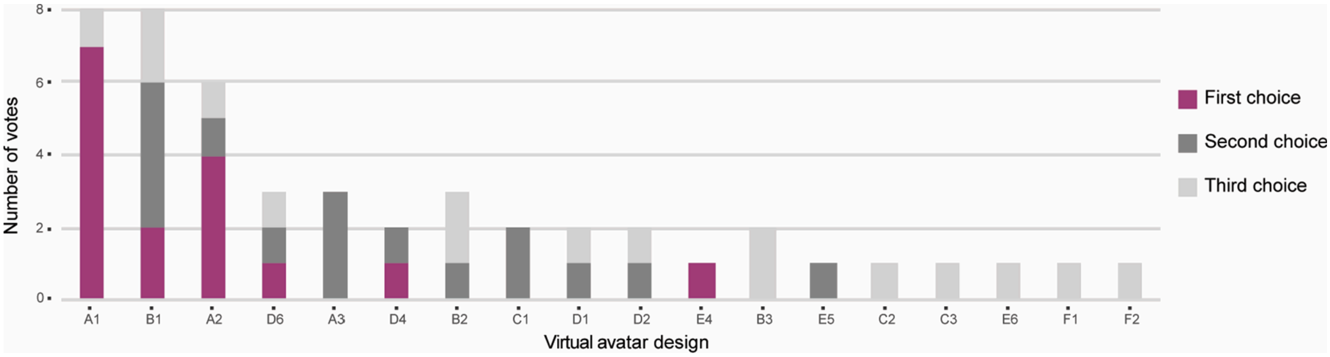

Fig. 10. The distribution of votes of ViDEs VR user's avatar augmented on a real environment (VRM/VRMC). Designs that did not get any votes are not shown in the plot.

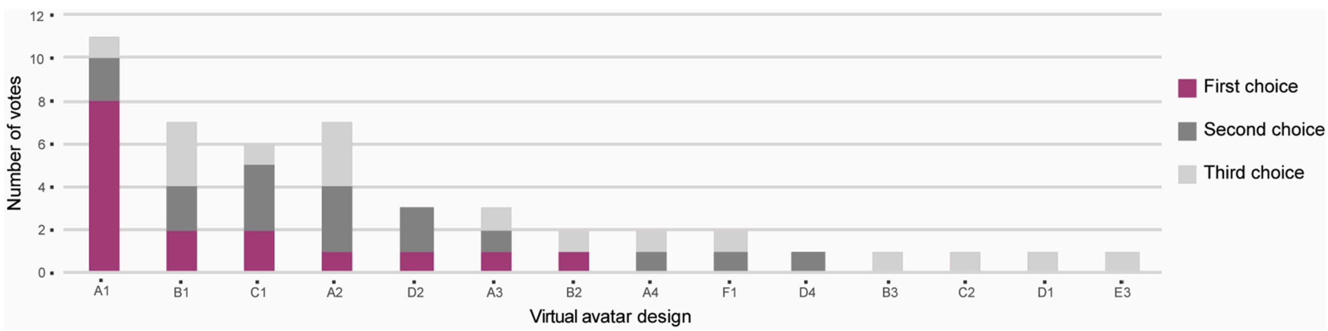

Fig. 11. The distribution of votes of ViDEs of AR user's avatar shown in virtual environment (ARM/ARMC). Designs that did not get any votes are not shown in the plot.

possible?" (P3).

It was also suggested that hologram avatar B1 creates a feeling of being in a virtual world. As after selecting suitable options, P2 commented on B1 as follows: *"I chose this as best as this is like, you know, it is virtual world.*" P11 favoured A1 and B1, but wanted to add some features to the chosen avatar designs and explained: "*I would like to combine the line that shows the direction of the gaze* [from shadow avatar, D1] *to the photorealistic* [A1] *and hologram* [B1] *full body avatars.*"

Some participants commented on photorealistic avatars missing body parts. Such as P4 stated: "*This one on top left* [A4] *makes me a feel a bit unwell.*" To which P3 responded: "*Yes, me too* [laughs]." P11 comments on missing half of the body of the avatar: "*Ha ha, that is funny* [A3]." P7 comments with laugh: "*For playing hide and seek, this* [A6] *would be cool as you can see only its eyes.*"

7. AUX evaluation: Online survey

To study further users' preferences with the ViDEs as well as achieve a larger and more geographically distributed sample, a survey was chosen as a platform for AUX evaluation. As suggested in user experience research, users can experience products or services prior to their actual use situation [16,29,39,49], and a person may imagine using the product during and after use, as well as over time [49]. According to Pakanen [39] Anticipated User Experience means: "*experiences, needs, and wishes that result from anticipated interaction with the concept of a product before the actual product exists*". Therefore, survey can be used as a platform if it is allowing to get sense of the experience. Due to the fact that respondents were not able to use the system, a video combining both the screen recorded view and user interaction in the real use of the system was shown before the ranking tasks. The video showed clearly the interaction and how avatar looks like in that use case. In addition, due to the fact that motion capture suits are not so common to lay people and in survey it might be difficult to understand its abilities in sufficient manner based on the video only, it was therefore left out and survey focused only on ARM/VRM use case.

7.1. Survey design

The survey topic was introduced through an illustration of both use cases (Fig. 3) accompanied with a brief textual description. Respondents were instructed to conduct the survey on a computer rather than on a mobile device. Most of the questions had predefined answer options, and only defining or more qualitative questions had open ended text boxes. At the onset of the survey, demographic information [e.g. age, gender, educational background, and nationality] and prior experiences with the technology in question was collected. To affirm that respondents were able to see the ViDEs correctly, respondents were asked to report their computer and screen in use. Prior to seeing all design options, respondents were shown a video of an AR use case (link to video: https://youtu.be/kfXAOQcr-js) (Figs. 3a & 7a) followed by questions of the current avatar design (Fig. 3c):

1. What do you think about virtual reality user's avatar's appearance (Fig. 3c)?
2. Is the avatar's visual appearance informative and detailed enough for this kind of use case?
3. If you could have any kind of representation of remote user augmented on the real environment, what would that be?

Respondents were then asked to rank ViDEs (shown in mixed order) for presenting VR user's virtual avatar in the augmented reality use case (Fig. 7a) and explain their choices. Based on the respondent's answer for gender in the beginning of the survey, either male or female ViDEs were shown. This procedure was repeated for the VR use case (link to video: https://youtu.be/1l4i-2evDS8) (Fig. 3b; Fig. 3d; & Fig. 7b). To prevent the effect of 'lazy respondents' simply clicking next without considering their preference, no option was preselected.

Qualtrics was used as a survey tool, with the survey available to respondents for four weeks. The link was distributed through university mailing lists, social media, and 3D UI mailing list. Participants were free to leave their contact details to take part in a raffle for five 10 EUR/~12 USD Amazon vouchers.

7.2. Respondents

The survey received 87 responses, of which 43 were complete. Only complete responses were considered in the analysis. The respondents' age varied from 21 to 54 year with a mean age of 30 (SD 7.89). 25 respondents were male and 18 were female. Twenty-eight of the respondents were European, nine Australian, and six Asian. The educational levels of the respondents were as follows: Master (16), Bachelor (13), High school (8), Doctoral degree (4), Licentiate (1), and Vocational school (1). Most of the respondents had prior experiences with 3D games (29). Respondents also had prior experiences in 3D technologies and applications: Oculus Rift (27), HTC Vive (18), as well as 3D-virtual worlds, e.g. Second Life (20). Most of them were familiar with AR applications and technology (29), such as Pokémon Go (5) and HoloLens (6). Participants accessed the questionnaire by using displays ranging from a 17″ tablet to a 47″ HD screen. One participant who used a Microsoft surface tablet had an external display connected to it in order to see the images in more detail.

7.3. Data analysis

To analyse the open-ended survey responses, general qualitative coding principles [8] were applied. The analysis was initiated by reading the answers per question on how the avatar should be presented and ranking task rationales. The focus of analysis was on gaining an understanding of the participants' perceptions and needs for the virtual avatar's appearance. For the ranking tasks, rationales for the selected designs were collected and categorized based on similarities. In the analysis of ranking task results, Borda count [50] was used to weight user preferences. Three-points were assigned to the respondent's first choice, two points to the second choice, one point to the third, and zero to all other possible choices. For statistical test a non-parametric Kruskal-Wallis test (given the non-normal distribution of the data) and *t*-test for pairwise comparisons were used.

8. Online survey results

In Section 8.1, the results related to the AR use case, where an AR user interacts with VR user's avatar in a real environment are presented. First, respondents' perceptions of the implemented VR user's avatar design and its suitability for the use case, as well as how to best present the VR users avatar are reported. Next, the ranking task results with a rationale for choices made are presented. In Section 8.2, the results related to the VR use case, where a VR user interacts with AR user's avatar in VE are presented in same order as in AR use case.

8.1. VR user's avatar augmented on a real environment

8.1.1. Perceptions of implemented virtual reality user's avatar (VRMC)

After seeing a video of AR use case describing the interaction with implemented VR user's virtual avatar in real environment (Fig. 3c), nineteen respondents commented its appearance to be *simple*, *basic*, *minimalistic*, or *abstract*. For many respondents (13/43), the simple design was perceived negatively and too polygonal (18/43), as one responded stated: "*Very boxy, I was honestly imaging something more realistic… Current Video games and new VR have really increased expectations*" (R13). Another respondent stated: "*It's great for the PlayStation 1 era graphics. Going for retro? A lot more could be done with the* (few) *polygons available. Why go to the effort of having a hairstyle on the avatar, but no face?*" (R14). Respondents commented VR avatar to serve its current use case shown in the video (31/43), however many pointed out that it might not function in other use cases. Respondents liked the guiding with audio and hand movements, however they wished more detailed hands to be able to use more detailed gestures than just pointing, as stated by respondent R20: "*The pointing direction is clearly visible, but the hands should be more animated to allow more expressiveness*."

Respondents wished to present remote user as realistic manner as possible (7/43) As one respondent explained: "*I'd like to have a remote designer participate into a* [service design] *project by using AR glasses myself and giving them a full body avatar with hands and feet tracked. But I'd also place much concern on the graphics quality of the avatar if augmented on the real space, because I wouldn't want it to stand out and catch unequal attention compared to everything else going on in the design space.*" (R4) Several respondents were quite satisfied with the current design, but hoped for a more detailed version (9/43). Some participants had a clear rationale, such as R26 explains: "*Ideally you'd want to iterate on this existing avatar and improve graphical fidelity. As a long-term goal, you could aim for complete realistic simulation* [very difficult to achieve] *or you could initially go with something simpler and more achievable like a Nintendo Mii avatar* [less susceptible to the uncanny valley effect]. *Alternatively, you could go with something more fun and cartoonish - humanoid animals, mythical characters etc.*" A handful of respondents did not provide any ideas (6/43).

8.1.2. Ranking of ViDEs of virtual reality user's avatar

The distribution of votes of ViDEs presenting the virtual reality users avatar augmented on a real environment (Fig. 3c) is presented in Fig. 12. A non-parametric Kruskal-Wallis test indicated significant differences between the sums of calculated points ($\chi2(12) = 24.538$, $p = 0.017$). Photorealistic full body avatar (A1) received the highest number of points in the Borda count (57); the second highest was Hologram full body avatar (B1), which received 44 points. Third was Hologram torso with arms & ½ thigh (B2) with 26 points. Separate pairwise comparisons using Dunn's test of multiple comparison [10] (with Bonferroni correction) between the three most popular designs (A1, B1, and B2) revealed a significant difference between A1 and B2 ($Z(1) = 2.125$, $p = 0.034$).

All respondents that chose the Photorealistic full body avatar (A1) (22/43), preferred it as it was the most life like representation of a human. As one respondent stated: "*It is realistic representation of the person, full body is shown, and facial expressions*" (R28). It was also perceived to have the most possibilities for guiding other user in the joint task: "*If the features can be used aka eyes and hands/fingers, can provide the most amount of detail for direction*" (R13). Another respondent stated: "*If you are just having fun with your friend with the AR, then the fox* [Furry] *Figure can work too, but if for professional use, then the realistic human is the best because when you communicate you pick little hints from people's faces and gestures even without thinking about it.*" (R39). It is interesting to note that in the realistic representation (A1), people commented that the avatar has to be complete, e.g. have full legs and not legs fading out, but in the holographic representation (B1-B3) full legs were not deemed necessary: "*…if it's transparent it isn't that weird that the girl is missing her legs* (B1 and B2). *On the contrary, if the girl is visible, I prefer that her legs are seen* (A1), *or otherwise it looks a little creepy to me.*" (R9). However, those who were more familiar with 3D and AR technology commented that they chose the one without incomplete legs as legs do not submerge well with the environment (R18) or are not moving naturally (R11). One respondent also stated: "*If something has to be sacrificed, the legs are the most dispensable body part, especially since people rarely walk around much in virtual spaces.*" (R22).

The hologram representation was selected as it shows the appearance of the person in a realistic 3D form but also clearly signals that the avatar is virtual, so that it is impossible to mix it with a person present in the physical environment. As one respondent stated: "*B1 is the best choice, because it gives all information that a real person would* [body

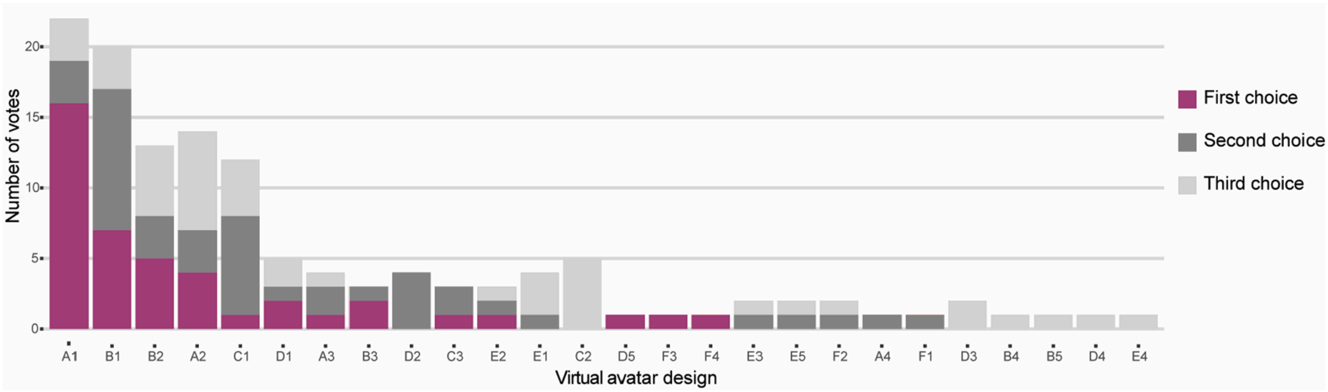

Fig. 12. The distribution of votes of ViDEs of VR user's avatar augmented on a real environment (VRM/VRMC). Designs that did not get any votes are not shown in the plot.

language, etc.] *but still appears as artificial, so it is not confused for a real person.*" (R34). Another responded stated: "…*a semi-transparent avatar helps the user remember that the other person is not actually there.*" (R31). The futuristic appearance of B1 and B2 was also positively perceived, as one respondent stated: "*I like the transparent version of the girl because it looks rather futuristic*." (R9).

8.2. AR user's avatar shown in a virtual environment

8.2.1. Perceptions of implemented augmented reality user's avatar (ARM)

Again, for many respondents (11/43) the existing avatar was *very basic* and *simple looking* and *too polygonal* and *pixelated* (7/43) for presenting augmented reality user's avatar in a virtual environment that represents the real environment where the user is located (Fig. 3d). Some of the participants commented that it was better fit with cartoonish and non-photorealistic virtual environment than in the earlier use case (4/43). For most respondents, the implemented avatar served its purpose in the presented use case (32/43). Respondents wished to present remote user as realistic as possible (11/43), or as a fantasy or cartoon Figure, such as Nintendo Mii, as it would fit with the cartoonish looking environment (7/43). For several respondents, the current design with slight modifications would work well (10/43). The suggested changes include a more detailed visual appearance, moving hands, sight and gestures, and/or face of the user projected on the avatars' face.

8.2.2. Ranking of ViDEs of augmented reality user's avatar

The distribution of votes of ViDEs presenting the augmented reality users' avatar in a virtual environment (Fig. 3d) is presented in Fig. 13. A non-parametric Kruskal-Wallis test indicated significant differences between the sums of calculated points ($\chi 2(14) = 26.823$, $p = 0.020$). The Photorealistic full body avatar (A1) received the highest number of points in the Borda count, 45; the second highest was the Cartoon full body avatar (C1), which received 27 points. Third was the Photorealistic torso avatar with arms and ½ thigh (A2) with 21 points. Separate pairwise comparisons using Dunn's test of multiple comparison (with Bonferroni correction) between the three most popular designs (A1, C1, and A2) revealed a significant difference between A1 and C1 ($Z(1) = 2.359$, $p = 0.018$) and between A1 and A2 ($Z(1) = 2.838$, $p = 0.005$).

Comments for the selection of the Photorealistic full body avatar (A1) as the best choice were similar as in the AR use case. However, it was perceived to sufficintly pop-up and still fit in the environment, e.g. be immersive. As explained by one participant: "*C1 or A1 would definitely have their wow-elements…but I'd still call them practical and very socially enjoyable for most use cases when I know and trust the other people.*" (R4) "[A1, C1, A2] *because they look like real avatars in the environment, like they are meant to be there - human and life like.*" (R40). In contrary to AR use case transparency was not perceived to fit with the virtual environment, as one respondent explained: "*Transparency would appear strange to use in a VR scene, it would make an impression that the other user is not actually there.*" (R31). The photorealistic torso avatar with arms and ½ thigh (A2) avatar was selected as it was perceived to be suitable with the technology as one respondent described: "*I think wearing the VR headset, your vision is obstructed so it's better to see half bodies. Also, half bodies may be less taxing on the VR program and on the user.*" (R25)

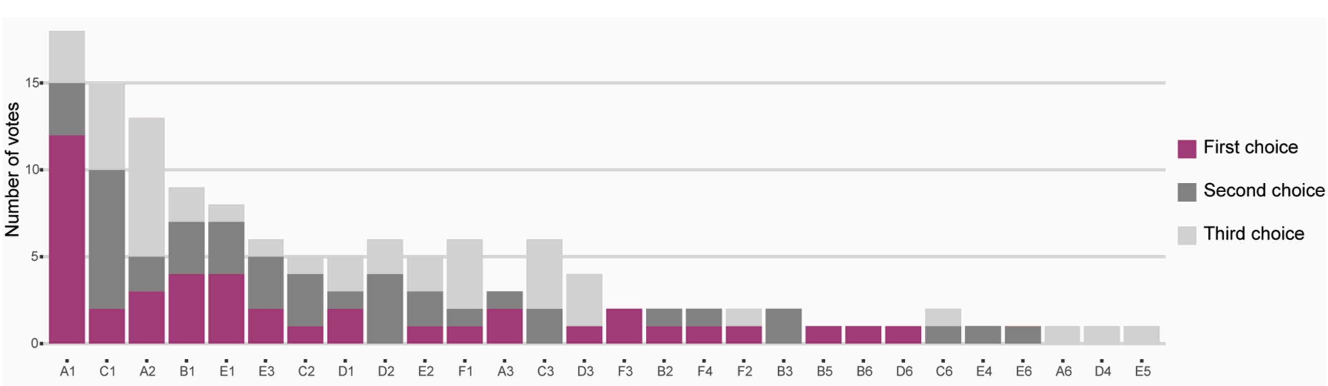

Fig. 13. The distribution of votes of ViDEs for AR user's avatar shown in virtual environment (ARM/ARMC). Designs that did not get any votes are not shown in the plot.

9. Discussion

9.1. Avatar representation for AR and VR use cases for presenting the other user

Prior research on avatar design has focused mainly on how people want to present themselves [11,28,55,62,47,51,55]. This paper presented a user study and follow-up anticipated user experience survey which investigated how people prefer to see other users presented as virtual avatar in AR and VR based telexistence system. The findings suggest that people preferred to see the other user as photorealistic full body avatars in both the AR and VR use cases. In addition to previous research suggestions that realistic looking avatars increase self-presence [54] and co-presence [7], the findings of this study suggest that it may also increase the presence of the remote user. Next, the findings are discussed and suggestions are presented on how to present other user in collaborative telexistence systems.

Use case affect to the how other user's avatar want to be seen. This study results highlight that games and professional contexts need different kinds of avatars. As suggested in prior self-presentation avatar studies, in games avatars can be more varied [47,51,55]. This study confirms these findings. However, in other use cases (e.g. helping family members or professionals in industrial settings remotely or hanging around with loved ones) a photorealistic avatar is desired in both AR and VR use cases. The need for recognizable avatars in professional use cases is obviously impacted by trust, as people need to be sure that the person is the one that they expect to be [40]. In a family setting it is important to see people in a recognizable manner, especially if the idea is to hang out with them remotely. Hearing the voice of remote participants was perceived to aid in the creation of a stronger sense of presence of another user and increases the feeling of trust that the avatar is really the person that it is supposed to be and not an artificial agent.

Augmented reality use case needs an avatar that cannot be mixed with real people in the space. The respondents stated that the photorealistic looking avatar might be mixed with a real person in the real space, which supports prior findings that in AR the photorealism of an avatar gives a feeling of person being 'there' [37]. Participants who interreacted with the system also commented that translucency would help in their interaction with the system as the avatar of the other user would not occlude with the environment. Therefore, as supported also by the findings of both studies reported in this paper, a hologram presentation might work best for the AR use condition. However, as perceived by one participant, a turquoise glow is not the best choice as it can be understood as a ghost, a full colour representation is therefore more suitable option such as presented in [43].

Photorealism requires full body representation. The findings of this study suggest that the full body of the avatar needs to be shown, especially when a photorealistic avatar representation is used. When a person is presented as photorealistic as possible, the removal of legs is perceived as disturbing. This phenomenon has been explained by immersion causing an almost realistic feeling of amputation. Prior research noted that even if a person's virtual hands are missing fingers, they behave as if their fingers were also missing in reality [52]. This study findings support the prior findings as some participants were confused both when interacting and when perceiving the ViDEs of missing body parts. However, in the hologram presentation it was not perceived as odd as the avatar was translucent. The participants that chose the avatar without legs, commented on their choice from a technological limitation point of view, which should not be the rationale for selecting a certain preferred design. Therefore, as technology develops, full body motion tracking and a full body designs should be used while avoiding feelings of disturbance.

Complicated interactions require more expressive avatar faces and hands. If a person is completing a complicated task in a telexistence system, such as guiding to repair a motor remotely, a more expressive design of avatar is needed. For example, allowing users to express more gestures by moving their fingers. Especially in official social interactions, a more expressive facial expression needs to be transmitted to allow for more realistic conversations. This study findings support prior research that indicates the importance of facial expressions and gestures in evoking higher level of co-presence [7], social attraction, and perceived competence [34,35,36]. In addition, technological developments [21,62] allow for the creation and customization of highly photorealistic human avatars, such as [64]. Therefore, telexistence systems using AR and/or VR will soon be able to make use of ultrarealistic yet highly customizable avatars that allow for richer communication.

9.2. Reflections of the rigorous design of ViDEs

Prior research has not investigated in a thorough manner the creation of different avatar designs for a user study. Most of the prior studies have used a limited number of examples, ranging from two to eight [7,12,14,24,47,54]. The most comparable study originates from Nowak and Rauh, which had issues in comparability of the examples (only two of the comparable five options were based on the same face, as well as varying colours and sizes and shapes of eyes, mouths, and faces – especially on non-humanlike avatar designs such as animals and objects) [36]. Based on prior research, this study makes a novel contribution in thoughtful altering the design parameters (e.g. both by altering the different visualization parameters on the same base avatar design and altering the amount of body shown which has not been investigated in prior studies). This rigorous design approach ensured that the ViDEs are directly comparable by confirming that the humanlike avatar designs resemble one another even if the visualization manner changes.

The thoughtful altering of visual characteristics is highly important for the reliability of the results. As people can easily be distracted by several secondary factors in the given examples [39], such as, in the case of avatar related studies, the colour of the avatar's hair, eyes, clothes, sizes of the eyes, mouths, and head, or the visualization styles and brightness of the examples. Therefore, designers should pay careful attention to the visual material creation for comparative studies and thoughtful alteration of visual parameters as it is critical in ensuring a fair comparison. This paper encourages other designers to pay attention to the thoughtful design of the examples in outlined and similar studies.

9.3. Limitations and future research paths

For generalizability of the findings, several limitations were acknowledged which should be considered when interpreting the results. First, due to the small sample size and vast number of ViDEs, the quantitative findings of the user study were not significant, however, the rich qualitative material gathered from the user studies turned out to be more valuable and complementary to the findings from the latter online survey. Second, the follow-up survey in an anticipated use situation had limitations. The size of the displayed pictures was limited compared to the user study versions. A few comments regarding this were received, although this did not pose a problem for the large majority participants. Third, the distinction between A and C avatar options was difficult to observe for some body types in the survey. We identified one such occurrence through the comments provided by the respondent. As this was spotted only in one response, it might have been caused by the quality of the screen that was used when responding to the survey. The distinction between the cartoon and the photorealistic avatars was also difficult in user study for one participant. Fourth, even though the videos were carefully made and able to show the use case in reliable manner, supported by almost similar ranking task results from both the user study and the survey, it is recognized that in a real use situation people might indicate a preference for different types of avatar representations.

Although the designer created clear and thoughtful designs, the female Furry avatar pose should have been modelled similarly to the human representation as it raised two comments from the female participants. One user study participant commented on the sexual appearance of the female furry (P8) and one survey respondent (R9) stated: "*And just to be heard, I would have chosen the female-cat avatar version if she hadn't been in a "sexy" pose.*" Prior research has recognized that female participants prefer not to select overly sexual characters [34] and that there are differences in how affective male or female gendered avatars are [1]. This brings forward a lesson for future studies, in which the pose and shape of an imaginary avatar should be identical to that of the humanlike avatar to avoid influence on the study participants' avatar selections. It also offers an interesting path for future research on studying the effect of avatar poses (or avatar animations) in relation to how they are perceived. In addition, the sample and avatar designs of this study were binary, future research should focus also in investigating non-binary participants' preferences for avatar design.

These results are not conclusive but aim to provide suggestions for other researchers who are designing avatar based telexistence systems or AR and VR combining games and applications. Future studies with implanted systems could, for example, investigate the optimal see-through level of the photorealistic looking full colour hologram avatar and different alterations of areas that are translucent in the avatar body. Avatars' head and hands could be opaque whereas rest of the body could be in varying degree translucent to help in AR blending and user interactions as the avatar's body will not block the view to the environment. When considering the quality of the hologram avatar and the tracking stability a rigorous technical implementation and study is needed. Furthermore, these studies should investigate how full body avatars fit with the limited field of view of wearable AR glasses. Finally, more investigation is needed in finding the most optimal way of incorporating gaze direction of the avatar.

10. Conclusion

Realistic avatars and their influence on user experience in AR and VR is only one aspect in the current amalgamation of these cross-reality technologies. This is especially relevant when these two technologies are combined into cross-reality telexistence system that allows remotely located users to connect and communicate with each other through a shared virtual environment. In addition, advances in computer graphics and high-speed networking will allow future telexistence systems to use truly photorealistic avatars, which is why the question to ask is how photorealistic the avatars need to be in AR and VR use cases? Prior research has been interested in developing such systems and has investigated various types of avatar representations. The focus of prior studies on avatar representation has, in general, been on how to present oneself rather than other users. Therefore, this study explored how users want to observe other user's avatars as visualized in a) augmented reality and b) immersive virtual reality. As prior studies have not thoroughly investigated user preferences on a) how much avatar body should be shown, or b) visual parameters of the avatars, a three-step design process was conducted for the thoughtful creation of 36 comparable ViDEs presenting virtual avatar designs for both AR and VR use cases. A user study with 16 participants was conducted to investigate user experiences and interaction with the avatars in the implemented system. To chart user preferences, 36 created comparable ViDEs were first used in a user study with 16 participants and subsequently in a follow-up online survey with 43 respondents. In the survey, a screen capture video of both use cases with avatars was presented prior to the task in order to collect respondents' perceptions on the virtual avatar designs of the implemented system and to make them aware of the use case before the ranking of the created avatar designs (ViDEs). The perceived best, second best, and third best options from participants choices were collected for the created ViDEs.

For future studies with implemented systems, a photorealistic full body human avatar both in augmented reality and virtual reality is suggested to be used due to its humanlike representation and affordances for interaction. In augmented reality use cases, the use of a hologram-like full body avatar can be a suitable alternative as it provides a realistic representation of a person while reducing the possibility for confusion with a real person. In addition, its see-through ability helps in user interaction. However, holograms should be used in varying degree of see-through (e.g. less in face and more in body) as well as fully coloured to make its appearance less ghost-like.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] J.D. Bailey, K.L. Blackmore, Gender and the perception of emotions in avatars, in: Proceedings of the Australasian Computer Science Week Multiconference, 2017, pp. 1–8.
[2] A. Beck, A. Kunert, B. Kulik, Froehlich, Immersive group-to-group telepresence, IEEE Trans. Visual Comput. Graphics 19 (2013) 616–625, https://doi.org/10.1109/TVCG.2013.33.
[3] E. Behm-Morawitz, Mirrored selves: The influence of self-presence in a virtual world on health, appearance, and well-being, Comput. Hum. Behav. 29 (2013) 119–128, https://doi.org/10.1016/j.chb.2012.07.023.
[4] B. Bell, S. Feiner, T. Höllerer, View management for virtual and augmented reality, in: Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology, 2001, pp. 101–110.
[5] G. Bente, F. Eschenburg, L. Aelker, Effects of simulated gaze on social presence, person perception and personality attribution in avatar-mediated communication, in, Citeseer (2007) 207–214.
[6] P. Boonbrahm, L. Sewata, S. Boonbrahm, Transforming 2D human data into 3D model for augmented reality applications, Procedia Comput. Sci. 75 (2015) 28–33, https://doi.org/10.1016/j.procs.2015.12.193.
[7] J. Casanueva, E. Blake, The effects of avatars on co-presence in a collaborative virtual environment, in: Annual Conference on South African Institute of Computer Scientists and Information Technologists, Pretoria, South Africa, 2001, pp. 19–28.
[8] K. Charmaz, Grounded theory as an emergent method, in: S. NagyHesse-Biber, P. Leavy (Eds.), Handbook of Emergent Methods, Guilford Press, New York, NY, US, 2008, pp. 155–170.
[9] K. Dotson, Object Theory brings futuristic HoloLens and Windows Mixed Reality-based real time collaboration to companies today, MSPoweruser, n.d. https://mspoweruser.com/object-theory-brings-futuristic-hololens-windows-mixed-reality-based-real-time-collaboration-companies-today/ (accessed April 8, 2020).
[10] O.J. Dunn, Multiple comparisons among means, J. Am. Stat. Assoc. 56 (293) (1961) 52–64.
[11] R.A. Dunn, R.E. Guadagno, My avatar and me–Gender and personality predictors of avatar-self discrepancy, Comput. Hum. Behav. 28 (2012) 97–106.
[12] A. Felnhofer, J.X. Kafka, H. Hlavacs, L. Beutl, I. Kryspin-Exner, O.D. Kothgassner, Meeting others virtually in a day-to-day setting: Investigating social avoidance and prosocial behavior towards avatars and agents, Comput. Hum. Behav. 80 (2018) 399–406.
[13] F. Giard, M.J. Guitton, Spiritus Ex Machina: Augmented reality, cyberghosts and externalised consciousness, Comput. Hum. Behav. 55 (2016) 614–615, https://doi.org/10.1016/j.chb.2015.10.024.
[14] J. Guegan, S. Buisine, F. Mantelet, N. Maranzana, F. Segonds, Avatar-mediated creativity: When embodying inventors makes engineers more creative, Comput. Hum. Behav. 61 (2016) 165–175, https://doi.org/10.1016/j.chb.2016.03.024.
[15] K. Inkpen, B. Taylor, S. Junuzovic, J. Tang, G. Venolia, Experiences2Go: sharing kids' activities outside the home with remote family members, in: Proceedings of the 2013 Conference on Computer Supported Cooperative Work, 2013, pp. 1329–1340, https://doi.org/10.1145/2441776.2441926.
[16] ISO, Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems, International Standardization Organization (ISO), Geneva, 2010, pp. 9241–10210.
[17] D. Jo, K.-H. Kim, G.J. Kim, Avatar motion adaptation for AR based 3D tele-conference, in: 2014 International Workshop on Collaborative Virtual Environments (3DCVE), IEEE, 2014, pp. 1–4.

[18] D.T. Kenrick, S.E. Gutierres, Contrast effects and judgments of physical attractiveness: When beauty becomes a social problem, J. Pers. Soc. Psychol. 38 (1980) 131, https://doi.org/10.1037/0022-3514.38.1.131.
[19] T. Koskela, M. Mazouzi, P. Alavesa, M. Pakanen, I. Minyaev, E. Paavola, J. Tuliniemi, Avatarex: telexistence system based on virtual avatars, in: Proceedings of the 9th Augmented Human International Conference, 2018, pp. 1–8.
[20] T. Koskela, M. Pouke, P. Alavesa, H. Kukka, M. Pakanen, T. Alatalo, T. Ojala, Hybrid avatars: enabling co-presence in multiple realities, in: Proceedings of the 21st International Conference on Web3D Technology, 2016, pp. 69–72.
[21] P. Kruszewski, T.J. Mahamad, The AI powered magic mirror: building immersive AR/VR experiences with only webcams and deep learning, in: ACM SIGGRAPH 2018 Virtual, Augmented, and Mixed Reality, 2018, pp. 1–1.
[22] B. Lang, Facebook Details Social VR Avatar Experiments and Lessons Learned – Road to VR, 2016. https://www.roadtovr.com/facebook-details-social-vr-avatar-experiments-and-lessons-learned/ (accessed April 8, 2020).
[23] G. Laurent, Free Xbox Onesies for everyone… as an Avatar accessory, OnMSFT. Com, 2016. https://www.onmsft.com/news/free-xbox-onesies-for-everyone-as-an-avatar-accessory (accessed April 14, 2020).
[24] J.K. Leding, J.C. Horton, S.S. Wootan, The contrast effect with avatars, Comput. Hum. Behav. 44 (2015) 118–123, https://doi.org/10.1016/j.chb.2014.11.054.
[25] J.-E.R. Lee, Does virtual diversity matter?: Effects of avatar-based diversity representation on willingness to express offline racial identity and avatar customization, Comput. Hum. Behav. 36 (2014) 190–197, https://doi.org/10.1016/j.chb.2014.03.040.
[26] Loom.ai, Real-time 3D Avatars for Enterprise, Loom.Ai, n.d. https://loomai.com/ (accessed April 8, 2020).
[27] A. Luoto, Systematic literature review on user logging in virtual reality, in: Proceedings of the 22nd International Academic Mindtrek Conference, 2018, pp. 110–117.
[28] M.N.A. Mazlan, M.A.A. Bakar, Students' Perception of Self-presentation towards Avatar, Proc.-Soc. Behav. Sci. 97 (2013) 361–367, https://doi.org/10.1016/j.sbspro.2013.10.246.
[29] John McCarthy, Peter Wright, Technology as experience, Interactions. 11 (5) (2004) 42–43.
[30] R. Mekuria, A. Frisiello, M. Pasin, P. Cesar, Network support for social 3-D immersive tele-presence with highly realistic natural and synthetic avatar users, in: Proceedings of the 7th ACM International Workshop on Massively Multiuser Virtual Environments, 2015, pp. 19–24.
[31] M. Minsky, Telepresence, Omni. 2 (1980) 45–51.
[32] C. Neustaedter, G. Venolia, J. Procyk, D. Hawkins, To Beam or not to Beam: A study of remote telepresence attendance at an academic conference, in: Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing, 2016, pp. 418–431.
[33] K. Nowak, F. Biocca, Understanding the influence of agency and anthropomorphism on copresence, social presence and physical presence with virtual humans, Presence: Teleoperat. Virt. Environ. 12 (2001) 481–494.
[34] K.L. Nowak, J. Fox, Avatars and computer-mediated communication: a review of the definitions, uses, and effects of digital representations, Rev. Commun. Res. 6 (2018) 30–53.
[35] Kristine L. Nowak, Mark A. Hamilton, Chelsea C. Hammond, The effect of image features on judgments of homophily, credibility, and intention to use as avatars in future interactions, Media Psychol. 12 (1) (2009) 50–76.
[36] Kristine L. Nowak, Christian Rauh, The influence of the avatar on online perceptions of anthropomorphism, androgyny, credibility, homophily, and attraction, J. Comput.-Med. Commun. 11 (1) (2005) 153–178.
[37] S. Orts-Escolano, C. Rhemann, S. Fanello, W. Chang, A. Kowdle, Y. Degtyarev, D. Kim, P.L. Davidson, S. Khamis, M. Dou, Holoportation: Virtual 3d teleportation in real-time, in: Proceedings of the 29th Annual Symposium on User Interface Software and Technology, 2016, pp. 741–754, https://doi.org/10.1145/2984511.2984517.
[38] O. Oyekoya, R. Stone, W. Steptoe, L. Alkurdi, S. Klare, A. Peer, T. Weyrich, B. Cohen, F. Tecchia, A. Steed, Supporting interoperability and presence awareness in collaborative mixed reality environments, in: Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology, 2013, pp. 165–174.
[39] M. Pakanen, Visual design examples in the evaluation of anticipated user experience at the early phases of research and development, Ph. D Dissertation. University of Oulu, Acta Univ. Oul. A 663, 2015.
[40] M. Pakanen, P. Alavesa, L. Arhippainen, T. Ojala, Stepping Out of the Classroom - Anticipated User Experiences of Web-based Mirror World Like 3D Virtual Campus, IJVPLE. 10 (2020) 23, https://doi.org/10.4018/ijvple.2020010101.
[41] M. Pakanen, J. Huhtala, J. Häkkilä, Location visualization in social media applications, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2011, pp. 2439–2448.
[42] Personify, 2018. Personify Teleporter on ARCore. Retrieved September 14, 2018 from https://youtu.be/O7XUuNlVusE.
[43] T. Piumsomboon, G.A. Lee, J.D. Hart, B. Ens, R.W. Lindeman, B.H. Thomas, M. Billinghurst, Mini-me: An adaptive avatar for mixed reality remote collaboration, in: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 2018, pp. 1–13.
[44] T. Piumsomboon, G.A. Lee, A. Irlitti, B. Ens, B.H. Thomas, M. Billinghurst, On the Shoulder of the Giant: A Multi-Scale Mixed Reality Collaboration with 360 Video Sharing and Tangible Interaction, in: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 2019, pp. 1–17. http://dx.doi.10.1145/3290605.3300458.
[45] B. Poussard, S. Richir, J. Vatjus-Anttila, S. Asteriadis, D. Zarpalas, P. Daras, 3DLive: A multi-modal sensing platform allowing tele-immersive sports applications, in: 2014 22nd European Signal Processing Conference (EUSIPCO), IEEE, 2014, pp. 356–360.
[46] I. Rae, B. Mutlu, L. Takayama, Bodies in motion: mobility, presence, and task awareness in telepresence, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Canada, 2014, pp. 2153–2162. http://dx.doi.10.1145/2556288.2557047.
[47] R. Ratan, Y.J. Sah, Leveling up on stereotype threat: The role of avatar customization and avatar embodiment, Comput. Hum. Behav. 50 (2015) 367–374, https://doi.org/10.1016/j.chb.2015.04.010.
[48] N. Rosa, Player/Avatar body relations in multimodal augmented reality games, in: Proceedings of the 18th ACM International Conference on Multimodal Interaction, Tokio, Japan, 2016, pp. 550–553. http://dx.doi.10.1145/2993148.2997618.
[49] V. Roto, E. Law, A. Vermeeren, J. Hoonhout, User Experience White Paper, 2011. http://allaboutux.org/uxwhitepaper (accessed March 19, 2018).
[50] D.G. Saari, The mathematics of voting: Democratic symmetry, Economist. 83 (2000).
[51] R. Schroeder, Social interaction in virtual environments: Key issues, common themes, and a framework for research, in: R. Schroeder (Ed.), The Social Life of Avatars, Springer, 2002, pp. 1–18.
[52] V. Schwind, P. Knierim, L. Chuang, N. Henze, Where's Pinky?: The Effects of a Reduced Number of Fingers in Virtual Reality, in: Proceedings of the Annual Symposium on Computer-Human Interaction in Play, 2017, pp. 507–515, https://doi.org/10.1145/3116595.3116596.
[53] Second Life Marketplace - Luskwood Creatures by eltee Statosky, n.d. https://marketplace.secondlife.com/stores/36173/ (accessed April 8, 2020).
[54] Y. Seo, M. Kim, Y. Jung, D. Lee, Avatar face recognition and self-presence, Comput. Hum. Behav. 69 (2017) 120–127, https://doi.org/10.1016/j.chb.2016.12.020.
[55] A.J. Seung-A, The virtual malleable self and the virtual identity discrepancy model: Investigative frameworks for virtual possible selves and others in avatar-based identity construction and social interaction, Comput. Hum. Behav. 28 (2012) 2160–2168.
[56] D. Shin, Empathy and embodied experience in virtual environment: To what extent can virtual reality stimulate empathy and embodied experience? Comput. Hum. Behav. 78 (2018) 64–73, https://doi.org/10.1016/j.chb.2017.09.012.
[57] Superdata, 2019 Year in Review Digital Games and Interactive Media, 2020. https://www.superdataresearch.com/2019-year-in-review (accessed April 14, 2020).
[58] S. Tachi, Evaluation apparatus of mobility aids for the blind, Japanese Patent 1462696, 1980.
[59] S. Tachi, Telexistence, second ed., World Scientific, 2015 http://dx.doi.10.1142/9248.
[60] Susumu Tachi, Telexistence: Enabling humans to be virtually ubiquitous, IEEE Comput. Graphics Appl. 36 (1) (2016) 8–14.
[61] R.E. Tagiuri, L.E. Petrullo (Eds.), Person perception and interpersonal behavior, Stanford University Press, Washington DC, US, 1958.
[62] J. Thies, M. Zollhöfer, C. Theobalt, M. Stamminger, M. Nießner, Headon: Real-time reenactment of human portrait videos, ACM Trans. Graph. (TOG) 37 (2018) 1–13.
[63] I. Torres, Daydream Labs: positive social experiences in VR, Google, 2016. https://blog.google/products/daydream/daydream-labs-positive-social/ (accessed April 8, 2020).
[64] J. Vincent, Samsung's 'artificial human' project definitely looks like a digital avatar, The Verge, 2020. https://www.theverge.com/circuitbreaker/2020/1/5/21050288/samsung-neon-artificial-human-digital-avatar-project-leaked-video (accessed April 8, 2020).
[65] A. Webster, Oculus Avatars look like the future of video game character creation, The Verge, 2016. https://www.theverge.com/2016/10/6/13177082/oculus-rift-avatars-vr-virtual-reality (accessed April 8, 2020).
[66] N. Yee, J. Bailenson, The Proteus effect: The effect of transformed self-representation on behavior, Human Commun. Res. 33 (2007) 271–290.