Re-located: Aligning Interaction Spaces to Support Remote Collaboration using Augmented Reality

Master's Thesis

submitted by

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Abstract

This thesis introduces a prototype called Re-located that facilitates synchronous remote collaboration in Augmented Reality independent of room architecture and furnishing. First, in a one-time room calibration process, the positions of screens in a room are calibrated. The purpose of every screen will be predefined in this process. Afterward, by wearing an Augmented Reality headset, remote users, and their movements, are visualized as 3D avatars in front of the screens with the same purpose. Furthermore, the prototype integrates a voice chat supporting spatial sound. The influence of the prototype was investigated through a usability study. The results of the study were that the prototype provides overall high user experience and a high sense of social presence and social richness, while the sense of spatial presence was rated rather neutral. The visual appearance of the avatar was rated as too abstract, and the missing gestures and facial expressions were noted. The spatial sound feature was noticed by over half of the participants and rated positively. Most participants have not noticed that the room settings were different. Overall, results indicate that the concept of Re-locations works and provide a foundation for future work.

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Abbrevations

2D two-dimensional

3D three-dimensional

AR Augmented Reality

AV Augmented Virtuality

FOV field of view

HMD head-mounted display

MR Mixed Reality

SSQ Simulator Sickness Questionnaire

TPI Temple Presence Inventory

UEQ User Experience Questionnaire

VR Virtual Reality

1. Introduction

Common remote collaboration systems like video conferencing systems and shared-document editors are often limited to screen sharing and communication over an additional audio and video signal. This two-dimensional type of remote collaboration has the disadvantage that social aspects like, e.g., the physical position in the room, gaze, or gestures of remote users, could be lost. Mixed Reality devices have the potential to overcome this gap of co-presence between remote collaboration and co-located collaboration by visualizing remote users in three-dimensional space. Furthermore, when using Augmented Reality devices, in contrast to other Mixed Reality devices, the surroundings are still visible. This has the advantage that interaction with people and physical objects in the room is still possible.

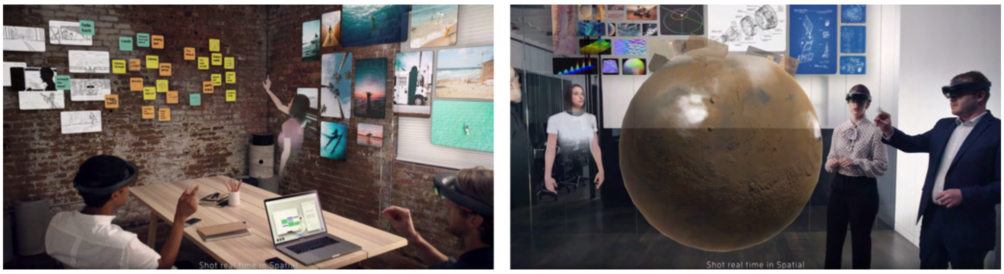

Figure 1.1.: Spatial is an Augmented Reality remote collaboration system that visualizes remote users as three-dimensional avatars hovering in the room. Furthermore, digital content is also visualized as part of the room. Taken from [1].

The demo video of the system Spatial [2] shows the opportunities of Augmented Reality as mediating technology for remote collaboration (see Figure 1.1). The system visualizes remote users as three-dimensional avatars. Spatial generates the avatars by using photos uploaded by the users. The generated avatars only have an upper body and therefore hover in the room. The system is not published yet, and consequently, the exact functionalities can only be speculated. From the video, one can deduce that the avatars imitate the position, rotation, head rotation, and arm gestures of the remote user. Furthermore, users can place digital content like documents, photos, or digital sticky notes on the walls in the room (see Figure 1.1 left). 3D models can be placed, e.g., in the middle of the room (see Figure 1.1 right). To make the visualization of avatars and digital content as part of the room possible, the users need to wear an Augmented Reality head-mounted display.

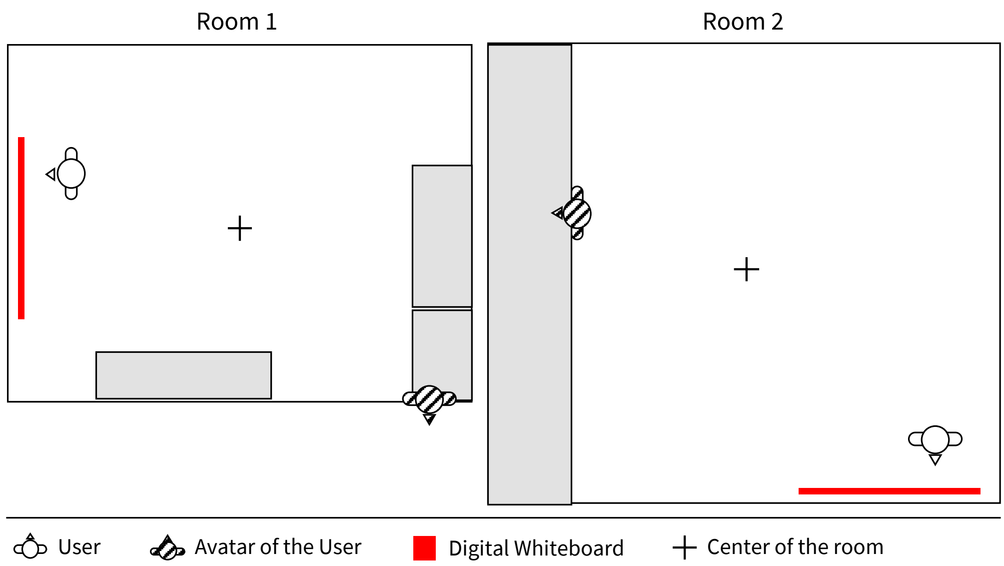

Figure 1.2.: Two users working together on a remote shared digital whiteboard in two different rooms. Avatars imitate the position and rotation of the remote users relative to the center of the room. While the user in Room 2 is in front of the whiteboard, the representing avatar in Room 1 is outside the room. Furthermore, the avatar stands not in front of the whiteboard in Room 1.

However, the use of Augmented Reality for remote collaboration cause problems. Usually, the rooms of remote users differ in architecture and furniture. Augmented objects can be located outside the local room when a room of a remote user provides more size. Furthermore, users can refer to physical objects in their rooms that are not at the same place or not available in the rooms of remote users. Figure 1.2 illustrates the problems with an example of two users working together on a remote shared digital whiteboard. The avatar in Room 1 represents the user in Room 2. It imitates the position and rotation of the user relative to the center of the room. Room 2 is larger than Room 1. When the user in Room 2 stands in front of the whiteboard, the representing avatar in Room 1 is outside the room. Furthermore, the avatar stands not in front of the whiteboard in Room 1. The position and rotation mapping are not aware of the position of the physical screen used for remote collaboration. For this reason, a technique is needed that visualizes augmented objects suitable for individual rooms.

This work aims to address this problem by presenting a prototype called Re-located that facilitates synchronous remote collaboration in Augmented Reality independent of room architecture and furnishing. First, in a one-time room calibration process, the positions of screens in a room are calibrated. The purpose of every screen will be predefined in this process (e.g., whiteboard, computer screen, ...). Afterward, by wearing an Augmented Reality headset, remote users, and their movements, are visualized as 3D avatars in front of the screens with the same purpose. The influence of Re-located, and the underlying concept, on user experience and the subjective perception of presence, was investigated through a usability study. The results of the study are described, evaluated, and discussed in this thesis.

Chapter two summarizes the underlying theoretical foundations of the related work presented in chapter three. Chapter four then introduces the Re-located prototype, which was developed by deriving requirements from the related work presented in chapter three. Chapter five describes the usability study conducted with the prototype introduced in chapter four. Furthermore, the chapter presents and discusses the results of the study. Finally, chapter six concludes this thesis and gives an outlook on future work.

2. Theoretical Foundations

This chapter summarizes the underlying theoretical foundations of the related work presented in the next chapter. First, the foundations of computer-supported collaboration are summarized. Afterward, the term Mixed Reality and its subterms Augmented Reality, Augmented Virtuality, and Virtual Reality are described. Finally, the definition of the term presence and its subterms co-presence, and social presence will be explained. Parts of this chapter were already described in the preceding seminar [3] and have been adopted and updated where appropriate.

2.1. Computer-supported Collaboration

Different categorizations for computer-supported collaboration emerged in the research literature. Johansen [4] first introduced a conceptualization of computer-supported collaboration with the CSCW Matrix in 1988. CSCW stands for computer-supported cooperative work. The CSCW Matrix categorizes collaboration by the two dimensions time and place. The time

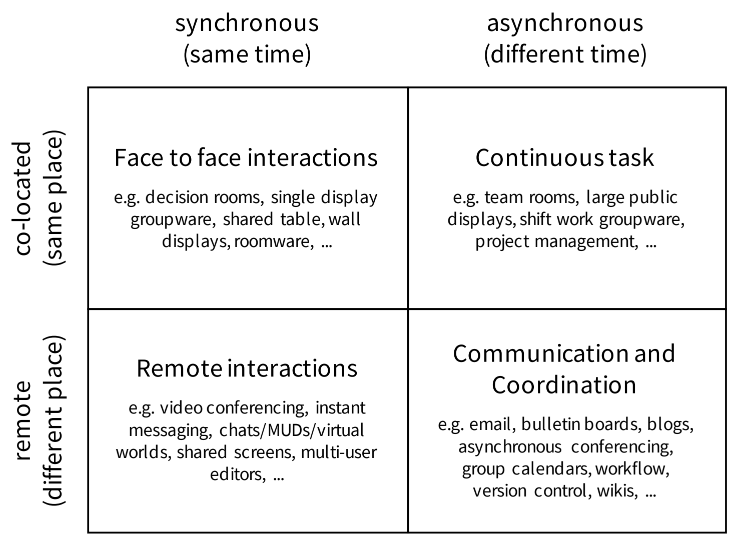

Figure 2.1.: The CSCW Matrix categorizes computer-supported collaboration by the dimensions time and place. Redrawn from [4].

dimension distinguishes between collaborative work at the same time (synchronous) or at different times (asynchronous). The place dimension distinguishes between collaborative work at the same place (co-located) or at different places (remote). The combination of the two dimensions and the two possibilities per dimension creates the 2x2 matrix shown in Figure 2.1 that covers four different types of computer-supported collaboration. For example, synchronous and co-located collaboration happens during a brainstorming session where several persons are working together on a whiteboard in the same room. The brainstorming session can also be held remotely using digital whiteboards whose contents are synchronized. In this case, the collaboration is synchronous and remote. An example of asynchronous and co-located collaboration is a public display where persons can leave messages for other persons. Finally, a typical example of asynchronous and remote collaboration is email communication.

The CSCW matrix differentiates between collaboration scenarios at the same or different time(s) or the same or different spaces(s). However, collaboration scenarios with more than two collaborators can often switch between the four different types of computer-supported collaboration and can not be assigned statically to one type. For these scenarios, Neumayr et al. [5] introduced the definition of Hybrid Collaboration. The definition consists of three different parts:

1. "Hybrid collaboration switches back and forth between all four quadrants of the time-space matrix. There are constant transitions between co-located and remote as well as synchronous and asynchronous collaboration;" [5]

2. "The team size S is greater than just two collaborators and multiple coupling styles can coexist simultaneously within a single team, effectively dividing the whole team in multiple temporary subgroups with each one having a size of $1 \leq S_{sub} \leq S$ and an individual coupling style;" [5]

3. "Users typically do not rely on a single groupware application or hardware device but simultaneously use different tools and devices during collaboration." [5]

An example scenario mentioned in their work [5] is a co-located team reviewing data on a large screen in a company. The team find anomalies in the data and highlight them. This highlighting triggers a notification on the mobile device of the manager in the responsible department. The manager reviews the data together with an employee, and afterward, the results of the review will be sent back to the co-located team in the headquarter where they can be further discussed. In this collaboration scenario, all four types of collaboration presented in the CSCW Matrix happen in only one scenario. It illustrates the necessity of the Hybrid Collaboration definition for collaboration scenarios with more than two collaborators.

Kiyokawa et al. [6] distinguish synchronous collaboration between communication space and task space. They describe that several verbal cues (e.g., speech) and non-verbal cues (e.g., gaze, gesture) are used during face-to-face collaboration. The space that provides these cues is called the communication space. The task space is the space in which the users perform the actual task. Schmalstieg and Höllerer [7] explain the terms in the book "Augmented Reality: Principles and

Practice". In the communication space, the users exchange information. Usually, co-located collaboration does not need technical solutions to provide the communication space. In contrast, the main purpose of a remote collaboration system is to provide a common communication space for all remote users. In the task space, the actual work is done. An example is the use of a shared-document editor in combination with a video conferencing system. The shared-document editor provides the task space, and the video conferencing system the communication space. However, the spaces are not always sharply separated. It is preferable to combine the communication space and task space to a unified space. Ishii et al. [8] observed, the more sharply separated the spaces are, the more difficult it becomes for the user to switch between communication and task. Furthermore, a non-unified space increases the cognitive load of the user. Therefore a unified task and communication space should be the aim of a collaboration system.

Schmalstieg and Höllerer [7] differentiate remote collaboration between symmetric and asymmetric collaboration. In symmetric collaboration scenarios, all users have the same capabilities. An example is a shared-document editor where all users can write everywhere and remove everything. However, in remote collaboration scenarios, the users are not in the same place, and therefore their physical situation and their technical capabilities can differ. These differences can lead to asymmetric collaboration scenarios, where users have different capabilities. Examples of asymmetric collaboration are remote expert scenarios. For example, one user performs a maintenance task in situ. The local user wears Augmented Reality glasses with a camera in viewing direction. A remote user who sits on a desktop computer can see the camera image and draw on it. The local user can see the drawings. Only the local user can control the viewing direction. For this reason, the collaboration scenario is asymmetric.

2.2. Mixed Reality

Different definitions of the term Mixed Reality (MR) emerged in the research literature. Milgram and Kishino [9] define Mixed Reality as part of their Virtuality Continuum (see Figure 2.2). The continuum ranges from Real Environment to Virtual Environment. An environment only consisting of real objects is a real environment. An environment only consisting of virtual

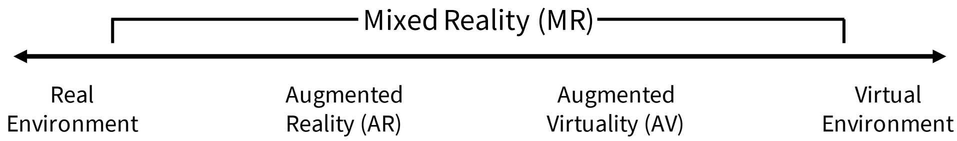

Figure 2.2.: The virtuality continuum of Milgram and Kishino [9] ranges from Real Environment (only real objects) to Virtual Environment (only virtual objects). Everything between, where real and virtual objects are presented together, is called Mixed Reality. Redrawn from [9].

objects is a virtual environment. Everything between, where real and virtual objects are presented together, is called Mixed Reality. The subterm Augmented Reality (AR) is defined as an environment where an otherwise real environment is augmented with virtual objects. In contrast, Augmented Virtuality (AV) is defined as an environment where an otherwise virtual environment is augmented with real objects. Virtual Reality (VR) is defined as an environment in which a user is totally immersed in a completely synthetic world. So in the definition of Milgram and Kishino, Virtual Reality is not a subterm of Mixed Reality. However, the Mixed Reality spectrum of Microsoft [10] defines Virtual Reality as part of Mixed Reality. Their explanation for the categorization is that the Virtuality Continuum only focuses on the visual component because the taxonomy was applied to displays. Current Virtual Reality devices also track the user's position, surfaces, and boundaries in the room. Because these components are part of the real environment, Virtual Reality is also part of Mixed Reality because real and virtual components are combined. For this reason, this work defines Virtual Reality as a subterm of Mixed Reality.

One technology frequently used for Virtual Reality is head-mounted displays (HMDs). Head-mounted displays consist of one or two small displays in front of the eyes [11]. Wearing a Virtual Reality HMD, the user can look around, move around, and interact with a computer-generated environment [12]. The interaction becomes possible by using e.g., controllers, gaze, or gestures [13]. HMDs can also be used for Augmented Reality. Schmalstieg and Höllerer [7] distinguish Augmented Reality HMDs between video see-through and optical see-through devices. Video see-through devices are similar to Virtual Reality HMDs but with cameras

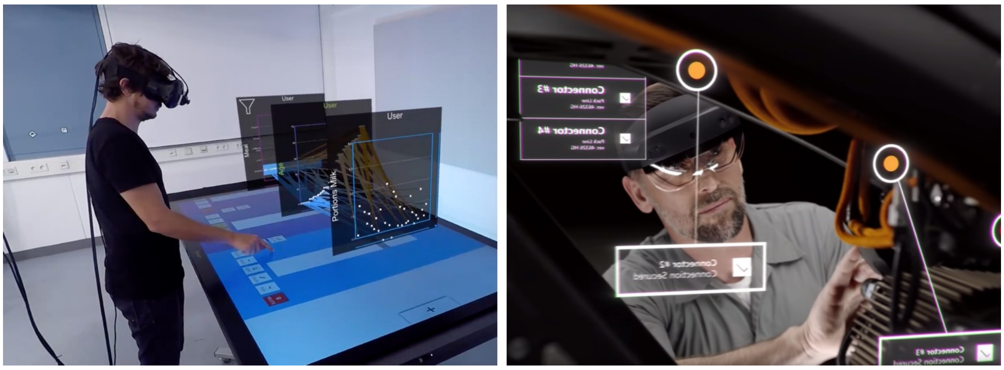

Figure 2.3.: Augmented Reality HMDs can be video see-through using a VR headset with a camera (left) or optical see-through (right). The augmentations are only visible when looking through the HMDs. Taken from [14] and [15]

mounted on them that pointing in the direction of view (see Figure 2.3 left). The cameras capture the environment. Afterward, the camera images are augmented with the virtual objects and finally shown on the display(s) of the HMD. In contrast, optical see-through devices mix the directly optical perceived environment with the virtual augmentation (see Figure 2.3 right). Semi-transparent displays or small projectors projecting on a special glass are current possibilities to realize optical see-through devices. Current optical see-through devices have the limitation that they only provide a small field of view (FOV). Only the middle area of the view is augmented. Video see-through devices provide a wider field of view. However, the resolution of the cameras and displays in currently affordable devices is not high enough that the human eye can no longer distinguish the video see-through environment from the directly optical perceived environment. Moreover, the captured camera image must be processed, and the processing can result in a lag.

Besides head-mounted displays, other technologies exist that facilitate Augmented Reality or even Mixed Reality in general. However, this work focuses on Mixed Reality using head-mounted displays, and for this reason, other types of Mixed Reality technologies are not discussed in detail.

2.3. Presence

The term presence has several definitions in research literature. Carrie Heeter [16] describes it as the subjective feeling of "being there". David Benyon [17] discusses some further definitions in his paper "Presence in blended spaces". He writes that Witmer and Singer extend Heeter's definition and define presence "[...] as the subjective experience of being in one place or environment, even when one is physically situated in another" [18]. Lombard and Ditton [19] define presence as the "illusion of nonmediation". They define "nonmediation" as not noticing the mediating technology. So the "illusion of nonmediation" occurs "when a person fails to perceive or acknowledge the existence of a medium in his/her communication environment and responds as he/she would if the medium were not there." [19]. Floridi [20] criticizes this definition of presence. He explains that presence cannot be defined by the not perceiving of something. This definition of presence would mean that a person cannot be present when the technologically-mediated nature of the experience is perceived. In contrast, Floridi defines presence as the successful observation of entities in the environment. He differentiates between forward and backward presence. Forward presence includes the ability to interact with entities in distant spaces while backward presence is only the ability to observe something distant without the ability to interact with it.

The terms co-presence and social presence define presence in combination with other people. Kristine Nowak writes "[...] copresence exists when people sensed that they were able to perceive others and that others were able to actively perceive them" [21]. The definition of social presence goes further. Short et al. define social presence as "the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships" [22]. Salience is in the psychology "[...] the extent to which a particular target draws the attention of an observer or group" [23]. So co-presence is only the mutual perceiving of other people, while social presence also includes how we interact with other people.

2.4. Summary

The previous sections introduced several terms used in the research of collaboration using Mixed Reality. The sections do not reflect the full range of the respective topics. The introduced terms only serve as a foundation of the related work presented in the next chapter. The term presence and its subterms were explained because they often used as one measure for collaborative Mixed Reality systems.

3. Related Work

This chapter summarizes related work in the area of remote collaboration using Mixed Reality technology. The basis for remote collaboration using MR is the representation of remote users in three-dimensional space. Therefore, the first section summarizes different 3D representations that have emerged in the research literature. Furthermore, the use of Mixed Reality and especially Augmented Reality for remote collaboration cause problems. Usually, the rooms of remote users differ in architecture and furniture. For this reason, techniques are needed that align different rooms. The second section summarizes related work that facilitates remote collaboration using MR by aligning different rooms of remote users. Parts of this chapter were already described in the preceding seminar [3] and have been adopted and updated where appropriate.

3.1. Representation of Remote Users in 3D Space

The possibilities representing remote users in three-dimensional space range from abstract visualizations to realistic live capturing of remote users. One method on the abstract site is to visualize the position and rotation of remote users as virtual viewing frustums. The frustum represents the field of view of a remote user. So it is perceptible where the remote user is looking at approximately. For example, Müller et al. [24] used this visualization method for

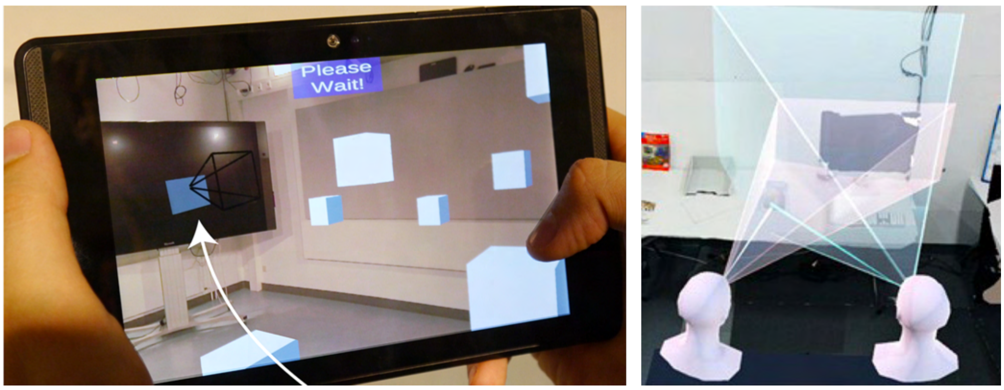

Figure 3.1.: Virtual viewing frustums with only the frustum (left) and extended with a eye gaze ray and head (right). Taken from [24] and [25].

remote collaboration using AR displays (see Figure 3.1 left). Piumsomboon et al. [25] used an eye tracker to extend the viewing frustum with an eye gaze ray inside (see Figure 3.1 right). Furthermore, they added a white head at the origin of the viewing frustum and added hand tracking to make interaction possible. In the following, only the parts of the study are discussed that are related to the remote user representation.

For their study, they used the CoVAR system [26]. CoVAR combines Augmented Reality and Virtual Reality for remote collaboration. The AR user captures the local room and shares it with a remote VR user. Afterward, the VR user surrounds the room of the AR user. Section 3.2 describes the system in more detail. Piumsomboon et al. [25] describe the CoVAR system in their later work as a combination of Augmented Reality and Augmented Virtuality and not Virtual Reality anymore. For this reason, the terms AR user and AV user are used below.

In their study [25], an Augmented Reality user and an Augmented Virtuality user collaborated remotely. The AR user has seen the own environment, and only the remote collaborator and task-related objects (e.g., cubes) were augmented. The AV user became part of the environment of the AR user and has seen the reconstructed environment of the AR user. In the first condition, only the head and the hands of the remote user were visible. In the second condition, additionally, the viewing frustum with eye-gaze was visible. They called the viewing frustum with eye-gaze awareness cues. The results were that the awareness cues helped to find the remote user's gaze area quicker. The eye-gaze ray helped to find the exact gaze target. The viewing frustum helped the AV user to empathize with the smaller field of view of the AR user. Furthermore, the awareness cues improved the performance.

Figure 3.2.: The Holoportation system captures a user with multiple cameras and reconstructs the user in 3D. Wearing an AR HMD, the user at the remote site can see the 3D model of the user in real-time. Taken from [27].

However, virtual viewing frustums are very abstract. Piumsomboon et al. [25] also added a model of a head and not only used the viewing frustum. Meanwhile, there are possibilities to represent a remote user with its real visual appearance. Microsoft Research developed a system called Holoportation [27] that captures a user with multiple cameras and reconstructs the user in 3D. Afterward, the data will be compressed and transmitted to the remote site. There, wearing an Augmented Reality HMD, the local user can see the 3D model of the remote user in real-time (see Figure 3.2). However, to use this technology for remote collaboration, the rooms of all users must be equipped with a high amount of high-end hardware, including multiple depth cameras and one high-end computer per camera pair. Therefore the real-time capturing of users in 3D is not practical.

The presented forms are the two extremes on a scale from abstract to realistic representations. Another representation form that is lying in between is 3D avatars. In this context, an avatar is a graphical representation of a user [28]. There are several ways to visualize avatars. The level of detail of an avatar can range from a white or grey body or body parts to an almost photorealistic reconstruction of an individual human. In the field of avatar visualization, a large amount of related work exists, dealing with the generation of avatars, and how the design of the avatar affects the perception. An often mentioned effect in the field of avatar design is

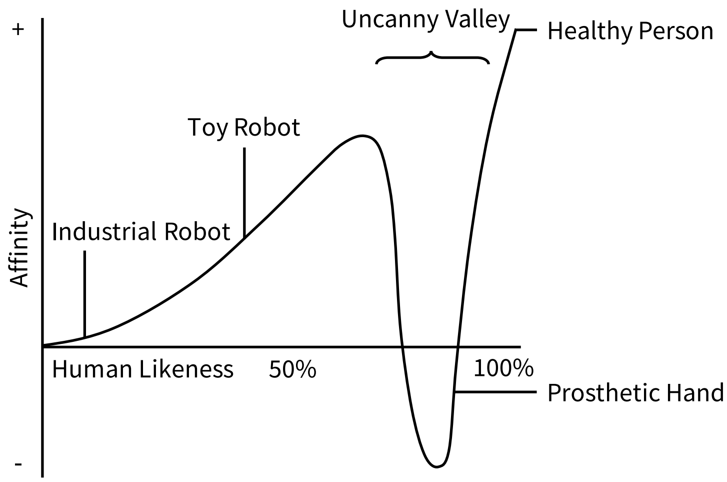

Figure 3.3.: The uncanny valley graph describes the relationship between the human-likeness of a character and the perceiver's affinity. Redrawn and adapted from [29]

called the uncanny valley. Masahiro Mori [29] already observed the effect in the 1970s. The uncanny valley graph in Figure 3.3 describes the relationship between the human-likeness of a character and the perceiver's affinity. With increasing human-likeness, the affinity to the character increases until a point where the character looks very realistic but not perfect. At this point, the affinity falls into the uncanny valley, and can only be increased again by further increasing the human-likeness. The effect should be kept in mind when designing an avatar. However, this work focuses not on the avatar design. The avatar is only a basic requirement to be able to represent remote users in three-dimensional space. For this reason, the following related work only focuses on the influence of different avatar types on presence.

Jo et al. [30] conducted a preliminary study on how the type of avatar visualization affects the co-presence in Augmented Reality and Virtual Reality. They built a 3D teleconference system and compared two different types of avatar visualizations. One avatar type was a pre-built 3D model that has no visual resemblance compared to the actual remote collaborator (except few basic features like skin color, wearing of a glass, approximate size) (see Figure 3.4 third and fifth from left). Both types of avatars were visualized in Augmented Reality (see Figure 3.4 second

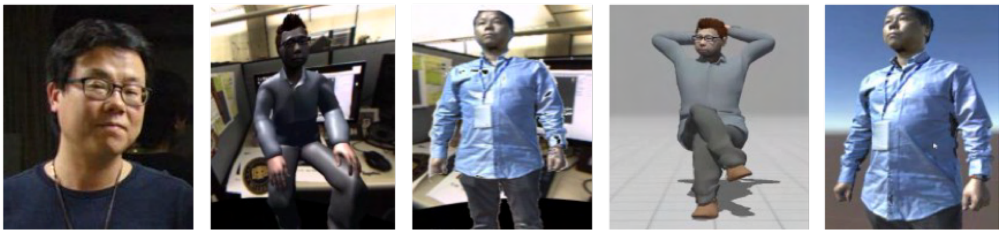

Figure 3.4.: The actual user and the different conditions in the study of Jo et al. [30] from left to right: The actual user, the pre-built 3D model in AR, the realistic reconstruction of the user in AR, the pre-built 3D model in VR, and the realistic reconstruction of the user in VR. Taken from [30]

and third from left) as well as in Virtual Reality (see Figure 3.4 fourth and fifth from left) using HMDs (video see-through for the AR conditions). They compared the four (2x2) conditions to regular 2D video conferencing. The co-presence was measured by asking the expected level of co-presence using a seven-point Likert scale. The results of the study showed significant differences between 2D video-conferencing, AR teleconferencing, and VR teleconferencing. The AR conditions had the highest score of co-presence, followed by the VR conditions. 2D video-conferencing had the lowest level of co-presence. The more realistic avatar visualization had in AR as well as VR, only a slightly higher score. However, the limitations of this study are that it was only conducted with five participants, and the measurement of co-presence was only one seven-point Likert scale.

Smith and Neff [31] conducted a study on how avatar visualizations affect the social presence and communication behavior during remote collaboration in Virtual Reality. In contrast to Jo et al. [30], they compared the remote collaboration in Virtual Reality, not with 2D video-conferencing but with co-located collaboration without the use of technology. In their study, the participants had to solve two apartment furnish tasks. The first task was to discuss which room of an apartment should have which function, using a floor plan of the apartment. The second task was to discuss where the furniture should be placed in the rooms, using the same floor plan. The participants had to solve both tasks under the three conditions shown in Figure 3.5. In the “F2F” condition, the participants solved the tasks in a real-world, face-to-face condition with a real floor plan lying on a table (see Figure 3.5 A and B). In the “embodVR” condition, the participants solved the tasks wearing a Virtual Reality HMD and earbuds. The participants were represented by avatars, making the same movements as the real persons (see Figure3.5 C).

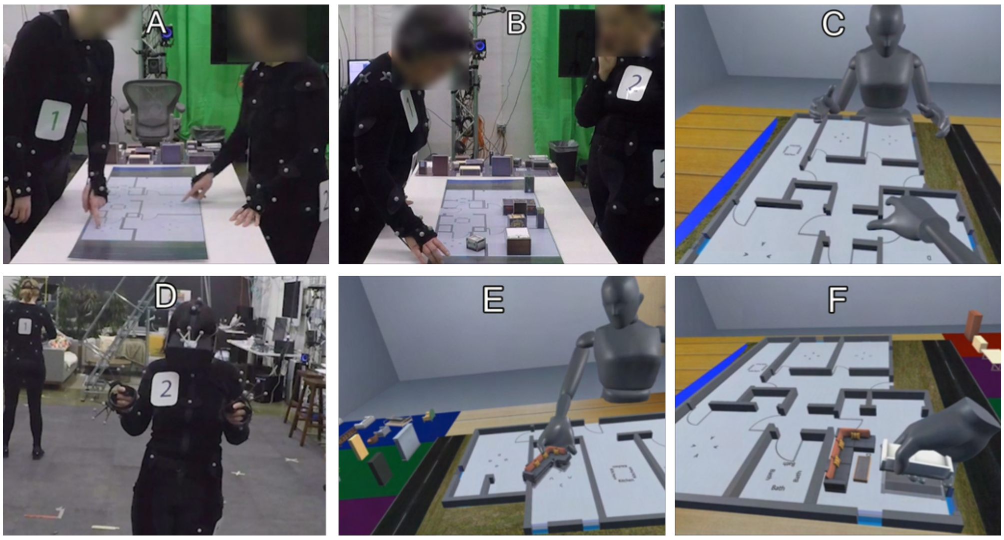

Figure 3.5.: The study of Smith and Neff [31]: The first (A) and the second task (B) performed in the face-to-face condition ("F2F" condition). The view of the participants in the Virtual Reality with avatar condition ("embodVR" condition) (C). During the VR conditions ("embodVR" and "no_embodVR" condition), the participants looked in the real world in the opposite direction (D). The view of the participants in the second task of the Virtual Reality with avatar condition ("embodVR" condition) (E) and the Virtual Reality without avatar condition showing only the own hands ("no_embodVR" condition) (F). Taken from [31].

The audio of the participants was transmitted using microphones and earbuds. During the VR conditions, the participants looked in the real world in the opposite direction (see Figure 3.5 D). In the "no_embodVR" condition, the setting was the same as in the "embodVR" condition, but without avatars representing the participants (see Figure 3.5 F). The participants were able to see their own hands because otherwise, they would not have been able to put furniture in the apartment. The hands of the remote participant were not visible. The communication behavior was measured by annotating verbal and non-verbal behaviors of the participants with a remote team. The social presence was measured by a questionnaire with eight bipolar word pairs. The results of the study were that the "embodVR" condition (Virtual Reality with avatars and audio) "[...] provides a high level of social presence with conversation patterns that are very similar to face-to-face interaction." [31] ("F2F" condition). The "no_embodVR" condition (Virtual Reality only with audio) "[...] appears to lead to degraded communication." [31]. They mention that the avatar in the virtual world helped the participants to feel that they are really interacting with another person.

The presented possibilities representing remote users in three-dimensional space can be classified from abstract to realistic. Figure 3.6 gives an overview of the presented work and classifies them.

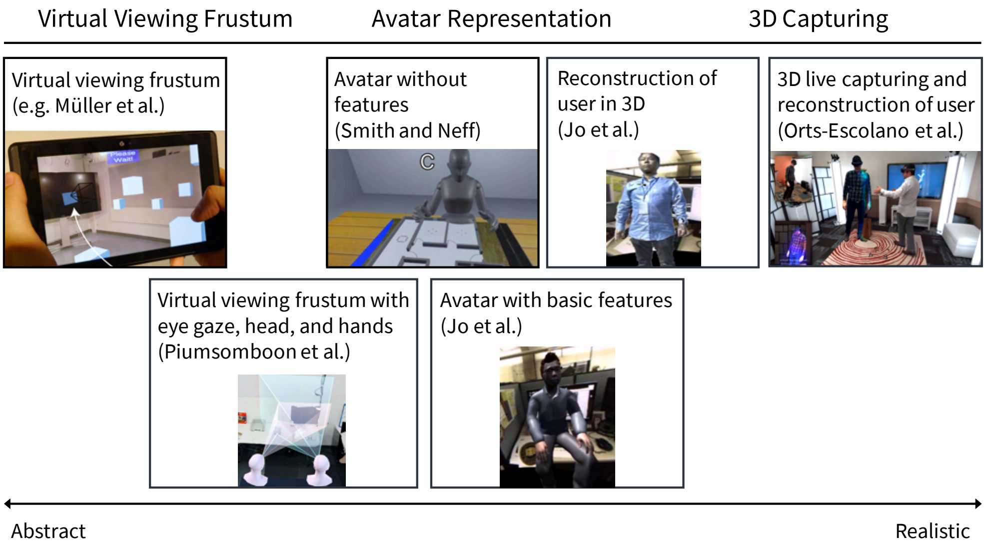

Figure 3.6.: The presented possibilities representing remote users in three-dimensional space classified from abstract to realistic. Images taken from [24, 25, 27, 30, 31]

3.2. Aligning Mixed Reality Environments

Remote collaboration using Mixed Reality technologies has the advantage that remote users and virtual objects can become part of the environment. However, the physical rooms of remote users usually differ in architecture and furniture. These physical differences cause several problems. One problem is that virtual objects can be located outside the walkable space when a room of a remote user provides more size. While in Virtual Reality, techniques like teleporting [32] can be used to reach objects outside the physical borders, these techniques are not suitable for Augmented Reality. Furthermore, when using Augmented Reality, a second problem occurs. Users can refer to physical objects in their rooms that are not at the same place or not available in the rooms of remote users. Therefore, room alignment techniques needed that adapt the visual representation of remote users and virtual objects individually to the local room.

Piumsomboon et al. [26] introduced a possibility to solve the problem that the positions of physical objects in the environments differ. They developed the CoVAR system that, instead of using only Augmented Reality devices, combines Augmented Reality and Virtual Reality for remote collaboration. Figure 3.7 shows the setup of the CoVAR system. The Augmented Reality user captures his or her local environment and shares it with a remote user in Virtual Reality. With this technique, both users are working in the environment of the Augmented Reality user, because the environment of the AR user surrounds the VR user. The AR user is already in his or her environment, so only the virtual working objects and the remote user need

Figure 3.7.: The CoVAR [26] system setup. (a) shows the AR user and (b) her physical environment. (c) shows the reconstructed environment for the VR user and (d) the VR user. Taken from [25]

to be augmented, using an Augmented Reality HMD. This setup tries to simulate symmetric co-located collaboration in the room of the Augmented Reality user. However, the use of Virtual Reality on one side provides further asymmetric scenarios. Using the CoVAR system, the Virtual Reality user can scale him or herself bigger (god mode), or smaller (miniature mode) relative to the real world. Another possibility is that the VR user can take the perspective of the AR user. Nevertheless, the limitation of the CoVAR system is that the Virtual Reality user needs to have an empty room that at least is as big as the room of the Augmented Reality user. So the problem that the walkable spaces of remote users usually differ is not solved. Piumsomboon et al. [25] use in their later work the term Augmented Virtuality instead of Virtual Reality. According to the virtuality continuum of Milgram and Kishino [9] (see section 2.2), the term Augmented Virtuality is more suitable because the system augments the virtual environment with real objects.

When the physical objects in the rooms are only used to refer to, another possibility is to add additional virtual objects to the rooms. These additional virtual objects can be used as shared virtual landmarks that possibly replace the referencing to physical objects in the environment. In the year 2017, Müller et al. [24] conducted a study on how shared virtual landmarks facilitate

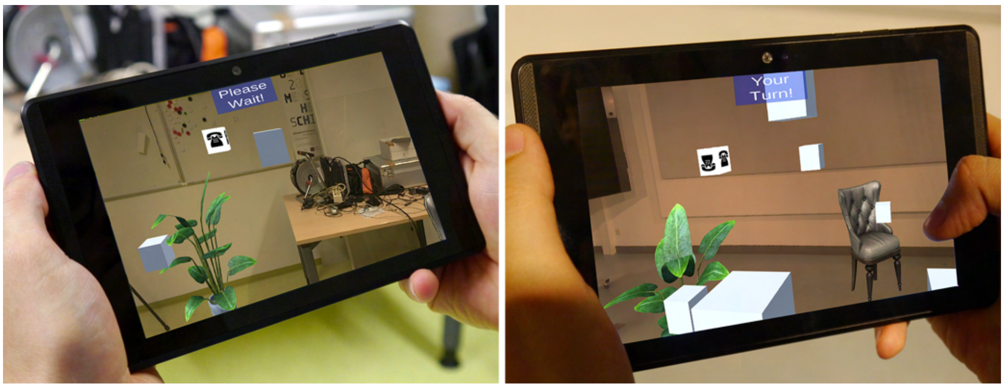

Figure 3.8.: In the study of Müller et al. [24] shared virtual landmarks, like an armchair or a potted plant, were provided. Taken from [24]

spatial referencing. They built a remote collaboration memory game with virtual 3D cubes that were distributed over the room. The cubes could be seen and uncovered with Augmented Reality tablets. In each turn, each collaborator had to uncover one cube. When the collaborators found a match, the cubes were removed from the environment. In the study, two conditions were compared. In one condition were shared virtual landmarks, like an armchair or a potted plant, provided (see Figure 3.8), and in the baseline condition not. The results were that the shared virtual landmarks "[...] reduced the occurrence of ambiguous deictic expressions which could cause conflict situations." [24]. A word or expression is deictic when the "[...] meaning is dependent on the context in which it is used (such as here, you, me, that one there, or next Tuesday)." [33]. So the communication behavior was positively influenced. Furthermore, the shared virtual landmarks significantly increased the user experience. However, in the study were the room architectures, or the area in which the cubes were placed, the same. So also, this technique does not solve the problem that walkable spaces of remote users usually differ in size.

However, also strategies that align different walkable spaces emerged in the research literature. Sra et al. [34] compared three different techniques to align VR environments with different walkable spaces. They used the term physical-to-virtual space mapping techniques. In their study, two remote participants learned together how to dance, wearing a Virtual Reality HMD. A virtual dancing instructor was standing behind each dancing partner. The dancing instructor

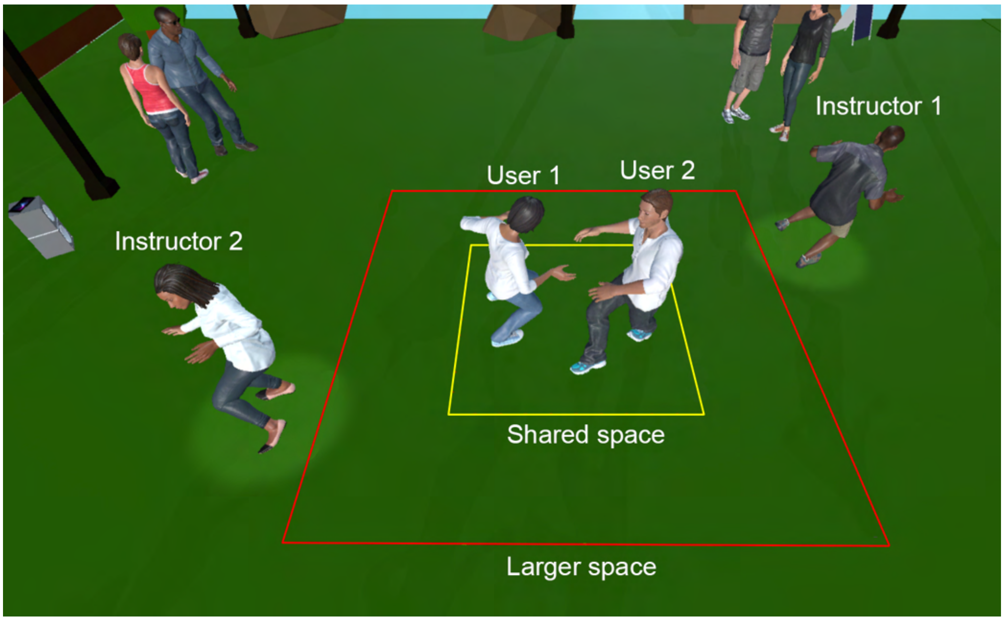

Figure 3.9.: In the study of Sra et al. [34], two remote participants, with different sized walkable spaces, learned together how to dance wearing a Virtual Reality HMD. A virtual dancing instructor was standing behind each dancing partner. Here the "Kernel" technique was used to create a shared space (see Figure 3.10 (a)). Taken from [34]

had its back facing the participant to make it easy to follow the dance moves (see Figure 3.9). An avatar represented the remote participant. The walkable space of one participant was smaller than the one of the other. They called their three mapping techniques “Scale”, “Kernel”, and “Overlap”. The “Scale” technique stretched the size of the smaller space to match the size of the larger space (see Figure 3.10 (a)). “Kernel” placed the smaller space in the center of the larger space (see Figure 3.10 (b)). The participant with the larger space could walk around in the

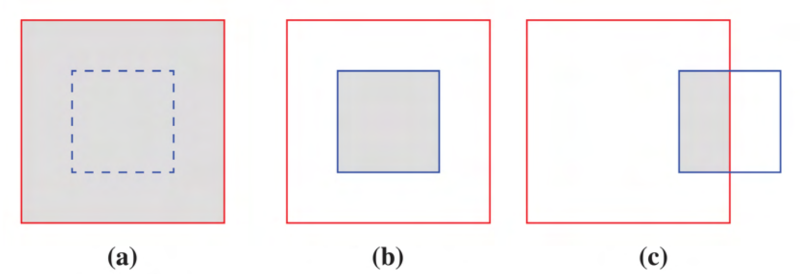

Figure 3.10.: The three physical-to-virtual space mapping techniques by Sra et al. [34]. “Scale” stretches the smaller space to match the larger space (a). “Kernel” places the smaller space in the center of the larger space (b). “Overlap” places the two spaces with an overlap next to each other (c). Taken from [34]

whole space, but interactions with the other participant were only possible in the shared space. In this technique, the shared space matched the smaller space, so only the participant with the larger space had a private space. For this reason, the third technique called “Overlap” placed the two spaces next to each other, so also the participant with the smaller space had a private space (see Figure 3.10 (c)). The results were that the “Scale” technique showed a significantly worse co-presence than the other two techniques. “Kernel” and “Overlap” “[...] provided a high sense of copresence and togetherness.” [34].

In the study of Sra et al. [34], the walkable spaces were always squares. However, the floor plans of rooms can be much more different, or they are furnished differently. To use the maximum available walkable space, Congdon et al. [35] developed a technique that merges two different walkable spaces for remote collaboration in Virtual Reality (see Figure 3.11). The technique presents a virtual environment differently to two users. Furthermore, it dynamically maps the movements of the users into their remote user’s environments. To make the mapping possible, the users have to predefine corresponding locations on the different floor plans. Their algorithm maps the position and rotation of the users into their remote user’s environments, using the relative position and direction to the corresponding points. Afterward, the calculated position and rotation can be used to visualize the remote user.

In the study of Congdon et al. [35], dyads had to solve together a short puzzle in Virtual Reality. The time limit for the task was five minutes. The participants of a dyad were in different rooms with different floor plans. Figure 3.11 shows the floor plans used in the study. Colored cubes visualize the corresponding locations of the floor plans. An avatar with a head, hands, and torso visualized the remote user. The white and grey arrows in Figure 3.11 show the position

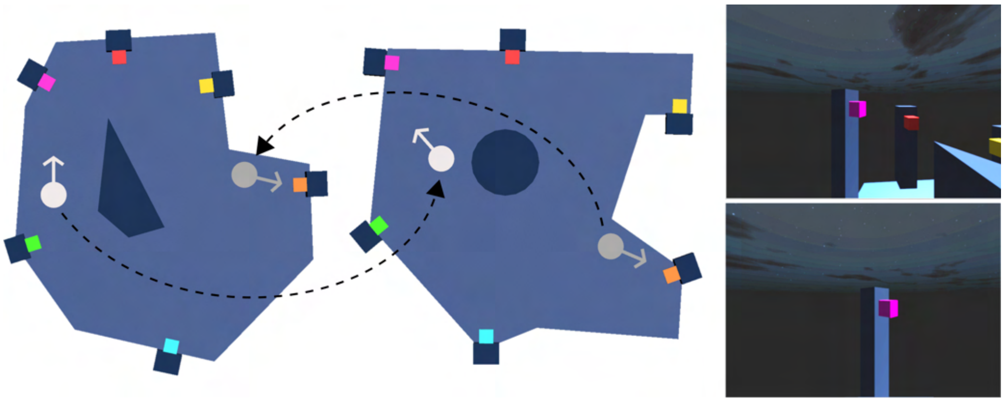

Figure 3.11.: The merging technique of Congdon et al. [35] merges two different walkable spaces for remote collaboration in Virtual Reality. On the left, the white and grey arrows show the position and orientation of users in their environment and by an avatar represented position and orientation in the remote environment. The two images on the right show the view of the white user (top) and the view of the representing avatar in the remote environment (bottom). Taken from [35]

and orientation of the users in their environment and by an avatar represented position and orientation in the remote environment. The position and orientation of the remote user were mapped by using the described algorithm above. The participants were not informed that the floor plans of the rooms are different, or a mapping was taking place. After the task, participants were asked to complete the Slater-Usoh-Steed (SUS) presence questionnaire that was extended with questions regarding the mapping. The results were that the co-presence scores were particularly high when compared with the other metrics like presence and embodiment. 2 of 38 participants had issues that were likely caused by the mapping. The problems concern the mapping of the hands. “The first noted that ‘when the other player pressed a button, it looked like they were missing on my screen’ while the second participant noticed their partner appeared to miss ‘when we tried to high-five’.” [35]. In the discussion of the paper, it is described that “hand placement is a particularly difficult task for the technique.” [35].

The presented related work solve either the problem that the position of physical objects in the environments can differ or the problem that the walkable spaces of rooms can differ. Figure 3.12 categorizes the works according to the solved problems. Although the strategies presented are designed for Virtual Reality, they can also be adapted for the use in Augmented Reality.

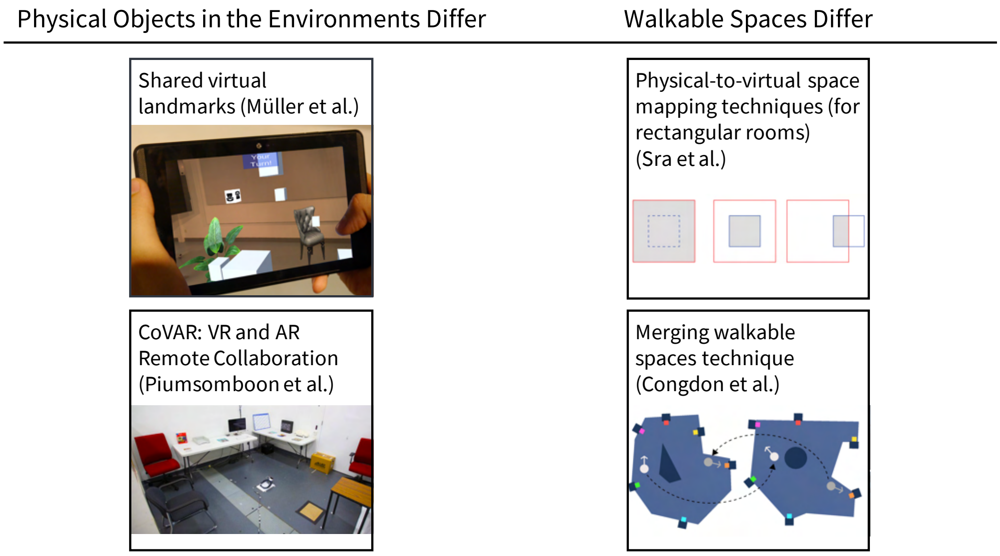

Figure 3.12.: The presented possibilities to align Mixed Reality environments categorized according to the problems they solve. Images taken from [24, 34, 25, 35]

3.3. Summary

This chapter described several possibilities to represent remote users in three-dimensional space and align different environments for Mixed Reality. The presented representations of remote users range from abstract visualizations to realistic live capturing of remote users. The 3D live capturing, and transmission of remote users would be desirable, but the method is not practicable because the rooms of all users must be equipped with a high amount of high-end hardware. The use of awareness cues, like a gaze ray, helps to find the remote user's gaze area quicker. However, representing remote users with virtual viewing frustums is very abstract. Therefore, avatar representations are a more realistic alternative to visualize remote users. The presented studies showed that even abstract avatar visualizations are sufficient to provide a high co-presence and social presence. The main problems of remote collaboration using Mixed Reality are that the position of physical objects in the environments can differ and that the walkable spaces of rooms can differ. The CoVAR [26] system solves the problem that the positions of physical objects in the environments can differ, by combining Augmented Reality and Virtual Reality for remote collaboration. However, the Virtual Reality user needs to have an empty room that at least is as big as the room of the Augmented Reality user. The provisioning of shared virtual landmarks in Augmented Reality applications can reduce the occurrence of deictic expressions. Therefore it is a possible solution to prevent referencing to physical objects and replace them with the referencing to virtual objects. Different sized walkable spaces can be made compatible by placing the smaller walkable space entirely or partially inside, the larger space. The scaling of the smaller space to the size of the larger space can lead to a reduced co-presence. The merging technique of Congdon et al. [35] allows using the maximum available walkable space by dynamically mapping the movements of the users into their remote users' environments. To make the mapping possible, the users have to predefine corresponding locations on the different floor plans.

4. Prototype: Re-located

Based on the findings from the related work presented in the last chapter, a prototype called Re-located was developed. The prototype facilitates remote collaboration using Augmented Reality independent of room architecture and furnishing. The first section describes the system requirements that arose from related work. Afterward, the concept developed based on the requirements is introduced. Finally, in the last section, the Re-located prototype, which is the implementation of the concept, is presented. Parts of this chapter were already described in the preceding project report [36] and have been adopted and updated where appropriate.

4.1. Requirements

The basis for remote collaboration using Mixed Reality is the representation of remote users in three-dimensional space. The 3D live capturing and transmission of remote users would be desirable, but the method is not practicable. According to Smith and Neff [31], abstract avatar representations already provide a high level of social presence. Therefore a requirement for the system is to visualize remote users as avatars. Furthermore, according to Piumsomboon et al. [25], the eye-gaze ray helped to find the exact gaze target. Therefore, the avatar should provide, additionally, a form of gaze visualization.

The main problems of remote collaboration using Augmented Reality are that the position of physical objects in the environments can differ and that the walkable spaces of rooms can differ. The merging remote environments technique of Congdon et al. [35] is designed for Virtual Reality, but the technique can also be adapted for use in Augmented Reality and with physical objects. In this way, the technique solves not only the walkable spaces problem but also the problem that the positions of physical objects in the environments can differ. By using the pre-definition process to predefine the position of important physical objects in the room, the system can react when the user looks at an object or stands nearby. Therefore, the predefinition of important physical objects in the room should be part of the system. However, for their merging, they use a kind of non-linear scaling algorithm. According to Sra et al. [34], the use of scaling techniques decreases the perceived co-presence. Congdon et al. [35] also mentioned hand mapping problems in their paper. Therefore, providing a 1:1 mapping of the movements is a further requirement of the system.

Concluding, the system should represent remote users as avatars (with gaze) relative to predefined physical objects and still provide a 1:1 mapping of the movements. Based on these requirements, the concept, presented in the next section, was developed.

4.2. Concept: Re-locations

Re-locations are user-defined locations in the room that can be used for remote collaboration. Every Re-location has a specific purpose that is specified in the predefining process. An example is a Re-location in front of a digital whiteboard, like in Figure 4.1. The purpose of this Re-location is working on the whiteboard. When a user enters the whiteboard Re-location, a 3D avatar will appear at the remote site, which represents the remote user. The 3D avatar becomes visible for the user by wearing an Augmented Reality head-mounted display (HMD). The avatar stands inside the remote Re-location in the same position as the user and imitates his

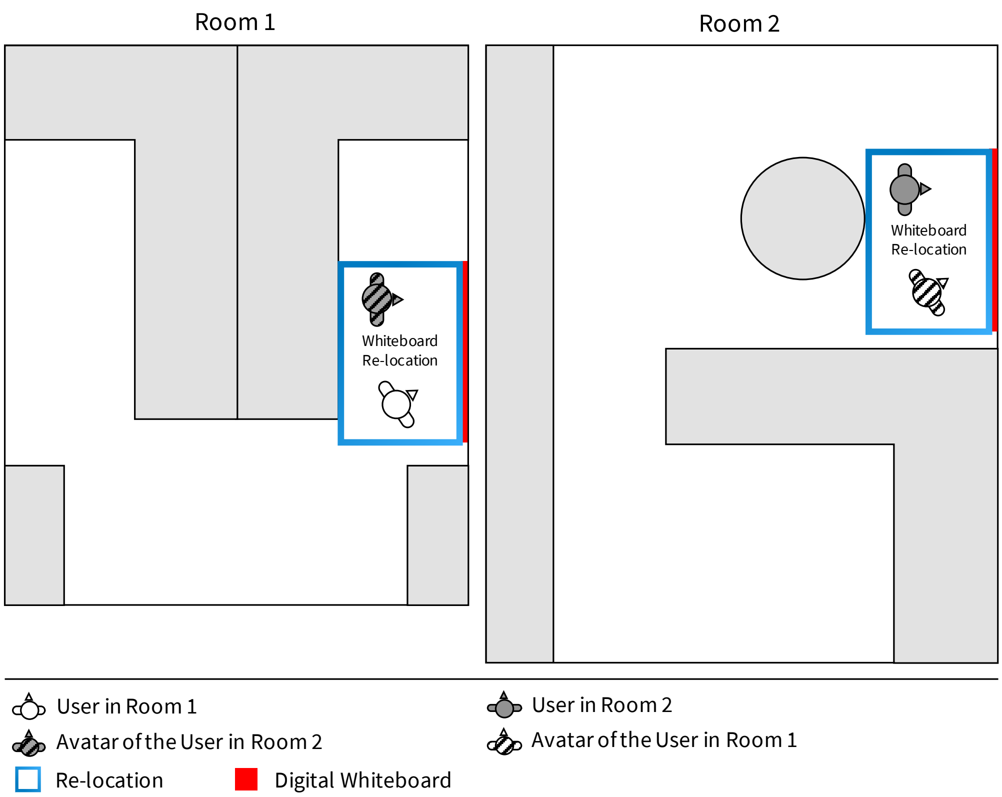

Figure 4.1.: Re-locations are user-defined locations in the room. Every Re-location has a specific purpose (here working on the whiteboard). Inside the Re-location, the remote user is represented by an avatar at the remote site.

or her orientation and movements. Prerequisite for this is that a Re-location with the purpose whiteboard has also been defined in the remote room. Moreover, Re-locations behave the same for all users. When the user in the other room also enters the whiteboard Re-location, he or she is also visible at the remote site as an avatar. When a user is leaving a Re-location, the avatar disappears. Besides the visual component of the avatars, the collaborators can also hear each other via microphones and speakers integrated into the Augmented Reality HMDs. Using a head-mounted display has the advantage that the user's hands are free to interact with devices and objects in the room.

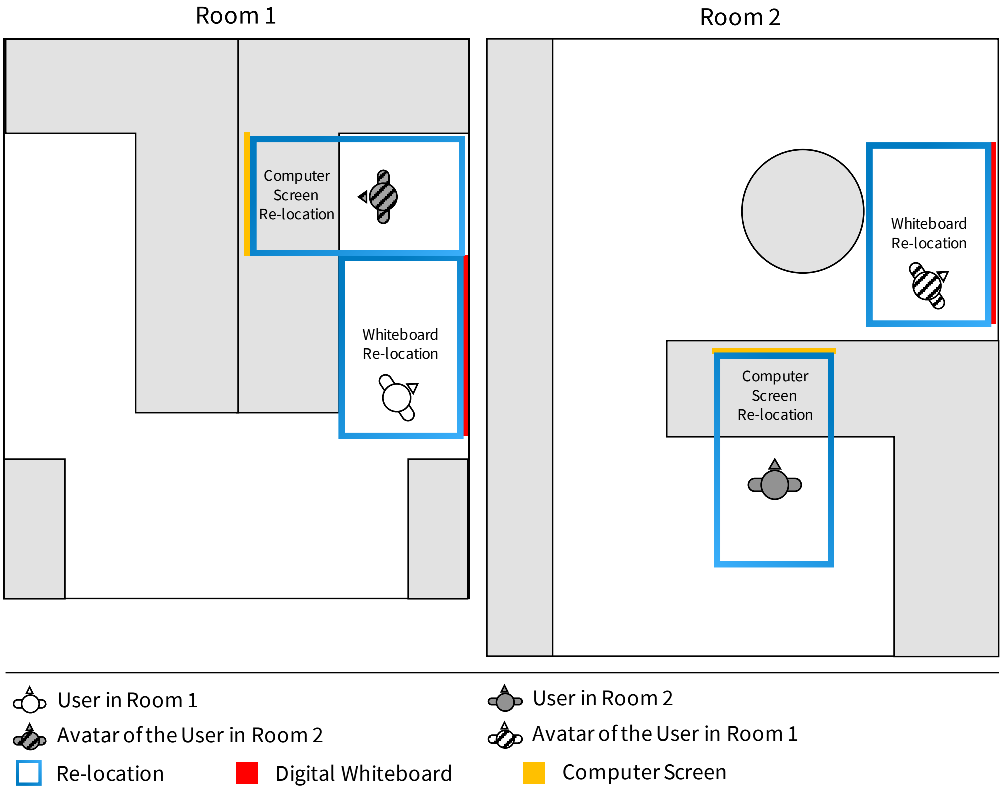

Figure 4.2.: Rooms can have multiple Re-locations. With more than one Re-location defined, avatars appear inside the Re-location with the same purpose.

Rooms can have multiple Re-locations. With more than one Re-location defined, avatars appear inside the Re-locations with the same purpose. For this reason, the purpose of a Re-location must be specified in the predefining process. An example of a second Re-location is a computer screen standing on a desk, like in Figure 4.2. When a user is leaving the whiteboard Re-location and entering the computer screen Re-location, the avatar will disappear at the whiteboard and appear at the computer screen. This behavior has the advantage that the collaborators can work together in different places with different devices in their room, although their rooms are completely different from the furnishing and architecture. The representation of remote users only within Re-locations allows a 1:1 mapping inside.

The Re-locations concept also supports gaze visualization. The gaze visualization can also be used across Re-locations. An example is Figure 4.3, where the user in Room 2 is looking from the computer screen Re-location to the whiteboard. The 1:1 mapping of the avatar at the remote site will be interrupted, and the avatar rotates towards the position of the whiteboard in the remote room (Room 1). The ray points then to the same spot on the whiteboard that the remote

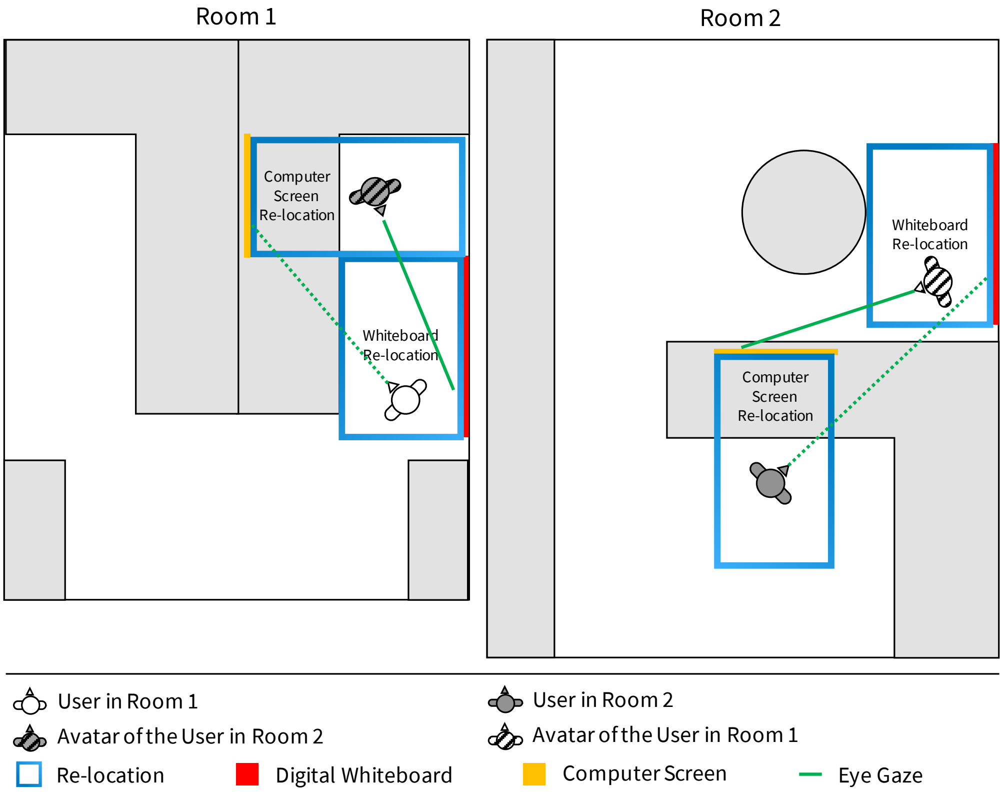

Figure 4.3.: The gaze of remote users are visualized by a ray (green lines). The ray can also be visualized across Re-locations. The cross Re-location gaze works not with every room combination (the avatar in Room 2 is looking at the back of the computer screen).

person is looking at. This is possible because the positions of Re-locations are known, and the definition of the Re-location screen position is part of the predefining process. However, this is not possible with every combination of room layouts. Figure 4.3 shows an example, where the avatar in Room 2 is looking at the back of the computer screen. The system can recognize these cases and then deactivate the across Re-location gaze.

Another edge case is when Re-locations are overlapping. When a user is standing inside an overlapping area, the gaze decides in which Re-location the avatar at the remote site will be visualized. The example in Figure 4.4 shows, when the user in Room 2 is looking at the whiteboard, the avatar will be visualized inside the whiteboard Re-location (Figure 4.4 top). When the user is looking at the table Re-location, the avatar will be visualized inside the table Re-location (Figure 4.4 bottom). When the user is not looking at a Re-location, the smallest angle to a Re-location decides.

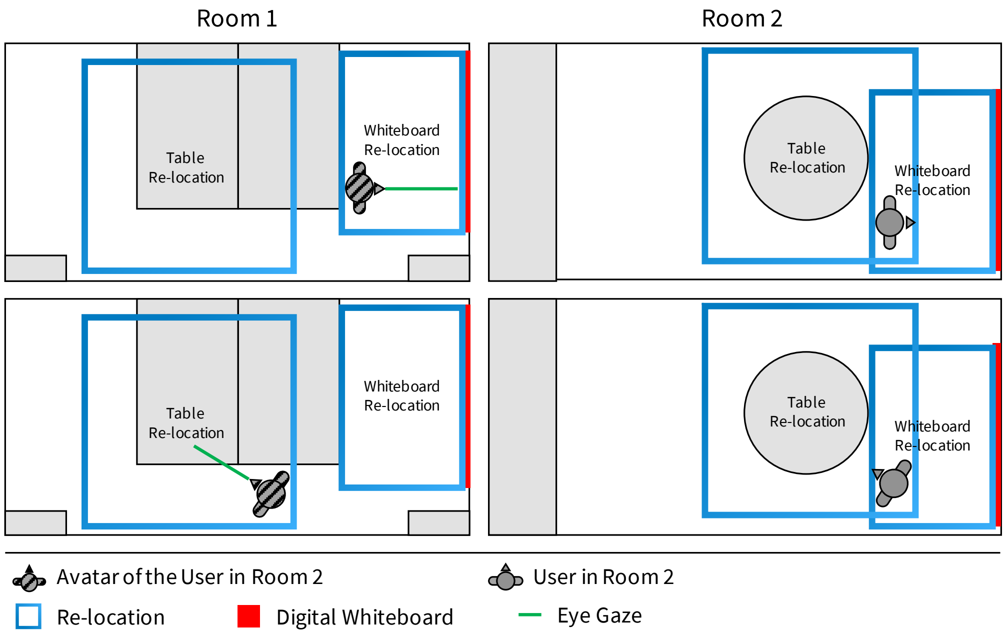

Figure 4.4.: When Re-locations overlap, the gaze decides inside which Re-location the avatar will be visualized. When the user in Room 2 is looking at the whiteboard, the avatar will be visualized inside the whiteboard Re-location (top), when looking at the table, the avatar will be visualized inside the table Re-location (bottom).

A further problem to consider is that the size of Re-locations with the same purpose can differ. To maintain the 1:1 mapping, all Re-locations with the same purpose must shrink to the size of the smallest Re-location. Figure 4.5 shows an example of different sized Re-locations and the shrinking process. An alternative to the shrinking would be scaling, but one of the requirements mentioned in the last section is to not scale the movements, for this reason, the Re-locations are shrinked similar to the “Kernel” condition of Sra et al. [34]. However, the gaze will be scaled to support different sized screens. For example, when a user with a large screen looks at the top right corner of the screen, the avatar at the remote site also looks at the top right corner of the smaller screen. In this case, the 1:1 mapping is interrupted, as in the case of the across Re-locations gaze.

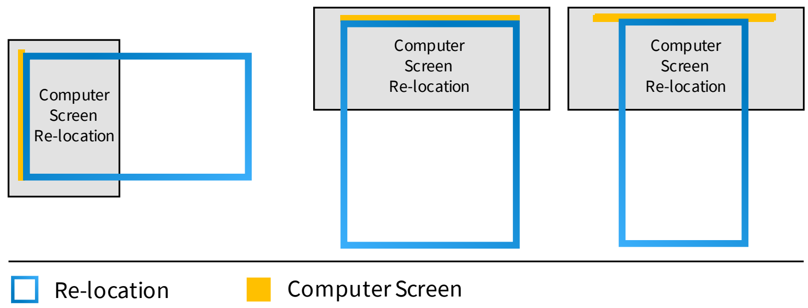

Figure 4.5.: When the size of Re-locations with the same purpose differ (left and middle), the bigger Re-location (middle) must shrink to the size of the smaller Re-location (right) to maintain the 1:1 mapping.

4.3. Prototype

The last section introduced the Re-locations concept. This section presents the Re-located prototype, which is the implementation of the concept. The prototype was implemented for the Augmented Reality HMD Microsoft HoloLens (First generation) [37] shown in Figure 4.6. Therefore, users must wear a HoloLens to use the system. The Re-locations concept described in the last section is not only limited to screens. For example, it would be possible to display 3D objects on a table Re-location. Because this thesis aims to investigate the basic concept, this implementation only supports Re-locations in front of physical screens.

Figure 4.6.: The Augmented Reality head-mounted display Microsoft HoloLens was used for the implementation of the prototype. Taken from [38]

After the start of the Re-located application, the user can either log in or calibrate the room. For the room calibration, the user needs two printed markers: a Room Marker and a Calibration Marker (see Figure 4.7). The Room Marker must be unique and identifies the room. The Calibration Marker is always the same. First, the Room Marker must be placed at a fixed position in the room. This position must not be changed after calibration. Otherwise, the room must be recalibrated. To start the room calibration, the user needs to press the "Calibrate New

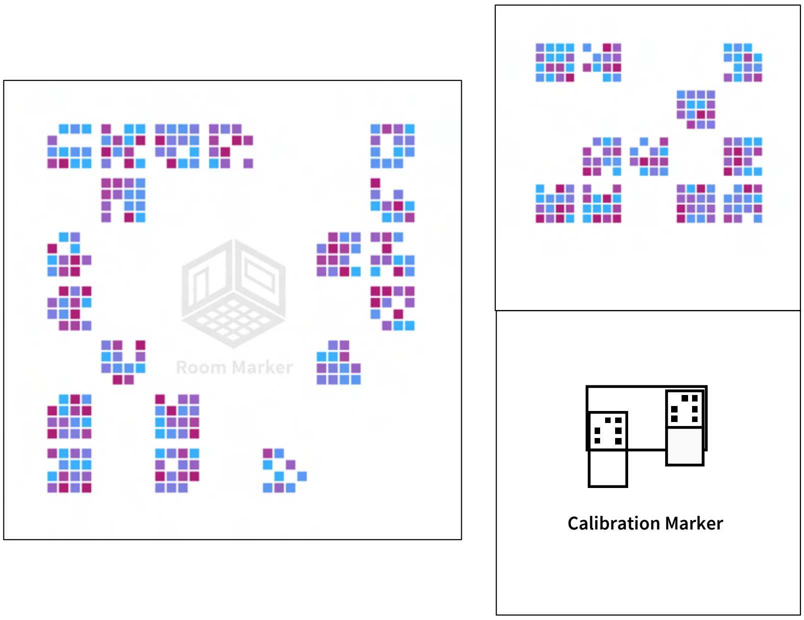

Figure 4.7.: The Room Marker (left) and Calibration Marker (right) are needed to calibrate the room. The Room Marker must be unique and identifies the room after a one-time calibration.

Room" button (see Figure 4.8 (a)). All buttons can be pressed by looking at them and making the standard air tap gesture of the HoloLens. The user is asked to stand up and look at the floor (see Figure 4.8 (b)). Afterward, the user is asked to look at the previously placed Room Marker (see Figure 4.8 (c)). Now the user needs to calibrate the screens in the room, which are used for collaboration. For the screen calibration, the user has to select which type of screen should be calibrated by pressing on the button with the right type (see Figure 4.8 (d)). Afterward, the user is asked to place the Calibration Marker on the bottom left corner of the screen and, after placed correctly, to look at the marker (see Figure 4.8 (e)). The same needs to be done for the top right corner. Afterward, the screen calibration is finished, and the last steps of the procedure can be repeated to calibrate further screens. To finish the room calibration, the user needs to press the "Finish Room Calibration" button (see Figure 4.8 (f)).

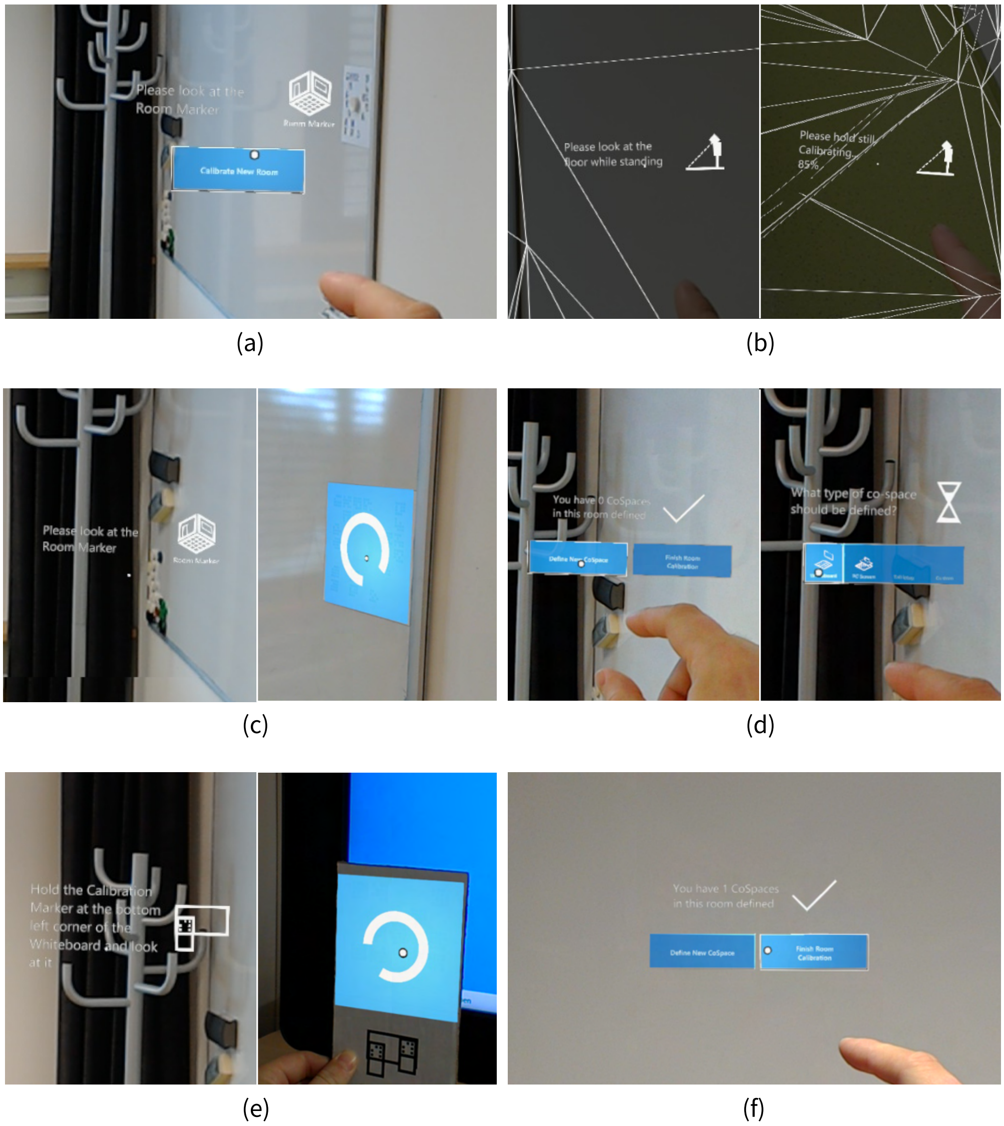

Figure 4.8.: The room calibration process of the prototype. The user starts the calibration by pressing the “Calibrate New Room” button (a). Afterward the user is asked to look at the floor (b), and the Room Marker (c). A Re-location is calibrated by selecting the type (d) and holding the Calibration Marker at the bottom left and top right corner (e). The procedure (d) and (e) can be repeated for several Re-locations. By pressing the “Finish Room Calibration” button the calibration is finished (f).

Once the room is calibrated, the user only needs to look at the Room Marker to log in. Figure 4.9 shows the final prototype from a third person view. After users are logged in, they can hear each other and, when standing in front of a calibrated screen, also see each other as a white three-dimensional avatar. The avatar has the same body size as the remote user, but no legs. The reason for the removed legs is that using only the HoloLens tracking, the feet of the user can not be tracked. When the remote user is inside a Re-location, the avatar hovers at the same position where the remote user is. The head of the avatar imitates the head movement of the remote

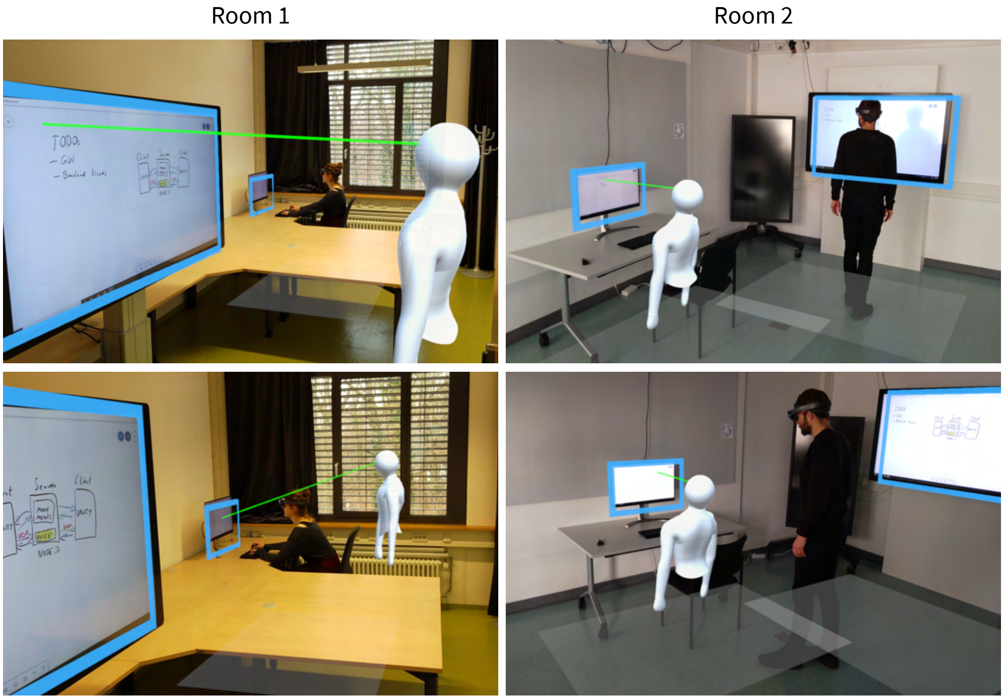

Figure 4.9.: The final prototype from a third person view. Representing avatars are visualized inside the same Re-location as the remote users are located. Users can be inside different Re-locations (top) or the same Re-location (bottom). The head gaze is visualized by a green line when the remote user is looking at an avatar or screen. The blue borders do not match the screen borders only on the screenshots (Issue of the HoloLens screenshot function).

user. An exception is when the user looks from one Re-location at an avatar or screen in another Re-location (see Figure 4.10). In this case, the avatar rotates towards the viewing point of the remote user in the local room. The head gaze is visualized by a green line when the remote user is looking at an avatar or screen. Blue borders around the screens show the user which screens are tracked. The size of a Re-location is visible by a white area on the floor. Furthermore, the prototype supports spatial sound. So the user can hear the voice of a remote user from the direction where the corresponding avatar is located in the local room. When the user closes the application, he or she is automatically logged out and disappears at the remote site. The prototype is completely independent of the applications running on the screens and can be used in combination with already existing remote collaboration systems like, e.g., shared-document editors.

Room 1 Room 2

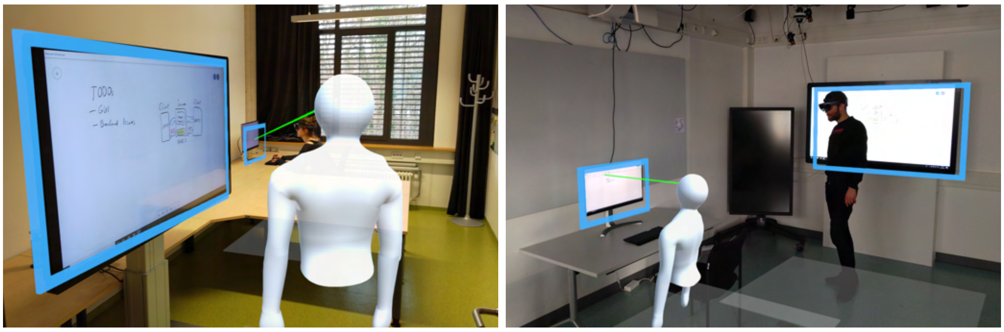

Figure 4.10.: When users are looking from one Re-location at another Re-location (right) the representing avatar rotates towards the viewing point of the remote user in the local room (left). The blue borders do not match the screen borders only on the screenshots (Issue of the HoloLens screenshot function).

5. Evaluation

This chapter reports on the evaluation of the prototype Re-located presented in the last chapter. The prototype was evaluated through a usability study. The first section defines the research objectives and related questions. Afterward, the study design and the data collection and analysis methods are described. Subsequently, the results of the study are presented. Finally, the results are discussed, and the limitations are specified. Since the study was conducted in german, the quotations in this chapter are translated from german.

5.1. Research Objectives

This thesis aims to investigate the influence of Re-located, and the underlying concept, on user experience and the subjective perception of presence. Therefore the research objectives were defined as follows:

Research Objective 1 (RO1): User Experience

- How does the avatar visualization influence the user experience?
- How does the spatial sound influence the user experience?
- How does the alignment of interaction spaces influence the user experience?

Research Objective 2 (RO2): Presence

- How does the avatar visualization influence the subjective perception of presence?
- How does the spatial sound influence the subjective perception of presence?
- How does the alignment of interaction spaces influence the subjective perception of presence?

5.2. Study Design

A usability study with ten dyads was conducted to investigate the defined research objectives. For the study, only dyads who knew each other before were acquired. For this reason, no get to know phase was needed. The study is exploratory and acts as a feasibility test for further studies with the prototype. The aim is to integrate the results into the revision of the system. In the following, the details of the study, including the task, participants, procedure, and apparatus, are described.

5.2.1. Task

For the task, two participants worked together in two different rooms, using the Re-located prototype as a facilitator for remote collaboration. A room setup consisting of a computer screen and a large touchscreen was provided. Both devices were present in both rooms. The computer screen acted as a place to gather information. The touchscreen acted as a digital whiteboard whose contents were synchronized with the remote site. So the touchscreen was used for the actual collaboration. The Re-located prototype provides a communication space for remote users but is independent of the applications used for collaboration. Therefore, applications were

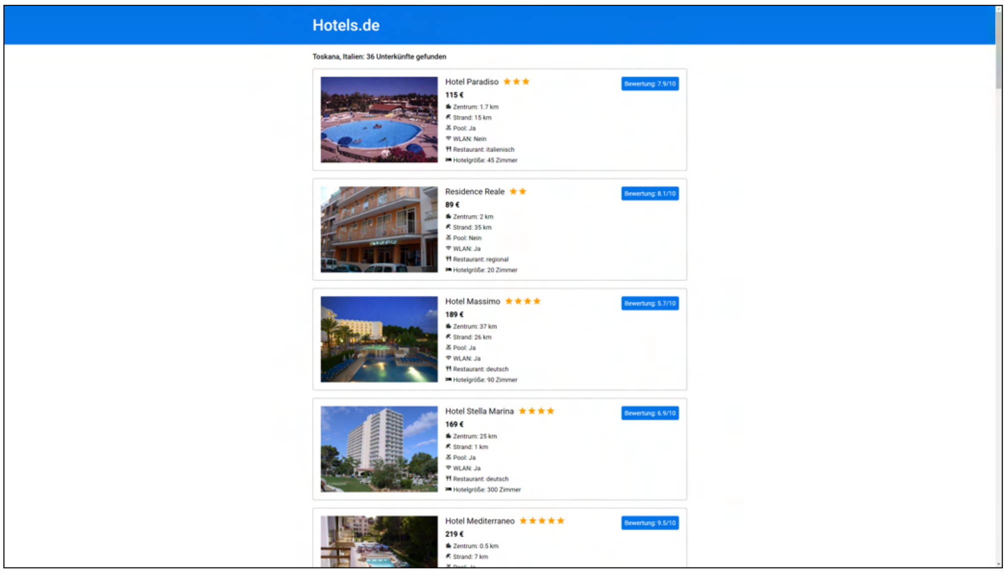

Figure 5.1.: For the task, a hotel website was developed, showing hotels and their attributes in a scrollable list similar to hotel booking websites. The website is shown on the computer screen.

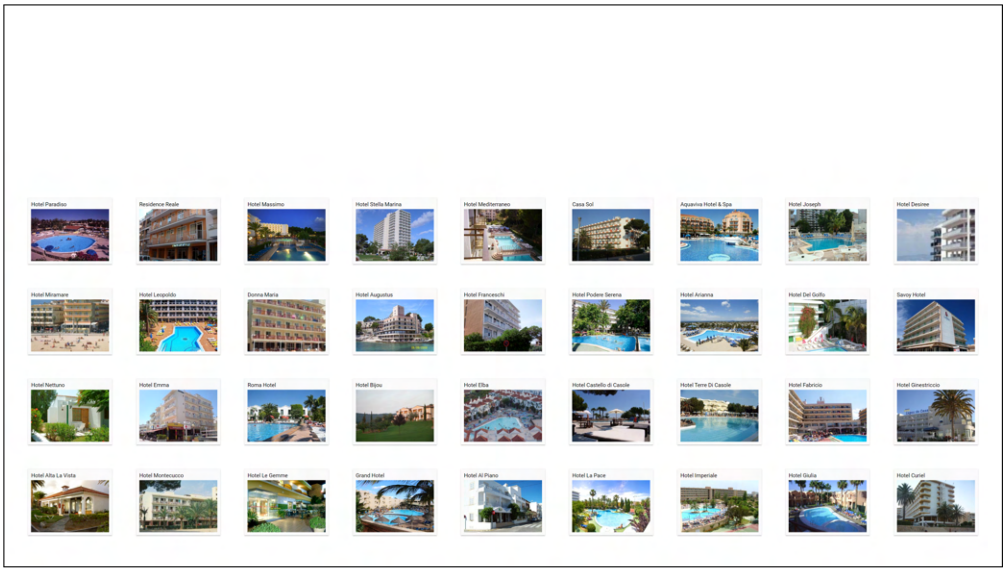

Figure 5.2.: Another web application was developed, showing the same hotels as sticky notes, containing only the name and image. The web application was shown on the touchscreen. The sticky notes could be moved, and the positions were synchronized between the rooms.

needed to perform a task. For the computer screen, a simple website was developed, showing hotels and their attributes in a scrollable list similar to hotel booking websites (see Figure 5.1). For the touchscreen, another web application was developed showing the same hotels as sticky notes, containing only the name and image (see Figure 5.2). Default, the order of the hotels on the touchscreen was the same as on the computer screen. The sticky notes could be moved with the fingers. The positions of the sticky notes were synchronized between the touchscreens of the two rooms. The computer screens were not synchronized.

The task is based on the hotel task of the study of Jetter et al. [39]. Two participants had to agree on a hotel from a set of 36 hotels. The participants were assigned different requirements for their desired hotel. None of the hotels fulfilled the requirements of both participants. Therefore the participants had to find a compromise. The hotels in the set had the following attributes:

Hotel Attributes:

- Name
- Image
- Number of stars (0-5)
- Price (€)

- Distance to the city centre (km)
- Pool (yes,no)
- Distance to the beach (km)
- Number of rooms
- Type of restaurant (none, region, italian, international, spanish, german)
- Wifi (yes,no)
- Rating (0.0-10.0)

The hotel images were provided by Holidaycheck.com for previous studies and were reused. The hotel attributes were fictitious and were created for this study. The participants had the following requirements (translated from german):

Requirements Participant 1:

- It may cost a **maximum of 150€**.
- You like bathing. Therefore, the **beach should be at most 5km away**.
- A small hotel is important to you. The hotel should have a **maximum of 50 rooms**.
- A **restaurant with regional food** should be available.

Requirements Participant 2:

- It should have **at least 4 stars**.
- You like bathing. That's why the hotel should have a **pool**.
- It should be **no more than 2km from the centre**.
- A **restaurant with regional food** should be available.

Because the fourth requirement was the same for both participants, a total of seven requirements were given. Ten hotels of the set met two of the seven requirements. Ten more hotels met three requirements. Ten further hotels met four requirements. Finally, five hotels met five requirements, and only one hotel six requirements. So there was no perfect hotel but one that fulfilled six of the seven requirements. In this way, the participants could not find a perfect hotel and had to agree on one.

In the task description, the participants were asked to make as few concessions as possible. Furthermore, it was described that the whiteboard (large touchscreen) should be used to organize the hotels. The participants were allowed to move freely in the room and solve the task as they liked. In the task description, the hint was given that, for example, the hotels could be sorted from the left (meets few requirements) to the right (meets many requirements). After the participants had chosen a hotel, they were asked to contact the study conductor. However, the participants were not allowed to use search or filter functions available from the browser or operating system. Furthermore, no other tools (e.g., pen) were allowed. During the task, all 9 dyads have chosen the hotel that fulfilled the most requirements (six of the seven requirements).

5.2.2. Participants

The study was conducted with 20 participants (10 dyads). Due to task violations, one dyad was excluded from the study. Therefore, the results of 18 participants (9 dyads) between 20 and 40 years ($M = 25.34$, $SD = 4.39$) were analyzed. Eleven were female, and seven were male. Among the participants were 13 students (psychology ($n = 3$), chemistry ($n = 2$), environmental technology ($n = 2$), literature arts media ($n = 1$), physics ($n = 1$), life science ($n = 1$), teacher trainee ($n = 1$), law ($n = 1$), digital innovation and business transformation ($n = 1$)), two doctoral candidates (physics and unknown), two employed persons (data scientist and language teacher), and one trainee (computer science). Five dyads consisted of one male and one female participant; three dyads were only female, and one only male. All participants already knew their team partner before the study. Seven participants were visual impaired (corrected by glasses ($n = 4$), corrected by contact lenses ($n = 3$)). Only three participants had made experiences with Augmented Reality applications before. The three participants were asked to rate themselves in the use of Augmented Reality applications on a five-point Likert scale (1 (inexperienced) - 5 (very experienced)) ($M = 2.34$, $SD = 0.57$). Two participants used Augmented Reality before in other studies. One mentioned “Nintendo 3DS” and “Pokemon Go” as already used AR applications. In contrast, 13 participants had made experiences with Virtual Reality applications before. Also, for Virtual Reality, the 13 participants rated themselves in the use of applications on the same five-point Likert scale (1 (inexperienced) - 5 (very experienced)) ($M = 2.54$, $SD = 0.66$). Three participants mentioned as used Virtual Reality applications VR HMDs, three VR games, two other studies, and one in a museum. Seventeen participants had made experiences with remote collaboration applications (e.g., Skype, Google Docs, ...) before. The participants were asked to rate on a five-point Likert scale (1 (very rare) - 5 (very often)) how often they use these applications ($M = 3$, $SD = 1.17$). Furthermore, they were asked which applications they use to work with persons in different locations (Skype ($n = 10$), Google Docs ($n = 6$), WhatsApp ($n = 5$), E-Mail ($n = 2$), Sharelatex ($n = 1$), Teamviewer ($n = 1$), Discovery ($n = 1$), Discord ($n = 1$), Dropbox ($n = 1$), Microsoft Teams ($n = 1$), Telegram ($n = 1$), Phone ($n = 1$), Latex ($n = 1$), FaceTime ($n = 1$)).

5.2.3. Procedure

The participants were welcomed in the hallway by two study conductors. This way, it was ensured that the participants did not know the room setting of the other participant. The participants were then guided into the different rooms by one study conductor each. From then on, the participants were separated. After reading the welcome sheet and signing the consent form, the participants were asked to fill out a digital version of the demographic questionnaire on a tablet. Then the study coordinators introduced the participants into the applications running on the computer screen and touchscreen, using an example dataset containing only letters instead of hotel names. The study conductors used an instant messenger to agree when the other participant was ready. When both participants had understood the applications, the Re-located application was started, and the participants put on the Microsoft HoloLens themselves. The participants were asked to look at the Room Marker to log in. Afterward, they were guided into a Re-location and asked if they can see and hear each other. When everything worked, the hotel dataset was loaded, and both participants received their respective tasks on a sheet of paper. One study coordinator started the data logging and video recording for both rooms. When the participants were finished with the task, they contacted the study conductors and let them know which hotel they have chosen. The participants took off the Microsoft HoloLens, and one study conductor stopped the data logging and recording. The participants were asked to fill out the digital version of three questionnaires (Simulator Sickness Questionnaire (SSQ) [40], User Experience Questionnaire (UEQ) [41], and Temple Presence Inventory (TPI) [42]). When both were finished, one participant was guided into the other room for a final interview with both participants simultaneously. Afterward, the participants received compensation for their time, and the study session was finished. The study session took approximately one hour, depending on how long the participants took for the task. The study procedure was revised and tested by a pilot study with two dyads.

Figure 5.3.: The study was conducted in two laboratory rooms of the Human-Interaction group of the University of Konstanz.

5.2.4. Apparatus

The study was conducted in two laboratory rooms of the Human-Interaction group of the University of Konstanz (see Figure 5.3). Both rooms were equipped with a 65-inch touchscreen and a 27-inch computer screen. All screens had a resolution of 4k (3840 x 2160 pixels) and were each connected to a separate computer. The computer screens stood on a table together with a mouse and keyboard to control the connected computer. The respective screens were positioned at the same height in both rooms. The height from the floor to the center of the screen was 107.6cm for the computer screen and 147.5cm for the touchscreen. However, the relative positions of the screens to each other were different. This way, the primary function of the prototype, which is the facilitation of remote collaboration in AR with different room configurations, could be evaluated. Figure 5.4 shows the relative positions of the screens (and the corresponding Re-locations). The task was implemented as web applications. The computers were running Windows 10 and Google Chrome to display the web applications.

Figure 5.4.: The relative positions of the screens to each other were different in the rooms. The screens in Room 1 were arranged in an L-shape. The screens in Room 2 faced each other and had a offset. The Re-locations had always the same size.

There was one study coordinator per room. Every study coordinator had a separate table with the study documents and a laptop to control the study procedure. All questionnaires were implemented as web applications. Therefore, an iPad Pro (9.7-inch) in each room was used to fill out questionnaires. Both rooms were equipped with a Microsoft HoloLens running the Re-located prototype and an individual room marker hanging on the wall. The participants had to wear the HoloLens during the task. In both rooms were cameras mounted on the ceiling to record the study. The larger room was additionally equipped with a microphone to record the final interview with both participants. All devices were connected to the same local network.

5.3. Data Collection and Analysis

Different data collection methods were used to investigate the research objectives. The data collection consists of a semi-structured interview, questionnaires, data logging, and audio and video recordings. In the following, the used methods are explained.

5.3.1. Semi-structured Interview

At the end of a study session, a semi-structured interview was conducted. The interview aimed to gain deeper qualitative insights regarding both user experience and presence. In the beginning, the interviewer clarified that the questions only refer to visualization and communication with the other person and do not concern the hotel applications on the screens. First, the participants were asked about their first impressions when using the system. Furthermore, they were asked about the strengths and weaknesses of the system and how it performed compared to other types of remote collaboration (e.g., using Skype). Afterward, they were asked questions regarding the Re-locations. So they were inquired whether they always knew where their team partner was. Furthermore, they were also asked whether they were aware that the other person was only visible in areas in front of the screens, and if so, whether they perceived it positively or negatively. Afterward, they were told that the other room had a different room setting and asked if they had noticed it. Subsequently, they were asked about the avatar and the green gaze ray and the positive and negative aspects of it. They were also asked for suggestions to improve the avatar. Finally, they were inquired about the voice chat and how it can be improved.

The interviews were audio-recorded. For the analysis, a procedure similar to the thematic analysis method of Braun and Clarke [43] was used. The interviews were transcribed. Afterward, interesting statements in the interviews were coded, and the codes were used to generate themes. The resulting themes were: avatar, voice chat, Re-locations, technology, and presence. The codes were assigned to the themes, and finally, the frequency of the statements in the codes was counted.

5.3.2. Questionnaires

During a study session, participants had to fill out several questionnaires. In the beginning, a demographic questionnaire intended to gain general attributes of participants, including age, gender, current activity, and visual impairment. The participants were also asked whether they knew the other participant before. Further questions were related to previous experiences with Augmented Reality, Virtual Reality, and remote collaboration tools. After the task, the participants had to fill out the following three questionnaires in that order: Simulator Sickness Questionnaire (SSQ) [40], User Experience Questionnaire (UEQ) [41], and Temple Presence Inventory (TPI) [42].

The SSQ [40] measures the simulator sickness that possibly occurred during the task. It questions 16 symptoms on a scale from 0 (not at all) to 3 (strong). The symptoms are assigned to one or more of the three subscales: nausea, oculomotor, and disorientation. The assignment of seven symptoms (items) per subscale results in 21 total items. The total score is calculated with the sum of all items multiplied by 3.74. It ranges from 0 to 235.62. The subscales are calculated with the sum of the assigned items multiplied with 9.54 for nausea, 7.58 for oculomotor, and 13.92 for disorientation. The subscales range from 0 to 200.34 for nausea, 0 to 159.18 for oculomotor, and 0 to 292.32 for disorientation. The possibly occurred simulator sickness is part of the user experience. It was the first of the three questionnaires to record the symptoms immediately after taking off the glasses. The german version of the SSQ was used [44].

The User Experience Questionnaire (UEQ) [41] measures the subjective user experience of products. At the beginning of the questionnaire, it was added that the following questions do not concern the hotel applications on the screens. The questionnaire consists of 26 items, and each item consists of a pair of terms with opposite meanings. The items are rated on a seven-point Likert scale. Furthermore, the items are assigned to the six dimensions attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The german version of the UEQ was used [45].

The Temple Presence Inventory (TPI) [42] consists of several questionnaire items that can be used to measure dimensions of presence. The three item sets spatial presence, social presence (actor within medium (parasocial interaction)), and social richness of the inventory were used. Questionnaire items of the TPI are rated on a seven-point Likert scale. Because no german version of the TPI exists, the english version was used.

5.3.3. Data Logging

A data logging functionality was implemented into the Re-located prototype that recorded the position, rotation, and viewing direction (head gaze) of participants inside Re-locations during the study. The obtained data were used to evaluate the work behavior (regarding the user experience) and the avatar viewing time (regarding the presence). Data was only logged while participants were inside Re-locations.

5.3.4. Audio and Video Recording

During the task, audio and video recordings were captured in both rooms. The recordings can be used to investigate the communication behavior of the participants using the system. Since a communication behavior analysis goes beyond the scope of this master thesis, the recordings were not used for the evaluation. However, the recordings can be used for future evaluations.

5.4. Results

This section presents the results of the conducted usability study. The results are assigned to the previously defined research objectives: user experience and presence. The contents of this section provide the basis for the discussion in the next section.

5.4.1. RO1: User Experience

The user experience was measured using the User Experience Questionnaire (UEQ) [41], the Simulator Sickness Questionnaire (SSQ) [40], a semi-structured interview, and data logging. In the following, the results of the different methods are presented.

User Experience Questionnaire (UEQ)

The UEQ [41] rates the user experience not with an overall score but with scores for the dimensions attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The scores range from -3 to 3. Figure 5.5 shows the results of the different dimensions. According to the UEQ analysis tool [45], mean values under -0.8 represent a negative evaluation, values between -0.8 and 0.8 a neutral evaluation, and values above 0.8 a positive evaluation. All dimensions achieved mean values above 0.8 and were therefore rated positively. The attractiveness dimension, which evaluates the overall impression of the system, reached a mean of 1.44 ($SD = 1$). The perspicuity dimension that measures how easy users become familiar with the system achieved the highest mean value with 2.15 ($SD = 0.61$). The efficiency dimension achieved a mean value of 1.46 ($SD = 0.92$). The lowest mean value, compared to the other dimensions, achieved the dependability dimension with 1.38 ($SD = 0.84$). The dependability dimension measures the predictability of a system. However, even the dependability score is rated as positive. The stimulation dimension, which measures the motivation to use the system, reached a mean of 1.78 ($SD = 0.9$) and the novelty a mean of 1.72 ($SD = 0.96$).

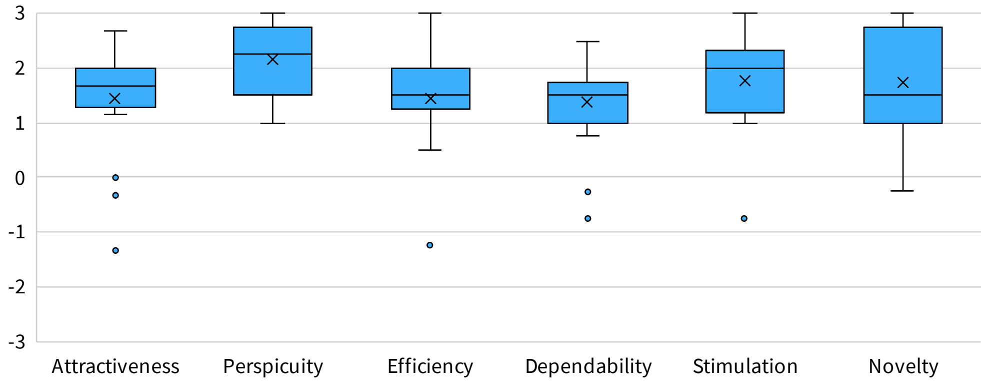

Figure 5.5.: The results of the different dimensions of the UEQ are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

Schrepp et al. [46] constructed a benchmark that allows comparing results of the UEQ with existing values from a benchmark dataset. The benchmark assigns the mean values of the dimensions to the five categories excellent (among the best 10% of the products in the dataset), good (10% of the products were better, 75% were worse), above average (25% of the products were better, 50% worse), below average (50% of the products were better, 25% worse), and bad (among the worst 25% of the products in the dataset). Figure 5.6 shows the results of the study assigned to the categories. Version 7 of the benchmark was used containing 20190 participants from 452 studies. All dimensions are rated at least above average. The attractiveness, efficiency, and dependability dimensions are rated above average (25% of the products were better, 50% worse). The other three dimensions of perspicuity, stimulation, and novelty are even rated as excellent (among the best 10% of the products in the dataset).

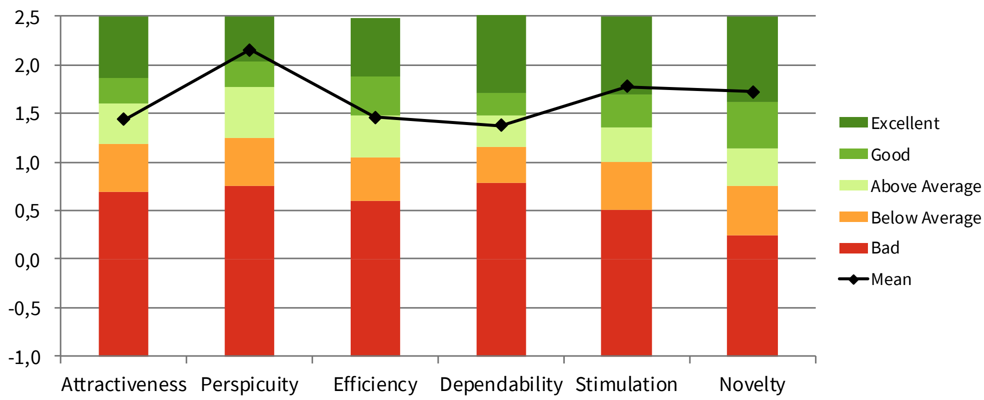

Figure 5.6.: The results of the UEQ compared with version 7 of the UEQ benchmark dataset [45]. Diamonds indicate mean values.

Simulator Sickness Questionnaire (SSQ)

The SSQ [40] measures the simulator sickness with the severeness of 16 symptoms resulting in a total score. Furthermore, scores for the dimensions of nausea, oculomotor, and disorientation are provided. The total score ranges from 0 to 235.62. The results show a total score of 15.58 ($SD = 14.53$). The dimension scores range from 0 to 200.34 for nausea, 0 to 159.18 for oculomotor, and 0 to 292.32 for disorientation. The results show a nausea score of 5.3 ($SD = 8.16$), an oculomotor score of 14.32 ($SD = 17.22$), and a disorientation score of 23.97 ($SD = 22.8$). The 16 symptoms are measured on a scale from 0 (not at all) to 3 (strong). Figure 5.7 shows the severeness of the individual symptoms. All symptoms reached mean values below 1. The highest value reached "Fullness of head" ($M = 0.83$, $SD = 0.92$). The other symptoms reached mean values below 0.5. The second highest mean value reached "Eyestrain" ($M = 0.44$, $SD = 0.61$) followed by "Headache" ($M = 0.38$, $SD = 0.69$) and "General Discomfort" ($M = 0.33$, $SD = 0.77$). Further symptoms were "Dizzy (eyes open)" ($M = 0.28$, $SD = 0.46$), "Fatigue" ($M = 0.22$, $SD = 0.43$), "Difficulty focusing" ($M = 0.22$, $SD = 0.55$), and "Blurred vision" ($M = 0.22$, $SD = 0.43$). The remaining symptoms reached mean values below 0.06.

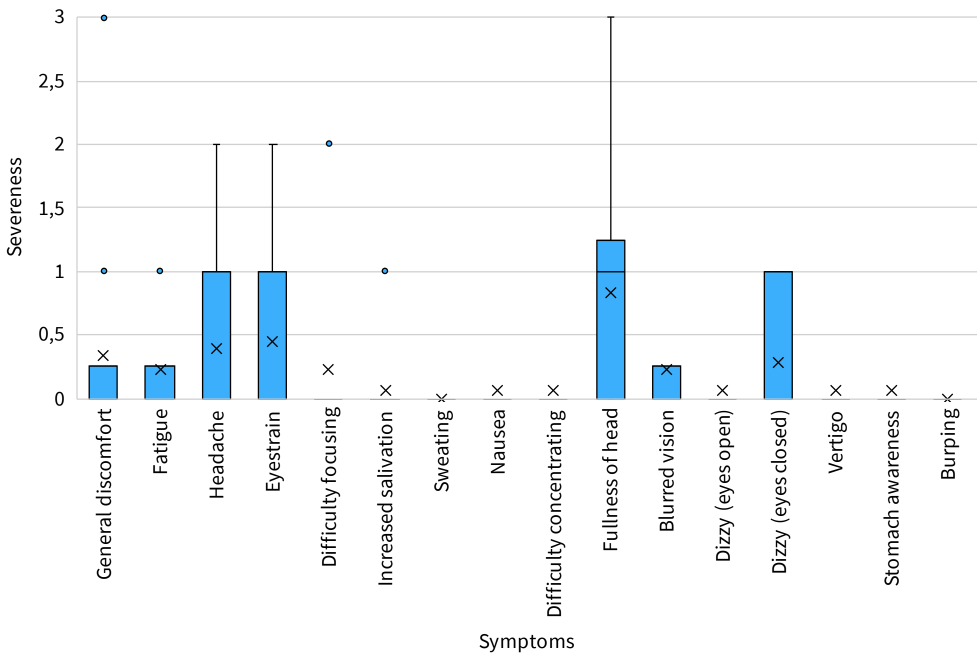

Figure 5.7.: The results of the measured symptoms of the SSQ are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

Semi-structured Interview

Similar to the thematic analysis method of Braun and Clarke [43], the statements of the participants were coded and assigned to themes (see Section 5.3.1). In the following, the user experience related themes: avatar, voice chat, Re-locations, and technology are presented. A pair x of participants is termed as Px (e.g., $P1$ for pair 1). The individual participants of a pair x are termed as Pxa and Pxb (e.g., $P1a$ and $P1b$ for the participants in pair 1).

Figure 5.8 lists the coded statements of the theme avatar and shows how often each of them was mentioned. During the interview, the participants were asked if the avatar was helpful. Four participants rated the avatar as helpful. Participant $P4b$ answered: "Yes, definitely. So I think it is cool because it makes things a little bit more personal." All other 14 of the 18 participants

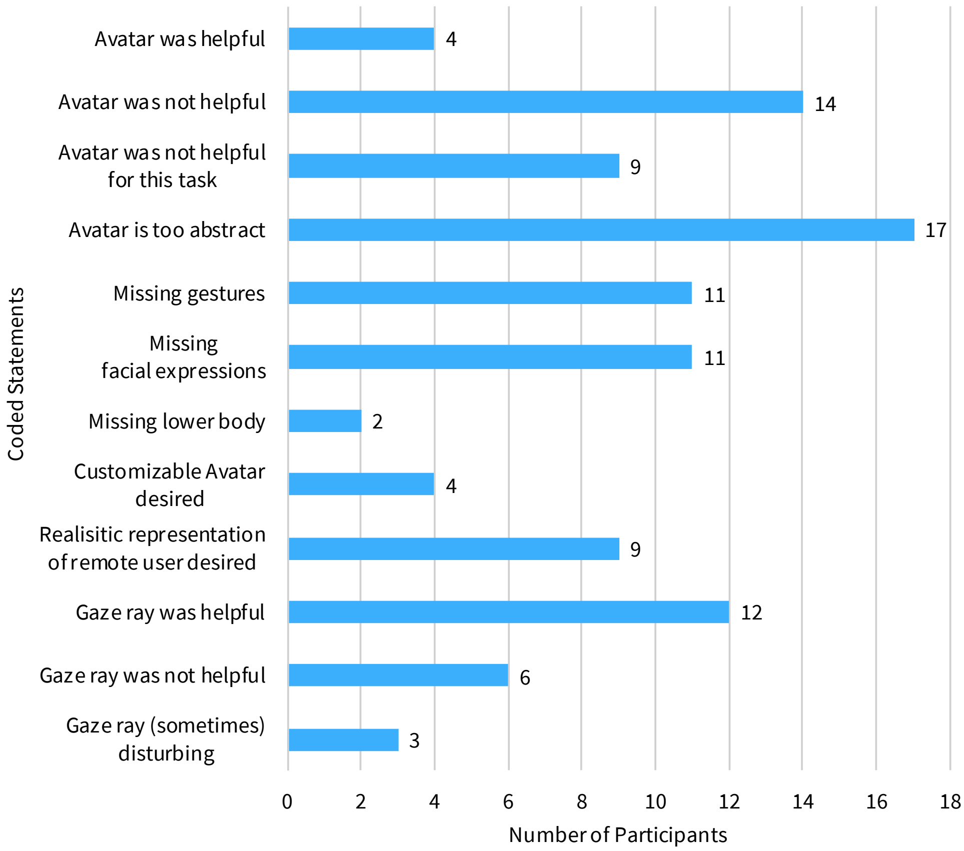

Figure 5.8.: The coded statements of the theme avatar and how often each of them was mentioned.

rated the avatar as not helpful. Nine participants said that it was not helpful for this particular task. For example, $P2b$ said: “Maybe it has advantages in other tasks where it is important to see where the other person stands or something? But in this task...”. Almost all participants (17) described that the avatar is too abstract. Eleven participants stated that they were missing gestures. $P2b$ stated: “If he really moved the way the person moved, I think it would have been helpful.” Furthermore, eleven participants missed facial expressions. For example, $P7a$ said: “[...] include gestures and facial expressions would make it even more realistic, and then I think it would work even better.” Two participants did not like the missing lower body. Nine participants desired a realistic representation of the remote person. For example, $P1b$ stated: “[...] if you could really see the other person in 3D, not as a schematic person but as a real person, I think that is really cool.” Four participants wished a customizable avatar. For example, $P2b$ said: “If you could make it like Sims.”, and $P4b$ said: “[...] like a Mii avatar.” In another question of the interview, the participants were asked if the gaze ray was helpful. Twelve participants rated the gaze ray as helpful, six as not helpful. Three participants described the gaze ray as (sometimes) disturbing. For example, $P4b$ said: “[...] annoying when you have a neon light shining through you all the time.”

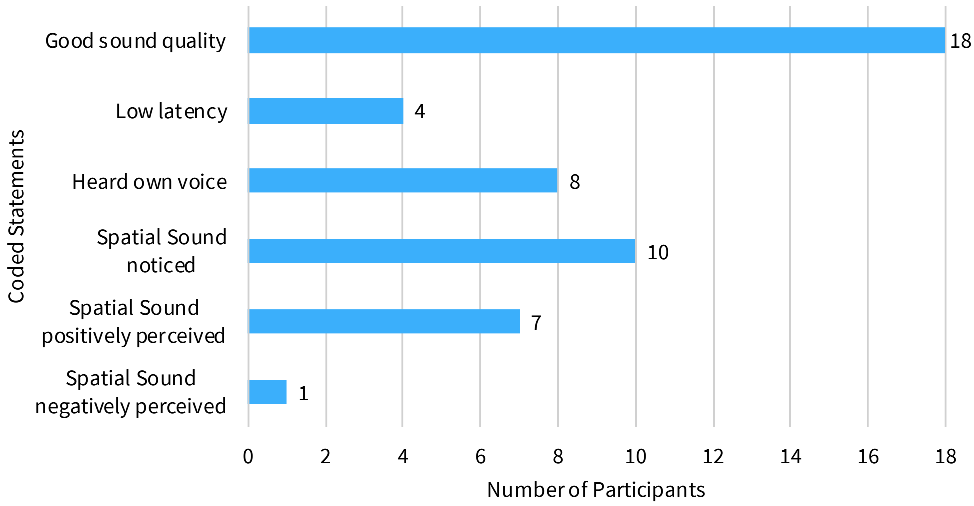

Figure 5.9.: The coded statements of the theme voice chat and how often each of them was mentioned.

The coded statements of the theme voice chat, and their frequency, are summarized in Figure 5.9. All 18 participants liked the sound quality of the voice chat. Four participants mentioned that they liked the low latency. For example, $P1a$ stated: “I never got the feeling it would somehow be delayed.” However, eight participants heard themselves. $P1a$ said: “I heard myself again.” Ten participants noticed the spatial sound. For example, $P1b$ said: “I just had the feeling it was so Dolby Surround.” Seven participants explicitly said they liked the spatial sound functionality. $P1a$ stated: “Well, it also seemed to me that I heard where she was talking from, and that was always very helpful. It was like: 'Okay, left ear behind me', and then I can turn there." Participant $P3a$ did not like the spatial sound and said: "I didn't quite understand why."

Figure 5.10 summarizes the coded statements according to the theme Re-locations. The participants were asked if they noticed that the room setting in the other room was different. Seventeen participants did not notice the other room setting. $P5a$ said to his/her team partner: "Well, it looked to me like your room was shaped exactly like mine." However, one participant noticed the other room setting. Participant $P3a$ stated: "At my place, she was so fast at the PC. So poof, and yes, it could not have been when the room was exactly like mine." The participants were also asked if they noticed that the other person was only visible in front of the screens. Eleven participants did not notice that the other person is not visible all the time. For example, $P5b$ said to his/her team partner: "I always saw you when I looked at you." Seven participants noticed that the other person was sometimes not visible. $P3b$ said: "[...] when she said, 'I'm gonna run over there now,' she was gone for a second, and then she came back."

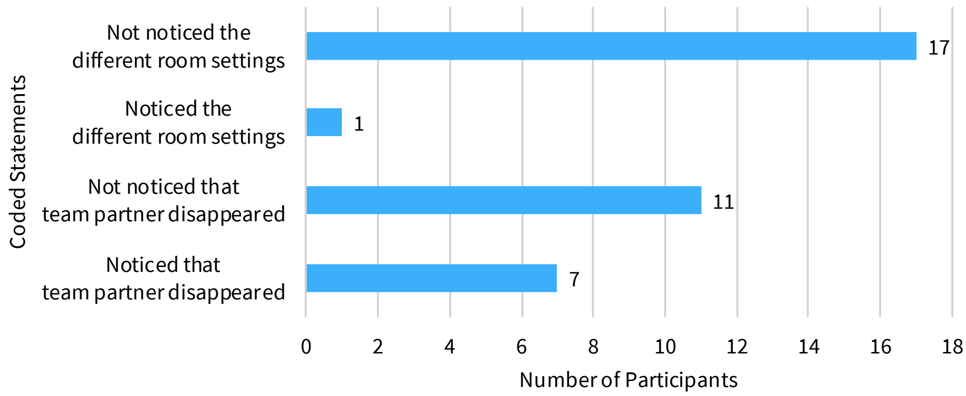

Figure 5.10.: The coded statements of the theme Re-locations and how often each of them was mentioned.

Finally, the coded statements of the theme technology, and their frequency, are summarized in Figure 5.11. Six participants mentioned during the interview that the device was uncomfortable. For example, $P1b$ said: "I found the thing on my head pretty heavy." Two participants even got headaches. Participant $P2a$ said: "[...] with this task you could have phoned. Then I wouldn't have had a headache." Six participants mentioned as negative point the small field of view of the display. Four participants liked the freedom of movement of the device, or that the hands were free. For participant $P8b$, tracking problems towards the end of the study caused the virtual elements to move upward.

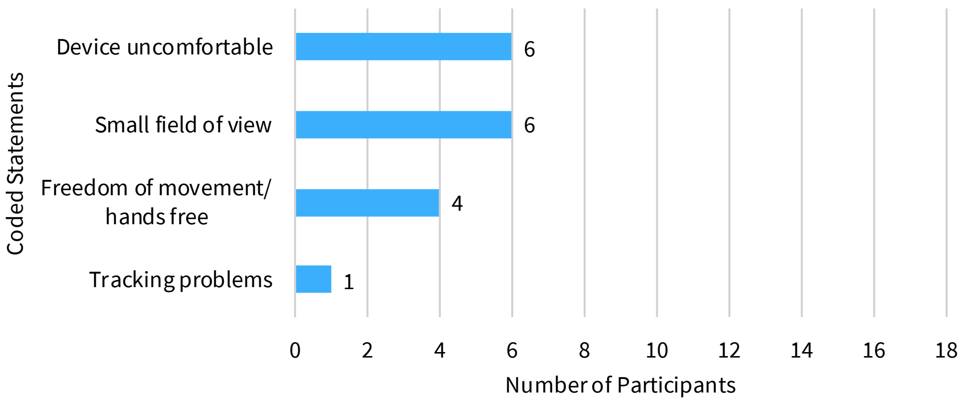

Figure 5.11.: The coded statements of the theme technology and how often each of them was mentioned.

Data Logging

The data logging was used to evaluate the work behavior. Concrete, besides the task completion time, it was calculated how long participants were inside the different Re-locations and how long they looked at the screens. The participants completed the task between 744 (12:24 minutes) and 1940 seconds (32:20 minutes) with a mean value of 1456.78 seconds (24:16 minutes) ($SD = 388.76$). They were, in the mean, 1425.56 seconds inside Re-locations ($SD = 356.85$,

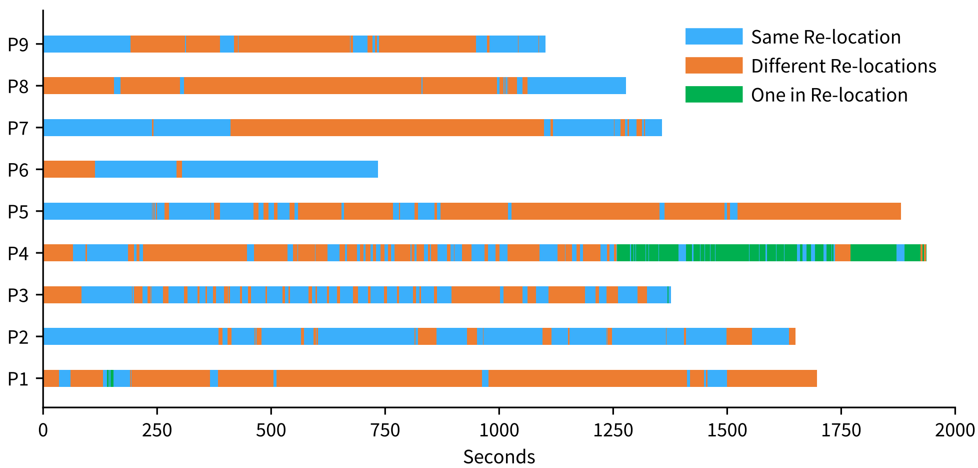

Figure 5.12.: The Re-location times of the single dyads over time. The participants were in the blue areas in the same Re-location, in the orange areas in different Re-locations, and in the green areas only one participant was in a Re-location.

98% of task completion time) and 31.22 seconds outside ($SD = 128.24$, 2% of task completion time). In the mean, the participants of a dyad were 610.67 seconds inside the same Re-location ($SD = 366.66$, 42% of task completion time), 783.89 seconds inside different Re-locations ($SD = 462.51$, 54% of task completion time), and 62.22 seconds were only one participant inside a Re-location ($SD = 181.08$, 4% of task completion time). It never happened that both participants of a dyad were outside Re-locations at a time. However, the Re-location times have a high range. Therefore, figure 5.12 shows the Re-location times of the single dyads over time.

For the calculation of screen times (how long did the participants look at the screens), the head gaze was used. Figure 5.13 shows the screen times compared with the task completion time. In the mean, the participants looked 1037.83 seconds at a screen ($SD = 315.45$, 71% of task completion time). The screen time can be differentiated by the time they looked at the screen of the Re-location they were inside, or at the screen of the other Re-location. The participants looked, in the mean, 997.5 seconds at the screen inside the same Re-location ($SD = 294.23$, 96% of screen time) and 40.33 seconds at the screen of the other Re-location ($SD = 82.33$, 4% of screen time).

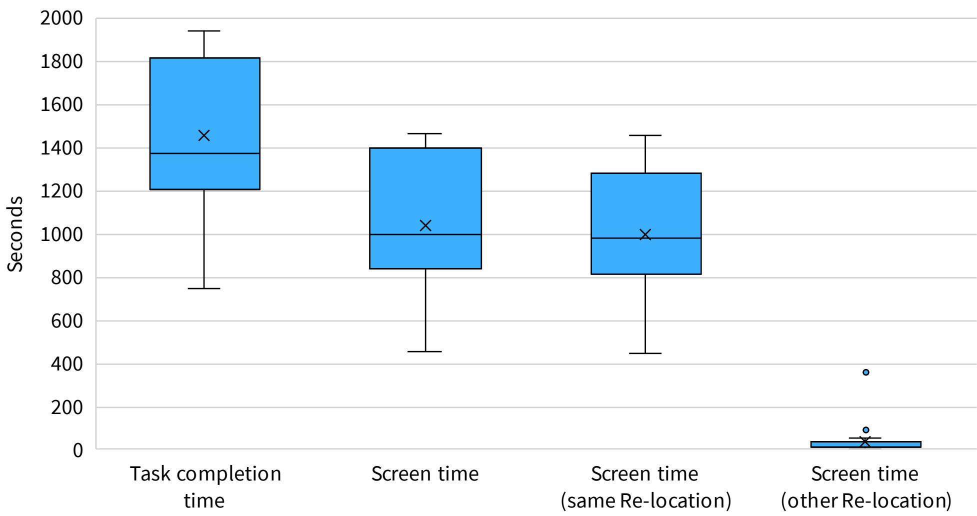

Figure 5.13.: The screen times (how long did the participants look at the screens) and the task completion time are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

Summary

The prototype achieved results above average in all six dimensions of the UEQ. The dimensions of perspicuity, stimulation, and novelty are even rated as excellent. Furthermore, regarding the simulator sickness, the prototype achieved overall low values in the SSQ. The interviews revealed that the avatar was, for the majority, too abstract and not helpful (for this task). The participants mentioned missing gestures and facial expressions. Furthermore, a realistic representation of the remote user or a customizable avatar was desired. In contrast, the majority rated the gaze ray as helpful. The voice chat was rated as good by all participants. Over half of the participants noticed the spatial sound. Only one participant rated the spatial sound negatively. However, as a negative point, some participants heard themselves. Regarding the Re-locations, only one participant noticed that the room settings were different. Furthermore, over half of the participants not noticed that the team partner sometimes disappeared. Regarding technological aspects, some participants perceived the device as uncomfortable. Moreover, some participants mentioned the small field of view as a downside. Positively mentioned was the freedom of movement or that the hands were free. The results of the data logging show that the participants were inside Re-locations, almost the whole task. Furthermore, the dyads were depending on their work behavior either longer in the same Re-location or longer in different Re-locations. Compared to the task completion time, the participants looked at the screens relatively long.

5.4.2. RO2: Presence

The presence was measured using questions of the Temple Presence Inventory (TPI) [42], a semi-structured interview, and data logging. In the following, the results of the different methods are presented.

Temple Presence Inventory (TPI)

The questions of the TPI [42] measure different dimensions of presence. The three item sets spatial presence, social presence (actor within medium (parasocial interaction)), and social richness of the inventory were used. Every question is answered on a seven-point Likert scale consisting of a pair of terms. The results range from -3 to 3.

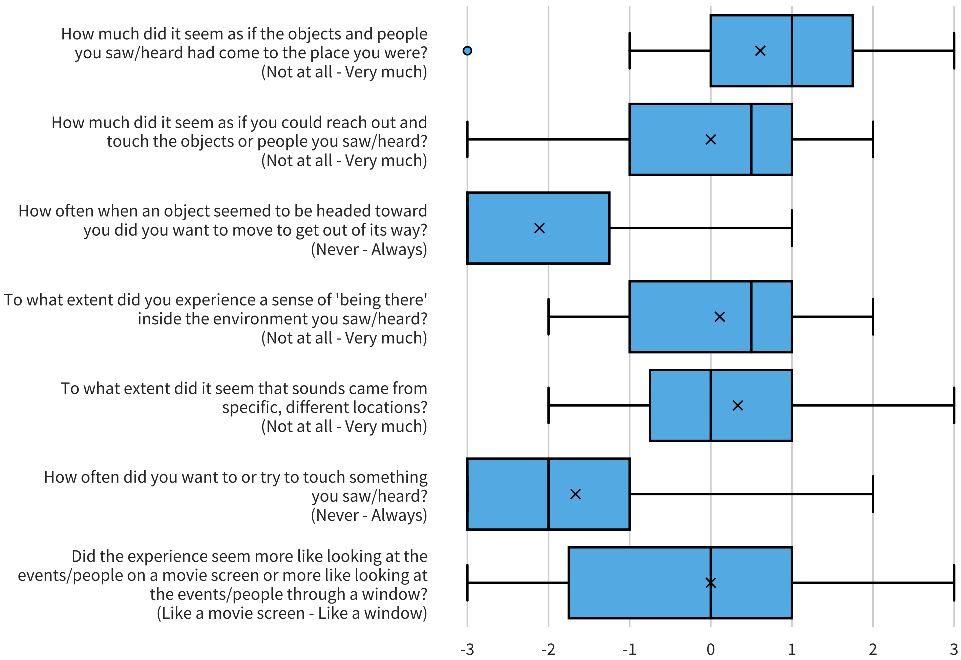

Figure 5.14.: The results of the item set spatial presence of the TPI are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

Figure 5.14 shows the results of the spatial presence questions. The range of the answers of all questions is very high. Except for two questions, the results of the mean values are neutral or slightly positive. The question about, if the objects and people the participants saw or heard, seemed to come to the place where they were, reached a quite neutral mean value of 0.61 ($SD = 1.46$). However, compared to the other results of the spatial presence questions, the question reached the highest mean value. Also, the question about, if it seemed they could reach out and touch the objects they saw or heard, achieved a neutral mean value of 0 ($SD = 1.49$). A mean value of -2.11 ($SD = 1.32$) indicates that the participants did not want to or did not move to get out the way of objects that seemed headed toward them. The question about the sense of being inside the environment they saw or heard reached a neutral mean value of 0.11 ($SD = 1.49$). Also, the question about, if it seemed that sounds came from specific or different locations, achieved a neutral mean value of 0.33 ($SD = 1.57$). A mean value of -1.67 ($SD = 1.65$) suggests that the participants did not want to or did not try to touch things they saw and heard. A wide answer range and a mean value of 0 ($SD = 1.85$) indicate that the participants disagreed on the question about if the experience seemed more like looking on a movie screen or through a window.

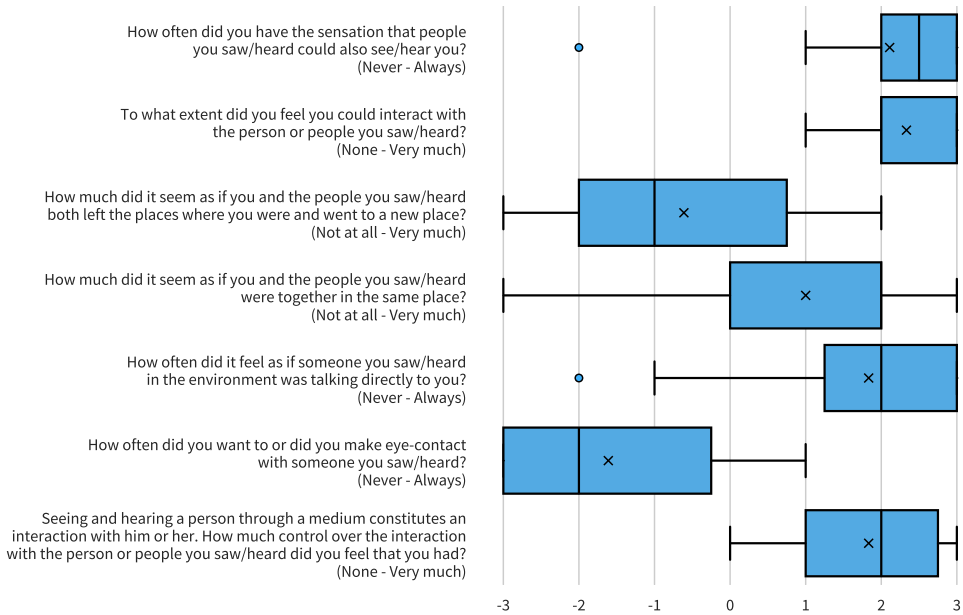

Figure 5.15.: The results of the item set social presence (actor within medium (parasocial interaction)) of the TPI are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

Figure 5.15 shows the results of the social presence (actor within medium (parasocial interaction)) questions. Except for two questions, the mean values are rather positive. With a mean value of 2.11 ($SD = 1.28$), the participants often had the sensation that people they saw or heard could also see or hear them. Also, the question about, if they had the feeling they could interact with the person or people they saw heard, reached a high mean value of 2.33 ($SD = 0.69$). A slightly negative mean value of -0.61 ($SD = 1.54$) indicates the participants had rather not the feeling they left the places and went to a new place. However, they had rather the feeling they were together in the same place ($M = 1$, $SD = 1.78$). A mean value of 1.83 ($SD = 1.5$) suggests that it often had felt like someone talked directly to them. With a mean value of -1.61 ($SD = 1.57$), the participants did rather not (want to) make eye-contact with people they saw or heard. The participants had the feeling they had much control over the interaction with people they saw or heard ($M = 1.83$, $SD = 0.92$).

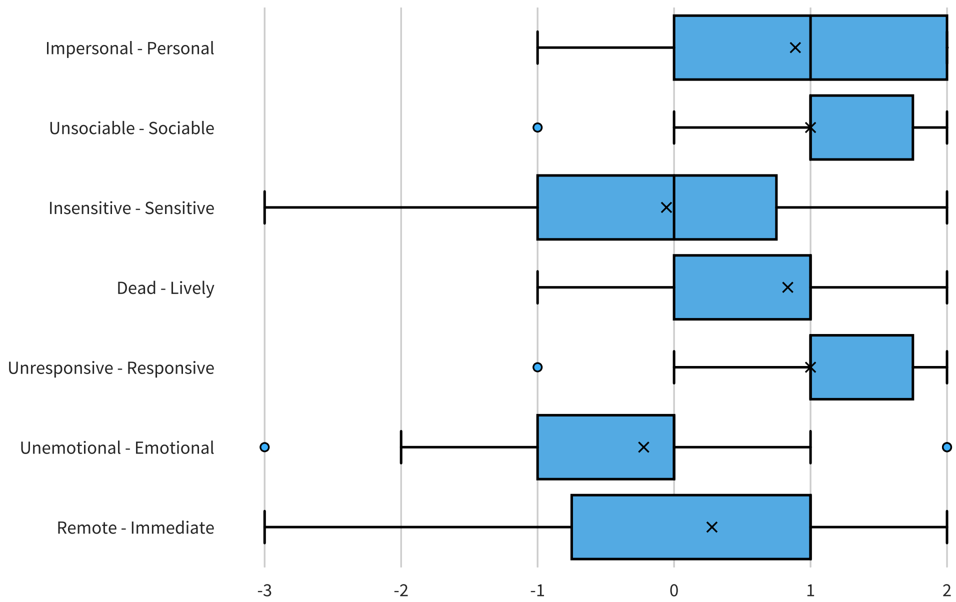

Figure 5.16.: The results of the item set social richness of the TPI are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

The social richness item set rates the media experience, similar to the UEQ, with pairs of terms with opposite meanings. Figure 5.16 shows the results of the social richness items. The highest values achieved the terms sociable ($M = 2$, $SD = 0.84$), responsive ($M = 2$, $SD = 0.84$), personal ($M = 1.89$, $SD = 1.02$), and lively ($M = 1.84$, $SD = 0.86$). However, also the terms immediate ($M = 1.28$, $SD = 1.53$), sensitive ($M = 0.94$, $SD = 1.21$), and emotional ($M = 0.78$, $SD = 1.26$) describe the media experience.

Semi-structured Interview

In the following, the presence related statements of the interview are presented. The participants are termed as in section 5.4.1 (e.g., $P1a$ and $P1b$ for the participants of pair 1). Figure 5.17 summarizes the coded statements according to the theme presence. The participants were asked if they always knew where the team partner was located in the room. Fourteen participants said that they always knew where the partner was. Four participants did not know it all the time. Two participants explicitly said that they knew the location all the time because of the spatial sound. Twelve participants felt (more) like they were in the same room. For example, participant $P6b$ said: “Ehh, I feel like you are just sitting there next to me somehow. Like we are in the same room." Furthermore, for example, participant $P2a$ said: "Well, it certainly felt more like the person was there than on the phone."

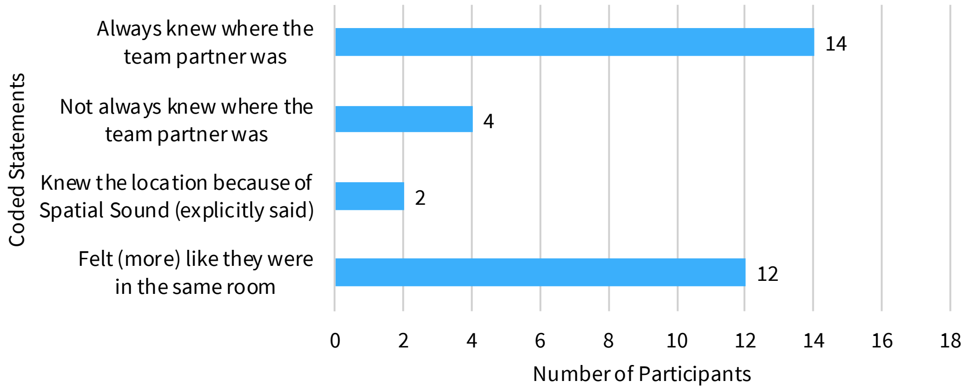

Figure 5.17.: The coded statements of the theme presence and how often each of them was mentioned.

Data Logging

Regarding the presence, the data logging was used to calculate the avatar viewing time of the participants (how long did the participants look at the avatar). For the calculation, the head gaze was used. Figure 5.18 shows the avatar viewing times compared to the task completion time. In the mean, participants looked 162.11 seconds at the avatar of the remote participant ($SD = 85.49$, 11% of task completion time). As a reminder, the mean value of the task completion time was 1456.78 seconds ($SD = 388.76$). Furthermore, the time both participants of a dyad looked at the avatar at the same time (participants looked at each other) was calculated. The participants, in the mean, looked at each other 4.22 seconds ($SD = 7.46$, 3% of the avatar viewing time).

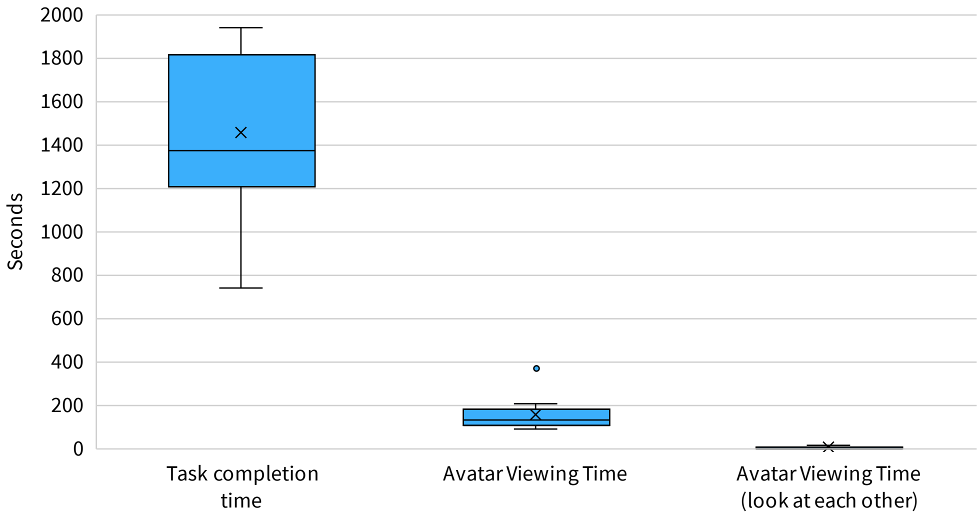

Figure 5.18.: The avatar viewing times (how long did the participants look at the avatar) and the task completion time are visualized as box-plot. Crosses indicate mean values, circles indicate outliers.

Summary

The spatial presence questions of the TPI, achieved, except for two questions, neutral or slightly positive results. Furthermore, the social presence questions were rated, except for two questions, positive. All items of the social richness item set achieved positive or at least above neutral results. The results of the data logging showed that the participants looked at the avatar, not for long. Furthermore, the participants looked at each other almost never.

5.5. Discussion

This section discusses the results regarding the previously defined research objectives of user experience and presence as well as the related questions. Furthermore, implications for the revision of the prototype and future studies are given.

5.5.1. RO1: User Experience

The prototype achieved an overall high user experience. According to the UEQ, the participants became very quickly familiar with the prototype (perspicuity) and were excited to use the system (stimulation). Furthermore, the system was rated as novel. However, this is probably the case because only 3 participants had made experiences with Augmented Reality before. Nevertheless, the attractiveness, efficiency, and dependability dimensions are all rated above average. The box plot of the UEQ results (see Figure 5.5) shows negative outliers in the three dimensions. The two negative outliers of the dimension attractiveness and all other outliers are attributable to the two participants that got headache during the study. Without these participants, the mean values of these dimensions would be higher. However, one-third of the participants mentioned, during the interview, that the device (Microsoft HoloLens) was uncomfortable. The results of the SSQ can also confirm this, where the symptom headache was the third-highest. Furthermore, the symptom "Fullness of head" reached the highest value. In the german version of the questionnaire, the symptom is translated with the german word "Kopfdruck" which literally translates "head pressure." Therefore it is possible that the participants have misunderstood the word with the physical pressure on the head. In this case, the SSQ would further confirm the statements of the participants that the device was uncomfortable. Therefore, for future studies, a more comfortable device should be used. Besides, the simulator sickness was, according to the SSQ, very low. The total score and the score of the dimensions were all low, and all symptoms achieved low mean values. Most symptoms achieved even mean values close to zero. Therefore, simulator sickness did probably not have a negative impact on user experience.

How does the avatar visualization influence the user experience?

Most of the participants mentioned that the avatar was not helpful. Half of all participants declared the task as one reason that the avatar was not helpful. The aim of the task was that participants have to agree, and therefore communicate. In this way, participants could not solve the task without their team partner. However, considering the overall screen time, and the screen time at the screen in the same Re-location, the participants spent most of the time just looking at their screen. This behavior is also reflected in the statements of some participants. For example, participant $P9a$ said: "I was just staring at the computer the whole time." So the task possibly resulted in the participants concentrating mainly on the screens and did not look at their team partner often. However, besides the task, over half of the participants mentioned, during the interview, missing gestures and facial expressions. Statements like "[...] include gestures, and facial expressions would make it even more realistic, and then I think it would work even better." ($P7a$), or "If he really moved the way the person moved, I think it would have been helpful." ($P2b$) suggests that the avatar could be helpful when these features are supported. This is also indicated by observations of the study conductors, where some participants tried to point at the screen and afterward, as a workaround, used the gaze ray or moved sticky notes. Therefore, the integration of gestures and facial expressions in the prototype could cause the avatar to be perceived as more helpful. Furthermore, in future studies, a task should be chosen that requires more spatial referencing or social dynamics (e.g., Affinity Diagramming) to study collaborative behaviors with higher ecological validity.

The visual appearance of the avatar was experienced as too abstract. Half of the participants desired a (more) realistic representation of the remote user. Some participants desired a customizable avatar. As examples, they mentioned avatar configurators from games. The integration of an avatar configurator could cause the avatar to be perceived as less abstract. However, also a more human 3D model could possibly improve the appearance because the current model has no face.

The gaze ray of the avatar was rated as helpful by two-thirds of the participants. However, some participants described the gaze ray as (sometimes) disturbing. For example, in situations where both participants sat at the computer screen, they saw the gaze of the team partner all the time. Therefore it may be better to deactivate the gaze ray when users are too close to each other or "inside" each other (i.e., both participants have the same position and orientation). An alternative could be to switch in these situations to another gaze visualization like a dot (similar to the gaze visualization of the Microsoft HoloLens).

How does the spatial sound influence the user experience?

Over half of the participants noticed the spatial sound feature during the study. Most of them perceived it positively. For example, participant $P1a$ said: "Well, it also seemed to me that I heard where she was talking from, and that was always very helpful. It was like: 'Okay, left ear behind me,' and then I can turn there." Statements like these indicate that the spatial sound was helpful. Furthermore, it could possibly be used as an off-screen technique to determine the position of the other person in the room. Therefore, the impact of spatial sound should be further investigated in future studies (e.g., as an auditive off-screen technique for objects and persons).

How does the alignment of interaction spaces influence the user experience?

Almost all participants did not notice that the room settings were different. For example, participant $P5a$ said: "Well, it looked to me like your room was shaped exactly like mine." So the intended illusion, that room settings are perceived equal, worked almost always. An exception was participant $P3a$, who noticed that the rooms must be different due to the speed at which the team partner changed the Re-location. However, the Re-locations were in both rooms close to each other. Futures studies could investigate how the distances between Re-locations influence the perception.

The results of the data logging showed that the participants were almost all the time inside Re-locations. Therefore, it can be suggested that the Re-location size was sufficient most of the time. An exception was participant $P4b$, who sometimes stepped back from the large touchscreen and then was slightly outside the Re-location (see Figure 5.12). However, the size of a Re-location could be dynamically adjusted at the task at hand (e.g., the user step back to overview).

Another finding was that over half of the participants did not notice that the team partner's avatar disappeared when leaving a Re-location. However, in the section about the influence of the avatar, it was already discussed that participants possibly did not look at the avatar often. Therefore, the suggested avatar improvements could lead to a higher awareness of disappearing avatars. However, this might not necessarily have a negative effect if it does not affect the subjective perception of presence. For example, during video conferences, users also understand that they are only remotely visible while in front of the camera.

5.5.2. RO2: Presence

According to the TPI questionnaire, the prototype achieved an overall high sense of social presence and social richness. Furthermore, two-thirds of the participants mentioned in the interview they felt (more) as they were in the same room, which also indicates a high social presence. The spatial presence questions of the TPI were rated rather neutral. The wide range of the answers and the neutral mean values suggests that the participants had a very different sense of spatial presence. However, during the interview, most participants answered that they always knew where the team partner was, which indicates a sense of spatial presence.

In the following sections, individual questions of the item sets are discussed. However, many questions of the questionnaire asked for visual and auditory components simultaneously (questions that contain "saw/heard"). Therefore, on many questions, it can not be differentiated if mainly the avatar or the spatial sound influenced the result.

How does the avatar visualization influence the subjective perception of presence?

The spatial presence question "How much did it seem as if you could reach out and touch the objects or people you saw/heard?" has a wide range of answers, which suggests that the participants were in disagreement. The low result of the question, "How often when an object seemed to be headed toward you did you want to move to get out of its way?" could indicate that the avatar possibly not provided a sense of spatial presence. The low avatar viewing time (calculated with the logged data) also suggests a low influence of the avatar on spatial presence.

One should note that these times were calculated with the head gaze, and therefore, the avatar must have been in the center of the field of view to be considered as seen. However, the low result of the question “How often did you want to or try to touch something you saw/heard?” should not be rated negatively. On the contrary, it could be interpreted positively because, during co-located collaboration, it would be a natural behavior not to touch other people.

Regarding the social presence, the participants had the sensation that people they saw or heard could also see or hear them. They also had the feeling they could interact with the person. Furthermore, they had the feeling they had much control over the interaction with people they saw or heard, which also indicates a high sense of social presence. That the participants did not make eye-contact with people they saw or heard, is very likely due to the fact that the avatar has no eyes.

How does the spatial sound influence the subjective perception of presence?

The spatial presence question, “To what extent did it seem that sounds came from specific, different locations?” was answered slightly positive with a high range of answers. This result is consistent with the result of the user experience section that over half of the participants noticed the spatial sound. Two participants mentioned explicitly that the spatial sound was the reason they knew where their team partner was. Furthermore, many participants felt (more) as they were in the same room but could not or had not articulated why. Therefore the spatial sound was possibly the reason for this feeling because, as mentioned in the last section, the influence of the avatar on spatial presence was probably rather low. That also suggests the result of the social presence question, “How often did it feel as if someone you saw/heard in the environment was talking directly to you?” which was answered very positively. Therefore, the impact of spatial sound on presence should be further investigated in future studies. One possibility would be a study with the spatial sound feature as an independent variable to have a clear comparison of whether or how spatial sound influenced the subjective perception of presence.

How does the alignment of interaction spaces influence the subjective perception of presence?

The intended illusion of the alignment of interaction spaces was that the participants had the feeling they work in the same room. The spatial presence question “How much did it seem as if the objects and people you saw/heard had come to the place you were?” was rated positively. Also, the social presence question, “How much did it seem as if you and the people you saw/heard were together in the same place?” was rated positively. The answers suggest that the alignment influenced the spatial and social presence positively. Furthermore, the question “How much did it seem as if you and the people you saw/heard both left the places where you were and went to a new place?” was rated negatively. The result further indicates that the intended illusion was achieved because it was not the aim that the participants had the feeling they went to a new place. However, in future studies, further alignments should be investigated.

5.6. Limitations

The conducted usability study has some limitations. A prerequisite for the study was that the participants already knew each other before. Therefore, the results can differ when participants work together with unknown people. Furthermore, mainly students have participated in the study. Besides, the task was artificial and performed under laboratory conditions. The results can vary when the participants perform a task with personal motivation as they would possibly do in real-world collaboration scenarios. Also, the type of task could have an impact, like, e.g., if it requires more or less spatial referencing or social dynamics. Another limitation is the room settings used. Different room settings were chosen to investigate the influence of the alignment. However, the Re-locations were in both rooms close to each other. So, larger distances between Re-locations could lead to different results. Also, other Re-location alignments and rotations could have an impact. Furthermore, the study was conducted with dyads and two Re-locations per room. The results could differ with more Re-locations and more participants. Also, the collaboration with a combination of co-located and remote participants should be investigated in the future.

6. Conclusion

Problems of remote collaboration using Augmented Reality are that the position of physical objects in the remote environments can differ and that the walkable spaces of remote rooms can differ. This thesis introduced a prototype called Re-located that facilitates synchronous remote collaboration in Augmented Reality independent of room architecture and furnishing. First, in a one-time room calibration process, the positions of screens in a room are calibrated. The purpose of every screen will be predefined in this process (e.g., whiteboard, computer screen, ...). Afterward, by wearing an Augmented Reality headset, remote users, and their movements, are visualized as 3D avatars in front of the screens with the same purpose. Furthermore, the prototype integrates a voice chat supporting spatial sound, so the users can hear the voice of remote users from the direction where the corresponding avatar is located in the local room. The areas in front of predefined screens are called Re-locations. The Re-locations concept was developed based on requirements that arose from related work. The influence of Re-located, and the underlying concept, on user experience and the subjective perception of presence, was investigated through a usability study. The results of the study were that the prototype provides overall high user experience and a high sense of social presence and social richness, while the sense of spatial presence was rated rather neutral. The visual appearance of the avatar was rated as too abstract. Furthermore, participants mentioned missing gestures and facial expressions. However, the spatial sound feature was noticed by over half of the participants and rated positively. Regarding the Re-locations, only one participant noticed that the room settings were different. Furthermore, over half of the participants not noticed that the team partner sometimes disappeared.

This work contributes to the area of remote collaboration using Augmented Reality in several ways. First, a novel concept called Re-locations was introduced that facilitates remote collaboration in Augmented Reality independent of room architecture and furnishing. The results of the study suggest that with the Re-locations concept, the participants had the feeling they work in the same room, although the room settings were different. Furthermore, the study has given insights into the perception of abstract avatars for remote collaboration using Augmented Reality. The results show which properties are desired from an avatar when used for remote collaboration. The gained insights can be used to improve the avatar. Finally, the study showed the potential of spatial sound for remote collaboration. It could possibly be used as an auditive off-screen technique to determine the position of the other person in the room and should be further considered.

Future work could investigate the influence of a less abstract avatar. Furthermore, with the use of next-generation hardware, like the Microsoft HoloLens 2, the support of hand gestures and eye gaze can be implemented. Moreover, a study with the spatial sound feature as an independent variable would give more in-depth insights into the influence of spatial sound. Further studies can investigate the influence of larger distances between Re-locations and other room alignments. Furthermore, the use of more Re-locations per room and with more remote participants, as well as the combination of co-located and remote participants using the prototype, can be investigated in the future.

While the avatar visualization can be further improved, the Re-located prototype already provides high user experience and a high sense of social presence and social richness. The Re-locations concept shows a promising way to solve the problems of different room settings during remote collaboration using Augmented Reality – potentially blurring the distinction between co-located and remote collaboration.

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A. Appendix

Declaration

Ich versichere hiermit, dass ich die anliegende Masterarbeit mit dem Thema:

Re-located: Aligning Interaction Spaces to Support Remote Collaboration using Augmented Reality

selbstständig verfasst und keine anderen Hilfsmittel und Quellen als die angegebenen benutzt habe.

Die Stellen die anderen Werken (einschließlich des Internets und anderer elektronischer Text- und Datensammlungen) dem Wortlaut oder dem Sinn nach entnommmen sind, habe ich in jedem einzelnen Fall durch Angabe der Quelle bzw. der Sekundärliteratur als Entlehnung kenntlich gemacht.

Weiterhin versichere ich hiermit, dass die o.g. Arbeit noch nicht anderweitig als Abschlussarbeit einer Bachelor- bzw. Masterprüfung eingereicht wurde. Mir ist ferner bekannt, dass ich bis zum Abschluss des Prüfungsverfahrens die Materialien verfügbar zu halten habe, welche die eigenständige Abfassung der Arbeit belegen können.

Darüber hinaus reiche ich die Arbeit zusätzlich auch in elektronischer Form, als Datei, bei den Dozenten ein.

Konstanz, den 17. März 2020

Daniel Fink

Study Documents

The following documents were used to conduct the study.

Welcome Letter

Herzlich willkommen!

Vielen Dank, dass Sie sich dazu bereit erklärt haben, an unserer Studie teilzunehmen. Sie unterstützen damit unsere Forschung maßgeblich! Bevor es losgeht, möchten wir Ihnen kurz vermitteln, um was es bei der Untersuchung geht und welche Rolle Sie dabei spielen.

Ziele und Ablauf der Studie

Im Rahmen der Studie untersuchen wir, inwiefern sich die verwendete Augmented Reality Anwendung für die computergestützte Zusammenarbeit eignet. Dazu werden Sie gemeinsam mit Ihrem Teampartner oder Ihrer Teampartnerin eine Aufgabe durchführen, während er oder sie sich in einem anderen Raum befindet. Mit Hilfe einer Augmented Reality Brille sehen Sie die andere Person als dreidimensionalen Avatar im Raum und können mit ihm oder ihr kommunizieren. Sie sind dabei nur für die andere Person sichtbar, wenn sie sich vor einem der beiden Bildschirme befinden.

Nach einer anfänglichen Übungsaufgabe, die dazu dient, sich an das System zu gewöhnen, erhalten Sie die eigentliche Aufgabe. Fragen zum generellen Ablauf oder zum System können Sie während der Übungsaufgabe stellen. Bitte haben Sie jedoch Verständnis dafür, dass wir während der eigentlichen Aufgabe keine Fragen beantworten können, um eine Verzerrung der Daten zu verhindern. Im Anschluss an die eigentliche Aufgabe bitten wir Sie, uns von Ihren Erfahrungen und Eindrücken zu berichten.

Um möglichst umfassende Erkenntnisse zu erhalten, zeichnen wir die Studie zusätzlich in Bild und Ton auf. Für diese Aufzeichnungen ist Ihr Einverständnis erforderlich. Im Gegenzug verpflichten wir uns dazu, das Material pseudonymisiert und lediglich zu Auswertungszwecken zu verwenden. In diesem Zusammenhang haben wir eine Einverständniserklärung vorbereitet, die diesem Schreiben beiliegt. An dieser Stelle möchten wir darauf hinweisen, dass wir nicht Sie oder Ihre Leistung bewerten, sondern ausschließlich an der Tauglichkeit der Anwendung interessiert sind.

Zeitrahmen und Entlohnung

Die Dauer der Studie beträgt insgesamt ca. 1 Stunde. Falls Sie sich zu irgendeinem Zeitpunkt unwohl fühlen und Ihre Teilnahme beenden möchten, ist das selbstverständlich auch ohne Angabe von Gründen möglich. Bitte wenden Sie sich dann an den Versuchsleiter.

Nach der Durchführung der Studie werden Sie für Ihre Hilfe mit 10 Euro entlohnt. Wir wünschen Ihnen jetzt gutes Gelingen und bedanken uns noch einmal recht herzlich für Ihre Unterstützung!

Daniel Fink

Arbeitsgruppe Mensch-Computer-Interaktion,
Fachbereich Informatik und Informationswissenschaft,
Universität Konstanz

Consent Form

Einverständniserklärung

ID: ______

Informationen zur Studienleitung

Studienleiter: Daniel Fink
Institution: Arbeitsgruppe Mensch-Computer Interaktion, Fachbereich Informatik und Informationswissenschaft, Universität Konstanz

Erklärung

Über das Ziel, den Inhalt und die Dauer der Studie wurde ich informiert. Im Rahmen dieser Studie werden in Fragebögen personenbezogene Daten erhoben. Zusätzlich wird die Studie auf Video aufgezeichnet, es werden Audioaufnahmen gemacht und Bewegungsdaten erfasst.

Hiermit bin ich darüber aufgeklärt, dass die personenbezogenen Daten vertraulich behandelt werden. Die Ergebnisse der Analyse der Video-, Audio- und Bewegungsdaten werden eventuell in späteren Publikationen pseudonymisiert veröffentlicht. Wir garantieren dabei absolute Diskretion. Es wird zu keinem Zeitpunkt Rückschluss auf Sie als Person möglich sein.

Optional *(Bei Zustimmung bitte ankreuzen)*

☐ Ich bin damit einverstanden, dass meine Video- und Bewegungsdaten zusätzlich zu internen Präsentationszwecken genutzt werden können.

Hiermit erkläre ich mich mit den unter „Erklärung“ genannten Punkten und den angekreuzten optionalen Punkten einverstanden:

	Konstanz,	
(Name)	(Ort, Datum)	(Unterschrift)

Hiermit verpflichtet sich die Studienleitung, die Video- und Audioaufzeichnung sowie sämtliche sonstigen gewonnenen Daten lediglich zu Auswertungszwecken im Rahmen dieser Untersuchung zu verwenden:

Daniel Fink	Konstanz,	
(Name)	(Ort, Datum)	(Unterschrift)

Demographic Questionnaire (Website)

ID: 1

Demografischer Fragebogen

Herzlichen Dank, dass Sie sich bereit erklärt haben an dieser Untersuchung teilzunehmen. Bevor wir anfangen, benötigen wir von Ihnen noch einige Angaben zu Ihrer Person. Wir möchten Ihnen hiermit noch einmal mitteilen, dass alle Daten vertraulich behandelt werden.

1. Alter

2. Geschlecht

○ männlich ○ weiblich ○ divers

3. Ihre momentane Tätigkeit/Studienrichtung

4. Kannten Sie ihren Teampartner/ihre Teampartnerin schon vor der Studie?

○ ja ○ nein

5. Haben Sie eine Sehschwäche?

○ Ja, korrigiert durch Brille ○ Ja, korrigiert durch Kontaktlinsen ○ nein

6. Haben Sie bereits Erfahrung mit „Augmented Reality“ (AR) Anwendungen?

○ ja ○ nein

7. Ich schätze mich in der Benutzung von „Augmented Reality“ (AR) Anwendungen ein als

unerfahren ○ ○ ○ ○ ○ sehr erfahren

8. Ich habe Erfahrung mit folgenden AR Anwendungen

9. Haben Sie bereits Erfahrung mit „Virtual Reality“ (VR) Anwendungen?

○ ja ○ nein

10. Ich schätze mich in der Benutzung von „Virtual Reality“ (VR) Anwendungen ein als

unerfahren ○ ○ ○ ○ ○ sehr erfahren

11. Ich habe Erfahrung mit folgenden VR Anwendungen

12. Haben Sie bereits Erfahrung mit Anwendungen, die die Zusammenarbeit mit Personen, die sich an einem anderen Ort befinden, ermöglichen? (z.B. Skype, Google Docs, ...)

○ ja ○ nein

13. Ich nutze diese Anwendungen

sehr selten ○ ○ ○ ○ ○ sehr häufig

14. Ich nutze folgende Anwendungen um mit einer Person an einem anderen Ort zusammenzuarbeiten

Senden

Task Description Sheet 1

Ihre Aufgabe

1

Im Folgenden werden Sie und Ihr Teampartner/Ihre Teampartnerin gemeinsam eine Aufgabe lösen. Hierfür haben Sie beide jeweils einen PC und ein digitales Whiteboard zur Verfügung.

Auf dem PC-Bildschirm sehen Sie eine Liste mit 36 Hotels und deren Eigenschaften. Die Liste kann nicht gefiltert oder durchsucht werden. Auf dem digitalen Whiteboard sehen Sie die gleichen Hotels, ohne deren Eigenschaften, als Haftzettel. Die Haftzettel können mit den Fingern verschoben werden. Wenn Sie einen Haftzettel verschieben dann wird er auch auf dem digitalen Whiteboard Ihres Teampartners/Ihrer Teampartnerin verschoben.

Aufgabe: Ihre Aufgabe ist es sich mit Ihrem Teampartner/Ihrer Teampartnerin auf ein Hotel zu einigen. Sie haben dabei persönliche Anforderungen an das Hotel die unten festgelegt sind. Versuchen Sie bei Ihren Anforderungen möglichst wenig Zugeständnisse zu machen. Das digitale Whiteboard sollte während der Aufgabe dazu genutzt werden die Hotels zu ordnen. Eine mögliche Strategie ist die Hotels, die weniger Anforderungen erfüllen eher nach links zu schieben und die die mehr Anforderungen erfüllen eher nach rechts. Ihr könnt aber auch eine andere Strategie wählen. Wenn Sie und Ihr Teampartner/Ihre Teampartnerin der Meinung sind sie haben von allen zur Verfügung stehenden Hotels das passendste gefunden, wenden Sie sich bitte an den Versuchsleiter. Sie dürfen sich während der Aufgabe beliebig im Raum bewegen, also auch jederzeit zwischen PC-Bildschirm und digitalem Whiteboard hin- und herwechseln. Bitte verwenden Sie keine Funktionen des Betriebssystems oder Browsers (zum Beispiel die Suchfunktion).

Ihre Anforderungen an das Hotel:

- Es darf **maximal 150€** kosten.
- Sie baden gerne. Deswegen sollte der **Strand höchstens 5km entfernt** sein.
- Ihnen ist ein kleines Hotel wichtig. Das Hotel sollte **maximal 50 Zimmer** haben.
- Ein **Restaurant mit regionalem Essen** sollte vorhanden sein.

Task Description Sheet 2

Ihre Aufgabe

2

Im Folgenden werden Sie und Ihr Teampartner/Ihre Teampartnerin gemeinsam eine Aufgabe lösen. Hierfür haben Sie beide jeweils einen PC und ein digitales Whiteboard zur Verfügung.

Auf dem PC-Bildschirm sehen Sie eine Liste mit 36 Hotels und deren Eigenschaften. Die Liste kann nicht gefiltert oder durchsucht werden. Auf dem digitalen Whiteboard sehen Sie die gleichen Hotels, ohne deren Eigenschaften, als Haftzettel. Die Haftzettel können mit den Fingern verschoben werden. Wenn Sie einen Haftzettel verschieben dann wird er auch auf dem digitalen Whiteboard Ihres Teampartners/Ihrer Teampartnerin verschoben.

Aufgabe: Ihre Aufgabe ist es sich mit Ihrem Teampartner/Ihrer Teampartnerin auf ein Hotel zu einigen. Sie haben dabei persönliche Anforderungen an das Hotel die unten festgelegt sind. Versuchen Sie bei Ihren Anforderungen möglichst wenig Zugeständnisse zu machen. Das digitale Whiteboard sollte während der Aufgabe dazu genutzt werden die Hotels zu ordnen. Eine mögliche Strategie ist die Hotels, die weniger Anforderungen erfüllen eher nach links zu schieben und die die mehr Anforderungen erfüllen eher nach rechts. Ihr könnt aber auch eine andere Strategie wählen. Wenn Sie und Ihr Teampartner/Ihre Teampartnerin der Meinung sind sie haben von allen zur Verfügung stehenden Hotels das passendste gefunden, wenden Sie sich bitte an den Versuchsleiter. Sie dürfen sich während der Aufgabe beliebig im Raum bewegen, also auch jederzeit zwischen PC-Bildschirm und digitalem Whiteboard hin- und herwechseln. Bitte verwenden Sie keine Funktionen des Betriebssystems oder Browsers (zum Beispiel die Suchfunktion).

Ihre Anforderungen an das Hotel:

- Es sollte **mindestens 4 Sterne** haben.
- Sie baden gerne. Deswegen sollte das Hotel über ein **Pool** verfügen.
- Es sollte **maximal 2km vom Zentrum** entfernt sein.
- Ein **Restaurant mit regionalem Essen** sollte vorhanden sein.

Simulator Sickness Questionnaire (SSQ) (Website)

ID: 1

Bitte kreuzen Sie an wie sehr die folgenden Symptome Sie jetzt gerade betreffen.

1. Allgemeines Unwohlsein

○ gar nicht ○ leicht ○ mäßig ○ stark

2. Müdigkeit

○ gar nicht ○ leicht ○ mäßig ○ stark

3. Kopfschmerzen

○ gar nicht ○ leicht ○ mäßig ○ stark

4. Überanstrengung der Augen

○ gar nicht ○ leicht ○ mäßig ○ stark

5. Probleme scharf zu sehen

○ gar nicht ○ leicht ○ mäßig ○ stark

6. Erhöhter Speichelfluss

○ gar nicht ○ leicht ○ mäßig ○ stark

7. Schwitzen

○ gar nicht ○ leicht ○ mäßig ○ stark

8. Übelkeit

○ gar nicht ○ leicht ○ mäßig ○ stark

9. Konzentrationsschwierigkeiten

○ gar nicht ○ leicht ○ mäßig ○ stark

10. Kopfdruck

○ gar nicht ○ leicht ○ mäßig ○ stark

11. Verschwommenes Sehen

○ gar nicht ○ leicht ○ mäßig ○ stark

12. Schwindel (Augen auf)

○ gar nicht ○ leicht ○ mäßig ○ stark

13. Schwindel (Augen zu)

○ gar nicht ○ leicht ○ mäßig ○ stark

14. Gleichgewichtstörung

○ gar nicht ○ leicht ○ mäßig ○ stark

15. Magen macht sich bemerkbar

○ gar nicht ○ leicht ○ mäßig ○ stark

16. Aufstoßen

○ gar nicht ○ leicht ○ mäßig ○ stark

Senden

User Experience Questionnaire (UEQ) (Website)

ID: 1

Bitte geben Sie Ihre Beurteilung ab.

Bitte beurteilen Sie nicht die Anwendungen auf den Bildschirmen sondern nur die Augmented Reality Anwendung die es ermöglichte, dass Sie die andere Person sehen und hören konnten.

Um das Produkt zu bewerten, füllen Sie bitte den nachfolgenden Fragebogen aus. Er besteht aus Gegensatzpaaren von Eigenschaften, die das Produkt haben kann. Abstufungen zwischen den Gegensätzen sind durch Kreise dargestellt. Durch Anklicken eines dieser Kreise können Sie Ihre Zustimmung zu einem Begriff äußern.

attraktiv ○ ◉ ○ ○ ○ ○ ○ unattraktiv

Mit dieser Beurteilung sagen Sie aus, dass Sie das Produkt eher attraktiv als unattraktiv einschätzen.

Entscheiden Sie möglichst spontan. Es ist wichtig, dass Sie nicht lange über die Begriffe nachdenken, damit Ihre unmittelbare Einschätzung zum Tragen kommt.

Bitte kreuzen Sie immer eine Antwort an, auch wenn Sie bei der Einschätzung zu einem Begriffspaar unsicher sind oder finden, dass es nicht so gut zum Produkt passt.

Es gibt keine „richtige“ oder „falsche“ Antwort. Ihre persönliche Meinung zählt!

Bitte geben Sie nun Ihre Einschätzung des Produkts ab.

unerfreulich	○	○	○	○	○	○	○	erfreulich
unverständlich	○	○	○	○	○	○	○	verständlich
kreativ	○	○	○	○	○	○	○	phantasielos
leicht zu lernen	○	○	○	○	○	○	○	schwer zu lernen
wertvoll	○	○	○	○	○	○	○	minderwertig
langweilig	○	○	○	○	○	○	○	spannend
uninteressant	○	○	○	○	○	○	○	interessant
unberechenbar	○	○	○	○	○	○	○	voraussagbar
schnell	○	○	○	○	○	○	○	langsam
originell	○	○	○	○	○	○	○	konventionell
behindernd	○	○	○	○	○	○	○	unterstützend
gut	○	○	○	○	○	○	○	schlecht
kompliziert	○	○	○	○	○	○	○	einfach
abstoßend	○	○	○	○	○	○	○	anziehend
herkömmlich	○	○	○	○	○	○	○	neuartig
unangenehm	○	○	○	○	○	○	○	angenehm

sicher	○	○	○	○	○	○	○	unsicher
aktivierend	○	○	○	○	○	○	○	einschläfernd
erwartungskonform	○	○	○	○	○	○	○	nicht erwartungskonform
ineffizient	○	○	○	○	○	○	○	effizient
übersichtlich	○	○	○	○	○	○	○	verwirrend
unpragmatisch	○	○	○	○	○	○	○	pragmatisch
aufgeräumt	○	○	○	○	○	○	○	überladen
attraktiv	○	○	○	○	○	○	○	unattraktiv
sympathisch	○	○	○	○	○	○	○	unsympathisch
konservativ	○	○	○	○	○	○	○	innovativ

Senden

Temple Presence Inventory (TPI) (Website)

ID: 1

Media Questionnaire

Thank you very much for agreeing to complete this questionnaire.

The questions on these pages ask about the media experience you just had. This may have been watching television, watching an IMAX or Omniverse film, or using a virtual reality (VR) system.

There are no right or wrong answers

Throughout the questions, the phrases "the environment you saw/heard" and "objects, events, or people you saw/heard" refer to the things or people that were presented in the media experience, not your immediate physical surroundings (i.e., the actual room you were in during the media experience).

Please click on the circles that best represent your answers. All of your responses will be kept strictly confidential.

1. How much did it seem as if the objects and people you saw/heard had come to the place you were?

   Not at all ○ ○ ○ ○ ○ ○ ○ Very much

2. How much did it seem as if you could reach out and touch the objects or people you saw/heard?

   Not at all ○ ○ ○ ○ ○ ○ ○ Very much

3. How often when an object seemed to be headed toward you did you want to move to get out of its way?

   Never ○ ○ ○ ○ ○ ○ ○ Always

4. To what extent did you experience a sense of 'being there' inside the environment you saw/heard?

   Not at all ○ ○ ○ ○ ○ ○ ○ Very much

5. To what extent did it seem that sounds came from specific, different locations?

   Not at all ○ ○ ○ ○ ○ ○ ○ Very much

6. How often did you want to or try to touch something you saw/heard?

   Never ○ ○ ○ ○ ○ ○ ○ Always

7. Did the experience seem more like looking at the events/people on a movie screen or more like looking at the events/people through a window?

   Like a movie screen ○ ○ ○ ○ ○ ○ ○ Like a window

8. How often did you have the sensation that people you saw/heard could also see/hear you?

   Never ○ ○ ○ ○ ○ ○ ○ Always

9. To what extent did you feel you could interact with the person or people you saw/heard?

   None ○ ○ ○ ○ ○ ○ ○ Very much

10. How much did it seem as if you and the people you saw/heard both left the places where you were and went to a new place?

Not at all ○ ○ ○ ○ ○ ○ ○ Very much

11. How much did it seem as if you and the people you saw/heard were together in the same place?

Not at all ○ ○ ○ ○ ○ ○ ○ Very much

12. How often did it feel as if someone you saw/heard in the environment was talking directly to you?

Never ○ ○ ○ ○ ○ ○ ○ Always

13. How often did you want to or did you make eye-contact with someone you saw/heard?

Never ○ ○ ○ ○ ○ ○ ○ Always

14. Seeing and hearing a person through a medium constitutes an interaction with him or her. How much control over the interaction with the person or people you saw/heard did you feel that you had?

None ○ ○ ○ ○ ○ ○ ○ Very much

15. For each of the pairs of words below, please click on the circle that best describes your evaluation of the media experience.

Impersonal ○ ○ ○ ○ ○ ○ ○ Personal

Unsociable ○ ○ ○ ○ ○ ○ ○ Sociable

Insensitive ○ ○ ○ ○ ○ ○ ○ Sensitive

Dead ○ ○ ○ ○ ○ ○ ○ Lively

Unresponsive ○ ○ ○ ○ ○ ○ ○ Responsive

Unemotional ○ ○ ○ ○ ○ ○ ○ Emotional

Remote ○ ○ ○ ○ ○ ○ ○ Immediate

Senden

Semi-structured Interview Sheet

Semi-Structured Interview

IDs: __/__

Die nachfolgenden Fragen beziehen sich nur auf die Darstellung und Kommunikation mit der anderen Person und ist unabhängig von den Anwendungen auf den Bildschirmen!

Allgemein:

Was ist euer erster Eindruck des Systems?

Worin seht ihr die Stärken des Systems?

Worin seht ihr die Schwächen des Systems?

Wenn ihr das System mit herkömmlicher Gruppenarbeit vergleicht wo sind die Stärken und Schwächen des Systems?

1

Spaces:

War euch jederzeit klar wo sich euer/eure Teampartner*in befindet? Warum?

War euch klar, dass die Person nur in dem Bereich vor dem Bildschirm sichtbar war? Wenn ja: warum?

Ist es positiv/negativ aufgefallen, dass die andere Person nicht jederzeit sichtbar war? (z.B. beim Verlassen des Bereichs vor dem Bildschirm)

Ist euch während der Aufgabe aufgefallen, dass sich die Bildschirme in dem anderen Raum an einer anderen Stelle befinden? Warum?

2

Avatar:

Fandet ihr es hilfreich, dass die andere Person als Avatar dargestellt wurde? Warum?

Ist euch etwas an dem Avatar positiv/negativ aufgefallen?

Fandet ihr es hilfreich, dass man sieht wo die andere Person hinschaut? (grüner Strahl)

Wie könnte man den Avatar verbessern?

3

Sound:

Wie fandet ihr die Sprachübertragung?

Ist euch etwas bei der Sprachübertragung positiv/negativ aufgefallen?

Wie könnte man die Sprachübertragung verbessern?

4

Compensation Sheets

Ich habe bei der Studie „Urlaub Studie (AR)“ teilgenommen und eine Kompensation in Höhe von 10 Euro erhalten:

___________ ___________________ _____________________________________

Datum Name Unterschrift

Ich habe bei der Studie „Urlaub Studie (AR)“ teilgenommen und eine Kompensation in Höhe von 10 Euro erhalten:

___________ ___________________ _____________________________________

Datum Name Unterschrift

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