# Remote Proxemics

Maurício Sousa, Daniel Mendes, Daniel Medeiros
Alfredo Ferreira, João Madeiras Pereira and Joaquim Jorge

**Abstract** Virtual meetings have become increasingly common with modern video-conference and collaborative software. While they allow obvious savings in time and resources, current technologies add unproductive layers of protocol to the flow of communication between participants, rendering the interactions far from seamless. In this work we describe in detail Remote Proxemics, an extension of proxemics aimed at bringing the syntax of co-located proximal interactions to virtual meetings. We also describe the role of Eery Space as a shared virtual locus that results from merging multiple remote areas, where meeting participants' are located side-by-side as if they shared the same physical location. Thus rendering Remote Proxemics possible. Results from user evaluation on the proposed presence awareness techniques suggest that our approach is effective at enhancing mutual awareness between participants and sufficient to initiate proximal exchanges regardless of their geolocation, while promoting smooth interactions between local and remote people alike.

**Key words:** Augmented Reality; Virtual Meetings; Presence; Collaboration

## 1 Introduction

When people get together to discuss, they communicate in several manners, besides verbally. Hall [14] observed that space and distance between people (proxemics)

Maurício Sousa (✉), e-mail: `antonio.sousa@ist.utl.pt`
Daniel Mendes, e-mail: `danielmendes@ist.utl.pt`
Daniel Medeiros, e-mail: `daniel.medeiros@tecnico.ulisboa.pt`
Alfredo Ferreira, e-mail: `alfredo.ferreira@ist.utl.pt`
João Madeiras Pereira, e-mail: `jap@inesc-id.pt`
Joaquim Jorge, e-mail: `jaj@inesc-id.pt`
INESC-ID/Tcnico Lisboa/University of Lisbon

impact interpersonal communication. While this has been explored to leverage collaborative digital content creation [22], nowadays it is increasingly common for work teams to be geographically separated around the globe. Tight travel budgets and constrained schedules require team members to rely on virtual meetings. These conveniently bring together people from multiple and different locations. Indeed, through appropriate technology, it is possible to see others as well as to hear them, making it easier to communicate verbally and even non-verbally at a distance.

The newest videoconferencing and telepresence solutions support both common desktop environments and the latest mobile technologies, such as smartphones and tablet devices. However, despite considerable technological advances, remote users in such environments often feel neglected due to their limited presence [24]. Moreover, although verbal and visual communication occur naturally in virtual meetings, other modes of engagement, namely proximal interactions, have yet to be explored. This is unfortunate, since proxemics can enable many natural interactions obviating the need for cumbersome technology-induced protocol, which is a plague of remote meetings.

In this work, we deepen the concept of *Eery Space*, introduced in Sousa et al. [30], as a virtual construct to bring remote people together and mediate natural proxemic interactions between everyone as if they were in the same physical place, a mechanism which we call *Remote Proxemics*. To this end, Eery Space allow us to merge different rooms into one virtual shared locus where people can meet, share resources and engage in collaborative tasks. Building on the notion that people do not need hyper-realistic awareness devices, such as virtual avatars, to infer the presence of others and engage in natural social behaviour, Eery Space employs an iconic representation for remote people. Also, to facilitate virtual meetings, we propose novel techniques for person-to-person and person-to-device interactions. We adopt a multiple interactive surfaces environment, which comprises an ecosystem of handheld devices, wall-sized displays and projected floors.

In the remainder of the document, we start by reviewing the related work that motivated our research, describe the Eery Space fundamentals, report the evaluations required to arrived at our proposed awareness techniques and detail our prototype implementation. Also we present both results and findings from our evaluation steps and, finally, we draw the most significant conclusions and point out future research directions.

## 2 Background

Our work builds on related research involving virtual meetings and proxemics applied to ubiquitous computing (ubicomp) environments. In virtual meetings, technology plays a decisive role in providing the necessary means for people to communicate and collaborate while not sharing the same space. Wolff et al. [34] argued that systems that enable virtual meetings can be categorised into *audioconferencing*, *groupware*, *videoconferencing*, *telepresence* and *collaborative mixed reality* *systems*. Regarding videoconferencing and telepresence, there is research addressing the interpersonal space of the people involved in virtual meetings, by providing a broadcast of a single person to the group. Buxton et al. [8] proposed a system where remote people were represented by individual video and audio terminals, called *HIDRA*. Morikawa et al. [23] followed the concept of the shared space and introduced *HyperMirror*, a system that displays local and remote people on the same screen. Although this approach enables communications, its focus on the interpersonal space renders the user experience not appropriate to jointly create content. People need to meet in a shared space to perform collaborative work [7]. Thereby, Buxton [6] argued that virtual shared workspaces, enabled by technology, are required to establish a proper sense of shared presence, or telepresence.

Using a shared virtual workspace, people can meet and share the same resources, allowing for collaboration and creation of shared content. Following this concept, Tanner et al. [31] proposed a side-by-side approach that exploits multiple screens. One was used for content creation and another to display a side view of the remote user. Side-by-side interactions allow people to communicate and transfer their focus naturally between watching and interacting with others and the collaborative work [31]. In addition, efforts to integrate the interpersonal space with the shared workspace, resulted in improved work flow, enabling seamless integration of live communication with joint collaboration. Ishii et al. [16] introduced *Clearboard*, a videoconferencing electronic board that connects remote rooms to support informal face-to-face communication, while allowing users to draw on a shared virtual surface. Differently, Kunz et al. [20], with *CollaBoard*, employed a life-sized video representation of remote participants on top of the shared workspace.

Shared immersive virtual environments [25] provide a different experience from “talking heads” in that people can explore a panoramic vision of the remote location. In the Office of the future, a vision proposed by Raskar et al. [25], participants in a virtual meeting can collaboratively manipulate 3D objects while seeing each other as if they were in the same place, by projecting video on the walls of each room, thereby virtually joining all remote places into one shared workspace. Following similar principles, Benko et al. [5] introduced *MirageTable*, a system that brings people together as if they were working in the same physical space. By projecting a 3D mesh of the remote user, captured by depth cameras, onto a table curved upwards, a local person can interact with the virtual representation of a remote user to perform collaborative tasks.

Beck et al. [4] presented an immersive telepresence system that allows distributed groups of users to meet in a shared virtual 3D world. Participants are able to meet front-to-front and explore a large 3D model. Following a different metaphor, Cohen et al. [9] described a video-conferencing setup with a shared visual scene to promote co-operative play with children. The authors showed that the mirror metaphor can improve the sense of proximity between users, making it possible for participants to interact with each other using their personal space to mediate interactions similarly to everyday situations.

The theory of Proxemics describes what interpersonal relationships are mediated by distance [14]. Furthermore, people adjust their spatial relationships with other accordingly to the activity they are engaged on, be it simple conversation or collaborative tasks. Greenberg et al. [11] argued that proxemics can help mediate interactions in ubicomp environments. Furthermore, they proposed that natural social behaviour carried out by people can be transposed to ubicomp environments to deal with interactions between people and devices, and even, by devices talking to each other.

When ubicomp systems are able to measure and track interpersonal distances, digital devices can mediate interactions according to the theory of Proxemics. Effectively, Kortuem et al. [19] demonstrated how mobile devices can establish a peer-to-peer connection and support interactions between them by measuring their spatial relationship. Proximity can also be used to exchange information between co-located devices either automatically or by using gestures [15]. This is illustrated by the GroupTogether system, where Marquardt et al. [22] explored the combination of proxemics with devices to support co-located interactions.

Vogel and Balakrishnan [32] developed design principles for interactive public displays to support the transition from implicit to explicit interaction with both public and personal information. By segmenting the space in front of the display, its content can change from public to private for distinct users or the same user at distinct occasions, and different interactions become available. Similarly, Ju et al. [17] applied implicit interactions using proxemic distances to augmented multi-user smartboards, where users in close personal proximity can interact using a stylus, while users at a distance are presented with ambient content. More recently, Marquardt et al. [21] addressed connecting and transferring information between personal and shared digital surfaces using interactions driven by proxemics. In this environment, digital devices are aware of the user's situation and adapt by reacting to different interactions according to context. Ballendat et al. [2] introduced a home media player that exploits the proxemic knowledge of nearby people and digital devices, including their position, identity, movement and orientation, to mediate interactions and trigger actions.

Based on social space considerations, Edward Hall [14] encapsulated everyday interactions in a social model that can inform the design of ubiquitous computing systems to infer people's actions and their desire to engage in communication and collaboration. Indeed, recent research uses proxemics theory, not only to infer the intentions when people want to start interacting with others, but also to mediate interactions with physical digital objects [22, 27, 17]. Despite the advances in both ubicomp and cooperative work, no attempts to extend proximity-aware interactions to remote people in virtual meeting environments, have been made so far. We strongly believe that remote collaborative environments have much to gain by applying proxemics to mediate interactions between remote people. By transposing the way people work in a co-located settings to telepresence environments, the constraints imposed by current technologies for computer supported collaborative work can be alleviated and the sense of presence by remote participants enhanced.

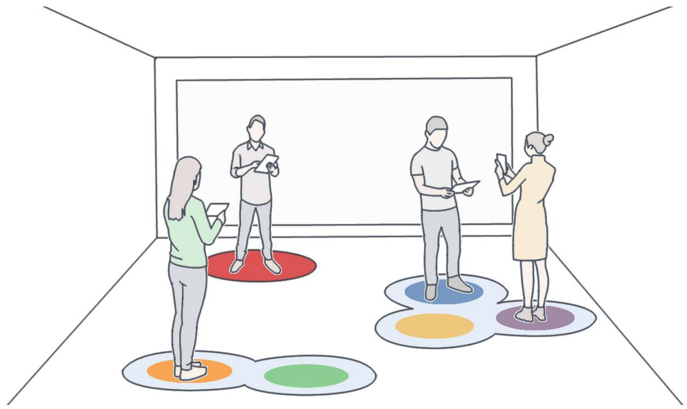

**Fig. 1** Eery Space.

## 3 Joining People Together

Our work focuses on mediating collaborative work in virtual meetings between geographically dispersed people, in order to tackle the issue of the remote people's lack of physical presence. By doing that we can say that proxemic interactions may improve people engagement on virtual meetings. The proposed solution succeeds at bringing geographically distant people together at the same space, and provides the necessary devices and feedback for participants in the virtual meeting to be able to proximally interact with each other at the distance. Therefore, we propose a solution that exploits Remote Proxemics and allows local people to improve the level of awareness of the remote participants' presence.

By bringing proxemic interactions to a remote setting, local and remote participants in virtual meetings can naturally relate to the presence of one another and engage in collaborative tasks as if they were co-located. Providing that they are aware of one another's situation and actions (Awareness). Subsequently, we present presence awareness techniques to render Remote Proxemics possible.

### *3.1 Eery Space*

We propose an approach to bring geographically distant people together into a common space. We call the ability to provide feedback on virtual meetings participants' devices for proximal interaction, Eery Space. Given that people are distributed across similar rooms in different locations, it attempts to consolidate these in a common virtual locus, while providing new opportunities for interaction and communication between participants. In this way, people equipped with personal handheld devices can meet, collaborate and share resources regardless of where they are.

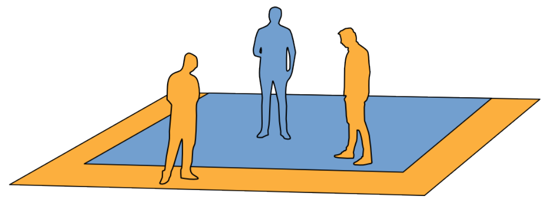

**Fig. 2** Eery Space, merging two different sized rooms into the same virtual space. The different colours match people to their corresponding physical room.

Instead of placing users in front of each other, as it is typical of commercial applications and other research works [4, 5], we place both remote and local people side-by-side, similarly to Cohen et al. [9]. Unlike the common interactions with remote people using the mirror metaphor, Eery Space provides remote participants with a sense of being around local ones in a shared space. This creates and reinforces the model of a shared meeting area where proxemic interactions can take place. Moreover, each person has a definite position and a personal space within Eery Space, as depicted in Figure 1. Allowing both local and remote people to collaborate by relating to their personal spaces strengthens the notion that everyone is treated similarly as if they were all physically local.

Furthermore, Eery Space makes it possible to accommodate differently-sized rooms. Its overall size and shape reflect the dimensions of the meeting rooms in use, as depicted in Figure 2. Eery Space's goal is to create an area that preserves the dimensions and proportions of the people's position and motion, thus avoiding unrealistic scaled movements by the meeting participants. Nevertheless, when a room is substantially smaller than the other, people can be located out of reach. This requires additional techniques to gather their attention in order to collaborate, which is described later.

### *3.2 Social Bubbles*

Hall's [14] model for proxemic distances dictates that when people are close to each other they can interact in specific ways. Within a proxemic social space, people do interact in a formal way, typical of a professional relationship. In contrast, the personal space is reserved for family and friends and people can communicate quietly and comfortably. Yet, as described by Hall [14], these distances are dynamic. Friendship, social custom and professional acquaintanceship decreases interpersonal distances [28]. We adapted these concepts to Eery Space, using a device we call *Social bubbles*.

Inside Eery Space, interactions are initiated by analysing the distribution of people within the shared virtual space. People having a closed conversation or involved in the same task usually get closer, and, therefore, we create social bubbles resorting to distance. People naturally create a bubble, by coming sufficiently close, and

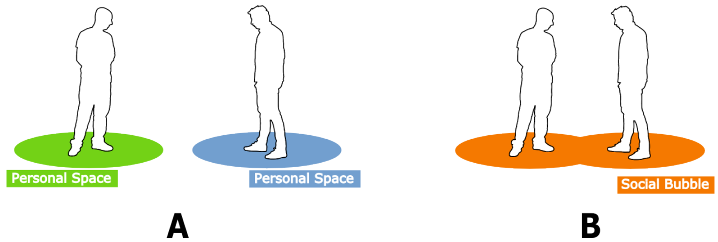


**Fig. 3** Social Bubbles: (A) While distant from one another, (B) A social bubble is formed when people's personal spaces intersect.

the destruction of bubbles is analogous to its creation - social bubbles cease to exist when participants move apart.

The intention of the people to perform a collaborative task is implicitly detected when they create a social bubble around them. Since we are in a working environment, people do not need to enter the personal space of each other, because they can be neither family nor friends. Instead, a social bubble is created through the intersection of the personal spaces, as depicted in Figure 3. This formulation of social bubbles' model allows people motivated by the collaborative work to easily create proximal interactions using a distance well inside their social space, without needing to violate each others' personal space. In our work, we considered the personal space to be a circle with a 0.6 meters radius, thus two people should be at maximum distance of 1.2 meters to create a social bubble.

To summarise, we define the concept of social bubbles as the virtual space that results from the intersection of the personal space of two or more people, where people can meet, share resources and engage in closed conversation.

### *3.3 Remote Proxemics*

Remote Proxemics captures the natural interactions between co-located people and makes them available to all meeting's participants, even when not physically present.

Thus, all interactions, within Eery Space, have the ability to work similarly for local and remote people. The success of our approach is to ensure that the local and remote people are always present and side by side so participants can create social bubbles in the same way, regardless of their physical presence in the same room. These social bubbles can encompass two or more users, either local or remote. When located in the same bubble, users can engage in collaborative activities.

Since Eery Space implements an environment with multiple people and devices, we have grouped these interactions into two groups: person-to-person, for interactions involving people and their own handheld devices; and person-to-device, for interactions between people and shared devices, such as wall displays or tabletops.

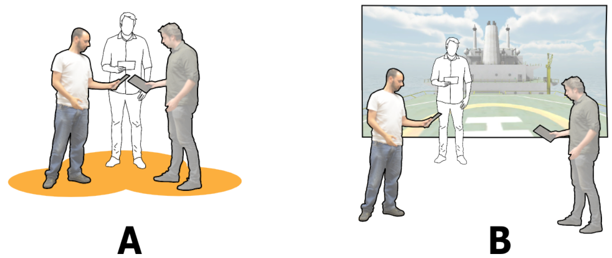


**Fig. 4** Remote Proxemics: (A) Two local people and one remote (white) compose a social bubble and are engaged in collaborative work. (B) The remote participant, closest to the wall display, acts as the moderator, controlling what it is shown in he shared visualization.

#### 3.3.1 Person-to-person Interactions

When people come together and create a social bubble, a set of tools are made available to support collaborative tasks in the form of person-to-person interactions. These interactions not only include the participants but also their personal handheld devices, as depicted in Figure 4(A). Since verbal communication is a key element for the success of virtual meetings, participants can talk and hear the other people in their bubble. When people establish a social bubble, their handheld devices automatically open a channel of communication between local and remote participants. This channel of communication is then closed immediately when the bubble is destroyed. Similarly and simultaneously, in case of existing a shared visualization device, such as a wall display, the handheld devices of participants in the same social bubble can be synchronised with the common visualisation. At this stage, participants can engage in a collaborative session around said visualization, either discussing or collaboratively creating content.

#### 3.3.2 Person-to-Device Interactions

The Eery Space may feature shared devices, that are well suited for shared visualization and collaborative settings, such as wall displays or tabletops. In our work, we explored more specifically the latter kind, as shown in Figure 4(B). Due to their large dimensions, such displays have the characteristic of providing a visualisation surface capable of serving multiple people at the same time. Also, they do not restrict people to a single position. Users of wall displays can freely move alongside the surface to better reach the displayed information, move forward to glimpse more details or move further back to get a general view. This kind of displays serve the purpose of relaying the information under analysis to all meeting's participants. Naturally, these shared devices must be located at the same position across all remote areas that make up the Eery Space, while displaying the same to ensure a consistent source the information to all.

When a participant establishes a proximity relationship with the display, he/she acquires the role of moderator. In Eery Space, the moderator has a special authority that allows him/her to take control of the common visualisation on all shared displays, local or remote, by mirroring actions made on the handheld device. This authority is granted to whom gets closest to the display, inside the moderator space. We define the moderator space as the area contained up to a distance of 1.5 meters away from the wall display, analogously to the place normally occupied by a person giving a talk to an audience. Furthermore, the role of moderator can only be handed over when the current person assuming this role abandons the moderator space, leaving it vacant for the next person to take over. Also, when a meeting participant becomes the moderator, a channel for speech communication is opened so that they can address all meeting's attendees. Moderator's speech is relayed through his/her handheld device to participants that are remote in relation to him/her, since local participants already can hear him. The current moderator relinquishes his role when leaving the moderator space. If this happens and another person is standing in that space, then they become the new moderator. Otherwise, the moderator role will be open for anyone to take.

## 4 Tech Overview

Our solution aims to join various rooms in a single virtual space, therefore each component of the environment needs to be aware of its physical location. The prototype is comprised of an ecosystem of multiple running modules communicating to each other using local networks and the Internet and a user tracker to determine the location of all participants. Since Eery Space thrives in merging together multiple physical rooms into one unique virtual space, there must be a similar setup in each physical room. We built our prototype using a multiple Microsoft Kinect-based user tracker, which is able to track six users in a room, dealing with occlusions and resolving each users' position. We used Unity3D to develop a distributed system for multi-peer 3D virtual environment exploration, with support for display-walls, tablets and smartphone clients (iOS and Android). In general, there is a software client for each device in Eery Space and follows the client-server network model for communication and synchronization. Each client has its own version of the data model, a representation of what happens in Eery Space, which is synchronized using messages that pass through the root server. The communication between the various components of the architecture and the server is made by invoking *Remote Procedure Calls* (RPC) over UDP, as depicted in Figure 5. Therefore, our prototype is distributed system responsible for the virtual meeting and manage participants, flow of communication and individual devices present in this environment.

For the purpose of this work, we developed a Graphical User Interface (GUI) approach to bind people with their handheld devices. This approach consists in displaying a map with the position of currently tracked people in the selected room, highlighting ones without association. Thereby, when entering the Eery Space, participants are required to select their representative icon on the handheld device screen before initiating any interactions. Also, we consider the position of an handheld device the same as the person holding it.

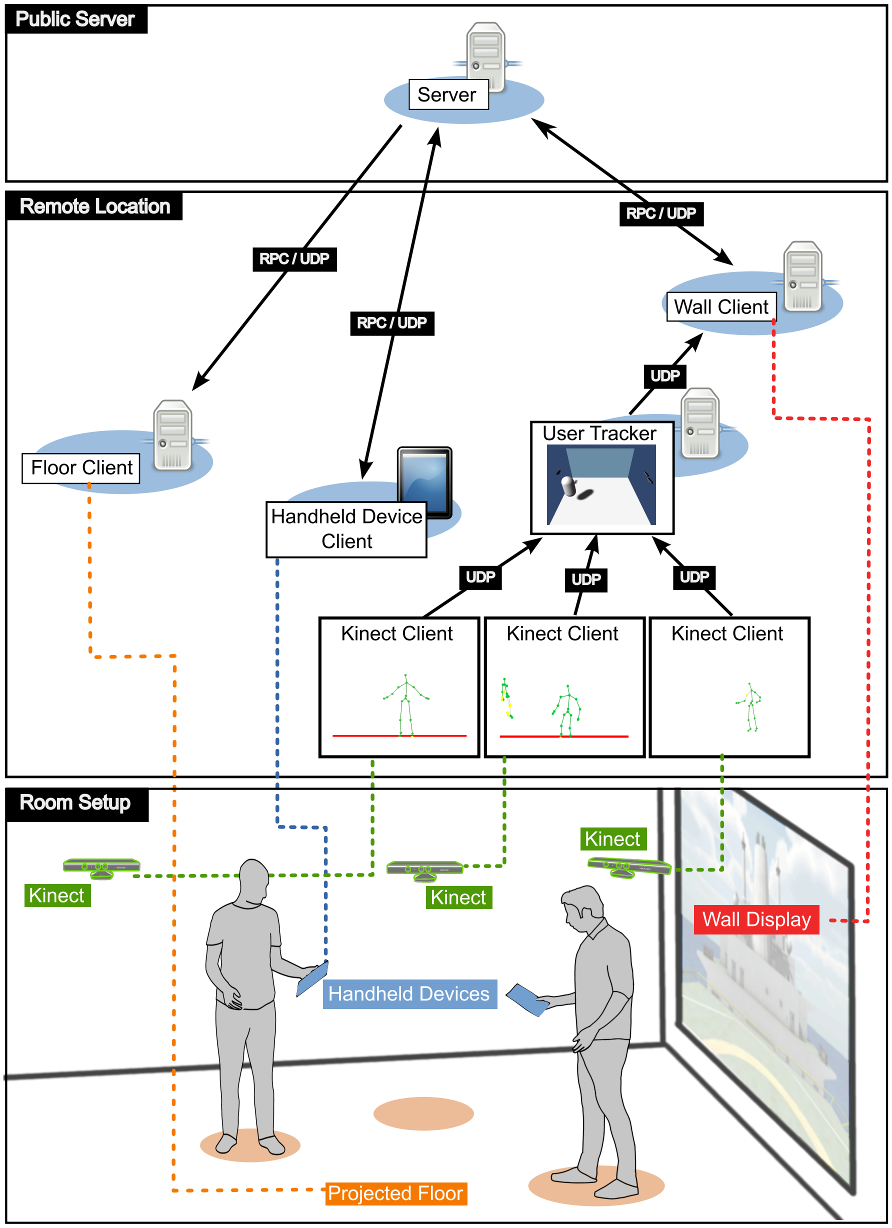


**Fig. 5** Overall architecture.

## 5 Providing Presence Awareness

While becoming and staying aware of others is something that we take for granted in everyday life, maintaining this awareness has proven to be difficult in real-time distributed systems [13]. Previous research indicate that people can respond socially and naturally to media elements [26]. Thus, we allow remote users to interact through appropriate virtual proxies, by making both the shared space and actions mutually visible. When trying to keep people conscious of other people's presence, an important design issue is how to provide such information in a non-obtrusive, yet effective manner.

### *5.1 First Iteration: Handheld Device-centered Approach*

The initial awareness techniques studied exploited the fact that all participants must hold an handheld device to participate in the meeting to perform collaborative tasks, while remaining in audio contact with remote participants. Following the collaborative guidelines proposed by Erickson and Kellog [10], we used the techniques described below to increase visibility and awareness of other users, namely for remote participants, spanning through two separate iterative phases.

**Bubble Map.**
Whenever someone tilts their handheld device to an horizontal position, a partial top view of the Eery Space is displayed, as depicted in Figure 6A. In the center of the screen, its owner is represented by a large white circle. Other users who are close enough to lie in the same Interactive Bubble as the device owner's are also portrayed as large circles, painted with the colour of each user. Users outside the bubble are considered off-screen. Resorting to an approach similar to Gustafson et al. [12], we place these circles (smaller than users in the same bubble) on the screen edge, indicating their direction according to the device owner's position.

**Virtual Windows.**
Virtual Windows provides a more direct representation of other users' position and orientation. These depict a view into the virtual world, in a similar manner to the work of Basu et al. [3]. Using the combined information of participants' position and the orientation of their handheld device, we calculate the user's own perspective, allowing them to point the device wherever they desire. The virtual window shows both local and remote users (Figure 6B), represented by avatars within the virtual environment. For the purpose of this dissertation, we used a 3D model of a generic clothed human.

**Wall Shadows.**
Every person has a representative virtual shadow on the wall display, distinguished by a name and a unique colour, as shown in Figure 6C similarly to the

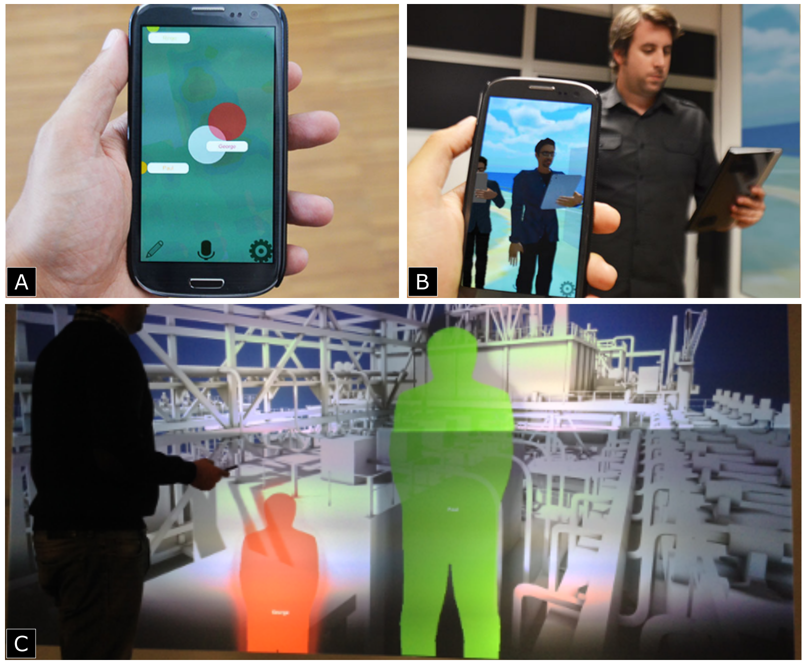


**Fig. 6** Awareness Techniques: A) Bubble Map; B) Virtual Window; C) Wall Shadows

work of Apperley et al. [1]. The location of the shadow reflects distance from the person to the wall to give a sense of the spacial relationship between the people and the interactive surface. Wall shadows takes in consideration an imaginary directional light source at the infinity and towards the wall display. Thus, the nearest person to the wall display, will have the shadow with more coverage area than the others. A much larger shadow also makes it clear who is the moderator. Furthermore, each user has a coloured aura around their shadow. When two or more people share the same aura colour, this means they are in the same social bubble and can initiate collaborative tasks.

### 5.1.1 Initial Evaluation

This evaluation session aimed on testing the proximity-aware interactions within the Eery Space, both with a local and with a remote person. It also served to evaluate the role of the moderator by grabbing control of the wall display using the person-to-surface interaction method. For this experiment, individual test users were placed in with one local and one remote person, scattered through the two separate rooms. With this, the user was encouraged to move freely in the space in front of the wall display and look for others to establish social bubbles in order to be able to do the collaborative tasks required.

**Methodology**

In this section, we describe the methodology performed to evaluate the feasibility of proximity-aware interactions in a remote virtual meeting setting. The expected duration for each session with users was about thirty minutes and was divided into three stages (Table 1):

1. **Introduction**
   First of all, an explanation of the objectives and the context of the virtual meeting, were given to the test subject, followed by a demonstration of the prototype's features with a description of all available awareness techniques.
2. **Evaluation Tasks**
   The local participant, acting as the evaluation session moderator, gave out commands to the test user, while engaging in conversation. Approximately, five minutes into this stage, the remote participant was signaled to enter the Eery Space environment.
3. **Filling in the questionnaire**
   At the end, the user was then asked to fill out the questionnaire. The questionnaire was comprised of a user's profile section and another section with nine questions in a *Likert* scale form of 6 values.

**Performed Tasks.**

Despite having been done informally, the set of evaluation tasks followed a strict order. Next, we present a description of the tasks performed during this stage.

1. **Associate user with mobile device**
   At first, participants were presented with a detailed description in how to become associated with the handheld device provided. This explanation was accompanied with a description of the user tracker and the depth cameras in the setup environment. Then, the they were asked to log into the system.
2. **Change role to moderator**
   This task started with a demonstration of the navigational technique on the handheld device and a demonstration of grabbing the control of the wall's common visualisation. While exploring the virtual environment on the handheld device, participants were encouraged to assume the role of moderator and share the point of view of the his device's virtual camera.
3. **Collaborative task with local participant**
   At this stage, the participants were asked to establish a social bubble with the

| # | Stage | Time |
|---|---|---|
| 1 | Introduction | 10 minutes |
| 2 | Evaluation tasks | 15 minutes |
| 3 | Filling in the questionnaire | 5 minutes |

**Table 1** Remote Proxemics' preliminary evaluation stages

| Question | Median (IQR) |
|---|---|
| **1.** It was easy to see who is present at the meeting. | 5 (1) |
| **2.** It was easy to see where each participant is. | 5 (0.5) |
| **3.** It was easy to see how I become moderator. | 6 (0) |
| **4.** It was easy to see who is the current moderator. | 6 (0.5) |
| **5.** It was easy to see who is in my social bubble. | 6 (0.5) |
| **6.** It was easy to join the social bubble of another local participant. | 6 (0.5) |
| **7.** It was easy to join the social bubble of another remote participant. | 5 (1) |
| **8.** The task of making a sketch with a local participant was simple to perform. | 6 (1) |
| **9.** The task of making a sketch with a remote participant was simple to perform. | 5 (1) |

**Table 2** Questionnaire's results of the initial evaluation (median and interquartile range).

local participant and start a collaborative sketch annotation. During this task, participants were made aware of the visual changes provided by the awareness techniques.

4. **Collaborative task with remote participant**
   Finally, participants were encouraged to find the remote participant and start a collaborative sketch annotation.

**Participants**

This initial evaluation session was attended by eleven users, two of them females. With ages ranging from 25 to 60 years, the large majority below 35 years. Also, all had at least a bachelor's degree and revealed different backgrounds, mainly in Engineering and Architecture.

**Results and Discussion**

The main objective of this initial evaluation was to study the feasibility of remote proxemics by exposing people to the concept. Therefore, the evaluation tasks were designed to expose the test users to local and remote proximal interactions, in order to correlate these two user experiences.

In the Table 2, are listed the answers from questionnaire in the form of median and the *interquartile range*, the measure of statistical dispersion of the data values. Since the beginning, the main driver of this work was to present a solution to mediate interactions between local and remote people seamlessly. Since the values obtained from the tasks are two related samples and come from the same population in an ordinal scale, we applied the *Wilcoxon Signed Ranks test* to highlight possible statistically significant differences between local and remote interactions. Accordingly to the *Wilcoxon Signed Ranks test* there are no significant differences between the making a sketch with local and remote participant. Nevertheless, establishing a social bubble, using the same test, shows a statistically significant difference between local and remote ($Z = -2.000$, $p = 0.046$), evincing a degree of difficulty while engaging in remote collaborative tasks, which brings us to the conclusion that the awareness techniques employed were insufficient and not adequate. In fact, from observation, test users were reluctant to utilise the virtual window and the bubble map awareness techniques and restricted their attention to the more expressive information from the wall shadows.

## 5.2 Second Iteration: Augmented Surfaces Approach

Since the results of the first evaluation show that the virtual window and the bubble map were inefficient in grabbing the attention of the participants, we choose to remove those awareness techniques and tryout an augmented floor approach. By introducing an iconic representation all participants on the floor, while preserving the participants intimate space in the Eery Space.

**Floor Circles.**
In Eery Space, every local and remote participant has a representative projected circle on the room's floor, as depicted in Figure 7. All floor circles are unique to its corresponding person and are distinguished from each other by a name (the participant identity) and the user's unique colour, analogous to the wall shadows. In addition, these circles move in accordance with the person's position within the Eery Space to visually define the participant's personal space and makes people aware of each other. The floor circles provides the necessary spacial information for participants to initiate proximity interactions. When people come together to start a social bubble, the circles on the floor inform on the status of their bubble, by displaying a coloured aura around the bubble's members. The projected aura gets its colour by the computation of the social bubble's members colour difference. This makes that

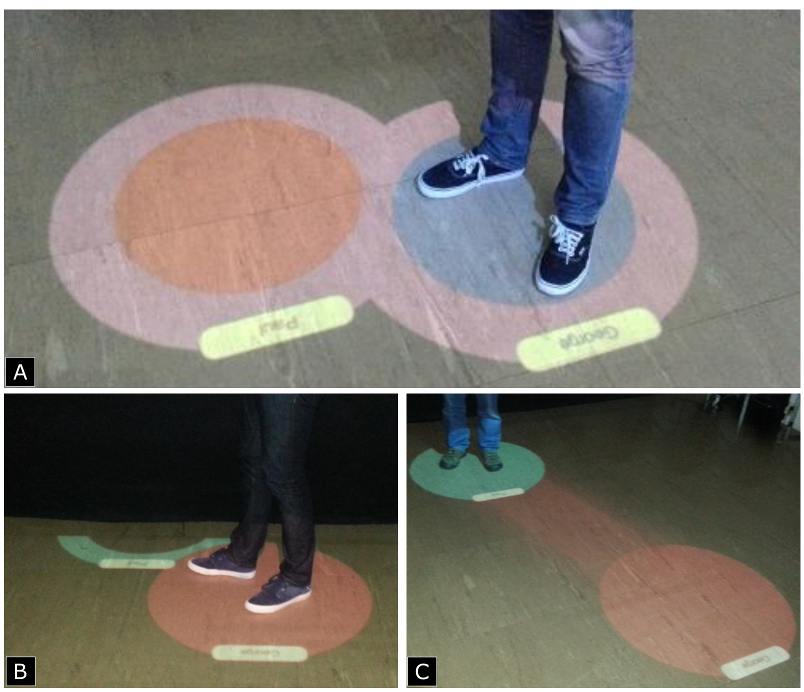


**Fig. 7** Test user interacting with the local participant during the an evaluation session.

new colour unique and unmistakably different from the other shadows on the floor. Also, the projected circles depicts the user's proxemic zones. The inner circle, with a radius of 0.3 meters, matches the participant's intimate space and the outer ring, the personal space, which in turn occupies the space until 0.6 meters.

Since Eery Space merges physical rooms of different dimensions into one shared virtual space, it may occur for some participants to be out of reach of others positioned in smaller rooms. To address this, we implemented a technique to gather the attention of participants out of reach. These participants appear on the edges of the smaller room's floor with only a portion of their circles showing their direction in the virtual space. To differentiate these participants, their intimate space is left blank (Figure 7B. When a participant tries to interact with another that is out of reach, a glowing path appears in the floor of the latter's room (Figure 7C, indicating that someone is trying to interact with him/her, but is unable to. He/she can then approach the circle of said person and normally initiate a proximal interaction.

**Intimate Space.**

We designed Eery Space keeping each person's personal locus in mind. Every user has their own space assured, even if they are not in the same physical room as the others. To prevent users from invading another user's intimate space, we provide haptic feedback by vibrating their handheld device, when this happens. In this way, participants can quietly adjust their positions without interrupting the main meeting, since this technique does not use audio or visual cues.

## *5.3 Solution Evaluation*

Since with the preliminary evaluation we can conclude that it is possible to interact with remote people using proxemics, this test session focused on the study of the overall developed solution. In general, this phase of evaluation is comprised of a proxemics interactions and awareness overview, as well as, a comparison of the awareness techniques employed in the final solution. Once the conclusion of the first preliminary study, the prototype had been altered. Accordingly to the noted low usage of the virtual window and bubble map awareness techniques, these features were discarded at this stage. Nevertheless, the floor shadows technique was developed and added to the final prototype, providing the precise information of the location of each remote participant. Similarly to the preliminary evaluation, a single user, for each session, was invited into the main setup environment and asked to interact with a local and another remote participant. Every test user had no previous experience with work in question.

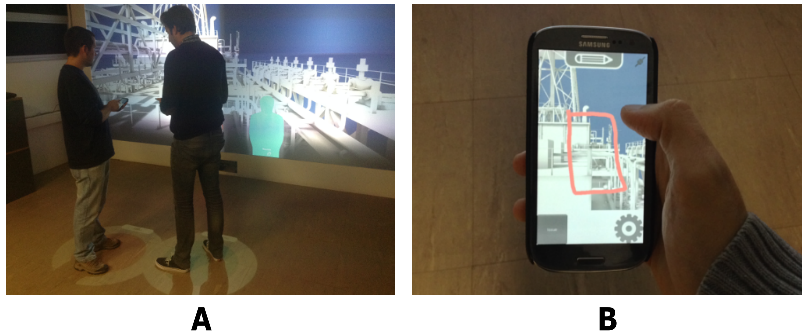


**Fig. 8** Test user interacting with the local participant during the an evaluation session.

### 5.3.1 Methodology

The solution evaluation phase maintained a similar methodology to the previous phase to guarantee the consistency of the data obtained. Table 3 demonstrates the three stages of each session with users. In total, each session lasted approximately thirty-five minutes. Below, we describe each stage of this session:

1. **Introduction**
   At the start, the new user was greeted with an explanation of the objective for this evaluation session, and with general consideration regarding the prototype. Firstly, was a description of the motivating aspects of our project, the design and review of 3D CAD models in virtual meetings and social interactions with remote people. The user was made aware that they would be interacting with another remote person. Secondly, the user was introduced in the basic features of the prototype, how to be associated with the handheld device and log on into the system. Thirdly, a brief description was made about the nature of the Eery Space and the awareness techniques. Fourthly, the concept of proxemics were discussed, accompanied with a demonstration on how to become the moderator and how to perform a collaborative task by forming a social bubble, emphasising the concept of intimate and personal space. This was followed with a demonstration of the haptic feedback by stepping on the user's intimate space. Finally, the user was encouraged to explore these concepts for a few minutes.
2. **Evaluation Tasks**
   The user was accompanied by both the local and the remote experienced participant. Thus, the user was receiving verbal commands for the tasks it should

| # | Stage | Time |
|---|---|---|
| 1 | Introduction | 10 minutes |
| 2 | Evaluation tasks | 20 minutes |
| 3 | Filling in the questionnaire | 5 minutes |

**Table 3** Solution's evaluation stages

perform. Since this evaluation requires an honest reaction from the test users, any posed questions were responded with another formulation of the commands, avoiding influences on the user's behaviour.

3. **Filling in the questionnaire**
   Upon completion of the tasks, the user was asked to fill out a questionnaire, not only to define the profile of the user, but also to gain an appreciation of the various components of our solution.

#### 5.3.2 Performed Tasks

The set of evaluation tasks was designed with the intention to check if there is any significant difference between local and remote interactions. Therefore, users were asked to perform a collaborative task, firstly with the local participant, following with the remote participant. Also, to verify if people do react to the presence of other remote people, even only being aware of the representation of their presence. Below, we describe the set of tasks performed by the test users:

1. **Interaction with Wall Screen Display**
   Since navigation in the virtual environment is beyond the context of this evaluation, which focuses on awareness and proxemic interactions, a button was placed on the prototype that automatically redirects the virtual camera to a specific point of interest in the model. This point of interest, common to all users, corresponds to an engineering detail in the virtual environment, and highlighted in red. Thus, the test user were encouraged to press the button and then displaying it on the wall display, by willingly assuming the role of moderator.
2. **Interaction with the local participant**
   To perform this task, user was asked to jointly create a collaborative sketch. For this, he had to physically move to establish a social bubble with the local participant and wait for instructions. Then, the local participant promptly drew a square around the point of interest in the virtual environment, and instructed the test user to draw a circle inside.
3. **Interaction with the remote participant**
   This task is essentially the same as that described with the local participant. The particularity of this task is that the test user was asked to create a collaborative task with the remote participant. To this end, the user had to move to establish a

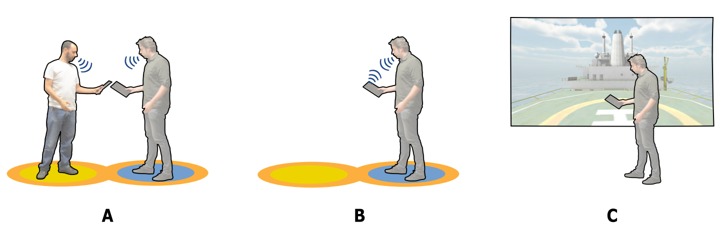


**Fig. 9** Evaluation tasks.

social bubble with the remote participant and wait for instructions. Similarly to the interaction with the local user and with the remote proxemics-enabled communication in the handheld device, the remote participant, then, instructs the test user to draw a cross inside his circle. At the same time, the remote participant intentionally steps in the test user's intimate space so as to arouse a reaction. Ideally, an adjustment in the position by the test user, demonstrating that he acknowledged the importance of preserving remote people's space in the meeting and also realising that he was interacting with another person.

4. **Intimate space invasion**
   For this task, the test user was instructed to watch the action performed by the remote user as moderator. The remote user moved into position and started to control the navigation on the wall display. At this stage, a computer generated remote user starts pursuing the test user in attempt to invade his intimate space. Again, this task is intended to observe the reaction of the user against an intrusion of their intimate space.
5. **Pathway between remote participants**
   This task was designed to realise if the test user understood the concepts exposed in this evaluation. The user was instructed to move to a target location while considering the presence of four computer generated remote participants. At no point in this evaluation, the user was informed that the computer generated remote users were in fact artificial.
6. **Stress test with multiple participants**
   The final task served as thanks to the test users for their participation in the evaluation session. This task was designed purely as a game and was not considered in the final analysis of the results. Therefore, the final task consisted of six computer generated remote users pursuing the test user in the attempts to invade his intimate space.

### 5.3.3 Participants

The participants in this trial were invited randomly and were mainly students attending our educational institution. Thereby, the set of test users was comprised of 12 participants, one of which was female, and all with a college degree. In regard to their age, the majority of the test users were between 18 years old and 24, remaining one of them between 35 and 55 years old. Nearly all reported having experience using smartphones in a daily base, except one of them that did not own a smartphone.

### 5.3.4 Results and Discussion

In this section, we present an analysis of the data obtained from the evaluation of the overall solution. The data gathered of the user's preferences were obtained from the *Likert* scale of 6 values, presented previously. Also, data from the observation of the performed tasks is considered in this analysis.

| **Question** | **Median (IQR)** |
|---|---|
| **1.** It was easy to control what is shown on the wall display. | 6 (1.25) |
| **2.** It was easy to start an interaction with a local participant. | 6 (0) |
| **3.** It was easy to start an interaction with a remote participant. | 6 (1) |

**Table 4** Questionnaire's results of the proxemics overview (median and interquartile range)

The main objective of this evaluation was to demonstrate the feasibility of remote proxemics by maintaining an adequate level of awareness of the people that are remote, since the main premise of this work was that remote proxemics is possible provided that local participants have the awareness of the location and status of the remote ones. Furthermore, this evaluation provides a study of each awareness technique present on the final solution. Therefore, the analysis of the results is divided into a *Proxemics Overview*, an *Awareness Overview* and a comparison between the awareness techniques employed. A discussion of the final results is also provided along this section.

**Proxemics Overview**

The user's preferences regarding proxemics interactions are related to their easiness to perform proximal interactions with both local and remote people, and also the ability to interact with the wall display. The latter, poses a conscious decision to become the moderator of the virtual meeting. In Table 4 are depicted the responses obtained from the questionnaire regarding those interactions, in the form of median and interquartile range. The presented data suggests that it was easy to assume the role of moderator. According to the *Wilcoxon Signed Ranks* test between the first and second questions ($Z = -1.890$, $p = 0.059$), there are no statistically significant differences between starting a interaction with the other participants, despite their local or remote statuses. What leads us to conclude that interacting with remote people is no different than local interactions. This result is encouraging insofar as it can prove that remote proxemics are in fact possible and do not add obstacles in the course of virtual meetings. In the trials, users did not demonstrate any difficulty in repositioning themselves to establish social bubbles in the collaborative tasks, although three users took up to five seconds to remember how to become the moderator while in the first task.

**Awareness Overview**

Regarding awareness, Table 5 summarises the data obtained from the test trials. In general, the presented data shows that people in the virtual meeting can relate to the presence of remote participants. User's preferences suggests that, despite exhibiting a slight dispersed data (Table 5, question 2), the absolute location of remote people is always visible. We can safely deduce that participants in the virtual meeting are always aware of the people involved. One of the requirements of our approach is the preservation of the intimate space of remote people. This design principle is required to impose their presence, while fostering remote interactions by establishing social bubbles. The *Wilcoxon Signed Ranks test* applied to the questions 6 and 7 shows no statistically significant difference between local and remote people, suggesting that test users were aware when their intimate space intercepted the others. Curiously, while performing the collaborative task, three test users made a point of informing the remote participant of his infringement on their personal space during the smartphone-enabled conversation before readjusting their position. While during the intimate space invasion task every one of them changed their positions, responding to the haptic feedback from the handheld device. Despite that, four users complained that the remote participant was invading their intimate space, and then proceeded to readjust their positions. In the final task, the pathway between remote participants, only one user did not take into account the presence of the remote participants and walked right through them, suggesting that almost every one accepted the presence of remote people and walked accordingly by dodging the floor shadows while walking to the destination. It is then safe to say, that in general, were aware of the presence of the remote participant and reacted accordingly. Nevertheless, one of the test subjects expressed the need to be aware of the others orientation in the meeting.

**Awareness Techniques Comparison**

To provide a model for future remote proxemic interactions, we compared the awareness techniques employed in the final solution to understand their decisive role in providing awareness of the presence of remote people. Not just presence in general, but also location and status. In out final approach, the awareness techniques encompass multiple devices and surfaces. Wall shadows provide the whereabouts of all users, in the meeting, on the wall screen display. The projected floor surface displays representative shadows of the absolute location of each person in the Eery Space. And handheld devices provide haptic feedback when the participants intersect their intimate spaces. In the Table 6 we show the results from the questionnaire regarding the awareness techniques. First of all, by design, the handheld device client do not provide awareness of the meeting's participants or their location. Also, the handheld device is not able to show who is the moderator. For this, we applied the *Wilcoxon Signed Tanks test* in every question between all awareness techniques. There was no statistically significant difference in providing the information of who was present in the meeting, between the floor and the wall shadows. This was the only question that the *Wilcoxon Signed Tanks test* did not demonstrated a statistically significant difference. Although the floor shadows has scored higher (median) in the questionnaire, we believe that this is due to the remote participant entering the Eery Space from the side and not from the rear, which could invert these results. Regarding the location of each participant, the floor shadows proved to be better at this task ($Z = -2.456$, $p = 0.014$). In return, the wall shadows proved to be more efficient in showing who is controlling the wall display ($Z = -2.966$, $p = 0.003$). In fact the representation of the moderator changes on the wall display, while the floor shadows only shows him at close proximity. Wall shadows proved insufficient to provide awareness of the formation of social bubbles while interacting with other people, against the floor shadows ($Z = -2.595$, $p = 0.009$) and the handheld device ($Z = -2.122$, $p = 0.034$). We believe that the auras on the wall shadows are not that expressive and the information on the floor and on the handheld device is more

| **Question** | **Median (IQR)** |
|---|---|
| **1.** It was easy to see who is present at the meeting. | 6 (0) |
| **2.** It was easy to see where each participant is. | 6 (1.25) |
| **3.** It was easy to see who is controlling the wall display. | 6 (0.25) |
| **4.** It was easy to see that I'm interacting with other people. | 6 (0.25) |
| **5.** It was easy to see which participant I'm interaction with. | 6 (1) |
| **6.** It was easy to see that I'm in the intimate space of another local participant. | 6 (0) |
| **7.** It was easy to see that I'm in the intimate space of another remote participant. | 6 (0) |

**Table 5** Questionnaire's results on the awareness overview (median and interquartile range).

prone to hold onto the participants attention. In a similar note, the floor shadows (Z = -2.956, p = 0.003) and the handheld device (z = -2.958, p = 0.003) both proved to be effective in providing the awareness while stepping in the intimate space of another participant. And finally, according to the *Wilcoxon Signed Tanks test*, the projected floor depicts a better representation of the people involved in a collaborative task, against the wall shadows (Z = -2.461, p = 0.014) and the handheld device (Z = -2.958, p = 0.003). Thereby, it is safe to conclude that the wall screen display is necessary for the tasks of design and review of 3D models, but proved to be somewhat irrelevant to the functioning of the social interactions in the Eery Space.

The final results clearly show an improvement in the awareness of the remote people's presence, in the way that local and remote interactions are virtually the same. We would not have gotten this result if we had not done the preliminary evaluation. The first evaluation trials, suggested the need for a more expressive awareness technique to depict the exact location and status of remote participants. With that, the projected floor has filled this requirement and presents a favourable acceptance by the test users.

## 6 Challenges and Opportunities

In Eery Space [29] people can see each others representation and quickly grasp their location and status on the virtual meeting through a large scale display, the projected floor and personal handheld devices. As a matter of fact, these awareness techniques render Remote Proxemics possible since they effectively highlight the presence of

| | **Median (IQR)** | | |
|---|---|---|---|
| **Question** | **Wall** | **Floor** | **Handheld** |
| **1.** Helped to realise who is present at the meeting. | 5 (1) | 6 (1.25) | - |
| **2.** Helped to realise where each participant is.* | 5 (0.25) | 6 (1) | - |
| **3.** Helped to realise who is controlling the wall display.* | 6 (0) | 4 (3) | - |
| **4.** Helped to realise that I'm interacting with other participants.* | 4 (1.25) | 6 (0.25) | 6 (1.25) |
| **5.** Helped to realize with whom I'm interacting with.* | 4 (2.25) | 6 (0.25) | 3.5 (1.25) |
| **6.** Helped to realize that I'm in the intimate space of a remote participant.* | 2.5 (1.25) | 6 (1) | 6 (0.25) |

* There are statistically significant differences

**Table 6** Questionnaire's results on the awareness techniques comparison (median and interquartile range for techniques available on the wall display, floor and handheld device).

remote people. The current state of the art regarding remote proxemics employs the usage of fixed proxemic dimensions [14] to engage people in collaborative tasks. Also, Eery Space counts on fixed distances to start and terminate interactions, which, despite being near to normal social interactions are still somewhat far from the way people locally interact, meaning that transitions between interactions are still abrupt. We believe that remote proxemic interactions can be improved by allowing a more fluid model like gradual engagement [21] and f-formations [18, 22].

In general terms, Eery Space can be enriched with new workflow dynamics. Gradual engagement can improve interactions in various tasks including data visualization, communication and content creation, instead of the previous way of interaction. Figure 10 depicts a future model for remote interactions, by dividing the distance between two people in proxemic distances. Another important aspect is the orientation of one person among the others which also is an crucial factor to define the Eery Space's interaction stages. Following the previous generalization of the interaction model, we can describe the an enrich Eery Space interaction stages:

**Ambient Interaction**

In this interaction stage, people present in the Eery Space can easily take a glance to the state of the meeting by looking to the projected floor. They can only get an overall glimpse of who is present and what are they doing. Despite that, people physically closer, or in any of the other stages, if their orientation do not match a close encounter [22], the system deal with them as if they were in the Ambient stage.

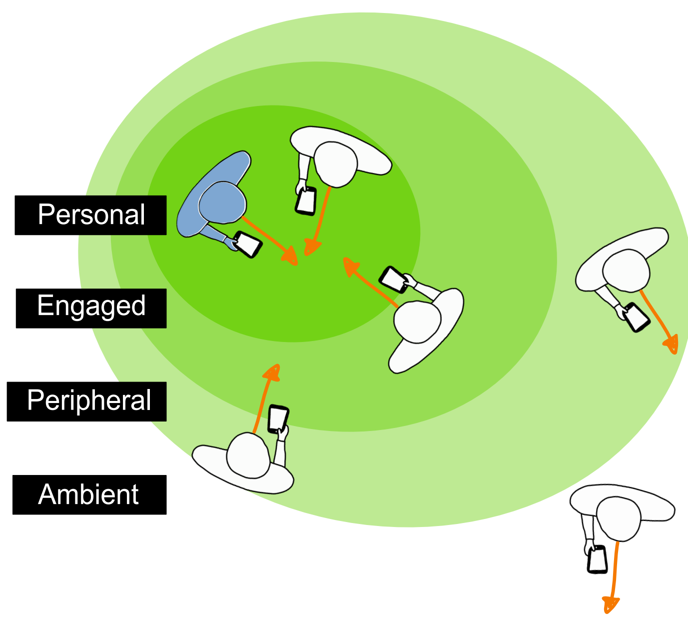


**Fig. 10** Gradual Engagement model for Remote Proxemics.

**Peripheral Interaction**
People passing by this stage are able to access peripheral information the collaborative tasks performed by the others.

**Engaged Interaction**
People inside this stage implicitly makes notice what is being discussed and can communicate with the contents owners.

**Personal Interaction**
On this stage users can interact directly with each other and edit content, if the content owner gives access to the other users.

Since people, in real life, rely on close encounters and orientation to communicate. The same approach can be used to establish group interactions and broadcast speech to other participants in remote proxemic environments.

## 7 Conclusions and Future Work

Virtual meetings play an important role in bringing geographically separated people together and are broadly used in business and engineering settings where experts around the world engage in collaborative tasks. While current videoconference and telepresence solutions do enable verbal and visual communication between all participants, other forms of non verbal communication, namely social interactions through proxemics, have not been explored to their full potential.

We have introduced Remote Proxemics, which brings social interactions to virtual meetings, and explores interactions between local and remote people as if they were in the same space. To this end, we created Eery Space, a shared virtual locus where people can meet and interact with each other using Remote Proxemics. We developed a prototype to explore both people-to-people and people-to-device interactions and study techniques for providing the appropriate awareness.Indeed, these awareness techniques render Remote Proxemics possible, since they highlight the presence of remote people. Using a projected floor and personal handheld devices, people can see others' representations and quickly realise their location and status on the virtual meeting. Results from our evaluation show the promise of Remote Proxemics, since we were able to achieve seamless interactions between local and remote people. We believe that the work here described extends proxemic interactions to augment the presence of remote users in virtual collaborative settings to address commonly-raised concerns. Furthermore, our results apply even in the absence of commonly explored devices such as avatars and eye contact.

We consider it is both possible and interesting to apply our innovative approach to additional purposes and scenarios, ranging from engineering to architectural projects. To bind people with their personal handheld devices in a more flexible manner, we intend to explore automatic approaches, for example using computer vision, as suggested by Wilson et al. [33]. Also, we consider that it would be interesting to assess whether adding support for f-formations [22] will also enrich remote interactions in the Eery Space.

## Acknowledgments

This work was partially supported by the Portuguese Foundation for Science and Technology (FCT) through the projects TECTON-3D (PTDC/EEI-SII/3154/2012), CEDAR (PTDC/EIA-EIA/116070/2009), and by national funds through FCT with reference UID/CEC/50021/2013. Daniel Medeiros would like to thank CAPES Foundation, Ministry of Education of Brazil for the scholarship grant (reference 9040/13-7).

## References

1. M. Apperley, L. McLeod, M. Masoodian, L. Paine, M. Phillips, B. Rogers, and K. Thomson. Use of video shadow for small group interaction awareness on a large interactive display surface. In *Proc. of AUIC '03*, 2003.
2. T. Ballendat, N. Marquardt, and S. Greenberg. Proxemic interaction: designing for a proximity and orientation-aware environment. In *ACM ITS*, pages 121–130. ACM, 2010.
3. A. Basu, A. Raij, and K. Johnsen. Ubiquitous collaborative activity virtual environments. In *Proc. of CSCW '12*, 2012.
4. S. Beck, A. Kunert, A. Kulik, and B. Froehlich. Immersive group-to-group telepresence. *Visualization and Computer Graphics, IEEE Transactions on*, 2013.
5. H. Benko, R. Jota, and A. Wilson. Miragetable: freehand interaction on a projected augmented reality tabletop. In *Proc. of CHI '12*, 2012.
6. W. Buxton. Telepresence: Integrating shared task and person spaces. In *Proceedings of graphics interface*, volume 92, pages 123–129, 1992.
7. W. Buxton. Living in augmented reality: Ubiquitous media and reactive environments. *Video Mediated Communication.*, pages 363–384, 1997.
8. W. A. Buxton, A. J. Sellen, and M. C. Sheasby. Interfaces for multiparty videoconferences. *Video-mediated communication*, pages 385–400, 1997.
9. M. Cohen, K. R. Dillman, H. MacLeod, S. Hunter, and A. Tang. Onespace: Shared visual scenes for active freeplay. In *Proc. of CHI '14*, 2014.
10. T. Erickson and W. A. Kellogg. Social translucence: An approach to designing systems that support social processes. *ACM TOCHI*, 2000.
11. S. Greenberg, N. Marquardt, T. Ballendat, R. Diaz-Marino, and M. Wang. Proxemic interactions: The new ubicomp? *interactions*, 18(1):42–50, Jan. 2011.
12. S. Gustafson, P. Baudisch, C. Gutwin, and P. Irani. Wedge: Clutter-free visualization of off-screen locations. In *Proc. of CHI '08*, 2008.
13. C. Gutwin and S. Greenberg. A descriptive framework of workspace awareness for real-time groupware. *CSCW*, 2002.
14. E. T. Hall. *The Hidden Dimension*. Doubleday, 1966.
15. K. Hinckley. Synchronous gestures for multiple persons and computers. In *ACM UIST*, pages 149–158. ACM, 2003.
16. H. Ishii and M. Kobayashi. Clearboard: A seamless medium for shared drawing and conversation with eye contact. In *CHI*, pages 525–532. ACM, 1992.

17. W. Ju, B. A. Lee, and S. R. Klemmer. Range: exploring implicit interaction through electronic whiteboard design. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, pages 17–26. ACM, 2008.
18. A. Kendon. *Conducting interaction: Patterns of behavior in focused encounters*, volume 7. CUP Archive, 1990.
19. G. Kortuem, C. Kray, and H. Gellersen. Sensing and visualizing spatial relations of mobile devices. In *UIST*, pages 93–102. ACM, 2005.
20. A. Kunz, T. Nescher, and M. Kuchler. Collaboard: a novel interactive electronic whiteboard for remote collaboration with people on content. In *Cyberworlds (CW), 2010 International Conference on*, pages 430–437. IEEE, 2010.
21. N. Marquardt, T. Ballendat, S. Boring, S. Greenberg, and K. Hinckley. Gradual engagement: Facilitating information exchange between digital devices as a function of proximity. In *Proc. of ITS '12*, 2012.
22. N. Marquardt, K. Hinckley, and S. Greenberg. Cross-device interaction via micro-mobility and f-formations. In *Proc. of UIST '12*, 2012.
23. O. Morikawa and T. Maesako. Hypermirror: toward pleasant-to-use video mediated communication system. In *CSCW*, pages 149–158. ACM, 1998.
24. L. Neyfakh. My day as a robot, May 2014. Online: `http://www.bostonglobe.com/ideas/2014/05/10/day-robot/6UAMgmUFn0mZhoMS8vy0GK/story.html`.
25. R. Raskar, G. Welch, M. Cutts, A. Lake, L. Stesin, and H. Fuchs. The office of the future: A unified approach to image-based modeling and spatially immersive displays. In *Proc. of SIGGRAPH '98*, 1998.
26. B. Reeves and C. Nass. *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*. Cambridge Univ. Press, 1996.
27. N. Roussel, H. Evans, and H. Hansen. Proximity as an interface for video communication. *MultiMedia, IEEE*, 11(3):12–16, 2004.
28. R. Sommer. Personal space in a digital age. *Handbook of environmental psychology*, pages 647–660, 2002.
29. M. Sousa, D. Mendes, A. Ferreira, J. a. Pereira, and J. Jorge. Eery space: Facilitating virtual meetings through remote proxemics. In *Human-Computer Interaction–INTERACT 2015*. Springer, 2015.
30. M. Sousa, D. Mendes, A. Ferreira, J. M. Pereira, and J. Jorge. *Human-Computer Interaction – INTERACT 2015: 15th IFIP TC 13 International Conference, Bamberg, Germany, September 14-18, 2015, Proceedings, Part III*, chapter Eery Space: Facilitating Virtual Meetings Through Remote Proxemics, pages 622–629. Springer International Publishing, Cham, 2015.
31. P. Tanner and V. Shah. Improving remote collaboration through side-by-side telepresence. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*, pages 3493–3498. ACM, 2010.
32. D. Vogel and R. Balakrishnan. Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In *UIST*, pages 137–146. ACM, 2004.
33. A. D. Wilson and H. Benko. Crossmotion: Fusing device and image motion for user identification, tracking and device association. In *ICMI*, ICMI '14, pages 216–223, New York, NY, USA, 2014. ACM.
34. R. Wolff, D. J. Roberts, A. Steed, and O. Otto. A review of telecollaboration technologies with respect to closely coupled collaboration. *International Journal of Computer Applications in Technology*, 29(1):11–26, 2007.