APPLICATION OF GRAPHICAL REPRESENTATIONS FROM VIDEO GAMES TO AMPLIFY CO-PRESENCE IN GROUP VISITS TO VIRTUAL HOUSES

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ABSTRACT

In real life, the ability that people have of observing the elements of their surrounding space contributes for the sense of presence and social co-presence in that physical space. Digital avatars are often the employed means for providing a similar sense of co-presence in virtual environments. Digital avatars of the users and other co-presence amplification strategies (e.g., co-presence inducing graphical representations) have been extensively studied and employed in multi-player videogames. This paper studies the application of some these strategies to amplify the sense of co-presence of people in virtual group house visits, which is an application scenario with value for real estate industry and participatory design in architecture. For this purpose, a Unity-based collaborative virtual environment was implemented and tested in a user study with 33 participants. The obtained results show that the implemented strategies enrich the sense of co-presence in the virtual environment and trigger interesting collaborative interactions.

KEYWORDS

Co-Presence, Virtual Environment, Videogames, Collaborative Interaction

1. INTRODUCTION

Ideally, users should feel fully present and immersed in the virtual environments with which they interact. However, there are still limitations to these virtual experiences, as they are not yet capable of fully replacing the benefits of real life and technical questions remain about how to effectively use this technology (e.g., how to avoid cyber-sickness), thus demanding for further research.

Virtual environments require strong support for spatial navigation, given that navigation without some assistance can be difficult to perform, inducing disorientation and discomfort to the user (Vinson, 1999). Spatial navigation and reasoning are particularly challenging in Collaborative Virtual Environments (CVE) (Casanueva et al., 2000), as these require users to share the same virtual space and perform collaborative tasks. In these environments, users need to have a sense of co-presence, otherwise they will not be able to collaborate. Digital avatars of the users, i.e., graphical representations of the users, are often employed for this purpose (Churchill and Snowdon, 1998) (Negron et al., 2020).

Digital avatars of the users and other co-presence amplification strategies (e.g., co-presence inducing graphical representations) have been extensively studied and employed in multi-player videogames (Warpefelt, 2016) (Steuer, 1992). Videogames are a special case of CVE, many of them capable of providing the players with a strong sense of co-presence when facing challenging complex collaborative navigation tasks. The value of studying videogames beyond their entertainment role is well established. For instance, previous studies addressed the role of videogames as learning tools in specific age groups and their effects on physical and mental health of the users (Stanney and Cohn, 2009).

This paper studies the hypothesis that some the co-presence strategies employed by videogames are capable of amplifying co-presence in virtual group house visits. Performing virtual group house visits is an important application scenario in the real estate industry. The ability to pre-visit houses virtually is a time and cost saver and being able to do it in group more closely resembles what people do when selecting a house. Group visits to virtual houses can also be a valuable tool for participatory architectural design: clients can be invited to jointly visit early house designs and provide timely feedback to inform subsequent design iterations.

To validate our hypothesis, we have designed and implemented a Unity-based CVE, hereafter VVApp (from Virtual Visit App), in which remote users are able to jointly visit virtual houses, with co-presence amplified by means of graphical representations borrowed from videogames. A user-study with 33 participants was conducted. The behavior of the users was observed during the execution of a set of tasks with the goal of assessing then ability of the implemented co-presence strategies to facility collaborative navigation, communication, and decision making. The obtained results show that the implemented strategies enrich the sense of co-presence in the virtual environment and trigger interesting collaborative interactions.

This paper is organized as follows. Section 2 presents related work. Then, the developed CVE is described in Section 3. The experimental setup and results are presented in Section 4 and 5, respectively. Finally, conclusions are drawn and future is proposed in Section 6.

2. RELATED WORK

Casanueva and Blake (2000) studied the effects that avatars have on co-presence in a CVE, namely the appearance and functionality of the avatar. The conclusion reached by the authors was based on the presence and co-presence scores and survey responses, which turned out to be quite positive. Buck et al. (2019) observed that co-presence can exist in a CVE at a level very similar to that of reality. Podkosova and Kaufmann (2018) concluded that users try not to collide in the virtual world even when aware that they were safe from real collisions. Pimentel and Vinkers (2021) refer the possibility of co-presence in mixed reality. Kim et al. (2018) showed the existence of co-presence between a virtual interlocutor and a human being. Cho et al. (2015) analyzed the influences of co-presence on the performance of virtual staging. They concluded that age and epistemological beliefs significantly influence physical and social presence, as well as the participants' sense of being present together in the CVE. Wienrich et al. (2018) showed that collaborative tasks increase levels of social presence and cooperation in a positive way in large-scale CVE.

In CVE, the base interaction is typically performed by digital avatars, i.e., graphical representations of the users. However, these interactions are limited. Negrón et al. (2020) concluded that interactions such as interactions verbal/non-verbal, kinesics and proxemics, were used in a positive and discriminating way (Negron et al., 2020). Zhang et al. (2019) developed a CVE and a series of collaborative games dedicated to children suffering from autism spectrum disorder, with the aim of establishing the viability and tolerability of the system. They concluded that their system greatly improved collaborative performance among children. Gamelin et al. (2021) confirmed the importance of avatar's fidelity regarding spatial interaction, since it can affect communication between users, especially when performing collaborative spatial tasks.

The previous studies address the effect that various factors have on collaborative interaction and sense of co-presence; however, most of them explored the digital avatar as the sole cue for inducing co-presence. The videogames industry has devised, implemented, and deployed many other alternatives for entertaining purposes. This paper contributes with a study on the value of these alternatives to amplifying co-presence in virtual house group visits, that is, in a non-entertaining setting.

3. VVAPP DESIGN AND IMPLEMENTATION

3.1 Avatar

A virtual environment is only considered to be a CVE when more than one user is simultaneously present (Casanueva and Blake, 2000) (Buck et al., 2019) (Knapp et al., 2014). Digital avatars are visual demonstrations of the users that contribute for them to feel present in the CVE. The avatar's visual appearance can be selected to be either stylized or realistic if it clearly represents the user in question. According to Buck et al. (2019), adding just one personalization element to a 3D avatar has more impact of distinguishing than adding several personalization elements. Hence, avatars in VVApp, which have a *stickman*-like look, are distinguished based solely on their colors. Their faces include a nose to cue partners regarding their gazing direction (Figure 1).

To generate interaction events or navigation events within a CVE, a mapping of controls is required. Cursor keys used to be used more in character-based systems, before new alternative control mappings came along outside the keyboard (Janet et al., 2004). In current 3D games, the cursor keys are less used since the inclusion of the mouse. Instead, the WASD mapping is more often used. User controls in VVApp are divided into two parts. The first part follows the pattern used in current video games to control the avatar, of which W moves it forward, S backwards, A to the left, and D to the right. The second part focuses on the mouse position, a variable that modifies the avatar's orientation and the user's perspective, in which the user sees the world in the first person, through the avatar’s eyes.

Hearing reveals significant importance in increasing additional information about a given physical or virtual space. Virtual hearing helps to inform the user the presence and type of sound propagation has occurred. However, it fails to indicate precisely where this sound was propagated in the virtual space. (Török et al., 2015) (Calado et al., 2017). VVApp contains a 3D sound system that fixes this flaw.

3.2 Virtual Houses

The CVE in VVApp presents clues that describe a habitable house so that users feel that they are visiting a real home, such house divisions, textures to identify the type of flooring or wall texture, and furniture for each room. All elements included in the virtual houses fit together correctly, otherwise the CVE would exhibit unfamiliar visual information, breaking the experience. Currently, VVApp includes three virtual houses of different sizes, structurally equivalent to real apartments (Figure 1).

Figure 1. Plan view of the houses CVE_1 (1), CVE_2 (2) and CVE_3 (3). The crosses in the white area indicate the starting position of the four users, i.e., house visitors (Left). Avatar’s graphical representations (Right)

House CVE_1 is small but beginner-friendly, comprising a spacious living room with kitchen, a medium-sized bedroom, and a bathroom; it is furnished in a simple and practical way. House CVE_2 is medium-sized, consisting of a large living room, two bedrooms, one bathroom and kitchen; the apartment is fully furnished and decorated. Finally, House CVE_3 is large and comprises a hall, two bedrooms, suite, office, living room, kitchen in open space, laundry, social bathroom, and pantry with wine cellar; a wide corridor guides users to enter the private area; the apartment is fully furnished and decorated.

3.3 Collaborative, Non-verbal and Spatial Interaction

One way to amplify the feeling of co-presence is to share necessary information from all users of the CVE. Each mechanism sends visual feedback about any event in the CVE to the user (Abrams and Gerber, 2013).

Video games, such as *Left For Dead 2* (Valve Software, 2004) or *Apex Legends* (Electronic Arts, 2020), provide the player with information about the partners’ avatars state. Similarly, VVApp contains a rectangular *Info-bar* (Figure 2), divided into four parts, each representing the information (name and location in terms of house division) of each user present in the CVE (in the current version only four users are allowed).

Video games often notify players using interfaces about recent events. These events must be clearly notified in advance so that the user experience is not abruptly interrupted. All users in VVApp are also notified of the others’ information, giving them the feeling that they are not in an empty space (Churchill and Snowdon, 1998). VVApp includes a transparent interface, called *Text box*, which reports the events registered on the CVE (Figure 2).

Allowing users to mark three-dimensional positions for others to see (a pointing mechanism) helps considerably collaborative task solving (Churchill and Snowdon, 1998). This reduces communication problems in CVE (Gamelin et al., 2021) and potentially amplifies the feeling of co-presence. In this line, the video game Counter Strike Global Offensive (Valve Software, 2012) includes a non-verbal communication tool called *Pointing*, which marks the location defined by a user in three-dimensional space. The similar interface included in VVApp is an animated icon that includes the relative distance, in meters, between the user and the focus point that works like in the mentioned video game (Figure 2).

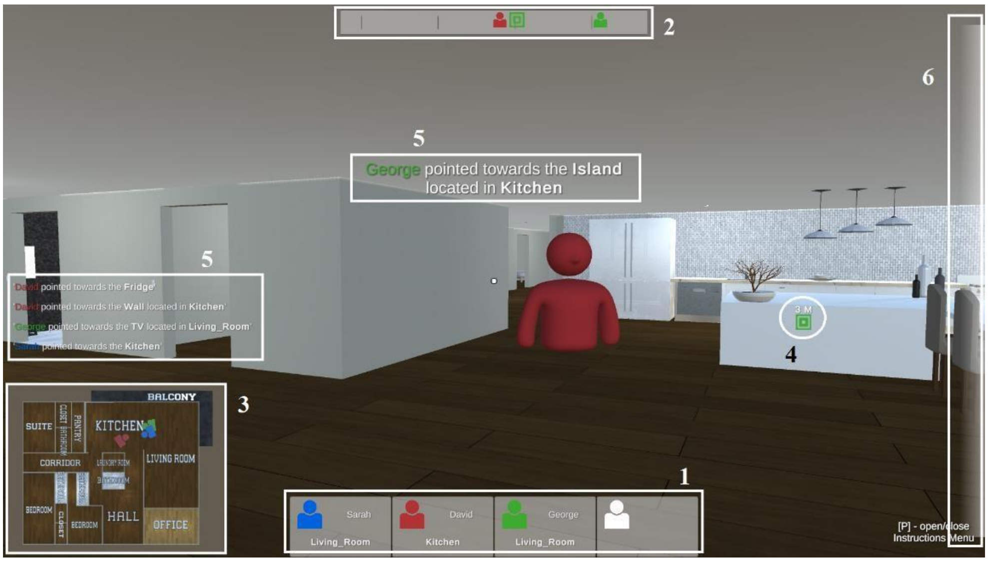

Figure 2. Point of view of Sarah’s avatar. In this screenshot, it is shown all the interfaces added to the application: *Info-bar* (1), *Compass* (2), *Mini-map* (3), *Pointing* (4), *Text boxes* (5) and *Collision warning* (6)

Kyriakou et al. (2017) concluded that people feel more present in the virtual environment when there are scenarios with intensive interactions. In videogames, such as *Gran Turismo 7* (Polyphony Digital, 2022), the player is often notified, via small 2D visual elements, when an opponent approaching from behind is too close. VVApp follows a similar approach by presenting to the user two rectangular graphical elements, by the name of *Collision Warning*, each occupying one of the two sides of the screen (Figure 2). The closer a partner is from the user, below a give threshold distance, the opaquer the rectangles become. To convey the information to the user clearly, the active graphic element flashes, regardless of its opacity.

Navigation (i.e., planning a path to a desired destination) in large-scale CVE can be challenging for most users if no access to a navigation guide. To cope with this challenge, videogames often provide the player with a (in)complete (mini-)map of the environment. Maps in CVE must ensure that the user is able to relate two points in the map’s graphical representation to the two corresponding points in the environment (Darken and Sibert, 1993). VVApp includes a rectangular *Mini-map* capturing the entire virtual area (Figure 2). To reduce visual clutter, the decorative objects present in the virtual houses are not rendered on the *Mini-map*. However, the *Mini-map* exhibits icons of the avatars present, pinpointing their current position and orientation. To facilitate localization on the *Mini-map*, a label per house’s division is overlaid in the map with the division’s name.

Although maps contribute positively for navigation, it is not always the most effective tool (Chen and Stanney, 1999). For instance, *The Elder Scrolls V: Skyrim* (Bethesda, 2011) provides the player with a *Compass* that, with its compact format, manages to guide the player in following the current locations of active objectives or enemies. A similar compass is included in VVApp (Figure 2). It indicates the current orientation of the user’s partners, as well as the orientation of the points marked with the *Pointing* tool. The interface of the *Compass* presents all the points in a 2D format. The *Compass* does not identify the poles that associate with the traditional *Compass*. It has the potential to amplify the feeling of co-presence, since the user can guide the partners through a pointing marker while the partner follows that marker with the support of the *Compass*.

3.4 Formative Evaluation

To detect points of improvement in an early version of VVApp, a formative evaluation session with a duration of forty minutes was carried out with three remote users. The ages of the participants varied between 22 and 28 years old, two males and one female. This test included the execution of three tasks to be performed in virtual house CVE_3. The participants were verbally questioned about the performance of the mechanics. In general, the test showed positive results regarding the use of interfaces and non-verbal communication mechanisms. Identified issues in the application were later corrected. The results presented in the following sections were obtained with the corrected version of the VVApp.

4. EXPERIMENTAL SETUP

To evaluate the co-presence mechanisms included in VVApp, 11 groups of three participants each (without reposition) were recruited. Participants belonging to the same group are hereafter called *partners* of each other. The ages of the participants varied between 17 and 40 years, with a mean age of 24.03 years ($\sigma = 5.02$), 30 males and 3 females. The experiments were designed to test the following working hypotheses: H1: participants use at least one of the co-presence inducing interfaces to solve tasks; H2: the proposed co-presence inducing interfaces give positive collaborative *feedback*, that is, they are used with some significant frequency by users; H3: the co-presence inducing interfaces, in general, enrich the visits of virtual houses, that is, they are well received by the users.

The experiments were conducted online. Video and sound of all sessions were recorded using *NVIDIA GeForce Video Capture software.* Each group was notified to participate days before the session. Participants had to meet the requirements to remotely enter the application: to use a Laptop or Desktop with a minimum memory capacity of 8 GB, running the operating system *Windows* or *MAC OS*; download the dedicated version and software *Zoom* or *Discord*, so that they could communicate verbally within the group. All participants consented to the recording of the session. At the beginning of the session, the group was introduced to the application through a video tutorial. The video shows an example of a user's POV interacting with VVApp's features. This will help the participants to learn the co-presence inducing interfaces functionality easily. After that, the person responsible for conducting the experiment described the first task and asked the group to achieve the objective of the task. After the group finishes a task, the responsible for running the test asks the participants to leave the server, since the application needs to be closed to download the data files. The server comes back up once everything is ready to move on to the next task. The process is repeated for every task. After completing all tasks, a session sheet containing a short questionnaire to fill in at the time of the session was provided to all groups. The first part of the questionnaire captures the familiarity of the participants with video games and looking for houses to buy or rent as a customer, as well as the experience of using the application. The second part of the questionnaire assesses the usefulness of the co-presence inducing interfaces included in VVApp via a set of statements that are to be responded by the participants with a 5- point *Likert* scale (from 1 for "totally disagree with the statement" up to 5 for "totally agree with the statement").

To being able to isolate the analysis of each co-presence inducing interface, a version of VVApp customized for the experiments was developed. This version disables certain interface elements (*interface* hereafter for the sake of compactness) by default, namely: Interface 1 - *Info-bar*; Interface 2 - *Compass*; Interface 3 - *Mini-map*. To enable them, users must use special keys on the keyboard, each corresponding to one of the three interfaces. Enabling one of the three interfaces results in automatic disabling of the other two. The remaining interfaces remain active regardless of the user's options. Additionally, VVApp contains a data collection system that saves essential data for the analysis of the experiment, in CSV format. Participants had to execute, in sequence, the following three tasks:

- **Task 1 (Evaluation of virtual houses)** - The group visits the three virtual houses. Participants go through what is necessary to be able to evaluate the house based on their own evaluation criteria (e.g., visual, architectural). The group has a time limit of 4 minutes to navigate inside the house and organize their critique. The evaluation is done individually, that is, each participant must transmit one's evaluation about the house in question. When the time limit expires, the person in charge of conducting the test asks the participants individually to evaluate the house, even if their assessment is incomplete. During the evaluation, participants can move and use the available co-presence mechanisms. The task ends when the evaluation of the three virtual houses is concluded.

- **Task 2 (Riddle solving)** - The group is asked to solve six riddles in virtual house CVE_3. The area is large enough to convince participants to explore more cautiously in search for the answers. The answers must be provided collaboratively, that is, all group members must agree with the given decision. The group must answer each riddle within a maximum of 2 minutes and 30 seconds. The group must verbally identify the object they consider to be the solution to the riddle. If they have not reached an answer, the group is given one last opportunity to reach an agreement within a short period of time. Participants are free to use all available tools in the application to find the object. The task is completed once the participants answer all the riddles.
- **Task 3 (Pre-defined route)** - The group must follow a predefined route inside virtual house CVE_3. The route contains several intermediate waypoints points that guide participants to their final waypoint. The task starts after the first waypoint is dictated to the participants and they must navigate to that point. This process is repeated from waypoint to waypoint, until the final waypoint. Participants must stop on the respective waypoint in order to proceed to the next one. The task has no time limit, nor a mandatory trajectory. Participants have the freedom move as desired between waypoints.

5. EXPERIMENTAL RESULTS

5.1 Interfaces Utilization Rate

Figure 3 shows the pie charts of the three co-presence inducing interfaces utilization rate. Of the 33 participants, 6 of them did not activate any of three interfaces in Task 1 (18.18%), which contradicts H1. The recordings reveal that these specific participants discussed in more detail the positions of the furniture, the visual appearance of each room, the proportion of the areas, among others, which may justify their lack of need to use to the co-presence interfaces. For the remaining participants, a variety of results were obtained. Interface 3 (*Mini-map*) exhibits a utilization rate of 52,22% (σ = 33,15%), which is higher than the 16.56% (σ = 20.91%) obtained for Interface 1 (*Info-bar*) and the 13,04% (σ = 16,03%) for Interface 2 (*Compass*). On average, 16.48 transitions between interfaces were recorded (σ = 12.70), which reveals that Interfaces 1 and 2, despite having average utilization rate below 15%, were used occasionally.

In Task 2, we can observe differences in relation to the data obtained in Task 1 due to learning effects. Of the 33 participants, 3 of them did not activate any interface, in which 2 of them are the same participants who did not use any of the interfaces in Task 1. These participants were always close to their partners, in the virtual house, while solving riddles. The data files report that participants who did not use any of the interfaces during Task 1, chose Interface 3 (*Mini-map*) in Task 2. For the remaining participants, different results were obtained compared to Task 1. Interface 3 (*Mini-map*) shows a higher utilization rate compared to Task 1. Interface 1 (*Info-bar*) exhibited a utilization rate of 12,33% (σ = 19,70%), whereas Interface 2 (*Compass*) and Interface 3 (*Mini-map*) exhibited 8,68% (σ = 23,05%) and 69,90% (σ = 36,93%), respectively. On average, 6.70 transitions between interfaces were recorded (σ = 7.27). Compared with the results of Task 1, there was a decrease of 25.54% in the average utilization rate of Interface 1 (*Info-bar*), a decrease of 33.44% in Interface 2 (*Compass*), and an increase of 25.30% in Interface 3 (*Mini-map*). Although participants resorted more to the *Mini-map*, the number of interface transitions indicate that users still used the other two interfaces.

In Task 3, we can observe differences in relation to the data obtained from Task 2. Of the 33 participants involved, the same 3 participants reported in Task 2 did not activate any interface. For the remaining participants, significantly different results were obtained compared to Task 2. Interface 3 (*Mini-map*) once again reveals a higher utilization rate compared to the other two. Interface 1 (*Info-bar*) exhibited an average utilization rate of 2,91% (σ = 6,33\%), Interface 2 (*Compass*) of 1,39% (σ = 4,53%), and Interface 3 (*Mini-map*) of 86,61% (σ = 29,10%). On average, 4.52 transitions between interfaces were recorded (σ = 9.28). Compared with the results of Task 2, there was a decrease of 76.40% in the average utilization rate of Interface 1 (info- bar), a decrease of 83.99% in Interface 2 (*Compass*), and an increase of 19.30% in Interface 3 (*Mini-map*). As Task 3 is purely linked to three-dimensional navigation, most participants opted for Interface 3 (*Mini-map*) due to the provided guidance simplicity.

In general, a mixed use of the three interfaces was observed. Interfaces 1 (*Info-bar*) and 2 (*Compass*) reveal a decrease in utilization rate throughout the entire experiment, whereas Interface 3 (*Mini-map*) reveals an increase. At first glance, the results shows that most participants ignored Interfaces 1 and 2 almost completely in the two last tasks. However, the registered interface transitions indicate otherwise. Participants used Interfaces 1 and 2 enough to learn about the identification of partners within the CVE and their positions. The obtained general results corroborate hypothesis H2, which states that the interfaces provide positive collaborative feedback.

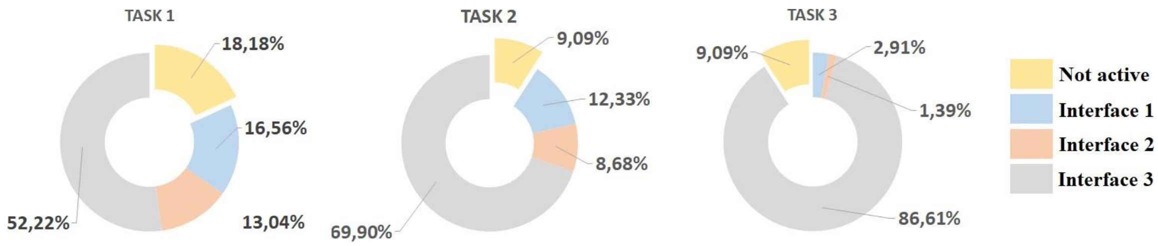

Figure 3. Average interface utilization rate for Interface 1 (*Info-bar*), Interface 2 (*Compass*), and Interface 3 (*Mini-map*)

5.2 Collisions and Pointing

Figure 4 presents the total number of *collisions* between users and the number of *pointing actions* (to insert a marker in the environment). The main objective of this analysis is to study the participant's behavior from the registered number of collisions and pointing actions. The comparison of values between tasks is not included. In Task 1, a total of 430 collisions and 1343 pointing actions were registered, with an average of 39.09 collisions ($\sigma = 27.79$) and of 122.09 pointing actions ($\sigma = 105.46$) per group (roughly 1 collision and 4 pointing actions per minute). Some participants showed care in navigation and curiosity in testing the application in Task 1 (e.g., two of the elements collided on purpose). Most participants used pointing actions to identify objects, furniture, and rooms in their speech, which draw the attention of their partners.

A total of 295 collisions and 1581 pointing actions were registered in Task 2, with an average of 26.82 collisions ($\sigma = 19.74$) and 143.73 pointing actions ($\sigma = 128.98$) per group. The participants resorted considerably to pointing actions, as they help users to jointly identify which object may be the correct answer to the riddle. A total of 506 collisions and 311 pointing markers were registered in Task 3, with an average of 46 collisions ($\sigma = 32.27$) and 28.73 pointing actions ($\sigma = 27.76$) per group. Participants collided more frequently in narrower spaces. The pre-defined route included these narrow spaces with the purpose of observing the trajectories chosen by the participants. The *Pointing* mechanism was used to help participants in indicating a clear space when a misunderstanding occurs.

In Task 1, participants made extensive use of pointing markers to comment on the style of the house or the position of furniture to the partners in the evaluation phase and to identify the objects, rooms, and furniture during their speech. Collisions between partners occurred from time to time. In Task 2, there was clear evidence that the pointing markers significantly helped participants in identifying objects and furniture. The frequency of collisions has decreased, which could mean that the collision avoidance mechanism helped participants navigate cautiously. In Task 3, a high number of collisions and a lower number of pointing markers were observed. This suggests that participants' navigation was compromised although most collisions happened in narrow passages. Participants used the pointing markers to correctly orient their partners.

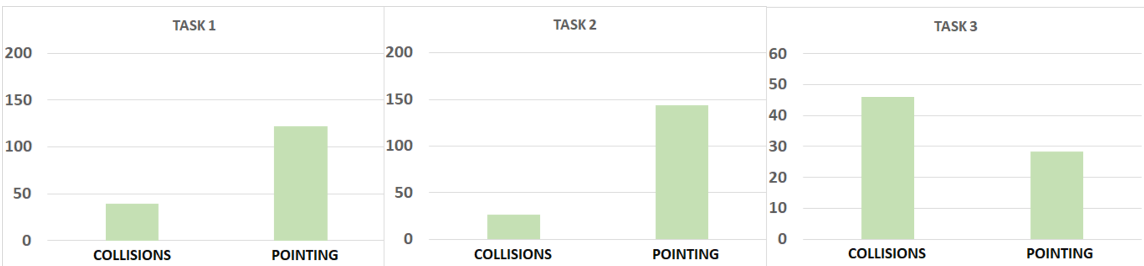

Figure 4. Bar graph of the total number of collisions and pointing

5.3 CO-PRESENCE Mechanisms Subjective Rating

Participants were asked to subjectively rate how often they used each co-presence inducing interface in a 5-point scale (1-not used at all, 5-used very often). Subjective data related to Interfaces 1 (*Info-bar*), 2 (*Compass*), and 3 (*Mini-map*) provided for a given task were discarded for the users that did not actually objectively used anyof these interfaces in that task (data in previous sections).

In Task 1, an average rating of 2.19 (σ = 1.04) was observed for Interface 1 (*Info-bar*), 2.52 (σ = 1.12) for Interface 2 (*Compass*), 4.74 (σ = 0.59) for Interface 3 (*Mini-map*), 4.06 (σ = 1.06) for *Pointing actions*, 3.24 (σ = 1.17) for *text boxes*, and 2.85 (σ = 1.15) for the *collision warnings*. Hence, all interfaces, except for the information bar, revealed a good result in terms of usage by the participants. The *Mini-map* and *pointing actions* were consulted with high frequency. Participants reported a neutral position regarding the *text boxes* and the *collision warning*. Some reported that these two mechanisms helped a lot in performing the task, others indicate the opposite effect. Although with lower frequency, participants reported that have consulted the *Compass* occasionally. *Info-bar* was classified as being even less used because participants studied the avatars' appearance right at the task's onset. In Task 2, an average rating of 2.63 (σ = 1.38) was observed for Interface 1 (*Info-bar*), 2.53 (σ = 1.17) for Interface 2 (*Compass*), and 4.53 (σ = 0.97) for Interface 3 (*Mini-map*), 4.61 (σ = 0.83) for *Pointing actions*, 2.79 (σ = 1.11) for the *text boxes*, and 2.24 (σ = 1.09) for *collision warning*. All implemented mechanisms, except the collision warning, revealed a good result in terms of usage by the participants. The *Mini-map* was heavily consulted, and *Pointing* was considered the top choice for riddle solving. Participants reported a neutral position regarding *text boxes*. The *Compass* and *Info-bar* were consulted a little more than in Task 1. The *collision warning* did not help much in solving the riddle. In Task 3, an average rating of 2.30 (σ = 1.29) was observed for Interface 1 (*Info-bar*), 2.17 (σ = 1.12) for Interface 2 (*Compass*), 4.83 (σ = 0.59) for Interface 3 (*Mini-map*), 3.03 (σ = 1.51) for *Pointing*, 2.30 (σ = 1.24) for the *text boxes*, and 2.76 (σ = 1.32) for the *collision warning*. The *Mini-map*, *text boxes* and *collision warning* reveal positive results in this task. The interface of the *Mini-map* was considered the top choice for navigation. Participants reported a neutral position regarding *text boxes*. The *Compass* and *Info-bar* were consulted less than in Task 2. The *collision warning*, for some participants, did not help in avoiding collisions and, for others, it helped considerably.

The participants consideration of the co-presence inducing interfaces implemented in VVApp varied from taskto task. For task 1, participants reported that the *Mini-map* was the most used to guide themselves inside the virtual houses, while *Info-bar* and *Compass* were used to identify their partner's avatars and position with small frequency. The *Pointing* showed to be a good non-verbal communication mechanism, the *text boxes* were consulted with a certain frequency to identify the registered pointing markers, and the *collision warnings* caught the attention of some. For task 2, participants claim that the interfaces 1 (*Info-bar*) and 2 (*Compass*) are used with some frequency but gave more priority to Interface 3 (*Mini-map*) in solving riddles. The *Pointing* mechanism showed to be very important in identifying objects and furniture, the *text boxes* were consulted with a certain frequency, and the *collision warnings* were not very helpful. For task 3, the participants claim the *Mini-map* to be an essential tool for navigating in the virtual house, using the *Info-bar* and *Compass* as an intermediate support. The *Pointing* mechanism was used only to guide the participants, while the *text boxes* were consulted with a certain frequency. The *collision warnings* got the attention of some participants to be careful when navigating. With this analysis, it can be stated that the implemented co-presence inducing mechanics, in general, enrich group visits to virtual houses, as predicted in hypothesis H3.

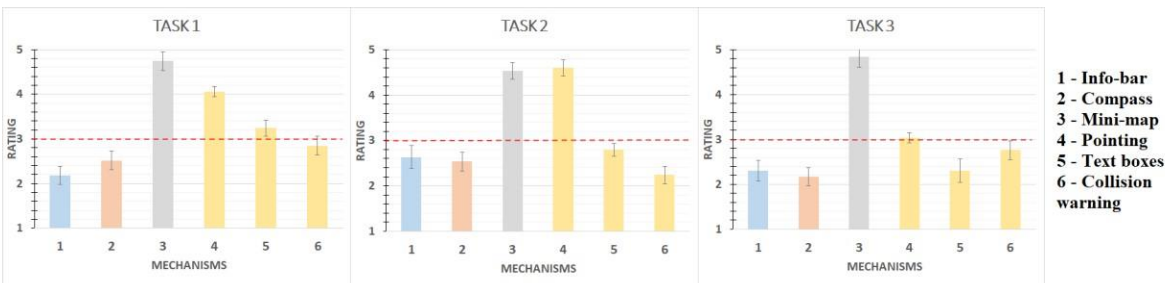

Figure 5. Bar graph of average mechanism rating. It includes a dashed red line that indicates the neutral rating (a value of 3) and the standard error for each mechanism

5.4 Session Form Questionnaire

Table 2 summarizes participants' responses to the session questionnaire: Q1: "Do you have experience with video games?" Q2: "Have you ever played co-op video games with partners you know?" Q3: "Have you been looking for houses to buy/rent before?" Q4: "Would you consider using a system like the one you've been experiencing to help you choose a house in the future?". The responses show that all participants have experience with videogames and recognized the mechanisms implemented in VVApp. All participants, except one, have already played multiplayer videogames with their partners. This reveals that these participants participated in this session with the awareness that they will perform tasks requiring team collaboration. The only participant who had never experienced multiplayer videogames expressed that VVApp's co-presence mechanisms helped a lot in identifying the group partners. A total of 17 participants have already looked for houses to rent or buy. Of these, 12 are over 21 years old. At the end of the session, all participants praised the collaborative experience.

Table 1. Participants' responses to the session questionnaire

Questionnaire							
Q1		Q2		Q3		Q4	
Yes	No	Yes	No	Yes	No	Yes	No
33	0	32	1	17	16	33	0

6. CONCLUSION

A Unity-based collaborative virtual environment, VVApp, designed to include videogame-inspired mechanisms to amplify the co-presence sense of people in virtual group house visits was presented. These mechanisms include an information bar, a visual compass, a small map, pointing actions, text boxes, and user- user collision warnings. Positive results were obtained in a user-study conducted with 33 participants, split in groups of three elements. Concretely, participants frequently used the several co-presence inducing mechanisms to navigate and communicate more efficiently while performing a set of given tasks. All participants had previous experience with multiplayer video games and showed willingness to reuse VVApp. As future work, it would be interesting to study the inclusion in VVApp of two additional co-presence inducing mechanics from videogames: text chat and voice chat. It would also be interesting to study the value of the co-presence inducing mechanisms included in VVApp in different age groups and with users that have no previous experience with videogames.

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