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Understanding the affordances of navigation metaphors in a collaborative virtual environment

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***Abstract*— When designing a collaborative virtual environment (CVE) one important decision is to identify the right interaction technique to be used. This paper takes the position that the interaction techniques used in a CVE have an effect on user's collaborative experience. Paper investigates the effect of three 3D navigation techniques on user's experience when interacting in a CVE. We report the affordances of navigation techniques using different aspects of user's experience such as awareness, perception of collaborative effort, presence and satisfaction. 40 subjects were grouped in pairs of two users to perform a collaborative navigation task. Our results show that giving the user's a direct control of their actions influences positively their copresence and awareness. A direct visual feedback of the partner's point of view is beneficial for the copresence and the awareness. Finally, the space reference and the orientation in the virtual environment (VE) have an impact on the user involvement. These results provide an initial set of guidelines for the design of collaborative virtual environments.**

***Index Terms*—CVE, 3D interaction, human factors**

I. INTRODUCTION

The designer of a virtual environment (VE) has to take into account several factors such as the input and output devices, the design of the interaction technique or the selection of adequate existing techniques, the application domain, etc… [1]. The designer of a VE seeks to optimize user's experience. In a CVE, in addition to the considerations above, the designer needs to take into account the collaborative aspect of user's experience. How does the use of a specific interaction technique affect collaborative effort?

In this paper we investigate the extent to which different navigation metaphors are affecting various aspects of user's experience in a CVE. Section 2 of this paper presents related work describing relevant empirical studies in CVEs and our research approach. In section 3 we describe our experiment, and our research hypotheses. Section 4 presents the experimental results, in section 5 we discuss our findings, in section 6 we propose some design guidelines for CVE then comes the conclusion.

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II. RELATED WORK

2.1 Navigation in VE

Navigation is a very important element in the 3D interaction in a virtual environment. According to Bowman navigation in VE consists of two components [1]: (1) a motor component of user movement or displacement in space, and (2) a cognitive component. There are several techniques of displacement, these techniques can be classified according to the navigation metaphors being used. Generally there are two categories of metaphors, the real metaphors like the walk or the driving metaphors [1], or the magic metaphors which give to the users magic capapability by eliminating the physical constraints from the real world. One can quote for example the map metaphor which allows users to move by specifying the coordinates target has to reach, or the "World in Miniature" [2]. The cognitive component also named "wayfinding", is a cognitive process which makes it possible to define a way in a virtual environment by building a "cognitive map" of the space [1]. The formation of a cognitive map of a virtual space requires three types of space knowledge: the landmark knowledge, the route knowledge and the survey knowledge. According to Passini during the exploration of a new environment, people start initially with "sweeping/scanning" the environment to locate the important points in the space (important places and objects) [3]. This is the process of landmark knowledge, then, they structure their knowledge to create relations between different landmarks composing this environment, to be able to move and reach their destination (route knowledge). During their displacement, additional spatial information is added to their knowledge, allowing them to gain an overall view of the environment (survey knowledge).

There are various metaphors of navigation which have been already proposed, these metaphors can be classified in two categories [4]:

1) **Direct Camera Control Metaphors**: In this type of metaphors the user controls directly the position and the orientation from his/her point of view by using an input device.

- **User Centric Camera Control:** among this category of metaphors we can quote the "eyeball in hand" and "scene in hand" metaphors, proposed by [5], also the "World in Miniature" proposed by [2].
- **Object Centric Camera Control:** we find the "scene in hand" [6].

2) **Indirect Camera Control Metaphors**: this category gives the user an indirect control of the position and the orientation of his/her point of view. We can quote for example the "Teleportation" metaphor [7], also the "small scene manipulation" [8].

In the literature one finds many work related to navigation in VE, in particular in space cognition. In their studies Ruddle et al show that the acquisition of space knowledge is possible in VE "navigation in real and virtual worlds was comparable" [9]. According to Ruddle et al the type of visualization (immersive or not), does not have an influence on the acquisition of space knowledge in VE, even if the perception of distance is in an immersive VE [10].

The work developed by Wilson et al showed that the mode of exploration (e.g., active exploration where the subjects can move freely in the virtual world or "passive" exploration where subjects must follow a preset route) does not have a significant effect on knowledge acquisition space for none immersive VE [11]. The study reported by Gaunet confirmed these results [12]. They didn't find any effect of the exploration conditions on the direction pointing task and the landmark knowledge identification task.

The study carried out by Scribante showed that in active mode of exploration, the techniques of displacement affect the space knowledge acquisition in non immersive VE [13].The result of the experiment described in this work showed that "walk" technique allowed better knowledge acquisition of routes than "fly" technique.

In Carassa's experiment the authors are interested in exploring the effect of the exploration conditions on the acquisition of space knowledge [14]. While Carassa's results converge with the results obtained by [11] and [12]. Carssa stressed the importance of others factors such as the type of activity the spatial knowledge supports, the type of environment and the learning mode. Vinson suggested the use of landmark knowledge in VE positioned in strategic places, in order to facilitate space reading [15]. Ruddle indicated the importance of the use of "realistic" and "familiar" landmark knowledge to facilitate the acquisition of space knowledge, landmark knowledge, and route knowledge [16].

There have been a number of empirical studies carried out for the evaluation and comparison of navigation techniques. Bowman used a testbed to compare seven navigation techniques for naïve search and primed search in virtual space [17]. Dodds et al developed new Mobile Group Dynamics (MGDs) to help people work together in a CVE. These MGDs are: teleoperating, awareness and multiple views evaluated in a context of urban planning application. One group of subjects used MGDs, and another group of subjects used conventional CVE. The result of this study showed that the communication between subjects is enhanced in the MGDs condition compared to conventional CVEs. The use of these MGDs improves the level of sensory information (the awareness of who spoke, who could hear, and the provision of multiple views which provides additional visual information). The subjects used these MGDs remained in proximity of their partner. They liked to be together over a long period of time, and they liked to gather after periods of separation [18,19].

The studies carried out by Ruddle showed that the use of a combination of various types of maps simultaneously presented in large scale VE, improves the participant capacity to search objects. The inclusion of the compass and the numerical co-ordinates does not affect the search effectiveness [10] [20]. The use of the map and the grid improved the participant navigation according to the work published by [21].

2.2 Empirical Studies in CVEs

A number of empirical studies in CVEs have been reported in the literature. These studies include:

Effect of realism of the avatar on social interaction - In order to investigate its impacts on social interaction in CVE, the level of realism has been studied under different perspectives.

Gerhard showed that the degree of presence is higher when using a humanoid avatar than an avatar of a shape type or a cartoon type [22]. The use of a humanoid avatar allows better immersion, communication between users, engagement and awareness. Nevertheless Garau showed that the use of a little anthropomorphic[1] representation leads to a higher sense of copresence and social presence than the use of a precise anthropomorphism or no anthropomorphic representation [23]. Bailenson suggested that visual and behavioral realism must be carefully balanced [24].

Effect of immersion on Groups dynamics - In order to investigate small groups' dynamics Slater conducted an experiment where three subjects carried out a collaborative task [25]. Two participants used a computer screen and the third participant used a head-mounted display (HMD). The collaborative task was performed in face-to-face condition and in virtual world condition. The results of this study showed that the participants using the HMD condition developed a leadership behavior. Schroder showed that users, immersed in CVE, naturally adopt dominant role compared to participants using the desktop setup [26].

Another study carried out by Casanueva showed that copresence score was higher in high-collaboration VE than in low-collaboration VE [27].

Effect of symmetric and asymmetric interaction on communication -The Roberts study investigate the effectiveness of supporting teamwork among a geographically distributed group in a task that requires a shared manipulation of objects [28]. The task used in Roberts study is a closely coupled task at a building site requiring the use of multiple tools to build an artifact. The results of this study shows that a task requiring various forms of shared object manipulation is achievable with today's technology. Also this study shows that the distributed building task has been undertaken successfully between remote sites on many occasions, sometimes linking up to three remote walk-in displays and multiple desktops.

The Pinho is focused on how to support cooperative interaction and how to modify existing interaction techniques to fulfill the needs of cooperative tasks [29]. Pinho presented a framework to allow cooperative object manipulation by using the collaborative metaphor concept that allows the combination

[1] Anthropomorphism : attribution of human characteristics, or behavior to inanimate objects, animals, or natural phenomena

of multiple manipulation techniques. This study shows that the use of a cooperative technique is applicable to those situations in which cooperation allows the users to control some DOFs that cannot be controlled with the single-user technique.

Rudlle in his studies looks at the verbal communication of participants in CVE. The authors used the task of piano movers' (maneuvering a large object through a restricted space) [30] and [31]. The task consisted of moving collaboratively an object from a starting point to an end point. Participants performed this task under two conditions: in a symmetric interaction where only the synchronized actions are allowed and in an asymmetric interaction using two different conFig.ations of the CVE, an Offset CVE and a C-shaped CVE. The study reports that the subjects communicate better in the symmetric interaction condition than in the asymmetric one. It also reports that the speed and the direction of the movements of the hand coordination were poor under the two conditions.

[32] study investigates the effects of frames of reference on collaboration in a distributed and collaborative spatial environment. The study compares three combinations of frame of reference (exocentric-exocentric, egocentric-egocentric, and exocentric- egocentric) using two roles (actor and director) to investigate awareness issues. The results demonstrate that frames of reference affect collaboration in a variety of ways and simple exocentric egocentric combinations do not always provide the most useable solution.

Yang and Olson have also investigated the effect of the dimension of egocentric-exocentric perspectives on collaborative navigation performance [33]. Yang and Olson found that when different perspectives are employed, groups struggle to perform the spatial, mental transformations required to see the same objects. The results of this study favor an egocentric perspective display.

In Hindmarsh study participants were asked to collaboratively arrange the lay-out of furniture in a virtual room and agree upon a single design [34]. They were given conflicting priorities in order to encourage debate and discussion. This study shows that participants were able to make reference to objects in the shared environment through pointing gestures. However, problems of fragmentation were observed. These problems were due to a discontinuous visualization during the realization of the task .caused by the desktop screen. In order to compensate for the fragmentation of the workspace, users increase their verbal communication using audio. Also Ruddle study explains that a high quantity of verbal communication is employed to compensate for the fragmentation of the work place on a desktop screen [30].

Effect of media on presence and communication - Nakanishi compared the movement of users in three different conditions that is face-to-face, videoconference and FreeWalk. FreeWalk is a desktop meeting environment that provides a 3D community common where everybody can meet and can behave as in real life [35]. Participants are represented as a pyramid of 3D polygons on which individual live video is mapped, and can move freely. The results show that the participants have better communication in FreeWalk compared to the other two conditions. Participants also moved better in FreeWalk.

Sallnas compared three types of communication (chat, audio, and audio-video) and their effect on presence [36] in CVE. Their findings show that the level of social presence and virtual presence is higher with the audio condition. The audio-video users dialogue less than with chat and audio.

Intuitivity - Greenhalgh investigated the notion of intuition using the teleconference platform “MASSIVE” (Model, Architecture and System for Spatial Interaction in Virtual Environments.) [37]. This system allows multiple users to communicate using arbitrary combinations of audio, graphics and text media over local and wide area networks. The results showed important role of the audio communication in collaboration and the field of view for graphical users, speed of navigation, quality of embodiment, varying perceptions of space and scalability.

Turn taking - Bowers addressed the problems of turn-taking in a CVE setting. Turn-taking is one of the basic mechanisms in all types of dialogues and multilogues (conversations involving more than two people) [38]. He concludes that users of this kind of environment take systematically advantage of their virtual representation in order to solve or to anticipate the problems of turn-taking, for example users position their avatar opposite the avatar of their partner in order to create a “face engagement”.

2.3 Conclusion from literature review

3D interaction in CVEs has been an important topic of research since several years. Published empirical studies on CVEs have investigated the effect of media on a number of aspects of user’s experience in a CVE (presence, communication, turn taking, intuition etc). Also a relatively recent number of empirical studies investigated 3D interactions techniques and metaphors in a CVE with a focus on the collaborative effort. Our work is an extension of this important research effort we propose to study the effects 3 metaphors of navigation in a CVE have on various dimensions of the user experience. This is an important research question and provides the basis for our work.

Several questions are asked when the interaction metaphors are to support a collaborative task in a CVE, these questions are psychological, social or even related to the task performance. Users in a CVE need:

- to know where their partner is,
- to know/ be aware of what their partner is looking at,
- to be aware of their partner’s orientation (their partner intentions in term of navigation).

The investigation of these metaphors, will allow us to understand how these 3D navigation metaphors influence the user’s experience, and the task performance (see Fig. 1).

III. EXPERIMENT

In this experimental study, we would systematically vary three conditions (MAP metaphor, AVATAR metaphor, LIGHT metaphor) and investigate their impact on several dependent variables (collaborative effort, involvement /awareness, copresence, social presence, usability, satisfaction, preference, task performance). In the following, the design of the experiment is described in more depth.

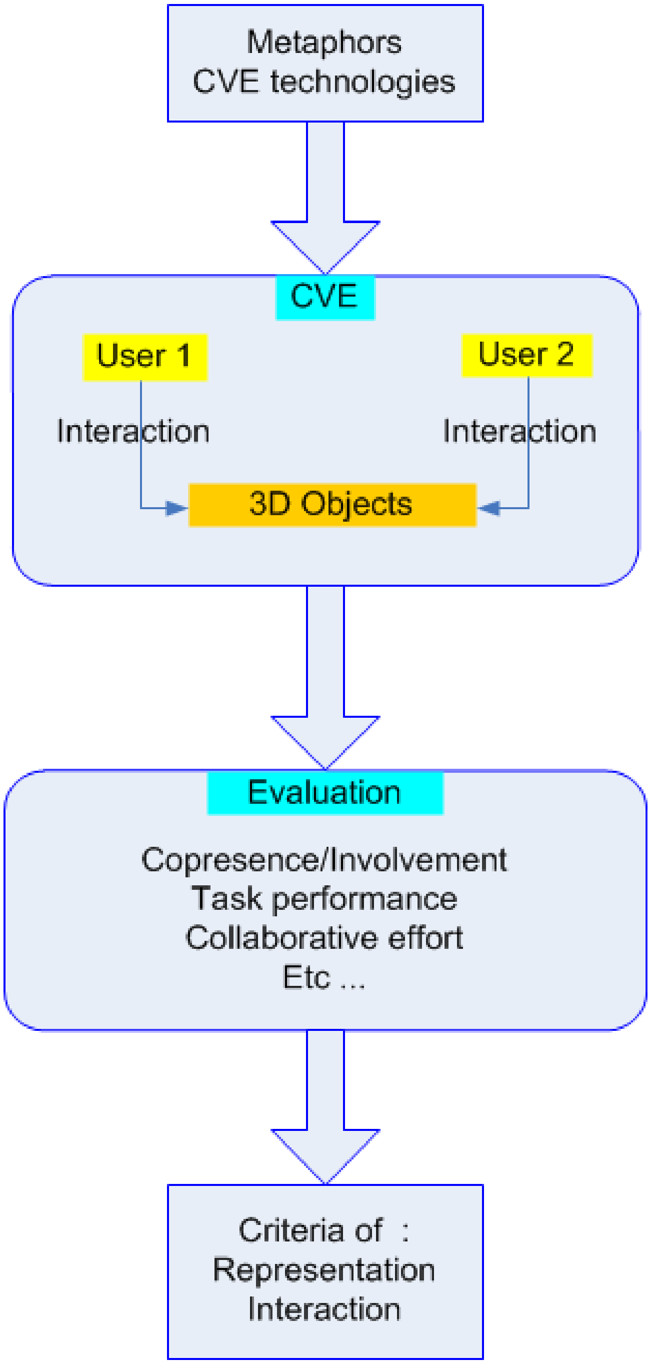


Fig. 1. Scientific approach used

3.1 Task

We asked two participants (a group of two participants per session in two geographically remote locations) to move in a VE (Fig. 2) using navigation metaphor to inspect three objects representatives virtual stone positioned in different locations in the scene and assessed the intensity of the yellow contain these stones. For each condition (metaphor) the stones change, that is, for the first metaphor participants must inspect three stones, then for the second metaphor they must inspect three other different stones of the previous three and so on.

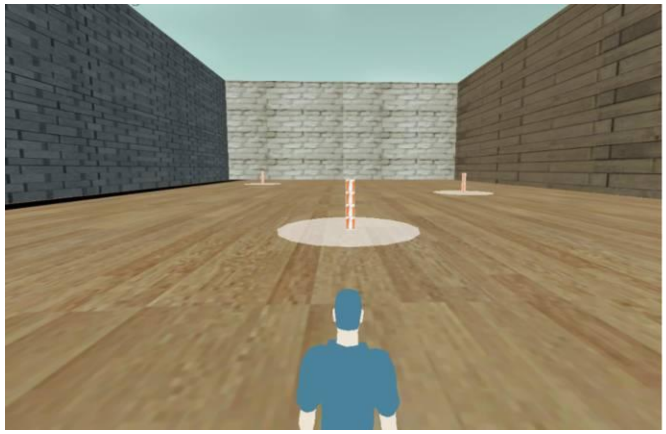


Fig. 2. The EV used in the experience

In this experience, it is important for users to inspect objects in a collaboratively; that is, users must inspect the same stone at the same time. To do this, we have introduced an additional condition to display the object if two users are close to this object (Fig. 3).

Fig. 3. Situation of two avatars inspecting a virtual object

Partners must agree and designate one among the three present objects in the scene. Carrying out this task requires navigation using a navigation metaphor and collaborative inspection. Participants must take into account the volume and the shape of each object and the distribution of the yellow spots and other spots on these objects. The task requires detailed observation and accurate evaluation of the existence of the yellow colour relative to the shape of each object. For these reasons that we decided to use this task to experience (Fig. 4).

This task is inspired by an industrial context, in the area of mines. Work teams are increasingly brought to gather people from different geographical locations, often very remote from each other, in order to inspect stones.

Fig. 4. Example of 3D objects used

3.2 Independent variables

In a collaborative inspection task, the user needs to know the position and the point of view of his/her partner in the scene. These are the criteria on which we based our choice of the three navigation metaphors:

- **The partner point of view**. It concerns the representation of the partner point of view. We analyzed two possible choices:
  - Direct partner point of view: the point of view of the partner is directly integrated in the scene.
  - Indirect partner point of view: the point of view of the partner is represented in a window outside the scene.
- **The spatial position control of the scene**. It concerns the way in which the user controls his position and orientation in the scene. Two types of control are possible:
  - Direct control: the user controls his space position in a direct way,
  - Indirect control: the user controls his spatial position via an intermediary.

Hence, we selected three existing metaphors of navigation which satisfy the characteristics established by the criteria. They are the following:

- **The MAP metaphor**: indirect control + the partner point of view in an additional window.
- **The AVATAR metaphor**: direct control + the partner point of view in an additional window.
- **The LIGHT metaphor**: direct control + the partner
- point of view integrated in the scene.

1) The MAP metaphor (condition 1)

This navigation metaphor is based on the pursuit of a priori known target, user is represented by a small icon on a small map of the VE, this map is located at the bottom left of the scene. User movements are indirectly controlled by change the 2D position of the icon.

Using a 3D optical tracking system coupled with the Wiimote (see section 4.5), user controls its position and its angle of view in the scene. The 3D tracking system is used to detect and track the position of a reflecting ball positioned on the Wiimote. The Wiimote system is used to get information on spatial orientation of the user, the Wiimote is also used for discrete inputs (buttons).

When the user points to a position on the map, and the Wiimote button B is pressed, then manipulation of the icon begins, the icon should follow the point position in the map coordinate system. When the button is released, the user icon is moved one last time to the point position.

To control its views the user manipulates the Wimote depending on the orientation axis (Pitch and Yaw). The MAP metaphor allows the user to have the point of view of its partner in a small window at the bottom right of the scene (see Fig. 5).

Fig. 5. Screenshot Condition “MAP”

2) The AVATAR metaphor (condition 2)

For this metaphor user moves through the CVE by directly controlling the position and the view of his avatar using the Wiimote.

Like the video games types FPS, the user navigates in the scene using the Wiimote buttons, arrow up to advance, arrow down to go backward, arrow right turn right, arrow left turn left.

Similarly the previous metaphor user uses the Wiimote to control its point of view that is manipulating the Wiimote as orientation axis (Pitch and Yaw). Also in this metaphor user can see the point of view of its partner in a small window at the bottom right in the scene (Fig. 6).

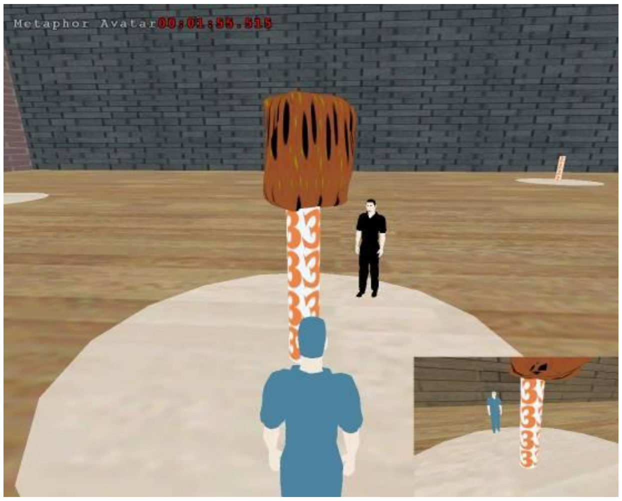


Fig. 6. Screenshot Condition "AVATAR"

3) The LIGHT metaphor (condition 3)

The LIGHT metaphor allows the user to navigate by using the buttons on the Wiimote in the same way as the avatar metaphor that is (arrow up to advance, arrow down to go backward, arrow right turn right, arrow left turn left), also the view of the user is controlled in the same way that the previous metaphors (by manipulating the Wiimote user change his point of view).

The difference between this metaphor and the AVATAR metaphor is the partner point of view, in this metaphor user can see the point of view of its partner directly into the scene without using any additional window. Indeed the scene a light attached to the point of view of the partner. This light was chosen in such a way has not to disrupt the user vision in the scene. Thus this metaphor allows the user to have a direct feedback from the point of view of its partner (Fig. 7).

Fig. 7. Screenshot Condition "LIGHT"

3.3 Dependent variables

We used the following measures in order to study the impact of the navigation metaphors on CVE:

– **Self-assessment measurements**

Via self-assessment we measured the following variables :

1) The collaborative effort

The collaborative effort is the work which two partners provide to achieve a specific task collaboratively. We use Biocca measure of collaborative effort [39]. Four statements addressed a perceived sense of collaborative effort, on a likert scale from 1 to 7. This questionnaire was used by Biocca in an experiment comparing face-to-face interaction with audio-video teleconferencing [39].

Four statements addressed a perceived sense of collaborative effort, on a Likert scale from 1 to 7.

☐	☐	☐	☐	☐	☐	☐
strongly disagree			undecided			strongly agree

Questionnaire items:

1. *My partner worked with me to complete the task*
2. *I did not help my partner very much?*
3. *My partner did not help me very much*
4. *I worked with my partner to complete the task?*

2) The copresence

Copresence means the subjective sense of being together or being co-located with another person in a computer-generated environment. Two items address copresence, on a likert scale from 1 to 7, from Schroder questionnaire [26].

Two items are addressed copresence, on a Likert scale from 1 to 7.

Questionnaire items:

1. *To what extent did you have a sense of being in the same room as your partner?*

2. *When you continue to think back on the task, to what extent do you have a sense that you are together with your partner in the same room?*

3) The satisfaction

Three items addressed the satisfaction, on a Likert scale from 1 to 7.

Questionnaire items:

1. *How satisfied are you by using this selection/manipulation technique?*
2. *I would recommend this navigation technique to a friend?*
3. *This navigation technique is fun to use?*

4) The usability

According to Brooke [40], usability is a general quality of the appropriateness to a purpose of an artefact [40]. That means the context which a system is employed influence the usability of this system or tool [41].

Four items captured the usability of each metaphor, on a scale of 1 to 7 [42].

Questionnaire items:

1. *It is easy to use this technique for navigation?*
2. *This interaction technique is flexible for navigation?*
3. *I can recover from mistakes quickly and easily?*

4. *I used this navigation technique successfully every time?*

5) The preference

User's preferences for the three conditions were assessed using four items.

Questionnaire items:

1. *"If I had the choice when solving tasks like these I would choose:"*

(1)The MAP metaphor (2) The AVATAR metaphor (3) The LIGHT metaphor

2. *It was easiest for me to coordinate my actions with my partner when I used*
3. *It was easiest for me to predict my partner action when hi\her used*
4. *It was easiest for me to navigate when I used.*

6) The Involvement /awareness

In the case or two people being in the same VE, these people generate signs enabling them to have knowledge of the actions and intentions of their partner. This knowledge of the other which results from its interactions with the environment is often indicated in the literature by the "awareness". The awareness makes it possible two partners to adapt and plan their behaviors according to what they mutually know of the other.

According to Hofmann [43] the involvement is a presence facets. Involvement describes to what extent the participant's attentional resources are directed to the VE.

We use Gerhard measure of awareness [22], four items captured the perceived sense of involvement and three items the awareness on a likert scale from 1 to 7. This questionnaire was used by Gerhard [22] to investigate the influence of the appearance of avatars on involvement and awareness. Subjects (n=27) performed a collaborative judgment task.

Four items captured the perceived sense of involvement and three items the awareness on a Likert scale from 1 to 7.

Questionnaire items: (involvement)

1. *"Were you involved in communication and the experimental task to the extent that you lost track of time?"*
2. *To what extent did events occurring outside the 3D scene distract from your experience in the virtual environment?*
3. *I was an active participant in the task.*
4. *I enjoyed the virtual environment experience.*

Questionnaire items: (awareness)

5. *"I was aware of the actions of other participants"*
6. *I was immediately aware of the existence of other participants.*
7. *How aware were you of the existence of your virtual representation?*

7) The Social presence

Social presence was measured with a semantic differential scale. The participants were asked to rate the respective communication media on a seven point scale with altogether 9 bipolar pairs [44].

I Rate the type of medium I just used to collaborate with others as:

Insensitive	☐	☐	☐	☐	☐	☐	☐	Sensitive
Small	☐	☐	☐	☐	☐	☐	☐	Large
Ugly	☐	☐	☐	☐	☐	☐	☐	Beautiful
Impersonal	☐	☐	☐	☐	☐	☐	☐	Personal
Colourless	☐	☐	☐	☐	☐	☐	☐	Colourful
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Passive	☐	☐	☐	☐	☐	☐	☐	Active
Unsociable	☐	☐	☐	☐	☐	☐	☐	Sociable

– **Objective measures**

We measured the task performance by measuring the total time required to complete the task.

3.4 Research hypotheses

The level of interaction with the virtual environment influences presence positively. Thus, we assume that the most interactive metaphor will benefit presence and copresense most. From this finding we derive hypothesis 1:

Hypothesis 1: The LIGHT and the AVATAR metaphors lead to higher copresence than that of the MAP.

According to the work of Singer immediate answers and the degree of control in the user's actions in VE positively influence presence [45]. From this finding we derive that metaphors with an immediate visual feedback and more control will increase copresense. Therefore, hypothesis 2 is:

Hypothesis 2: The LIGHT metaphor increases copresense and awareness more than the MAP metaphor.

The engagement of a user compared to a CVE is related to the knowledge of their spatial orientation, i.e. spatial orientation improves involvement. If the user does not know their position or orientation in the environment, a feeling of nonmembership of this environment is the consequence. We derive hypothesis 3:

Hypotheses 3: The spatial orientation will improve involvement; this implies a MAP metaphor will lead to higher involvement than a LIGHT or an AVATAR metaphor.

3.5 Experimental platform

For providing motion capture into our platform, we integrate a hybrid motion tracking system. This system is the result of the combination of our own 3D tracking system and the Nintendo Wiimote. Our 3D tracking system works with two infrared cameras and reflecting markers. Our tracking system uses stereoscopy where two cameras are used and equipped with infra-red projector. The infra-red rays are then returned by reflective markers, the resulting monochromic images are analyzed in order to give 3D positions of our markers in real-time. The Nintendo Wiimote is a wireless versatile interaction device with several functions. We use this device for capturing orientation in the (Pitch and Yaw) axis.

In order the make the Wiimote communicate with our application we used the Bluetooth Technology. Thanks to a

USB adapter and the corresponding software called BlueSoleil, we can connect the Wiimote to the PC.

In our system the position is given by the 3D tracking system. The Wiimote only used get orientation (Pitch and Yaw) and discrete input buttons.

Our collaborative platform is made of two Braccetto systems (Fig. 8). The platform is composed of a computer Intel ® Xeon ™ CPU 3.0 GHz, equipped with two 1920x1080 resolution LCD screens. The conFig.ation of these two screens can be changed depending on the application. These two systems are connected by UDP/IP network architecture (Fig. 9). Concerning the implementation part we used the C++ programming language as well as opensource libraries (we have used graphics engine Irrlicht.) Also, we used FMOD audio engine for managing sounds in the application. (For the network, we used the network RakNet engine).

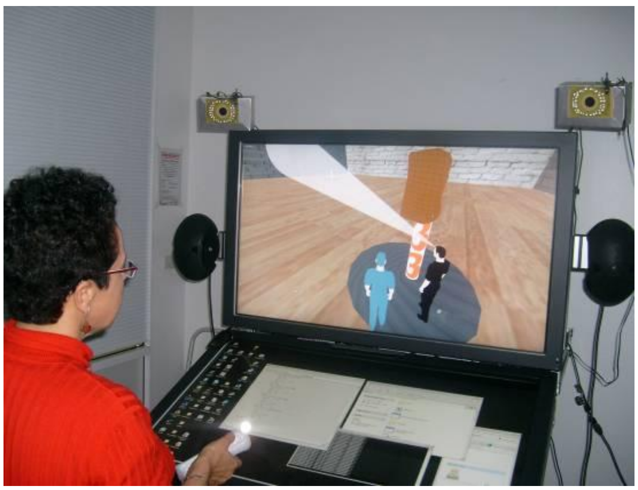


Fig. 8. The experimental platform

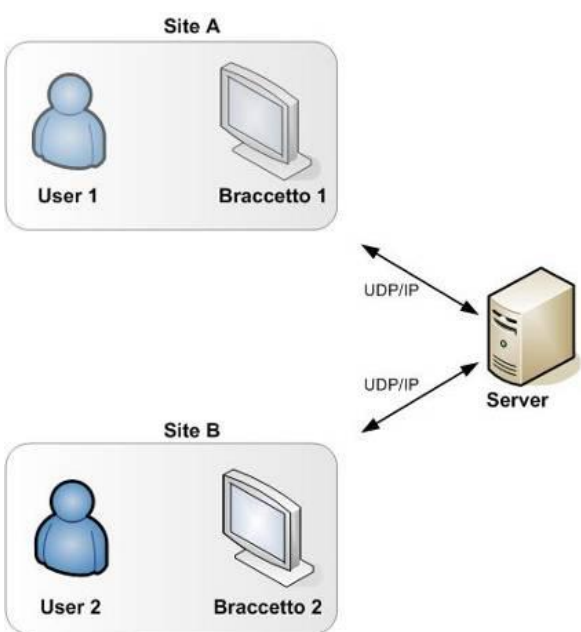


Fig. 9. Diagram of the system architecture

3.6 Participants

We recruited the majority of our participants at the Macquarie University in Sydney, Australia. Participants were recruited via email advertisements and by flyers posted around the campus. The total number of participants is 40 (female participants represents 32.5% of the sample). Altogether, they were 20 sessions (two participants for each trial). The age of these participants is from 18 to 55 years with an average age (M) of 26.05 years and a standard deviation (SD) of 8.44. The necessary conditions for including potential participants were: age more than 18 years, a normal or a correct vision, and fluent in spoken English. At the end of the trial participants received each a movie ticket for their participation.

3.7 Procedure

We placed the participants in two rooms that were approximately about thirty meters apart from another. Before the experiment, participants read the general instructions. Then, they signed a consent form. Then we trained the participants how to control the system and explained the use of each metaphor. This took approximately 10 to 15 minutes. They then answered an entry demographics questionnaire on-line to collect some details about the participants such as gender, age, occupation, proficiency of English language, video game experience, previous use of Wiimote, etc.

We asked the participants in each session to carry out the task collaboratively by using navigation metaphors and to answer after each condition an on-line questionnaire. For the last condition they also answered an exit questionnaire where they expressed their preferences.

During the experiment participants could not see their partners directly, but only in the virtual environment via their virtual representation, i.e. their avatar. They solely communicated using the audio connection.

Each trial lasted approximately 45 minutes. At the end of the experiment the participants were brought together in one room for a debriefing and to ask them about their experiences and impressions of the trial.

IV. RESULTS

The results presented in this section have been analyzed using SPSS version 16. We used one-way ANOVA to compare mean differences using both 5% and 1% confidence levels. We used Scheffe post-hoc comparisons to determine which pairs of groups are significantly different. Also, we used a Person's correlation analysis to investigate the relationship between dependent variables.

– **Copresence :**

The average copresence value of the participant using the LIGHT metaphor is 5.67, compared 4.95 of the AVATAR metaphor user and 4.62 for the MAP metaphor user. The differences between the three groups are significant (F (2,117) =5.2, p=0.007, see Fig. 10) Post-hoc testing revealed that MAP and LIGHT are significantly different (p=0.006) (see Table 1).

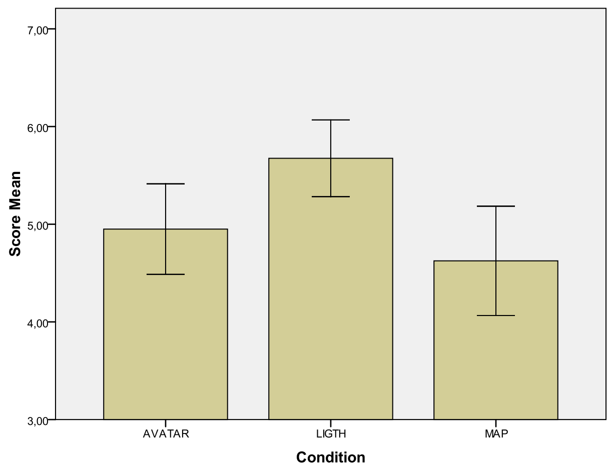


Fig. 10. Mean difference in copresence

TABLE 1: POST-HOC COMPARISONS BETWEEN CONDITIONS (COPRESENCE)

Condition	Significance
AVATAR -MAP	p=0.623
MAP-LIGHT	p=0.006**
AVATAR-LIGHT	p=0.098

– **Social Presence:**

The average social presence value of the participant using the AVATAR metaphor is 4.90, compared to 4.89 of the LIGHT metaphor user and 4.68 for the MAP metaphor user. The differences between the three groups are no significant (F (2,117) =0.59, p=0.591) see Fig. 11.

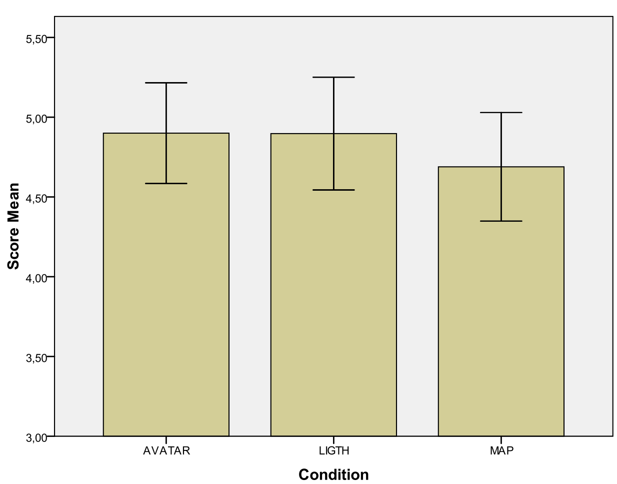


Fig. 11. Mean difference in the Social Presence

– **Involvement:**

The average involvement value of the participants using the MAP metaphor is 5.03, compared to 4.75 of the LIGHT metaphor user and 4.35 for the AVATAR metaphor user. The differences between the three groups are significant (F (2,117) =5.1, p=0.007, see Fig. 12). Post-hoc testing revealed that MAP and AVATAR are significantly different from each other (p=0.007) (see Table 2).

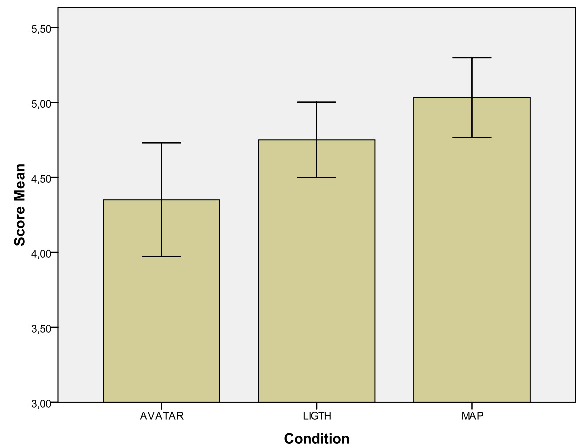


Fig. 12. Mean difference in the involvement

TABLE 2: POST-HOC COMPARISONS BETWEEN CONDITIONS (INVOLVEMENT)

Condition	Significance
AVATAR -MAP	p=0.007**
MAP-LIGHT	p=0.421
AVATAR-LIGHT	p=0.176

– **Collaborative effort:**

The average collaborative effort value of the participant using the LIGHT metaphor is 4.58, compared to 4.28 of the AVATAR metaphor user and 4.03 for the MAP metaphor user. The differences between the three groups are significant (F (2,117) =4.98, p=0.008, see Fig. 13). Post-hoc testing revealed that MAP and LIGHT are significantly different from each other (p=0.008) (see Table 3).

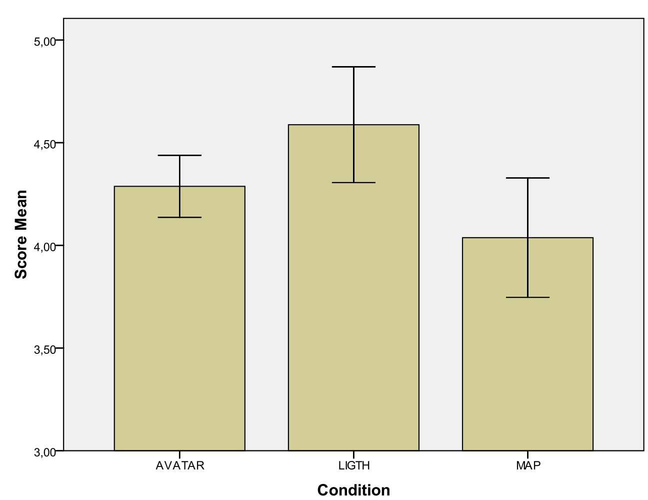


Fig. 13. Mean difference in the collaborative effort

TABLE 4: POST-HOC COMPARISONS BETWEEN CONDITIONS (COLLABORATIVE EFFORT)

Condition	Significance
AVATAR -MAP	p=0.361
MAP-LIGHT	p=0.008**
AVATAR-LIGHT	p=0.232

– **Awareness:**

The average collaborative effort awareness value of the participant using the AVATAR metaphor is 6.00, compared to 5.78 of the LIGHT metaphor user and 5.17 for the MAP metaphor user. The differences between the three groups are significant (F (2,117) =5.15, p=0.007, see Fig. 14). Post-hoc testing revealed that MAP and AVATAR are significantly different from each other (p=0.01) (see Table 4).

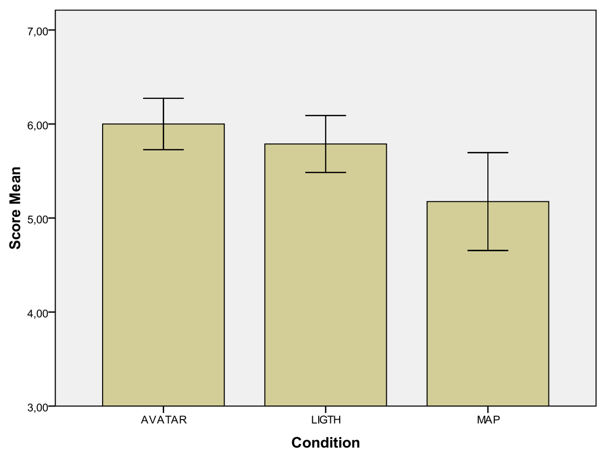


Fig. 14. Mean difference in the awareness

TABLE 3: POST-HOC COMPARISONS BETWEEN CONDITIONS (AWARENESS)

Condition	Significance
AVATAR -MAP	p=0.01**
MAP-LIGHT	p=0.076
AVATAR-LIGHT	p=0.729

– **Usability:**

The average usability value of the participant using the LIGHT metaphor is 5.75, compared to 5.23 of the AVATAR metaphor user and 4.28 for the MAP metaphor user. The differences between the three groups are significant (F (2,117) =11.44, p=0.001, see Fig. 15). Post-hoc testing revealed that MAP and LIGHT are significantly different from each other (p=0.001) and AVATAR and MAP are also significantly different from each other (p=0.01) (see Table 5).

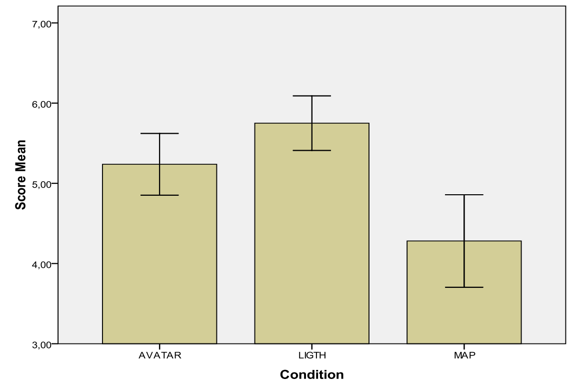


Fig. 15. Mean difference in the usability

TABLE 5: POST-HOC COMPARISONS BETWEEN CONDITIONS (USABILITY)

Condition	Significance
AVATAR -MAP	p=0.011**
MAP-LIGHT	p=0.001**
AVATAR-LIGHT	p=0.263

– **Satisfaction:**

The average satisfaction value of the participant using the LIGHT metaphor is 5.08, compared to 4.60 of the AVATAR metaphor user and 4.17 for the MAP metaphor user. The differences between the three groups are significant (F (2,117) =3.15, p=0.046, see Fig. 16). Post-hoc testing revealed that MAP and LIGHT are significantly different from each other (p=0.047) see Table 6.

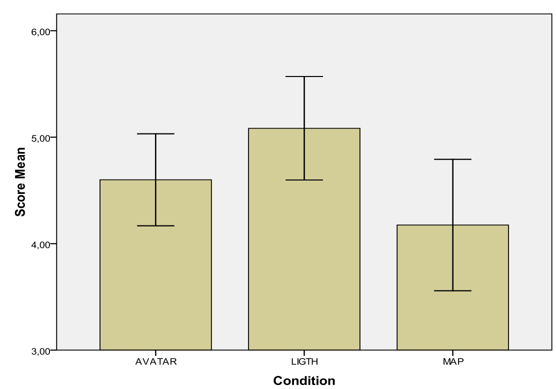


Fig. 16. Mean difference in the SATISFACTION

TABLE. 6 POST-HOC COMPARISONS BETWEEN CONDITIONS (SATISFACTION)

Condition	Significance
AVATAR -MAP	p=0.504
MAP-LIGHT	p=0.047*
AVATAR-LIGHT	p=0.413

– **Preference:**

The analysis of the results of the questionnaire about relating to the user preference shows that 40% of users prefer the LIGHT metaphor, 31% of the participants preferred the AVATAR metaphor and 29% of participants prefer the MAP metaphor.

– **Task performance :**

All participants succeeded in choosing the correct object collaboratively. The time to complete the task shows that participants using the MAP metaphor spend 131.23 seconds to perform the task whereas AVATAR metaphor user spend 137.488 seconds, and LIGHT metaphor user needed 142.21 seconds without significant differences between the conditions ($F(2,117) = 0.029$ $p=0,971$).

– **Correlations**

An analysis was performed between the various variables, in each condition, to check if any it significant relationship between variables may exist. We obtained a significant correlation between the following variables:

- Usability and satisfaction ($r = 0.606$, $p = 0.001$)
- Social presence and copresence ($r = 0.415$,$p = 0.001$)
- Social presence and satisfaction ($r = 0.475$, $p = 0.001$)

V. DISCUSSION

The results of this study show that the LIGHT condition has significantly higher scores over the MAP condition in copresense measure. This result confirms our research hypothesis. The LIGHT condition also reports higher score over the Map condition in collaboration effort, useability and satisfaction measures. Also 40% of the participants preferred the LIGHT condition and 29% of the participants preferred the Map condition. These results suggest that the LIGHT condition is best suited for supporting collaborative inspection task in a CVE then the Map condition. The LIGHT condition not only provides direct control for navigation it also integrates the information in the visual windows directly into the scene. We did assume that the LIGHT condition will have higher score in awareness over the Avatar condition but this hypothesis was not verified. We have yet to find an explanation for this.

We found that users reported lower sense of copresence and awareness when using the MAP condition This may be explained by the fact that this metaphor contains three views of the VE: one overall view of the VE, one view of the partner's point of view and another view of the map . The provision of multiple views may have confused users and affected negatively their spatial perception.

While users involvement/engagement was reported high when using the MAP metaphor, users did find the Map difficult to use and their satisfaction with the Map was low. In our view the Map metaphor did not match the navigation requirements of the collaborative visual inspection task. This task required mostly small displacements not easily performed with a Map which is better used for big displacement, Users did have to work harder in the Map condition which may have resulted in an increase of users level of involvement/ engagement in the VE just to be able to perform the task.

We notice that there is a statistically significant relationship between copresence and awareness. According to Ruth copresence refers to the mutual awareness between participants [46]. This explains the relationship between the copresence and the awareness.

We found a significant correlation between usability and satisfaction. We argue that navigation metaphors that are easy to use contribute to the user's satisfaction. We also found a relationship between copresence and usability. According to Gerhard presence is the key indicator for the usability of the CVE which may explain this result [22]. We found collaborative effort was positively correlated with satisfaction, we assume that when an interaction metaphor has the advantage of being easy to use, and the user is satisfied by useing it that motivates them, and supports the process of collaboration.

In this study we did not state any hypothesis for task performance. During the design phase of our navigation metaphors we decided to choose metaphors that allow collaborative visual inspection of objects.

The analysis of the experimental data did not show any significant difference on the level of task performance. However on basis of the video footage analysis we noticed that subjects deployed important effort in inspecting the objects. The task is not limited to colour observation. The subject had to visually evaluate existence of yellow colour relative to the volume of each object. The significant difference in the collaborative effort obtained from the analysis of the experimental data confirms that the users needed to exchange information in order to make the appropriate decision.

The results of this study show that the navigation metaphors did not affect social presence, and did not improve the social information.

We chose a generic navigation ask, this task consists in inspecting collaboratively virtual objects in 3D scene. We were interested only in the travel component of the 3D navigation in virtual environment [7], we did not approach in our study the wayfinding because there exists much of work on this second component [16,13,15].

In this study we chose three navigation metaphors according to criteria's which corresponds to the context of our application (the type of the input device, the output display), we think that it would be interesting to evaluate the metaphors of navigation in other type of environment like the CAVE, or the head-mounted display -HMD.

VI. SOME GUIDELINES FOR THE DESIGN OF INTERACTION TECHNIQUES IN CVE

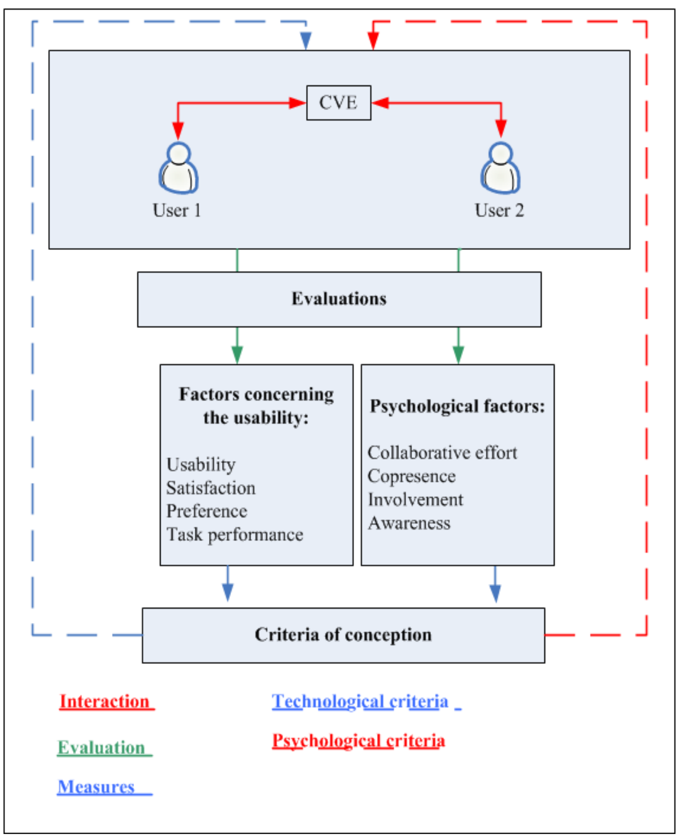
We think that these results are of potential interest for the design of a new generation of CVE, in these new CVEs, the human factors would be essential elements in the design process. In this way and based on our experimental study, we propose some design guidelines which were conceived for facilitating the collaboration within CVE:

- Use direct visual feedback from the partner point of view in the scene. The results of the experiment show that the metaphors with direct visual feedback in the scene make it possible to increase the feeling of copresence, involvement and awareness. These concepts are necessary to perceive the presence and the actions of the partner present in the same CVE.

- Use direct control of the user actions. The fact of having an interaction metaphor with a direct control the metaphor makes the experience more interactive and improves collaboration level in CVE.
- Avoid the use of several windows in the same virtual scene and try to integrate the visual information as much as possible.
- The spatial reference and the spatial orientation are very important elements for the involvement of the user in CVE.
- Choose an interaction metaphor that is relevant to all aspects of the collaborative task.
- It is important to take into account the ergonomic factors of the interaction metaphor. These factors influence the usability, satisfaction and the collaborative effort. It is thus necessary to use interaction metaphors that are intuitive and pleasant to use.

VII. CONCLUSIONS

Through this research work, we have explore the effects of 3 interaction metaphors on some of the process involved in collaborative work, such as social presence, copresence, awareness, involvement, the usability and satisfaction. We propose a new methodology integrating two types of factors.



The proposed approach is to develop a methodology for evaluation of the user experience based on the interaction metaphors on CVE. In order to improve the collaboration between remote sites using virtual reality technologies, interaction metaphors are implemented. The user experience in a CVE must be evaluated on criteria which are those of the collaborative work remotely coupled with virtual reality. The criteria used, supported by the literature of these areas, are expressed by:

- Factors concerning the technical aspects in CVE
  - Usability
  - Satisfaction
  - Preference
- Psychological factors in CVE
  - Collaborative effort
  - Copresence
  - Involvement
  - Awareness

The work completed in this experimental study enabled us to show the importance of the choice of the interaction metaphor. Also thanks to the results of our experiment, we could draw up a list of recommendation to support the 3D interaction in a CVE where the human factors elements are the essential elements in the loop of the design of CVEs.

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