# Collaborative Virtual Environments: You Can't Do It Alone, Can You?

Arturo S. García, Diego Martínez, José P. Molina, and Pascual González

LoUISE Research Group
Instituto de Investigación en Informática de Albacete, Universidad de Castilla-La Mancha
Campus Universitario, Avda. España s/n, 02071 Albacete (Spain)
{arturo, diegomp1982, jpmolina, pgonzalez}@dsi.uclm.es

**Abstract.** Many Collaborative Virtual Environments (CVEs) have been developed to date. However, when focusing our attention on the way users perform their task in these systems, there is still little research on understanding the impact of different platforms on the collaboration experience. This paper describes not only a CVE, in this case, one that reproduces a block building game; but also an experiment that was carried out to evaluate both the interaction using different input and output technologies and the impact of collaboration on task performance and overall experience.

**Keywords:** Virtual Reality, Collaboration, Performance.

## 1 Introduction

Virtual Reality (VR) is usually related to technologies such as three-dimensional graphics, touch and force feedback, and spatialized sound. VR developers use all those technologies trying to achieve one common aim, which is to make users experience the Virtual Environment (VE) as a real one. If that environment is meant for multiple users joining the virtual space from different physical locations, for the purpose of a particular task or just to serve as a social meeting place, there is one more technology that gets involved: computer networks.

Nowadays, there is a common agreement that using computers to connect people together and allow them to collaborate is a must, having the potential in communication that computer networks and specially Internet provide. The technology has been successfully applied to the field of individual work, as most of the current applications are focussed on a single user that, in general, produce a result or reach a goal. At present, the research community is trying to change this limited focus, so that several users can use one application at the same time, in other words, participate simultaneously in the production of a result or collaborate to reach a goal. An example of this is the design of a 3D model of a single piece or a whole environment, which is usually tackled by a single engineer or artist using their CAD/CAM or 3D authoring tool, but now it is possible to work together with other people, collaborating in its realization, as in [1].

R. Shumaker (Ed.): Virtual Reality, HCII 2007, LNCS 4563, pp. 224–233, 2007.

On the other hand, VR seems to be suitable to simulate a virtual space where tasks take place and where people, even geographically distributed, collaborate to reach a common goal. This leads to a definition of Collaborative Virtual Environments (CVEs) that is concise, clear and widely accepted [2]: *CVEs are a form of telecommunication technology that bring together co-located or remote, participants within a spatial social and information context*.

In this context, this paper describes an educational and collaborative building game and its evaluation. Even though other similar systems can be found in the bibliography [3][4][5], none of these ones tackles the problem as the reproduction of a real game, but as a puzzle similar to the Rubik's cube, Heldal et al. 2005 [3]; as the building of a gazebo, Roberts et al. 2003[4]; or as a two-handed 3D modeller, Kiyokawa et al. 1996 [5].

Besides, focusing our attention on the way users perform their task in these systems, there is still little research on understanding the impact of different platforms on the collaboration experience –see, for instance, Heldal et al. 2005 [3]-. However, it is even more difficult to find studies which compare individual versus collaborative performance on the same task. Ruddle et al. 2002 [6], focused on cooperative manipulation, and Hendal et al. 2006 [7], continuing the work done in [3], may be the only published works on this regard. However, as these last studies are focused on only one task, there is a question how general the findings are. For that reason, we aim to study collaboration when performing different tasks in different situations and to compare the results with the ones obtained from performing the same tasks in the same situations by an individual user, and even to compare those results with the real physical game.

This paper is organized as follows: firstly, section 1.1 shows an introduction to the topic of the CVE developed, and section 2 gives a brief description of its architecture; after that, section 3 describes the evaluation carried out; finally, section 4 shows the results of that evaluation.

### 1.1 VRPrismaker

Education usually relies on games, and many games are considered to be not merely entertainment but pedagogical tools. Games usually imply several participants, sometimes as opponents, in other cases as members of the same team that collaborate to achieve a common goal. Education and entertainment, often referred as edutainment, are then fields where collaboration can be studied and, considering the application of VR to them, they also allow to study collaboration in CVEs. One of those games is Prismaker, a game designed for children over three years old, consisting of several types of blocks with which different models can be built.

As part of two previous projects, our research group carried out the implementation of two different computer versions of this game. The first of them was a desktop application that was written in Java3D. The second one [8] was similar to the previous one, but this time the environment was completely immersive. However, none of these two previous versions allowed to study Prismaker as a game where several people can collaborate, simultaneously, to build a model, as both applications were single-user. Thus, a third project was proposed to obtain, based on the code written for the immersive version, a CVE in which several participants can join the game and play together, some of them wearing helmets and gloves, and others using a standard desktop. This CVE is described in the following section.

## 2 CVRPrismaker

*Collaborative Virtual Reality Prismaker* (CVRPrismaker) is a CVE developed as an experimental platform where collaboration in cyberspace can be studied and compared to collaboration in real places. Focus is then on communication and interaction between subjects, but also on interaction with the models and the computer itself, and how all these factors have an impact on collaboration.

The immersive version of Prismaker tried to replicate precisely the interaction of the real game, in other words, by means of a tracking system and a pair of data-gloves the user can use his or her own hands to build models by grabbing, assembling and dropping blocks using several gestures.

In this case, the user can basically perform two actions: pick up an object and drop an object. Performing an action in different places of the scene may result in a different outcome (for example, dropping a block on another one will join them and dropping it on another point of the space will make the block stay in that position). Therefore, the system takes into account not only the action that the user carries out, but also the context in which it is carried out.

Since one of the objectives of this project was to get insight into the interaction within these systems, it was also developed another version that made use of a conventional desktop system, but with adapted interaction to overcome the limitations of this platform (for example, restricting the rotations to 90 degrees).

### 2.1 Description of the Collaborative System

The most important aspects that define a collaborative system are the following:

*Collaboration*: Users of CVRPrismaker are able to work following different strategies, from splitting the models to building in separate parts and joining them later, working by turns or even simultaneously on the same model. Therefore, the strategy of collaboration is freely decided by users while using the system.

*Communication*: There are two types of communication in the system. As regards to the communication between users, it was thought that voice communication was the more important mean of communication in this system. Although in this first development the users shared the same space, and so they can speak freely, in the future it is planned to make use of voice transmission through the network.

To solve the problem of the communication between collaborative systems, it was chosen a moderator that controlled the actions carried out by the clients. With this moderator and its set of clients, the system turns to be a client-server architecture.

*Information Sharing*: Another important issue of every collaborative system is the information sharing between users. In CVRPismaker, users share the blocks they are using to build models, and the model they are building. Thus, the user's awareness of the state of the world becomes one of the main concerns. More precisely, it is important to be aware of the position of the other users' hands, as well as what model is building. In order to do so, the users must be placed in the right position so that they are able to see their partner, as well as to locate them in the 3D space.

### 2.2 Network

There are several options to consider when choosing the appropriate architecture for a CVE, from client-server, to peer-to-peer, or even more complex hybrid models [9]. Among them, a client-server architecture was chosen for implementing CVRPrismaker. In this system, the server is responsible for managing the incoming connections and ensuring the consistency of the data over the network. The server, however, does not store a copy of the scene model. Instead, each client keeps its own copy, which is modified according to the update messages sent by the server.

The server acts then as a moderator in the working group and resolves, in real time, the conflictive situations that arise between users, such as ownership of objects, making their collaboration possible.

### 2.3 Consistency and Synchronization

Each object of the virtual world has a unique identifier. This identifier is generated by the server and allows clients to reference objects in a non-ambiguous way. Furthermore, each client also keeps its own client identifier.

To keep consistency, each client sends an interaction request each time a virtual action on an object happens. If the objects are not already locked, the server will lock them. This exclusion over the objects is held until the interaction ends, which avoids conflicts as it is impossible to produce two different actions over the same object at the same time.

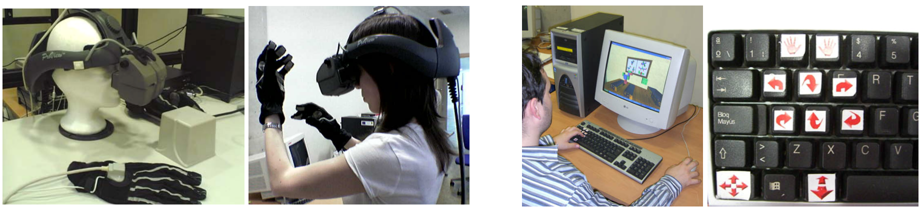
To keep all the clients synchronized, for each interaction request received that can be satisfied, the server sends an interaction acknowledgement to each client indicating the objects taking part and the necessary data. This way, each change in the state of the world happens in the same order and with the same data in all the clients.

### 2.4 Hardware and Software Platforms

For the development of this system, an immersive VR setup was used. It was composed of a HP Compaq XW6000/PL station (dual 2.4GHz Intel Xeon, 512 MB, 3Dlabs Wildcat III 6110), an Ascension Flock of Birds tracking system with three trackers, a pair of Fakespace Pinch Gloves and a ProView XL35 stereoscopic head mounted device (Fig. 1a and 1b).

For the desktop system, a HP Compaq XW4000 (P4 2.4 GHz Intel, 512 MB, NVIDIA Quadro4 900 XGL) station was used with a conventional mouse, desktop and keyboard (Fig. 1c). Some keys of the keyboard were labelled with symbols representing its associated function, to make it easier for the user to use (Fig. 1d).

As regards the software platform chosen, the development of the system mostly relied on VRJuggler [10], mainly because its easy management of hardware devices. Regarding the graphics API, OpenGL was selected as it is a standard supported by many different platforms. The VRML/X3D file format is used to store the scene model, the user-built models and the users' avatars. Finally, a free and widely used library for network games, Raknet (by Rakkarsoft [11]), was selected for the transmission of data over the network.



(a) (b) (c) (d)

**Fig. 1.** Hardware used in the immersive (a-b) and desktop configuration (c-d)

## 3 Evaluation

This section describes the experiment that has been carried out as a first approach to the evaluation of some parameters in this kind of systems. With this experiment, we want to evaluate not only the usability of different input technologies but also the performance of the different platform configurations. This way, it is not only our interest to test an immersive platform, but also to check if a desktop-based system is also useful as a platform for a CVE. The satisfaction of the users taking part in the evaluation was also taken into account.

Obviously, it was also our purpose to evaluate the performance of the system in each different platform in terms of collaboration support. To get insight into all these issues, it was decided to carry out an experiment that allowed us to test the following hypothesis: Collaborative work is more efficient than individual work.

### 3.1 Description of the Experiment

In order to verify the initial hypothesis, an evaluation with real users was designed. In this experiment, a set of independent participants passed through several tasks, and the time taken to fulfil each task was annotated.

The participants built two different models. These models where designed with collaboration in mind, so that one of them was difficult to divide and the other one had easily distinguishable subparts. Fig. 2 shows the instructions given to the participants to help them in their tasks.

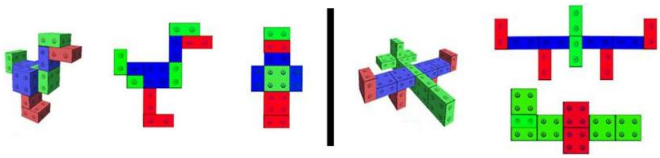


**Fig. 2.** Instructions given to users

As measuring the performance at different platforms was one of the objectives of the experiment, the participants had to fulfil their tasks using the real game, the desktop based system and the immersive one. There was only one immersive system available for this experiment, and so the combination of the platforms used by each couple is the one shown in table 1.

**Table 1.** Tests done by each participant

| *Individual Tasks* | *Collaborative Tasks* |
|---|---|
| Real (R) | Real – Real (R-R) |
| Desktop system (D) | Desktop – Desktop (D-D) |
| Immersive System (I) | Immersive – Desktop (I-D) |
| | Desktop – Immersive (D-I) |

As a result, each participant completed 3 x 2 = 6 individual tasks (3 platforms x 2 models) and 4 x 2 = 8 collaborative tasks (4 platforms x 2 models). When designing the tests, the order in which each task was taken was modified so that some users started with the individual tasks and others with the collaborative ones. This was done so to avoid any influence of learning on the measures related to performance.

### 3.2 Virtual Environment

The VE (Fig. 3) consists of a 3x2m room where the following objects can be found: Blocks (basic units used to build models), Boxes (place where the user can get new blocks), Table (place to build the models on), Shelves (place to store user-created models), and Picture (instructions of how to build two test models).

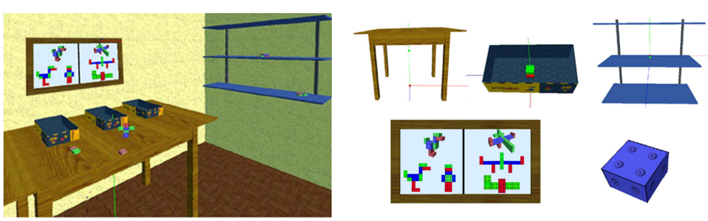


**Fig. 3.** The virtual room and the elements it comprises

### 3.3 Participants

The number of participants in the experiment was 18 people, 11 men and 7 women. The differences in the number of participants of each gender, as shown in former experiments, was thought to not affect results [12].Finally the age of the participants was varied from 19 to 31 years old.

## 4 Results and Analysis

In order to analyze the data gathered during the experiment, different ANOVA (*ANalysis Of VAriance*) were carried out to confirm if the differences observed in data were significant or not, in particular when any of the tests previously described was performed in less time than the rest, and more specially when that test was carried out in pairs.

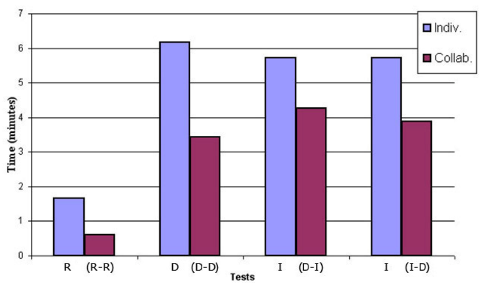



**Fig. 4.** This bar chart shows mean completion times for the first object (Duck)

After performing ANOVA with the selected data, the result of the analysis showed that completion times were not independent from the platform used, whether real or virtual, individual or collaborative, as $F(6,42) = 21.94$; $p < 0.05$ for the first object –the duck-, and $F(6,42)=7.54$ ; $p < 0.05$ for the second object –the airplane-. Having a look at the bar charts shown in Fig. 4 and Fig. 5, it can be clearly stated that there is one platform that outstands from the others, as the average time took by users using the real game (R, as single user, and R-R, working in pairs) is less than using any VE. This means that, even though we tried to reproduce in the VE the naturalness of the real game, the implementation did not achieve the same degree as the real one, mostly because they were limited by the available input devices as regards manipulation, which forced to use a hand-block metaphor instead of a full-realistic finger-block one.

After this finding, the analysis was repeated without the completion times from real game trials, remaining only data from trials performed with the VEs. This time, ANOVA showed no evidence that building the first object was different from one platform to another ($F(4,30) = 1.08$; $p > 0.05$), even though the completion times in collaborative tests were slightly lower. However, this was not the case for the second object, for which ANOVA showed that there was a significant difference in time ($F(4,30) = 3.15$; $p < 0.05$). This outcome confirmed our expectations when designing the experiment and choosing the two objects to build, as the first one –the duck- was supposed to be difficult to split in parts that could be completed by pairs of participants in parallel, so it was not expected any significant improvement in time when performing the task in pairs. On the other hand, the second object –the airplane- was thought to be easier to divide in smaller objects which could be build by a different participant of each pair, and then put all them together, so some improvement in time was expected in comparison with single user trials.

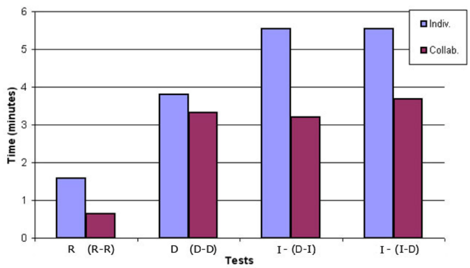



**Fig. 5.** This bar chart shows mean completion times for the second object (Airplane)

Finally, the analysis was repeated once again without the completion times from individual tests, so that only collaborative tests in VEs were taken into account this time, using ANOVA to check if any particular pair of platforms performed better than the others. This time, the results for the duck model ($F(2,18) = 0.91$; $p > 0.05$) and for the airplane model ($F(2,18) = 0.27$; $p > 0.05$) showed no evidence of significant difference in data gathered for each pair of platforms. This means that performance in collaboration does not depend on platforms but on the models to build, as stated before. However, these results may be a consequence of the presence of the desktop platform in every pair, lacking this study of completion times when performing the tasks in a pair of immersive environments. Better completion times may be expected if tested with this combination, as a better perception of the space seems to make manipulation easier in comparison to the desktop setup, mostly as the third dimension is concerned, which causes problems to desktop users.

**Table 2.** Ease of use of each setup, as perceived by participants

| *Single user* | *Score* | | | | | *Avg.* | *Collaborative* | *Score* | | | | | *Avg.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | 1 | 2 | 3 | 4 | 5 | |
| Real (R) | 6 | 4 | | | | 1.4 | Real– Real (R-R) | 10 | | | | | 1.0 |
| Desktop (D) | 1 | 3 | 5 | 1 | | 2.6 | Desktop – Desktop (D-D) | 3 | 5 | 2 | | | 1.9 |
| Immersive (I) | 1 | 1 | 3 | 3 | 2 | 3.4 | Desktop – Immersive (D-I) | 5 | 1 | 3 | 1 | | 2.0 |
| | | | | | | | Immersive – Desktop (I-D) | 2 | 3 | 2 | 3 | | 2.6 |

In addition to completion times gathered from the trials, each participant filled in a questionnaire, answering some questions about their own experience when using each platform, a questionnaire that was designed to get insight into the problems each user may have faced when using each platform, and whether they preferred to work alone or collaborate in pairs.

Table 2 shows the scores given by users as regards the operation of each platform in particular. In the questionnaire, they were asked to mark, with a number from 1 to 5, the perceived ease of use of the platform, bearing in mind that a value of 1 meant it was easy to use, and a value of 5 meant that it was difficult to use. At the end of each row in the table, it is shown the average score for the corresponding setup, computed by summing all scores given and then dividing them by the total number of participants. For instance, the average score for the (D-I) setup is $\frac{1\times 5+2\times 1+3\times 3+4\times 1}{10}=2.0$, as can be seen in the table.

As it can be expected, the participants gave better marks to the real game, as it was not hampered by input technology. Surprisingly enough, the desktop is the second most valued system by users, which in turns makes it also the preferred VE when collaborating with other users. This may be caused by the way rotations were performed in the desktop environment, not as smooth as in the immersive environment but in successive amounts of 90 degrees, which was introduced to facilitate the task to users. Following that finding, it can be observed that the combination desktop-immersive systems is the third most valued. As the desktop was found easier to use by single users, this result is not surprising, as it gives us the perception of the user from the desktop side of the coupled systems, no matter which platform used the other participant.

In the questionnaire given to participants, there was also a blank space for them to express their thoughts regarding the collaboration with their mate in trials. Only one of them complained about being hindered by the other user, the rest of them used that blank space to suggest improvements to the system, and to comment about the operation of the input and output devices. Regarding the immersive system, some of the participants complained about the amount of wires around them, as well as the weight of the helmet and the fatigue it caused to them. As for the desktop system, the comments were related to problems when perceiving the third dimension (moving blocks further or closer), which may have been solved by using stereo graphics, not used in this experiment.

## 5 Conclusions and Future Work

In this paper, it has been described a CVE that reproduces a block building game, a system that has been named CVRPrismaker. Besides, it has also been described an experimental evaluation of the VE in different setups, real and virtual, individual and collaborative, and the results of that experiment have been presented and analyzed.

As the most important conclusion, this evaluation has showed significant differences in performance depending on the task, which should be taken into account by designers when assessing the suitability of collaborative systems. This result has been confirmed using different ANOVA studies, which have also shown that users collaborating in the VE employed less time than performing the tasks in an individual way. Another conclusion of the evaluation is that the VE can be experienced using immersive devices as gloves and goggles as well as conventional devices such as mouse and keyboard, resulting in similar outcomes.

As a future work, it is planned to carry out a new evaluation using immersive systems at both ends of the collaborative system, and also study collaboration in Internet as opposed to a local network. Both issues are currently under development.

**Acknowledgments.** This work has been partially supported by the Ministerio of Educación y Ciencia of Spain (CICYT TIN2004-08000-C03-01), and by the Junta de Comunidades de Castilla-La Mancha (PAI06-0093).

## References

1. Caligary TrueSpace 7 (Last visit 09-02-07) http://www.caligari.com/
2. Roberts, D., Wolff, R.: Controlling Consistency within Collaborative Virtual Environments. In: 8th IEEE International Symposium on Distributed Simulation and Real Time Applications DS-RT, Budapest (2004)
3. Heldal, I., Steed, A., Schroeder, R.: Evaluating Collaboration in Distributed Virtual Environments for a Puzzle-solving Task. In: HCI International 2005, the 11th International Conference on Human Computer Interaction. Las Vegas (2005)
4. Roberts, D., Wolff, R., Otto, O., Steed, A.: Constructing a Gazebo: Supporting Teamwork in a Tightly Coupled, Distributed Task in Virtual Reality. Presence: Teleoperators and Virtual Environments 16(6), 644–657 (2003)
5. Kiyokawa, K., et al.: VLEGO: A Simple Two-Handed Modeling Environment Based on Toy Blocks. In: Proc. ACM Virtual Reality Software and Technology, pp. 27–34 (1996)
6. Ruddle, R.A., Savage, J.C.D., Jones, D.M.: Symmetric and Asymmetric Action Integration During Cooperative Object Manipulation in Virtual Environments. ACM Transactions on Computer-Human Interaction 9(4), 285–308 (2002)
7. Heldal, I., Spante, M., Connel, M.: Are Two Heads Better than One? Object-focused Work in Physical and in Virtual Environments. In: 13th ACM Symposium on Virtual Reality Software and Technology (VRST 2006), Cyprus (2006)
8. Molina, J.P., García, A.S., Martínez, D., Manjavacas, F.J., Blasco, V., López, V., González P.: The development of glove-based interfaces with the TRES-D methodology. In: 13th ACM Symposium on Virtual Reality Software and Technology (VRST). Cyprus, pp. 216–219 (2006)
9. Singhal, S., Zyda, M.: Networked Virtual Environments: Design and Implementation. Addison Wesley, London, UK (1999)
10. Juggler,VR.: (Last visit 09-02-07) http://www.vrjuggler.org/
11. Rakkarsoft.: Raknet. (Last visit 09-02-07) http://www.rakkarsoft.com/
12. García, A.S., Molina, J.P., González, P.: Exemplar VE design guidance tool for selection and manipulation interaction techniques. In: HCI International 2005, the 11th International Conference on Human Computer Interaction, Las Vegas (2005)