Supplemental Material

A Multimode Immersive Conceptual Design System for Architectural Modeling and Lighting

Marcio Cabral* Peter Vangorp Gaurav Chaurasia Emmanuelle Chapoulie Martin Hachet
REVES/INRIA Sophia Antipolis IPARLA/INRIA Bordeaux
George Drettakis
REVES/INRIA Sophia Antipolis

Figure 1: One of the participants of the experiment.

This document provides more details regarding the preliminary user study. The main goal of this preliminary user study is to give us indications of of what would be interesting to study in detail in future experiments.

1 Introduction

The integration of the prototype modeling system described of [**?**] and a simple lighting control interface into an immersive interface allows us to study the relative effectiveness of the different modes (table, immersive and mixed) for several different tasks.

The study has three parts: a training session, then a first set of specific tasks and finally a more open task in which the user is asked to construct a three room house. The specific tasks are: resize a wall, add/move/resize a window, and move the sun. For placement and resize tasks, the user is presented with a target guide in wireframe which allows objective error in the task to be measured. For the sun task, the user is presented with a square having a target intensity, and is asked to move the sun to match the target intensity (see video).

Table 1 gives an overview of which actions can be accomplished in which modes:

*e-mail: Firstname.Lastname@inria.fr

	Table	Immersive	Mixed
Add window	✔	✔	✔
Move window	✔	✔	✔
Resize window	✔	✔	✔
Resize wall	✔	✔	✔
Add door	✔	✔	✔
Add room	✔	✗	✔
Move sun	✔	✗	✔

Table 1: Available actions for each interaction mode.

The participants are also presented with a questionnaire with subjective questions after the experiment.

2 Experimental Procedure

A total of 8 participants completed the study in the iSpace of our institute, all male with ages varying from 25 to 40. All reported normal vision except for one subject who had stereo deficiency. Although we did not test the vision of the subjects, 3D glasses can be worn over corrective glasses and the subjects were instructed to do so.

We did not test handedness but we instructed people to hold the wand in their dominant hand. We will now detail the experimental procedures.

2.1 Training Session

The experiment starts with a training session so the participant can learn the interface.

The participant is introduced to the interface by an experimenter who guides the user through the process. The participant starts in table mode, with a simple room created and is then guided through each action available in each mode. The participant is then asked to perform the action until the experimenter is satisfied that the knowledge of the action has been acquired. The training session is extensive to minimize learning effects during the follow up part of the experiment.

The training session takes between 10-15 minutes. The detailed procedure for the training is described in Algorithm 1.

Algorithm 1 Training Session Detailed Procedure

```
for all modes {table, immersive, mixed} do
    put the user in the mode
    start by showing a simple room
    for all actions available in the current mode do
        give detailed step-by-step instructions
        let the user perform the action
        correct and retry if necessary
    end for
end for
```

The training session can be extended until the experimenter is satisfied that the user knows how to accomplish all tasks.

2.2 Objective Specific Study

After a short break, the participant is asked to perform the set of tests involving the actions listed above. The window and sun tests are performed for each of Table, Immersive and Mixed mode; the wall resize test is only performed in Table and Mixed mode (see table above). For all add/move/resize tests, we record time to achieve the task and error compared to the wireframe target. Completion time is also recorded for the sun test and the error in color between the target square and the corresponding square on the wall is computed (see Figure 2, second row).

Users performed the tasks in the following order, executing all tasks for a particular mode before proceeding to the next mode.

1.Table Mode: resize room, move/resize window three times, sun task

2.Immersive Mode: move/resize window three times

3.Mixed Mode: resize room, move/resize window three times, sun task

The Objective Specific Study session took between 10-30 minutes. The detailed procedure is described in Algorithm 2.

Algorithm 2 Objective Specific Study

```
for all modes {table, immersive, mixed} do
  for all actions available in the current mode do
    start by showing a simple room
    give a specific task:
    action: resize room to match the constraints shown
    for i = 1 to 3 do
      action: move / resize window
    end for
    action: move sun and/or window until the room's front wall
    appears the same as the target front wall shown
    let the user perform the task
  end for
end for
```

2.3 Objective Open Study

For the open task, we want to measure speed, accuracy, and behavior in an open-ended task with a specific goal. The participants were instructed to construct a three room house within a time limit of 5 minutes and to make sure that all rooms have enough sunlight in winter but not too much in summer. The participants had 10-15 minutes to complete the task.

2.4 Subjective Questionnaire

At the end of each study a questionnaire is presented to the participant. The post questionnaire covered the following topics:

Satisfaction How pleasant is each mode? How much is your creativity hindered by each mode? How pleasant is the iSpace?

Comfort How tiring (mentally and physically) is it to use the system?

Presence Did you feel that you were really "there" in the virtual world while using the different modes? Did you feel that you were directly manipulating a physical object or just a representation? How aware were you of the control devices and the display system?

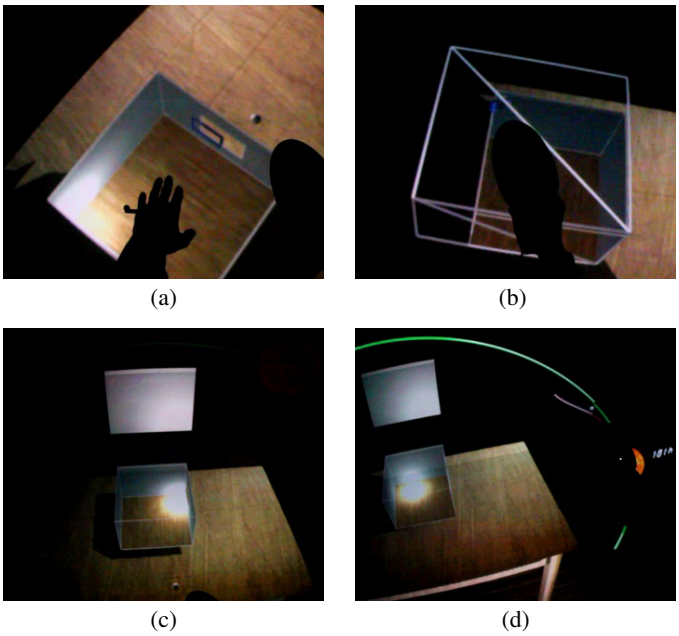

Figure 2: (a) Target wireframe for a window resize and (b) a room resize task. (c) Sun target in table mode (start of test) (d) Sun target at the end of the test.

The responses to the questionnaire were all positive about the system overall, finding the experience to be interesting and engaging. There was a small preference for table mode (4 subjects). Overall users appreciated the immersive nature of the system, and found interaction to be natural and pleasant.

3 Experimental Results

Tasks in the immersive mode can take slightly longer (e.g. approximately 30 seconds longer than the 42 seconds it takes on average for each window manipulation task in the other modes, two-sample t-test with unequal variances $p < 0.05$) if the user first needs to walk, virtually or physically, to get closer to the object. Some participants reported that it was difficult to reach the corners of the large windows when they were standing too far away. On the other hand resizing the windows from a suitable location was a little more accurate in immersive mode than in the other modes.

Timings for the task of room resize are equivalent both in Table and Mixed modes (73 ± 28s versus 54 ± 27s, $p > 0.05$). This is also the case for the sun positioning task (283 ± 17s versus 149 ± 8s, $p > 0.05$).

In Table mode, completing the first window resize task is marginally slower than for subsequent windows resize tasks (second and third window) because of a learning effect. Timings of first window versus second/third window resize in Table mode: 55 ± 28s versus 32 +/- 28s, $p > 0.05$.

Again, we observe the same pattern in Immersive mode: completing the first window resize taks is marginally slower than the window resize task for the third window because of a learning effect. Timings of first versus third window resize in Immersive mode: 70 ± 55s vs. 53 ± 54s, $p > 0.05$.

In immersive mode, the second window resize task obliged the user to walk towards it using the wand's joystick. This caused the second window resize task to perform marginally slower than for the third window (97 ± 76s versus 53 ± 54s, $p > 0.05$ so non-significant difference).

Table 2 shows detailed timings for the Objective Specific Study session.

We measure accuracy for the Add / Move window task as the average positional error of the 4 corners of the window in virtual space. The virtual space matches the real space of the CAVE system, which is about 2.5 meters tall and 2x2 meters in length. Room resize task accuracy is proportional to the positional error of the corner of the room and is computed using the following formulae: $\frac{\|extent_u - extent_t\|}{t_{height}}$, where $extent_u$ is a 3-d vector containing the user's choice for the room's height, depth and length; $extent_t$ is a 3-d vector of the room's target extent and; t_{height} is the target room's height.

The match criteria for the Sun task was a subjective measure: a comparison between brightness of two texture patches. Accuracy values for the Sun task are not included in Table 3 because different window positions and sun positions can yield similar brightness.

Room resizing accuracy in both Mixed and Table mode are equivalent (0.081 $\pm$ 0.073m versus 0.076 $\pm$ 0.076m, $p > 0.05$). On the other hand, for accuracy, we do not observe a learning effect for the window resize task for all modes.

In Immersive mode, completing the second window resize task has marginally larger error because the virtual window is too close to the real projection screen if the subject did not walk far enough with the joystick (0.104 $\pm$ 0.085m versus 0.050 $\pm$ 0.033m, $p > 0.05$).

Table 3 shows accuracy measurements for the Objective Specific Study session.

The Sun is harder to select in Table mode than in Mixed mode: 7.25 misses $\pm$ 10.32 for Table mode versus 2 misses $\pm$ 2.83, $p > 0.05$. Users perform better in Mixed mode, possibly because of a learning effect.

The widgets and the selection sphere that floated just in front of the flystick cast a shadow on nearby surfaces. For widgets in the house, participants could use these shadows as a depth cue to guide them to the correct position. Most participants initially had some difficulty selecting the sun widget because there was no shadow to guide them and they had to rely on the stereoscopic depth cue.

During the 5 minutes of the open task, participants switched between modes on average 13 times (average 12.86 $\pm$ standard deviation 3.72), suggesting that they preferred to perform some operations in specific modes. Most editing was performed in table mode, while immersive or mixed mode were used mainly for inspection and even for fun. Participants used the undo functionality on average only twice (average 1.86 times $\pm$ standard deviation 1.95)since any move or resize operations could easily be corrected manually.

	Table	Immersive	Mixed
Add Move Window 1	54.81s	52.57s	47.06s
Add Move Window 2	28.74s	96.82s	48.18s
Add Move Window 3	35.09s	52.57s	41.15s
Room Resize	73.19s	✗	54.01s
Move sun	283.38s	✗	149.43s

Table 2: Objective Specific Study timings

	Table	Immersive	Mixed
Add Move Window 1	0.218	0.046	0.027
Add Move Window 2	0.146	0.025	0.093
Add Move Window 3	0.214	0.054	0.101
Room Resize	0.081	✗	0.076

Table 3: Objective Specific Study accuracy