Title:
Evaluation of User Preferences for 3D Modeling and Design Reviews in Virtual Reality

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Introduction:

The recent COVID-19 outbreak and pandemic has revealed a number of weaknesses in health care systems around the world and has required that millions of people to work virtually and hold meetings online [4]. Although sharing screens live, emailing model files, and annotating 3D mock-ups for review partially approach face-to-face collaboration, a virtual platform in which multiple people can interact seamlessly with the models and with each other in a safe, virtual environment where everyone is physical separated is ultimately needed [5, 2]. Expanding the implementation of virtual reality platforms can, in part, potentially help reduce the deleterious effects of COVID-19 induced economic recession by keeping more workers employed and engaged on active projects.

Regardless of this recent uptick in demand, virtual reality is slowly becoming a more useful and capable tool which designers and 3D modelers have yet to fully adopt [3, 1]. As the benefits of computer-aided design (CAD) are integrated into VR platforms and expand [6], a number of questions into how engineers will interface and adopt the synthesis of these technologies remain unanswered. User studies have been conducted in novice and industrial settings, with positive results [7]. Since navigation and tool selection comprise a large portion of time dedicated by modelers who use CAD tools, these two elements are considered two of the most important for successful integration of CAD in VR. This paper explores a user study evaluating the navigation and manipulation/selection capabilities of future CAD systems for design review platforms in VR.

Methodology:

CAD models for a cube with inset shapes and a room-scale maze were prepared in NX 11.0 and migrated into a VR environment in preparation for experimentation. The HTC Vive was used in conjunction with a VR application currently in development by an industry partner. An approximately 3x3 meter ($9m^2$) physical play area was used for all experiments. Thirty volunteers for testing were solicited through university engineering channels and no compensation was provided for participation in the study. Volunteers spent approximately 30 minutes participating in the study.

Experimental Description:

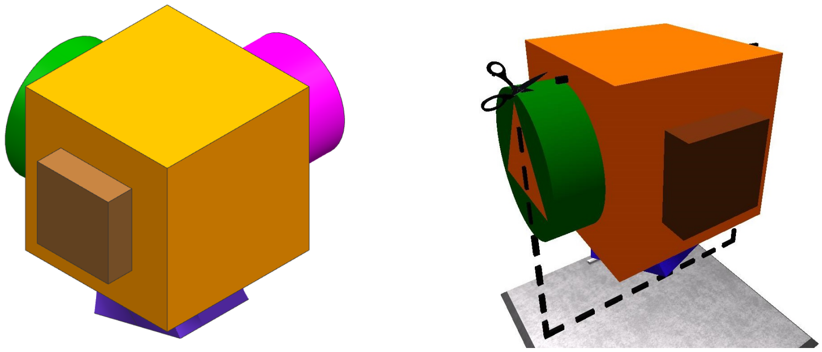

Fig. 1: (a) Screen shot of cube model and cube inset shapes in CAD platform and (b) inside the VR environment.

At the beginning of the experiment, users were provided brief instructions on the use of the HTC Vive system. Users were instructed on the controls and tools of the VR platform (see Tab. 1). Among the 11 tools evaluated, only “Fly” and “Teleport” are considered Navigation tools whereas all the others are associated with Manipulation activities. After brief instruction about each tool, users were free to manipulate a cube assembly (see Fig. 1) and to move about a large virtual room in VR (see Fig. 2 (a)).

Tool	**Description**
Grab	Allows user to grab components
Measure	Deploys virtual measuring tape
Model	Allows user to manipulate assembly of all components in original positions
Camera	Allows user to aim and take screenshots
Fly	Forward and backwards flying according to controller direction
Teleport	Projects a play area that can be rotated and teleports user to it in virtual space
Rotate	Sets an axis of rotation about which the model can be rotated
Laser	Infinitely extends reach along laser projected from controller
Cutting Plane	Activates a cutting plane for cross-section views
Draw	Allows user to draw temporary shapes to highlight features
Reset	Reset the location of objects

Table 1: Description of VR Tools Used During Experimentation

Navigation Tools Preference Test

In the navigation portion of the experiment, users were placed in the center of a virtual room with four different mazes. Two of the mazes were to be performed by Flying and two by Teleporting. To evaluate the three-dimensional nature of “Fly” mode, the two "Fly" mazes were comprised of two levels, with red walls at sections indicating a required vertical up or down motion. The higher level was designated by a green horizontal platform (see Fig. 2).

Participants were tasked with retrieving one component or inset shape of the cube assembly (shown previously in Fig. 1) from the end of each maze and returning it to the cube at the center of the virtual room. This was accomplished by concurrently using the navigation tool specified for the maze (i.e. Teleport or Fly) and the “Grab” tool. Time to complete this task was measured for each maze. Participants were stopped between completion of each maze. Both mazes for a navigation style (“Fly” or “Teleport”) were completed and then the user changed styles and completed the other two mazes.

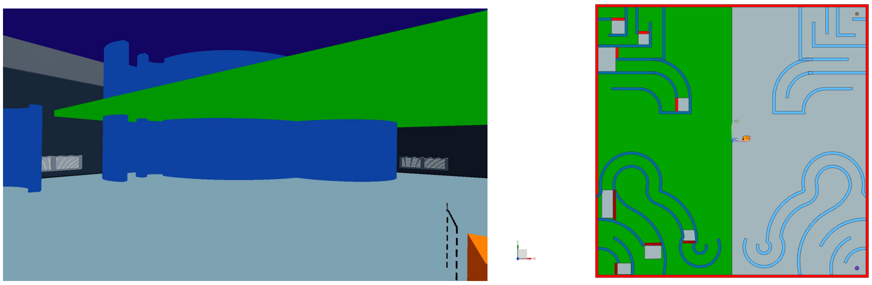

Fig. 2: (a) Navigation environment and the green platform as seen in VR, (b) the top view of the room model.

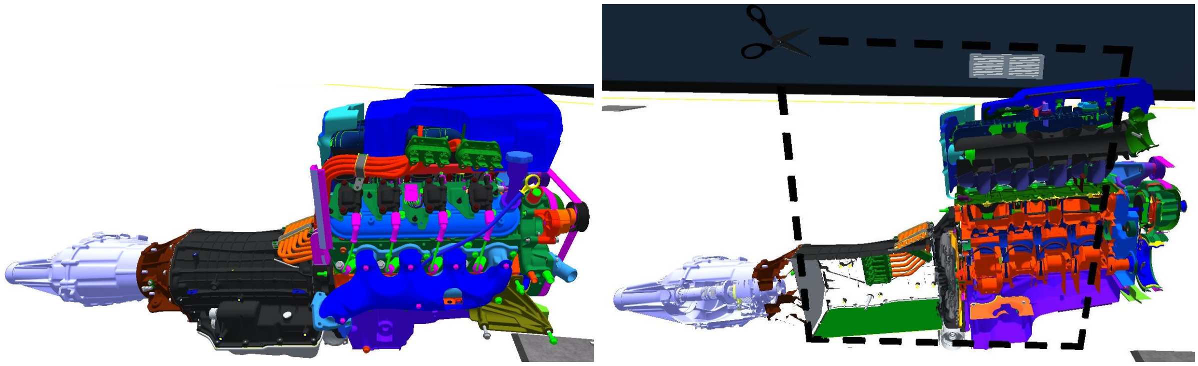

Fig. 3: (a) Screen shot of engine in the VR environment. (b) Screen shot demonstrating cut plane

Manipulation Tools Preference Test

After completion of the navigation tasks, the maze environment was replaced by a neutral environment with a car engine with hundreds of components (see Fig. 3). Each component was assigned one or more colors. Users were instructed that they would undergo multiple trials of thirty seconds to remove as many parts of a given color as possible, using any combination of tools desired, including Navigation tools. Removing a part entailed grabbing the part and manipulating it to a location approximately 1 foot (.3 m) away. A total of four trials were performed, with users removing parts colored (1) neon green, (2) pink, (3) dark blue, or (4) orange. All participants were assigned colors in the same order as indicated above. Parts varied in shape, size, and location. Colors were not uniformly distributed by size or location. At the conclusion of the manipulation tasks, users were instructed to remove the HTC Vive headset and take a survey administered electronically.

Performance Results:

Users were able to learn the functions of the various tools quickly and effectively. Minimal help from the proctor was solicited during the familiarization portion.

Navigation

As expected, novice VR users spent more time in each of the four mazes than any other experience group. However, the difference in time between those who had spent some time (but less than 5 hours)

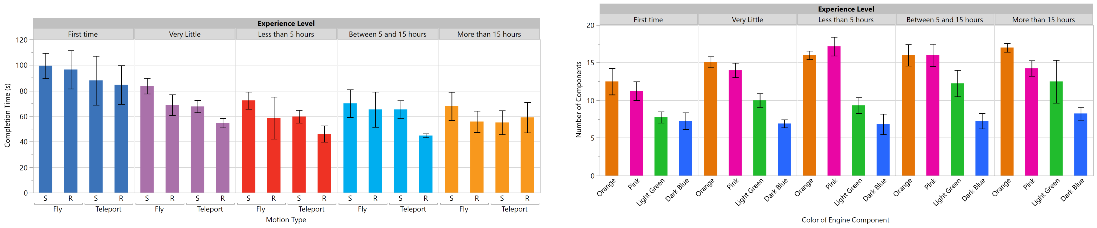

Fig. 4: (a) Maze completion time by experience level. S and R refer to square and round mazes, respectively . (b) Number of pieces captured by experience level. Bars represent standard error in both (a) and (b).

in VR and those who had spent more than 15 hours in VR was negligible (see Fig. 4(a)). This suggests that while a learning curve to navigating in VR exists, it is quickly overcome during the first few hours of VR exposure.

As indicated in Fig. 4, participants tended to complete the round mazes faster than the square mazes. This was expected, as both "Fly" and "Teleport" are more amenable to gradual changes in direction than to the sudden, sharp changes required by square mazes.

Figure 4 also indicates that less experienced participants completed the "Teleport" mazes faster than the "Fly" mazes. Because the "Fly" and "Teleport" mazes were mirror images of each other and the order randomized between participants, the difficulty of these mazes can be assumed to be comparable. Slightly longer times to complete the "Fly" mazes were expected because these mazes also incorporated vertical up and down motions. Interestingly, the most experienced users displayed no significant difference between "Fly" and "Teleport" times. Because of the vertical motion required in the "Fly" mazes, this actually suggests that experienced users were faster with "Fly" than "Teleport."

Several strategies were employed by users during the navigation task. Some users shuffled their feet as they repositioned themselves between teleportations whiles others rotated their torsos without replanting their feet. In terms of specific procedures, some users maximized the distance of each teleportation jump to minimize the number of jumps required while others performed multiple, shorter teleportations in rapid succession. Each of these decisions evidently impact performance, cybersickness, and ergonomic factors.

Similar patterns were observed with use of the “Fly” tool. Some users preferred to fly in short, discrete bursts while others preferred long, continuous paths. Although users were technically able to fly backwards, this was not observed and perhaps was avoided due to line of sight limitations and real-world biases.

Manipulation

Performance results for the manipulation test are summarized in Fig. 4(b). As in the navigation test, first-time VR users generally performed worse than their more experienced counterparts. However, the value of previous experience was less pronounced in the manipulation test; this may have been due to the limited time (30 seconds) provided in each trial. A longer experiment would better illustrate the differences between new and experienced users.

A wide variety of approaches were used to complete the manipulation tasks. The strategies employed can be lumped into the following categories: number of hands used, full-engine manipulation, navigation method employed, laser use, and cut plane use. Because complete data on strategies was not obtained, quantitative analyses of strategy cannot be performed. Many participants’ strategies evolved as they progressed through the color trials. For example, one participant used one hand for the first color trial, two hands for the second color trial, two hands with lasers for the third color trial, and two hands without lasers (again) for the fourth color trial. Many participants initially used a single hand to grab all parts, but eventually transitioned to using both hands.

Survey Results

Over half of the responses indicated some degree of motion sickness during testing. Among those users who claimed to experience motion sickness during the test, a Likert scale from 1-10 with 1 identified as "no motion sickness" and 10 as "extreme motion sickness" was used to quantify motion sickness. “Flying” made users feel more sick (4.9 average rating among sick users) compared to “Teleporting” with a average rating of 2.2. Although experienced users performed better on the navigation and manipulation tasks than their novice peers, they also tended to claim motion sickness with greater frequency.

One survey item asked users about tools they wished they could have used. Users expressed preference for tools common in other computer applications, likely due to mere-exposure effect, where participants like and desire tools they have seen before.

Conclusions:

First-time VR users and VR veterans alike were able to learn a new VR platform in a matter of minutes. This makes VR a very appealing tool for engineering collaboration in a dispersed, global environment. Although first-time users were slower than more experienced users in navigation tasks and less effective in manipulation tasks, this learning curve appears to be quickly overcome. Overall, based on the performance results, users with little (but some) prior experienced in VR performed similarly to users with 15+ hours of prior VR experience. User testing confirms that there is great potential for collaborative engineering tools through virtual reality. As these tools continue to be developed, a delicate balance must achieved between familiarity and innovation.

Acknowledgments:

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