Title:
Exploration and Evaluation of CAD Modeling in Virtual Reality

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Introduction:

Current commercially available computer-aided design (CAD) software is limited to interfacing with the user at a computer terminal using common peripherals, such as a mouse and a keyboard, to interact with the software through windows, icons, and menus. While this method is effective and allows for the rapid transfer of ideas from the user to the computer, there exist methods of altering the traditional workflow that can enhance the user experience. For example, extensive work has been done to allow multiple users to interact with the same virtual model at the same time [5]. Similarly, virtual reality (VR) has been explored to aid in the review process of CAD models [2]. The task of creating and editing CAD models from within a VR environment has also been researched to some extent [1].

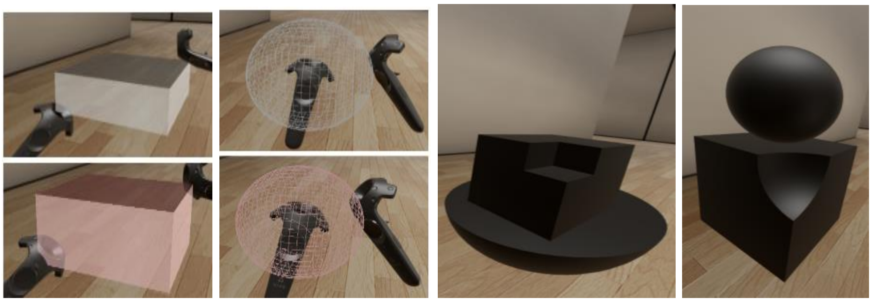
The objective of this research was to develop and test a proof of concept for VR software that would programmatically create BREP models in a traditional CAD system through the use of the developer's application programming interface (API) extending the work of [7]. Through the application of this API, it is possible to rapidly create geometry in the VR environment that can then be parametrically edited and refined in the CAD software through the traditional terminal interface with all the supported windows, icons, and menus. This application and proof of concept allows the user, from within a VR environment, to create models consisting of simple rectangular prisms and spheres utilizing the Fusion 360 software developed by Autodesk. To test this application, users were asked to create four simple models, two of them in the traditional Fusion 360 interface, and two within the VR application. The results of these tests enabled the evaluation of the effectiveness and efficiency of creating CAD models in VR when compared to modeling from the traditional interface. We examine the number of features created for the models, the overall model quality and accuracy, the level of creativity exhibited, and the user preference in modeling systems.

Methodology:

Implementation

At a high level this implementation of VR modeling is accomplished by a network connection between the CAD software and game engine software that has built-in VR integration. The game engine used was Autodesk's Stingray game engine and the CAD software package was Autodesk's Fusion 360. The benefits of leveraging a game engine include prefabricated rooms or levels which have significant innate animation capability, built-in support for VR headsets and controllers, functionality for first person perspective, and built-in mesh rendering capabilities. Using preexisting CAD software offers easier geometry creation, files being saved in a format that will allow them to be edited in the terminal version of that software later, and triangle mesh data accessible through the API [3, 6]. An HTC vive was integrated for its immersive VR capabilities and a TCP network connection was established between Stingray and Fusion 360 that allowed for the transfer of text data.

Part of the effectiveness of this application comes from using Fusion 360 to create geometry, which allows for more complicated geometric features such as Boolean subtractions or "cuts". The ability to cut away geometry is one that is not seen frequently in other virtual reality creation applications because it requires the CAD kernel to perform such operations. While simple previews can be created and maintained using Stingray Lua API calls, using the CAD kernel also allows meshes to be created for more complicated geometries (shown below in Fig. 1).



(a) (b (c) (d)

Fig. 1: (a) Previews of prisms in both creation and cut modes, (b) Previews of spheres in both creation and cut modes, (c) and (d) Preliminary test models showing the capabilities of VR modeling proof of concept and the appropriate sense of depth and proportion from the user's perspective.

User Testing

Using the software developed, testing was performed to determine the value of modeling in a VR environment as opposed to a traditional computer set-up. Participants in the testing phase were given instructions on how to use both systems to create rectangular prisms and spheres and perform cuts of each feature. Each participant was given up to five minutes in each system to feel comfortable with the controls. They were then tasked to create four models, having a five minute time limit for each model. These models include a simple chair, a truck, a sculpture of a person to be made from a starting block, and a maze. Immediately after the conclusion of each modeling session the testers completed a short survey to evaluate their experience. In order to remove confounding variables from the testing, participants modeling in either system were only allowed to create rectangular prisms and spheres and cuts of both. The final stage in the testing was the evaluation and ranking of the four different models for all the participants through blind judging. The eleven judges were given as much time as they needed to sort the participants' models for each category from most to least creative.

Results:

Almost all of the participants (sample size of N=21) used the full five minutes allotted for the creation of each model. In addition, most participants would use less than 5 minutes to familiarize themselves with each system before creating their models for a total testing period of around 50 minutes, which includes time for completing the survey. The resultant 84 models (21 from each category) developed as part of this study were then assessed, analyzed, and evaluated as described previously.

The ranking by 11 different judges shows that the creativity was evaluated as higher in general for VR. Fig. 2 shows the rank ordering for the chair (left) and sculpture (right) models for each of the 11 judges (J1 through J11). Each of the 21 lines in Fig. 2 represents how the 11 judges ranked each of the 21 models within a category from 1 (top) through 21 (the bottom). The models created in the VR environment are in red while the models developed in Fusion are in blue. Overall, more chair models were ranked better in VR, evidenced by a larger percentage of judges ranking VR models on the top half. A similar trend was observed in the sculpture models on the right hand side of Fig. 2.

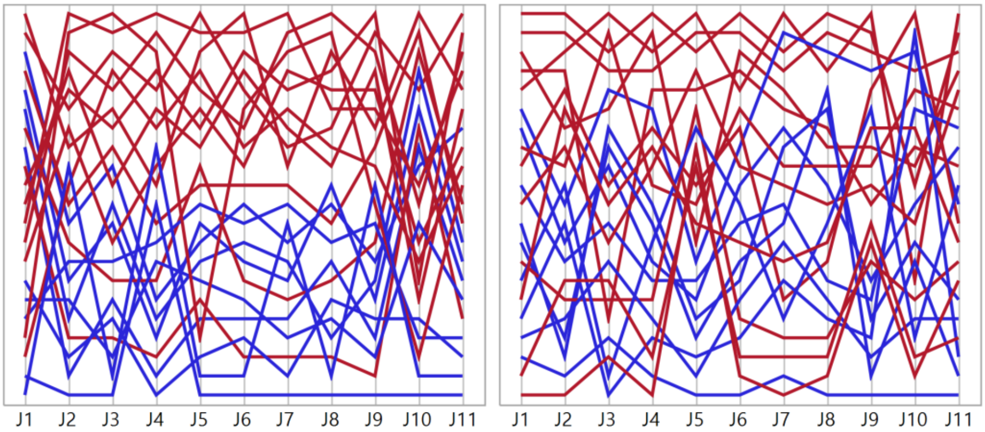
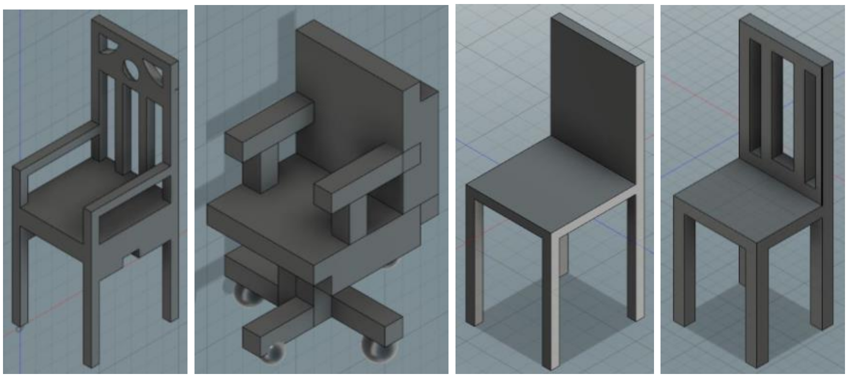


Fig. 2: Rank Ordering by the 11 judges for the 21 chair models (left) and sculpture models (right). Top ranked models are at the top (VR environment - red, Fusion 360 - blue).

Evaluation of Model Quality

Evaluation of the chairs modeled shows that the models created in VR exhibit a wide variety of styles and show much more freedom in the interpretation of a “chair” (see Fig. 3). Furthermore, we see the use of spheres in the chairs that were created in VR compared to a complete lack of spheres in any chairs developed in Fusion. Although, both environments were able to create both spheres and rectangular prisms, the participants that implemented spheres in their chair designs were those using VR. In the survey that participants completed after the testing they frequently commented that it was much easier to create and position spheres in VR and we suspect that contributed significantly to their use in VR and increased creativity.



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

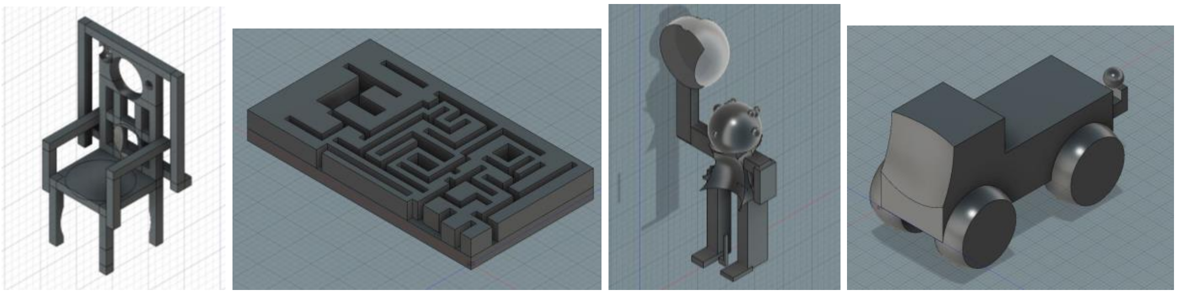
Fig. 3: Four models of chairs made by testers. Models (a) and (b) were made in virtual reality; models (c) and (d) were made in traditional Fusion 360.

One problem encountered in VR however was that participants were often less accurate in the positioning of the legs which resulted in lopsided chairs. A selection of the chairs that were created in VR were 3D printed in order to more fully validate and evaluate their appearance. As seen in Fig. 4 two of the four chairs are leaning significantly and do not sit flat on the surface. In the second chair from the left, the lopsided models could have been corrected had the spheres snapped to a grid in the same way done for the creation of the rectangular portions. Since post processing reveals that the legs are all equal, the lean is caused solely by the varying sphere size at the base of the legs.

Fig. 4: Validation of VR chair models through 3D printed designs.

In other experiments, both good and poor truck models were observed in both environments but in general the models in the VR environment were ranked better by the judges. Precise placement of the wheels and matching the sizes of the wheels in the four or six different locations was considered one major factor in developing good truck models. While the chairs in VR tended to have more extra features, the trucks in Fusion 360 seemed just as likely to have extra features compared to the trucks modeled in VR. Head lights, side mirrors, windshields and flat wheels are all examples of common extra features seen in both environments. As expected, the trucks modeled in Fusion tended to have more accurately placed wheels that avoided problems such as being off center or disconnected from the base of the truck. Fusion 360's capability to snap to grid in two steps was advantageous in these instances because participants could accurately place the center, and then dimension the radius. One thing that the VR application excelled at however was encouraging the users to focus on idea creation without concern for dimensioning or tolerancing. With respect to the current implementation, the results suggest that virtual reality is well suited for idea expression, but not as much for precise accuracy in modeling.

The sculpture models were the most challenging and opened ended modeling assignment given to the participants and it had the largest variability as a result. It was also different in that the participants were given a starting block from which to make their sculpture by removing or cutting material away. Overall, modeling the sculpture was easier in virtual reality because VR lends itself to an immediate sense of position and proportion, and allows easier access for placement of geometry. For example, users were free to place spheres wherever they wanted and were not bound to finding a construction plane on which to center the sphere. As could be expected, spheres were a more common modeling element in the VR models. Likewise, modeling in virtual reality allowed participants to work on the sculptures faster and thus end with a noticeably higher feature count in the same amount of time as shown previously. The complicated 3D shapes involved with sculptures seemed to be a high barrier for those working in Fusion.



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

Fig. 5: The four models developed from the participant with the highest total ranking score. Models (a) and (c) were made in virtual reality; models (b) and (d) were made in traditional Fusion 360.

After the testing each user was asked which system they would prefer to use overall as well as which system they would have preferred to use for each of the four individual models. The overall preference for modeling system was almost equally split with 10 of the users preferring to use Fusion 360 and 11 users preferring to use the VR system. Interestingly, when asked about individual models the majority preferred to model in VR for many of the models. The maze is the exception to this case where there was 11 who preferred Fusion with 10 who preferred VR. Testers were also asked what improvements they thought could be made to the application. Some of the most common suggestions were an undo button and a way to move the model in the VR environment.

Conclusion:

Modeling in virtual reality is an exciting new possibility that will become more important as virtual reality technology becomes more affordable and common. This research has shown that modeling in VR is possible and that there are already some noticeable benefits such as increased enjoyment, potential for accelerated or elevated creativity and ideation, a reduction in some obstacles for adding features [8], and a more realistic sense of scale [4]. In order for modeling in VR to become viable in the professional world, however, it must be developed further to rival the current capabilities of traditional CAD systems. Initial CAD in VR capabilities that would be required include implementing translation, rotation, scaling and toggling snap to grid on and off. Offering more geometry features would also be essential. The ability to make sketches in both 2D and 3D would also allow for additional actions such as sweeps and lofts. It is also clear that undo/redo capabilities are very important to users. After these initial capabilities were added, more advanced capabilities would be beneficial such as parametric modeling, dimensioning, and developing the possibility for multi-user CAD in VR.

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