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

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Abstract. Virtual reality tools hold great promise for revolutionising how engineers interact and review designs together in a global environment. A user study was performed to evaluate navigation and selection tools available in CAD design review platforms in VR. The learning curve of virtual reality tools was shown to be as short as a few hours. Although participants were similarly successful using "Fly" and "Teleport" tools, the "Fly" tool induced greater motion sickness. When manipulating objects, test participants did not converge on a single set of tools that were most effective; individual preferences dominated. With appropriate tools, VR provides a promising framework for modern collaborative engineering, however, modularity and adaptability are two key characteristics necessary to satisfy the variety of strategies future VR users will employ.

Keywords: Virtual Reality, Design Reviews, User Preferences, 3D Modeling, Cybersickness
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1 INTRODUCTION

The recent COVID-19 outbreak and pandemic has revealed a number of weaknesses in health care systems around the world [16] and has required that millions of people to work virtually and hold meetings online [6]. Many engineering companies and organizations such as NASA, Raytheon, and Boeing have likewise stipulated that employees work from home and interact with colleagues through virtual platforms to reduce the spread of this type of the coronavirus, COVID-19 [14]. Although some of these positions still require physical contact with hardware (e.g. machining and physical assembly), most design and engineering tasks can be performed on computers. Where the tasks involved multiple people, the individual employees can remain physically distributed at their own home office and communicate through online platforms [11, 15]. However, much of the engineering work requires collaborative teams discussing, sharing, and reviewing 3D models [1, 22] and designs [4] that will eventually be fabricated as part of some system or product.

The inadequacy of the tools necessary to effectively facilitate this type of engineering intercommunication with 3D models has been emphasized as many design engineers and other subject matter experts moved online during the COVID-19 outbreak. 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 physically separated is ultimately needed [7, 3]. The answer to this apparent weakness in how we operate within our engineering firms is likely found through virtual reality. Virtual reality can meet the needs of the "social distancing" requirement, imposed by government leaders for pandemics, while maintain a high level of engineering capability when collaboration on 3D models is unavoidable [21, 12]. 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 [5, 2]. As the benefits of computer-aided design (CAD) are integrated into VR platforms and expand [8], 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 indicating that VR allows users to identify more faults in a model than a conventional review [20]. Although progress has been made, determining and developing effective tools for communication [21] and interaction to be used in VR systems remains a challenge [18]. Once development of these tools has reached a sufficiently mature level, technician-training platforms [17] and other collaborative engineering activities in VR [5, 10, 19] can become common. While approaches to analyzing motion sickness in VR have been developed [13], much remains unknown about how navigation and other tools may impact motion sickness. 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 various navigation and manipulation/selection capabilities of future CAD systems for design review platforms in VR.

2 METHODOLOGY

As introduced above, navigation and tool selection and use were identified as the two major factors for experimentation. Manipulation and Navigation experiments were designed as described and outlined in the following sections. CAD models for a cube with inset shapes (see Fig. 1) and a room-scale maze were prepared in Siemens NX 11.0, a commercial CAD software, and migrated into the VR environment in preparation for experimentation

The HTC Vive, a popular and commercially available VR system, 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: 10 minutes familiarizing themselves with the equipment, 10 minutes in the navigation experiments portion, 5 minutes in the manipulation portion, and 5 minute completing a survey. Of particular interest was the performance of first-time users compared to experienced VR users and how veterans and novices would respond to the capabilities and features of a VR platform to perform representative engineering tasks.

2.1 Familiarization Portion

At the beginning of the experiment, users were provided brief instructions on the use of the HTC Vive system. For participant safety, the test proctor explained how the system indicates the boundaries of the real-world space within the virtual play area. Following this introduction, users were instructed on the controls and tools of the VR platform. The functions and limitations of each tool were described, and the test proctor verified basic user competency with each tool. Users were then given time to practice using all of the tools for

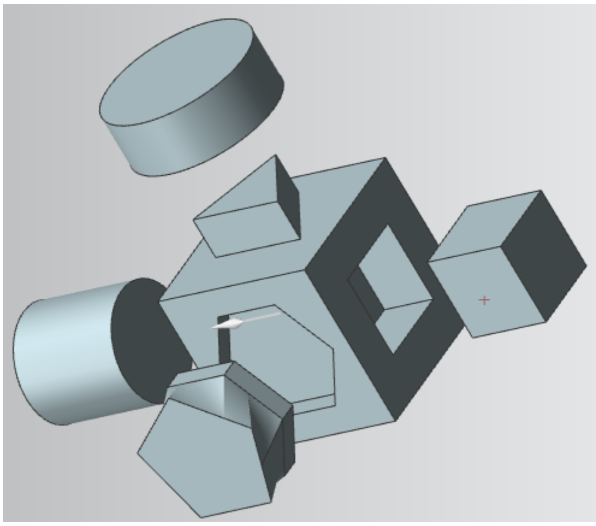

Figure 1: Exploded view of cube CAD model

approximately five minutes. Any additional questions about the functionality and/or limitations of the tools were answered during this time. Users were free to move about a large virtual room in VR (see Fig. 2(right)) and manipulate a cube assembly (with associated cube inset shapes shown previously in Fig. 1) that would be used in subsequent portions of the experiment (see Fig. 2(left)).

The tools available in the VR platform and demonstrated during the initial instruction phase by the proctor are presented in Tab. 1 with brief descriptions. Among the 11 tools evaluated, only "Fly" and "Teleport" are considered Navigation tools whereas all the others are associate with Manipulation activities.

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

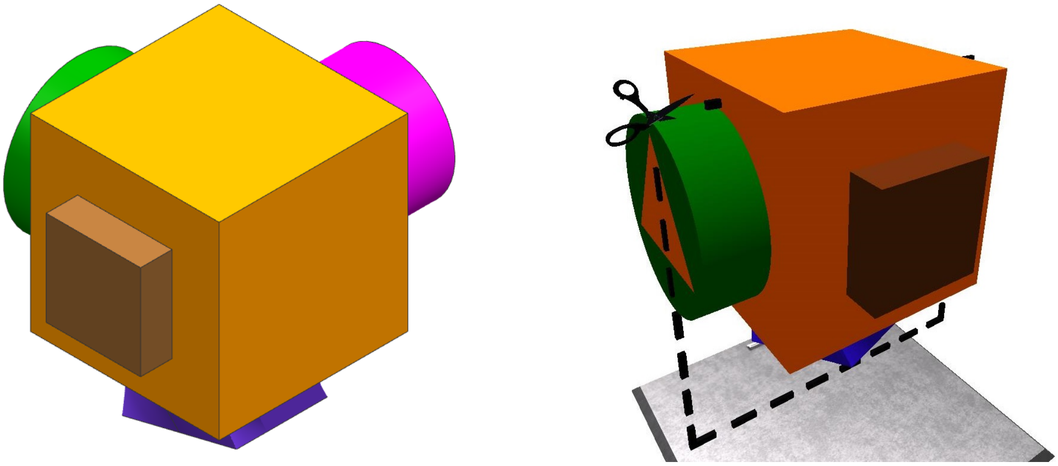

Figure 2: Screen shot of cube model and cube inset shapes in CAD platform (left) and inside the VR environment (right)

2.2 Navigation Tools Test

In the navigation portion of the experiment, users were placed in the center of a virtual room with four different mazes, one in each quadrant. An isometric view of the virtual room is presented in Fig. 3. Two of the mazes were 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 upper level was designated by a green horizontal platform (see Figs. 4 and 5). The mazes to be completed with the "Teleport" tool were single-level mirror images of the "Fly" mazes. Passages through the mazes were 3-5 feet wide to represent narrow hallways in common, real-world structures.

Participants were tasked with retrieving one component or inset shape of the cube assembly (shown previously in Fig. 2) 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. Initial navigation style assignment was randomly selected.

The VR environment did not explicitly prevent users from walking and/or flying through the walls of the mazes. However, users complied with instructions not to pass through the walls in this fashion. Two novice users were unable to complete one or both flying mazes without violating the boundary; these data were removed from analysis.

2.3 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. 6). 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. This distance requirement was based on a platform capability to snap objects back to their original position if placed in close

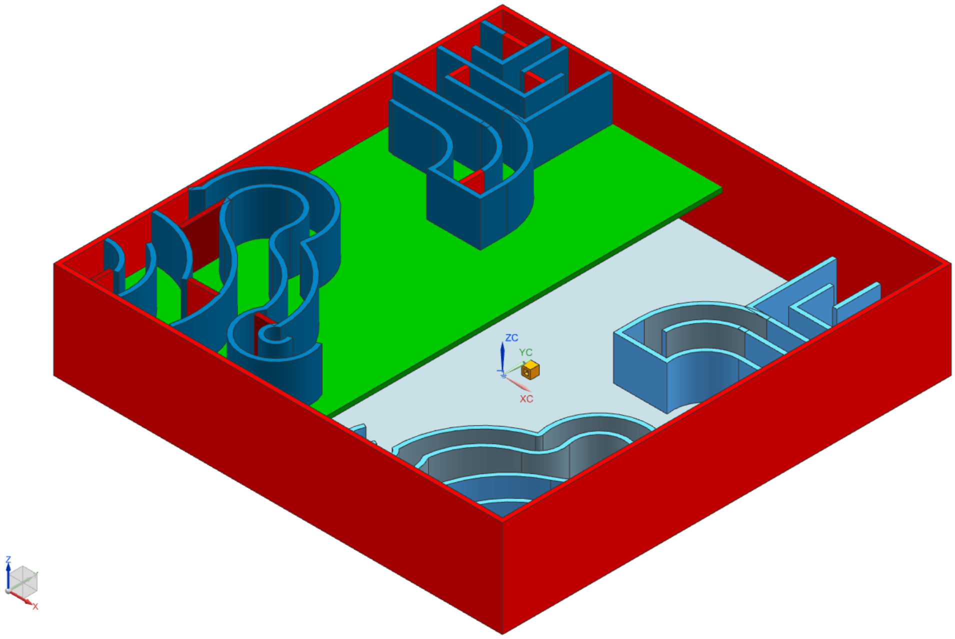

Figure 3: Isometric view of the large room with a maze in each of the quadrants

Figure 4: Navigation environment and the green platform as seen in VR separating the two levels

proximity to the original position.

Users were also told that no penalty would be imposed for moving parts of different colors; however, only parts with the given color would be counted. Before each trial, time was given for the user to adjust menus, their position, and the position of the engine model. For example, if a user had initially disabled the cut plane for his or her first color trial, the user would be able to enable the cut plane (and obtain a view such as Fig. 7) before initiating the second color trial. Following any adjustments to the model and at the beginning of

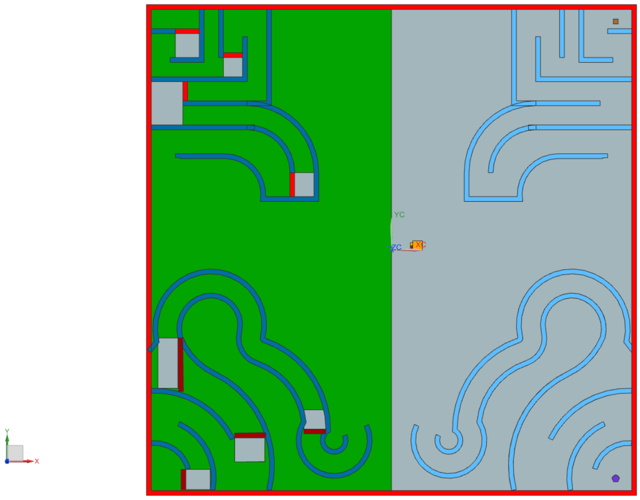

Figure 5: Navigation environment from the top view of the room model

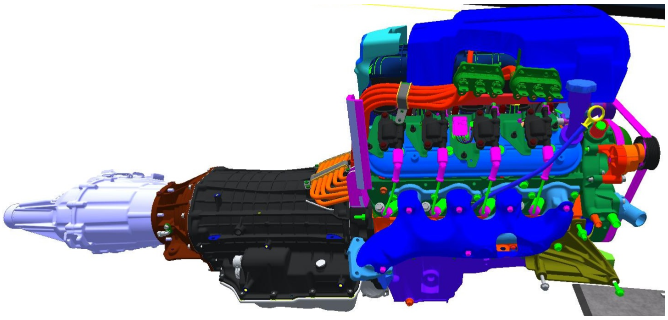

Figure 6: Screen shot of engine in the VR environment.

each trial, a color was given by the proctor and the user was instructed to touch a part of that color with the controllers to confirm participant understanding. Any discrepancies in color identification were corrected at this point, before the 30 second time frame began. No participant complained or indicated they were colorblind and could not discriminate between the colors of the components on the engine.

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. Figs. 8 and 9 show torn-apart views of the engine.

2.4 Electronic Survey

At the conclusion of the manipulation tasks, users were instructed to remove the HTC Vive headset and take a survey administered electronically. Questions, if any, about the survey questions were answered by the proctor.

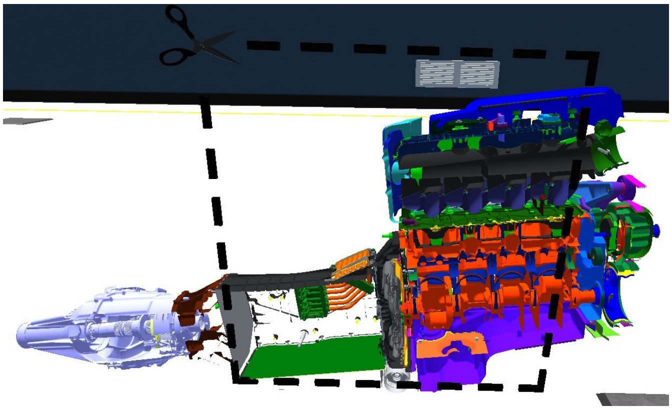

Figure 7: Screen shot of demonstrating cut plane with parts colored in neon green, pink, dark blue, and orange.

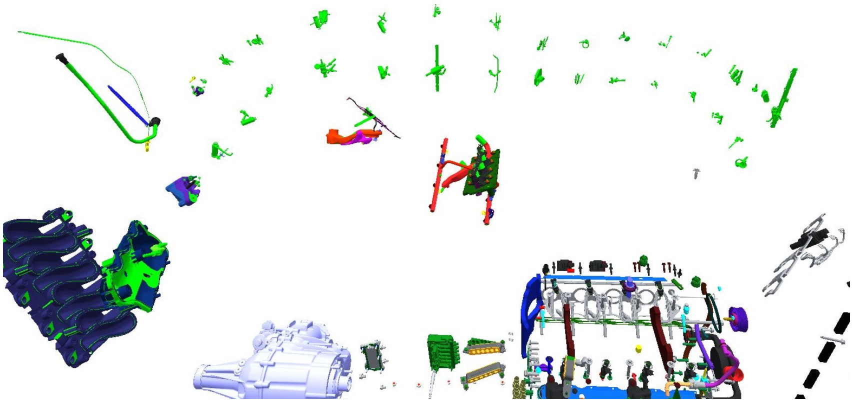

Figure 8: Green parts extracted from the engine. Note that each grouping of parts is actually five separate parts.

3 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. Several tools, particularly "Draw" and "Fly" had a notable "wow" factor effect on users. At the end of the explanation period, most users felt confident about the tools and opted to move into the testing portion with little additional practice.

3.1 Performance Results

3.1.1 Navigation

As expected, novice VR users spent more time in each of the four mazes than any other experience group on average (see Fig. 10). Although the sample size was small, two-sample t-tests were performed to compare the mean maze completion times of users with less experience ("First time" and "Very Little"; 16 users) and those with more experience ("Less than 5 hours", "Between 5 and 15 hours" and "More than 15

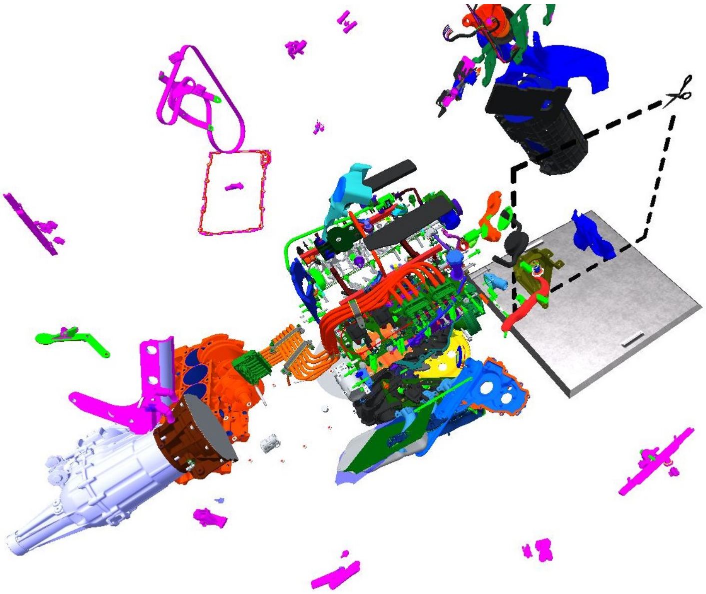

Figure 9: Pink components extracted from the engine. Note that each grouping of parts is actually five separate parts.

hours"; 14 users). Multiple categories of experience levels were lumped together in this statistical analysis to allow general comparison despite small number of participants in some categories. The square mazes showed a more statistically significant difference in means with p-values of .041 and .084 for flying and teleporting, respectively. The same tests for round mazes had p-values of .15 and .12 for flying and teleporting, respectively. This suggests that, while a learning curve to navigating in VR exists, it appears to be quickly overcome during the first few hours of VR exposure.

As indicated in Fig. 10, 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 10 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."

Some users experienced difficulty in grabbing the cube part upon reaching the end of the maze; similar difficulty was observed when users were required to navigate while holding a part in one hand. This was especially prevalent among users who both grabbed the part and navigated with their dominant hand. Because the trajectory of the teleport path could be intercepted by the part in hand, this had a greater effect in the "Teleport" mazes.

Although users reported experiencing varying levels of motion sickness in conjunction with the motion tasks, it was found that users who reported motion sickness performed similarly to their peers who reported no motion sickness. This could be in part due to the short nature of the test. In a longer use case, motion

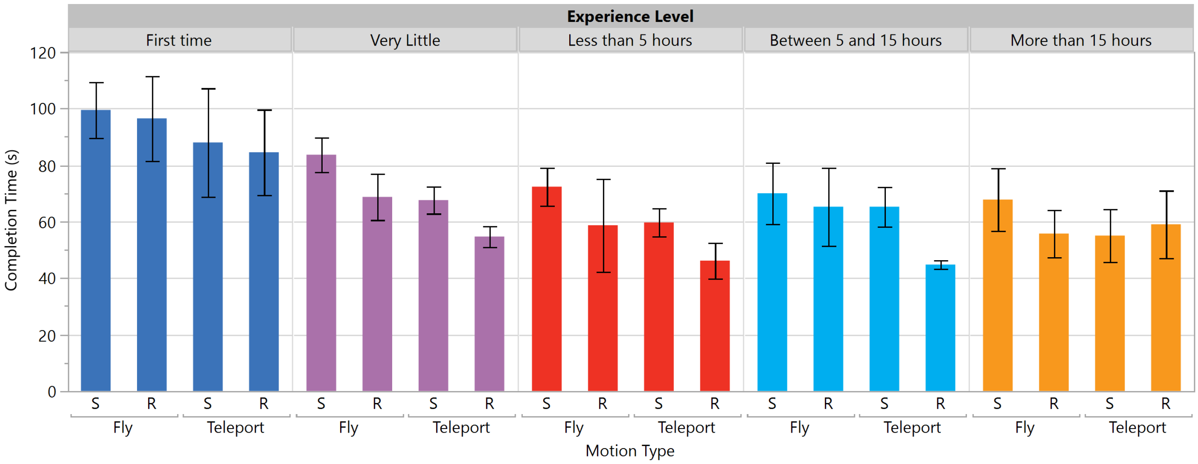

Figure 10: Maze completion time by experience level. Bars indicate standard error; S and R refer to square and round mazes, respectively.

sickness would likely have a greater effect on cumulative performance than was observed.

3.1.2 Manipulation

Performance results for the manipulation test are summarized in Fig. 11. As with the navigation tests, two-sample t-tests were performed to compare the mean maze completion times of users with less experience ("First time" and "Very Little") and those with more experience ("Less than 5 hours", "Between 5 and 15 hours" and "More than 15 hours"). The p-values between the two groups for each color were as follows: orange, .04; pink, .02; light green, .21; dark blue, .66. As noted previously, these tests are from small sample sizes; the results of these statistical tests can be taken to indicate that the learning curve for VR systems is on the order of a few hours. The results for orange and pink parts indicate that first-time VR users generally performed worse than their more experienced counterparts. A longer experiment with even distributions of part colors and sizes would better illustrate the differences between new and experienced users.

As previously indicated, colors were unevenly distributed in both position and size. Because of these differences, comparing absolute numbers of parts captured between different colors is not recommended. There were 12 orange pieces that were readily visible on the surface of the engine (see Fig. 6); this benefited all users equally. There were many pink parts of small to moderate size. Light green parts were plentiful, but tended to be small nuts and bolts that required greater dexterity to grab. This may explain some of the difference observed between experience levels. Dark blue parts tended to be large and several were very visible. In contrast to the differentiation seen with light green parts, all groups performed similarly when grabbing dark blue parts, likely because they tended to be large and easier to select and manipulate.

3.2 Strategies

3.2.1 Navigation Strategies

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

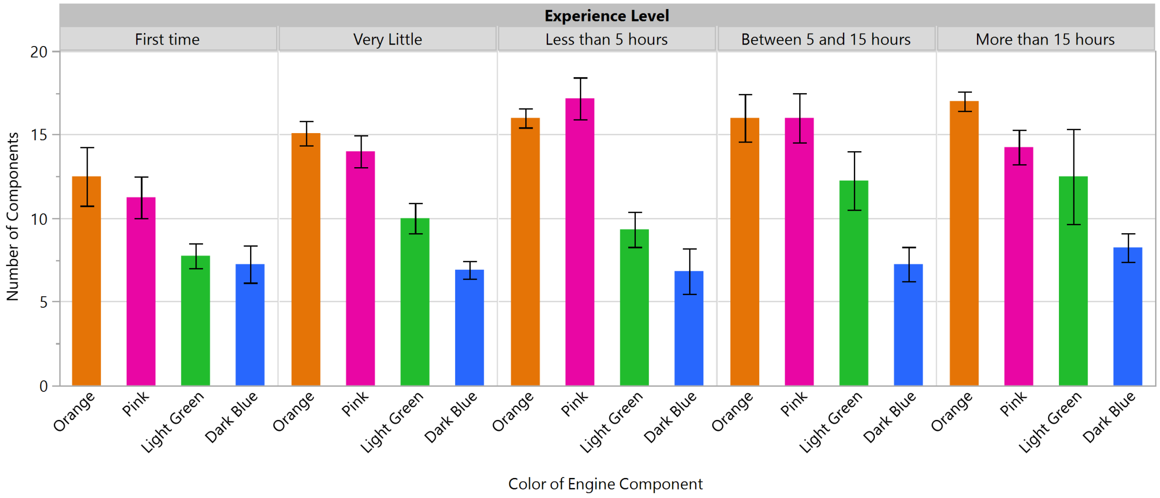

Figure 11: Number of pieces captured by experience level. Bars represent standard error. Total part counts: Orange, 37; Pink, 65; Light Green, 177; Dark Blue, 37.

the number of jumps required while others performed multiple, shorter teleportations in rapid succession. A few users attempted to rotate the orientation of their landing before teleporting. However, this was generally ineffective and quickly abandoned. 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.

A variety of pros and cons for each of these strategies can be assessed for future CAD in VR platform designers.

3.2.2 Manipulation Strategies

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. However, the qualitative data collected suggests that higher-scoring users tended to use one hand rather than two, manipulate the full model (to a more favorable viewpoint at eye level), avoid navigation by teleporting or flying, and use the laser. Participants sometimes got caught up trying to use their non-dominant hand and may have been slower with divided attention than with full attention on one hand. Navigating reduced the amount of time during which participants were actively removing parts, which hurt their score. Using the laser effectively eliminated one axis of motion, allowing participants to focus on the remaining two axes and grab parts more efficiently.

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

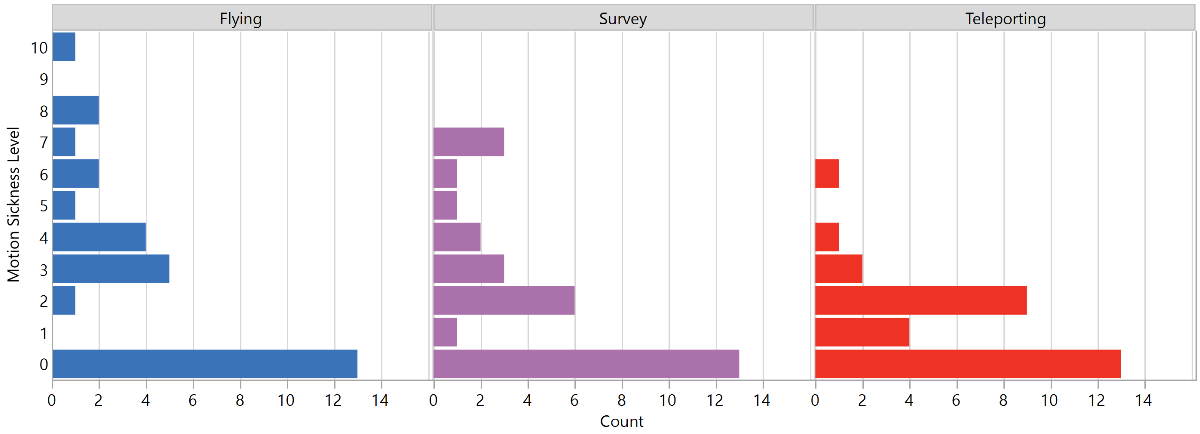

Figure 12: User-reported sickness levels at various times during testing

used a single hand to grab all parts, but eventually transitioned to using both hands. Another participant stood 4.5 feet (1.5 m) from the model and used the laser to grab parts from a substantial distance. Navigation tools and the cutting plane, if used, were typically abandoned after the first use; this was likely due to the 30 second time limit.

The engine model was initially placed about 1.5 ft (.5 m) off the ground. Although this presented an ergonomic challenge for most participants, only 20% chose to move the model to their eye level. Although participants were virtually capable of easily moving the engine in the VR environment, most did not. This may have been observed because users wouldn't be able to easily move an engine in the real world. This demonstrates a bias towards the real-world capabilities that will potentially need to be overcome as VR is adopted by professional groups. Interestingly, despite the enhanced capabilities offered the study participants, 10% achieved better positioning relative to the model by kneeling or sitting on the ground. Again, this observed behavior may be symptomatic of real-world biases brought into virtual reality, and may be overcome as individuals gain exposure to the tools and capabilities available in VR.

3.3 Survey Results

3.3.1 Motion Sickness

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 (see Fig. 12). At the time of the survey, typically 5-10 minutes after completing the navigation tasks, users reported an average motion sickness rating of 3.6. This suggests that flying clearly induces greater motion sickness than other methods of navigation which persisted up to 5 or 10 minutes after the conclusion of the VR experience.

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 as seen in Fig. 13. The participant who ranked their motion sickness during flying as 10 made the following comment in the survey: "I flew around with the intention of trying to make myself motion sick, I'm a pilot... it was fun." It is not unreasonable to

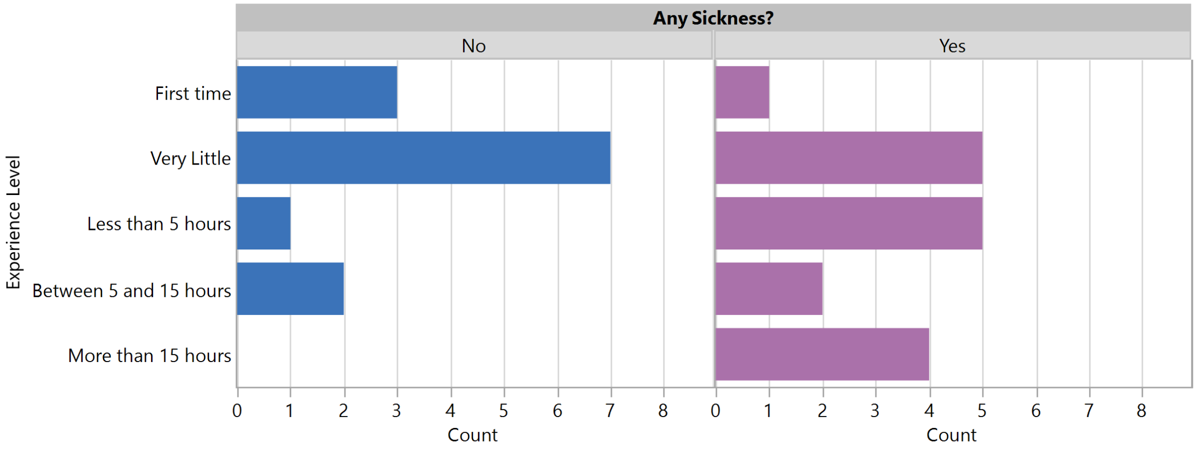

Figure 13: Reported Presence of Cyber or Motion Sickness versus Experience Level during Experiment

suppose that other more experienced users may have acted more aggressively when flying, resulting in greater motion sickness. There may be other causes for this phenomenon including a desire to be self-consistent with the participants declared experience level and pushing themselves harder similar to the "Pilot" above. However, identifying this precise effect would necessitate additional testing with these types of research questions in more detail.

3.3.2 Tools

The majority of users identified "Grab," "Fly," "Teleport," and "Laser" as among the "most useful" tools. The first three of these were absolutely necessary to complete the given tasks. Laser, although not necessary, was used by many participants and elicited a "wow" factor from many. On the other end of the spectrum, users reported that "Measure," "Rotate," and "Cutting Plane" were among the least useful tools. Users cited the lack of usefulness of these features for the tasks at hand as the principle reason for their selections. This was particularly justified with the "Measure" tool, which no participants were observed to use in any portion of testing. Several users claimed that the cutting plane was difficult to use; this may have been because it made objects transparent, but did not prevent them from being grabbed. This resulted in users grabbing invisible parts instead of the visible parts they had intended to select. Despite its low ranking in the survey, the "Rotate" tool was used very effectively by some users during the manipulation portion of the test. This discrepancy between apparent actual and perceived usefulness may be due to the novelty of such a tool. In a traditional environment, rotating a large engine would not typically be feasible; most people might naturally choose to navigate around it instead. A similar phenomenon was observed with participants kneeling to interact with the model in a more comfortable fashion instead of simply moving the model up. Effectively overcoming real-world habits such as these when in VR is necessary for the full value of VR to be realized.

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 [9], where participants like and desire tools they have seen before. Some of the tools suggested by participants in the user study were the following:

- *Shift-click to select* - Allow simultaneous selection of multiple parts for mass manipulation.

- *Undo* - Undo the effects of the most recent discrete action.
- *Resize/zoom* - Scale the size of the model and/or environment .
- *Bookmark position* - Bookmark a location relative to the environment or model and allow the user to return to that position on command.
- *Teleport Improvements* - For example, an arrow pointing the direction to face after teleport.
- *"Video game-type controls"* - Allow use of alternate controls like those used in first-person video games.

One standout item in this list is the ability to bookmark positions. This is a relatively simple feature that could improve user mobility without incurring motion sickness; popular VR games incorporate a similar concept. Innovative and intuitive controls will be essential for wide adoption of VR in professional settings.

3.3.3 Free Responses

The survey provided users an opportunity to explain their like and dislike of tools and comment on their overall experience. A few representative responses are provided below:

Navigation Tools

- *"Fly was useful, but it was a little bit nauseating at the same time. Teleport was nice because I didn't feel nauseous, but it wasn't as natural."* This comment summarizes many participants' feelings on the navigation tools: Fly is intuitive but sometimes nauseating while teleport is less natural and less nauseating.
- *"[Teleport] seemed to put you at a disorienting angle and the feature to change your land angle wasn't intuitive enough to make it a solution for first or maybe even long time users."* Users prefer tools that are intuitive and simple.

Manipulation Tools

- *"Grab was like laser, but too sensitive to distance."* Determining appropriate sensitivity for tools is critical. Giving greater user control over tool sensitivity (e.g. flying speed, grab distance) would be beneficial.
- *"The cutting plane was awkward to use quickly, and it was difficult to tell which side it was cutting."* The tasks users performed influenced their opinions of the tools. Because use of tools like "Rotate" and "Measure" was not required in the tests, many users did not use them when given the option.

4 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 and confirms that VR tools are easy to learn [20]. Although first-time users appeared to be slower than more experienced users in navigation tasks and less effective in manipulation tasks, this learning curve appears to be quickly overcome. This ease of adoption makes VR a compelling addition to existing engineering tools.

While the end usage case ultimately dictates what navigation strategies are feasible for a given application, it is evident that users experience greater cybersickness when flying than when teleporting. With few exceptions, even novice users were quickly able to navigate in a VR environment while multitasking. Although cybersickness remains a risk to VR users, it can evidently be mitigated through the use of appropriate methods of navigation. Further research into cybersickness in VR navigation and tool selection is warranted to expand the existing body of knowledge [13]. Future research should also be performed on the effects and ergonomics of merely rotating one's torso versus lifting and re-planting one's feet while navigating in VR.

A basic level of prior familiarity with VR enhances a user's ability to manipulate models. Manipulation preferences vary widely and it is unclear if a universal optimal manipulation strategy exists or whether the most effective strategy is dependent on the user. Further research may examine the effectiveness of using one hand versus two and/or the effectiveness of using grab-distance enhancing lasers.

User testing confirms that there is a delicate balance to be achieved between familiarity and innovation in development of VR tools and platforms. Users like intuitive, familiar tools, but also love VR for its innovative nature and potential. Because individual preferences vary widely, it is recommended that VR platforms be designed with end-user customization in mind. As VR tools continue to be developed, special attention should be given to making controls intuitive and ergonomic.

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REFERENCES

[1] Betsos, G.; Heger, R.: Visualisation of cad models in a virtual reality environment. Proceedings of Circuits, Systems and Computers, 96, 1996.

[2] Bourdot, P.; Convard, T.; Picon, F.; Ammi, M.; Touraine, D.; Vézien, J.M.: Vr–cad integration: Multimodal immersive interaction and advanced haptic paradigms for implicit edition of cad models. Computer-Aided Design, 42(5), 445–461, 2010. https://doi.org/10.1016/j.cad.2008.10.014.

[3] Cascio, W.F.: Virtual workplaces: Implications for organizational behavior. Journal of Organizational Behavior, 6, 1, 1999.

[4] Castronovo, F.; Nikolic, D.; Liu, Y.; Messner, J.: An evaluation of immersive virtual reality systems for design reviews. In Proceedings of the 13th international conference on construction applications of virtual reality, vol. 47, 2013.

[5] Coburn, J.Q.; Freeman, I.; Salmon, J.L.: A review of the capabilities of current low-cost virtual reality technology and its potential to enhance the design process. Journal of computing and Information Science in Engineering, 17(3), 031013, 2017. https://doi.org/10.1115/1.4036921.

[6] Dans, E.: As Covid-19 Forces Millions Of Us To Work From Home, Which Are The Best Tools For The Job?, 2020. https://www.forbes.com/sites/enriquedans/2020/03/27/as-covid-19-forces-millions-of-us-to-work-from-home-which-are-the-best-tools-for-thejob/#19cc188961e0.

[7] Eves, K.; Salmon, J.; Olsen, J.; Fagergren, F.: A comparative analysis of computer-aided design team performance with collaboration software. Computer-Aided Design and Applications, 15(4), 476–487, 2018. http://doi.org/10.1080/16864360.2017.1419649.

[8] Feeman, S.M.; Wright, L.B.; Salmon, J.L.: Exploration and evaluation of cad modeling in virtual reality. Computer-Aided Design and Applications, 15(6), 892–904, 2018. https://doi.org/10.1080/16864360.2018.1462570.

[9] Hekkert, P.; Thurgood, C.; Whitfield, T.A.: The mere exposure effect for consumer products as a consequence of existing familiarity and controlled exposure. Acta psychologica, 144(2), 411–417, 2013. https://doi.org/10.1016/j.actpsy.2013.07.015.

[10] Jayaram, S.; Vance, J.; Gadh, R.; Jayaram, U.; Srinivasan, H.: Assessment of vr technology and its applications to engineering problems. J. Comput. Inf. Sci. Eng., 1(1), 72–83, 2001. https://doi.org/10.1115/1.1353846.

[11] Jensen, G.: Collaborative multi-user synchronous and asynchronous modeling, analysis and design. In Keynote Presentation, Defense Manufacturing Conference, Orlando, FL, 2012.

[12] Jung, B.; Lenk, M.; Vitzthum, A.: Structured development of 3d applications: round-trip engineering in interdisciplinary teams. Computer Science-Research and Development, 30(3-4), 285–301, 2015. https://doi.org/10.1007/s00450-014-0258-8.

[13] Kim, H.K.; Park, J.; Choi, Y.; Choe, M.: Virtual reality sickness questionnaire (vrsq): motion sickness measurement index in a virtual reality environment. Applied Ergonimcs, 69(1), 66–73, 2018. https://doi.org/10.1016/j.apergo.2017.12.016.

[14] Miller, R.; Kelly, E.: Coronavirus and space: NASA tells employees to work from home; SpaceX launches rocket; Europe-Russia mission delayed, 2020. https://www.usatoday.com/story/news/nation/2020/03/18/coronavirus-affects-space-nasa-sends-employees-home-spacex-launches/2863179001/.

[15] Rabatje, R.: Integration of basic cad functions into a vr environment. In Proceedings. Computer Graphics International (Cat. No. 98EX149), 238–241. IEEE, 1998. https://doi.org/10.1109/CGI.1998.694271.

[16] Scott, D.: Coronavirus is exposing all of the weaknesses in the US health system, 2020. https://www.vox.com/policy-and-politics/2020/3/16/21173766/coronavirus-covid-19-us-cases-health-care-system.

[17] Smith, J.W.; Salmon, J.L.: Development and analysis of virtual reality technician-training platform and methods. In Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), Orlando, 2017.

[18] Steger, W.; Kim, T.S.; Gebert, M.; Stelzer, R.: Improved user experience in a vr based design review. In ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers Digital Collection, 2016. https://doi.org/10.1115/DETC2016-59840.

[19] Weidlich, D.; Cser, L.; Polzin, T.; Cristiano, D.; Zickner, H.: Virtual reality approaches for immersive design. CIRP annals, 56(1), 139–142, 2007. https://doi.org/10.1016/j.cirp.2007.05.034.

[20] Wolfartsberger, J.: Analyzing the potential of virtual reality for engineering design review. Automation in Construction, 104, 27–37, 2019. https://doi.org/10.1016/j.autcon.2019.03.018.

[21] Wu, T.H.; Wu, F.; Liang, C.J.; Li, Y.F.; Tseng, C.M.; Kang, S.C.: A virtual reality tool for training in global engineering collaboration. Universal Access in the Information Society, 18(2), 243–255, 2019. https://doi.org/10.1007/s10209-017-0594-0.

[22] Zhong, Y.; Yuan, X.; Ma, W.: Virtual reality based solid modeling. In Fifth World Congress on Intelligent Control and Automation (IEEE Cat. No. 04EX788), vol. 4, 3214–3218. IEEE, 2004. https://doi.org/10.1109/WCICA.2004.1343116.