Virtual and Augmented Reality in the Design Process

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Abstract

This paper explores how Virtual Reality and Augmented Reality can be used to enhance the CAD design process. VR and AR technologies are showing rapid increases in complexity and the adopting of such devices is rising. Current applications for these technologies are explored in this paper to form a research proposal to explore how different factors impact the experience of 3D modelling within VR. This research led to the proposal of a design that aims to make desktop CAD modelling a richer and more informative experience by enabling aspects of VR and AR.

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Introduction to AR and VR

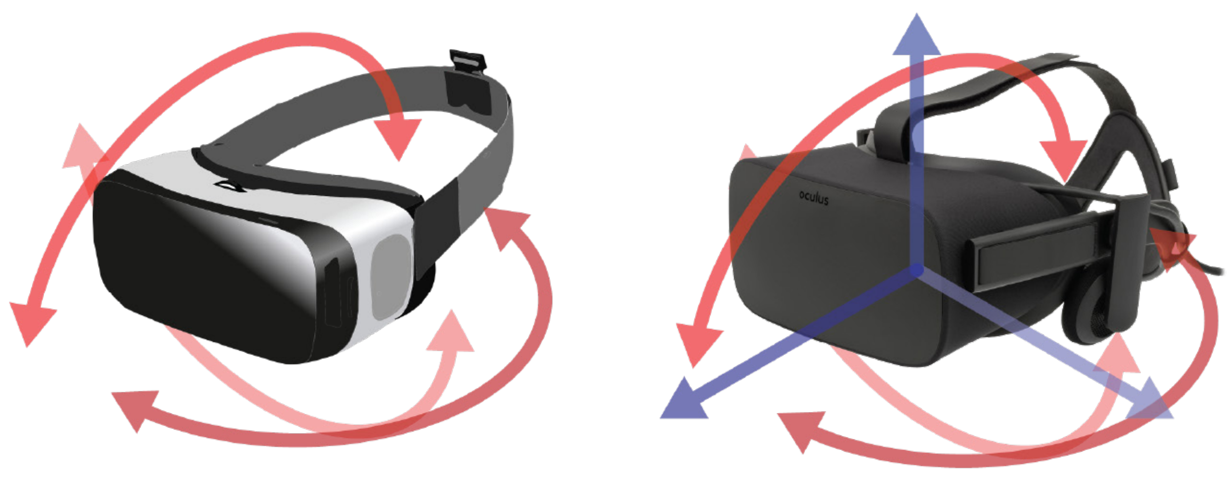
Introduction to AR and VR

Virtual Reality and Augmented Reality (VR and AR) are proving to be significant technologies that enable users to interact with the virtual world in a unique yet intuitive way. Both technologies commonly utilise Head Mounted Displays (HMD's) to immerse the user into a digital environment that they can interact with using the full movements of their body.

Typical desktop interactions are limited to flat screens and two-dimensional control methods such as mouses, keyboards, and styluses. In the context of 3D model making and visualisation, users' must take on an extra load to mentally transform the 2D image on the screen into a 3D one in their mind. Advanced modern VR and AR technologies use headsets and controllers that can track themselves in three dimensions. This significant advantage of VR and AR mirror the 3D nature of the real world and allow users to quickly gain an intuitive understanding of the virtual world and how to control it. The stereoscopic nature of both AR and VR technologies gives users depth perception abilities which removes the extra mental load required to imagine objects in three dimensions.

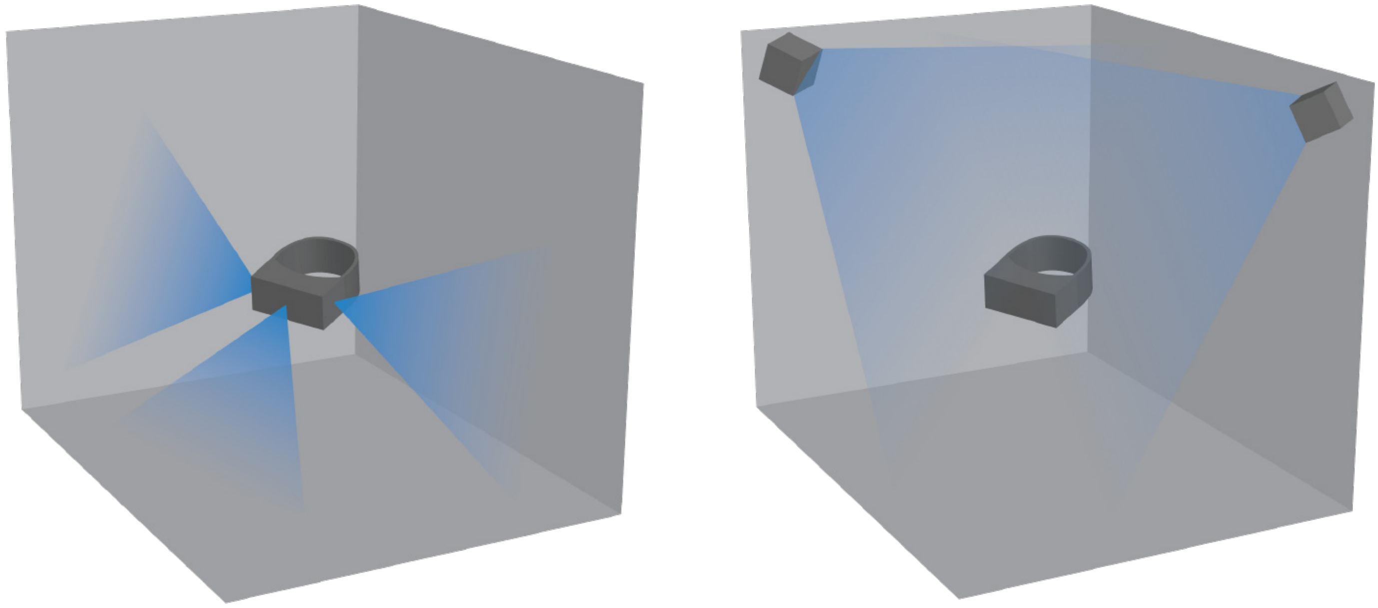
The aim of this project is to explore how VR and AR is currently being used in the design process and to identify the shortcomings of current solutions. The experience of users will be explored in this paper to identify how the experience of AR and VR can be improved in industry settings and introduced into fields that could benefit from the technology.

Early forms of VR/AR and many modern phone-based VR/AR systems rely solely on internal sensors such as gyroscopes, accelerometers, and magnetometers to track the users head movements in three degrees of freedom (3DoF). More advanced VR and AR systems can track the position of the headset relative to the real world which allows for more advanced interactions within the virtual environment. This is referred to tracking with six degrees of freedom (6DoF) and is achieved in varying ways across different devices with some solutions being more accurate than others at the cost of increased cost and complexity. (A quick guide to Degrees of Freedom in Virtual Reality, n.d.)



3 Degrees of Freedom **6 Degrees of Freedom**

Figure 1: 3Dof and 6Dof



Inside-Out Tracking

Basestation Tracking

Figure 2: Tracking Types

6 DoF tracking requires the use of hardware that either tracks the room with internal cameras and sensors on the HMD itself or with the use of external base stations.

VR and AR are similar technologies but have key differences that significantly change the types of activities that can be achieved with each of them. VR entirely replaces the vision of the user with an artificial environment that is separate from the real world and the objects around the user. AR on the other hand aims to blend the virtual world with the real world by overlaying objects and infographics onto real world objects and environments. (What is the difference between VR and AR?, 2019)

Normal Reality

Augmented Reality

Virtual Reality

Figure 3: Reality Levels

Literature Review

VR/AR in the Design Process

VR and AR technologies have the ability to enhance the design process by giving designers the opportunity to create and evaluate their designs within a virtual environment that allows them to see their designs as if they were real and in front of them.

Traditional CAD Interactions

The current and most popular option for engaging in Computer Aided Design (CAD) is through a traditional desktop experience with a WIMP interface (Windows, Icons, Menus, Pointers). This limits the user to common peripherals such as a mouse and keyboard (Freeman, Wright, & Salmon, 2018) which prevent the user from using the natural, three dimensional, movement of their body to create and evaluate designs. With the use of VR, an in depth understanding of the created model can be achieved and new ways of creating and manipulating models are possible with the use of advanced 3D tracking systems. This change also makes it more intuitive for new designers to model and understand the models they create.

Understanding 3D Models

VR technology allows users to immerse themselves in a computer-generated environment and interact with the virtual world (Wang, Ng, Ong, & Nee, 2013). Because of this, Elizabeth P. and Matt C. suggested that VR gives users a better and more in depth understanding of scale and details of a space (Pober & Cook, 2019). This was confirmed when the results of their research showed that most of the students studied reported that VR helped them understand the impact of their designs in relation to volumetric space. These students had 2.5 years of experience using CAD software such as Autodesk Revit, AutoCAD Architecture, and SketchUp and none had used VR for design related purposes. This information shows that VR has the potential to drastically change the way models and spaces are evaluated and understood before bringing them into the real world.

Model Complexity and Error Identification in VR/AR

Elizabeth P. and Matt C. also found that the students they studied felt that VR helped them find more errors in their designs as compared to methods such as sketching, computer drafting, and modelling. The typical errors found related to circulation in spaces not being adequate and features not being positioned correctly in relation to eye-line (Pober & Cook, 2019). These findings are expected as VR is very good at giving a life-sized representation of spaces and objects. It is worth noting that each experience for each person within VR is tailored to their specific height and therefore may be difficult to evaluate spaces at different heights without the implementation of scaling tools.

Describing and Evaluating Models with VR/AR

The same students also reported that understanding and explaining their design both visually and verbally became easier once they were able to evaluate their designs within VR (Pober & Cook, 2019). A. Benjamin Spaeth and K. Ramez also found through research that "architects perceived it easier to articulate their ideas to the clients using VR" (A. & Khali, 2018). This is likely due to the fact that VR gives users a spatial understanding of an environment which can then be easily translated into words for easy communication. This shows that VR and AR have the ability to enhance communication of designs inside and outside of the virtual environment.

Spatial Evaluation in VR/AR

As VR can accurately represent the scale of spaces using stereoscopic vision, students who tested VR for analysis of their designs often found that their ceiling heights were higher or lower than expected and that certain spaces were larger than expected. One student quoted "The experience of the restaurant (in VR) made me more aware of how much bigger the dining area is than I had expected it to be and how open the circulation spaces are" (Pober & Cook, 2019). Sexton went as far to say that VR may be the most important advancement in architectural presentation since the rediscovery of one-point and two-point perspective representations in the renaissance (Sexton, 2017). This ability to evaluate the size of a space is one of VR's strongest points and should be utilised whenever possible for CAD experiences within VR.

Model Creation

The use of accurate 3D tracking for controllers in VR and AR allows users to create 3D models using the natural motions of their bodies. This has been shown to result in higher overall scores in assessments with students that were able to benefit from rapid iteration within VR (Pober & Cook, 2019). Some current commercially available software for VR allows users to sculpture and edit geometry using an addition and subtraction method, similar to clay modelling. This can be effective for creating detailed models but is not capable of producing the parametric, boundary representation models that form the basis of CAD (Freeman, Wright, & Salmon, 2018). Software developed by Mindesk Inc for Rhino 5 allows users to create CAD models directly within VR, however, the software is limited in functionality as compared to the desktop experience. Research also found that participants were able to create models in VR at a faster rate than using Fusion 360 on a desktop (Freeman, Wright, & Salmon, 2018). Past work proves that VR and AR have the ability to improve the efficiency of model making which will help to accelerate the production of models for both new and experienced designers.

Engagement

When VR was utilised for meetings between architects and clients, it was found that the clients participated more and provided more concise feedback compared to traditional meetings, and the architects perceived it easier to articulate their ideas to the clients (A. & Khali, 2018). Reasons for the higher engagement could be down to the fact that the clients were able to immerse themselves into the design of architect without having to take on the mental load of imagining themselves in the environment. The presence of being in the design with the designer may also play a part in this engagement.

Current Usage Statistics

In the UK, 52% of architecture firms surveyed currently use some type of immersive technology in-house. HMD's were the leading type of technology followed by other methods, such as Space Domes and CAVE systems, at a lower rate of adoption (A. & Khali, 2018). Most of the HMD technologies used in these firms were mobile VR solutions which are severely limited in their processing power and are only able to display 360-degree still images or low fidelity models. These firms mainly used VR for client meetings, presentations, final visualisations, marketing, during the design process, and for project coordination. Mobile VR hardware still requires the use of a desktop to generate the models and 360-degree images of these models. The use of a desktop VR headset with 6-degrees of freedom could enable more advanced model viewing experiences and more in-depth interactions with these models.

Issues

VR is not however free of issues. A common issue that many people experience during their early hours in VR is motions sickness. P. Elizabeth and C. Matt found that many of their research participants experienced motion sickness at some time when using VR (Pober & Cook, 2019). This could have been down to low framerates, smooth locomotion in VR, or many other reasons. It is possible to become accustomed to these affects but many of the users likely will not use VR for long enough to become used to it.

In the case of AR in the use of assembly planning, many users found it visually unconvincing due to a limited field of view (FOV). Users also found it hard to manipulate small objects using bare hand pinch gestures and found that larger and heavier parts did not translate their weight well visually (Wang, Ng, Ong, & Nee, 2013). When it comes to assembly processes in VR and AR, it is essential to accommodate for these issues by making interactions easier and more detailed for the user.

Collaboration with VR/AR

Flexibility

VR and AR allow for complex remote communication between users through the internet. This is particularly important in inter-organizational supply chains where many of the processes that need to be modelled, improved and/or automated, span organizational or even geographical boundaries (Poppe, Brown, Johnson, & Recker, 2011). This makes one-on-one sessions hard or impossible to schedule. This is where VR and AR technologies shine as it allows users to place a virtual version of themselves into the same environment as a remote user. This creates the experience of being co-located with other users (S., M., L., & K., 2015) which helps to emulate a typical meeting environment. Being co-located with collaborators improves communication and productivity which is why it is important to consider in the design process.

Web-Based Collaboration

Web-based desktop software for collaboration currently exists that enables users to work on the same projects with each other from remote locations. This is however limited in terms of communication and decision making due to the separation of work-space from communication-space (Poppe, Brown, Johnson, & Recker, 2011). This is an opportunity for VR and AR technologies in the realm of CAD modelling as users can place themselves in the area they are modelling and others who are working with them can both see the work they are doing and communicate with them.

Representation of Space and Spatial Relationships

Body language makes up a large amount of communication and is what differentiates face-to-face communication with online communication. Collaborative Virtual Environments (CVE's) have the ability to communicate body language, gestures, and gaze through the tracking of the user's head and their hands/controllers (Poppe, Brown, Johnson, & Recker, 2011). A surprisingly high amount of body language can be read from just the position of a user's head and hands in VR.

Interacting with Objects

Sharing content in VR and AR is very similar to how it would be done in real life. Users can share objects by handing them between each other and users can gesture towards other objects and people to guide the view of others. AR reduce the separation between task-space and communication-space and enhances natural face-to-face communication cues (S., M., L., & K., 2015). This mirroring of real-world interactions allows them to be enhanced with the use of AR technologies and allows such interactions to happen from remote locations.

VR and AR also enable "God-like interactions" which is where users can scale themselves up to a larger size in a virtual environment to enable observations of people or objects from a birds' eye view (S., M., L., & K., 2015). This is particularly helpful for activities such as monitoring a group of users in the virtual environment.

Model Annotations and Measuring

Advanced annotations can be made in VR and AR environments using 3D sketches and virtual notes. Written notes can be created simply be selecting a location and using voice-to-text to dictate the annotations. These annotations remain persistent and can be accessed by different people at different times (S., M., L., & K., 2015). Like annotations, measuring objects in VR and AR can also easily be done similarly to how it is done in real life using a virtual measuring tape or ruler. Being able to leave annotations and take measurements in VR and AR with others in real time increases the efficiency of collaboration. These features should be used whenever possible in CAD scenarios to benefit the users.

Representing Other Users

When collaborating with others in a virtual environment, it is essential to represent other users using some form of avatar so that others have a visual indication of the position and pose of other users. These avatars become visual representations of other users and can theoretically communicate non-verbal cues such as facial expressions (Nathan, 2016). Technology to track a user’s facial expressions and translate them onto virtual models is currently in the works by companies such as Oculus but it is not currently commercially available. This kind of technology also requires the use of a bulkier system to create the initial dataset used to read a user’s facial expressions with more streamlined hardware. With HMD and controller VR and AR systems, only the position of the user’s head and hands is tracked. This does however communicate a high level of body language despite only having 3 spatially tracked objects.

AR VS VR in Local Collaboration

When it comes to local collaboration, AR is typically more desirable than VR as AR still allows users to see the full body of others while interacting with virtual objects. In this setting, AR is able to bridge the gap between in-person meetings and immersive conferencing experiences while still maintaining a comfortable experience (Nathan, 2016). Local collaboration in AR also shares the same room which means virtual objects placed with such a room are in the same location for everyone else using VR at the location.

Impact of Immersion

What is Immersion?

Immersion in the context of VR and AR refers to the ability for a user to become convinced that the experience within the virtual world is real. Immersion can be split into two categories; mental and physical. Mental immersion refers to when a user submerges themselves into a certain storyline or situation within the virtual world. Physical immersion refers to how well the user's movements in the real world translate into the virtual one and how influential they are to the virtual environment (mobfish, 2019).

Representation of Objects

VR and AR can successfully represent objects visually but struggles to emulate the feel of them. Work is being made in this area with gloves that control and limit the movement of a user's fingers, but these only work effectively with small, lightweight virtual objects. Similar tech to emulate scents in virtual environments has been made but may not help when it comes to collaborating in VR (S., M., L., & K., 2015). Being able to feel objects in VR greatly increases how well objects are communicated to users but the technology to create a sense of touch on immovable objects in VR and AR does not currently exist and most likely will not without the use of bulky equipment.

Spatial Sound

The ability for a virtual environment to produce accurate spatial sound is essential to the immersion level of the user. Good spatial sound communicates to the user the geometry of the environment and the way sound bounces on objects around the user. From personal experience, spatial sound plays an equal role to visuals in determining how immersing a virtual experience is. In the design process, particularly in interior design or architecture, good spatial sound would give the designer an idea of the sound-scape of their designed environment.

Interactivity and Immersion

Being able to interact with every object around you in real live experiences is what people expect. When a virtual world is unable to be interacted with in detail, it breaks the presence and immersion for the user as it no longer mirrors real-life experiences. To feel present in a virtual environment, the user needs to be able to interact with it in a coherent way (Harth, et al., 2018). The ability to interact with a design in AR or VR would greatly increase the illusion that the design is real.

Representation of Users in VR

The way a user's body is visually represented in VR is also important for establishing immersion. The representation does not necessarily need to reflect the form of a human body, it just needs to move and behave in a way that accurately reflects the user's movements. Studies concerning interaction and immersion identified the role that tracking technology, the visual representation and virtual hands of the user's avatar, and the avatar's walking technique to be significant for improving the user's immersion (Harth, et al., 2018). In a design process setting, representing the user accurately in VR would help maintain a higher level of immersion and help to increase work-flow and reduce distractions.

User Orientations

One study identified that the prior mental orientation had an influence on the users' immersion within a virtual environment. The study also identified that immersion wasn't just down to good interaction design or vivid visuals alone (Harth, et al., 2018). This means that a user's level of immersion can be influenced by their primordial orientations of VR and AR technology.

Research Gap

The literature reviewed shows a research gap in how the hardware itself and different types of control methods affect the way the modelling is carried out in VR and AR. The limitations of model creating in VR and AR is also not explored very thoroughly. One of the studies reviewed found that the primordial orientations the user had towards VR and AR influenced the immersion of the user but the effect this had on the experience of model making was not investigated. Another research gap is how well users were able to translate mental images of designs into 3D forms using VR and AR.

Research Design

Research Design

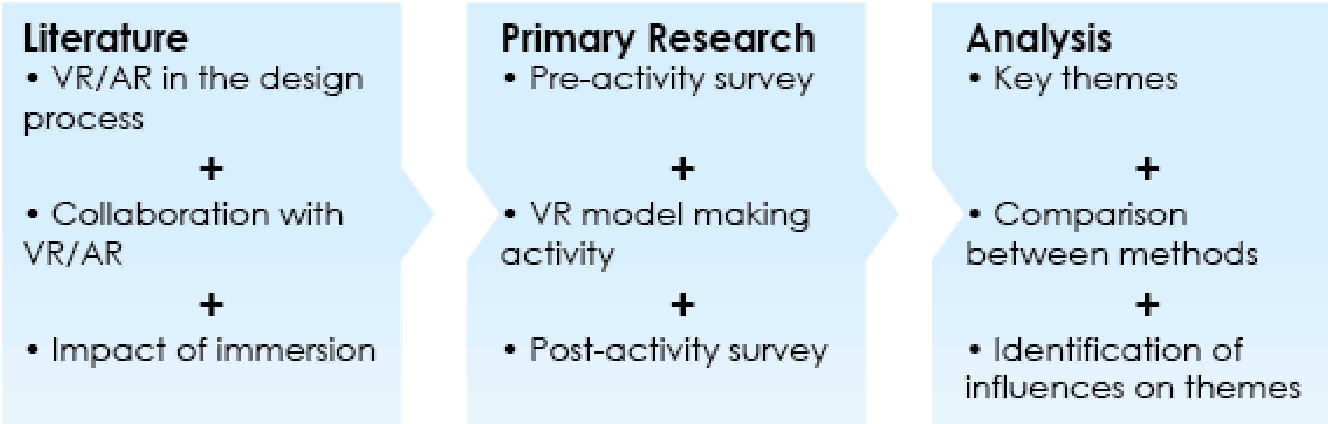


Figure 4: Research Structure

Purpose of Research

The purpose of the primary research is to investigate the current viability of modelling within VR and the struggles associated with such activities. The hardware that each participant uses will also be investigated to reveal how different controllers and HMD's influence the creation of the models within VR. The literature review showed that immersion can have an impact on engagement within VR and that the "primordial orientations" of VR users can influence their immersion. Because of this, the methodology will include techniques to gauge the participants opinions about modelling in VR so that this information can be compared against how well they did during the research activity and how engaged they were during it. The analysis of the research will show the viability of commercially available hardware within the context of the design process and how this hardware may be improved.

Methodology

Due to the current health situation, all activities will be carried remotely out on the participants VR hardware. As a result, the specific brand of hardware used by each participant will vary. This factor has been considered and will be used as an advantage to gauge the effect that specific controller types have on the activity process.

Pre-Activity Survey

For the pre-activity survey, general information on the participants hardware will be collected. The primordial orientations of the participant will also be gauged so that this information can be used to see if there is a correlation between user's opinions of modelling in VR and the result of their modelling. The survey will be conducted using the QUT provided service, "Key Survey".

VR Modelling Activity

For the modelling activity, participants will be required to model 3 different models in 5-10 minutes for each model. The three models chosen are a water bottle, a shoe, and a pair of over ear headphones. These models were chosen as they are all forms that most people are familiar with. The order of the models during the activity is also arranged to gradually increase in difficulty and introduce a new style of modelling for each model. This choice will aid the participants in the brief learning of a modelling software they are most likely not familiar with.

For this activity, participants will be encouraged to vocalise their thoughts during the process. This is known as a "Think Aloud" protocol. With the participants permission, an audio recording, or at the least, a transcript of what they say will be recorded for later analysis. If possible, a video recording of the participants view within VR during the modelling activity will be recorded so that specific things said by the participant can be matched up with the task they were carrying out in the activity.

Post-Activity Survey

After the modelling activity has been completed, the participants will fill out a second, longer survey to gather their thoughts on how difficult they found the activities, how they felt their specific hardware influenced their designs, and how well they were able to translate their mental image of their design into a physical one within VR. This survey will also be completed with "Key Survey".

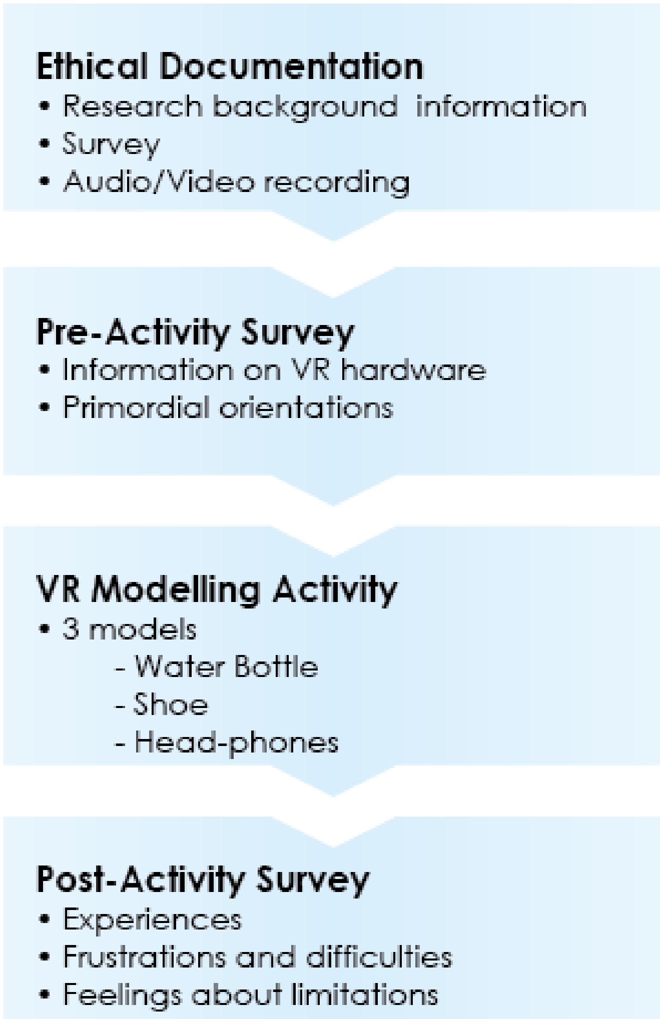


Figure 5: Methodology

Participants
The participants will be recruited through the online community chat service, Discord. Access to multiple servers within Discord with potential participants has been established prior to research. These potential participants all currently own VR headsets and regularly use them for gaming purposes. Most of these potential participants are already experienced in the operation of the VR devices but have not utilised them for modelling purposes.

Data Collection
Each participant will be assigned a number that is to be kept separate to their name. This number will be used to tag surveys, audio/video recordings, transcripts, and model files so that they may be analysed together. Survey data will be collected by "Key Survey" which is a QUT online survey service. Audio and video during the modelling activity will either be recorded on the participants end if they are able to, or easily live-streamed through features built directly in Discord and recorded onto a local drive. Discord does not save any audio or video streamed with their software. The resulting models from the modelling activity will be sent back and stored locally for analysis to complexity and key features.

Data Analysis
The survey data, audio/video recordings, and resulting 3D models will be analysed together to triangulate towards valid findings that properly reflect the data from the research. Figure 6 shows the hypothesis for how each aspect of the research will influence each other. These relationships will be analysed in the analysis to verify whether they are true or not and to possibly find new relationships.

Survey data will include both Likert scale questions and written responses which will be compared against the resulting models from the modelling activity, and key themes from what participants think-aloud during the modelling. The primordial orientations of the participants will be sorted into different themes to see the correlation between orientations and model outcomes. Common struggles across the board will be identified to reveal where these struggles originate from. The models produced by the participants will be ranked on their complexity by analysing features such as geometry manipulation, how well they resemble the brief, and the detail of the model. This information will be compared with results from the post-activity survey which will question how complex the participants think their models are.

Ethics
The ethics documentation required for this study is an information and consent form for the methods of collecting data, which includes surveys, audio, video of software usage (doesn't include any images of the participant), and if the participant does not agree to audio and video recording, a transcription option will be available. If a participant chooses to withdraw, this can either be done via the withdraw consent form or a simple message.

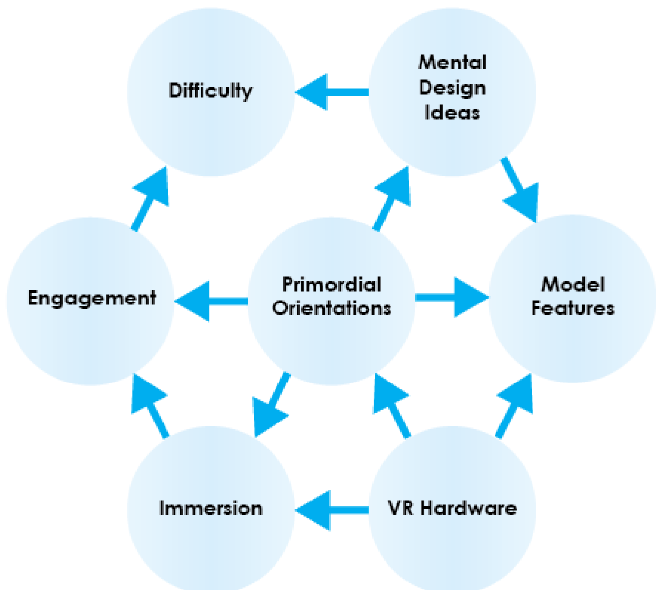


Figure 6: Influences Hypothesis

Analysis and Findings

Analysis and Findings

Analysis Methods

Model Ranking

In order to compare and correlate the quality of models produced by participants to other data and statistics, a quality ranking system was devised that included three categories. These categories were Brief Similarity, Model Elegancy, and General Aesthetic Quality. These were ranked from 1 to 10 where 1 is the lowest grade, and 10 is the highest grade. The categories were defined as stated below:

- **Brief Similarity:** How closely the finished model looked to the target design (i.e. How closely the "Water bottle" model looked like a water bottle)
- **Model Elegancy:** How elegant the usage of shapes and geometry manipulation was to make the desired object (i.e. Best model detail with minimal complexity)
- **General Aesthetic Quality:** The general aesthetic visual quality of the models (i.e. Neatness and concept design)

Figure 7 shows the scores achieved by each model produced by the participants.

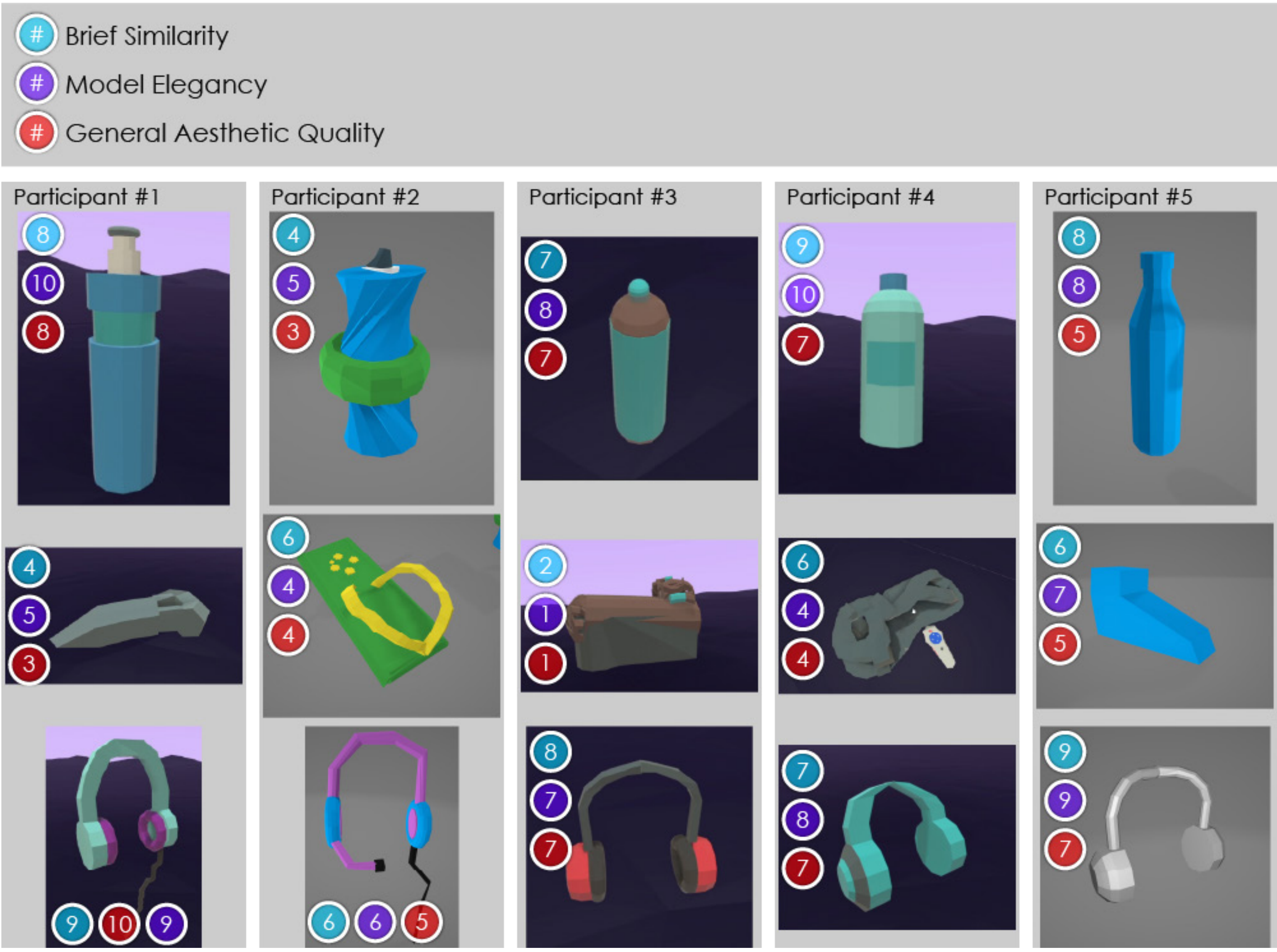


Figure 7: Participant Models

A good example of the “Brief Similarity” criterion can be seen in the Water Bottle models produced by participants #2 and #4. The bottle produced by participant #2 is much more abstract than the model produced by participant #4 which looks much closer to a traditional water bottle design.

An example of the “Model Elegancy” criterion can be seen in the shoe models produced by participants #3 and #5. Participant #3’s shoe model required more shapes and higher model complexity to achieve a shoe aesthetic, while participant #5’s shoe model was able to convey the design of a shoe with a drastically lower model complexity. As such, participant #5’s shoe scored much higher than participant #3’s shoe in the Model Elegancy criterion.

An example of the “General Aesthetic Quality” criterion is visible in the models produced by participants #1 and #2. Participant #1’s model was much neater, more aligned, and was more aesthetically pleasing than participant #2’s model and as such, it scored higher in this criterion.

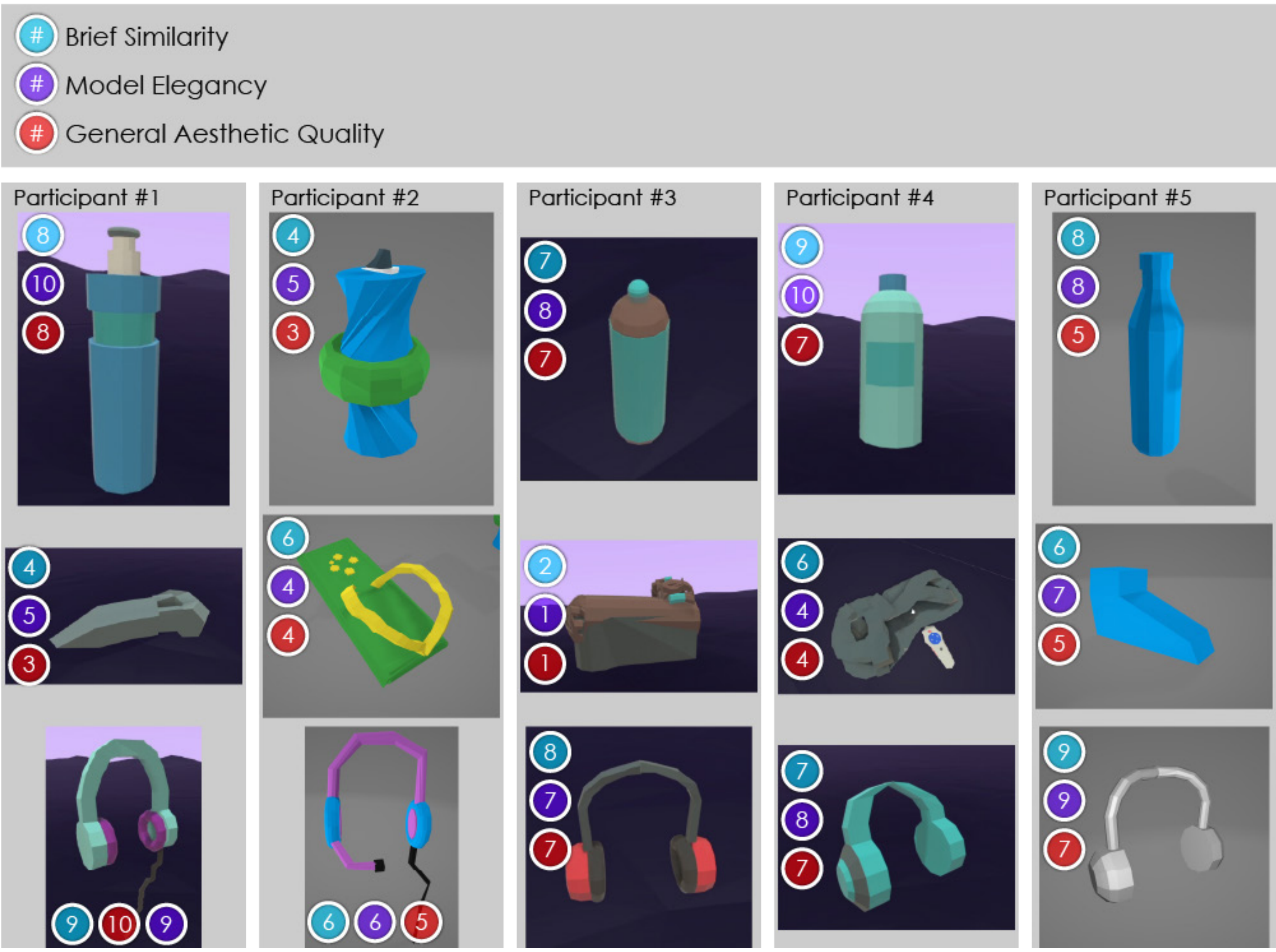


Figure 7: Participant Models

Thematic Analysis

In order to analyse the spoken data from participants during the modelling activities, key points spoken by participants were transcribed and sorted into categories. These categories included Struggles, Positives, and Hardware Improvement Wishes. The Struggles and Positives categories were further sorted down into sub-categories which included hardware induced, environmental induced, and software induced struggles/positives. These categories were created so that the source of the struggles and positives can be clearly identified, and design recommendations can be made based upon them. As the design proposal will be based mainly on a physical product, the software induced struggles and positives categories were created so that software suggestions can be created to support the physical design.

The written data collected from surveys was also sorted into the same categories as stated above and integrated into the data collected from the transcripts. With this data sorted and combined, a thematic analysis was conducted to identify the key struggles, positives, and wishes of the participants and the source of these factors.

Multivariate Analysis

The quantitative data collected from the survey and the model quality analysis was compared with each other to find correlations between factors such as Primordial Opinions, CAD Experience, Model Quality and Perceived Difficulty. These factors were compared with each other on a per-participant basis to complete a multivariate analysis. This analysis allowed for correlations between these factors to be formed.

Findings

Multivariate

An analysis between Participant CAD Experience and Quality showed that participants with prior CAD experience generally scored slightly higher than participants without prior CAD experience (Figure 8). However, participants without CAD experience were still able to produce models of substantial quality by using the VR hardware. This suggests that users that have prior CAD experience can translate some of their mental processes into the drastically different VR modelling environment. It also suggests that users without CAD experience can be aided using VR for 3D modelling.

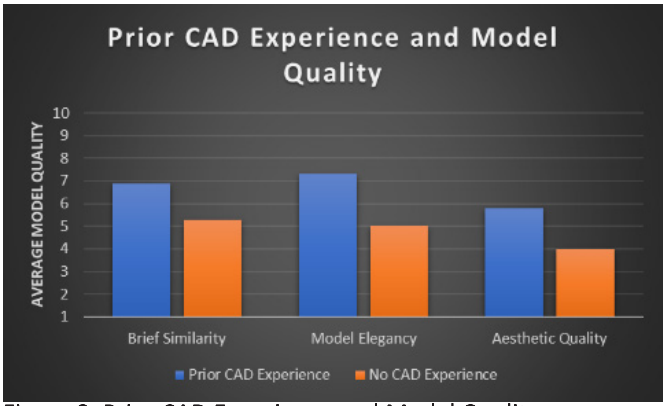


Figure 8: Prior CAD Experience and Model Quality

The Primordial Orientations of the participants was hypothesised to influence the quality of the models produced during the modelling activity. This correlation showed evidence of validity through the data collected. Primordial Orientations of the participants opinions towards VR 3D modelling were collected both before and after watching a short stimulus promotional video advertising the "Blocks by Google" software.

This was conducted to analyse if participants whose opinions were boosted from the video showed a different standard of quality than other participants. As shown in figures 9 and 10, participants who had more positive primordial orientations generally scored higher in the model quality criterions. The participants whose primordial orientations were boosted from the promotional content also showed to produce higher quality models on average. This data suggests that the mental opinions users have towards modelling in VR can influence the produced quality of the models.

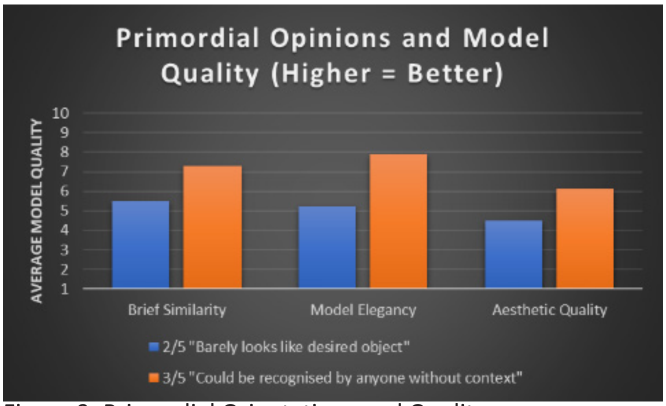


Figure 9: Primordial Orientations and Quality

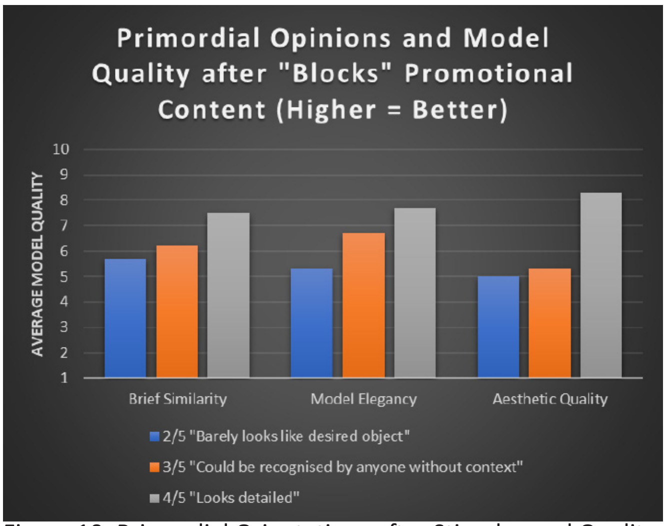


Figure 10: Primordial Orientations after Stimulus and Quality

Analysis and Findings

The self-perceived difficulty that the participants had with each model was compared with the quality criterions to identify if there was a correlation between these factors. As seen in figures 11, 12, and 13, the Water Bottle and Shoe models suffered from lower quality when participants found it more difficult to model them. However, it is interesting that by the time the participants started modelling the headphones later in the activity, the perceived difficulty did not show an influence on the model quality. The reasoning behind this decrease of correlation between the model quality and the perceived difficulty could be down to a multitude of factors, however, this cannot be proven without further research.

A hypothesis for this characteristic could be that as the participants became more experienced with VR modelling throughout the course of the study, they found it easier to use the software, and such were limited by other underlying factors, such as creativity. It can therefore be assumed that as users become more familiar with VR modelling, the more other factors, such as creativity, start to influence the quality of the models produced using the hardware.

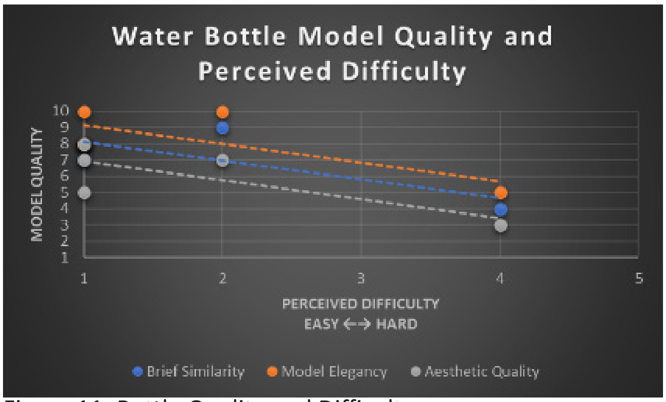


Figure 11: Bottle Quality and Difficulty

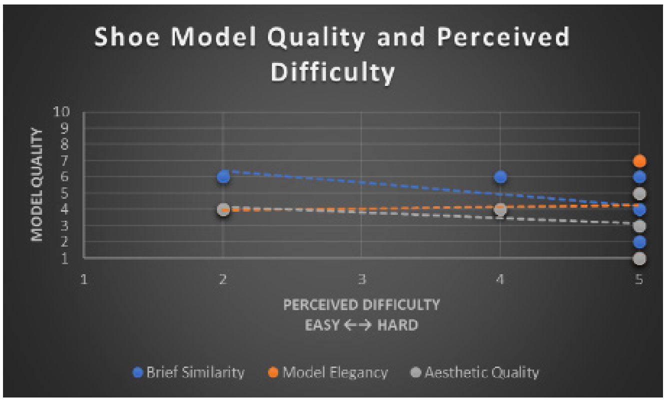


Figure 12: Shoe Quality and Difficulty

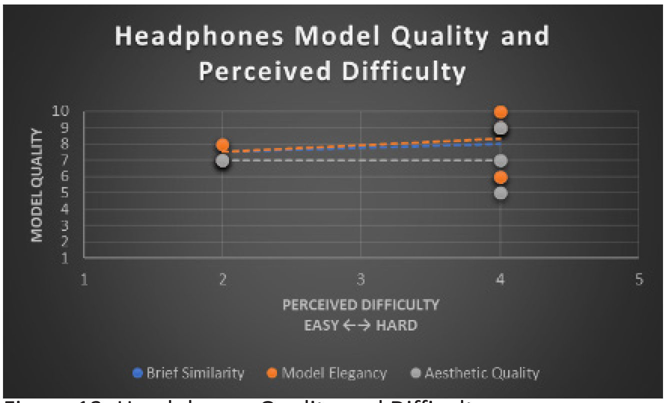


Figure 13: Headphones Quality and Difficulty

Analysis and Findings

As stated in the Research Design section of this paper, the three models chosen for the participants were each chosen as they all challenged the participants in a certain way. The Water Bottle model required the usage of CAD like operations such as extrusions, while the Shoe model required skills in surface mesh manipulation, a technique that is not often used for parametric CAD modelling. The Headphones model combines skills from both the Water Bottle and Shoe to evaluate how well participants can combine both methods of modelling.

The data shows that participants who had prior CAD experience found it easier to produce models with CAD-like geometry and found it significantly more difficult to produce models that required the usage of mesh manipulation skills. The participants who did not have prior CAD experience found it easier to produce models that required mesh manipulation, but harder to produce models that required any form of modelling skills typically used in parametric CAD modelling. (Figure 14)

This data suggests that designers with CAD modelling experience can transfer CAD operations in VR with ease but will not find it easier at first to design using mesh-manipulation techniques. The data also suggests that new designers without CAD experience will find it easier to model more organic forms with the assistance of VR hardware.

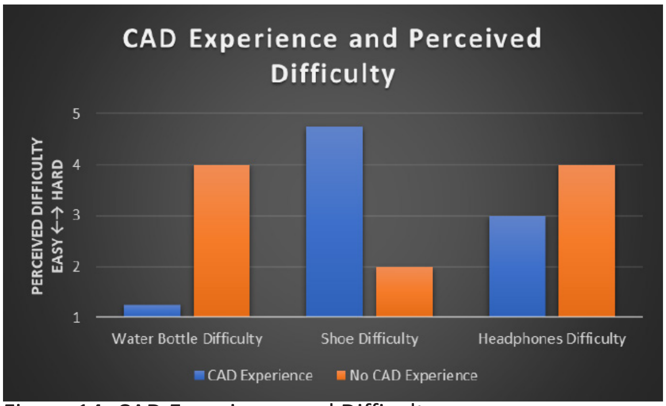


Figure 14: CAD Experience and Difficulty

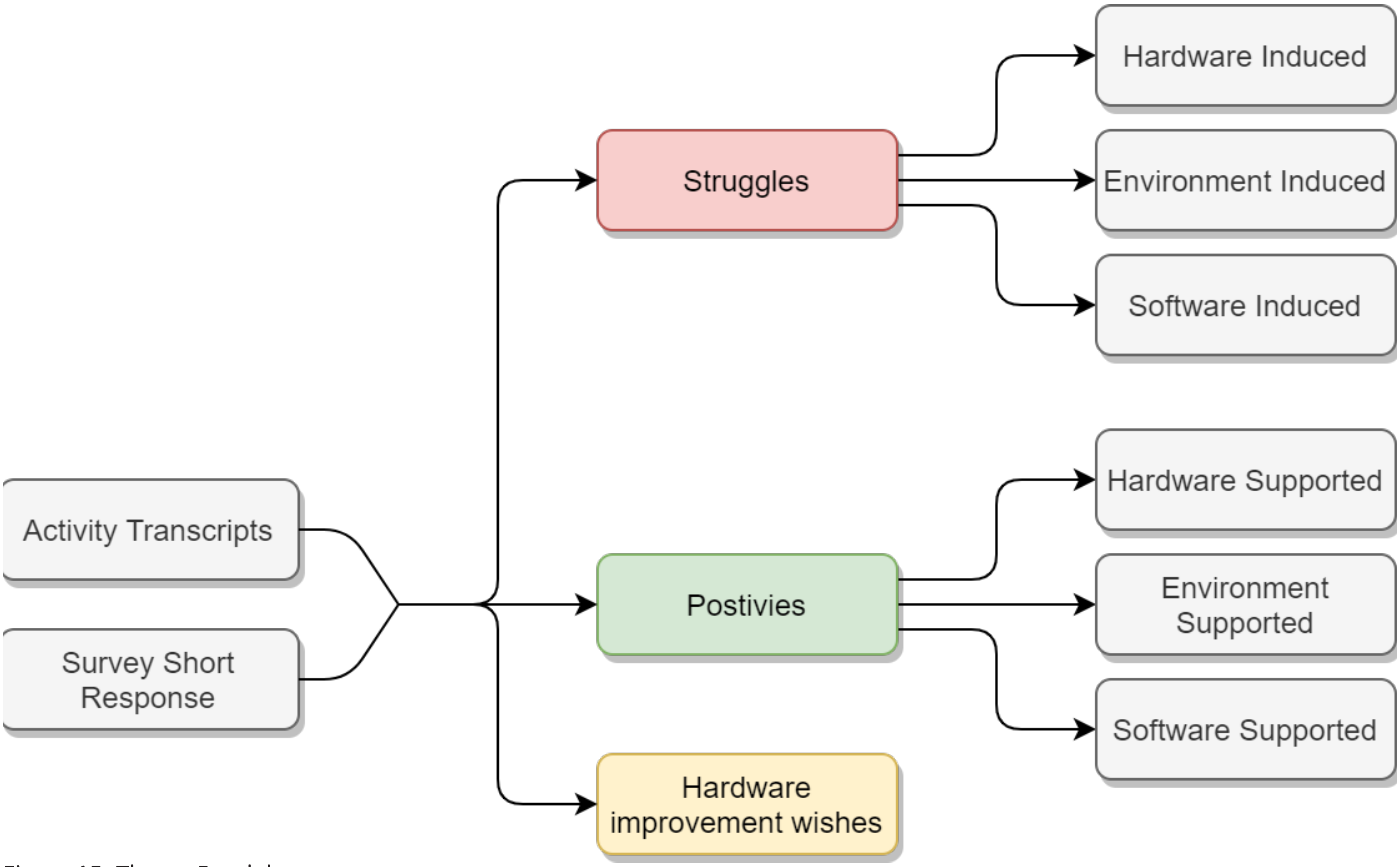


Figure 15: Theme Breakdown

Thematic

The transcripts from the modelling activity and written responses from the post-activity survey were split into Struggles, Positives, and Hardware Improvement Wishes. The Struggles and Positives themes were then broken down further into Hardware Induced, Environmental Induced, and Software Induced themes in order to target the source of the positive and negative experiences.

Hardware Induced Struggles:

One of the most common struggles that participants faced regarding the VR hardware used was the limited number of buttons and inputs available on the VR controllers. This resulted in participants being forced to rely heavily on the software-based menus which drastically increased the time spent in the menus, which in turn slowed down the modelling process.

During the modelling activity, participant #3 brought up the interesting point that the use of a mouse and keyboard for CAD modelling allows for the precise and calculated placement of features in relation to other features using constraints and dimensions. One of the main attracting features of VR 3D modelling is that these constraints and dimensions are not needed in order to create a model, which is intended to drastically speed up the modelling process at the cost of having less precise and less constrained placement of features.

It was clear from observing the recordings of participants that the participants with prior CAD modelling experience relied heavily on the snap functionality provided within the software and were disappointed when this functionality did not meet their expectations generated from experience in CAD software. Participant #2 had some losses in headset and controller tracking accuracy during the modelling activity. Such tracking losses can cause undesired inaccuracy in the placement of objects and features within the virtual environment.

Environmental Induced Struggles:

The main struggle that all participants faced during the modelling activity was that they were unable to keep the position of the controllers steady enough to make fine adjustments to the models. This resulted in forcing the participants to use the software-based predictive snapping functionality which often produced undesirable results. Another struggle that participant #3 experienced was that their controllers collided with their wall and surrounding objects a few times during the study.

Virtual chaperone boundaries exist to prevent such accidents from occurring, however, these boundaries are only based on static environmental geometry that exists at the time of setup and cannot accommodate for dynamically moving objects such as people walking past, or changes of furniture within an area. This issue may become more apparent in a design industry space with multiple people and objects that are constantly moving.

Hardware Supported Positives:
A key feature of VR and AR is the ability for it to communicate environments and objects accurately in a 3D appearance. This aspect of VR was greatly appreciated by participant #3 who mentioned that it is "unparalleled to a monitor and I really enjoyed that". Participant #4 commented on how the use of 6-DOF tracked controllers within VR allows for quick 3D sketching in order to make a quick mock-up of a 3D form. This same participant also utilised the accurate 3D rending within VR to use the size of their head as reference in order to model the headphones at the correct scale. These positives supported by the VR hardware demonstrate the effectiveness of being able to see a model in 3D during its creation.

Hardware Improvement Wishes:
Participants mentioned several wishes regarding the hardware they used, both during the modelling activity and in the post-activity survey. Both participants #3 and #4 mentioned that more buttons and controls available on the controllers would reduce the dependency on the software menu's which would in turn improve the speed at which the models could be generated. The same participants also mentioned that the inclusion of finger tracking would allow for more accuracy and freedom of manipulation with the created models. Such finger tracking is currently available in hardware such as the Oculus Quest and the Valve Index (see figure 16), however, there is a lack of modelling software that use the technology to enrich the modelling experience. Participant #4 mentioned that being able to see their own body within VR would allow for easier comparison to real-life scale. This would enable users to get a better sense of scale within the virtual environment. The same participant also wished that the "Blocks" modelling software supported eye tracking so that their gaze could be used to aid in the alignment of objects. These hardware improvement wishes mentioned by the participants are key focus areas that provide an opportunity to create a new product.

Figure 16: Oculus Quest Hand Tracking

Figure 17: Valve Index Controllers

Effect of software on results:

In order to understand how the software used for the study affected the quality of models produced by the participants, a list of software induced struggles was devised from the thematic analysis of the recordings. This list is showed below, with the respecting participant number that the problem was identified with in brackets:

- Inability to cut and subtract geometry to create new forms (#1)
- Limited zooming functionality (#1)
- Hard to created rounded and smooth surfaces (#2)
- Limited functionality in colouring and texturing (#3)
- Limited modelling operations available (#3)
- Limited snapping functionality and lack of dimensioning (#3 & #5)
- Some menu items split between both controllers and often not obvious (#3)
- Software only allows for stacking shapes /inability to create a single mesh (#4)
- No planar alignment (#5)

These struggles provide an opportunity to enable easier usage of software through the use of more advanced hardware, or they can act as focus areas for the software that will be proposed to support the design outcome.

Discussion & Recommendations

Relation to Literature

VR/AR in the Design Process

Literature regarding the involvement of VR and AR in the design process focused on the effect that the advanced hardware has on the creation and evaluation of designs within a virtual space. Typical aspects that accelerated the experience of such activities were based around the 6-DOF tracking capabilities of the hardware, and the ability to perceive 3D features intuitively and accurately.

Research conducted by Elizabeth P. and Matt C. showed that VR gave users a more in-depth understanding of scale and the details of a space (Pober & Cook, 2019). This was enabled through the stereoscopic vision, and the ability to move the position of your view in the virtual world with 6-DOF. These results from Elizabeth and Matt were reflected in the research for this paper. Participants found that the freedom of camera movement within the virtual environment provides an advantage over 2D desktop monitors with one participant mentioning that the experience is “unparalleled to a monitor” (Participant #3).

Additional research from Elizabeth P. and Matt C. showed that the stereoscopic view and 6-DOF of VR enable rapid iteration. This advantage of VR was confirmed with their research which found that students were able to achieve higher scores on assessments when they were given the opportunity to iterate their designs within a VR driven virtual environment. This ability to quickly iterate models within VR was shown to be true through the research conducted for this paper, however, many participants still struggled with tasks that required the creation of organic geometry. The ability to create organic geometry in VR was hypothesised to be easier due to the ability to manipulate objects with the natural movements of the body. However, this required a new way of thinking as compared to traditional desktop CAD modelling, which negatively impacted participants who were familiar with desktop CAD modelling processes.

Collaboration with VR/AR

While this topic was not able to be heavily focused on in the research study, this literature still provides important insights and considerations that are applicable to the topic of the paper and should be considered in the creation of the design brief.

VR and AR give users the unique opportunity to be in the virtual presence of other, remotely located users. This aspect of VR and AR technology is one that should be taken advantage of if the proposed design enables some form of remote collaboration.

Collaboration with VR/AR Cont.

The factors identified in the literature that enable such a virtual presence include the ability to manipulate and communicate by interacting with virtual objects, the communication of non-verbal body language, and being able to quickly and intuitively annotate and make measurements of virtual objects. These forms of interactions are enabled through the 3D tracking of user's bodies, and VR/AR hardware. As most VR and AR systems focus on the tracking of the user's head and hands, this opens an opportunity to enhance the collaboration process with more advanced 3D tracking of user's bodies.

Impact of Immersion

The literature based around the impact of immersion on the productivity of users within VR and AR suggested that the primordial orientations a user has towards a particular VR or AR experience before using it can have an effect on the outcome of the activities they perform within the virtual environment (Harth, et al., 2018). This particular aspect was a focus on the research design for this paper, and the findings suggest that this hypothesis is true. Participants who had more positive primordial orientations towards the quality of objects that they would produce during the modelling activity ended up creating designs that were of a higher quality.

Another influencing factor on immersion is the representation of the user's body within VR (Harth, et al., 2018). The software used for the study does not have a virtual representation of the user's body in VR. As such, one of the participants stated that they wished they were able to see their body within VR so that they could have a visual reference of scale from within VR.

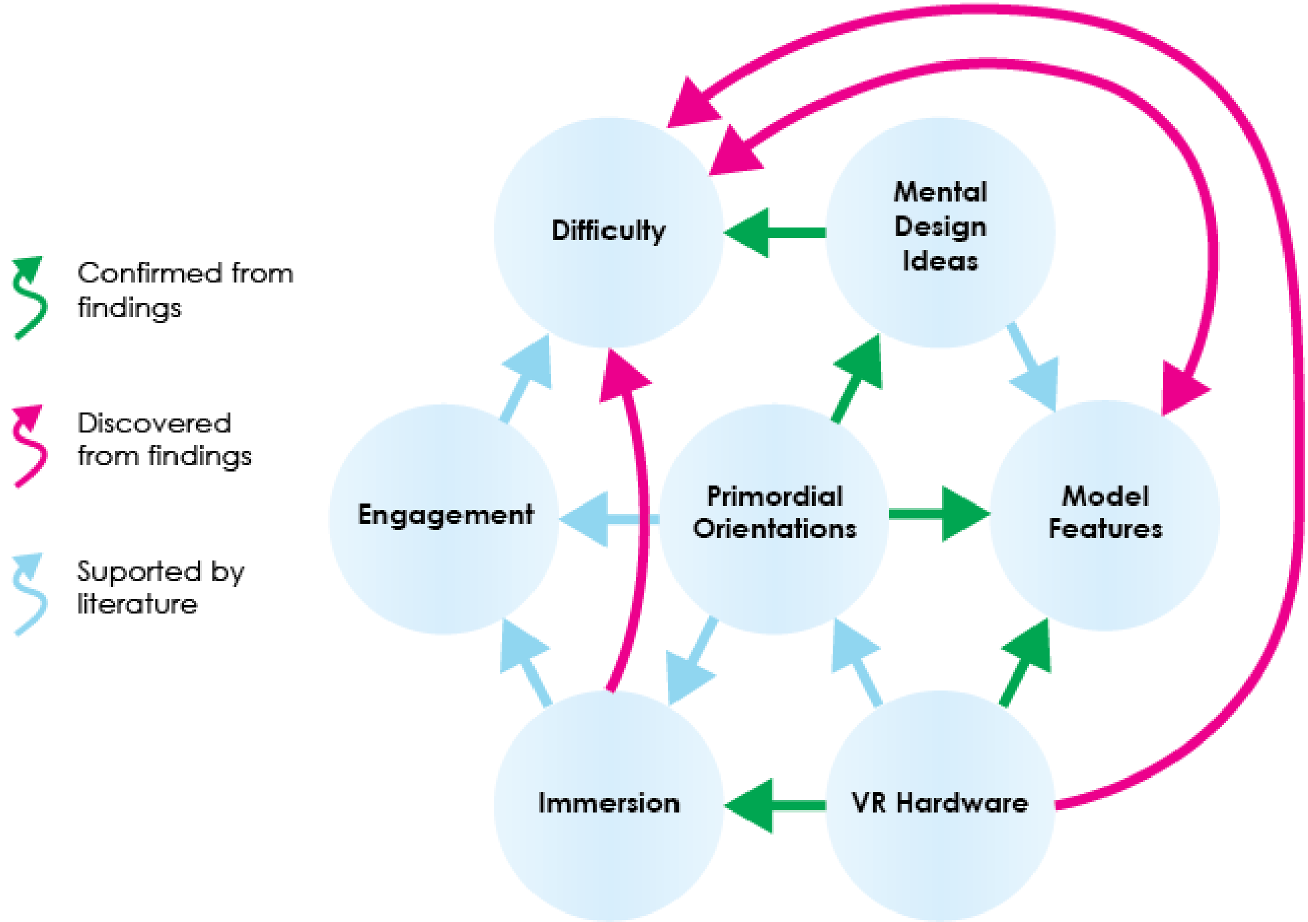


Figure 18: Comparison to Hypothesis

Comparison to Hypothesis

Figure 18 shows a visual representation of the relationships formed in the hypothesis. Light blue arrows show relationships that are supported by the literature, green arrows show confirmed relationships that were originally theorised after reading the literature, and magenta arrows show new relationships that were discovered by analysing the research data.

Confirmed:

Relationship hypotheses that were confirmed through the findings were the way VR Hardware affects Model Features and Immersion, the way Primordial Orientations affect Model Features and Mental Design Ideas, and the way Mental Design Ideas affect the perceived Difficulty of modelling. These findings can be used to support the reviewed literature and will contribute to the design criteria that will be produced as a result of this research.

New:

New relationships that were discovered through the findings were the way Model Features and perceived Difficulty influence each other, and the way both VR Hardware and Immersion influence the perceived Difficulty of modelling. These new relationship discoveries play a part in contributing to the knowledge gap in this topic and will be critical to the design of a product that fits into a Design Industry space.

Contribution to Knowledge Gap

To re-iterate the identified research gap, areas of research in the literature that were lacking are listed below:

- How VR hardware and control schemes influence the way people model in a virtual world, and the final outcomes of their modelling
- The limitations of creating within VR and AR
- How users Primordial Orientations of VR modelling effect the experience and 3D model outcomes
- How well users can transform their mental ideas into 3D models using VR hardware

In order to relieve this gap in knowledge, the research methodology was designed to find and investigate factors that contribute to the gap.

Information that contributes to the research gap on the influence of VR hardware on the modelling process can be used to inform the physical and tactile design, and the available functions, on a design the aims to make VR and AR modelling easier and more available. An important factor that contributes to this gap is the way CAD experienced users think, and how this way of thinking is challenged when modelling using 6-DOF movements as compared to a mouse and keyboard experience. Normal mouse and keyboard modelling rely heavily on constraining and dimensions parts and features to a precise value. VR and AR modelling aim to make modelling faster by switching out this constraining and dimensioning with 6-DOF movements. This however had an adverse effect on participants who were used to, and expected, a parametric CAD modelling experience. This burdened these participants, which contradicted the idea the VR would make 3D modelling easier for users experienced with CAD software.

Findings that support the gap regarding the limitations of modelling in CAD can be used to inform how far a VR or AR product based around modelling should differ from the desktop modelling experience. Typical CAD modelling programs rely on the vast number of shortcuts available to the user through a keyboard. As opposed to a keyboard, VR and AR hardware typically lacks the vast amount of inputs compared to a mouse and keyboard. This forces VR and AR software developers to rely heavily on software menus to house all the program's functions. This proved to be a challenge for CAD experienced participants as the lacklustre amount of inputs on their controllers forced them to use the menus, which severely hindered their performance.

Contribution to Knowledge Gap Cont.

In the literature, minor research was conducted on how primordial orientations affect immersion, however, the way these orientations affect the modelling process, and the modelling outcome, was not focused on. This research gap was explored through findings that suggested that users' primordial orientations towards modelling in VR and AR can influence the quality outcome of their models. Participants who had more positive primordial orientations about VR modelling tended to produce 3D models of a higher quality, compared to those with more negative primordial orientations.

Although VR and AR was shown to help users gain a better understanding of virtual 3D objects and environments, limited research was done on how well VR and AR helps to translate mental ideas into virtual object designs. The research conducted for this paper identified key factors that helped users translate mental thoughts into a 3D model. These factors included: stereoscopic vision on the model, ability to move camera (the users head) intuitively around the model to view it from different angles, and the ability to intuitively manipulate the position of the model by "grabbing" it with their controllers.

Impact of Findings

The insights identified through the conducted research have revealed several impacts that will affect the resulting product design from this research paper.

VR modelling still requires some form of learning before a user becomes fluent with it:

The 6-DOF movement and stereoscopic nature of VR and AR do not instantly give its users an intuitive understanding of how to use the software that supports them. This means a significant learning stage is still needed before a user becomes fluent with the hardware. This learning stage of using VR and AR for 3D modelling needs to be supported and encouraged by the hardware to ensure that the design makes a positive impact on the users.

More positive Primordial Orientations resulted in higher quality models:

The primordial orientations of users were shown to impact the quality of the models produced in VR, as identified by research participants. Therefore, the design of products to enable modelling in VR and AR should aim to maximise these orientations through its capabilities and aesthetics.

Impact of Findings Cont.

More difficult VR modelling experiences resulted in lower quality 3D models:
This result was expected, and may seem obvious to many, but the way to combat this issue must be thoroughly though out. To combat this issue, one step would be to design the VR and AR hardware to make the modelling process easy and intuitive. Another important step would be to design a VR/AR product in a way so that the entire process of learning to model with VR/AR is encouraging and motivating.

CAD experienced users struggle with non-CAD VR/AR modelling operations while CAD inexperienced users thrive at organic, mesh-manipulation operations:
Desktop CAD skills will almost always still be a required skill for design modellers in industry settings. Because of this, a VR/AR modelling-based product should aim to bring desktop experiences into the usage experience or use VR or AR to enhance the desktop CAD experience. In order to succeed in this area, the design needs to be supported with well-integrated software. Unfortunately, software design or program integration is out of the scope of this project, and as such, a description of software recommendations will be required to support the resulting design.

Limited inputs on VR and AR hardware drastically impede user's efficiency in the modelling process:
Many VR and AR modelling programs attempt to combat this issue by creating complicated menu structures within their software, which often hinders the performance of its users. In order to relive this issue, the resulting design needs to allow for a balanced range of different inputs that allows for quick selection of options and operations without overwhelming the user. To make the learning process easier, these inputs need to be distinct from each other as to reduce confusion around getting them mixed up.

Heavy reliance on 6-DOF in VR/AR modelling software caused struggles for precise placement of features and objects:
For users with shaky or un-steady hands, placing and moving features proved to be difficult. This problem is also possible to relieve with software refinements, but by mixing in aspects of the mouse and keyboard modelling experience, CAD experienced users could potentially have a familiar environment to work within.

Small environments and environmental obstacles are problematic for VR experiences:
As VR covers the users entire view of the real-world, physical obstacles can become an issue. This is a known problem that AR aims to solve as it still allows users to see the real world while using the hardware. As such, an AR solution may be more elegant for CAD usage in an industry space.

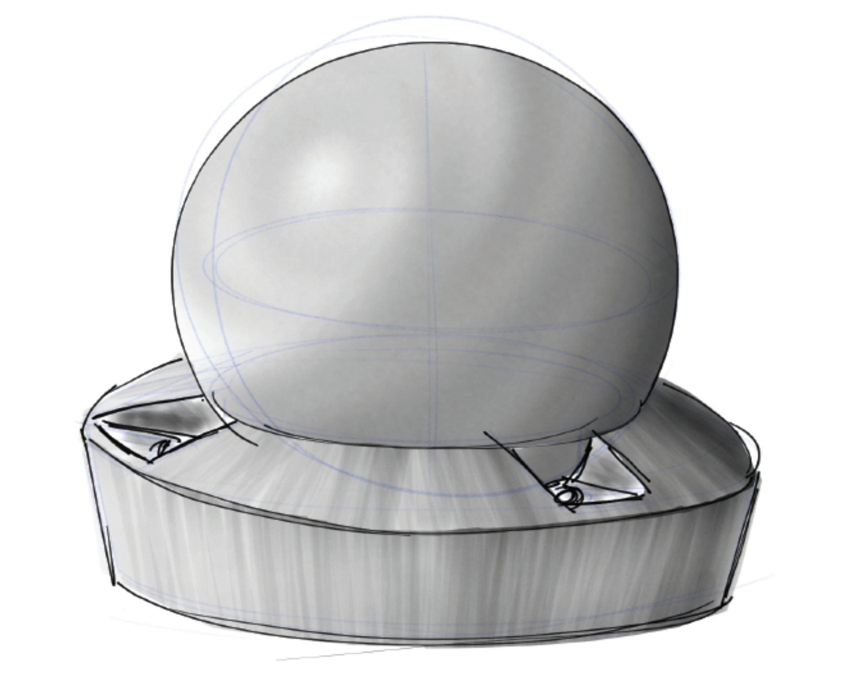
Impact of Findings Cont.

The ability to see a model in 3D with 6-DOF camera movement is a significant advantage:
The research showed that many users found the 3D 6-DOF aspect of VR a massive advantage over desktop modelling experiences. As such, it is essential to support these aspects in the final design.

3D sketching works well for creating extremely quick form mock-ups:
One participant from the research study noted that this aspect of VR is very useful. This also includes making quick annotations to existing 3D models. This aspect could possibly be a focus for one of the design suggestions.

Design Opportunities

Design Opportunities



Manipulate the view of 3D models on a desktop

Makes view manipulation intuitive

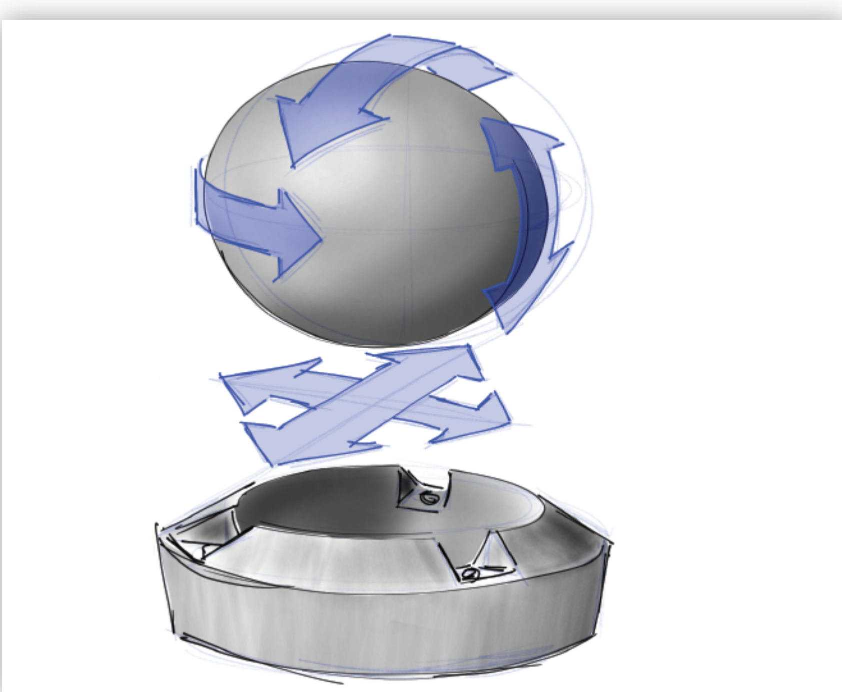
Tracked with 6-DOF by base

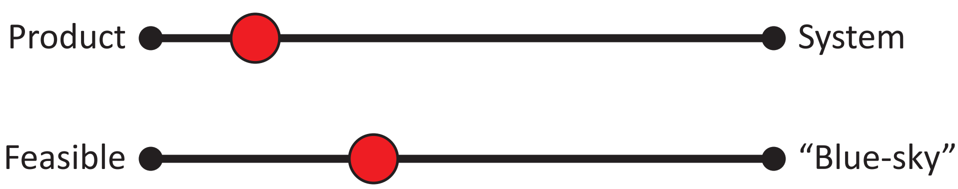
Can be used for other functions

6-DOF Desktop CAD View Tool

Limitations/Constraints:
- Software integration with CAD programs
- Dependent on motor skills of user
- Bulky size / not portable

Key Considerations:
- Requires development of custom tracking system
- Ergonomics
- USB / Connectivity standards





Integrates with desktop CAD programs (e.g. Solidworks)

Allows user to see model in 3D

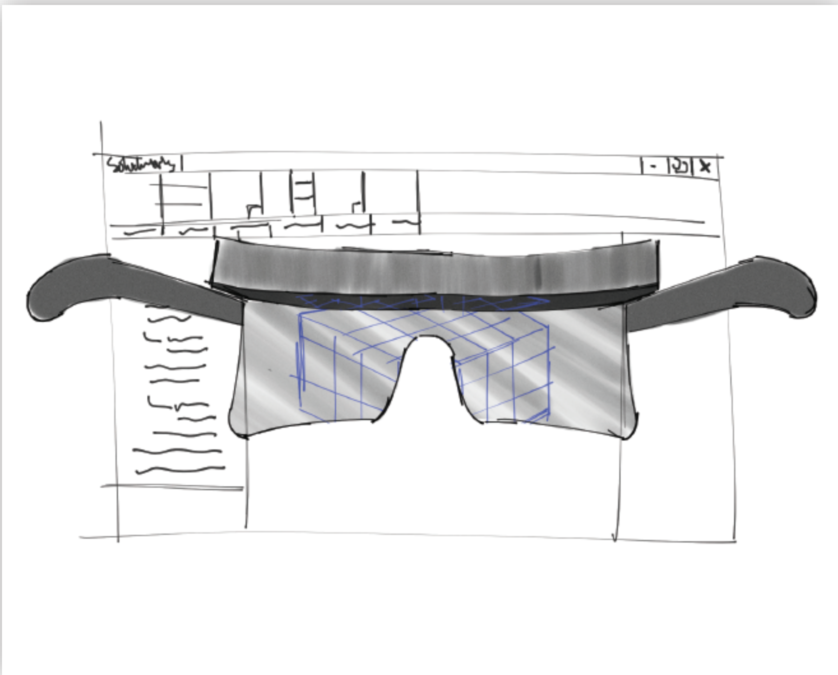
Enhance surrounding workspace with extra UI elements

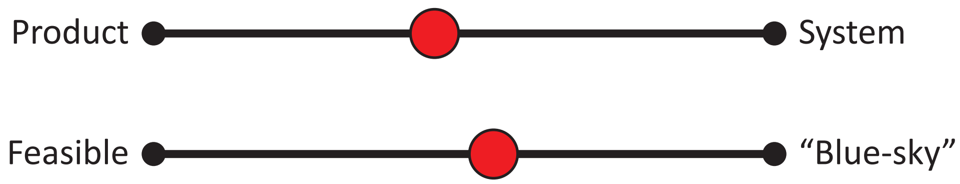
Model can be placed anywhere in physical workspace

CAD Desktop Enhancer

Limitations/Constraints:
- FOV may be an issue
- Size of monitor

Key Considerations:
- Would require development of an optical system for AR functionality
- Needs to suit different head sizes (Ergonomics)
- USB / Connectivity standards
- Software integration





Controls design specifically for CAD

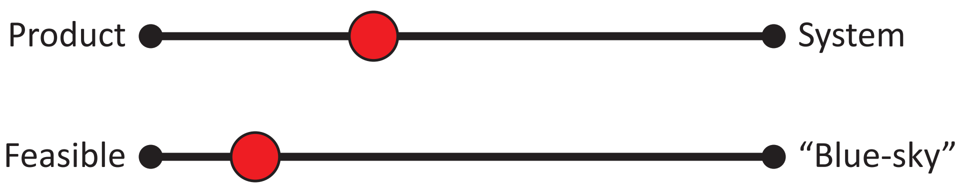
Tip for point-of-reference
Can be used for AR or VR applications

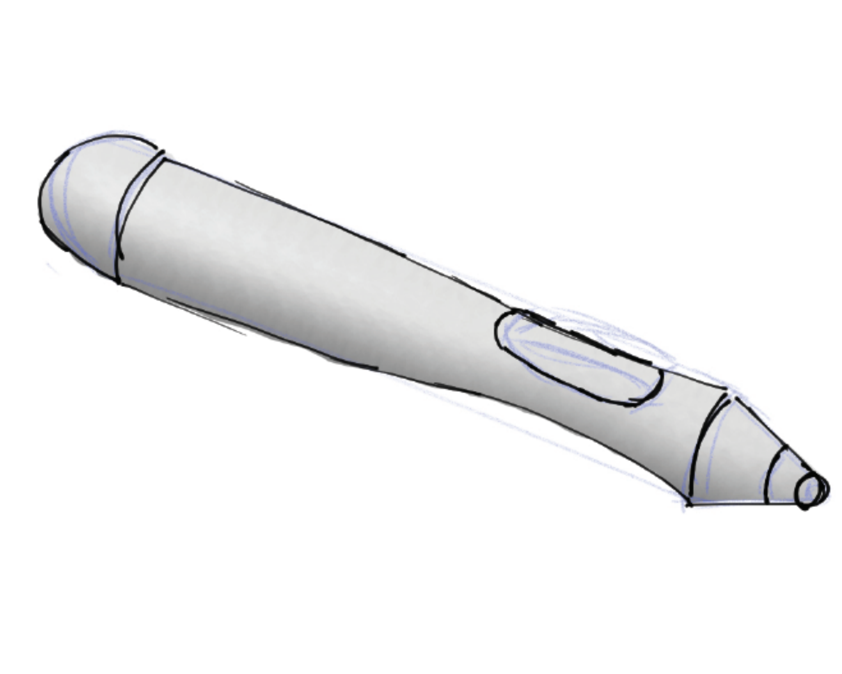
Should use established tracking methods (e.g. SteamVR Tracking)

CAD Based VR/AR Controllers

Limitations/Constraints:
- Limited area available on controllers for inputs
- Concept would require advanced integration with CAD software
- Would need to be wireless

Key Considerations:
- Requires a VR/AR headset
- Needs to rely on an established tracking system (e.g. SteamVR Tracking)
- Ergonomic suitability for a range of users





Used with AR headset on desktop screen

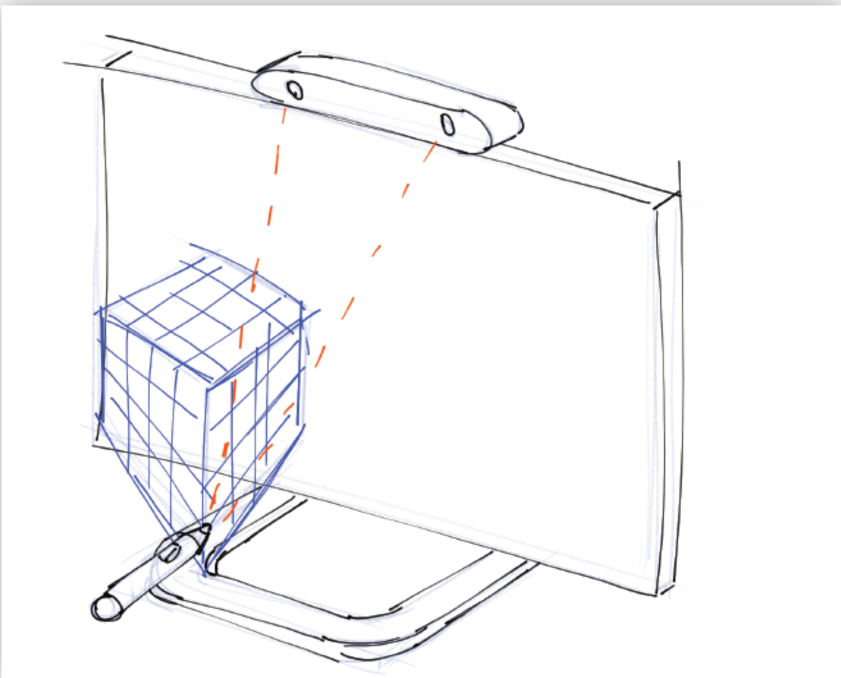
Select points in 3D space

Tracking apparatus on monitor

6-DOF AR Pen for Desktop CAD

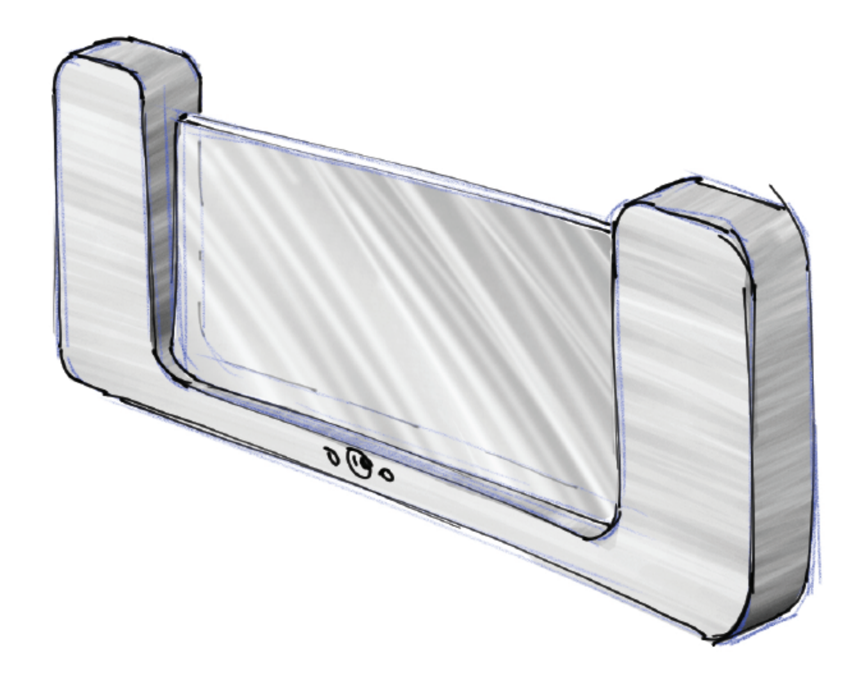
Limitations/Constraints:
- Small formfactor means limited on-device controls
- Requires a dedicated tracking system

Key Considerations:
- Needs to rely on an established tracking system
- Requires a VR/AR headset for full functionality
- Used alongside a keyboard/ mouse/display



Product — System

Feasible — "Blue-sky"



Visualise model at accurate scale in real world

Handheld device

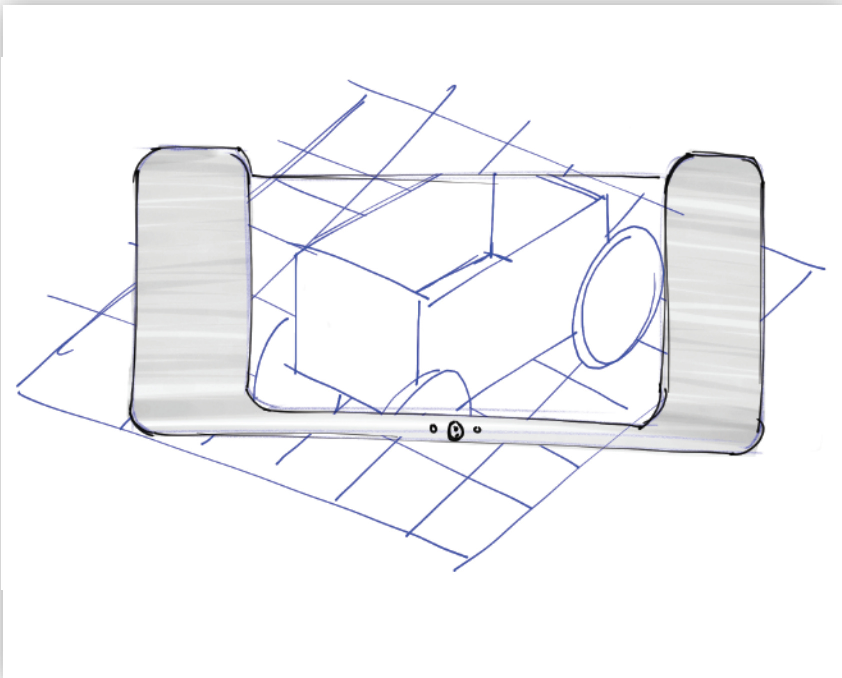
Transparent screen technology

Head position tracking for accurate model representation

Transparent AR Model Viewer

Limitations/Constraints:
- Only suitable for use by one person at a time
- Transparency of display may be an issue

Key Considerations:
- Advanced display technology for screen
- Ability to display in stereoscopic vision



Product ●——●——————● System

Feasible ●————●——● "Blue-sky"

Design Proposal

VR technology provides users with the opportunity to visualise models in three dimensions with the freedom to move their view around intuitively with six degrees of freedom. AR on the other hand allows users to enhance their view of the real world by integrating virtual elements into it using a transparent head mounted display.

The goal of the proposed design is to enhance the work-flow of desktop CAD modellers by taking advantage of the pros from both VR and AR experiences. The proposed design, codenamed “CADAR View” for the sake of reference, is a CAD based AR system that will allow for users to visualise their developing designs in stereoscopic vision with 6-DOF head movement while maintaining a familiar mouse and keyboard experience.

The design will be mainly aimed at design firms and design industry spaces with consideration for advanced CAD modellers at home or in smaller businesses. The name “CADAR View” comes from the combination of CAD + AR to enable advanced interactions between the user and the desktop.

Justification

VR and AR technologies enable the rich viewing experience of environments and objects in stereoscopic vision with 6-DOF. There are a few VR modelling programs designed to take advantage of this, however, these fall short of being useful in a design industry space. One of the main problems with such programs are the vastly different control schemes used which interfere with the modelling process used by CAD designers. Typical CAD modelling relies on the usage of a mouse and keyboard which gives users a large range of quick shortcuts, easy input of constraints and dimensioning, and a consistent interaction platform across other software platforms. This familiar and useful mouse and keyboard environment is excluded from VR modelling programs. This proved to make modelling difficult for research participants that experimented with VR modelling software. This makes the learning curve for such VR modelling programs very steep which could drastically slow the adoption rate of such systems in industry spaces and reduce the overall quality of designs made using the systems. VR typically also requires users to stand up in a cleared area which can take up a significant amount of floorspace when multiple VR workstations are set up locally.

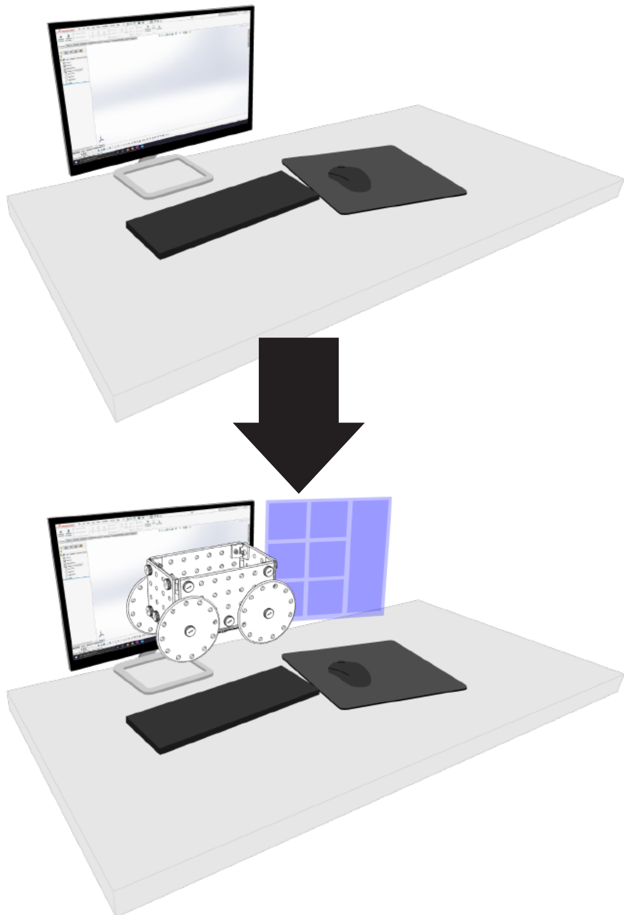


Figure 19: CADAR View Enhanced Workspace

The proposed concept takes the best parts of VR and AR technologies and integrates them into a seamless desktop experience that enriches the modelling process without differing from the familiar environment that CAD modellers are familiar with.

Model Viewing
The ability to see the 3D details of models in VR showed to be a significant advantage over the flat desktop experience among research participants. CADAR View takes advantage of this aspect by allowing its users to see their developing models and all their 3D features in detail with a high degree of accuracy. This means that there will be a lower discrepancy between what the user perceives while modelling, and the actual geometry of the model, allowing for a more accurate modelling by designers.

Cleaner Workspace
CADAR View would also allow for an extended virtual workspace by expanding upon the exiting monitor/s used by the user without actually requiring an extra monitor. This feature would work by moving UI elements off the monitor, and into the empty area around the monitor in order to expand upon the tool-set and information available to the user. This would free up space on the user's main monitor, allowing for a tidier and more efficient workspace.

Mouse and Keyboard Familiarity
The mouse and keyboard form a strong pillar of CAD modelling as the main form of interaction between the user and the program. Challenging this control scheme causes productivity problems in users which is why the proposed design aims to merge the best of both worlds by allowing for familiar desktop interactions that are enhanced by the inclusion of AR elements. This allows the user to work with the same work-flow that they are used to except with an additional AR element to accelerate and better inform their design thinking and design process.

Intuitive Model Viewing
The ability to view environments and objects in 3D with 6-DOF is important to gaining an intuitive understanding of the object's 3D geometry. The proposed design enables this important aspect of viewing 3D objects by tracking the users head position with 6-DOF while providing them with a 3D view of their design. This allows users to understand the different features of their designs at a glance without having to meticulously rotate the view of the model on-screen.

Quicker Workflow
By minimising the time spent rotating the view of the model to properly understand it and time spent browsing the menus for hidden options or statistics, the work-flow of the CAD modeller can be sped up and made easier with the usage of CADAR View. This is achieved by using AR to add additional elements into the space around the monitor, without clogging up the main monitor, and by displaying the model in the 3D space in front, or within, the monitor where the user can use their natural head movements to view the different angles of the model.

Context

The context that CADAR View will be designed for will influence numerous aspects of the design, and the supporting services around it. The main context for the proposed design is its usage by CAD designers within design industry spaces. In such an environment, multiple of the proposed product will be used concurrently and will be shared among many different people. This brings up considerations for how the product will adapt for users with different ergonomic measurements, particularly height, head height, and Interpupillary Distance (the distance between both pupils). Another important consideration is that the product will be used heavily which brings up durability issues. One more consideration for the usage of multiple devices within the same space is ensuring that each device works independently from each other without interference from the other CADAR View devices.

As CADAR View will also consider its usage by CAD modellers at home, there are a few other considerations that will also apply to the design. The first is that the device will need to support compatibility with a range of set-ups. Factors that can change among different set-ups include monitor size, keyboard type, and general layout of the user's desk space. Another consideration is the different types of modelling programs, or even non-3D-modelling programs a user may wish to use the proposed design with. This is where an open-source aspect of the product may come into play, allowing hobbyists to create their own compatibility layer to use the device for other applications.

Figure 20: Example Context

The context regarding the type of workstation the proposed design will be used at is also important to determining how the product will function. The product will be designed to work with a PC that uses a mouse, keyboard, and monitor to interact with the user. For the user of the proposed product to maintain the typical CAD interaction methods that they are familiar with, the mouse and keyboard usage aspect will need to remain untouched. The focus of CADAR View will be on the viewing experience of CAD modelling in order to support the familiar mouse and keyboard experience. Another way to aid in this focus of CADAR View will be to allow the user to switch their view of their desktop in and out of AR mode quickly and easily.

Key Criteria

Physical Features

Ergonomics:

The sizing of CADAR View must be variable and adaptable to suit different sizes of user's heads, different Interpupillary Distances of users, and different sitting heights of users. This will ensure that the product can be used comfortably for extended periods of time.

The adjustment of the system must also be easy and quick to complete as many different users may use the same system within a short time-frame.

Manufacturing:

The manufacturing quality of the CADAR View needs to be of a high standard as the product is to be used by design firms and businesses who expect a robust system.

The technologies used to manufacture the product either need to be existing, or feasible to develop within the time-frame of the design process.

Materials:

The materials of the device that come into contact with the skin of the participant for extended periods of time need to avoid causing any discomfort of irritation of the skin.

These materials also need to provide comfort while wearing the device.
The durability of these materials is also important if the device is to be used heavily.

Hygiene:

The hygiene of the product is very important to the usage, and lifetime of the product.

The product needs to be made to stay as clean as possible from usage of it and needs to be easy to clean without damaging the product.

To aid in this hygiene, the ability to remove parts of the product for cleaning and swapping should be included.

Functionality

Stereoscopic Viewing:

CADAR View needs to provide users with the ability to see their models in 3D. The 3D viewing needs to accurately reflect the actual geometry of the model that the user is working on.

This aspect of the product also needs to be incorporated in a way that prevents it from interfering with the normal work-flow of the user.

6-DOF:

The device needs to be able to be tracked in 3D space relative to the user's computer screen to enable 6-DOF.

The user needs to be able to move their head around naturally to look at their 3D model from different angles.

CAD Enhancing Functionality:

The CAD enhancing functionality of the product needs to accelerate and improve the work-flow of the user. It needs to be incorporated in a way so that the users are still able to use their CAD software of choice without too much differentiation.

Workflow Integration

Design Firm Integration:

CADAR View needs to be designed in a way that allows it to be integrated easily into the work-flow and physical space of users within a design firm environment.

Special consideration will need to be taken to ensure that the product will be suitable for usage in these environments.

Casual at-home integration:

CADAR View should be able to be adopted by at-home users as well. This means it will need to be able to be advertised and distributed to customers other than businesses.

Mouse and Keyboard Control Schemes:

The usage of CADAR View needs to be compatible with a mouse and keyboard experience in order to maintain the familiar work-flow that CAD designers are familiar with.

The ability to easily switch between AR and non-AR modes will assist this criterion.

Monitor/Display Integration:

CADAR View will need to be able to function with a range of different monitor sizes and types.

This includes different monitor technologies, such as LCD, OLED, and LED.

The ability for the product to work on unique monitors, such as ultra-wide or curved, should also be considered.

Semester 2 Project Schedule

Figure 21 shows the planned schedule for the design and presentation preparation of the proposed design.

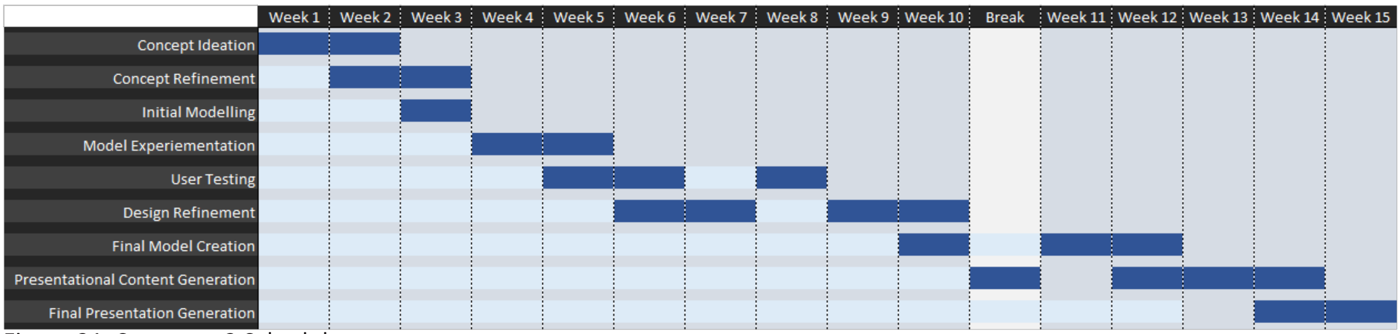


Figure 21: Semester 2 Schedule

Research Project Summary

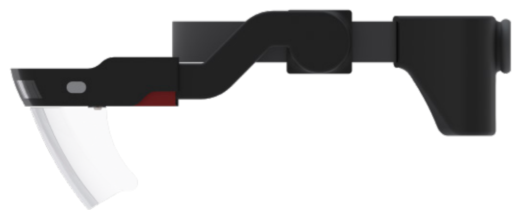
This research project investigated the viability of using VR and AR as a design tool within industry environments. Factors that influence the way AR and VR are used, and their success for use in 3D modelling were researched and investigated with a research study. This resulted in identification of aspects of VR and AR that enable or otherwise prevent the usage of such technologies in the design process. From this research, a design proposal was made on an Augmented Reality product that enhances the desktop modelling CAD experience. The product is aimed for usage within design firms with consideration for casual or at-home designers.

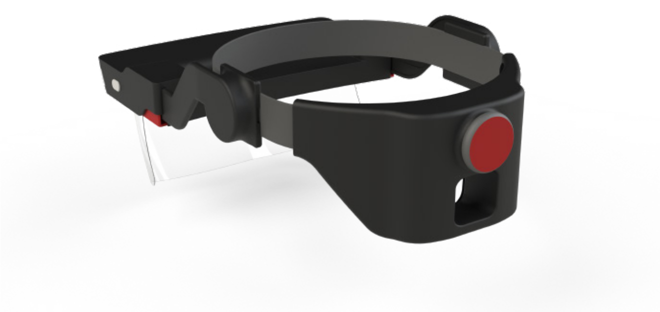
Final Design Justification

Final Design Justification

Introduction

CADAR is an augmented reality headset that improves on the familiar desktop CAD modelling experience by adding a layer of virtual interactivity and visibility to the desktop modelling workflow. It is designed to fit into a designer's environment where interaction with other objects and people is commonplace. The scope of the project included the design of the headset itself, the mechanisms that make up the tactile experience of the device, considerations for the electronics and their mounting within the device, and also the user experience design of the augmented reality UI.





Further Research

Other AR headsets such as the Microsoft Hololens or the Magic Leap have been broadly designed to work across many contexts, and as such, may not fit into a design firm or designing space. Alternatively, the CADAR headset has been designed to suit such environments, and also has an AR UI designed to maximise productivity and understanding of 3D CAD models on a desktop.
In order to inform the design of the optics system, research was conducted into existing technologies used to create virtual AR imagery. Advanced systems, such as the Hololens, use complex methods of channelling light through a flat, transparent lens. However, the FOV of these systems is limited as the overall size of these lens grows exponentially in relation to the achieved FOV. Therefore, a simpler method of reflecting light was employed for use in the design.
During the design of the CADAR UI experience, workflow issues with typical CAD programs, such as Solidworks and Autodesk Inventor, were analysed. These issues revolved primarily around ease of workflow, efficiency, speed, and available screen space. These issues were then solved with the design of the UI which was thoroughly visualised in the final presentation video.

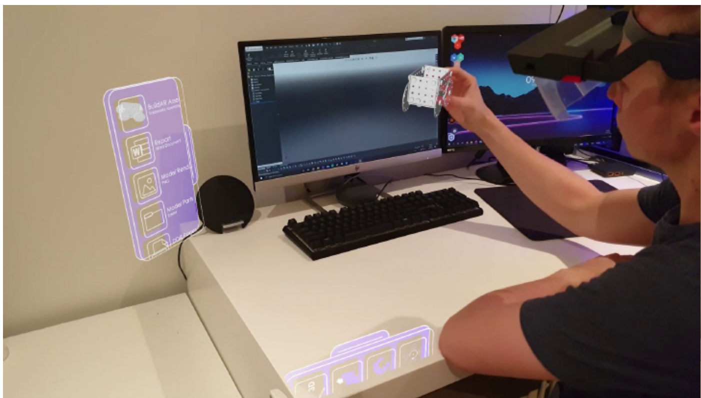
Context

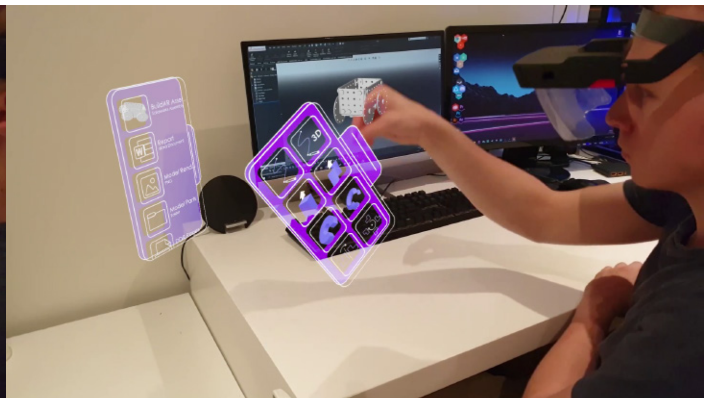
The CADAR headset is designed to work within a specific context, but it is possible for it to be applied to other situations. The main context that CADAR is designed for is for use within design spaces at a desktop setup where a monitor, mouse, and keyboard are primarily used. This design space could be situated within somebodies' home, or within a design firm. Another considered context is when multiple people are collaborating on a project.

The people targeted within these contexts include designers, 3D modellers, and potentially other people involved in the project who wish to view a 3D model within AR. This could people such as clients, or investors.

The main activities that CADAR enhances within a designing space is CAD modelling, 3D model visualisation, and model exploration using hand controls. When used at a desktop, CADAR also allows the user to manage other desktop functions such as file management, program management, notifications, etc.

In order to function correctly, the CADAR headset needs to be paired with a PC, and requires further integration with CAD software for a polished experience. Pairing to a PC is completed by connecting the headset to the same network using Wi-Fi. In the case that the PC isn't connected to a network with Wi-Fi available, a Wi-Fi USB dongle capable of hosting a network can be used in place. The integration with CAD software will allow for the viewing of and interaction with 3D models currently being worked on. It will also allow for easily customisable panels to be created for shortcuts to modelling operations. In the case that CADAR needs to be used with software that it is not integrated with; panels can be customised that emulate keyboard shortcuts in order to allow for a pseudo-integration with software.





Final Design Justification

Design Process

The design process of the CADAR headset consisted of the following key stages in rough order:

- Problem Exploration
- Design Development
- UI/UX Design
- CAD Modelling
- Design Iteration
- Prototyping
- Final Model Making
- Presentation Preparation

From the end of the design development, to the final design, the main function of CADAR remained the same. However, aspects regarding the form, mechanism design, and the technology changed significantly throughout the entire design process.

The direction taken for the form of the model aimed at making the design suitable for integration within workspaces, both functionally, and aesthetically. This was achieved by incorporating aesthetical features that are typically found on minimalist office hardware, such as matte black surface finishes, and clean, defined curves.

A focus was placed on the development of the adjustable mechanisms incorporated in the design as these form the tactile experience of the design. To achieve a satisfying feel when actuating the mechanisms, features that make audible and feelable clicks were incorporated. This resulted in feedback and reassurance to the user when they successfully used the mechanisms.

Design Validation

Throughout the design of the physical CADAR headset, multiple prototypes ranging from rough to refined were created. The first 2 prototypes created were made as a proof of concept to the operation of the design and helped to understand ways that users would put on and take off the headset, and how the users' hands would physically interact with the design. After the design was further refined, a detailed prototype was created for the purpose of user testing. This user testing resulted in helpful feedback and allowed for the refinement of certain aspects of the design such as the pivot point position for the flip-up mechanism, and the size of buttons and knobs.

In order to gather opinions of the AR interactions, short clips featuring interactions with 3D models and panels within an artificial AR environment were created. While these clips showed rough representations of the interactable 3D model and panels, they thoroughly showed how these AR elements exist within the context of a desktop computer workspace.

Business Case

CADAR is intended to be a product that can either be purchased outright or loaned to organisations who wish to use it within their workflow. Both methods of purchase include the software required to setup and configure CADAR, and initial support. When the device is loaned, ongoing support is available that will assist with any problems that are encountered.
Developers would be needed in order to integrate CADAR with 3D modelling programs, which would be covered by the cost of purchased products. It is also possible that a community effort may be put in to integrate the headset with more niche programs.

Final Design Discussion

The design set out to target four key areas, which were:

- Allow users to visualise models in three dimensions
- Allow users to move their view freely and naturally around 3D AR models
- Incorporate the pros from both VR and AR experiences into a desktop CAD experience
- Maintain the familiar mouse and keyboard CAD modelling experience

In the context of this project, CADAR successfully meets these needs with a design that provides an unobtrusive layer of immersion to the CAD modelling process.
A focus was placed on the development of the mechanisms that form the tactile experience of the headset. To an extent, the design of these mechanisms was successful but would need to be tweaked in order to function correctly with the chosen materials. This adjustment of the mechanism design would allow it to function with the correct amount of resistance to allow for a satisfying experience. The mechanism used for eye relief did not function as intended in the final prototype model and would also need a re-design in order to provide this functionality.
While the placement of electrical components was considered, the wiring between each component was not. This aspect was omitted from the final design as it was not essential to the development of the user experience which was the main aspect that drove the usability of the CADAR headset. As part of the design of the flip-up mechanism however, the routing of the power through this component was successfully integrated into the design.
The augmented reality user interface formed the main driving force of the user experience, and as such, was thoroughly visualised for the final design presentation. This gave viewers a detailed vision of how the CADAR headset could integrate into their workflow, and the advantages it provides.

Final Design Justification

Summary

This project resulted in the design of a product with a real-world opportunity to accelerate and improve on the existing CAD modelling experience of many designers. With further development, it is possible for the CADAR headset to become a product and software package that is suitable for use in personal workspaces, and within industry design spaces. Some aspects of the physical design, such as the optics and electronics, require further development or re-designing in order to create a resolved product. The augmented reality UI in its current state is only a visualisation of the system, but it still successfully displays how the CADAR headset would incorporate itself into the CAD workflow, and how it would better inform its users.

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