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Virtual Reality: A literature review and metrics-based classification

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Abstract

This paper presents a multi-disciplinary overview of research evaluating virtual reality (VR). The main aim is to review and classify VR research based on several metrics: presence and immersion, navigation and interaction, knowledge improvement, performance and usability. With the continuous development and consumerisation of VR, several application domains have studied the impact of VR as an enhanced alternative environment for performing tasks. However, VR experiment results often cannot be generalised but require specific datasets and tasks suited to each domain. This review and classification of VR metrics presents an alternative metrics-based view of VR experiments and research.

CCS Concepts

•***Human-centered computing*** → ***Virtual reality;***

1. Introduction

[Tac13] explains that VR allows humans to experience events and participate in a computer-generated environment as if they are physically present in that environment. It is distinguished by its ability to provide an unprecedented immersion for the user [MAM18]. This paper attempts to classify VR research into several metrics or quality measures. The terms 'metrics' and 'quality measures' are used interchangeably due to an overlap in their meaning [Sou09] and for purposes of this paper 'metrics' is used throughout to denote the aspects of VR, '2D' is also used to denote 'non-VR'.

1.1. History of Virtual Reality

VR started with Morton Heilig's Sensorama in 1962, a multi-sensory simulator [MG96], and with Ivan Sutherland's Ultimate Display in 1965, the first head-mounted display (HMD) [Sut65]. However, the term 'virtual reality' was coined much later in 1989 by Jaron Lanier [SSV16]. VR started gaining a great deal of media attention circa 1990 [MvD91] and has seen a lot of research, development [OJC*17] and consumerisation [Jar17] till date. [Tac13] outlines an extensive history of VR showing the phases of development from the Ultimate Display to the CAVE (Computer Augmented Virtual Environment) [CNSD*92, MSB*14].

1.2. Background and Justification

Several studies have reviewed the suitability of VR in different scenarios. A resounding conclusion has been the fact that VR can be a useful environment for performing tasks, however a number of experiments have also indicated how insignificant the improvement was using VR [TGA12]. VR adoption in several fields include medical [AKP*17], education [BKEE18] and identified improvements such as knowledge improvements [XMN*17, SSS13].

A review of literature identified metrics considered during an evaluation of a Virtual Environment (VE) as an alternative to an existing non-VR environment. These include 'presence' and 'immersion' which are the core VR affordances, 'navigation' and 'interaction' being the actions that can be done in the environment, 'knowledge improvement' which is an outcome and 'performance' and 'usability' as evaluation metrics. An identified VR research challenge is that experiments require specific datasets and results are not applicable to other fields [LB12]. However, a classification of research focused on the metrics evaluated allows researchers to quickly search an overview of results achieved with experiments along metrics under consideration. The selection method for the literature was based on quality, relevance, impact and timeliness. Importance was placed on research that performed an experiment and specifically evaluated one or more VR metric. Emphasis was also placed on recent VR research as well as earlier supporting research. A tabular classification is also given to show a graphical overview.

2. Metrics-based Classification

2.1. Presence

Presence describes a user's sense of being in a VR environment [ZWB*17] and this relies on specific perceptual cues to activate emotions [DAP*15]. [Pas09] argued that the presence provided by VR motivates the user to become more engaged and active in the tasks delivered in the environment. This conclusion was drawn in a study of 2D and 3D VR intervention programs for children with learning difficulties where it was concluded that children using the 3D VR environment required less mediation (intervention) due to the presence experienced as they were immersed in the environment.

The OpenSimulator [Ope] environment was used to provide virtual cybersecurity training in the form of games [XMN*17] and it was concluded that presence perception of the participants was high. Likewise, the potential of VR in a simulated store was explored and findings indicated that VR technology has the potential to outperform conventional desktop applications with regards to telepresence [SWH18]. This agrees with other research that investigated influences of control devices, display type and audio cues on telepresence [SS18].

With a focus on maximising presence amongst other aspects of VR in the VE, [ZWB*17] described a deskVR scenario allowing an analyst to be fully immersed at their desk which can benefit in the gain in productivity when immersed in their data spaces. This finding also agrees with VEs increasing task performance compared to a workstation [SLUK96, BH95].

2.2. Immersion

Transparent immediacy is thought of as a new form of media that thinks of itself as 'interfaceless' [Bol00]. For instance written words are an interface for speech however VR is a self-contained environment that is experienced.

[LPLK17] explained 'transparent immediacy' as a property of VR that allows users to forget the existence of media and believe that they are immersed in the virtual world. They further noted how metrics such as interaction can affect the overall measure of immersion. For instance, the poor interaction in a game can affect the overall immersion the user experiences.

[SLUK96] referred the term 'immersion' to mean what the VR technology delivers from an objective point of view. The more that a system delivers displays (in all sensory modalities) and tracking that preserves fidelity in relation to their equivalent real-world sensory modalities, the more that the system is 'immersive'. This view supports states of immersion such as full or partial [Kje01, SP10] and this may have pointed later research to suggest the provision of empirical results of aspects of immersion for validity [LB12] because several other aspects of VR such as manipulation, selection, navigation and usability are the focus of immersion [dCN17]. Whilst [SLUK96, Sla03, SG02] argue of the separation between immersion and presence it is commonly seen to be loosely used interchangeably in other research [McM03].

Other studies have concluded that as a user interacts with a VE, the user's perception that the entire environment is within their grip causes the user to enter a flow state [CKK07, ZD09, APYO11, CCC14]. [JCC*08] also described it as extreme immersion. However, some differences exists in the degree of realism. [BC04] describing the flow state put it as a realisation "when you stop thinking about the fact that you're playing a computer game and you're just in a computer".

Stated preference (SP) experiments are techniques used to collect information about products and services that are not yet available publicly [MK17]. They are usually used to ascertain the public's preference for a particular product yet to be launched. These experiments usually lack a sense of realism because the product is not available, However [FC17] explored the introduction of realism, immersion and interactivity into SP experiments using VR and concluded that realism of scenario was improved resulting in a near-realistic, immersive, and interactive experience for respondents. Other positive results from SP experiments include tenant-mix for shopping centres [BBK*10].

Similarly, natural body motions [ZDK*01] were also employed in the study of overall immersion in medical image visualisation, and it was concluded that VR display and interaction helped the user better to interpret complex geometric models representing neural structures.

[LB12] discussed the importance of VR research measuring immersion, to compare individual components of immersion rather than evaluating the whole user interface display and proposed the need for empirical results to back claims of immersion experiments. Their arguments are also supported by [CB16] who concluded that technological immersion (quality of visual content) has a medium-sized effect on presence compared to increased levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays which are significantly more impactful than improvements to most other immersive system features.

[LBS14] further analysed volumes of scientific data and concluded that search and spatial judgement tasks with isosurface visualisation and a stereoscopic display provides better performance, but for tasks with 3D texture-based rendering, displays with higher field of regard (The visible areas to an eye even when the head is moved) [Muh15] were more effective, independent of the levels of the other display components such as field of view (The visible scene to an eye at a moment) [RBK*15]. However, one of the major issues in fully immersive VR especially using HMDs is 'cue conflict' [MEC14] which sometimes causes physiological effects [KG98].

[Mor13] discussed issues with immersion to be related to technological constraints of VR interfaces and physiological characteristics of the human being (especially the way the eyes perceive images). The research further identified common immersion issues such as stereoscopic vision in artificial environments such as VEs to contribute to application failures and rejection of VR. Notwithstanding, the potential of immersion is demonstrated in the medical field including immersive therapy for treating psychological, psychiatric, medical education and self-help problems [Lam97], learning performance in VR simulation for robotic laparoscopy [FCJ*07] and manipulation of molecules [dCN17].

2.3. Navigation

Navigation is one of the core actions and tasks that is performed in VEs and spatial knowledge gained in the environment is used to navigate successfully [SDP*09].

[AKP*17] illustrated the superior navigation and conceptual advantages of viewing complex neuroscientific data in an immersive, stereoscopic context. The experiment allowed users to manipulate

MRI scans as well as perform volumetric tasks and the exceptional navigation experienced allowed users to manipulate brain segments offering a compelling neuroanatomical experience, or 'digital dissection' of an actual brain. Similar positive results for navigation were concluded in [JRA*17] where 2 VR environments were used to visualise the internals and surface of a cell allowing the user to navigate seamlessly between both environments.

Contrary conclusions were drawn in [SDP*09] where it was observed that users performed better in their navigational task on 2D desktop screens than using an HMD. This could be because of several complaints of users concerning the VE set up including distractions by cables which might have affected their experience and overall performance on the task.

Virtual navigation of 3D environments was found to be challenging with the standard mouse and keyboard interface [CM02]. However, [SDD*16] recommended a new approach that facilitates more intuitive exploration of 3D visualisation to unlock the full potential of areas such as scientific analysis. [SDD*16] researched navigation in immersive analytics using neutron scattering (Process used to understand material properties at the atomic level) and the Oculus Rift HMD and concluded that using HMDs represents a viable path toward unlocking the full potential of large and complex scientific data because the HMD provided a more intuitive and natural navigation and interaction with the data and this increased efficiency of the analysis and improved knowledge discovery timeliness.

Similarly, a mix of results in the study of the usability of VR was identified in [CC17]. The research explored how elderly cohorts could learn navigation of tasks in the VE. Making use of Google Earth-based navigational tasks, it was concluded that users generally expressed their view of the tool being exploratory however many more indicated their frustrations that include difficulties with using triggers and buttons on the controllers and issues with the weight and tethering of the headset. This group of users could potentially benefit from wireless HMD displays and full body tracking devices which might have improved their experience.

2.4. Interaction

[Kje01] noted that the central issue of human-computer interaction (HCI) is the creation of better ways of interacting with computers. This agrees with [BH99] and interests in VR interaction research. It also highlights interaction design problems with no consideration of 3D interaction techniques. This was proven by [RO13], in concluding that different input devices can strongly affect performance on the same task. [KSB93] similarly concluded that different devices gave different performance with marking menu selection. This can be explained with the fact that successful VR interaction design depends on understanding the user's perceptions, capabilities and behaviours, and bringing this understanding to bear on the design process [RO13].

[Kje01] also argues that the terms 'interaction' and 'interactivity' have become buzzwords and very vague terms for computer applications. These findings stem from not being able to precisely and clearly differentiate specific problems encountered during VR interaction experiments. He suggested the division of the concept of interaction into orientating, moving and acting. [Wlo95] argued that the three features that characterise VR interaction are immersion, rich interaction and presence and it was noted that direct manipulation could allow interaction with objects using multiple input devices with higher degrees of freedom.

[Muh15] explains interactivity as the virtual world giving participants the ability to interact and modify virtual objects. This study proposed a taxonomy of VR to aid researchers with reference to the VR interactivity study performed by [BH99] where 3 interaction techniques were identified with complex VEs, namely viewpoint motion control, selection, and manipulation.

[CZT17] proposed a depth based recognition framework that recognises mouth gestures to overcome the occlusion of the upper half of the display when using HMDs and as such improve interactive VR applications by providing information rich facial actions as a way of interaction. [WP17] similarly identified the opportunity of improving VR navigation due to occlusion of parts of scenes by large HMDs and proposed a secondary view that allows the occluded regions of interest to be brought into the users perspective providing multi-perspectives to the scene.

[NBNM11] evaluated the use of freehand menu selection interfaces using tilt and pinch gestures using a novel menu selection interface called the rapMenu [NMB08]. This approach was found to outperform the tilt menu technique [RGIS09] in both speed and accuracy when the menu has a breadth of 12 or more items. Moreover, a well arranged rapMenu was found to be expert-friendly, allowing for reliable eyes-free selection after a short period of learning. This kind of technique had been proposed earlier for VR [DH07].

Focusing on interaction, fear of VR adoption by the elderly cohorts was studied by [CC17] and findings showed that many of the participants held the view that VR was a frivolous undertaking. However, they concluded that the trusted acceptance of VR that incorporates authentic tasking is unlikely to suffer from technology rejection if a range of physical and sensory adaptations can be introduced. In fact, there were sufficient instances of auditory problems to suggest that higher volume levels are required, but also that the quality of the audio should properly match the rich 3D visual quality of the VR environment to improve immersion [Kru95].

In architecture, VR has been applied to allow interaction in virtual spaces, indoors or outdoors, with different levels of realism. In these spaces, the users move freely and, in some cases, make changes to the environment, the placement of furniture, and lighting [CSCC13]. The potential for VR in urban planning and architecture has been explored [Wan07, Guo08, SW12]. [SW12] particularly, identified certain problems of VR technology in architecture design including VR applications not having proper integration with architecture software and no interactive performance in architecture behaviour due to the traditional nature of keyboard, mouse and terminal, however, the research proposed enhancing the interactive performance of VR in related simulations as well as optimising the convenience of VR technology in design by expanding VR vision by exploring multi-screens. This suggestions also agrees with later research into multi-perspective views in VR scenes [WP17].

VR has also been found to improve big data analytics. In a study visualising Twitter data on the MIT campus it was concluded that VR can also be used as a data visualisation platform and that a more immersive environment enables interaction [MGHK15].

2.5. Knowledge Improvement

[EB11] explored 2D and 3D intervention programs on the behavioural aspects of children with intellectual disability. The study used animated 2D and 3D scenarios [EP07] and findings indicated less mediation (intervention) for users in the 3D VR.

Other researchers have investigated VR and its impact on populations with special needs [BGH02, HR05, PE00, RSB04, SBC01]. For example, [EP07] concluded that children with hearing impairments perceive sequential time better via VR than via other presentation methods such as pictorial, verbal, written and signed modes. Other researchers have also investigated the influence of VR among populations with intellectual disability. These studies were designed to see whether it is possible to improve independence and various functioning skills, and to determine whether it is possible to increase self-confidence [SBC01].

[XMN*17] evaluated a VR learning environment that allowed users to experience information security threats for computer engineering education. The study presented an environment that allowed all simulations to put the users in a mission. An initial survey of the participants suggested they were attracted to the system and had overall good impressions. Around 72% of the participating students indicated the tool had helped them improve their information security knowledge. Similar knowledge improvement was found in neurosurgery learning [PNL*17], elderly cohorts [CC17], geography [DCL17] and cell biology [JRA*17].

[CH18] evaluated learning in brain-computer interfaces (BCI) by testing the performance and learning rates using VR and found no knowledge improvements for users using VR compared to a desktop screen. It was rather concluded that users with prior experience of VR performed better in the VR environment. The subtle difference here with other experiments includes the BCI device that was placed directly on top of the head together with the HMD. This device was also noted to have sometimes interfered with the HMD. It can fairly be assumed that it might have also added an extra weight to the already heavy HMD.However, this extra weight and expected latency issues of network transmission as well as distraction of the users showed no detrimental effects.

2.6. Performance

Measuring the performance of a VR system is more beneficial when combined with usability studies of the same environment [TGA12]. This approach would have improved research evaluating immersive environments [WL04, CM02, DJK*06, CHHC16].

The performance of a VR system in computer-aided design (CAD) was evaluated using an experiment allowing participants to model and assemble 3D objects using a 2D desktop display and a CAVE [TGA12]. Results showed that the immersive environment provided better depth perception of the objects. However, the approach did not prove to be a powerful tool because it did not provide a sufficient improvement to the efficiency of operations compared with the 2D desktop interface. Hand movements in VR also caused increased physical fatigue. It was also suggested for the VR interface to be redesigned with consideration of reducing the significantly larger distances experienced in the 3D environment.

VR interfaces were shown to outperform traditional tasks on a 2D display in an experiment assessing performance for navigational tasks [SDP*09]. On the contrary [CH18] concluded that user performance did not increase compared to traditional 2D desktop displays for motor-imagery based tasks where users used brain control interface to perform interaction tasks with virtual avatars. Both experiments made use of a VR application built with the Unity game engine and whilst [SDP*09] used a game-based scenario approach with a mobile-based Google Cardboard HMD, [CH18] used an HTC Vive HMD.

The performance assessment of carotid angiography was simulated in VR to measure reliability [PGNC06]. It was also an opportunity for using VR to explore this complex and high risk procedure as the demand for learning is rising among medical professionals [GC04]. Seven measures of the participants' operative performance were collated and repeated tests performed and it was concluded that VR simulation allows for a reliable and consistent assessment of improvement in operator performance during carotid angiography training. This result also agrees with findings on the potential of VEs in fostering improved performance for communication with autistic people [PROL17].

2.7. Usability

[TGA12] argues that usability is the ability to carry out tasks effectively, efficiently and with satisfaction and that comparative evaluation is the way to measure usability. Previous research had identified issues with usability studies such as reliance on one method and difficulty of usability studies based on user guidelines [BGH02] because of non-existent user interface guidelines for VR. [LB12] also argues that current usability studies for VR environments lack generalisability of results to other VR systems and domains.

Depth cues (occlusion and relative size of labels and objects) and gestalt cues (proximity and connectedness of labels and objects) in text label layouts were identified to affect usability of immersive environments [BGH02]. [BGH02] presented an evaluation methodology for usability that explored the effects of these cues in designing VE layouts. It was concluded that the consistent performance of continuous scaling across tasks suggests that legibility is more important than relative size and users rely on different combinations of depth and gestalt cues depending on the task and the display size.

[TGA12] designed an experiment to evaluate a VR CAD system for modelling and assembly use case scenarios. Users were allowed to model 3D objects to measure the usability of the VR CAD system. It was concluded that VR presented a physical stress factor because the distance for hand movement in VR was larger than on a desktop.

The system usability scale (SUS) standardised questionnaire [Bro96] was used to measure the usability of a VR learning environment using the Opensimulator tool and the Moodle learning

Table 1: *Classification of studies by domain, metrics, and devices used.*

Domain	Reference	Metrics	Devices	Experiment	Findings
E-commerce	[APYO11]	Interactivity, presence	PC, stereo-scopic display	Second Life virtual shopping	Flow mediates the impact of technological and spatial environments on intention to purchase virtual products.
	[CCC14]	Immersion	Six-axis simulator	Measure virtual experience in the VR environment	Flow is affected by characteristics of the mediated environment, the consumer's assumptions, the state of entering the flow and the consequences of the flow.
Education	[BH95]	Presence	Stereoscopic display	Navigate a virtual representation of Stonehenge and search for a rune, inscribed upon the wall of one of Stonehenge's edifices	The subjective presence within the virtual environment was less using an update rate of 5 and 10 Hz when compared to update rates of 20 and 25 Hz.
	[CM02]	Performance	Desktop	Repeat storage and retrieval exercises for sparse, medium and dense conditions to access using spatial memory	Ability to conclude tasks much faster than thought
	[SG02]	Immersion, presence	Unknown	Interaction and movement in virtual library.	
	[EP07]	Knowledge improvement	Generic HMD	Re-order images in sequence to study pictorial representation, written representation, aural representation	VR technology is an important and efficient mode of representation in attaining a higher level of abstraction when compared with other modes such as 2D desktop.
	[dCN17]	Immersion, interaction	HMD, desktop	Interact with molecules in the HMD	Users who performed the various tasks using the VR had a shorter execution time, smaller amount of errors and a higher level of comfort
	[CC17]	Usability, navigation	HTC Vive	Navigate a virtual Google earth.	Trusted acceptance of virtual reality exercises that incorporate authentic tasking are unlikely to suffer from technology rejection if a range of physical and sensory adaptations can be introduced.
	[CZT17]	Interaction	Samsung Gear VR	Mouth gestures as a form of interaction	The system could handle the face occlusion introduced by the head mounted displays with a high correct classification rate.
Games	[JCC*08]	Immersion	2D desktop-based VR	Measuring the time taking to complete game tasks at variable immersion levels	The greater the immersion the less time spent on tasks.
	[HDY17]	Usability	HTC Vive	Two VR games were played in Latin square sequence according to the system guidance in each game.	EEG (Electroencephalogram), a test used to evaluate the electrical activity in the brain, can be a good tool to analyse UX (User experience) of a VR game.
Medical	[ZDK*01]	Immersion	CAVE	Tensor-valued volumetric data visualisation	VR helped the users better interpret the complex geometric models representing neural structures.
	[DJK*06]	Performance	CAVE, 2D desktop VR	Visual search task, identify a feature on a potato-like object with a noisy surface in different visual contexts	Users were significantly faster and more accurate on the fish tank VR system than in the CAVE.
	[EB11]	Knowledge improvement	Generic HMD	Children with intelligent disability were put through 2D and 3D VR tasks	Children who performed their tasks in 3D VR required less mediation (Intervention in the process of the experiment).
	[AKP*17]	Navigation, immersion	HTC Vive	Perform tasks by manipulating neuroimage 3D data Cube	Advantages demonstrated in viewing neuro imaging data in stereoscopic displays.
	[BKEE18]	Usability	Oculus Rift, desktop	Urinary catherization-related task in a game-based VR system and on a desktop	Users were found to have completed more tasks in the VR environment than the 2D desktop as well as finding the IVE (Interactive virtual environment) enjoyable and engaging.
	[CH18]	Knowledge improvement, performance	HTC Vive	Evaluate a VR-based BCI for performing tasks	Performing BCI tasks in VR does not affect one's ability to perform the task. Also, immersion does not impede performance in VR.

Table 1: *Continued.*

Domain	Reference	Metrics	Devices	Experiment	Findings
Science	[DJK*06]	Performance	CAVE, 2D desktop based VR	Identify a feature on a potato-like object with a noisy surface in different visual contexts	Significantly faster and more accurate on the fish tank VR system than in the CAVE.
	[JRA*17]	Navigation, knowledge improvement	Google Cardboard	Experience mechanisms by which drugs and nano-particles are internalized into cells and compared with real-world exam.	Students who completed the VR performed 5% better on the cell biology question than they did on the rest of the exam. In comparison, students who did not experience the VR performed 35% worse on the cell biology question.
	[NYW*17]	Interaction	Tiled Wall HDTV, HMD	Explore an area of high dimensional scientific data	A lot of small details in the high dimensional scientific data was identified with the 8K tiled wall display and the HDM provided local data exploration in stereoscopic view.
General	[Kje01]	Interaction	2D monitor, HMD, Holo bench, large wall-mounted, panoramic display, CAVE	Different experiments to study display types and interaction	The use of six-sided CAVEs and panoramic displays result in different requirements to the design of interaction techniques and use of interaction devices.
	[WL04]	Interaction	Desktop VR System	Training application for maintenance of a refinery pump	Virtual maintenance training could offer intelligent assistance in generating disassembly sequence.
	[SDP*09]	Usability, navigation	Stereo HMD i-glasses SVGA Pro	Perform a series of tasks in maze	Better performance when using the desktop than when using VR
	[SSS13]	Interaction, Knowledge improvement	CAVE	Explored an immersive extended-humanoid avatar	People can quickly learn how to remap normal degrees of freedom to control exotic virtual body forms.
	[CHHC16]	Performance	Google Cardboard, Samsung Gear VR, 3Glasses D2, Oculus Rift DK2	Comparative analysis with physical and virtual world on timing and positioning accuracy	Some VR systems opt for higher precision at the expense of sensitivity and this awareness is useful for quantifying system-wide performance in both objective and subjective experiments.
	[WP17]	Navigation	Generic HMD	Gain and maintain sight of static and dynamic synthetic objects placed in the scenes.	Significant improvement in navigation efficiency while using multi-perspective visualization compared with using conventional visualization.
	[ZWB*17]	Presence	Generic HMD	Explored items that may be on a user's desk as virtual entities in a node diagram	The deskVR prototype showed how analysts can gain in productivity when immersed in their dataspaces.

environment [XMN*17]. The focus was on usability aspects such as efficiency, clarity and dependability. Using a game-based scenario for usability evaluation, the resulting SUS score of 67.3% was acceptable and comparable with usability scores achieved by similar systems. A more complex usability study was performed on a similar game-based scenario for practising urinary catheterisation. Evaluation performed using the SUS showed results with an overall mean rating of 72.5% [BKEE18]. This positive result also agrees with a study into the potential of VR assistive technology for autism spectrum disorder [PROL17].

[HDY17] pointed out issues with measuring usability of VEs such as whether the user experiences are as a result of VR or of the product being studied and noted the popularity of using eye-tracking to measure usability but hinted on the difficulties in having accurate eye-movement. However, other research that used eye tracking to measure usability includes, the study of diseases such as Parkinsons's where VR was rated as potentially useful for diagnosis [OIR*17], automatic one-point eye-tracker re-calibration for assessing visual attention in VR which was found to be faster and more accurate compared to a user having to take-off the HMD each time to re-calibrate [LK17].

[VS18] explained that usability testing is the most effective way of understanding what works and what does not in an interface and the best way is to watch people use the system under testing. [VS18] further performed an experiment to evaluate the usability of a VR application for interior design using the Oculus Rift HMD and the Leap Motion controller for interaction. The experiment tasked 25 participants to perform actions such as drawing floor plans, placing furniture in appropriate places in the scene and it was observed that the application looked realistic and was found to be usable for interior designs. However, it was noted that it may cause dizziness for beginners as well as the Leap Motion controller not accurately detecting hand movements and patterns because of self occlusion (problem in hand pose estimation because of the sophisticated expressions of the hand) [JNC*15] and distal phalanges (bones that forms the fingers) [TKYU12].

3. Conclusion

A review of VR research has been presented showing a general trend of advantages using VR to improve and optimise tasks and processes. This review has detailed VR experiments performed in several domains by focusing on the metrics evaluated. Many results of these experiments have shown the benefits of VR as an alternative display environment for performing tasks. Key metrics of VR have been explored whilst noting some concepts, issues and relationships between them such as concept of flow and the relationship between the metrics.

The tabular classification of the experiments allows students and researchers to quickly approach VR literature from a viewpoint of the aspects of VR being explored, allowing for a more focused approach as researchers will be directed to works that studied their metrics under consideration rather than the entire body of general VR literature. It also extends similar studies such as those comparing HMD with desktop displays [SDP*09] by not limiting the reviewed experiments to a specific hardware form factor.

In conclusion, we find that further work can be done in the area of evaluating the attributes measured under each metric. For instance, sensitivity and real-time feedback can be measured whilst considering interaction as a VR metric and standardising these measurement attributes can contribute to a VR taxonomy and help promote research in this area.

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