Depth and Distance Perceptions within Virtual Reality Environments - A Comparison between HMDs and CAVEs in Architectural Design

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The Perceptions of Depth and Distance are considered as two of the most important factors in Virtual Reality Environments, as these environments inevitability impact the perception of the virtual content compared with the one of real world. Many studies on depth and distance perceptions in a virtual environment exist. Most of them were conducted using Head-Mounted Displays (HMDs) and less with large screen displays such as those of Cave Automatic Virtual Environments (CAVEs). In this paper, we make a comparison between the different aspects of perception in the architectural environment between CAVE systems and HMD. This paper clarifies the Virtual Object as an entity in a VE and also the pros and cons of using CAVEs and HMDs are explained. Eventually, just a first survey of the planned case study of the artificial port of the Trajan emperor near Fiumicino has been done as for COVID-19 an on-field experimentation could not have been performed.

Keywords: *Visual Perception, Depth and Distance Perception, Virtual Reality, HMD, CAVE, Trajan's port*

INTRODUCTION

The basic elements of Virtual Reality (VR) systems defined as Immersion, Interaction, and Imagination, are well developed as the technology of computer graphics and 3D displays advances. With the basic elements of immersive systems developed, many pieces of research have started to look at practical applications, utilization, side-effects, methodologies, philosophy, etc. of VR (Armbrüster et al., 2008). VR tools have been used more frequently in psychological experiments and clinical applications for their ability to present stimuli in the environment. For example, psychologists used Virtual Reality Environment - from now on VE- to test the likelihood for people to help under different situations. In Cognitive Science, VE technology could also be viewed as a unique asset, which provides the possibility of presenting dynamic entities for precise measurement of human cognition and interaction. Despite the usefulness of VR, some raising concerns over the use of VR systems as the tool in experimental psychological research, increased attention had been brought to the aspect of human spatial perception. In architectural design, it is important to ensure that the VR systems could be used as an experiencing tool in all aspects without any other adjustment (Naceri et al., 2010). A useful experiencing environment should provide an accurate measurement while containing minimum cues. In another word, in an architectural studio, a VE should provide the viewer with accurate depth perception, the ability to perceive an object in three dimensions, and the distance of the object. Other important aspects to be considered in architecture and in general in the design are the actual perception of proportions and the accuracy of colours and finishing of entities' surface.

DEPTH AND DISTANCE PERCEPTIONS

The mental cycle of perceiving, recording and interpreting is important for distance calculation. Next, through the image of the objects, the spectator perceives the external environment; s/he utilizes her or his vision to measure the distance of the target. In order to increase precision, knowledge should then be analyzed with certain criteria and techniques (Carrara et al., 2017). A person's interpretation can include several variables. The reliance on depth metrics has been shown to influence the output of the subjects.

Instead of depending heavily on the scale, those who rely on various types of depth indicators had just one kind of profound indicator. The field of vision is typically divided into three categories (Fig.1). The first one is the *Personal Space*, which is around the observer and identified as the distance within 2 m. The second one between 2 m to 30 m, is known as the *Action Space* where people can move and communicate quickly, and the third one is called *Vista Space* that occurs beyond about 30 m and spans to the horizon line (Cutting, 1997).

Within this room of motion in the VE structures or in actual life, binocular disparity and motion parallax will be used. Motion parallax is a significant profile comparison in physical reality's depth and distance perception (Buck et al., 2018). The Merriam-Webster Dictionary defines Parallax as: *"the apparent displacement or the difference in apparent direction of an object as seen from two different points, not on a straight line with the object."* Figure 2 shows the parallax of an object against a distant background due to a perspective shift.

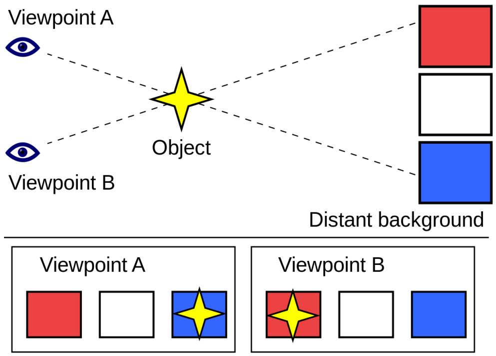

Figure 2
illustration of the parallax of an object against a distant background due to a perspective shift. When viewed from "Viewpoint A", the object appears to be in front of the blue square. When the viewpoint is changed to "Viewpoint B", the object appears to have moved in front of the red square [1].

By using this technique by companies like Nintendo (Japanese video game firm) in its new version of game consoles, people can understand and reconstruct the stereoscopic view (binocular) by putting sight barriers in between eyes and the observed object (Fig. 3). This effect can be performed also by means of glasses with different polarized lenses.

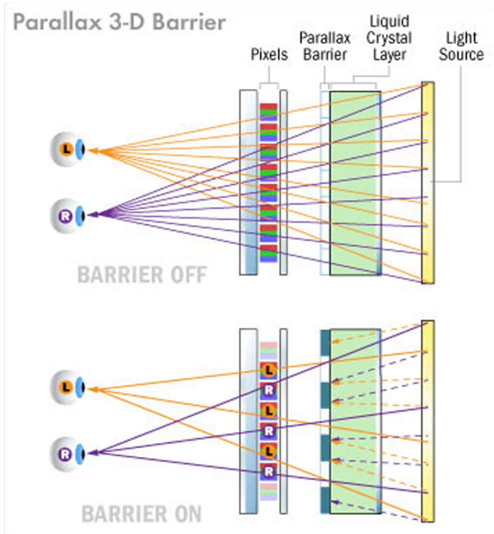

Figure 3
The parallax barrier in the Nintendo Company to create the illusion of depth on the 3DS screen by directing light to each of the eyes [2].

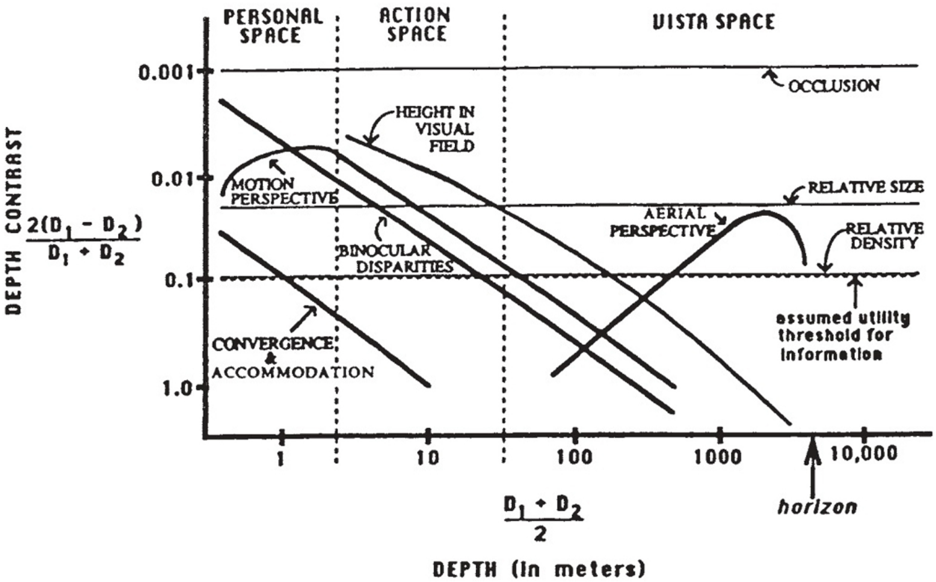

Figure 1
Three Types of Field of Vision; (Cutting, 1997).

The actor (according to ISO definition) is fundamentally at the center of the mechanism in any system that uses Virtual Reality since the virtual application is aimed at the user. Therefore, when establishing the virtual environment and its interfaces (Fig. 4), it is necessary to use a human-centered approach (focusing on the person) starting with the "perception, cognition, action" loop rather than a technical-centered approach (Richir et al., 2015).

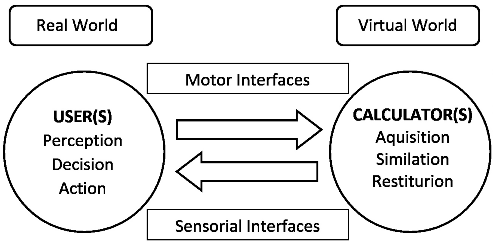

Figure 4
The "perception, cognition, action" loop passing by the virtual mode; (Richir et al., 2015).

In the virtual environment, the user must have a behavior. He needs to have the interface transparent. Concretely, this activity is realized physically through the motor skills of the user and an effective perception between the person and the interfaces. These physically depend on instruments and are used according to the mental schemes of the involved actors. On a theoretical basis, the "behavioral interfaces" are designed to convey sensory feedback from the machine to the human and vice versa, the "motor interfaces" are designed to transmit motor responses from the individual to the device. Some sensor motor interfaces, force feedback interfaces, transmit the motor responses and, as a reaction, the computer feeds sensorial stimuli (Fig. 5).

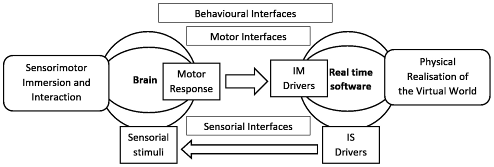

Figure 5
Technical centered schema of sensorimotor immersion and interaction; (Richir et al., 2015).

The human visual system depends on distance and depth measures in a virtual setting, including binocular disparity, adjustment, convergence, motion parallax, etc., for assessing the spatial position of a virtual entity within a virtual world (Cho et al., 2012). Observers are completely isolated from the physical world in HMD systems. In certain cases, although such systems allow greater presence and communication with the virtual environment, recent studies into absolute distance knowledge utilizing HMDs shown a significant underestimation (Ghinea et al., 2018). In large display screen CAVE Systems, the role of HMDs on recognizing the depth and distance measurements of VE is more important.

A third completely different approach to problems is the Mixed Reality one where actors are within a real environment wearing special glasses (Rossini et al. 2016). In the following pages, it has been compared only CAVE and HMD systems.

PERCEPTIONS IN CAVE SYSTEMS

CAVE is a virtual reality interactive environment, where projectors are placed on three to six walls of a CAVE (Fig. 6). Observations and output trends have revealed that at distance learning learners sought to utilize actual CAVE boundaries (Kalisperis et al, 2006). In order to enable virtual distance calculations, users/actors should use distance indicators in a physical device.

PERCEPTIONS IN HMDS

HMDs made real-world consumers desperate by being unwilling to fulfill over-hyped demands. However, that does not require the usage of HMDs. Although certain places still do not have the equipment, properly built HMDs may be incredibly valuable devices (Ghinea et al., 2018).

The resolution in most HMDs needs to be enhanced and individual pixel filling factors need to be increased. Many common HMDs use optical resolution and weight lightness characteristics that are suitable for use as instruments. No prototypes are therefore enough advanced to persuade a true immersion. Unique prototypes for a program are typically very cost-effective and of restricted general usage (Ghinea et al., 2018). Many HMDs have struggled to produce their anticipated results. Although some constraints exist, a careful design that takes into consideration whatever factors are required for the visual system and how well it needs to be matched to appropriate HMD technology can lead to a reasonable HMD as an instrument for the architectural design objectives. In this perspective, the HMDs are able to help architects and designers perform a sufficient Deep/Distance effect during the architectural design process.

Figure 6
The CAVE System of HLRS Center in Stuttgart University; Germany, in a demo at Sapienza University of Rome [3].

Figure 7
An HMD Application in Architecture Studio and Design Practice [4].

COMPARISON BETWEEN PERCEPTION IN CAVE SYSTEMS AND HMDS

The visor-centric VR device offers a wide angle of view, dynamic power, and (stereo) binocular (real-time) viewpoint. HMDs, accomplish this by using small display screens which are near to the viewer's eyes and are with the viewer (Fig. 7). In particular for science and technological uses, CAVE was planned to circumvent those constraints of HMDs (Armbrüster et al., 2008). The CAVE is more remote from the viewer to use big, fixed displays. It reduces the pressures that consumers bear or wear and encourages many individuals to express their VR experience (Naceri et al., 2009).

CAVEs obviously allow for more accurate estimates than HMD's. Figure 8 states that the standard deviation dispersion in HMDs is smaller than that in the CAVEs (Ghinea et al., 2018).

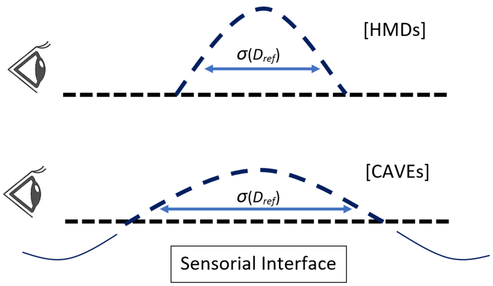

Figure 8
Evolution of the dispersion for both the CAVE and the HMD systems; (Ghinea et al., 2018).

The CAVE provides extra advantages, as well as the option to access the interactive world with other users. The CAVE, for example, is interactive but does not separate actors entirely from the physical world. The actual loneliness of the universe may be deeply disruptive and unsettling. The user is always aware of the natural world and will feel things like walls. Measuring failures and measuring lag in CAVE have often been found to be less distractive than in HMD devices. That is because the projection plane does not move as it does in an HMD with the direction and angle of the viewer (Naceri et al., 2010).

The CAVE is suitable for use for data exploration and concept examination in architecture design (Buck et al., 2018). The CAVE provides a pleasant space for many hours for developers, students, programmers, and executives. They can communicate face to face, experience the expression of each other's body, quickly pause or have a drink and also use certain gadgets (Kalisperis et al, 2006).

CASE STUDY

The artificial port of the Trajan emperor near Fiumicino airport in Ostia (Italy) has been chosen as an urban scale area to examine the theoretical parts in practice (Fig. 9, 10). It is a very interesting place as there, it can be applied studies on *Personal Space*, *Action Space*, and *Vista Space*. Another important factor is that Ostia municipality planned to use that archaeological site for a mixed use: tourism, ecosystem, and farming. We are been asked to study these exceptional remnants and ruins for these goals, but the COVID-19 lockdown prevented us to measure HMD and CAVE system perceptions and to model the field. The process is based on the observations and field experience in order to find out the difference of a perceived real environment through the immersion in a CAVE system versus HMD. The actors of both display systems requested to assess and measure a variety of real dimensions on-site by experiencing both systems in a location far distant from the Trajan's Harbour. This one was so important that the actual noun of *port* derives from the ancient Latin name of the site: Portus. It was the equivalent of the *Docklands* inside the Imperial Port of London in the nineteenth century.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The current study is driven by the desire for a real scale perception of the distance for architecture-related problems. The area of architecture has some main characteristics that differentiate it from most of the former spatial perception literature. As a matter of facts, architects focus on peculiar aspects of space, just to cite a few: dimensions at human scale, pro-

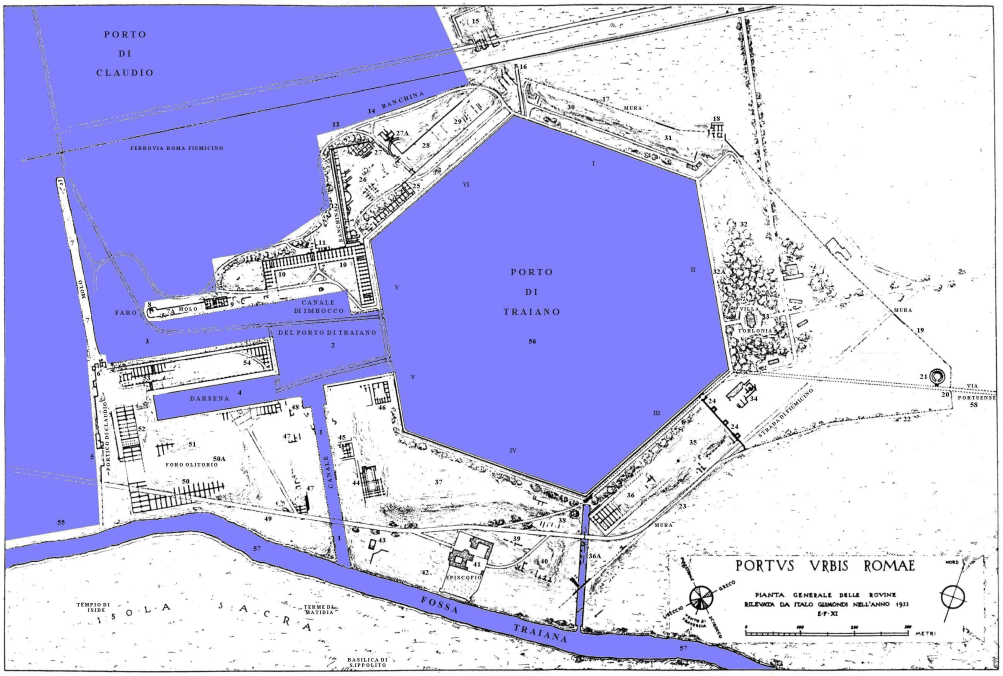

Figure 9
Case Study, The Artificial Port of Trajan Emperor near Fiumicino; Ostia; Italy [5].

portions among spaces, relationships among height, length and wide, perspective sight (that can stress dimensions as in lithographs of Giovanni Battista Piranesi), motions among spaces as a continuous alternance among hide/reveal/show spaces (Baker, 1989), etc. These vast and important aspects will be treated in a future paper. The aim of this paper was to compare and assess the actor perception experience in a virtual environment using two different displaying systems: CAVE and HMD. Based on the observations and experiments, the findings are summarized as first the perception deviation increases with distances in both systems. Secondly, the virtual entities are more precise in the CAVE system than with the HMD. The Shape, accuracy in resolution, and dimensions of CAVE System directly impact on the user perception of the real environment in VE. Inevitably the immersive environment of CAVE systems can enrich the architectural design labs and studios as well as a more influential representation style that will equip architects and designers with its powerful impact. A deep survey on-site should be performed after the lockdown together with a questionnaire, and an experimental comparison between HMD and CAVE systems on Trajan's hexagonal harbour.

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Figure 10
Portus (Port of Trajan's Harbour) with its distinctive hexagonal harbor by Jean-Claude Golvin; Ostia; Italy [6].

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