A Discussion on User Experience of Virtual Reality Simulators vs. Head Mounted Displays

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ABSTRACT
Virtual reality (VR) offers new possibilities for exploring the various digital worlds that are more and more present around us and that are constantly evolving. The user experience is a very important factor when it comes to VR, as users can experience VR through headsets, simulators and immersive cameras. Usability, when it comes to virtual reality, brings together aspects such as the simplicity with which users can use a headset / simulator, the variety of areas in which it can be used and aspects related to the user's motion sickness. This paper aims to conduct a study on the experience that the users have when they use a headset and a virtual reality simulator, respectively, to determine which of the two types of VR experiences are more advantageous. We observed that headset devices were preferred to simulators, even though the latter are easier to use since users are already familiar with a mouse and keyboard. The headsets make the users forget that they are in a virtual world, hence the popularity. VR headsets add this kind of immersion to the user experience, making the difference between an application that runs on a normal desktop/laptop screen and an application developed specifically for a VR headset.

Author Keywords
Virtual reality; headset; simulator; virtual environment; user experience.

ACM Classification Keywords
CCS Concepts: Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Virtual reality

CCS Concepts: Human-centered computing → Human computer interaction (HCI) → HCI design and evaluation methods → Usability testing

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INTRODUCTION

Virtual reality (VR) is a technology that has the potential to change the way people work, enjoy, communicate, learn, and live in the near future. In the so-called second wave of virtual reality, there has been a huge advance in VR technologies, with many products and manufacturers appearing in the last five to ten years. In addition to technological maturity and economic viability, user experience, usability, accessibility and health consequences are also important factors in user adoption [1]. Virtual reality has become increasingly popular in recent years, thanks to the development of hardware technology that has led to the emergence of consumer-friendly head-mounted displays (HMD). The captivating nature of HMDs creates a strong sense of presence, allowing users to discern virtual environments (EVs) as if they were real. As a result, games, entertainment, training, education and work benefit from these technological developments [2].

Due to the rapid evolution of the technology needed to create virtual environments, it becomes possible for VR application makers to develop worlds as realistic and as faithful as possible. The two main characteristics that define the quality of a virtual world are processing power and screen resolutions, which have improved considerably in recent years. It has not yet been established exactly when it is necessary to create high quality worlds (with high realism) because, to do this, you need resources, both financial and electronic [3]. It is desired to establish a quality level of the virtual environment created so that it meets the needs of the users (without feeling the need for superior quality) depending on the actions performed by them in the environment in which they are.

This paper aims to study the different types of experiences that the users can have in a computer-generated virtual environment. Access to such environments is possible either through head-mounted displays (HMDs) or through simulators of different types based on Visual Display Terminals (VDTs). The structure of the paper is as follows: Section II presents the literature review. Sections III and IV describe aspects related to the different virtual reality systems through which the user can enter the virtual environments. Section V contains the conclusions and future research directions.

LITERATURE REVIEW

An analysis of virtual reality systems was made in the works of Rhiu [4] and Somrak [1]. Rhiu made a comparison between walking and driving in VR, respectively, using both headsets and virtual reality simulators, while the work of Hooks complements the previous paper with an analysis of motion sickness in VR (between 20% and 80% of users are affected by this). The studies contributed to the elaboration of two of these works, following which the advantages of using one technology to the detriment of the other were identified.

Although studies have been conducted to assess the user experience, these studies are not enough to determine a holistic perspective of user experience in VR. We must also keep in mind that VR systems are provided with various types of interactions and that they are constantly evolving, new ways to interact with VR systems are emerging, therefore, it is necessary to have new studies to investigate the user experience in within virtual reality systems [5], [4].

User Experience (UX) in VR is how the user explores and interacts with the virtual world, how easily they adapt to new ways of interacting with various objects and / or situations. Because users interact directly with virtual reality systems, studies must be performed from the user's perspective. UX is defined as "the perceptions and responses of a person resulting from the use and / or anticipated use of a product, system or service" [4]. At the moment, we want the interactions in virtual environments to be as natural and intuitive as possible so that the user has a great freedom of movement. It is also necessary for the application developer to keep in mind that a VR session should not last more than 20-30 minutes, as it is proven that users lose their concentration after this period of time. It must also be taken into account that the virtual spaces that the developer creates should not be too small so as not to trigger the feeling of claustrophobia, and, if they are too large (complex), the users may get lost if they do not have a precise way of orientation (map) [6].

DESIGN PRINCIPLES

In order to have the most natural interactions between the users and the VR systems, we must consider the following principles of designing the interaction according to the book "The VR Book Human-Centered Design for Virtual Reality" by Jason Jerald [7]:

- Intuitive - How easy it is for a user to understand how their virtual environment works.
- Accessibility - The actions that a user can perform and how they can be performed, but also what can interact with the user.
- Signals - Indicators that explain how they operate and the behaviour of various objects depending on how the user interacts with it.
- Limitations - Constraints of actions and behaviours in order to guide the user on a certain logical thread and for increased security. These constraints can be in several ways (logical, semantic and cultural limitations) and have the role of guiding actions and facilitating interpretations.
- Feedback - Creates a way in which the virtual environment communicates the users' status or the results of an action that they have taken.

Considering these design principles, Table 1 list the main differences between CoSpaces Edu and Unity, two popular VR platforms.

Characteristics	**CoSpaces Edu**	**Unity**
Strengths	Easy to use	Creating interactive experiences
Weaknesses	Limitation	Hard to use
Platform	Web/mobile	Desktop, Mobile, Extended Reality (XR), Consoles, WebGL and Embedded

Table 1. Comparison between CoSpaces Edu and Unity

One of the strengths of CoSpaces is that the web application is very easy to use. Even if Unity is harder to use, the applications developed with Unity can be more interactive and better looking. If we talk about weaknesses, CoSpaces is limited to simple 3D models and the predefined 3D models created by the developers of the platform. Users can upload custom 3D models, but can't use custom animation and custom textures for those 3D models. One of the main advantages of Unity is the multiplatform capability, CoSpaces being available only in a web browser or the mobile application.

VR experience

In order for the users to have VR experiences as immersive as possible, it is necessary for them to be subjected to multimodal interactions that involve several senses. The human brain must process in real time all the information (vision, hearing, vestibular and proprioceptive inputs) that it receives from the external environment and combine them to produce a captivating feeling of immersion in a virtual reality environment [1]. When it comes to VR, the display (HMD display) and the effect it has on the human vision system are the most important parts, because 70% of human receptors are dedicated to vision [8]. In order to have an immersive experience, the other human senses need to be stimulated (hearing, touch, smell, taste). Haptic devices, vibrating controllers, omnidirectional walking simulators and other devices are used to achieve this.

In recent years, HMD VR devices equipped with high-resolution displays, headphones, and motion tracking technology have been marketed, and you can interact freely with VR systems with manual controllers using both hands. But there are different ways to interact with VR systems depending on the equipment you use. If you use Google Cardboard the way to interact with objects is simple; you usually use the gaze for different types of interactions, you have no controllers and the VR system uses your personal smartphone as a processor and display (if it is able to run VR applications) [9]. Samsung Galaxy Gear VR is designed only for Samsung devices and is accompanied by a controller that allows you to interact much more easily with the virtual environment [10]. Oculus Go users are no longer limited by the smartphone, but its performance is similar to that of a phone. The most immersive VR devices are Oculus Quest (2)[1], Oculus Rift (S)[2], HTC Vive[3], etc. The latter are devices designed specifically for VR; they have tracking sensors, controllers and high processing power; some also work independently, but for a better experience they must be connected to a computer with high processing power (in doing so, the user may lose their freedom of movement by being connected to a PC via a cable) [11]–[13].

Advantages and disadvantages

A problem that persists in the field of virtual reality is that of how the user moves and interacts with objects in virtual space. Because of this, many types of methods have been proposed and implemented to move in virtual environments, including using your eyes, user hand gestures, or both virtual and physical controllers to move. Of these methods, virtual controllers are the most versatile, can be used in any field, they can take any form in the virtual environment, but they do not have haptic feedback, not having a way for the user to interact with it outside the virtual environment. Hand gestures and the use of the gaze, respectively, are simple and intuitive ways in which the user can move, but can create confusion and disorientation for new users. Physical controllers are the least flexible because they exist in the real environment and cannot change their shape and characteristics, but can be used in specific scenarios, such as flight simulators, driving, surgical, etc. [14], [15].

According to Figure 1, VR has the following advantages: it reduces transport costs (opens new possibilities for tourists, museums and artists of all kinds) and we no longer need to travel to participate in various activities; increased safety in various types of training; the possibility to repeat these workouts individually or in a team without major risks. Those who use this technology for learning are much more involved in what they do because these systems immerse the user in virtual environments designed to prepare them in a certain field.

[1] https://store.facebook.com/quest/products/quest-2

[2] https://www.oculus.com/rift-s/

[3] https://www.vive.com/

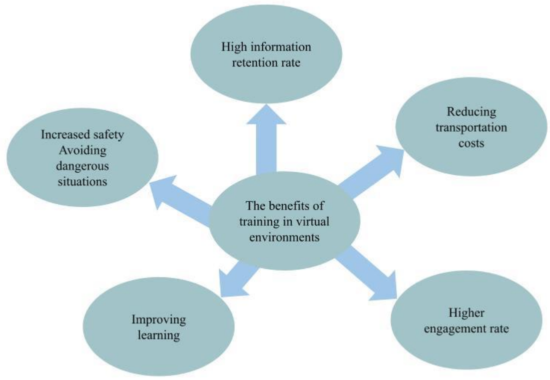

Figure 1. The benefits of VR in training include higher levels of captivation and safety [16]

Applicability

VR technology can be divided into three types of categories: 3D monitors, HMDs, and immersive cameras. HMDs are the most common VR devices; they allow the user to experience virtual space based on a real-time motion tracking system. These devices have become easier to use, smaller, more comfortable, more practical and less expensive due to the evolution of graphic design, computing and human-computer interaction technology. At the moment, users of VR technology can enjoy it with the help of HMD VR devices and their own smartphone screen. Of course, the experience differs from one device to another, from smartphone to smartphone, in that you can get the most immersive experiences with the help of specialized equipment in the field, but most of the time, it is much more expensive [4]. HMDs can also be divided into two categories: those connected to a computer (which deals with information processing) via a data cable, and those that work on their own (for examples, Oculus Quest 2) [1].

Objectives

One of the purposes of virtual reality is to create the possibility for the users to perform actions / tasks in a virtual environment, in real time, without them realising that everything happens in a simulated environment on the computer. To create the sensation of a real world, the technology used must "trick the brain" by giving external stimuli as close as possible to those in the real environment. VR can also be defined as the ability to allow one or more users to perform a set of tasks within a virtual environment; this immersive simulation is based on user interactions with the computer-generated world and how it responds to different stimuli [17].

VR applications

In order to create a VR application that is as user-friendly as possible, you need to take into account several aspects, namely: the target audience, the age of the people you want to attract, the type of application, the purpose of the application, etc. Let's not forget that the user experience is given by various factors from a multitude of disciplines, such as: interaction design, visual (graphic) design, usability, content strategy, user interface design, information architecture, user research, etc.

VR smartphone applications turn smartphones into real HMDs; they need only a virtual reality headset inside which the device is inserted; the headset is positioned as comfortable as possible so that the user can see the virtual environment clearly. Thus, a simple smartphone becomes a portal to new worlds that the user is to explore.

VR applications for HMDs connected to a computer or stand-alone ones usually need more processing power. Controllers and various sensors are used to stay within the area designated as safe (area that the user indicates at the beginning of the VR session). This area sets virtual barriers in the real environment, alerting the user in the virtual environment if these barriers are violated. Sensors are also used to synchronise the movements of the user's body with those of the avatar in the virtual environment.

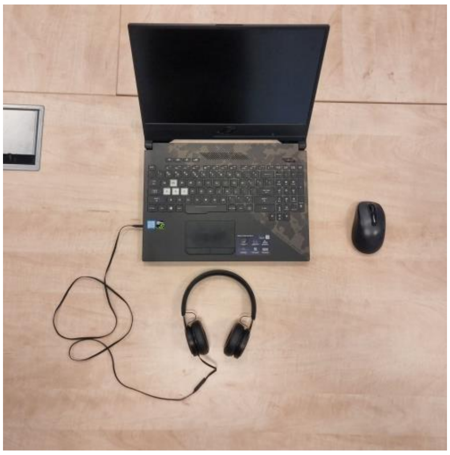

Figure 2. Example of hardware configuration for a Video Display Terminal

VR uses

In the Figure 3 we have presented the simplified way in which a virtual reality application works depending on the users' choices. The users are presented with two choices: "Immersive Experience" and "Teaching Experience". If they select the first option, then they will have a better real experience; otherwise, only the specific details of the respective lesson will be presented, without the possibility to interact too much with that scene; in both situations, the users will have access to information [18].

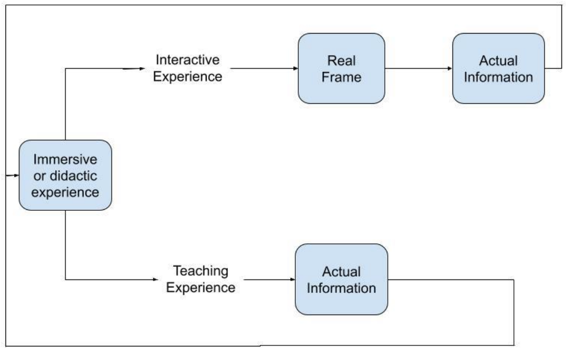

Figure 3. Different types of experiences depending on the choices the user makes [18].

Virtual reality systems: VDT vs. HMD

Visual display terminal, also called video display terminal, is actually a computer screen. According to the study of Rhiu [4] we can see in Table 2 the difference between the use of a VDT and the use of an HMD in two different situations, namely, walking and driving. From Table 2 we conclude the following:

- HMDs demand more of the mental side, both when it comes to walking and when it comes to driving.
- Physical demands are relatively similar in both situations.
- The pressure felt by the user was higher when using VDTs.
- The user achieved better results using VDTs.
- The effort was higher when HMDs were used.
- The highest level of frustration was reached when the user used VDTs for driving.

Figure 4. Example of hardware configuration for a Head Mounted Display

Metric	Walking (VDT)	Driving (VDT)	Walking (HMD)	Driving (HMD)
Mental demands	2.625	2.000	4.000	4.250
Physical demands	0.500	0.500	0.375	0.375
Temporary requests	3.000	1.875	1.750	1.000
Performance	3.750	3.750	2.875	3.250
Effort	2.375	2.875	2.750	3.250
Frustration	2.750	4.000	3.250	2.875

Table 2. Weight calculation results in NASA-TLX for each device and situation [4].

From the above it appears that HMD users feel a greater mental effort both when walking and when driving. Evil movement and dizziness, respectively, being much more pronounced while the user uses a virtual reality headset, compared to a VDT, as shown by the score in the section effort and mental demands. Comparisons between the above columns show that HMDs are better when it comes to the user experience, especially when the user is walking or doing physical actions that might not be possible in the real environment. VDTs should be used in the future in simulators with 3D monitors and physical controllers (simulators that simulate driving a car, piloting an airplane or any other vehicle that requires it to be maneuvered by a pilot) [4], [14].

SPOTLIGHT HERITAGE VR - STUDY CASE

In this section, we discuss the user experience in HMD (Unity) and in VDT (CoSpaces Edu) using a study case of the Spotlight Heritage VR application.

The applications were developed through the International Spotlight Heritage Student Contest 2021. Here, the winning teams created four virtual tours of two churches from Timișoara, using 3D elements, 360 images, old and new pictures, audio elements and information about the history and the architecture of the buildings. The members of each team were from three different countries: Italy, Denmark, and Romania. Every student had its place in the team, so the Italians were students in the specialisation of "Heritage Education and Digital Technologies", and they came with the storyline for each virtual tour, combining existing information in a virtual story and extending them with their own ideas. The Danish were students in the specialisation "Games (Medialogy)", and they developed the main structure of the virtual story, along with a series of tools to create faster the points of interest where the information was placed. The Romanians were students in the specialisation "Multimedia Technologies", and they created the 3D models for the two churches and the statue in front of one of the buildings, inserted all 360 images and glued everything together [19].

Unity

First version of the application was developed in Unity and can be played on all VR headsets. The users can move freely wherever they desire and interact with all elements presented before in the paper.

The first scene that the user interacts with is the "Main Menu" where the user can choose to visit one of the churches or play a video of each church and two flags to change the language of the application. All the elements that the user can choose from in this scene are simple buttons, even the flags. We tried to keep a simple user interface, so every user would find his or her way easily through the application.

Figure 5. "Main Menu" scene of the VR application

The second scene of each virtual tour is different for both churches. For the Millennium Roman-Catholic Church, the users get in a full 3D world where they can use VR headset controllers to move around the church and listen to the narrator, here represented by the statue of St. John of Nepomuk, located in front of the church.

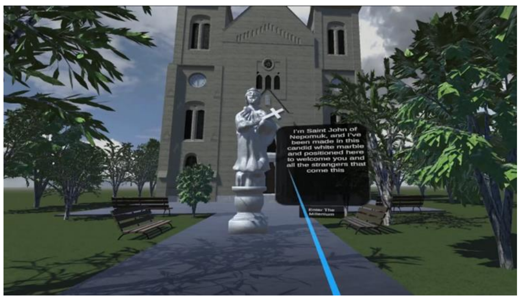

Figure 6. Second scene of the Millennium Roman-Catholic Church virtual tour

For the Roman-Catholic Church of the Sacred Heart of Jesus, the second scene is represented by a 360 image from outside of the church where the user can find a 3D model of the church and interact with it and can hear and read what the narrator is saying, this time represented by the church itself.

Figure 7. Second scene of the Roman-Catholic Church of the Sacred Heart of Jesus virtual tour

The third scene of both virtual tours is technically the same, but with different information. Here the users can go from a 360 image to another. They can move through both churches using the yellow arrows placed on the floor, around the user's feet. The 360 images were placed in Unity in the same location they were made in reality to help the students from Italy and Denmark to understand better how the churches are looking in real life.

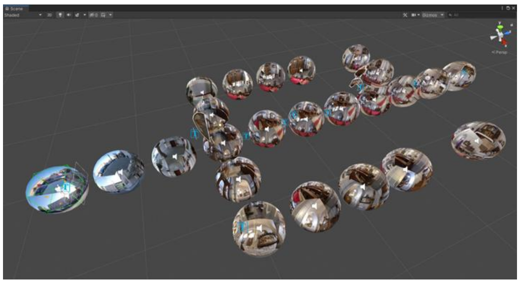

Figure 8. Map of 360 images, composing the virtual tour of the interior of the churches, as seen in development mode in Unity [19]

Cospaces Edu

The second version of the application was created in CoSpaces using the same information, 3D models, 360 images and old and new photos.

With CoSpaces Edu, students may build their own 3D creations, animate them with code, and then explore them in Virtual or Augmented Reality. It can be used with students of any age or subject.

By teaching students 21st Century learning skills like collaboration and coding, CoSpaces Edu helps kids prepare for the future while also enabling them to be creators [20].

They can make virtual museums on any subject, build virtual worlds, write interactive stories, learn to code by creating games that they and others can play [21].

The students created two virtual tours of the churches, but this time without a 3D scene where the user can move freely around the church. The user can move freely only from a 360 image to another using the yellow arrows placed in the same way the arrows were placed in the Unity version of the app.

Figure 9. Scene from the application created using CoSpaces

Comparison

In both versions of the application, we tried to keep the same UI design to study the way the users interact with the same application, but with different devices.

The main difference in these versions is the way the users can interact with the application. On CoSpaces, the users must use a mouse and a keyboard to move through the application and, on the Unity version, the users must use a VR headset with controllers.

We had the opportunity to test both versions of the application at various public events where we disseminated the Spotlight Heritage Timisoara project: exhibition openings, city tours, technology festivals, science fairs, and others. The users ranged from primary school children to seniors, with varying knowledge of how to use a VDT/HMD. All users confirmed that the input using the controllers and a VR headset is more immersive, but all the playthrough was easier on CoSpaces, because they were used with a keyboard and a mouse, more than an HMD.

CONCLUSIONS

Knowing the advantages and disadvantages of different types of virtual reality systems is very important as can be seen from the analysis of the two types of virtual reality systems referred to in this paper. The usability of headsets has increased exponentially in recent years due to the evolution of technology that has unlocked new barriers in this field. The user can have an immersive experience using virtual reality headsets as well as VR simulators, but simulators require a larger area, additional costs and often have a predefined domain, being limited by physical controllers.

On our study case, we observed that the users liked to use the HMD devices more than VDT devices, but it was easier to go through the application using VDT devices because they were already familiar with a mouse and a keyboard.

The HMD devices looked more interesting because the users almost forgot they were in a virtual world. This is the type of immersion a VR headset adds to the user experience, making the difference between an application that runs on a normal desktop/laptop screen and an application developed for a VR headset.

This study shows that of the two VR technologies, HMDs are more advantageous when it comes to mobility, ease of use and portability, but there is still motion sickness, and the way users interact with the virtual environment can be improved. Because of this, studies of the user experience with HMDs are and will be needed. In the future we aim for a more detailed analysis of the user experience using several types of HMDs using a demo application.

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