Fully Immersive Virtual Reality in Logistics Modelling and Simulation Education

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FULLY IMMERSIVE VIRTUAL REALITY IN LOGISTICS MODELLING AND SIMULATION EDUCATION

ABSTRACT

With the increasing development and popularisation of information and communication technology, new challenges are posed to higher education in the modernisation of teaching in order to make education and training of students as effective as possible. It is therefore very important to develop and experiment with appropriate development tools, explore their benefits and effectiveness, and integrate them into existing learning strategies. The emergence of a computer-generated digital environment that can be directly experienced, actions that can determine what is happening in it, growth of technological characteristics, and decline in prices of virtual reality hardware leads to a situation that cannot be ignored. This paper investigated users' perceptions on the potential use of fully immersive virtual reality head-mounted displays in a discrete-event simulation of logistics processes. The dynamic nature of virtual environments requires active participation which causes greater engagement, motivation, and interest aided by interaction and challenges.

KEYWORDS

virtual reality; modelling; simulation; education; logistics; immersive VR.

1. INTRODUCTION

Fully immersive virtual reality (VR) gives the user a realistic feeling or a perception of being physically present inside an artificial, computer-generated digital environment where users can interact with virtual objects. Immersive virtual reality is produced with the aid of VR hardware and software using 3D computer graphics and real-time rendering. There are many of VR products on the market, but due to their popularity and affordability, head-mounted displays (HMDs) have become a mainstream way to easily experience VR content. Three different kinds of immersive VR can be identified: non-immersive, semi-immersive, and fully immersive. Non-immersive VR is based on a standard computer monitor where the user can indirectly manipulate 3D environment using a keyboard, mouse and game controller [1]. Semi-immersive VR is somewhere between non-immersive and fully immersive VR; examples are flight, driving, or maritime simulators with concaved monitors and wall projectors. Cave (Cave Automatic Virtual Environment) is an example of a VR system which is between semi-immersive VR and fully immersive VR. It is a specially constructed room made up of rear projection screens for walls and ceiling, and a down projection screen for the floor [2]. Fully immersive VR is completely filling the user's field of view with a head-mounted display. Although a huge amount of VR content comes from video games and the entertainment industry, VR offers the chance to many areas of education [3] from STEM, medicine, and humanities for various visualisations (big data, difficult structures, prototypes, human anatomy, digital heritage, etc.) [4, 5, 6, 7] to practical training courses especially if a real system is very expensive or poses hazard/health risks or does not even exist (flight, driving, or maritime simulators, firefighting, factory operations, etc.) [8, 9, 10, 11]. With the advancement of technology, students can learn more by using technology-based learning compared to the traditional methodology [12]. Users' perceptions about technology-based learning of logistics processes [13] by using modelling and simulation methodology, more precisely, discrete-event simulation (DES) software enhanced with fully immersive virtual reality, is the main focus of this paper. The paper shows the usage of the VR HMD and what the users felt during its usage. The paper also explored whether immersive VR simulation models can provide added value to the users' learning process and if they can supplement the traditional teaching process to accelerate learning and comprehension of the model's information. 3D/VR visualisation significantly improves users' understanding and behaviour of the DES model during runtime, experimentation, and analysis [14]. For the presentation of models or simulation projects outcomes, 3D/VR offers considerable benefits over the 2D display and helps in the verification and validation process of the model logic and behaviour [15, 16]. VR provides immersion as users can move around the simulation, although in many papers 3D display is usually referred to as VR, but it is not a fully immersive VR.

The rest of the paper is organised as follows: Section 2 reviews the development of immersive virtual reality head-mounted displays. Section 3 explains the research methodology and immersive VR models. Section 4 shows the results of the study and discusses the findings. Section 5 concludes the paper.

2. IMMERSIVE VIRTUAL REALITY HEAD-MOUNTED DISPLAYS

Immersive virtual reality head-mounted display was first introduced in 1968 by Ivan Sutherland's Ultimate Display [17] which is nowadays widely considered to be the first VR head-mounted display. Small display devices (half-inch monochrome CRTs) showed virtual wireframe shapes that changed perspective when the users moved their heads to compensate for the motion so that the virtual objects appear to be stationary. Ultimate Display was also known as the Sword of Damocles, which was so heavy that it had to be suspended from the ceiling and the user had to be strapped in [18]. In 1984, NASA used Leep optics (Large Expanse, Extra Perspective) [19] to create project VIVED and to demonstrate that cheap immersive systems were possible. A few years later, project VIEW was derived from the VIVED project and was used to study operator interaction [20]. In the late 1980s, commercial VR headsets started to appear. The company VPL Research developed a wide range of both virtual reality software and hardware including the Dataglove and the EyePhone HMD. They were the first company to sell and thereby popularise VR goggles and gloves [21]. In the 1990s, the Virtuality Group launched a range of arcade games with VR goggles and gaming machines to which the public had access [22]. In 1995, Nintendo introduced the Virtual Boy (VR-32) console capable of displaying stereoscopic 3D graphics. Since there was no colour in the graphics, no software support and there were some ergonomic issues, Nintendo discontinued its production and sale the following year [23]. Due to the low quality of VR experiences and the high cost of entry, VR systems of that time did not attract mass interest. In later years there were no serious attempts to launch VR devices to the mass market until the Oculus startup created the prototype of the Oculus Rift HMD in 2012 and launched the Kickstarter campaign which raised almost $2.5 million [24]. Facebook bought the Oculus VR Inc. in 2014 for a total of approximately $2 billion [25]. This new VR momentum once again increased the interest in VR technology and by 2016 lots of companies were developing their own VR headsets, applications, and content. The same year Facebook released the first hardware product Oculus Rift (also known as CV1) and by the end of the year Rift had a hand presence with Oculus Touch. Oculus showed off a new standalone HMD Oculus Quest and a new Rift S in 2019. A year later, the new Oculus Quest 2 was launched with improved performance, resolution, and lower price. In 2014, Sony announced the Project Morpheus, a VR headset for its PS4 console and two years later they launched the PlayStation VR (PSVR) [26]. In 2015, HTC officially presented its VR HMD, Vive, and pre-orders started in 2016 [27]. In 2018, HTC released an upgraded Vive model HTC Vive Pro. A year later they presented an upgraded variant of the HTC Vive Pro model, HTC Vive Pro Eye, and in the same year they released a new, more mass market-oriented headset HTC Vive Cosmos. In 2021, HTC released an upgraded Vive Pro model HTC Vive Pro 2. Microsoft released the Windows 10 Mixed Reality upgrade in 2017, and in the same year several computer hardware manufacturers (Samsung, Acer, HP, etc.) announced their Mixed Reality headsets. Valve Index released its first headset in 2019. The headset has its own Valve Index Controllers, but is backward compatible with the HTC Vive/Pro controllers and also HTC Vive/Pro base stations [28]. Pimax Technology released its first product in 2016, the Pimax 4K, which was

Figure 1 – Development of immersive virtual reality head-mounted displays

the first commercially available 4K headset. In 2017, they ran a Kickstarter campaign for the Pimax 8K headset, raising $4.2 million, and in 2019 the headset became commercially available [29].

The current generation of VR head-mounted displays has vastly improved the quality of VR exposure due to the lightweight, high resolution LED/OLED display screens, a wide field of view (FOV), and even tracking sensors of translational/rotational motions (DoF) built into the headset to track the user's movements while significantly lowering the barrier of entry for mainstream VR adoption. This also caused a high interest in VR hardware and software applications. *Figure 1* shows the development of immersive virtual reality head-mounted displays over time.

3. METHODOLOGY

An experiment with 38 students was performed as a part of the modelling and simulation course from the second year graduate study programme Logistic and Management in Maritime Industry and Transport at the Faculty of Maritime Studies, University of Rijeka. The experiment took place in a computer laboratory, where it is possible to observe the interaction between students and a VR HMD. All students had previous experience with building simulation models as well as running and analysing simulations. An experiment was conducted in two phases; in the first phase, students were asked to explore the VR simulation model, and in the second phase, students were asked to explore the VR simulation model and interact with virtual objects. Student feedback was collected and assessed in a structured and systematic way by using a questionnaire [30]. The questionnaire consisted of a total of 12 questions. Limesurvey [31], an open source survey software, was used to build the questionnaire and to collect the data. Limesurvey was installed on the faculty web server with LAMP environment. Once the students had explored VR simulation models, they completed a questionnaire related to the overall experiment.

Students used 6 HMDs (Oculus Rift and HTC Vive), headphones, and hand controllers (Oculus Touch and HTC Vive). They also used 6 computers with Intel i7 processors, 32 GB RAM, 500 GB SSD, 6 TB SATA disks and NVIDIA RTX 2080 Ti GPGPU cards. FlexSim [32] simulation software was used to run VR simulation models.

3.1 Immersive VR models

Immersive VR models are based on production logistics models (storage, materials handling, automatic sorting, packaging, warehousing, etc.). They are divided into a virtual walk and interactive models. The models consist of several fixed and mobile FlexSim objects (processors, multiprocessors, conveyors, cranes, forklifts, operators, robots, etc.).

In FlexSim, VR mode is achieved by opening the Properties dialog box and selecting the VR Mode. FlexSim works with HTC Vive VR and Oculus Rift. VR Mode also handles inputs from motion controllers (HTC Vive or Oculus Touch controllers) through which walking and object interaction in a model is realised (teleportation).

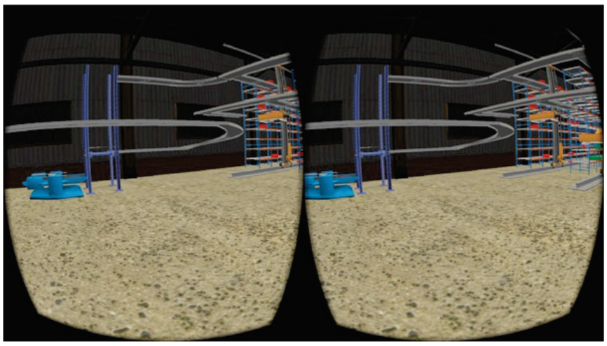

Figure 2 – Virtual walk model

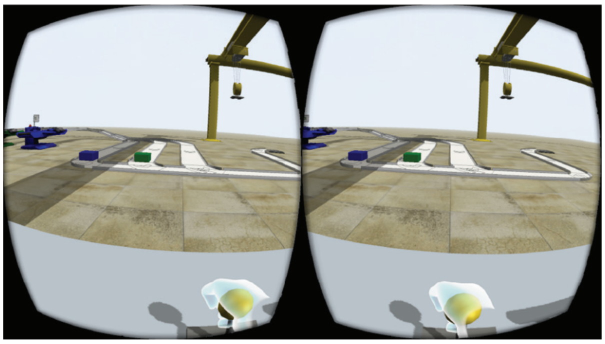

Figure 3 – Interactive model - Crane

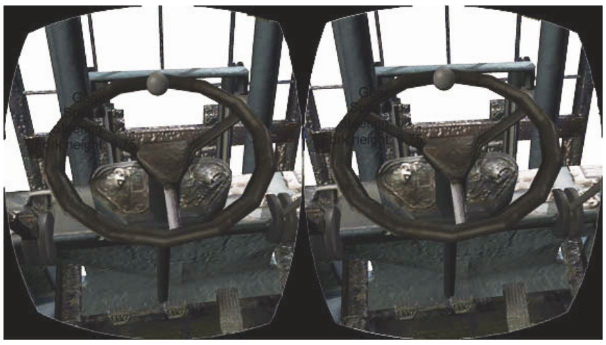

Figure 4 – Interactive model - Forklift

In a virtual walk model, *Figure 2*, the user is in a 3D model (warehouse) space through which they can move 360 degrees using controllers, but there is no interaction with 3D objects.

In the interactive model, *Figures 3 and 4*, the user is in the 3D space of the model through which they can move 360 degrees using controllers and there is interaction with 3D objects. Users can operate a crane and conveyor lanes or they can drive a forklift in an actively running simulation.

4. RESULTS AND DISCUSSION

After the simulation, students completed and submitted the questionnaires online. The questionnaire was filled by 38 students in total.

The first question from the questionnaire was regarding the usage of the VR HMD, *Figure 5*. It is interesting that 24 of the students have never tried VR HMD before this experiment. 12 of the students have tried VR HMD before this research and they stated that they tried VR HMD at video game industry events and conferences or that they have their own VR HMD.

Eight of the students have a VR HMD at home and 25 of the students do not, *Figure 6*.

Students who answered that they have a VR HMD at home got an additional question to answer which kind of VR HMD they have, *Figure 7*. Three students have a high-end VR HMD (Oculus Rift, HTC Vive, HTC Cosmos, and Oculus Quest), two students have a mobile VR (Samsung Gear VR), and three students have a gaming console VR (PlayStation VR).

From the list of offered terms (feelings), there was a significant presence of excitement (19), interest (7), and curiosity (5) in the responses, *Figure 8*.

There were 15 comments about the first time fully immersive VR feeling (words and phrases used were ‘literally life changing’, ‘thoroughly enjoyed it’, ‘blown away’, ‘just wow’, ‘impressive’).

Twelve students reported that VR HMD can provide added value to their learning process, *Figure 9*. Thirteen students responded 'No' and 10 students do not know if VR HMD can provide added value to their learning process. Among the students that have never tried VR HMD before this experiment,

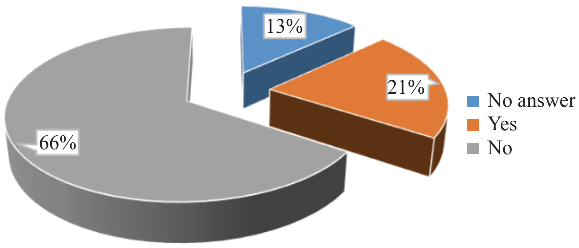

Figure 5 – Responses to the question: Have you ever tried a VR HMD before this experiment?

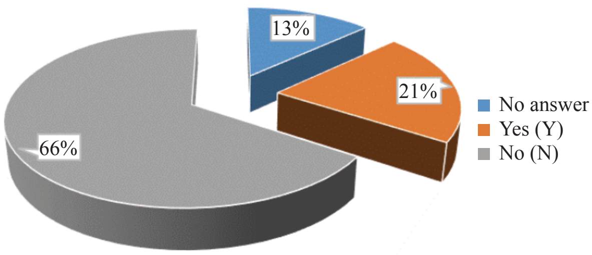

Figure 6 – Responses to the question: Do you have a VR HMD at home?

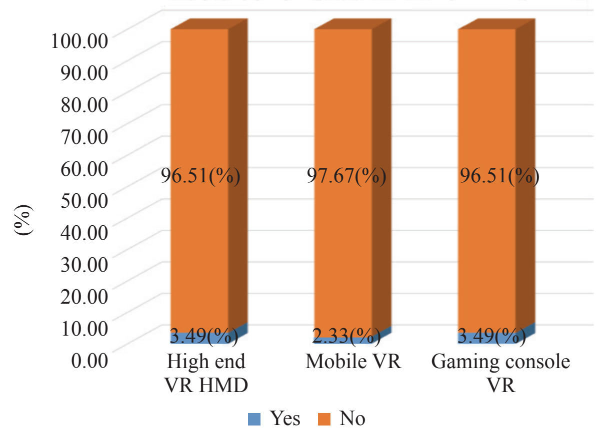

Figure 7 – Responses to the question: Which kind of VR HMD do you have?

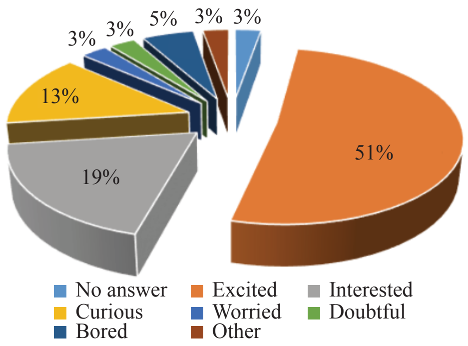

Figure 8 – Responses to the question: How did you feel using the VR HMD?

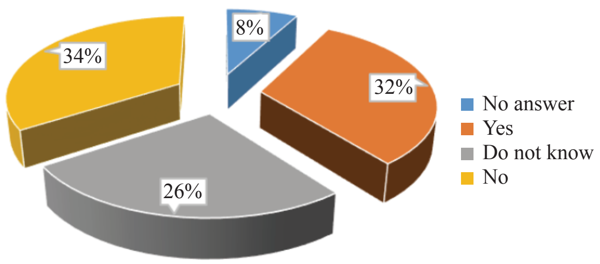

Figure 9 – Responses to the question: Do you think learning using VR HMD can provide added value to your learning process?

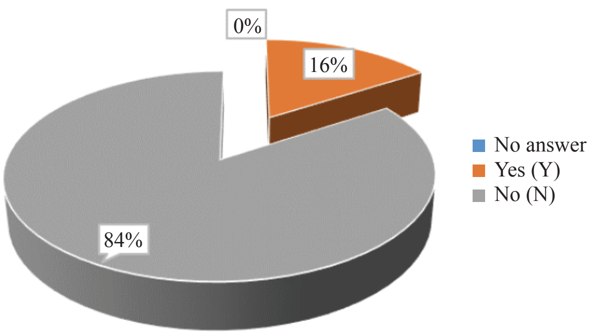

Figure 10 – Responses to the question: Did you have problems using the VR HMD?

8 responded that VR HMD can provide added value to their learning process, 9 students responded 'No' and 7 students do not know if VR HMD can provide added value to their learning process. There was one comment that VR is making the model easier to understand because it is like walking in a real warehouse.

Nearly all students (32) said that they did not have any problems using the VR HMD, only six students responded that they did have problems using the VR HMD, *Figure 10*. They specified that they had problems with hand controllers and teleportation, interacting with objects, eye fatigue, and finding a comfortable fit for a headset. No one has experienced VR motion sickness (sensations like nausea, dizziness, headaches, sweating, etc.)

In our questionnaire we used the same question as Akpan et al. [33], but without the first activity (model building) because in the FlexSim simulation software there is no option to directly build a model from the VR mode option. In FlexSim, model development is done directly in a 3D workspace from scratch. The questionnaire asked the students to compare fully immersive VR and 3D performance in the five DES modelling activities (model validation and testing, model run and experimentation, and demonstrating the model), *Figure 11*. Twenty-five students considered that VR is better for model validation and testing, 5 selected 'no difference', and 7 responded that 3D is better. For model run and experimentation, 20 students selected VR as better, 12 preferred 3D, and 5 students responded a 'no difference'. Most students (30) responded that fully immersive VR is more superior to 3D for demonstration and presentation purposes, 5 students selected 'no difference', and one selected '3D better'.

There were 16 comments about seeing the model behaviour better (easy to identify and correct errors, logical check of the model, and model fine–tuning). One of the comments considered that 3D presentation is better because of the 'birds-eye' view of the model (FlexSim has orthographic and perspective 3D view modes), but in VR mode there is also a possibility to rise above the model or fly over it.

Almost all students responded that they would use a VR HMD again, *Figure 12*. They said that they will use it again to learn new facts about simulation models.

After testing the VR HMD, students reported their positive attitude towards the idea. They liked it because the simulation content was familiar to them

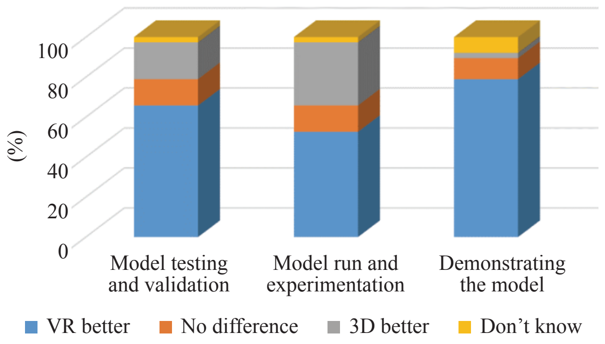

Figure 11 – Responses to the question: Please compare VR and 3D performance in the following activities

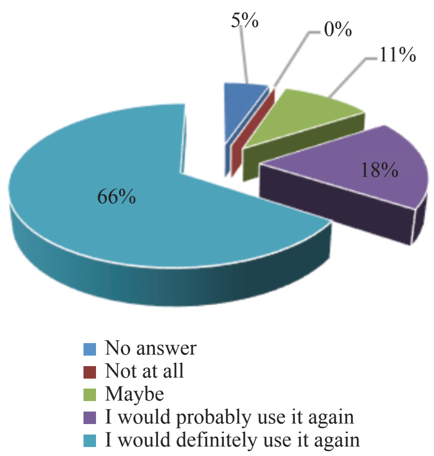

Figure 12 – Responses to the question: Would you use a VR HMD again?

since they had experience with the previous simulation models and they tried to explore and interact with many virtual objects as they could. Students were excited, interested, and curious when they used the VR HMD and almost all of them agreed that they would try the VR HMD again to learn new facts about simulation models. They also thought it would be an excellent added value for the learning process as well as an e-learning tool.

5. CONCLUSION

The paper results show that a majority of the students have never tried a fully immersive VR before this experiment. Students used head-mounted displays with a head motion–tracking sensors, headphones, and hand controllers to interact with immersive VR simulation models. They felt excited, interested, and curious using the VR HMD, especially the first time fully immersive VR users. They responded that VR HMD can provide added value to their learning process because it was easy to visualise what they were modelling and experience it as they learn. At the end of questionnaire, almost all students responded that they would use a VR HMD again. Immersive VR simulation models are an alternative or supplement to the traditional teaching process to accelerate learning and comprehension of the model's information. In real production systems, immersive VR simulation allows them to avoid costly design mistakes that can be detected in simulation. A fully immersive VR has a great potential for logistics modelling and simulation education in the design and content of the learning experiences. Future work will involve implementing complex interactive models, learning analytics, and assessment.

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POTPUNO IMERZIVNA VIRTUALNA STVARNOST U OBRAZOVANJU MODELIRANJA I SIMULACIJA U LOGISTICI

SAŽETAK

Sve većim razvojem i popularizacijom informacijsko komunikacijske tehnologije pred visoko obrazovanje postavljeni su novi izazovi u modernizaciji nastave kako bi obrazovanje i usavršavanje studenata bilo što učinkovitije. Stoga je vrlo važno razviti i eksperimentirati s odgovarajućim razvojnim alatima, istražiti njihove prednosti i učinkovitost te ih integrirati u postojeće strategije učenja. Pojavom računalno generiranog digitalnog okruženja koje se može izravno doživjeti i radnjama odrediti što se događa u njemu te rasta tehnoloških karakteristika i istovremenog pada cijena konzola za virtualnu stvarnost dovodi do situacije da ih nije moguće zanemariti. U radu su istražene percepcije korisnika o mogućoj upotrebi potpuno imerzivne virtualne stvarnosti u simulaciji diskretnih događaja logističkih procesa. Dinamična priroda virtualnih okruženja zahtjeva aktivno sudjelovanje što uzrokuje veći angažman, motivaciju i interes potpomognute interakcijom i izazovima.

KLJUČNE RIJEČI

virtualna stvarnost; modeliranje; simulacije; obrazovanje; logistika; imerzivna VR.

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