Virtual and Augmented Reality game-based applications to Civil Engineering Education

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***Abstract*—*Gaming scenarios and virtual environments have shown beneficial results in Engineering Education. Various activities conducted in different fields demonstrate that students reveal appraisal for the integration of innovative technologies such as Virtual or Augmented Reality in the learning process. In this paper, Virtual Reality (VR) applications developed by first year students during an introductory class of the Integrated Masters in Civil Engineering are described. Additionally, two trials concerning the application of VR and Augmented Reality (AR) to Civil Engineering held at a local school (K-12 students) are also detailed. After the tests, students were surveyed and data was collected. Results and considerations are revealed in the final sections of this paper.*

Keywords— Virtual Reality; Augmented Reality; Serious Games; Engineering Education; Civil Engineering

I. INTRODUCTION

In the last few years the number of applicants to Civil Engineering courses in Portuguese Higher Education Institutions (HEIs) has decreased sharply. Some institutions face the challenging endeavour of motivating and engaging pre-university students in pursuing professional careers in Civil Engineering. Moreover, the recent financial and economic crisis and its impact on the Architecture, Engineering, Construction and Operations (AECO) sector, may have contributed to the paucity of candidates.

The introduction of new methodologies and practices in Engineering Education, especially designed to motivate young students, could improve and engage students in to the learning process.

Virtual Reality (VR) and Augmented Reality (AR) interfaces have long since been experienced in learning contexts in Engineering Education. These interfaces are usually presented in association with game scenarios. Some examples of such applications are described in section II of this paper.

The third section of this work relates to virtual environments developed by first year students of the Master in Civil Engineering during a 6-week introductory class project.

Section IV describes VR and AR interfaces applied to Civil Engineering presented at a local school during a career fair. All participants in the activities taking place at the school were surveyed about the potential of these interfaces to improve learning experiences.

Data analyses and considerations are made in section V.

Lastly and given the accumulated experience obtained in several outreach activities taking place at the university campus, the ELBigMAC project was found. This initiative intends to disseminate Civil Engineering amongst K-12 students relying on different methodologies and activities, including virtual and augmented reality.

II. GAMING, VR AND AR TECHNOLOGIES APPLIED TO CIVIL ENGINEERING EDUCATION

Gaming applications as well as Virtual and Augmented reality have been tested by several authors, and the usage of such technology applied to Engineering Education have shown relevant results.

Deshpande and Huang [1] suggest that simulation games are rarely developed in terms of educational software, and that most engineering courses are still centred in teaching through lecture-based format. The authors discuss the changes in teacher and student roles made possible by the methodology using simulation games: Teachers may become “promoters” of knowledge, and students have a more active and collaborative role.

Häfner, Häfner and Ovtcharova [2] designed a VR practical course for university, developed to bring together interdisciplinary teams and teach students to use VR hardware, software and applications. In their work, it was verified that students were highly motivated by the given tasks and worked even during their spare time. The tasks were designed concerning engineering topics and related to the expertise and interests of the participants.

Messner, Yerrapathruni, Baratta and Whisker [3] implemented VR interfaces in an undergraduate Architectural Engineering programme. The authors used a CAVE-like projection system where students were able to develop a plan of the construction of a nuclear power plant within an hour, and with little experience in construction phases of this type of building. The authors suggest that immersive VR displays can be beneficial to improve the education of students. Additionally, this technology will allow them to understand planning issues many times restricted by their present knowledge and visualization capacities concerning buildings and infrastructures.

Building Information Modelling (BIM), besides a modelling technology, is also an association of procedures to analyse buildings, develop and communicate information [4].

Various aspects of BIM technology have been integrated and explored to enhance teaching and learning processes.

Yan, Culp and Graft developed a prototype that integrates BIM, providing geometric and nongeometric information, and gaming to improve architectural visualization. The prototype allows the user to navigate through a virtual model (first or third person view) and evaluates the accessibility aspects of a virtual wheel chair. Architects, engineers and educators can use BIM models and integrate them with the authors' BIM-Game software. [5].

Chen et al. designed an AR based system to enhance spatial awareness and comprehension problems for Engineering Graphics Education. The interface developed can superimpose virtual objects using the camera of a smartphone and 2D markers. The objects are visible from a computer screen and the users can interact with them (split, rotate, zoom and move the 3D virtual object) [6].

III. Virtual Environments and Games Applied to Civil Engineering – First Year University Students' Project

A. Development of 3D virtual environments using a game engine

Associating games with learning experiences has been subject of some initiatives taking place at the university. In the first semester in the Integrated Master's in Civil Engineering, students must participate in an introductory class and collaborate in a group project. This project intends to engage students in activities related to Civil Engineering, while simultaneously encouraging research in their individual domains of interest. During 6 weeks and having only 2 hours of direct contact with teachers per week, students need to develop a project to be presented in a final conference. Organized in groups of 4 or 5, students must collaborate with colleagues, interact and be proactive, develop teamwork as well as soft skills to be able to present their solution and meet the deadlines. Throughout the current academic year (2016/2017), a classroom developed their project's theme about the application of VR environments to Civil Engineering.

To achieve this task, a dedicated lecture took place, where within 2 hours 22 students had their first contact with a game engine. This software allows users to create virtual environments and it also accepts data inputs from diverse building design programs. The objective was to motivate students to ponder and create 3D virtual scenarios that could be explored and applied to Civil Engineering situations.

Without having to learn a specific programming language, and using the assets and features included in one of the most popular game engines, Unity 3D, students were able to present their projects and meet the deadlines.

1) VR applications presented by the students

There were different solutions presented at the final conference demonstrating how virtual environments can be applied to Civil Engineering contexts. Nevertheless, all groups submitted a presentable virtual model with a reasonable application.

a) . Health and Safety measures – Improving the communication between the different participants in the construction process

In this project, a solution using a 3D model of the Civil Engineering Department (represented as a building site) was imported to Unity 3D from a BIM software. The VR model is intended to enhance the visualization of the building, thus warning the observers for possible dangerous situations and inadequate behaviours. The user can navigate through the VR model and explore the construction site from a first-person view (*Fig 1*).

Fig. 1. Temporary equipment placed in the virtual worksite.

Another group presented a similar proposal although, besides the navigation through the VR model, the user was also warned with visual information (*Fig. 2*). These signs alerted the user to dangerous behaviours and recommended the use of safety equipment.

Fig. 2. Risk of falling alert presented in the virtual environment when approaching a hazard area.

b) Improving the visualization of building projects

VR was also explored as a visualization tool that can be used to communicate design intentions to participants and major players during the construction process. The solution illustrated in *Fig. 3* represents a VR interface developed from CAD drawings of a single-family house. Students designed a model of the building which was then exported to the game engine. Within Unity 3D, textures and physical properties were added and collisions were activated in order to achieve a more realistic aspect to the virtual environment. The VR interface allows the user to freely navigate in the building without the need of a professional BIM software.

Fig. 3. Perspective of a single-family house inside the virtual environment.

c) Enhanced navigation and user orientation

As newcomers to the university, a group of students suggested that VR could be used to help finding points of interest in the campus. A solution concerning user orientation through a virtual model was presented. Throughout the project, students designed a series of visual pointers (floating arrows) to guide the user along two different routes through the building. *Fig. 4* shows the arrows pointing the way to an entrance.

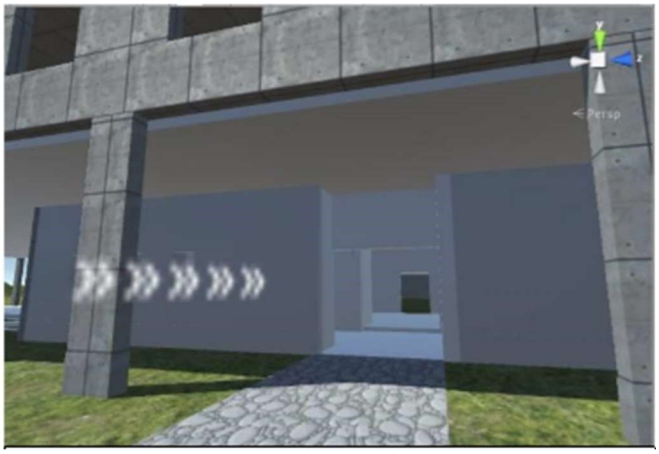

Fig. 4. Floating arrows indicating one of the routes to be explored in the virtual environment.

IV. APPLYING SERIOUS GAMES IN THE CLASSROOM – K-12 STUDENTS

A. VR hands-on test – Visit to a local school

A VR presentation and trial took place at a local school during a career fair. Pre-university students had the opportunity to learn how virtual games can be applied to Civil Engineering topics.

18 students attended the workshop where they had the opportunity to use a Head Mounted Display (HMD) and a regular gamepad to explore a virtual model of an unidentified school (*Fig. 5*).

After a brief introduction, students demonstrated that they did not fully understand the scope of activity of a Civil Engineer. Indeed, the majority of K-12 students taking part in the test associated Civil Engineering with heavy machinery work and structural calculations. The VR experience was also intended to motivate and engage students, changing their initial opinion concerning the lack of technological and innovative solutions related to Civil Engineering work.

Fig. 5. Presentation of the Virtual platform at local school.

Using a regular gamepad and the HMD Oculus Rift Development Kit 2, participants were able to explore the virtual building. Additionally, the user could press a button on the gamepad and all the elements fitting in to a discipline of Civil Engineering had their colour changed. Hence, students could understand, in general, the composition of a building in different disciplines: structural, construction and hydraulics projects. Thus, by consecutively pressing this button, structural elements changed their colour to green, construction objects were designated with red and hydraulics elements had their original colour altered to blue (*Fig. 6*).

Fig. 6. Visualization of the different Civil Engineering disciplines integrating the virtual model.

B. AR hands-on test – Visit to a local school

An AR application of the same building was also presented to participants. In this trial, students had the same objective of identifying the different design disciplines involved in the conception of a building (see also section IV.A of the present paper). However, the AR application allowed participants to use mobile devices' cameras to recognize a precise image. This image was previously saved in a database and through the

application, students could visualize and interact with an augmented model of the school (*Fig. 7*).

Fig. 7. Students testing the AR application during the workshop.

The application was programmed so that users could press different virtual buttons. Each button highlighted a different discipline of the building's project (*Fig. 8*).

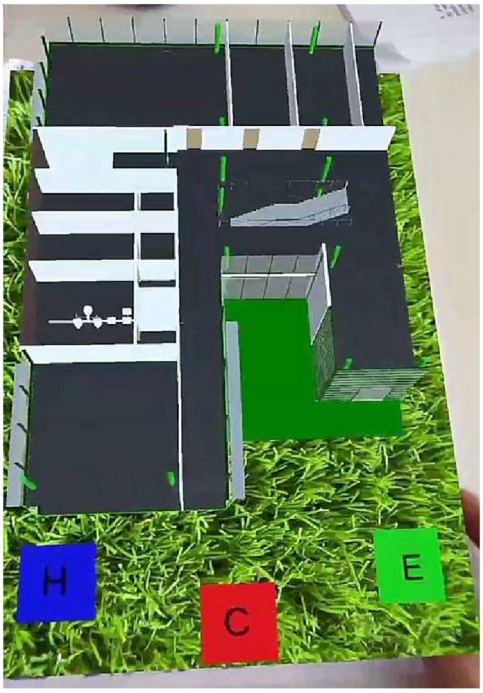

Fig. 8. Virtual buttons and AR 3D model of the school.

After the workshops (VR and AR tests) all participants were surveyed. The objective of the questionnaires was to identify if VR and AR were effective tools to improve the comprehension of the concepts being presented. In other words, to assess if these particular technologies could be used to transfer knowledge between participants.

Through a four point Likert scale, students could rank each interface (VR and AR) regarding its significance to improve the comprehension of the concepts being presented.

V. VR AND AR TESTS – DATA ANALYSIS

The data collected during the tests conducted at a local school (K-12 students), demonstrates that most students assessed the interfaces (VR and AR) mainly with the two upper ranks of the given Likert Scale (*Fig. 9* and *Fig. 10*). Indeed, both interfaces displayed good acceptance from participants as they classified them as significantly, or even essential to understand the subject of the test.

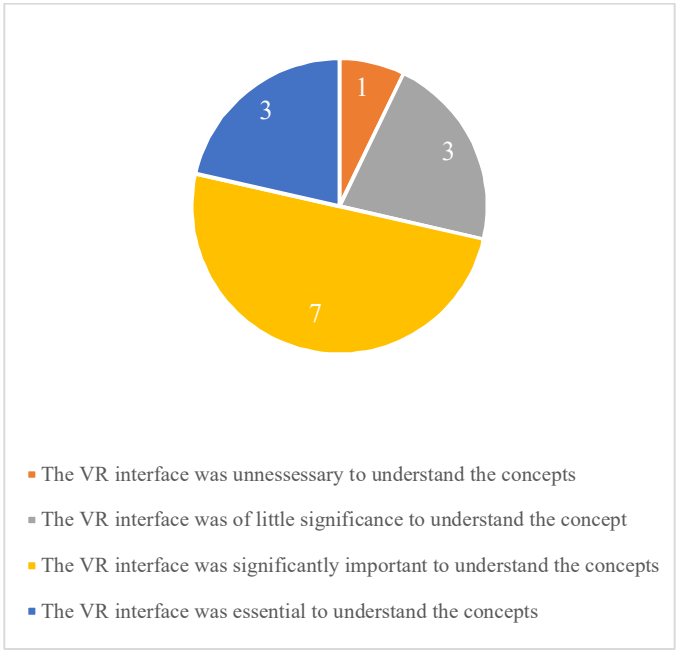

Fig. 9. VR interface improvement in the learning process.

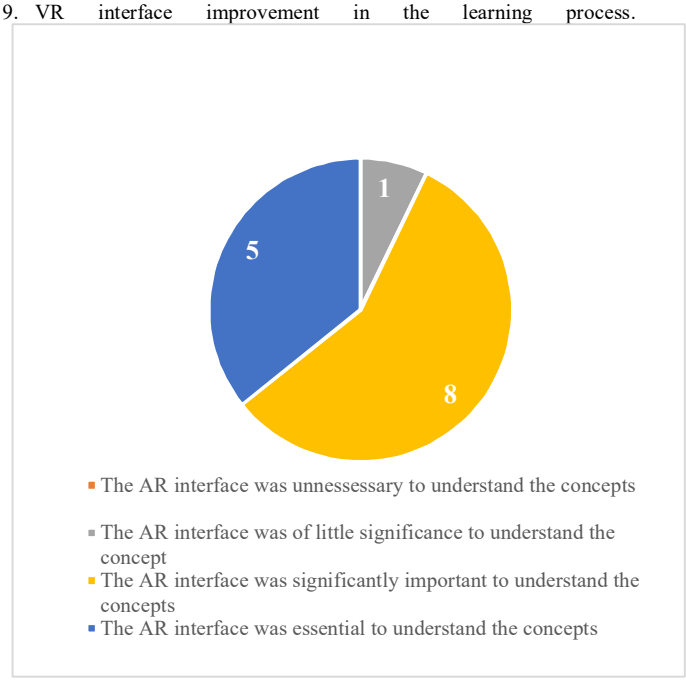

Fig. 10. AR interface improvement in the learning process.

The motivational aspect associated with these interfaces confirmed to be a relevant asset for education. Most of the

students classified the interfaces as very important regarding their motivational relevance for the learning process (*Fig. 11*).

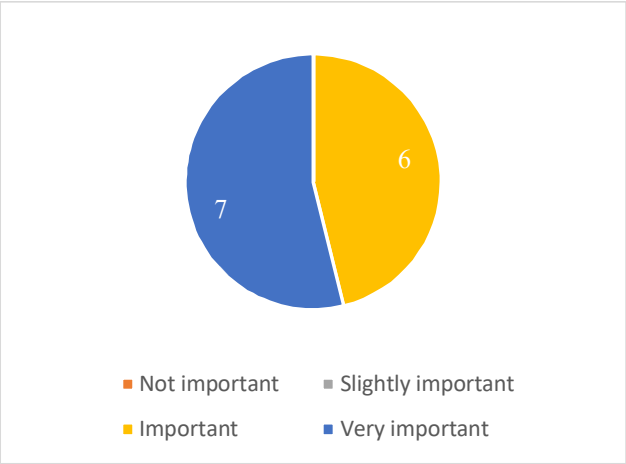

Fig. 11. Motivational factor of the interfaces.

VI. ELBIGMAC

Several outreach events take place regularly to show to pre-university students the role and scope of Civil Engineering professional activities. Every year, competitions and events are held at the university campus where students (pre-university and university students) are invited to participate. These events include: building spaghetti bridges (co-organized by the International Association of Civil Engineering Students (IACES)) (*Fig. 11*); Junior University, a series of visits to the Civil Engineering Department's laboratories, Professions Week: Engineer. and; "Põe as Mãos na Massa" (which can be roughly translated as "hands-on"), an initiative where pre-university students learn how to build paper bridges (*Fig. 12).*

Fig. 12. Building spaghetti bridges competition [7].

Fig. 13. "Põe as Mãos na Massa" initiative [8].

Given the experience acquired in the workshops, initiatives and outreach activities mentioned before, it was considered that the authors had the required know-how to present an application for an international programme.

The Educational Laboratory - Big Machine (ELBigMAC) consists in a partnership project, co-funded by the Erasmus+ programme.

ELBigMAC aims to develop an "educational laboratory" that will be built in partnership with three European universities and will promote several ludic and pedagogical activities. This project intends not only to explain the role of a Civil Engineer to K-12 students, but also its relevance for society, where is Civil Engineering present as well as to promote interaction and collaborative experiences between students and institutions.

It is expected that pre-university students from different schools engage in the project's activities and learn that a house is, in fact, a big machine. Simultaneously, participants will have the opportunity to learn about Civil Engineering, sharing teamwork experiences and interact with other pre-university students from the partner's countries during the planned activities.

The educational laboratory – Big Machine House, should be able to be deployed and adapted to match different climate conditions and needs. Construction techniques and building solutions shouldn't be replicated regardless of the surroundings and climate context. Revision and reuse of local construction techniques and resources will take part in the building solutions applied to the Big Machine House.

International students will have the chance to participate in competitions with local students in a collaborative, interactive and project-based programme. It is envisioned that these interactions will promote new ludic and pedagogical methodologies and practices.

To show students how to build different solutions on site as well as presenting innovative tools as VR and AR applied to Civil Engineering contexts are contemplated in the various project's objectives.

VII. Conclusions

In this paper, numerous interfaces regarding the usage of game environments in Engineering Education are described. as well as the outcomes in the learning process. It can be considered, as a preliminary study, that the integration of VR and AR game-based interfaces eased the transferability of knowledge between the participants in the learning activities. Furthermore, VR and AR integrated within games can help disseminate Civil Engineering as well as motivate students during the learning process.

During the ELBigMAC project, new and more complex gaming solutions will be developed and integrated in a variety of events. All participants will be surveyed and more data will be analysed concerning the implementation of innovative technologies such as VR and AR in game-based learning.

Acknowledgments

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