

Combining Serious Games and 4D Modelling for Construction Health and Safety Training

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ABSTRACT

Health and safety (H&S) is a major concern in the construction industry. Recent and historical data from the construction industry worldwide demonstrate that the human, social, and economic burden, inflicted as a result of H&S fatalities, is still significant. Training is considered one of the main strategies to reduce H&S risks. In recent years, the use of serious games for H&S training in construction has emerged in an attempt to overcome issues associated with traditional training methods.

Current research in serious games has mainly focussed on scenario-led training where trainees interact with the same environment through a pre-selected number of options in discrete sections. This approach has limitations in terms of variety and amount of skills that trainees perceive from the game. In this paper, an approach that combines serious games design with 4D (3D + time) modelling is presented and tested in terms of its influence on increasing the capability of labourers to spot hazards at different time periods during the construction process, providing them with increased immersion in the virtual training environment. The results demonstrated that a combination of serious games and 4D approaches can improve users' engagement and affect their abilities to spot H&S hazards.

INTRODUCTION

The construction industry is inflicted by a high rate of fatalities. A large number of construction accidents are caused by human factors associated with employees' actions, behavioural traits and competency (Addison et al. 2013). In recent years, research in the use of serious games for H&S training in construction has attracted significant attention. Research efforts to date have been limited to discrete training environments where trainees interact with a pre-designed set of scenarios. Experts have criticised current approaches in the field of serious games for their distinct lack of examination of gameplay elements (Portnow, Floyd and Theus 2010). In this research, an effort to provide a 'sandbox' style game environment is attempted through the merging of serious games and 4D approaches. A virtual replica of a real construction site based on industry case study data (design and process data) is produced. It is hypothesised that combining serious games and 4D approaches in the development of the virtual training environment would increase the range of potential knowledge the game imparts, as trainees would interact in a similar fashion as they would on site. In subsequent sections, the objectives of this research, the review of previous studies, the proposed environment, its testing and results are presented.

APPLICATIONS OF SERIOUS GAMES FOR H&S IN CONSTRUCTION

The construction industry is still facing challenges in implementing and complying with health and safety approaches and procedures. Extensive research analysing ways for improving health and safety in construction (Addison et al. 2013; Goldenhar, Williams and Swanson 2003; Kamardeen 2013; Zhou, Whyte and Sacks 2012), has been undertaken.

Construction projects require the consideration of H&S issues from the early stages of project development and throughout the project lifecycle (Zhou, Whyte and Sacks 2012; Kamardeen 2013). Indeed, designers' decisions have a significant influence on H&S issues that can occur in later stages, such as the construction stage where designers are typically no longer involved. The construction industry needs to be able to incorporate H&S at the design phase and experiment with different scenarios before moving to the construction site (Wong et. al. 2010). However, although H&S risks can be minimised or eliminated at the earliest design and planning stages, the risks left at the work interface within construction remain very high. In this context, recent advancements in gaming technology have fostered new avenues and possibilities to improve H&S in construction.

There are a number of drivers that are influencing this phenomenon. First and foremost, serious games have the ability to simulate innumerable conditions, while avoiding potentially hazardous and expensive field training. Second, serious games provide numerous advantages, such as modelling physics (i.e. gravity, collision) that increase the realism of the virtual training environment. Finally, the application of serious games in construction constitutes a natural progression of earlier applications developed for the communication of construction activities (Dawood et al. 2006, Kam et al 2003; Jongeling et al. 2008, Kang et al. 2007, Chavada et al. 2012), that have now made their way into the industry. Research in this field has shown that the use of serious games is adequate for hands-on training purposes, which are most appropriate for construction workers (Addison et al. 2013; Dickinson et al. 2011; Lin, Son and Rojas 2011).

Serious games or serious gaming refers to the use of computer games technology to generate tools to solve real world problems. Serious games also offer the possibility of simulating issues that are not possible with field-based training, such as high risk activities (Lin, Son and Rojas 2011), providing workers with knowledge of what occurs on-site beforehand. Serious games can provide virtual computer-based tools to create interactive simulations that can impart knowledge and skills to the user. This includes the consideration of the outcome of workers' actions, which can contribute to diminishing human-error based accidents in construction sites. Studies have been focused on the use of serious games for hazard identification purposes (Chen, Golparvar-Fard and Kleiner 2013; Chi, Kang and Wang 2013). Hazard identification is the focus of numerous H&S training programs and has been previously considered at the operation level using entity-based 4D CAD technology in the Construction Hazard Assessment with Spatial and Temporal Exposure (CHASTE) tool (Sacks, Rosenfeld and Rozenfeld; 2009). The visual capabilities of serious games, together with 4D modelling, can contribute to raise the awareness of H&S issues to safety experts and designers, along with more effective training of workers (Chi, Kang and Wang; 2013). A review of recent developments in the use of

serious games and related technologies for H&S in construction is summarized in Table 1.

Table 1. Review of recent developments (2010 – 2013) serious games and related technology for H&S training in construction industry

Tool/project name	Approach	Technology	Scenario vs. sandbox	Source
SAVES	Safety training environment for construction hazard recognition and severity identification - based on training scenarios	mixed AR/VR	scenario-led	Chen et al. 2013
Game-based trench safety education	Development of a trench safety game based on Construction Safety of Ontario training document	gaming engine - Microsoft XNA Studio	scenario-led	Dickinson et al. 2011
Construction industry offsite production	Development of a VR solution prototype for training of AEC professionals based on OSP (offsite production) practices	VR training environment	scenario-led	Goulding et al. 2012
4D Interactive Safety Assessment	Proposal of a visual safety assessment system for hazard identification	Game engine - Unity 3D	scenario-led	Li et al. 2012
Safety Inspector	A pilot study of a 3d game environment for construction safety education	Game engine - Torque 3D	scenario-led	Lin et al. 2011
The Situation Engine	Proposal of a hyper-immersive platform based on the cry engine game engine, support of bodily immersion through hardware controllers and HMDs (Oculus Rift)	multi-user gaming environment - cryengine	sandbox	Newton et al. 2013

Table 1 shows that with the exception of “The Situation Engine” (Newton et al. 2013), current research has mainly focused on providing scenario-led virtual solutions. Sandbox learning environments, on the other hand, are interactive virtual areas where users can engage in activities that are part of the core learning experience and in side-activities that have no direct connection to the core learning experience and serve to enhance the verisimilitude of the virtual environment from the user’s perspective. Current efforts are still rooted in scenario based design (Lin, Wook, Son and Rojas 2011). Sandbox environments have yet to be rigorously applied in a serious gaming setting for the purpose of hazard identification and could be exploited for H&S hazard training in the

construction industry. This research aims to investigate this hypothesis by developing a sandbox environment that emulates a real construction site through the merging of serious games with 4D.

DEVELOPMENT OF THE VIRTUAL ENVIRONMENT

To test the research hypothesis, a full scale site was developed within the virtual environment as a replica that ensures a truly open world. A complete site plan, project schedules and a temporary evacuation diagram including temporary structures in the site layout were provided by a construction company, Morgan Ashurst, who agreed to be part of a case study.

To recreate this virtual site, the 'OpenSim' platform was used. OpenSim is an open source multi-platform, multi-user 3D application server. This platform was selected because of its in-built functionality that supports multiple users interacting with both the environment and each other. The building schedules and 3D models were manually imported and incorporated into the environment. The model was built up in a series of sections that reflected construction processes as would be the case in a 4D modelling tool. These sections were then grouped by task, using their textures and spatial position to visually identify which structures belong in which task.

The building of the environment in this fashion allowed the virtual site to be linked with the timing of the schedule to emulate an emerging construction environment. The navigation between sections in the virtual environment was achieved through the use of 'Holodeck' technology. This is a process whereby the environment within OpenSim can be changed from one world to another through a simple command. This replicates the effect of the time axis that would be present in a traditional 4D model. By linking the individual models to the start and finish dates of each task this technology can be used to display how the site appears at any point on the timescale the simulation or scenario requires (see Figure 1).

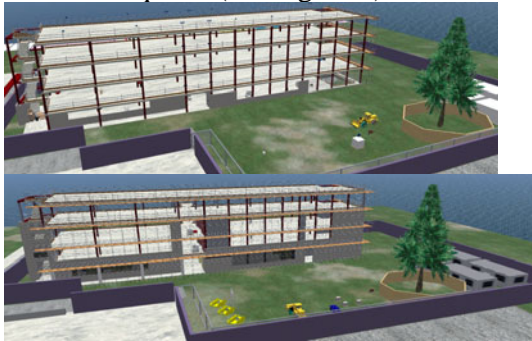


Figure 1. Modelled virtual environments at different stages of construction development

TESTING OF THE VIRTUAL ENVIRONMENT

To test the effect of this game design approach on the ability of trainees to spot H&S hazards, a number of hazards were modelled throughout the construction site at different stages of building development. An activity worksheet was developed so that the participants can record what types of hazards they found while exploring the environment on the different weeks. It also included a brief overview of what the session was about and details on logging in

to the environment. As an example, a list of modelled hazards for week 1 is displayed in Table 2.

Table 2. List of on-site hazards for week 1

Week 1 Hazards		Hazard Type
h11	Loose cabling around first floor	Loose/Untidy cables
h12	No railings on stairway	Improper stair railings
h13	Rubbish blocking stairway	Pathway obstructions
h14	Gas tanks unsafely stored	Poor storage
h15	No Railings around pool	Missing railings

Circa 70 hazards were modelled in two stages of testing. Tests were performed on 5 groups of subjects encompassing research students, undergraduate students, and college students in engineering and construction fields. This paper reports the result from the test conducted with 12 college students, specialising in building construction. The tests were carried out in the Teesside University CAD labs using Singularity Viewer to access the test environment. The testing involved the identification of hazards by the test subjects and in answering a score-based 10 question feedback sheet. The results from this analysis are presented in Figures 2 and 3. In Figure 2 the performance of each tester in terms of amount of identified hazards in different weeks is displayed. Each data point is scored out of a maximum of five, corresponding to the number of hazards present in the environment in any one week. This data shows that in the majority of cases the testers recognised more hazards in week one than in the following weeks. Figure 3 illustrates the testers' performance in terms of type of hazards spotted in different weeks. Each data point is scored out of a maximum of three, corresponding to the number of weeks were the hazard could be spotted in. This seems to show hazards hx1, hx2 and hx4 being the most consistently recognised and recorded by the testers. Hazards one and two were expected to be easily noticed as they are the most visually distinct of the five hazards. With hazard four it is likely that this particular group of testers explored areas of the site where that hazard was more predominant and were less thorough in areas where hazards three and five stood out.

DISCUSSION

During the development of the virtual environment there were several issues related to asset creation and interoperability. Various features of the construction site were limited in appearance by the size and quality of texture files that could be created and imported into the development environment in use. This resulted in a decrease in visual quality for the environment which according to users' feedback had an impact on their performance.

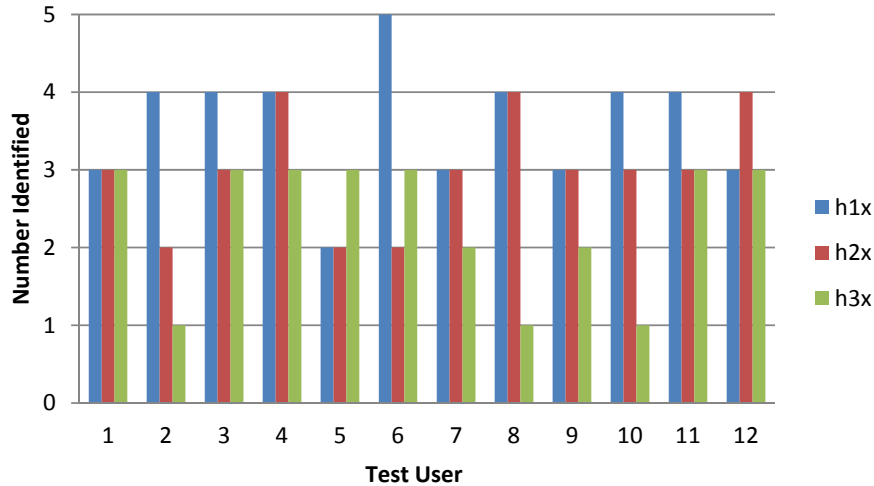


Figure 2: Number of H&S hazards identified by each tester week by week

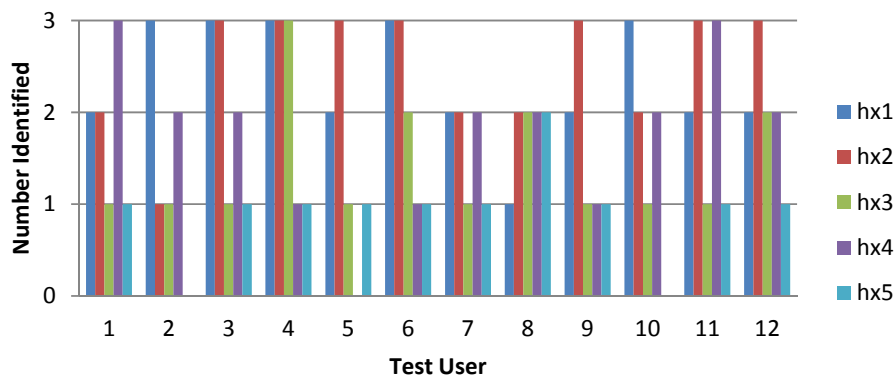


Figure 3: Type of hazards identified by each tester on each week

The use of 4D elements in the virtual environment proved to have an influence on users’ ability to spot hazards. As the site progressed, users had increasing difficulties in spotting hazards on-site which could be attributed to the increasing complexity of the site. This is a reflection of the real world situation where safety incidents occur in more complex sites. This suggests that the sandbox style environment should be further exploited despite current interoperability issues that result in time consuming and expensive development. In accordance with the notion that a sandbox environment can provide side-activities that have no direct connection to the core learning experience, the testing showed that the majority of the testers tended to include hazards not part of the testing schema but that would be an issue on a live construction site. Some of these were out of the scope of testing, like the lack of a welfare office or a manned first aid station. Others were un-documentable hazards based on user behaviour of other trainee sharing the same environment, like running on site or people not wearing the correct PPE. This demonstrates the additional training that a sandbox style game can provide for H&S training in construction.

CONCLUSIONS

This research presented a sandbox virtual training environment for H&S hazard spotting in construction. This research adopted a cross-pollination approach of serious games and 4D concepts to develop a full virtual replica that emulates the progression of a real construction site over time. This work has been sponsored by Dynamic Distance Learning; a company involved in the creation of training tools for the construction industry, and is partly financed by The Engineering and Physical Sciences Research Council (EPSRC), UK. A multi-user training environment was developed utilizing OpenSim platform and a full replica of a real site was developed using the floor plans and schedule programme provided by Morgan Ashurst. The testing of the environment, with groups of researchers and students, showed that a combination of 4D and gaming approaches can influence users' engagement and affect their abilities to spot safety hazards. The virtual environment showed that as the site becomes more and more complex over time, the ability of testers to spot hazards decreases. This suggests that such an approach can be useful if it is exploited in developing virtual environments to train workers on hazard spotting at stages where the site is complex. Moreover, this approach provided site activities, not originally part of the testing schema, to provide additional training elements. The current limitations in implementing the proposed approach are related to the lack of interoperability between VR, CAD and project management applications.

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