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Using Serious Games and Virtual Simulations in Construction Technology Education

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Abstract

In tertiary construction education programs, it is becoming increasingly difficult to take students to site to obtain first hand experience of construction technology. This is especially the case with large classes, sites that have limited safety capacity to take students, and the general logistical problems of getting students to and from site. The brevity of site visits provides novelty but restricts the depth of learning. Computer gaming simulation offers a potential alternative. Though not the real thing, the simulation environment provides targeted activities and problems; it also offers the potential to engage students for long periods of time and in an immersive environment. This paper looks at the use of virtual simulation games available in construction and then focuses on the implementation of a specific type of simulation suited to construction technology and construction processes. It involves the hands-on virtual usage of site equipment including excavators, cranes, forklifts and concrete placement equipment in the context of an active construction site. Students control and manipulate the machinery according to assigned tasks. The pros, cons and educational merits of such an approach are analysed including student evaluation of the simulation as a learning vehicle.

Keywords: serious games, virtual simulation, construction technology, education

1. Introduction

In the context of this paper, "serious games" are those that go beyond pure entertainment and have the purpose of motivating students to learn about specific aspects of their chosen profession or discipline. The concept has been around since the early 1970s with early texts by Abt's (1970) followed by the introduction of benchmark games such as Sim City (Electronic Arts, N.D.) which was released in 1989 and forced players into making complex decisions about the business of creating a productive and socially progressive built environment.

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Importantly, this paper looks at "serious games" in the context of andragogical usage which by definition deals with learning strategies for adults as distinct from pedagogy, which deals with learning for children. The distinction seems important because Knowles (1984) concept of andragogy puts forward the premise that adults need to know why they should learn something; need to learn experientially; generally approach learning as problem-solving; and learn best when the topic is of immediate value. Consequently, games must be designed accordingly to seek relevant learning outcomes.

Authors such as Zyda (2005) defines “Serious Games” as a mental contest, played with a computer in accordance with specific rules and uses entertainment to further educational and communication objectives. When this is coupled with the likes of Mihaly Csikszentmihalyi's concept of “Flow” (Csikszentmihalyi, 1990), serious games become an even stronger learning proposition. For instance Csikszentmihalyi's seminal psychological research about the daily activities of people, found that they felt best and most positive when completely engaged in an activity where time seems to fly by - “Flow” is his term for this feeling. He also identified that engagement is particularly strong when people are exposed to a challenge that is just beyond their current ability, but can realistically be reached via greater application (Csikszentmihalyi, 1990). It is clear that many video games make use of this very feature in engaging players to spend large amounts of time gaming, by creating tougher challenges in order to reach higher levels.

Within the gaming genre Aldrich (2009) draws the distinction between games, simulations and virtual worlds and this is useful in terms of better defining the specific type of “serious games” to be used in construction technology education reported in his paper. His categorisation includes:

- Games - are relatively simple and meant to encourage awareness of a certain thing,
- Simulations - are more associated with skill-building (such as the likes of flight simulator programs). These involve structured environments drawn from real life activities, with stated levels and goals.
- Virtual worlds - are 3-D environments where participants in remote locations can meet online and connect through detailed interactive models and undertake real-time collaboration, such as Second Life (Linden Lab, N.D.).

In applying this to construction technology, it is clearly important that students be immersed in the types of activities that they will encounter in professional practice. It is also important that a serious game provides a dynamic dimension that offers an alternative to the static learning typically associated with listening to a lecturer with hundreds of other people - a form of learning that tends to be common in university construction management programs (Forsythe et al 2011).

In trying to address this point, it is apparent that the video gaming industry has advanced in leaps and bounds and nowadays, most university age students have grown up playing such games. It is therefore not surprising that authors such as Prensky, (2001, p. 76) refer to this generation as “digital natives”. Research by Zyda (2007) serves to indicate the size of the video gaming industry by stating that it now generates more revenue than the movie industry and it is now a preferred way for much of the population to spend time, ahead of watching television. Obviously, such a pretext augurs well for the prospect of utilising highly visual gaming technology for construction technology learning, and having students who will willingly use such games.

Bearing these points in mind, this study aims to focus on the aforementioned “simulation” level of applying serious games to learning. This is to be applied to undergraduate construction project management students and more specifically, the construction technology subjects their-in. These subjects are often difficult to teach in an applied way because of the practical difficulties involved in taking them onsite (Forsythe 2009). Here, Messner and Horman (2003) make the point that it is difficult but important to provide students with the opportunity to observe and experiment with the building construction process, and that virtual technology offers a pathway forward. Consequently, the high-end visual capabilities of modern games are thought to provide a degree of experiential learning that can be readily controlled and implemented by University educators, without the associated difficulties of going onsite.

2. Serious Games Applied to Learning in the Construction Context

Whilst there are not that many well known games and simulations within the construction project management discipline, those that do exist can be readily categorised. For instance, simulations that have been around for some time such as AROUSAL (Irwig and Lansley 1986) and MERIT (Meritgame), make little to no use of visually oriented gaming technology - both focus more on running a fictional organisation and making financial decisions pertaining to things like the allocation of resources, tendering on projects, making strategic decisions, team interaction and developing company management structures. Others, such as Virtual Construction Simulator (Lee 2011) have much higher visual capability but focus on scheduling the workflow of a building using time scheduling tools and assumptions about the time and resources required to construct each element in the building.

Whilst all of these scenarios have valid learning outcomes in their chosen areas of specialisation, none address the problem of helping students to understand hands-on construction processes and a detailed understanding of construction technology. As a result, it would seem that this is an area that could benefit from the serious game concept - especially in the form of video games simulation – hence directing the ongoing direction of research undertaken in this paper.

Applications in this specific area are still in the process of development including the likes of Newton and Lowe’s (2011) use of Cry Engine 3 as means of creating a virtual environment for domestic construction. Here, are a variety of tools are used to analyse a range of domestic building representations. The game focuses on analytically investigating design and construction features, diagnosing design faults and building regulation breaches. Newton and Lowe (2011) acknowledge that the benefits of such an approach are still to be qualified, and consequently take a conservative position regarding the potential benefits until it can be fully evaluated.

On this issue, Horne and Thompson (2008) investigate the values and challenges of integrating visualisation technologies into built environment teaching – mainly from the tutors' perspective. Whilst the feedback they received was varied, the main underlying drivers concerned an extended learning process, increased student motivation and more diverse methods of teaching. Not withstanding this, there is still considerable work to be done in terms of executing such ideals. Killi (2010) makes the point that even though there has been increased interest in learning games, the development of appropriate game design methods has been inadequate – especially the lack of integration of education principles into games.

Further to the above, it is apparent that such technology is still ostensibly a surrogate for real life experience and so there is a need to consider the worthiness of such an approach compared to other "more real" types of learning. An obvious and traditional option here, involves site visits which can be used to supplement the principles learnt in class. A benefit of this approach is the ability to situate site visits within individual subjects but as alluded to previously, significant difficulties arise when large classes are involved. For instance, large classes typically need to be divided into smaller sub-groups and this can often fragment and disrupt the continuity of weekly classes. In other instances, the perceived safety risks of taking students onto site can often thwart such endeavours or at a minimum, create so much administration and paperwork that in real terms, site visits become very difficult to implement. Further, when site visits do occur, they are often for only short periods of time and may ultimately only consist of a talk in an onsite meeting room followed by a brief look at completed construction work – thus making it a novel experience but well short of gaining any hands-on experience of what the actual work activities involve. An alternative is workshop based learning especially where it can be used to regularly supplement lecture room activities. It is most effective where construction can effectively be scaled down to the limits of the space available without loosing the reality of the experiences involved. It has its merits but many construction degree programs now focus on management more than the technical aspects of construction and so unfortunately, the luxury of having ready access to such facilities – especially for fabrication and erection purposes – is now the exception rather than the norm. Still further, is the application of work-integrated-learning which has the advantage over both of the previous options by virtue of situating students in the work place, which potentially allows strong exposure to seeing (and perhaps even doing) what happens on onsite. In principle this is ideal but the main practical difficulty here, is the need for a program-wide approach that encourages concurrent work and study. Many programs are not able to support this degree of integration either internally or in externally coordinating with industry employers.

So from this discussion, it would seem that even though strong options exist for experiential learning about construction technology there are significant practical problems in implementing some of these approaches, at least some of the time. Though this paper in no way discourages the use of such approaches, alternative methods such as the use of serious games, should be considered as a supplementary approach where appropriate.

This raises a question of "when and where is appropriate?" Here it would seem that serious games provide a case for an alternative way of learning in construction technology where more ideal options (as discussed above) do not apply and particularly where:

- Students are in the early years of tertiary study and have little or no direct experience of construction because they have insufficient skills to obtain site based work.
- Students cannot predictably obtain the required experience of construction because the work they are involved in on-site, is not well synchronised with what they are learning in their degree program.
- Educators want to simulate on-site construction in a timely way that directly compliments and coordinates with class learning.
- Educators want a learning vehicle that can be readily deployed at a subject specific level and can compliment, but not be dependant on, program wide approaches to learning.
- Educators want to provide a type of experiential learning in large class settings that requires minimal resources in administering the learning vehicle.

The above factors have been taken into account in the logic applied to the current study and in the research method stated below.

3. Research Method

Due to the nature of the research aims and the previous discussion, one of the first tasks in undertaking the research was to target a first year construction technology course (low rise apartment building) and an area within the subject that would have generalisable appeal to students. The search for an appropriate pre-existing video simulation game was undertaken with the assistance of an international network of academic contacts and with the help of professional associations.

As consistent with previous discussion, attention was given to gaming technology that offered a fairly high degree of realism and visualisation. Within the chosen construction technology subject, attention was given to materials handling equipment (such as cranes, excavators, forklifts and concrete placement equipment). The game that was ultimately used allowed users to progress to upper levels after completing lower-level tasks. Each new task enabled use of a new piece of equipment on a larger building project. The scope of the game enabled students to operate equipment in a virtual onsite environment using the typical controls of real-time operation. As one example, students were able to drive and operate an excavator to excavate a site including the ability to present the machine to the workface, setup the out-riggers, then operate both the bucket and excavator arm hinging mechanisms, as well as pivoting the excavator around its central axis in order to dump dirt away from the excavation area. Students were required to excavate down to a certain depth and stockpile the soil. In another instance, students were required to operate a forklift including lifting pallets of bricks and moving them to different locations and then stacking pallets on top of each other - with a view to showing them the difficulties in manipulating the controls and also the dangers that occur when stacked pallets for fall over.

An initial tutorial was held to show students how to use the game and then they were required to undertake the simulation individually, in their own time.

The above was undertaken by 100 students and of those, 56 students (56%) undertook a questionnaire based evaluation of the simulation. Informal feedback from students and related email correspondence was also recorded.

Five of the questions used a 9 point Likert scale (Likert 1932) to canvass opinion on the extent to which students liked or disliked the simulation. This included questions asking if it helped them understand the site operations better than previously; if they better understood the constraints under which the targeted equipment worked on site; and the extent to which they thought it would assist them make more informed site management decisions.

Another bracket of questions inquired about the individual student's level of onsite experience and open questions about the best and worst features of the simulation and how its usage for learning could be improved.

4. Findings

The Likert scale questions provide the most targeted detail concerning opinion on specific learning related issues. Here, the 9 point scale was calibrated such that a score of "1" indicated that the student "strongly disagreed" with a given statement in the questions, and at the opposite end of the scale, a score of "9" indicated a student "strongly agreed". A score of "5" represented a neutral score at the changeover point between positive and negative opinion.

With this in mind, Table 1 shows the mean score for a number of the Likert scale questions. Here, it can be seen that even though there were positive responses to the simulation, most were close to a neutral score. Here, the strongest score was 5.8 and concerned the ability of the game to help students understand the operating issues of materials handling equipment onsite. In another instance, there was only very mild support (almost neutral, at 5.05) when questioned about whether or not the simulation provided a better understanding of the practicalities of managing such equipment on-site.

Table 1: Quantification of Likert Scale Questions

Questions	Mean score
1. The simulation helped me to understand the operating issues of materials handling equipment on site	5.8
2. The simulation provided a better understanding of the practicalities managing equipment on-site	5.05
3. The simulation provided an acceptable compromise to site-based learning	5.01
4. A game-driven approach has much potential for learning outcomes and should be used more often.	5.31

Similarly, opinion about whether the simulation was an acceptable compromise to site experience or not, indicated a mean response that was very close to neutral at 5.01. Here, it is difficult to say from the responses whether students actually accept compromise on such issues or not. Or, whether or not they have an understanding of the constraints that occur in trying to provide an appropriate learning environment. As one example of this, a student suggested in the open question responses, that it would be better if the University organised forklift and excavator training and students could then drive such equipment around onsite-hence indicating a somewhat idealised view of what is realistically possible.

In addition to the above, students were asked a more general question concerning whether or not they thought that a game-driven approach had much potential for assisting learning outcomes and should be used more often. The mean score for this question was 5.31 - which is nestled in between the previously discussed scores - and so it can be said that the general attitude about simulation games and the specific game under evaluation in this paper, were ultimately quite similar. Adding to this, the ambivalent attitude towards simulation games indicated above is somewhat surprising given the "digital native" tag discussed earlier in the paper. For instance, it was expected that students would be eager to use such games but this now seems to be a more contentious issue (irrespective of the success or failure of the specific game under evaluation).

This and the generally low positive scores reported earlier prompted the need to investigate the data further in order to obtain a better understanding of the spread of responses. For instance, there was a need to know if significant numbers of students either strongly agreed or strongly disagreed with the statements in Table 1. For instance, such a scoring pattern would indicate that two opposing extremes of opinion would serve to cancel each other out – thus causing a relatively neutral score – but as distinct from many scores occurring in mid range. To test this, Table 2 collapses the Likert scale scores into a lesser number of categories reflecting only low, medium and high categories (for the same questions reported in Table 1).

Table 2: Collapsed Likert Scale Scores into Low, Mid and High Categories

Questions	% of low Likert scale scores (i.e. scores from 1-3)	% of mid range Likert scale scores (i.e. scores from 4-6)	% of high Likert scale scores (i.e. score sfrom 7-9)
1. The simulation helped me to understand the operating issues of materials handling equipment on site	24	27	49
2. The simulation provided a better understanding of the practicalities managing equipment on-site	24	49	27
3. The simulation provided an acceptable compromise to site-based learning	23	48	29
4. A game-driven approach has much potential for learning outcomes and should be used more often.	20	44	36

As can be seen in Table 2, the most significant difference in opinion occurs under statement 1 where 49% of students provided “high” scores for this aspect of the simulation game, but this was to some extent offset by 24% of markedly “low” scores. Whilst this issue is discussed further in the following paragraph, it is also noteworthy that with regard to the other statements analysed in Table 2, the difference between high and low scoring was less pronounced as evidence by the strong proportion of mid range scores for these questions.

Given the above, it would seem that the best use for the simulation – in its current form - is primarily for the purpose of helping students understand how equipment operates at an experiential and immersive level. From the data, there is a near majority of students who strongly support this position. Even so and of equal interest, is the need to find out why others are so strongly opposed to it. Responses to the open questions were found to provide a degree of insight into both this and related issues. Here, responses relating to the main “pros and cons” of the game were categorised using thematic analysis where the coding method was developed under the guidelines recommended by Boyatsis (1998). Only on popular themes are reported as distinct from rarely mentioned content. With this in mind, the main themes (based on frequency of response) are presented in Table 3.

Table 3: Main themes relating to “Pros” and “Cons of the Simulation Game

Pros	Cons
• Experience machine usage and process onsite • Convenient/flexible/simple to use • Novel/fun/engaging • Realistic format and interactive	• Slow/time consuming/not fun • Relies on gaming skill over real understanding of the site • Poor controls, technical glitches and poor user instructions • Already have real experience/doesn't reflect reality

In considering the main “pros” presented in Table 3, it can be seen that most reflect the experiential, immersive and flow concepts discussed earlier in the paper. It is however clear, and ultimately not surprisingly, that not all students like this kind of game and therefore the “cons” provide some indication of the issues that may have influenced the Likert scale scores. This is thought to be especially the case where students believe educational outcomes should be less reliant on gaming skills, thus suggesting that there is a threshold point beyond which students become intolerant to the gaming approach. It is suspected that such a perspective is further fuelled where technical problems in using the game and where slowness in reaching new levels of game resulted in frustration. Last but by no means least, it is apparent that those who already have real world experience of the simulated equipment found the process to be of little use to them – hence suggesting the future need to qualify the experience of those who may already have real world experience – so as not to impose redundant learning upon them.

In the open questions, students were also asked for ways of improving the game. Few distinct themes emerged. Even so, one interesting and relevant insight suggested the option of using the virtual environment provided by the game as a means of not only experiencing the intended operation of materials handling equipment but in addition, allowing teachers to create more analytical management questions by simply using the virtual environment as a backdrop for context. For instance, students could be asked to study the situational variables of the site and then undertake research on about finding appropriate real-world machines that would be most appropriate for undertaking the type of excavation involved and with the work rate required. Another option is to situate regulatory questions in the context of the virtual site (such as hoarding requirements and safety procedures). This approach would provide an extended and more management oriented use of the game which from the previously discussed Likert scale scores, may help address the apparent lack of appeal in this area of learning.

5. Conclusions

In testing the use of a virtual simulation game (i.e. concerning materials handling equipment in construction technology subjects) there was positive support for the game in the context of helping students immersively experience operational usage of such equipment. Though a near majority provided strong support for this, it was also apparent that an alternative point of view existed in the student cohort for a smaller but still significant group of students. Consequently, there is a need to improve the design and execution of such games or provide alternative arrangements in order to provide appropriate engagement for students who for various reasons are not engaged by this form of learning. More specific conclusions include:

- The success of construction simulation games as a means of experiential and immersive learning for students is dependent on students not having first-hand experience of the work processes being simulated by the game i.e. there is no motivation in playing learning games about things you already know
- Given the previous point, it is best to use such games in the early years of University study when students are unlikely to have much site experience. If some students in the group already have the relevant site experience then they should possibly be diverted to an alternative learning activity.
- The usage of construction simulation games can be fun, engaging, instructive and experiential in terms of finding out about the operating parameters of commonly used equipment on-site.
- Students who are not naturally drawn to virtual simulation games are likely to be critical of the skill and dexterity required by the game versus the underlying learning outcomes that the game is trying to assist. Further, the experience can be quickly eroded for many by the frustration brought about by the likes of poor gaming controls, instructions and other functional aspects of the simulation. For this reason, it is considered best that simulations (of the kind tested in this study) are best used in relatively short bursts that support lecture content about core principles rather than dominate learning activities.
- In extending learning outcomes, the game needs to go beyond purely providing experiential usage of the machines and must create situated problems that have an analytical context about the usage of the machines and the impact on site management. One way of doing this is for educators to leverage the virtual environment by create their own problems which can be developed separately to the game, yet can use the game environment in a parallel and supportive way.

Obviously, another option is to design such features into the game, but a problem with this approach is mainly the fact that once it becomes hard wired into the game, it becomes difficult to change, thus reducing the ability to respond to changing needs and to refine learning objectives.

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The 19th Triennial CIB World Building Congress, 5th – 9th May 2013 was organised by the International Council for Research and Innovation in Building and Construction (CIB), and hosted by the Queensland University of Technology (QUT) in conjunction with the Sustainable Built Environment National Research Centre (SBENRC).

The theme of this year's Congress was 'Construction and Society', and it showcased some of the world's best research and development in the built environment and construction sectors, focusing in particular on how research helps to optimise the contribution of constructed assets to social objectives. The Congress captured research from a global network of over 5000 CIB members and more than 50 CIB Working Commissions and Task Groups. In celebration of the CIB's 60th anniversary, this Congress underscored the CIB's continuing role as a world leader in innovative Building and Construction Research.

A broad range of papers was presented in oral and poster format, with representation from both academics and practitioners across a range of sub-themes. Submitted papers were subject to blind peer review by members of the International Technical Committee, which was comprehensively represented by academics from the CIB Working Commissions and Task Groups. 396 papers were accepted during this process. The papers presented at the Congress are published in full in these Proceedings of the Congress. The papers have been subject to a blind academic review process by international experts, except for those denoted as 'Industry Papers', which were subject to editorial review.

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